PERFORMANCE OPTIMIZATION OF AN OXYGEN PLANT USING A COMPUTER SIMULATOR

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خلاصة

هذه الرسالة تبحث الدارة التشغيلية لمصنع أكسجين سوفييتي الصنع وهو من النوع K-O.15 الذي يستخدم دورة تبريد ذات ضغط متوسط. إن هذا البحث يطمح أساساً الى تقصي إمكانية تحسين القدرة الإنتاجية للمصنع لمواجهة الطلب المتزايد على الأوكسجين .

ولإنجاز حسابات الإتزانين الحراري والكتلي للعمليات التي تؤديها معدات المصنع فقد تم استخدام برنامج حاسوب للمحاكاة يعرف باسم CODE حيث تم بمساعدته إنشاء مخطط عمليات يحاكي دارة التشغيل للمصنع المذكور .

إن متطلبات الطاقة تعتبر العامل الأساسي في حساب كلفة الإنتاج ضمن مصنع الأكسجين . ومثل هذه المتطلبات يمكن التحكم بها من قِبل شبكة المبادلات الحرارية الموظفة في المصنع .

وللتنبؤ بشبكة مثلى للمبادلات الحرارية تم تبني تحليل تكاملي للطاقة باستخدام اسلوب يعرف بجدول المسألة (المشكلة). وهو أسلوب غايته تحديد المتطلبات الدنيا من الطاقة للدارة التشغيلية.

ولما كانت دارة المصنع تتوفر على نوع واحد من هذه المتطلبات (متطلبات تبريد) أصبح ممكنا استخدام ما يعرف بالتصميم ذي الإسترداد الأقصى للطاقة ويرمز له بِ MER Design . وعن طريق الأخير أمكن توقع ومن ثم الإختبار بالحاسوب للوضع الأمثل الذي ينبغي أن تكون عليه مسارات العمليات. إن ما تم الحصول عليه من نتائج يبين أن الوضع المشار اليه يتفق مع الظروف التشغيلية لدارة المصنع . إضافة الى أنه تم التثبت من أن الوضع الجديد لمسارات العمليات يحقق خفضا مقداره (٢١٪) من المساحة اللازمة للانتقال الحرارة وذلك بثبوت القدرة الإنتاجية .

وعلاوة على ما تقدم ، فقد ظهر أن عمودي (برجي) التكرير بإمكانهما استيعاب معدل اضافي من المائع قيد التكرير يصل الى (٦٠٪) من أصل القيمة الإسمية لمعدل التدفق . مع ذلك فإن معدات رئيسية في المصنع (الضاغطه، مضخة الأكسجين السائل، منقي الهواء، الممدد التوربيني، وبعض أجزاء من شبكة الأنابيب) ينبغي إعادة تصميمها اذا تقرر التوسع في القدرة الإنتاجية .

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وبدراسة اقتصادية مقارنة في آخر البحث تبين أن كلفة الوحدة المنتجة (متر مكعب واحد من غاز الأكسجين) في المصنع بعد رفع قدرته الإنتاجية بمقدار (٦٠%) تعادل ما نسبته (٩٠%) من الكلفة ذاتها اذا ما تم استخدام مصنع آخر مماثل للموجود حالياً.

أن النتائج التي ينتهي اليها هذا البحث لا تشجع على الأخذ بقرار توسعة المصنع الحالي.

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ABSTRACT

This thesis investigates the operating circuit of a Soviet made oxygen plant of type K-0.15 which employs a medium-pressure refrigeration cycle. The purpose of this investigation is to explore the possibility of improving the production capacity of the plant to meet the increasing market demand on oxygen.

A computer program, CODE, which is a steady state process simulator has been used to calculate heat and material balances of process equipment. A flowsheet is generated to simulate the operating circuit of the plant under consideration.

Energy requirements are considered to be the primary factor determining the production cost of the oxygen plant. Such requirements are controlled by the employed network of heat exchangers of the plant.

To predict the optimum exchanger network, the Energy Integration analysis is adopted using the Problem Table method. This method determines the minimum energy requirements of the operating circuit.

Since the plant circuit includes only one type of energy

requirements (that is cooling requirement), it has become possible to use the Maximum Energy Recovery (MER) design. Such type of a problem is sometimes referred to as threshold problem.

Using MER, an optimum configuration of process streams are predicted and checked by the computer simulator. The results obtained show that the predicted configuration complies with the operating conditions of the plant circuit. A reduction in heat transfer area of about 21% is found possible while keeping the production capacity invariant.

Furthermore, it is determined that the rectifying columns are capable of handling a flow rate 60% higher than the nominal flow rate value. However, major components of the plant (compressor, pump, purifier, turbo-expander and some piping) should be redesigned if expansion is implemented. A comparative economical study shows that the cost of unit production after expanding the existing plant by 60% points to 90% of the unit production cost if a new similar plant is erected. This result indicates that a decision to expand the plant may not be favourable.

NOMENCLATURE

A : Surface area of heat transfer, m^2

A1 & A2 : Moisture separators

A3 : Preliminary heat exchanger

A4 : Heat exchanger

A6 : Three-way subcooler

A7 : Lower column

A8 : Plate-fin condenser

A9 : Upper column

A15 & A16 : Cylinders of the air purifier

BP1, BP2 & BP3 : Throttle valves

CP : Heat-capacity flow rate, kW/^oC

CP_i : Heat-capacity flow rate of stream i, kW/^oC

Cp : Specific heat, kW/kg.^oC

d : Tube diameter, m

D_e : Hydraulic diameter, m

D_i : Inside diameter of the outer tube for tube-in-tube section, m

d_i : Inside diameter of the inner tube for tube-in-tube section, m

D_o : Outside diameter of the outer tube for tube-in-tube section, m

d_o : Outside diameter of the inner tube for tube-in-tube section, m

$d\dot{Q}$: differential heat flow-rate, kW

$\dot{H}$: Enthalpy flow rate, kW

H1 : Liquid-oxygen pump

HAF : Heat availability function

h : Film coefficient of heat transfer, $W/m^2.^oC$

h_i : Film coefficient of heat transfer based on the inside diameter of the tube, $W/m^2.^oC$

h_{io} : Modified h_i, $W/m^2.^oC$

h_o : Film coefficient of heat transfer based on the outsibe diameter of the tube, $W/m^2.^oC$

JISICO : Jordan Iron and Steel Industries Company

K1 : Air compressor

L : Tube length, m

LMTD : logarithmic mean temperature difference, ^oC

$\overset{o}{m}$: Mass flow rate, kg/s

MER : Maximum Energy Recovery (design)

O_2 : Oxygen

Pr : Prandtl number

Q : Heat flow rate, kW

Re : Reynolds number

T : temperature, ^oC

T1 : Air temperature before preliminary heat exchanger, ^oC

T2 : Air temperature after preliminary heat exchanger, ^oC

T3 : Air temperature after air purifier, ^oC

T4 : Nitrogen temperature after heat exchanger

A4, °C

T5 : Nitrogen temperature after preliminary heat exchanger A3, °C
T9 : Air temperature before turbo-expander, °C
T10 : Air temperature after turbo-expander, °C
TA1 : Turbo-expander
T_s : Supply temperature of a stream, °C
T_t : Target temperature of a stream, °C
U : Overall coefficient of heat transfer, $W/m^2.°C$
UA : The "UA" product of U times A, W/ °C
v : Flow velocity, m/s
ΔT : Temperature difference, °C
ΔT_i : Temperature difference for stream i, °C
ΔT_{min} : Minimum temperature difference, °C
$\Delta \hat{H}$: Difference of enthalpy flow rate, kW
μ : Kinetic viscosity, Pa.s
ρ : Density, kg/m^3

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Chapter One

INTRODUCTION

1.1 Problem Statement

In 1988-89, Jordan Iron and Steel Industries Company (JISICO) has installed and commissioned a new imported oxygen plant at its factories in Zerka. The installation and commissioning were done under the supervision of the manufacturer.

During his work as plant engineer at JISICO, the author tried to investigate the plant circuit and its operating conditions. During this investigation, the following questions were raised

- Do the operating conditions set by the manufacturer lead to the optimum performance of the plant ?
- Is it possible to increase the production capacity of the plant without replacing any parts of the plant? If so, what will be the individual contribution of each component to this increase?
- Is there a bottleneck in implementing such an

increase ? If yes, how is it possible to get through this bottleneck ?

- Is it possible to increase the plant capacity by changing the present configuration of the process streams and/ or the operating conditions of the plant only ?

These questions are the basis of the present research. In this thesis, answers to the questions listed above are presented.

The following section is a brief description of both the circuit and components of the oxygen plant under consideration.

1.2 Oxygen Plant

1.2.1 Application

The plant under consideration is of type K-0.15 (1) and is designed to produce gaseous oxygen of grade 1 according to the USSR standard ГОСТ 5583-78. The plant is manufactured in versions intended for operation in temperate and tropical climatic regions; It displays stable operation in the ambient temperature range of -40 to 40°C.

The oxygen produced by this plant is intended for use mainly in machine building and metal working - welding and flame cutting of metals -as well as in chemical industry and other fields of technology.

The plant can also be used to produce technical gaseous oxygen of higher purity (99.9%) according to the standard ГОСТ 5583-78 or technical liquid oxygen of grade 1 according to the standard ГОСТ 6631-78 or liquid nitrogen of grade 2 according to the standard ГОСТ 9293-74.

1.2.2 Circuit arrangement and operating principle

a. General information

Air is precooled in the preliminary heat exchanger. Water vapor, hydrocarbon products and carbon dioxide are removed from air by the zeolite air purifier. The refrigeration losses are compensated by the medium pressure refrigeration process employing the turboexpander. Refrigeration is recuperated in a tubular heat exchanger. The air is separated into oxygen and nitrogen by a two- column rectification system.

b. Modes of operation

The plant has the following four modes of operation :

Mode i : Making grade 1 gaseous oxygen

After passing through a dust filter, air is compressed by

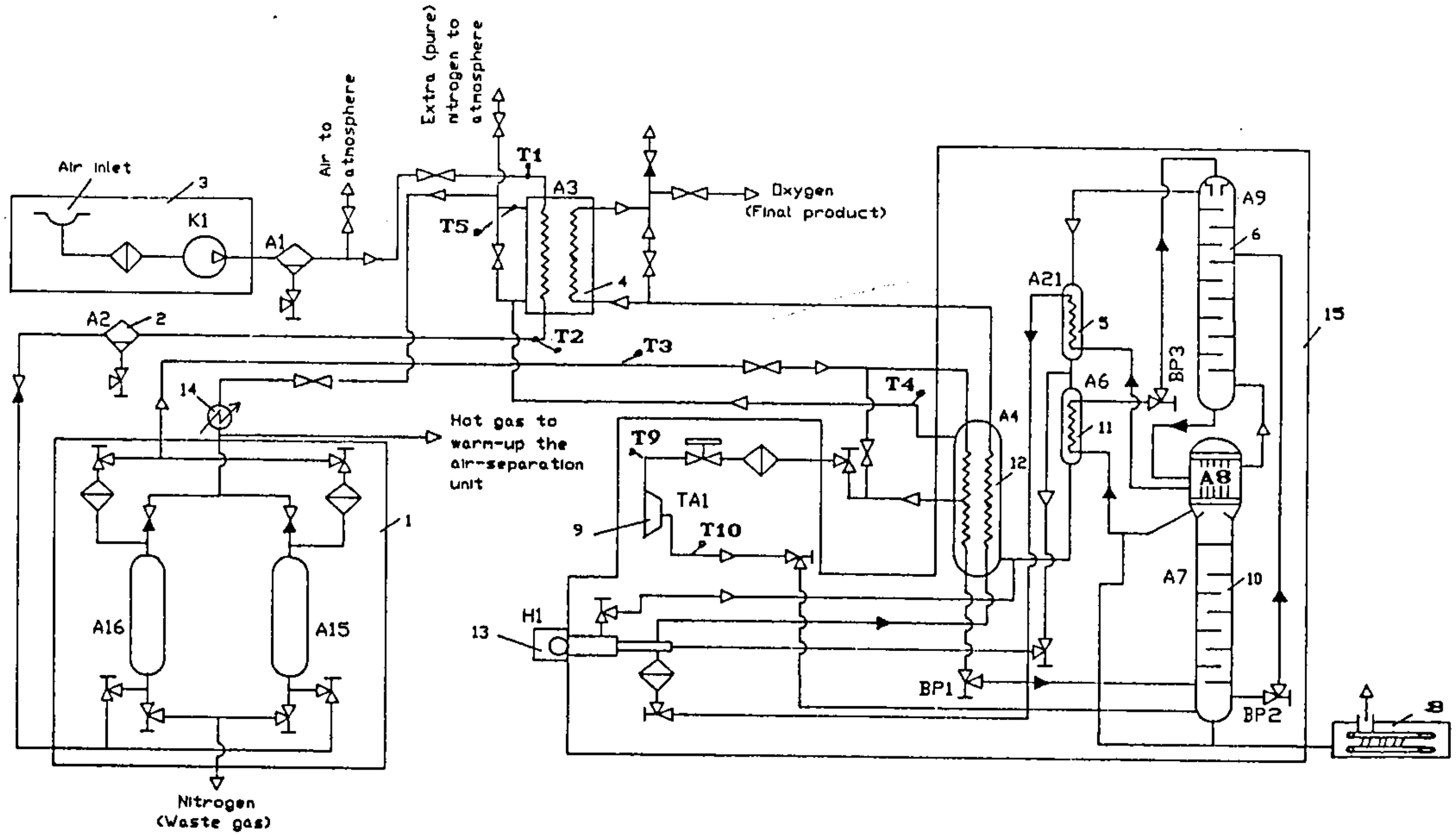

Figure 1.1 : Schematic flow diagram of the oxygen plant type K-0.15

1-Air purifier, 2-Moisture separator, 3-Air compressor, 4-Preliminary heat-exchanger, 5-Two-way sub-cooler, 6-Upper column, 7-Plate-fin condenser, 8-Emergency oxygen-evaporator, 9-Turbo-expander, 10-Lower column, 11-Three-way sub-cooler, 12-Heat exchanger, 13-Liquid-oxygen pump, 14-Electric heater, 15- Casing of the air-separation unit

In the lower column, air is separated into oxygen-rich (33.5%) liquid and nitrogen reflux containing 2.0-2.5% oxygen.

The still liquid in the amount of 60% of the processed air is throttled to a pressure of 0.04 MPa by valve BP2 and passed to the 40th plate of the upper column A9 (if counting from bottom to top).

The nitrogen reflux in the amount of 40% of the processed air is passed to subcooler A6 in which it is cooled by the gaseous nitrogen leaving the upper column. Then the nitrogen reflux is throttled by valve BP3 and passed to the top plate of the upper column.

In the upper column, air is finally separated into gaseous nitrogen and liquid oxygen.

Liquid oxygen is withdrawn from the still of the upper column to condenser-evaporator A8. Liquid oxygen in the amount of 19% of the processed air is passed from the condenser-evaporator to subcooler A21. On passing through the subcooler, liquid oxygen is used for cooling the jacket of the liquid oxygen pump H1 whereupon it is passed to the suction side of this pump. Liquid oxygen is pumped at any required pressure within the range of 0 to 20 MPa and directed to the heat exchanger A4 in which it is evaporated and passed to the preliminary heat exchanger. Gaseous oxygen from the preliminary heat exchanger is passed to a filling manifold.

Gaseous nitrogen in the amount of 80% of the processed air is passed from the upper column to subcooler **A6** and then to heat exchanger **A4** in which it is heated to temperature **T4**. Thereafter it is directed to preliminary heat exchanger **A3** and heated to temperature T5. Part of the gaseous nitrogen is passed to the air purifier for regeneration of the zeolite and cooling the absorbers. The remaining gas is released to the atmosphere.

Mode ii : Making high purity gaseous oxygen

When the plant is operated in mode ii, higher purity gaseous oxygen is produced by reducing the rate of product withdrawl (decreasing the pump delivery.)

Mode iii : Making grade 1 liquid oxygen

When the plant is operated in this mode, liquid oxygen is withdrawn and transferred to a storage tank. In this case the liquid oxygen pump is kept inoperative. The air pressure at the compressor exit is increased to 6.4 MPa.

Mode iv : Making liquid nitrogen

When the plant is operated in this mode, a part of the sub-cooled nitrogen reflux is withdrawn as product. In this case the pressure after the compressor is raised up to 6.4 MPa. The liquid oxygen pump is kept inoperative.

1.2.3 Technical data

The nominal production capacity of the plant is 170 m^3/hr of 99.7% pure gaseous oxygen at 10°C and 15 MPa. This capacity is restricted to the following conditions

- Delivery of the air compressor employed in the plant complies with the technical specifications in its certificate and its negative tolerance does not not exceed 5%.

- Suction conditions conform with ГОСТ 2939-63, whereby the pressure equals 101,325 Pa (760 mm Hg), and the temperature equals 293.15 K (20°C).

- Temperature of the cooling water delivered to the compressor is 283.15 K (10°C).

- Purging losses of air do not exceed 3% .

The plant will normally operate with the volumetric flow rate of the air supplied for separation ranging from 750 m^3/hr to 1056 m^3/hr .

1.2.4 Equipment list

(a) Air separation unit KK 0216.00.000 (15)

(b) Turboexpander AT-0.6/4 (9)

(c) Air purifier KK 0926.000 (1)

(d) Set of testing instruments and devices KK 0036.10.000

(e) Preliminary heat exchanger KK 3283.000 (A3)

(f) Air compressor 305 ВП 16/70 (K1)

(g) Two moisture separators KK 5013.000 (A15,A16)

The complete list also incorporates valves which are installed on the pipelines interconnecting units of the plant, as well as instruments for measuring purity of the product and a set of spare parts, service tools and accessories.

1.2.5 Individual description of equipment

* Separation unit

The separation unit is designed for cooling, liquefying and separating compressed atmospheric air into oxygen and nitrogen. A medium pressure cycle employing a turboexpander is used for cooling the air. Oxygen and nitrogen are produced from air by double-column rectification.

The separation unit consists of a housing, apparatus for separating air into oxygen and nitrogen (high- and low-pressure rectifying columns, condenser-evaporator), heat exchanger, liquid oxygen subcooler and subcooler of still liquid and nitrogen reflux, turboexpander, liquid-oxygen pump, valve equipment and instruments.

All the apparatus of the separation unit are accommodated in the housing. This housing is filled with a heat insulating material (expanded perlite powder), which reduces refrigeration losses to environment.

*** Heat exchanger, A4**

The heat exchanger is designed for cooling the air coming into the separation unit by the outgoing nitrogen and by compressed oxygen.

It is a three-stream wound tube-in-tube type apparatus. Air is the hot stream while oxygen and nitrogen are the cold streams. The number of wound tube layers is 8, and the number of tubes is 19. The outer tubes are of 10x1* mm diameter while the inner tubes are of 5x1 mm diameter.

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* The outsidesdiameter ofmmthe Ttube cequalsio10mmf while its thickness equals 1mm. This convention of tube diameter is adopted all through this thesis.

The apparatus weighs 274 kg. The working pressure in 5x1 mm diameter tubes is 20 MPa. These tubes are subjected to a test pressure of 25 MPa.

The working pressure in 10x1 mm diameter tubes is 7.0 MPa. These tubes are subjected to a test pressure of 9.0 MPa. The working pressure in the space between tubes is 0.07 MPa.

The operating temperature is from +10°C to -176°C. The external heat exchange surface of 10x1 mm diameter air tubes is 9.16 m^2. The external exchange heat surface of 5x1 mm diameter oxygen tubes is 4.58 m^2.

The operating temperature is from +10°C to -176°C. The external heat exchange surface of 10x1 mm diameter air tubes is 9.16 m^2. The external exchange heat surface of 5x1 mm diameter oxygen tubes is 4.58 m^2.

When the exchanger is in operation, the high pressure oxygen is passed through the 5x1 mm diameter tubes; the air to be cooled is passed through the annular space inside the 10x1 mm diameter tubes while the cooling nitrogen flows through the space between the tubes.

The hydraulic resistance in the inter-tubular space as determined by testing at 20°C is as follows :

- in the upper zone it is of 330 80 mm H_2O,
- in the lower zone it is of 30 10 mm H_2O,

The air flow rate during testing is 400 m^3/hr.

*** Preliminary heat-exchanger, A3**

The preliminary heat-exchanger is intended for cooling the air before it enters the purifier. It is a coiled-tube three -stream apparatus with parallel wound coils of air and oxygen tubes. The coils are wound in eight layers. The air tubes are 8x1 mm in diameter and 16 in number. The oxygen tubes are 8x1.5 mm in diameter and 3 in number.

The working pressure in the air tubes amounts to 7.0 MPa. The tubes are subjected to a test pressure of 9 MPa. The working pressure in the oxygen tubes amounts to 20 MPa. The tubes are subjected to a test pressure of 25 MPa.

The working pressure in the space between the tubes and casing amounts to 0.07 MPa.

Technical characteristics of the preliminary heat exchanger intended for use in temperate conditions are as follows :

- The mass of the apparatus is 311 kg.
- The height of the tube winding is 293 mm.
- The height of the apparatus is 1605 mm.

- The outside heat exchange surface of :

  - Air tubes is 7.1 m^2 and,
  - Oxygen tubes is 1.4 m^2.

When the apparatus is in operation, air to be cooled is passed through 8x1 mm diameter tubes and high pressure oxygen is passed through the 8x1.5 mm diameter tubes while gaseous nitrogen flows through the space between the tubes.

The hydraulic resistance in the inter-tubular space as determined at $20^{\circ}C$ is 390 90 mm H_2O at air flow rate of 700 m^3/hr.

*** Sub-cooler, A21**

This sub-cooler is designed for subcooling oxygen by means of still liquid.

The sub-cooler is a coiled tube two-stream apparatus with 4 tubes coiled in 2 layers. The apparatus weighs 12.0 kg. The working pressure in the tubes is 0.07 MPa. The tubes are subjected to a test pressure of 0.2 MPa. The working pressure in the space between the tubes is 0.2 MPa. The test pressure applied in the space is 0.3 MPa.

The design temperature is within -186oC to -188oC. The outside heat exchange surface of the 8x0.8 mm diameter tubes amounts to 0.41 m^2.

When the sub-cooler in operation, liquid oxygen is passed through the tubes while the still liquid flows through the space between the tubes.

*** Sub-cooler, A6**

This sub-cooler is designed for sub-cooling the still liquid and nitrogen reflux by the outgoing nitrogen. It is a coiled tube three-stream heat exchanger with two bundles of 8x0.8 mm diameter tubes which are parallel-coiled in four layers.

There are 8 tubes in each section of the apparatus (in still liquid section and nitrogen reflux section). The outside heat exchange surface area of the still liquid tubes is 0.85 m^2,while the outside heat exchange surface area of the nitrogen reflux tubes is 2.12 m^2.

The apparatus weighs 55 kg. The working pressure in the tubes with still liquid is 0.6 MPa, while the test pressure is 0.9 MPa. The working pressure in the tubes with nitrogen reflux is 0.6 MPa and the test pressure applied to these tubes is 0.9 MPa. The working pressure in the space between the tubes is 0.07 MPa while the test pressure is 0.2 MPa.

* Lower column, A7

The lower column is designed for the separation of air into oxygen-rich liquid, nitrogen reflux, and gaseous nitrogen.

The column is a cylindrical vessel accommodating 20 circular perforated plates. These plates are secured in special creases on the column casing by means of rolling them in.

- Working pressure = 6 MPa.
- Testing pressure = 9 MPa.
- Operational temperature = 93 K.
- Column capacity = 200 liter.
- Mass of column = 75 kg.
- Plate diameter = 0.4 m.

The column complies with the standards for construction and safe operation of high pressure vessels.

* Upper column, A9

The upper column is designed for the final separation of air into gaseous nitrogen and liquid oxygen.

The column is a cylindrical vessel accommodating 56 circular rectifying sieve plates which are fixed in special creases on the column casing by means of rolling them in. Installed in the column still a plate-fin condenser (called "packet" hereinafter).

- Working pressure in column	0.07 MPa
- Testing pressure	0.14 MPa
- Operational temperature	80 K
- Column capacity	900 liter
- Mass of column with packet	300 kg
- Plate diameter	0.5 m.

* Packet (plate-fin condenser), A8

The packet is built into the upper column still and is designed for condensing nitrogen incoming from the lower column owing to the oxygen boiling.

The packet consists of a number of 1 mm thick identical flat spacer plates silumin-coated on both sides, which are inter-laid with corrugated aluminum-foil packing of 0.2 mm thick (working portion) and 0.7 mm thick (distribution portion).

On the opposite ends of the spacer plates are lateral packing bars made of aluminum section. At top and bottom the packet is fitted with 4-mm thick cover plates coated inside with silumin. The spacer and cover plates are made of an aluminum alloy, as well as the aluminum packing foil.

The channels of nitrogen are communicated by means of headers. The oxygen space channels are at the end faces of the packet so that oxygen passes through the packet from top to bottom.

- Working pressure in nitrogen space	0.6 MPa
- Testing pressure in nitrogen space	0.9 MPa
- Working pressure in oxygen space	0.07 MPa
- Testing pressure in oxygen space	2.0 MPa
- Operational temperature	77 K
- Number of nitrogen space channels	16
- Number of oxygen space channels	17
- Mass of packet	76 kg

*** Moisture separator, A1 & A2**

The moisture separator is designed for removing moisture droplets from air before the preliminary heat exchanger and before the air purifier inlets.

The water separator is a welded cylindrical vessel into which the air flow is directed tangentially.

The capacity of the apparatus is 16 liters and it weighs

40 kg.

The working pressure in the separator amounts to 7.0 MPa while test pressure applied to the apparatus is 8.8 MPa.

When the apparatus is in operation, moisture is separated from the air due to the sharp change in the velocity and direction of the air flow.

* Liquid-oxygen pump, H1

The pump used is one of the Russian pump series 2НСГ. These pumps are designed for use in air separation plants or gasifiers to transfer super-cooled or compressed liquefied oxygen, nitrogen or argon.

- Mean delivery per charging cycle at a piston stroke of 30 mm, m^3/s (l/h) . ... $(7.0 \pm 0.7)*10^{-5}$
  (252 ± 25)
- . Delivery control range, % ....$(100 - 40) \pm 10$
- Mean discharge pressure per cycle, MPa 14.7
- Maximum discharge pressure, MPa .... 22.5 - 1.2
- Maximum power (at maximum delivery), kW 4.4

* Turboexpander, TA1

The expansion turbine type AT-0.6/4 incorporated in the air separation plant is designed for expansion cooling of compressed air in a low-temperature refrigeration cycle. The air to be expanded must be free from mechanical admixtures and carbon dioxide.

- Refrigerating capacity, W 6400
- Inlet air pressure, MPa :
    - Working .... 3.96 ± 0.49
    - Maximum 6.28
- Air-handling capacity, kg/hr .... 600^{+60}_{-30}
- Outlet air pressure, MPa, ... 0.59
- Inlet air temperature, K (°C) .... 173 ± 5 (-100 ± 5)
- Outlet air temperature, K (°C) .... 120 (-153)
- Rotor speed, thousands of rpm .... 150^{+25}_{-15}
- Cooling water consumption, kg/hr 3
- Cooling water pressure, MPa, ... 0.196

*** Air purifier, A15 & A16**

The air purifier is intended for removal of moisture, carbon dioxide and any other hydrocarbon from air to be distilled. It is designed to operate at the medium pressures (3.5 - 7 MPa).

The purifier may be incorporated in an air separation plant or in air complex purification installation.

An electric heater is provided with the purifier. This heater is intended for warming regenerating gas. When the air purifier is incorporated in an air separation plant, The heater is also used for warming the air or nitrogen used for warming up the separation unit.

Technical Data

1. Air purifier capacity, m^3/s	0.227 - 0.267
2. Working pressure, MPa	3.5 - 7.0
3. Air temperature at purifier inlet, K (^oC)	278 - 283 (5 - 10)
4. Content of CO_2 :	
a) in purified gas, ppm	3 max.
b) at the end of adsorption cycle, in 8 hours on completion of parallel operation, ppm ...	20 max.
5. Dehydration level, dew point, K (^oC)	203 max. (-70) max.
6. Length of adsorber working cycle in air purification, with parallel operation taken into consideration, hr	9 max.
7. Length of desorption cycle, ...	2 hrs and 10 -20 min.
8. Length of adsorber cooling cycle	4 hrs and 45 min. to 5 hrs

9. Duration of adsorbent operating
   cycle prior to replacement, ... 2 years approx.

10. Temperature of regenerating gas
    after it is raised by electric
    heater, K (°C) 673 (400)

11. Temperature of regenerating gas
    at the adsorber outlet by the end
    of regeneration cycle, K (°C) 493 (220)

12. Regeneration flow rate, m^3/s :
    a) At a temperature of 0 to 5°C
       at the electric heater inlet 0.0472
    b) At a temperature of 35 to 45°C
       at the electric heater inlet .... 0.061 to 0.695

13. Electric heater consumed power, kW 30

14. Weight of zeolite used
    as adsorbent, particle size 4 mm, kg 460

15. Main dimensions of air purifier, m :
    a) Height 3.35
    b) Width 1.845
    c) Depth 2.05

16. Total weight of air purifier, kg 2565
    including weight of zeolite .... 460 ± 50

*** Air compressor, K1**

It is a stationary, reciprocating, direct action, four-stage, with perpendicular cylinders and with inter- and terminal coolers compressor.

Technical Data

1. Discharge pressure, MPa	7
2. Free air delivery, m^3/min	16 ± 5%
3. Power consumed, kW	190
4. Speed, rpm	500
5. Cooling water requirements without terminal cooler with entrance 15°C, liter/min	110
6. Recommended cooling water requirement for terminal cooler with entrance temparature 15°C, liter/min	40
7. Number of cylinders	4
8. Cylinder bores, mm :	
1st stage	500
2nd stage	270
3rd stage	145
4th stage	100
9. Piston stroke, mm	220
10. Stage outlet pressures, MPa :	
1st stage	0.22 - 0.28
2nd stage	0.8 - 1.2
3rd stage	2.2 - 2.85
4th stage	7
11. Lubrication :	
a) Crank mechanism	circulation system with gear pump
b) Cylinders	central force - feed

	from a lubrication unit incorporated with the compressor
12. Oil capacity of compressor frame, liter	136
13. Force - feed delivery rate, g/hr	70
14. Overall dimensions, mm :	
a) length	2,670
b) width	1,880
c) height	2,560
15. Mass, kg	4,400
16. Automatics	protection and signaling for main compressor parameters.
17. Drive	synchronous motor, direct coupled.
18. Synchronous motor :	
a) Rated power, kW	200
b) Speed, rpm	500
c) Voltage, V	380
d) Mass, kg	1,660

Chapter Two

LITERATURE SURVEY

Oxygen is the most abundant element on the earth's surface. It occurs both as the free element and combined in innumerable compounds: It comprises 23% of the atmosphere by weight, 46% of the lithosphere, and more than 85% of the hydrosphere (~ 85% of the oceans and 88.81% of pure water).

2.1 Oxygen Discovery

In the 15th century, *Leonardo da Vinci* noted that air has several constituents, one of which supports combustion.(2)

The *discovery* of oxygen, however, is generally credited to *C. W. Scheele* and *J. Priestley* independently in 1773-4, though several earlier investigators had made pertinent observations without actually isolating and characterizing the gas(3-5). Indeed, it is difficult to ascribe a precise meaning to the word *discovery* when applied to a substance so ubiquitous present as oxygen; particularly when (a) experiments on combustion and respiration were interpreted in terms of the phlogiston theory, (b) there was no clear consensus on what constituted "an element", and (c) the birth of *Dalton's* atomic theory was still far in the future.

Moreover, the technical difficulties before the mid-eighteenth century of isolating and manipulating gases compounded the problem still further, and it seems certain that several investigators had previously prepared oxygen without actually collecting it or recognizing it as a constituent of "common air".

Scheele, a pharmacist in Uppsala, Sweden, prepared oxygen at various times between 1771-3 by heating KNO_3, $Mg(NO_3)_2$, Ag_2CO_3, HgO and a mixture of H_3AsO_4 and MnO_2. He called the gas vitriol air and reported that it was colorless, odorless and tasteless, and supported combustion better than common air, but the results did not appear until 1777 because of his publisher's negligence.

Priestley's classic experiment of using a "burning glass" to calcite HgO confined in a cylinder inverted over liquid mercury was first performed in Clone, England, on Monday, August 1, 1774; he related this to *A. L. Lavoisier* and others at a dinner party in Paris in October 1774 and published the results in 1775 after he had shown that the gas was different from nitrous oxide. *Priestley*'s ingenious experiments undoubtedly established oxygen as a separate substance (dephlogisticated air) but it was *Lavoisier*'s deep insight which recognizes the new gas as an element and as the key to our present understanding of the nature of combustion. This led to the overthrow of the phlogiston theory and laid the foundations of modern chemistry(8). *Lavoisier* named the element "oxygêne" in 1777 in the erroneous belief that it was an essential constituent of all acids (Greek όζυς, oxys, sharp, sour; *γεινμαι*, geinomai, I produce; i.e. acid forming).

H. Cavendish (1781) reported that water constituents of oxygen and hydrogen. The decomposition of water into its two constituents was first performed in 1800 by *W. Nicholson* and *A. Carlisle* through electrolysis.(7)

2.2 Old Production Techniques

Before the development of low-temperature distillation route oxygen was made by chemical methods. In the United Kingdom *Brin's* process was operated commercially from 1886 to 1906(7). It depended on laboratory observations that barium oxide would react with atmospheric oxygen at about 500°C and that the peroxide so formed would decompose if the temperature was raised to about 800°C,

$$2\ BaO + O_2 \xrightarrow{500^{\circ}C} 2\ BaO_2 \xrightarrow{800^{\circ}C} BaO + O_2$$

In commercial practice it was found that the barium oxide lost its power to react after a few cycles unless the incoming air was first freed from carbon dioxide, organic matter and dust.(7) It was also found that, instead of the expensive and time-consuming practice of raising and lowering the temperature by 300°C, the process could be operated at about 600°C using two different pressures :

$$2BaO + O_2 \xrightarrow{2.0\ atm} 2BaO \xrightarrow{0.05\ atm} 2BaO + O_2$$

The gas produced by this process was impure by modern standards, usually containing 90-96% oxygen together with nitrogen and smaller amounts of argon and other gases. Occasionally, small-scale laboratory preparations of oxygen are required and the method chosen depends on the amount and purity required and the availability of services. Electrolysis of degassed aqueous electrolytes produces wet O_2, the purest gas being obtained from 30% potassium hydroxide solution using nickel electrodes. Another source is the catalytic decomposition of 30% aqueous hydrogen peroxide on a platinized nickel foil.

Many oxoacid salts decompose to give oxygen when heated. A convenient source is $KClO_3$ which releases oxygen when heated to 400-500°C according to the simplified equation(2),

$$2\ KClO_3 \xrightarrow{\Delta} 2\ KCl + 3O_2$$

The decomposition is reduced to 150°C in the presence of

MnO_2 but then the product is contaminated with up to 3% of ClO_2. Small amounts of breathable oxygen for use in emergencies (e.g. failure of normal supply in aircraft or submarines) can be generated by decomposition of $NaClO_3$ in "Oxygen candles". The best method for the controlled preparation of very pure oxygen is the thermal decomposition of recrystallized pre-dried, degassed $KMnO_4$ in a vacuum line. $Mn^{(VI)}$ and $Mn^{(IV)}$ are both formed and the reaction can be formally represented as(2),

$$2\ KMnO_4 \xrightarrow{215\ -\ 235^{o}C} K_2MnO_4 + MnO_2 + O_2$$

Where electric power is exceptionally cheap, oxygen may be manufactured by the electrolysis of water,but the amount made by this process constitutes a very small percentage of total production in USA and Canada(8).

By far, the most important method of manufacturing oxygen is by means of fractional distillation after the liquefaction of air. Liquid air is essentially a mixture of approximately one-fifth oxygen and four-fifths nitrogen. Nitrogen, having a lower boiling point, is allowed to escape, leaving oxygen in the liquid form, which may then be purified.

2.3 Gas Liquefaction

Air-separation plants are built for a wide variety of outputs: To produce one or more of the products in liquid form; and to make products of various purities. The precise practical method employed depends to some extent on the definition of these requirements.

An air-separation plant, however, always has three basic stages, namely purification, liquefaction and distillation. The other processes of prime importance is that of heat transfer, so as to keep losses of coldness to minimum. Among these four processes, liquefaction of a gas presented a serious challenge which was the first article in establishing the gases industry.

Michael Faraday (1845) was able to liquefy many gases for the first time, including ammonia, chlorine, sulphur dioxide and hydrogen sulfide(7). He generated his gas in one arm of a sealed tube shaped like an inverted V and immersed the other arm in an appropriate cooling mixture, so that a combination of high pressure and low temperature was achieved in one piece of equipment.

Despite the efforts of other workers who used still high pressure there remained a number of gases which could not be converted to liquid form and these became known as "permanent gases". It was only when the concept of critical temperature was developed following Andrew's work on carbon dioxide in 1869 that the liquefaction of permanent gas became possible.(6) The critical temperature is defined as that temperature above which it is impossible to liquefy a gas however great the applied pressure. It should be noted that the critical pressure is the pressure required to liquefy the gas at its critical temperature. At lower temperatures a lower pressure suffices.

Oxygen was first liquefied in 1877 by two workers quite independently using quite different methods.(7)

Cailletet (France) cooled oxygen to -29°C by bath of evaporating sulphur dioxide,compressed to a pressure of 200 atm and released the pressure suddenly. A mist of liquid oxygen was seen. He observed the same phenomenon when using carbon monoxide, acetylene and nitrous oxide but not with hydrogen.

Pictet (Switzerland) used a method now known as the "cascade method" which involves proceeding to lower and lower temperatures in a series of stages using different coolants. Thus he liquefied oxygen compressed to 320 atm by cooling it in liquid carbon dioxide at 140°C. The latter had in its turn been obtained by cooling in sulphur dioxide

Wroblewski and *Olszewski* in the period 1880-90 were the first to obtain relatively large quantities of liquid oxygen.

They employed a cascade method sometimes combined with gas expansion.(7)

Another feature of work with liquefied gases is the difficulty of keeping any product obtained. The influx of heat from the surroundings posed serious problems for the workers in this field. The major advance was made by *Dewar* (1892) when he invented a vacuum flask to store liquefied gases originally designed by *d'Arsonval* in 1887.(7)

Production of oxygen on an industrial scale was pioneered by *Linde company* (1900) who built an air liquefier using ammonia for precooling(9). Further development have been carried out by the same company in 1902 and 1907 when they erected the single and double-stage air separation column, respectively.

Other companies, *Claude*, *Heylandt* and *Messer*(9&10) became involved in the air liquefaction and separation of air constituents since 1902.

The first commercial plants for oxygen production by the low temperature distillation method were started up almost simultaneously in England, Germany and France (1912) based on technical developments by *Hampson*, *Von Linde* and *Claude* respectively.(9)

Further improvements to the air liquefaction plants were added by Linde Co. (1926) who in 1932 introduced expansion turbines for the first time in air separation plants[10].

Kapitsa (1937-39) built a high efficiency expansion turbine permitting air separation on the basis of a low pressure cycle alone. *Kapitsa's* low-pressure cycle is the basis of all existing tonnage air separation plants.

Continued increase in efficiency and capacity resulted in plants capacities of 70,000 cubic meter per hour in the seventies[9]. In 1985, the world production of liquid oxygen to half million tons with a purity of around 99.5%[11]

2.4 Heat Exchanger Network Optimization

In the oxygen plant under question, the liquefaction duty is actually performed through network of heat exchangers. Any possible optimizing of this network will support an optimum final design of the plant. Due to the rising costs of energy, the design of an optimal heat exchanger network between hot and cold process streams becomes an important problem. A heat exchanger network is defined as several heat exchangers arranged in series and/or parallel to affect the heat exchange between several hot and cold streams. The target was always to minimize the total area required for heat exchange using a thermodynamic approach. Other economic factors were not taken into consideration.

Early optimization work on heat exchanger networks was reviewed by *Hendry et al.*(12) and *Raghavan* (13). Some of the early authors used heuristic approaches for stream matching which do not guarantee optimality. A practical method of evaluating the heat exchange among multiple streams in parallel and in series was developed by *Chato et al.*(14). This can be used most effectively in the final design stage of a heat exchanger network. *Lee et al.*(15) used a mathematical approach based on a branch and bound method to synthesize networks and find the optimum. This procedure requires too much time for large-scale problems.

Nishida et al.(16) used an algorithm which they claimed give the least total heat transfer area and, by using a few heuristic rules, reduced it to a final form. *Raghavan* argued that this method did not guarantee optimality and proposed a Heat Availability Function (HAF) with which the maximum recoverable energy could be computed. An algorithm to determine an optimal network was also presented. In 1978, *Linnhoff* and *Flower* (17) presented a method similar to that presented by *Raghavan* in that they proposed a method which first generated preliminary networks which gave maximum heat recovery and then a final network was evolved using the preliminary networks as starting points. *Malhotra et al.*(18) used the Discrete Maximum Principle to minimize the total cost of heat exchanger chains in which one cold stream was heated by several hot auxiliary streams. In an extension to this work, *Siddique et al.*(19) considered the optimization of a heat exchanger train (as a network sometimes called) in which one cold stream to be heated by several hot streams using the same procedure as in their earlier work. Recently, *Siddique et al.*(20) extended their earlier work to include two cold streams. This method can only be applied to small-scale problems and is thus restrictive.

Parkinson et al. (21) considered the optimal design of resilient heat exchanger networks. A resilient network is defined as one which can tolerate fluctuations in stream temperatures and flow rates. They presented an algorithm which synthesized networks resilient for all stream fluctuations and minimized network investment costs for the conditions of maximum energy recoverable. In an extension of their earlier work, *Parkinson et al.*(22) also solved the problem of resilient heat exchanger networks optimization using Monte Carlo simulation.

Hesselmann (23) presented an approach which incorporated the economic aspect of heat exchanger design. A functional relation between minimum investment costs and energy losses was determined and, by plotting the investment costs against energy losses, an optimal network could be determined.

The above approaches to the problem of heat exchanger network optimization rely on large computer algorithms and are time consuming. A hand application technique has been used by *Linnhoff* and *Turner* (24) and *Hindmarsh et al.*(25) to optimize various process systems, including heat exchanger (or heat-recovery) systems. In 1980, Chato et al.(26) presented a simpler method based on the second law of thermodynamics, using the load curves for a particular problem. The method can be easily performed on a graph.

In this literature survey, the ideas and sometimes the expressions of the cited papers were used.

Chapter Three

METHOD OF ANALYSIS

It has been understood that oxygen production is compromised of four processes: compression, heat removal, liquefaction, and rectification of air. For these processes to be evaluated and analyzed, a large set of thermodynamic calculations are needed. The multiple parameters of plant circuit (like flow rate, pressure, temperature, product purity, product state, etc.) make it more complicated.

To perform necessary calculations for the plant parameters when operating under steady state, it has been thought of a computer program which is able to simulate the actual design of the plant as close as possible. Through the plant simulation program, a large set of runs could be performed in order to evaluate the circuit parameters under a set conditions of operation.

To get the required program, two options exist. The first one is to construct an independent, specific and comprehensive program which should meet all details given by the plant design. Although it is direct and attractive, this option calls for a tedious and complicated work because of the wide variety of processes and equipment. Even, the resulting program will still satisfy only the plant under question , which in turn seems a simple gain when compared with the efforts behind.

The second option suggests to search for a program among several of them available in the market.; Fortunately, the Faculty of Engineering and Technology at the University of Jordan possesses and provide a quality computer software.

Finally, after the investigation of different technical softwares available at the faculty, a computer simulating program referred to as COMPUTER CODE has been chosen to perform the simulation of the oxygen plant. In the coming section, CODE is briefly described.

3.1 CODE Program

CODE is a steady state process simulator that calculates heat and material balances around process equipment. It is able to

1. prepare process design,
2. analyze design alternatives,
3. predict the effect of changes on plant operating conditions,
4. optimize energy consumption and
5. eliminate bottlenecks and increase throughput.

CODE contains a database with physical properties of 427 pure substances. The user can also create his own database containing other components by supplying the required physical properties.

Flowsheets containing up to 100 streams and 50 pieces of equipment can be simulated. With the aid of 16 built-in equipment modules, it is possible to model virtually all process plants. A brief description of each equipment module will follow.

3.1.1 CODE skills

These skills are listed in the CODE menu shown below.

```
                    C O D E        M E N U

A. ------------>  Input/Edit Data File
B. ------------>  Input Data Checking
C. ------------>  CODE Flowsheet Simulation
D. ------------>  Run Time Message
E. ------------>  Report Generation
F. ------------>  Pure Components Databank
G. ------------>  HP Plotter Driver
H. ------------>  Apple Laser Writer Driver
I. ------------>  List Data Files
J. ------------>  Type Files
K. ------------>  Tray Sizing Input
L. ------------>  Exit - Return to DOS
```

This menu is the interface with different phases of the package.

A. Input/Edit Data File

This is the user interface with the system. With Option A one can create new problems, review results of problems already run, or build case studies or make modifications of previously run problems.

B. Input Data Checking

Once a problem has been created or modified, this phase of system is used to check or detect input errors in the problem data.

C. CODE Flowsheet Simulation

This is the computational phase of the program. Phase C reads the problem data file, performs the calculations, and records the results in the problem data file.

D. Run Time Message

This program allows to review any screen messages or error messages which may have occurred during a problem run. Phase D should be run each time when the problem calculations are performed.

E. Report Generation

This phase reads the problem output file and generates a report containing the problem results.

F. Components Databank

This program accesses the physical properties in the pure component databank. It allows inspection of the databank and the addition of new components and pseudo components.

G. HP Plotter Driver

This program provides an interface to the Hewlett-Packard 7400 series plotters. This phase is used to generate a graphical hard copy of the flow sheet outputs.

H. Apple Laser Writer Driver

This program provides an interface to the Apple Laser Writer. It is used to generate graphical hard copy flow sheet outputs.

I. List of Data Files

This program will list all data files (files with .DAT extension) on the default directory.

J. Type Files

This program will print a file to the screen. This option can be used to type out various files, such as Data, Result, or Report files.

K. Column-Tray Sizing

This program allows to enter data for tray sizing. It must be executed before the Report program.

L. Exit - Return to DOS

This program allows users to leave CODE and return to DOS.

3.1.2 Run procedure

1. Through phase A a data file is created. By the graphics option within this phase a set of equipment modules are selected, laid down and then connected to each other according to the problem being dealt with. Both equipment and streams are automatically numbered. Necessary information are provided by using the spreadsheets option. Local menus are so helpful to indicate the required information either for equipment or streams. Of course, the user should begin with specifying the components handled by his process(es) and thermal options of solution.

2. Phase B is used to survey errors accompanying step # 1. If errors are assigned, phase A is recalled to correct them or their causes. When phase B shows a well refined data file, it becomes possible to move further to the next step.

3. Phase C is selected and the required data file is assigned. Calculations will be performed upon a number of loops depending on how far entered data can help accuracy.

4. Phase D is then loaded to display errors detected during performing the calculations.

5. Using phase E a report file is generated. There is a variety of report files : comprehensive, stream details only, equipment details only, both stream and equipment

details or what is referred to as the user report.

3.1.3 Equipment modules

The following list introduces the equipment modules available in CODE.

ABSR : Absorber-stripper module using absorption and stripping factor method of Edmister.

ADBF : Two-phase equilibrium flash module with a third product stream containing a free water phase in hydrocarbon systems.

COLM : Comprehensive, rigorous multistage equilibrium routine using a modified simultaneous corrections algorithm. COLM can handle up to 300 stages and is relatively fast for problems with few components. It may be used for simulating absorbers, and fractionators.

CTRL : Flow sheet controller with feed forward and feedback control.

DISC : Short-cut distillation rating or design module. In the design mode, three options are available for feed tray location. In the rating mode, the fractional recovery of the light key component is computed.

DIST : Component splitter module.

DVDR : Stream and component divider module. It divides one input stream into two to six streams with flow or proportional control and arbitrary component separation.

ENTM : Isentropic compressor or expander for vapor or gas.

EVLP : Phase envelope module which generates dew point, bubble point, and condensing curves.

FHTR : Fired heater module controlling either output temperature or heat addition.

HXER : Multi-pass heat exchanger module with ten modes. Change of phase is allowed and single- or two-stream cases can be used.

MIXR : Rigorous mixing point module with flash equilibrium at the output.

MMIX : Simple stream adder module. It should always be followed in the layout by an ADBF if thermal conditions are important.

PUMP : Liquid pump or multistage polytropic vapor compressor module.

REAC : Simple stoichiometric reactor module with heat of reaction.

TOWR : Fast, comprehensive , multistage equilibrium routine using a state-of-the-art "inside-out" algorithm. This module should be used instead of COLM to save run-time. TOWR is limited to 100 stages. It may be used for simulating absorbers, strippers, reboiled absorbers, and fractionators.

VALV : Downstream pressure controller module.

The modules have been used in simulating the plant are : DVDR, ENTM, HXER, MIXR, PUMP, TOWR and VALV.

3.2 Plant Simulation

This section describes the simulation steps with reference to Figure 3.1.

Prior to the implementation of plant simulation the following assumptions have been established :

a) The plant operates under steady-state conditions.

b) Air is assumed to be a binary mixture of only nitrogen and oxygen with molar ratios of 81% and 19% , respectively. This means that other constituents of air (water vapor, carbon dioxide other hydrocarbons, argon, helium, etc.) were neglected based on their very small total contribution to an air sample when compared with that of the two major constituents (N_2 and O_2.)

c) Also, air is assumed to follow the laws of perfect gas when necessary for the simulating program.

d) Refrigeration losses to ambient were neglected along the heat transfer blocks of the simulated layout.

e) The whole quantity of air fed to the compressor is processed by all the rest of equipment; i.e. no purging losses are allowed.

Figure 3.2 shows the scheme of equipment connection.

- Air compressor

In the plant description, its operation has been reported to be normal with a volumetric flow rate of air supplied for separation ranging from 750 m^3/hr to 1056 m^3/hr. A flow rate of 40 mol/hr (961.62 m^3/hr at 20°C and 1.0 atm) has been selected. Under temperature of 15.6°C and pressure of 1.0 atm, this is equivalent to 947.608 m^3/hr. Both values are in good agreement with the range specified before.

The four-staged , inter-cooled compressor is simulated using the two equipment modules ENTM and HXER.

The temperature increase of the compressed air due to deviation from isothermal compression has been limited to the final (fourth) stage of compression.

According to Figure 3.1, ENTM # 1 through ENTM # 4 stand for the respective four compression stages. Heat exchanger modules HXER # 5 through HXER # 7 simulate the respective three inter-coolers of the compressor, while HXER # 8 represents the terminal cooler.

In fact, the compression process could be simulated as a one-staged process without altering the final state of air at compressor delivery.

– Preliminary heat exchanger

Through this exchanger, air is precooled to its purification temperature (10 - 12°C). Moisture separators have not been included in the analysis because moisture (water vapor) was not assumed as a constituent of air.

According to the operating principle of this exchanger, direct heat exchange only occurs between the hot stream (air) and one cold stream (nitrogen). The other cold stream (oxygen) is not allowed to exchange heat directly with air; its effect is to sustain the temperature of nitrogen as long as the heat transfer mechanism is valid.

Three units of equipment module HXER are connected to simulate the function of the preliminary heat exchanger.

- Air purifier

Following the assumption that air is a binary mixture of only nitrogen and oxygen, air purifier is automatically dropped off. The only effect produced by this equipment is the temperature rise of air across the purification process by 2°C. This effect is considered in the analysis. Equipment module HXER # 13 is used to provide the required temperature rise.

- Heat exchanger/upper half

For this exchanger, the part before the branching of air stream will be termed as upper half while that part after the branching will be termed as lower half.

Through the upper half of the heat exchanger air is to be cooled to the inlet temperature of the turboexpander.

Two units of equipment module HXER (HXER # 11 HXER # 12) are arranged to represent a three-stream heat exchanging unit. A divider module (DVDR # 14) precedes the formed unit to split the air stream into two streams. Splitting ratio complies with thermodynamic equilibrium which requires that air (as a single stream) has a unique temperature at any specified location of the heat exchanger.

- Heat exchanger/lower half

Through this section, part of the processed air (40%) is allowed to exchange heat with the two cold streams (N_2 and O_2). A divider module (DVDR # 17) precedes the exchanger section to partition the air stream. The rest of the air (60%) is directed to the turboexpander (ENTM # 18). A divider module (DVDR # 19) is again used to split the main hot stream in order to have the arrangement of three-stream heat-exchanging section.

Beyond this section of the heat exchanger, the outgoing hot stream is throttled by equipment module VALV # 23.

The outlet pressures of both turboexpander and throttling valve comply with the requirements of the separation unit

- Lower column

An equipment module, TOWR # 24, is used to simulate the lower column of the separation unit. The selected mode of operation guarantees the distillation fraction assigned by the manufacturer.

- Sub-cooler A21

This sub-cooler is also a three-stream equipment. Its function is to sub-cool each of the two streams (liquid nitrogen, liquid oxygen-riched air) leaving the lower column. HXER # 25 and HXER # 26 are the simulating modules.

Across both outlet streams, two valve modules (VALV # 28 and VALV # 29) throttle the running streams to the pressure range required by the upper column follows.

- Sub-cooler A6

For sub-cooling the main product (liquid oxygen) emerging from the upper column by the incoming liquid oxygen-riched air, HXER # 27 exists to simulate the required sub-cooler.

- Upper column

A tower module (TOWR # 30) is used to represent the upper rectifying column. The selected operating mode guarantees the flow rate of the final product as assigned by the manufacturer.

A pump module PUMP # 31 is used across the sub-cooled liquid oxygen stream for the latter to be compressed to the required handling pressure.

The two streams outgoing from the upper column (gaseous nitrogen and liquid oxygen) are the same cold streams encountered by the heat exchangers later.

HXER # 33 & HXER # 34 are being used as temperature controllers to isolate the liquefaction block (preliminary heat-exchanger, heat exchanger and turbo-expander) from temperature variations that may occur at the exit of the rectification block whenever some parameters of the latter are altered.

A divider module, DVDR # 32, is located across the nitrogen stream at the entrance to the preliminary heat-exchanger. This divider corresponds to an actual one in the plant layout design. Its function is to make part of the nitrogen stream bypass the preliminary heat-exchanger for the outlet temperature of the precooled air not to violate its assigned range (5 - 7^{o}C).

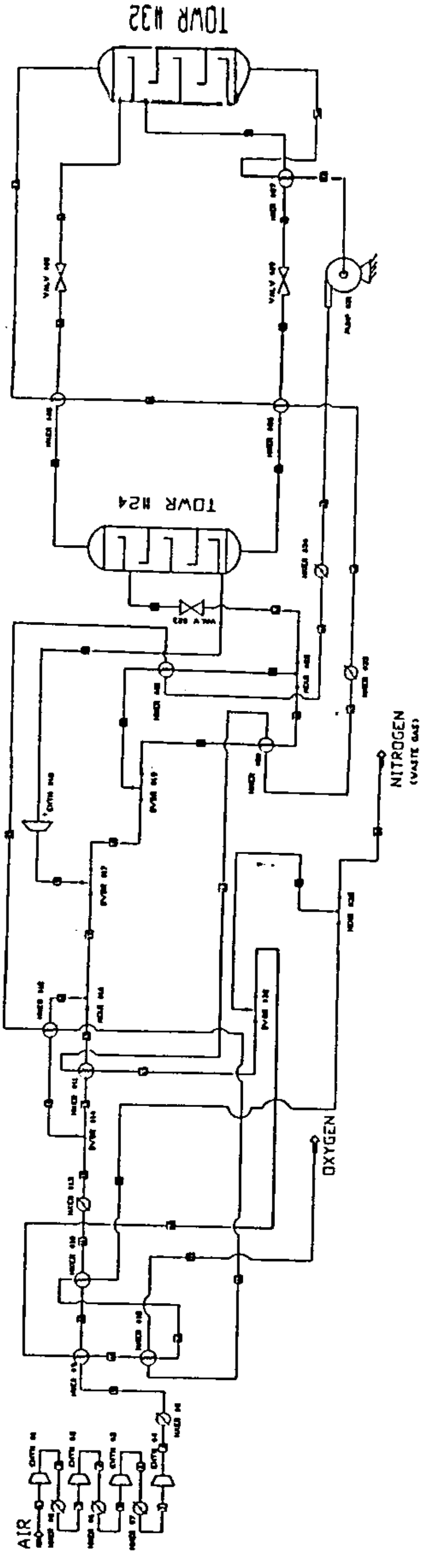


Figure 3.1 Simulating flowsheet of the oxygen plant of type K-0.15

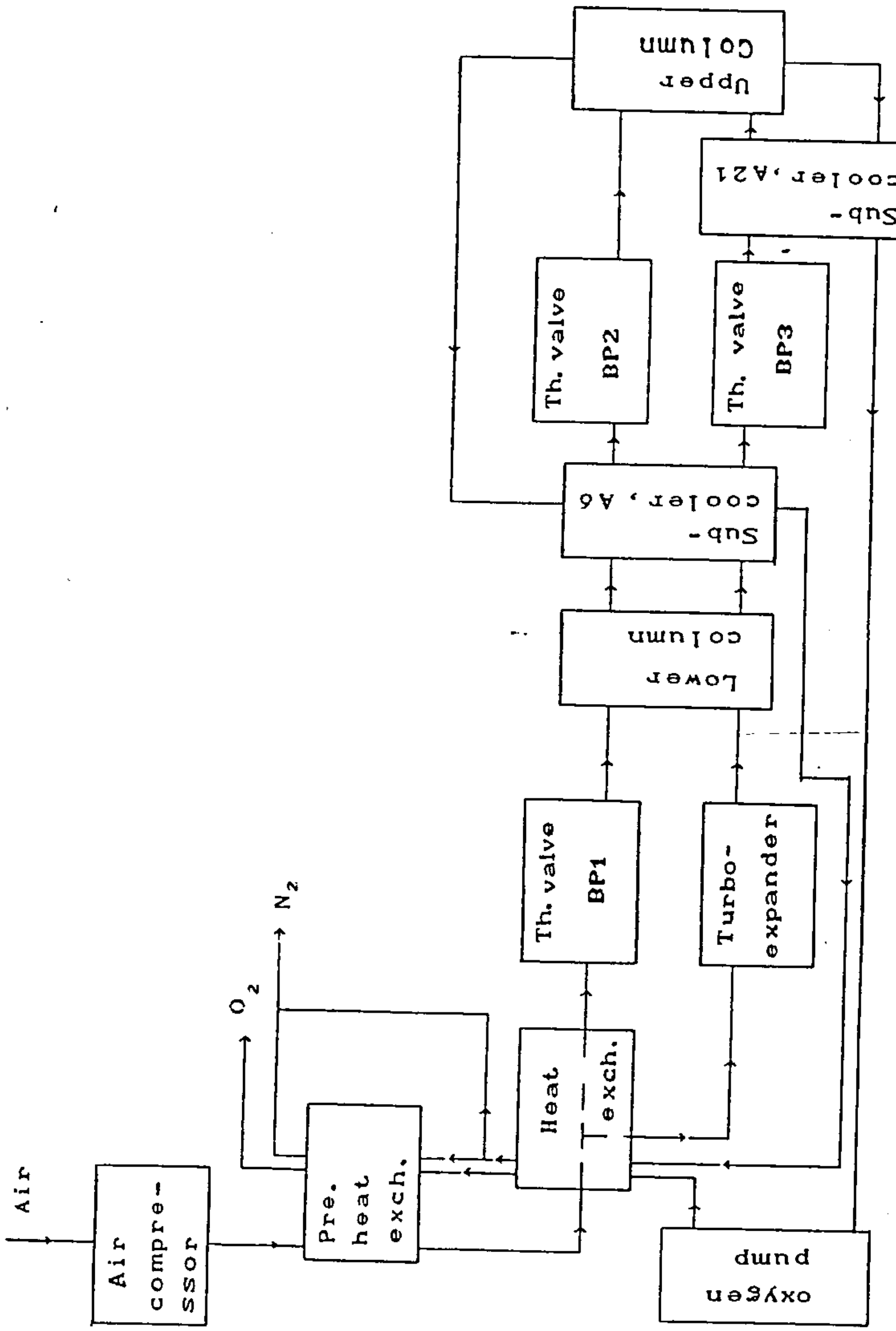


Figure 3.2 : Scheme of equipment connection

Chapter Four

INVESTIGATION OF THE EXISTING PLANT

4.1 Introduction

4.1.1 Optimum process design

Air-separation process may be considered as a series of unit operations. The various components are closely integrated by the process designer and optimized to suit the particular requirements and to suit available energy source(s).

The important factors which influence the selection of the process within the oxygen plant are

- energy consumption,
- product quantity,
- investment cost,
- product purity,
- product state (temperature, pressure, phase)
- continuity of product supply,
- plant flexibility,
- maintenance cost and
- permissible plant dimension.

These factors remain in continuous conflict when searching for an optimum design. The primary factor determining the cost of the product is the energy cost.

As to our plant, energy is lost due to the following causes

a) low efficiencies of energized equipment (compressor, pump, electric heater)

b) heat in-leak to cold blocks due to the imperfect insulation.

c) incomplete heat transfer resulting from imperfect heat exchanger network.

To improve the efficiencies of the compressor, the pump and the electric heater, it is necessary to increase the capital cost of the plant. Also, to improve the efficiency of the insulation, more expenditure is necessary. However, increasing the efficiency of the heat exchanger network does not necessarily require higher cost.

The plant circuit shows that heat is being exchanged across three locations within the plant. These locations are

1. compressor inter-coolers,
2. sub-coolers contained in the air-separation unit and
3. cooling and liquefaction block (preliminary heat exchanger, heat exchanger and turbo-expander).

A compressor inter-cooler is a water-cooled air cylinder.

Its effectiveness depends on inlet temperature of the cooling water which in turn is determined by the flow rate of water.

For the sub-coolers contained in the air-separation unit, the configuration of streams is controlled by the operation principle of the rectifying columns and so their efficient operation is an integrated part of an effective rectification block.

Since the circuit arrangement does not employ an independent refrigerating system for the liquefaction of air, the cooling and liquefaction block becomes of most importance to focus on. Within this block, expansion of air by the turbo-expander provides the necessary cooling effect. After the separation of air into liquid oxygen and gaseous nitrogen, a heat exchanger network is used to utilize the coolness within the separation products to cool the incoming air.

The following section is an energy integration analysis to investigate the present layout of the plant and to suggest improvements that may be necessary.

4.2 Energy Integration Analysis

4.2.1 Method of approach

The starting point for an energy integration analysis is the calculation of the minimum heating and/or cooling requirements for a heat exchanger network. These calculations can be performed given the input and output streams without having to specify any heat exchanger network. Similarly, we can calculate the minimum number of heat exchangers required to obtain the minimum energy requirements without having to specify a network. Then the minimum energy requirements and the minimum number of heat exchangers provide targets for the subsequent design of heat exchanger network.

Two well-known approaches are available to estimate the minimum requirements of energy; they are

1. Composite Curves and
2. Problem Table.

In the first approach a single composite of all hot and a single composite of all cold streams are produced in the temperature-enthalpy (T-H) diagram, and handled just in the same way as a two-stream problem. This method will not be used because it would require graph paper and cut and paste approach (for sliding the graphs relative to one another) which would be messy and imprecise.

The second approach which has been published by Linnhoff and Flower (1978)(17), is used for considering the energy targets algebraically. This approach will be adopted because of its simplicity and applicability to computer handling.

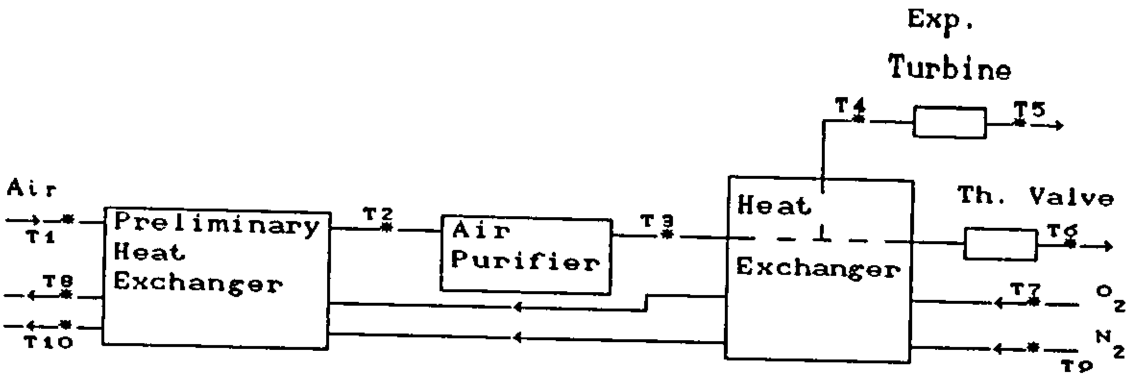
4.2.2. Stream definition

Figure 4.1 shows the connection scheme within the stream-equipment layout of the cooling and liquefaction block in the plant. Also, design-temperature ranges at the equipment boundaries are shown.

Figure 4.2 illustrates the formation of streams according to which the coming analysis is based.

Considering the fluid type, three streams are formulated, they are air, oxygen and nitrogen. The first one is hot stream while the other two are cold streams. Physically, the hot stream, H, 1is splitted into two parts at the middle of the heat exchanger, A4. The first part, H2, moves through the turboexpander while the other part, H3, is throttled by valve BP1.

The oxygen stream conserves itself as one cold stream, C1. The nitrogen stream, C2, is divided into two parts. The first part travels through the preliminary heat exchanger. The second part bypasses the exchanger such that the outlet temperature of incoming air is controlled. The latter part is excluded from the formed streams. The part which goes through the exchanger is chosen to be the third cold stream,



T1 :(15 to 40 °C), T2 :(5 to 10 °C), T3 :(7 to 12 °C)
T4 :(-130 to -115 °C), T5 :(-173 to -168 °C), T6 :(not specified)
T7 :(-183 to -180 °C), T8 :(10 to 35 °C), T9 :(-175 to -173 °C)

Figure 4.1 : stream-equipment layout

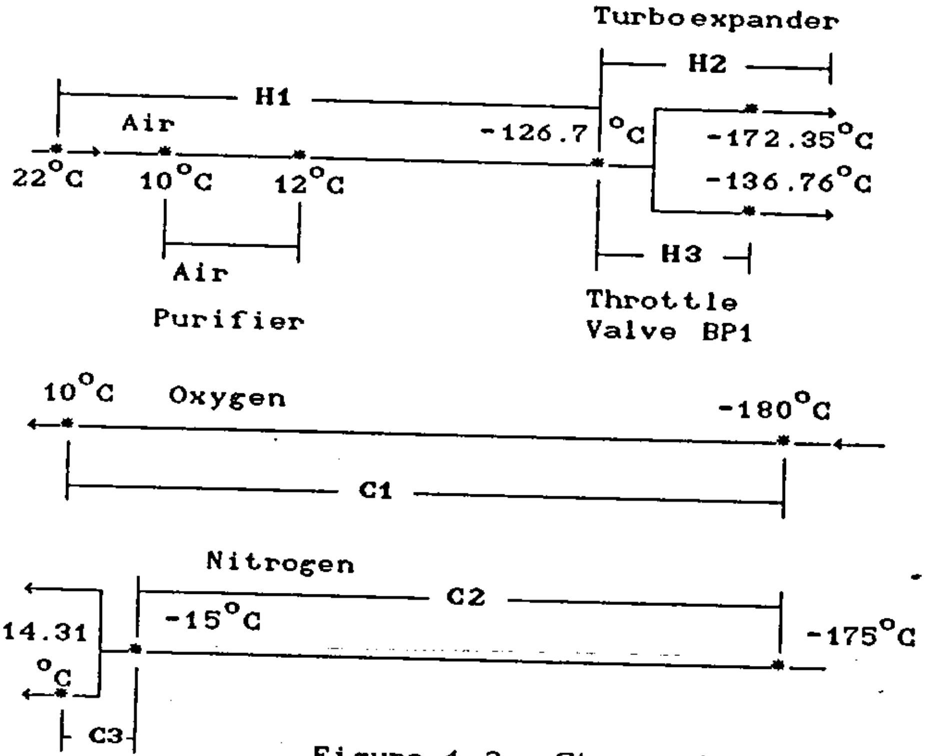


Figure 4.2 : Stream formation

C3.

Using the flowsheet shown in Figure 3.1, hot and cold streams are defined as follows :

Hot stream no.1; H1 (22.0 to -126.69°C)

Comprises air streams numbered in the flowsheet as *9, 10, 11,12, 13, 14, 15, 16* and *17*.

Hot stream no.2; H2 (-126.69 to -172.35°C)

Comprises air streams numbered as *19* and *26*.

Hot stream no.3; H3 (-126.69 to -136.76°C)

Comprises air streams numbered as *18, 20, 21, 22, 23* and *24*.

Cold stream no.1; C1 (-180.0 to 10.0°C)

Comprises oxygen streams numbered as *42, 45, 46* and *51*.

Cold stream no.2; C2 (-175.0 to -15.0°C)

comprises nitrogen streams numbered as *43,44,47*.

Cold stream no.3; C3 (-15.0 to 14.31°C)

Comprises nitrogen streams numbered as *48, 49, 36* and *38*.

The temperature-enthalpy diagram can be used to represent the thermal characteristics of process streams, as illustrated in Figure 4.3. When a differential heat flow dQ is added to a process stream, it will increase its enthalpy (H) by CP*ΔT, where,

CP = heat capacity flow rate (kW/K)

= mass flow rate, $\overset{o}{m}$ (kg/s)* specific heat, C_p (kJ/kg.K)

ΔT = differential temperature change

Recalling the assumption of air as an ideal gas and assuming that CP = constant then, the following balance becomes possible,

$$\overset{o}{m}*C_p*\Delta T = CP*\Delta T \qquad (4.1)$$

Hence dQ will be the same as ΔH.

Then CP may be calculated as follows,

$$CP_i = \Delta H_i \,/\, \Delta T_i \qquad (4.2)$$

where i denotes the stream number.

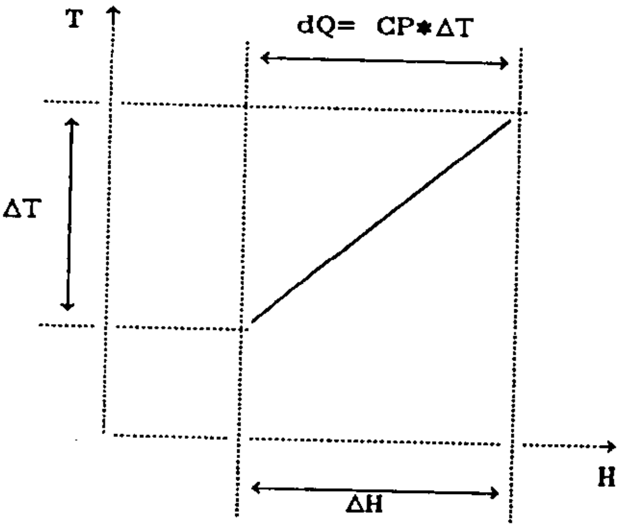


Figure 4.3 temperature — enthalpy diagram

Table (4.1) shows the streams defined before along with their supply and target temperatures, enthalpies and heat capacity flow rates.

TABLE 4.1 – STREAM DATA

Stream No & Type	T_s (°C)	Enthalpy at T_s (kW)	T_t (°C)	Enthalpy at T_t (kW)	CP (kW/°C)
H1, hot	22.0	222.82	-126.69	161.10	0.4151
H2, hot	-126.69	96.66	-172.35	89.94	0.1472
H3, hot	-126.69	64.44	-136.76	59.63	0.4776
C1, cold	-180.00	16.72	10.00	38.55	0.1149
C2, cold	-175.00	130.99	-15.00	173.98	0.2687
C3, cold	-15.00	57.41	14.31	59.96	0.0870

4.2.3 Calculation of minimum energy requirements

A very simple way of incorporating the second law of thermodynamics into the energy integration analysis was presented by hohmann(27), Umeda et al(28) and Linnhoff and Flower(17). Their analysis will be followed.

Initially, a minimum driving force (temperature difference), ΔT_{min} should be specified. The economical value of ΔT_{min} is usually estimated by trading off energy against capital cost. However, an experience value of ΔT_{min} will be adopted. For a refrigeration system the experience value of ΔT_{min} is $5^{o}C$. Now, we can establish two temperature scales on a graph , one for hot streams and the other for cold streams, which are shifted by $5^{o}C$. See Figure (4.2).

Then the stream data are plotted on this graph. Next we establish a series of temperature intervals that correspond to the heads and tails of the arrows , i.e., the inlet (supply temperature, T_s) and the outlet (target temperature, T_t) of the hot and cold streams as given in Table (4.1). Temperature intervals are superimposed.

Setting up the intervals in this way guarantees that full heat interchange within any interval is possible since the driving force is already adequate. Hence, each interval will have either a net surplus or a net deficit of heat as dictated by enthalpy balance, but never both. This is shown in Table 4.2. Knowing the stream population in each interval (from Figure 4.4), enthalpy balances can easily be calculated for each according to

$$\Delta H_i = (T_i - T_{i+1})(\Sigma\ CP_{cold} - \Sigma\ CP_{hot})_i \quad \text{.........} \quad (4.3)$$

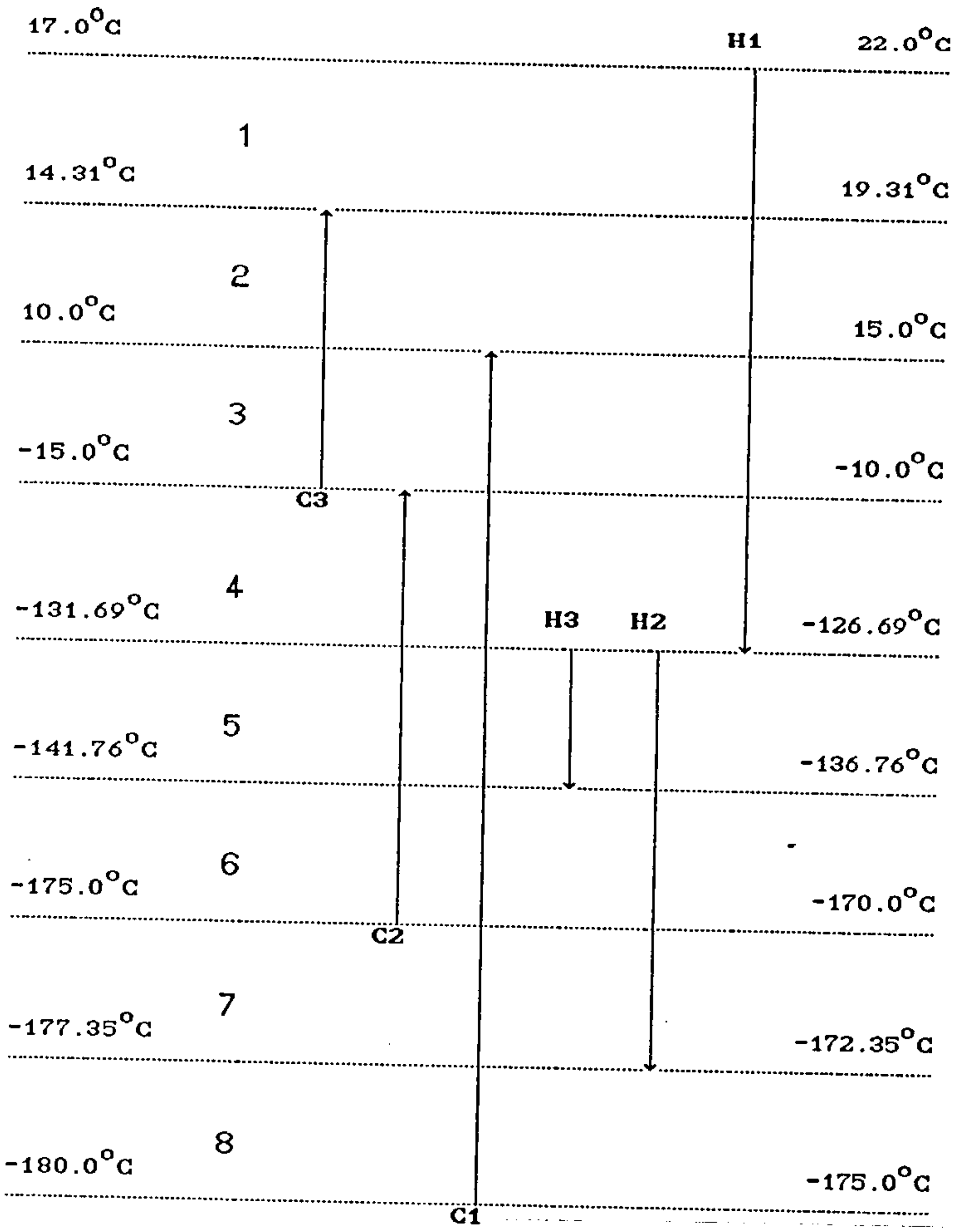


Figure 4.4 — Temperature interval analysis

for any interval i. The last column in Table 4.2 indicates whether an interval is in heat surplus or heat deficit. It would be possible to produce a feasible network design based on the assumption that all "surplus" intervals rejected heat to cold utility, and all "deficit" intervals received heat from hot utility.

Now, considering the results shown in Table 4.2, Figure 4.3 explains what is called *HEAT CASCADE PRINCIPLE* by which it is possible to evaluate the minimum requirements of energy for a specified process..

TABLE 4.2 – TEMPERATURE INTERVAL ANALYSIS

	Interval No. (i)	$T_i - T_{i+1}$ (°C)	$\Sigma CP_{cold} - \Sigma CP_{hot}$ (kW/°C)	ΔH_i (kW)	Surplus or Deficit
17.0°C					
	1	2.69	- 0.4151	-1.1166	Deficit
14.31°C					
	2	4.31	- 0.3281	-1.4141	Surplus
10.0°C					
	3	25.0	- 0.2132	-5.3300	Surplus
-15.0°C					
	4	116.69	- 0.0315	-3.6757	Surplus
-131.69°C					
	5	10.07	- 0.2412	-2.4289	Surplus
-141.76°C					
	6	33.24	+ 0.2364	+7.8579	Deficit
-175.0°C					
	7	2.35	- 0.0323	-0.0759	Surplus
-177.35°C					
	8	2.65	+ 0.1149	+0.3045	Surplus
-180.0°C					

Assuming that no heat is supplied to the hottest interval (1) from hot utility, a surplus amount of 1.1166 kW is cascaded into interval (2). Interval (2) has a 1.4141 kW surplus which will be joined with the income from interval

(1) to produce a heat flow of 2.5307 kW passed to interval (3). The cascading process continues through the rest of intervals as shown in Figure 4.5.

By completing the cascading process, the minimum energy requirements are shown to be 5.8788 kW cold.

Appendix B shows the results of the temperature interval analysis for values of ΔT_{min} ranging from 0.0 to 10.0°C .

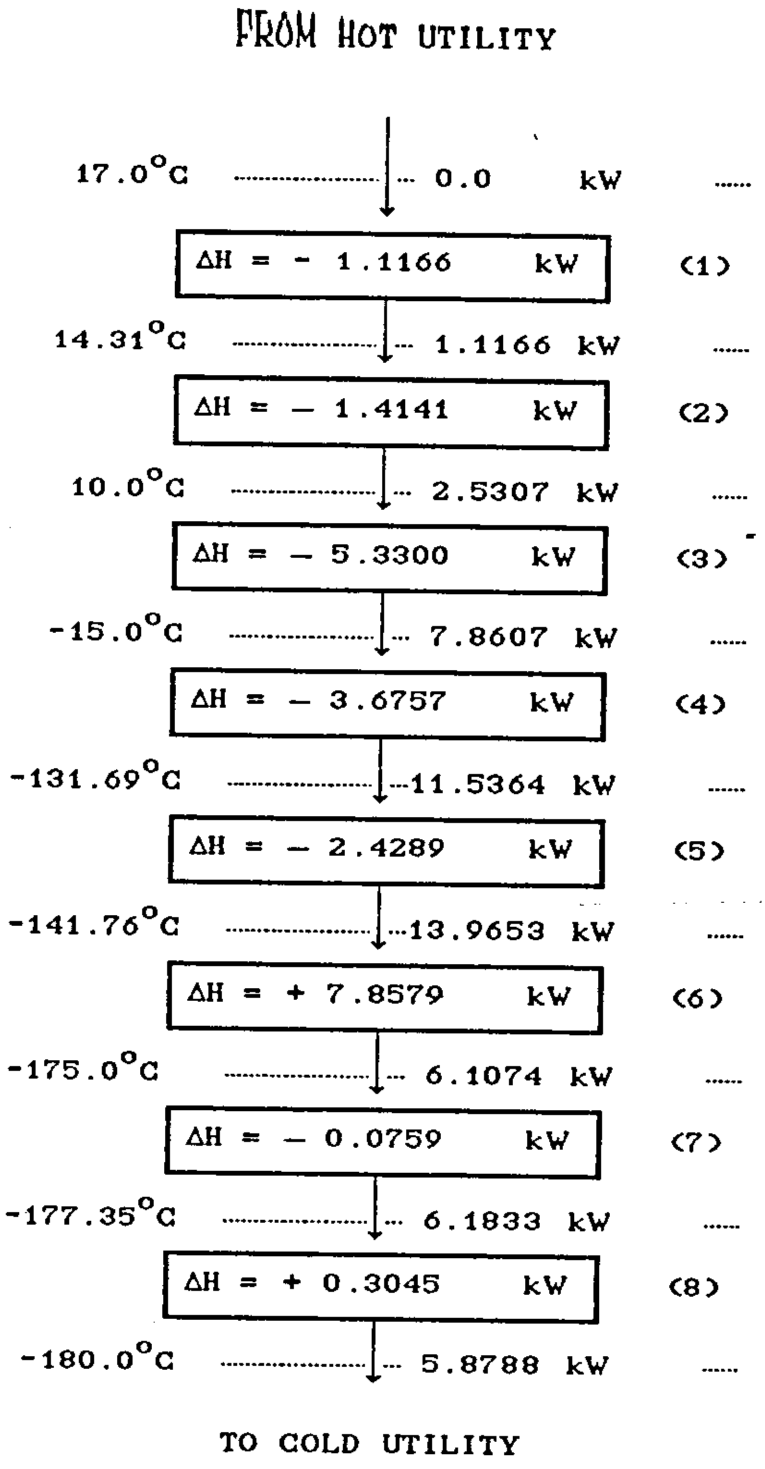


Figure 4.5 – Heat cascading

4.3 Maximum Energy Recovery Design

There are other characteristics of the optimum heat exchanger network. An optimum network should use the minimum area of heat transfer. Also, the number of employed heat exchangers within such network should be minimum. These two characteristics could be investigated for a certain design by using an analysis called MAXIMUM ENERGY RECOVERY (MER) design.

4.3.1 Stream matching / exchanger network

The ruling criterion , is to maximize the individual loads of matches (exchangers) in order to have the minimum number of operating units. This aspect is simply imposed by the fact that the capital cost increases as the number of employed units increases.

Figure 4.6 illustrates the working streams and their enthalpies. The actual cooling utility is also shown.

H 1 air 61.725 kW	H 2 air 6.72 kW	H 3 air 4.805 kW	
C 1 oxygen 21.83 kW	C 2 nitrogen 43.00 kW	C 3 nitrogen 2.35 kW	Turbo - expander 5.8764 kW min 6.4 kW rated

Figure 4.6 — Stream enthalpy

A simplification of the configuration shown in Figure 4.6 is possible; that is to let both C2 and C3 be one stream, say C2'. This unification is justified as follows

a) physically, C2 and C3 are one stream (both are nitrogen and also have the same pressure) and

b) outlet temperature of C2 is the same as the inlet temperature of C3.

When the plant is under operation, the partitioning of nitrogen stream into two streams (C2 & C3), Figure 1.1, occurs at inlet to the preliminary heat exchanger.

In order to sustain thermal equilibrium, the newly formed stream C2' must have

a) a total enthalpy equivalent to the summation of the individual enthalpies of both C2 and C3 and

b) a target temperature similar to that of the two streams when mixed at the exit from the preliminary heat exchanger, (1.2°C). Then,

$$\text{Enthalpy of } C2' = \text{Enthalpy of } C2 + \text{Enthalpy of } C3$$

$$= (CP * \Delta T)_{C2} + (CP * \Delta T)_{C3}$$

$$= (0.2687)(175 - 15) + (0.087)(15 - 12)$$

$$= 45.341 \text{ kW} .$$

The resulting heat capacity flow rate of the new stream will be

$$CP = \frac{\Delta H}{\Delta T} = \frac{45.341 \text{ kW}}{(175 + 1.2)^{o}C}$$

$$= 0.2573 \text{ kW}/^{o}C$$

Now, the streams configuration may be redrawn as illustrated by Figure 4.7.

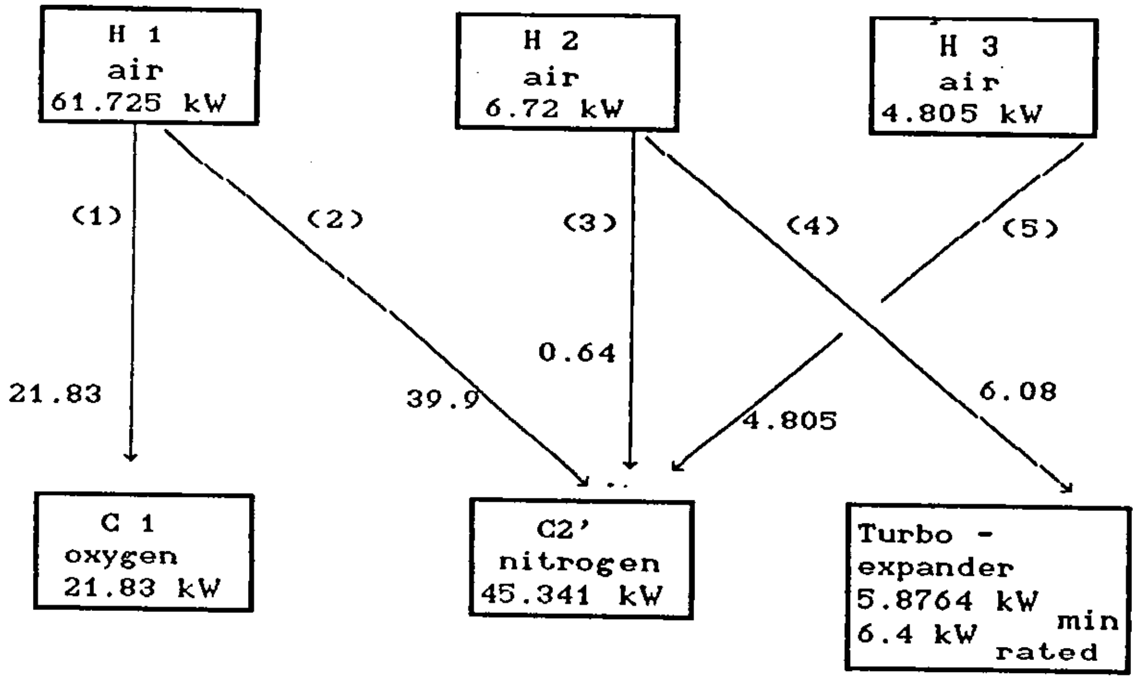


Figure 4.7 — Stream matches

The Figure also illustrates 5 matches started from the cold end (oxygen stream) with their loads.

In this configuration, it is noticed that match (3) is relatively so small to deserve an independent heat exchanger. H3 could be cooled further if the load of match (3) is reloaded upon match (5). This in turn, will leave the cooling load required by H2 handled by only one match; that is match (4). What we have truly done is that we increased the minimum cooling requirement a bit. There is nothing being sacrificed, since the rated capacity of the available cooling utility (turboexpander) allows for such an increase, recall that its rated capacity is 6.4 kW min.

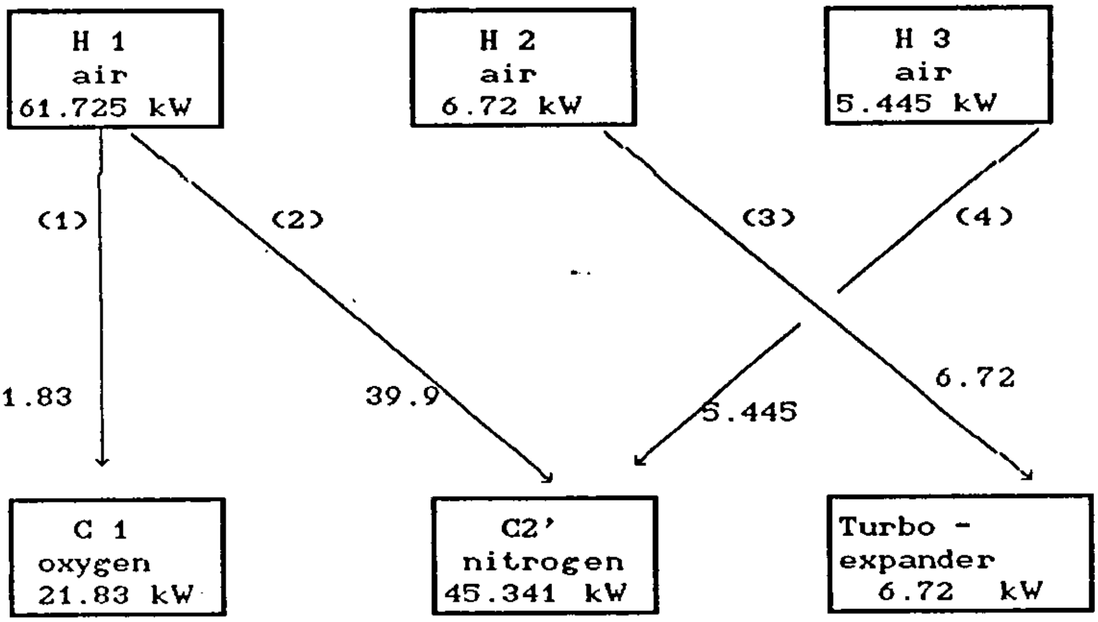


Figure 4.8 —Final configuration

Figure 4.9 shows the final configuration of stream matches and the relevant loads. This configuration indicates that three heat exchangers are needed plus a cooling utility.

It is a common practice to start a design at its most restrictive location. The hot air stream H1 should be interrupted at a certain point; that is, air purifier with a predetermined temperature interval. A temperature increase of 2^{o}C across the air purifier is reported by the manufacturer. The inlet temperature to this unit ranges from 5^{o}C to 10^{o}C.

As a result of this restriction, it becomes necessary to implement matching of streams starting from the hot end bearing in mind that both matches (1) and (2) will be upon two stages to allow for cooling interruption imposed by the air purifier.

Match 1/ 1st stage : H1 is let to exchange heat with C1 such that the outlet temperature of H1 permits a feasible matching with C2'; the minimum temperature difference across the warm end of a match (a heat exchanger) should be equal (or even greater than) $\Delta T_{min} = 5^{o}C$ as presumed at the beginning of analysis. This match stage will be denoted by 1-1.

Match 2/ 1st stage : H1 matches with C2' after it has been cooled through match 1-1. This match stage will be denoted by 2-1.

Along the match stages; 1-1 & 2-1, H1 is to be cooled from its supply temperature down to $10^{o}C$ which is the maximum permissible value of inlet temperature of air to the purifier. The accompanying temperature drop is chosen to be divided equally among the two match stages.

Supply temperature of C1 is

$$(T_s)_{C1} = (T_t)_{C1} - \frac{(CP * \Delta T)_{H1}}{(CP)_{C1}}$$

$$= 10 - \frac{(0.4151)(6)}{0.1149}$$

$$= -11.7^\circ C$$

Supply temperature of C2' is

$$(T_s)_{C2'} = (T_t)_{C2'} - \frac{(CP * \Delta T)_{H1}}{(CP)_{C2'}}$$

$$= 1.2 - \frac{(0.4151)(6)}{(0.2573)}$$

$$= -8.5^\circ C$$

See Figure 4.8.

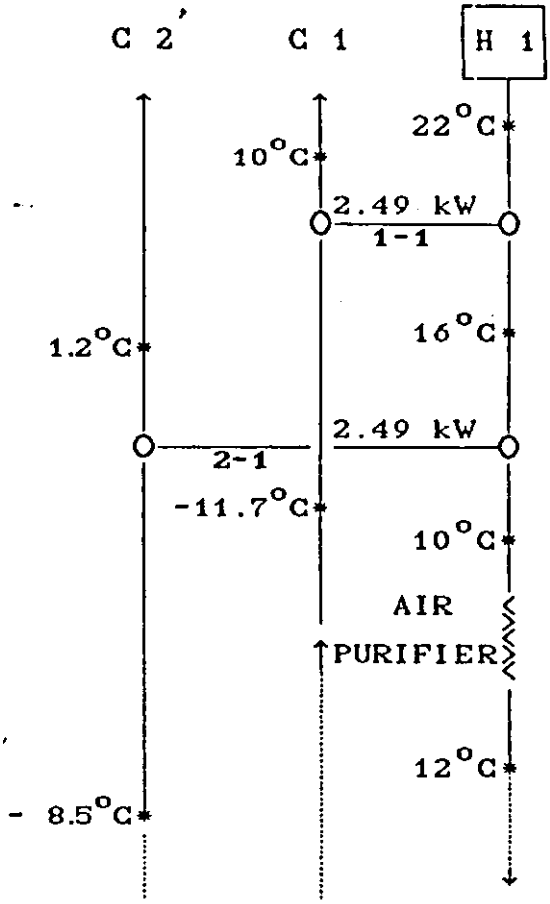


Figure 4.9 Matches 1 and 2/ first stage

By the end of this stage we have :

Supply temperature of H1 = 12°C,

Target temperature of C1 = - 11.7°C and

Target temperature of C2' = - 8.5°C.

The load left to the 2nd stage of match 1, denoted by 1-2, will be 21.83 -2.49 = 19.34 kW. Similarly, the load of the 2nd stage of match 2; denoted by 2-2, will be

39.9 * 2.40 = 37.41 kW. See Figure 4.10.

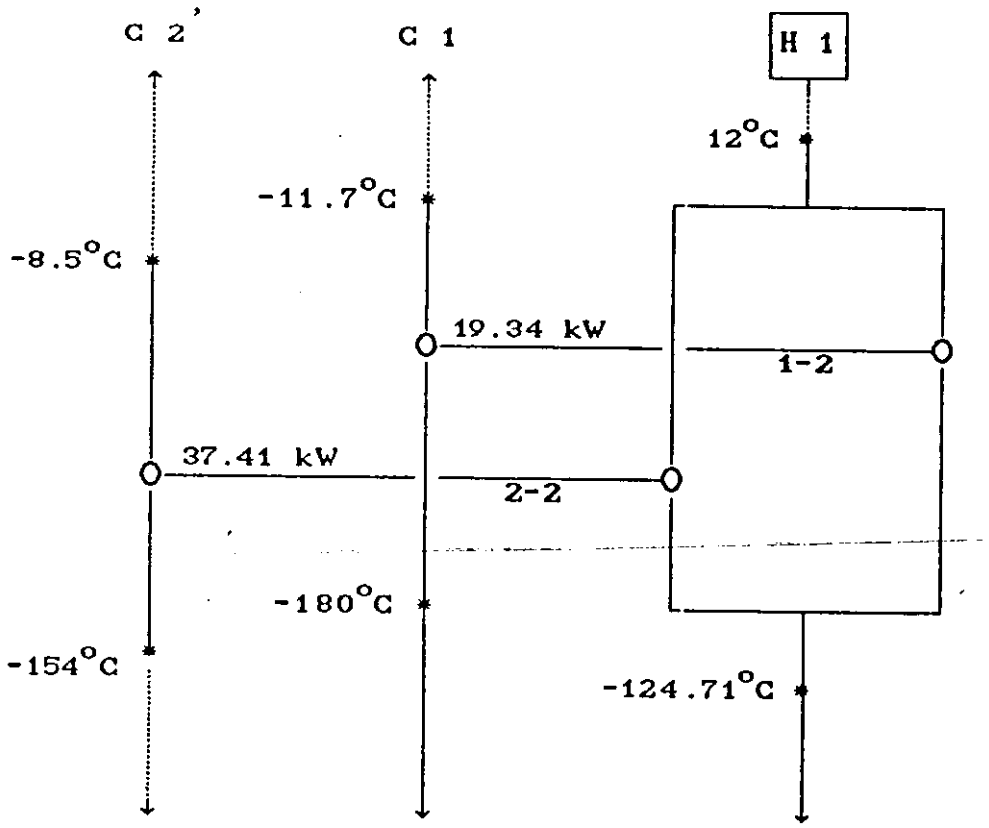


Figure 4.10 – Matches 1 and 2/ second stage

For stream H1 it has been splitted because air stream (H1) actually exchanges heat in parallel with both oxygen stream (C1) and nitrogen stream (C2'). On the other hand, the ratio of splitting should keep air temperature always having the same value of temperature within both resulting parts.

The ratio of air stream splitting is determined in accordance with the decided partial loads. Then :

$$\text{H1-part for match 1-2} = \frac{19.34}{19.34 + 37.41}$$

$$= 34\%\ \text{H1}$$

$$\therefore \text{H1-part for match 2-2} = 1.0 - 0.34$$

$$= 66\%\ \text{H1.}$$

Now, target temperature of H1 is

$$(T_t) = T_s - \frac{\Delta H}{CP}$$

$$= 12.0 - \frac{19.34 + 37.41}{0.4151}$$

$$= -124^{o}C,$$

which confirms with technical characteristics of the turbo-expander; since it includes that the inlet temperature of air to the expander should be within (-130 to -115)°C.

Supply temperature of C1 is

$$(T_s)_{C1} = (T_t)_{C1} - \frac{(\Delta H)_{\text{match 1-2}}}{(CP)_{C1}}$$

$$= -11.7 - \frac{19.34}{0.1149}$$

$$= -180^{o}C$$

Supply temperature of C2' is

$$(T_s)_{C2'} = (T_t)_{C2'} - \frac{(\Delta H)_{\text{match 2-2}}}{(CP)_{C2'}}$$

$$= -8.5 - \frac{37.41}{0.2573}$$

$$= -154.0^{o}C.$$

Now, match 4 must handle a load of 5.445 kW still available in stream C2'.

Target temperature of H3 is

$$(T_t)_{H3} = (T_s)_{H3} - \frac{(\Delta H)_{H3}}{(CP)_{H3}}$$

$$= -124.71 - \frac{5.445}{0.4776}$$

$$= -136.11^{\circ}C$$

Supply temperature of C2' is

$$(T_s)_{C2'} = (T_t)_{C2'} - \frac{\Delta H}{(CP)_{C2'}}$$

$$= -154.0 - \frac{5.44}{0.2573}$$

$$= -175.0^{\circ}C$$

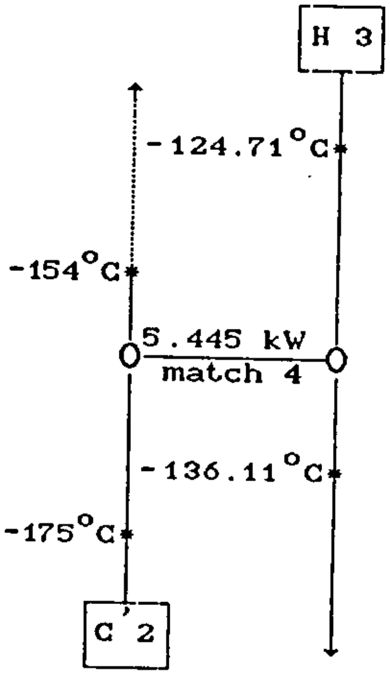


Figure 4.11 — Match 4

A process flowsheet has been established to check the resulting configuration of streams and the relevant matches ; See Figure 4.12.

This flowsheet was exposed to the simulation program of CODE. The results obtained are listed in the Appendix C.

4.4 Column-Tray Sizing

As the simulating program CODE comprises the facility capable for sizing distillation columns, it has been possible to extend our investigation towards the air-separation unit.

A flowsheet segment representing only the double-column rectifying unit is shown in Figure 4.13.

For this segment, the tray sizing calculations were performed using the program phase "Tray Sizing Input". Such calculations aim to estimate the minimum diameters of the distillation columns under operation. The method being used is the Smith-Dresser-Ohlswager technique(30).

The program prompts the user to enter the following data: Tray spacing, down comer area, weir length and weir height; then it calculates a diameter for each tray.

The results obtained and shown in Appendix D reveal that:

- The estimated diameter of lower column $\simeq$ 0.30 m.
- The estimated diameter of upper column $\simeq$ 0.40 m.

But the actual diameters of lower and upper columns within the air-separation unit are 0.4 m and 0.5 m, respectively. This means that both of the rectification columns employed in the plant are capable to separate an additional amount of air into oxygen and nitrogen. Also, this introduces a possibility of expanding the production capacity of the plant while still using the existing air-separation unit. Of course, such expansion should also consider the rated capacities of other existing equipment.

To evaluate the allowance which has already been noticed within both of the rectification columns, CODE program was used. The flow rate of air incoming to the separation unit was increased by increments and then the program phase "Column-Tray Sizing" was run. When the calculations have given column diameters similar to the actual design, a flow rate of air approaching 1.7 times the operating value was permitted. See the results as obtained in the Appendix E.

Figure 4.12 : Optimized exchanger-network of the oxygen plant

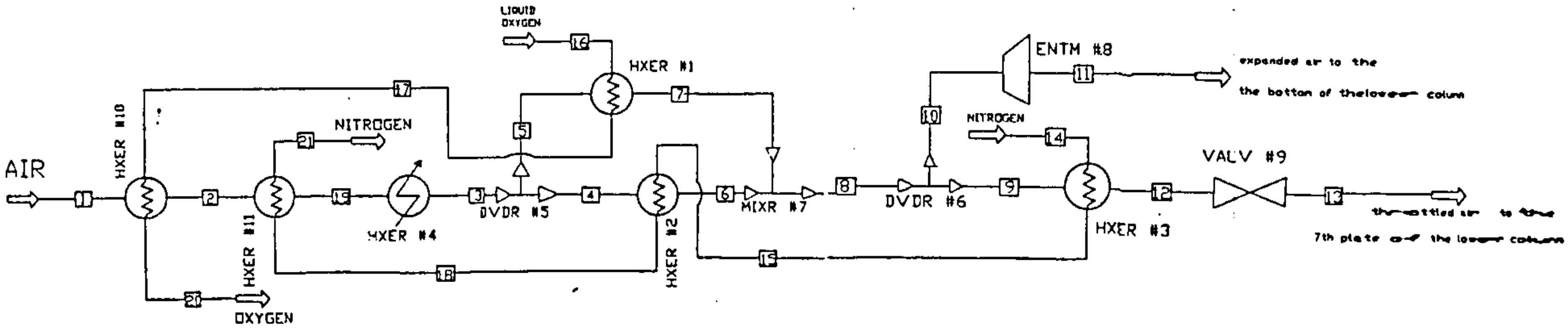
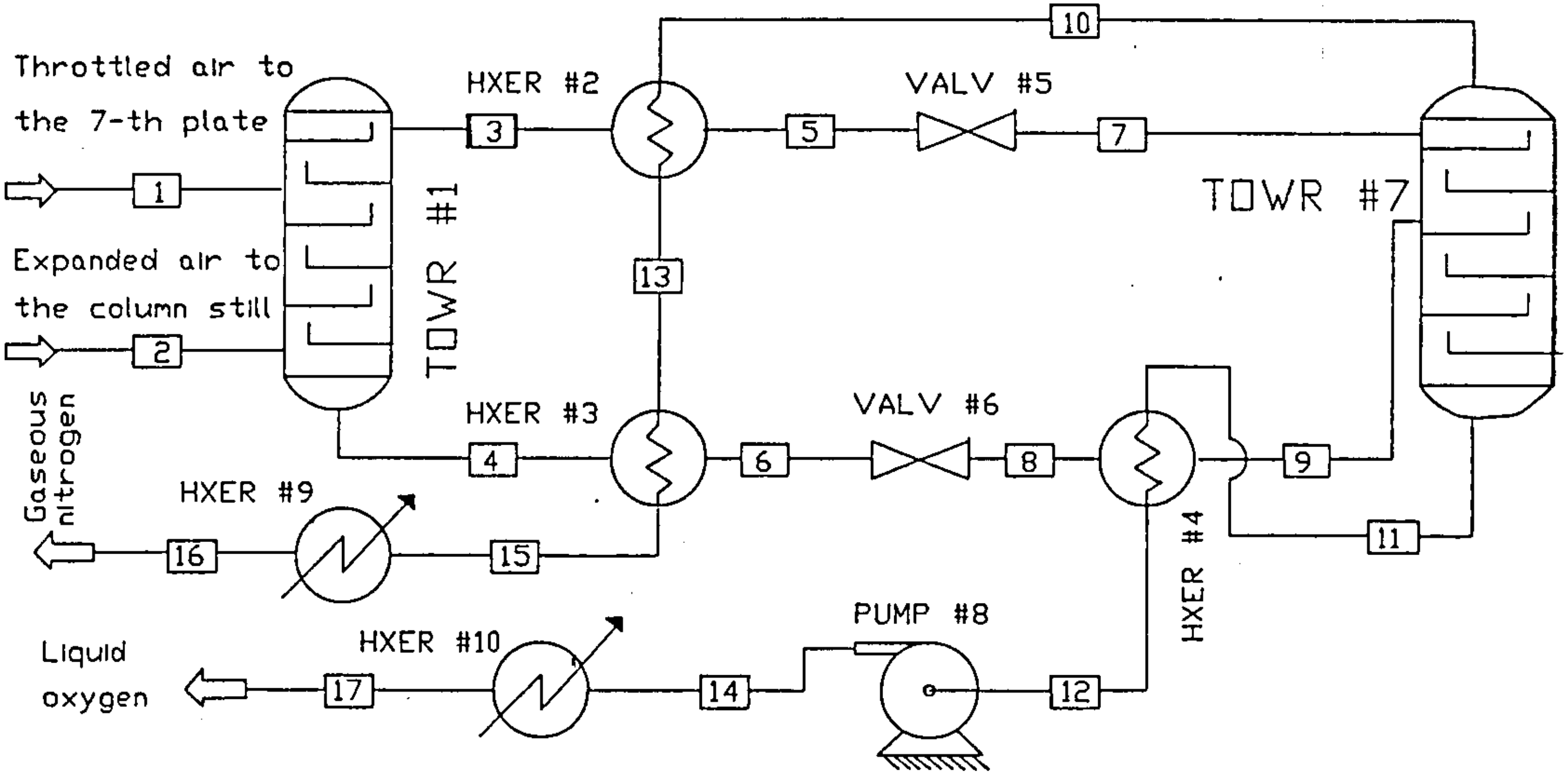


Figure 4.13 : Tray-sizing of the air-rectification columns



Chapter Five

DISCUSSION OF RESULTS

5.1 Base Design

5.1.1 Plant simulation

The results obtained for the simulating flowsheet, shown in Figure 3.1 which are listed in Appendix A, comply with the technical data of the plant as given by the manufacturer. Oxygen purity is only 2% less than stated in the plant certificate. This deviation does not affect the energy requirements of the circuit; Oxygen purity depends only on the operation characteristics of the rectifying columns. According to the module TOWR, its routine comprises several options that may produce values of purity as high as desired by the user. However, this requires larger number of computer runs and hence longer time necessary for the calculations to converge.

In regard to the modules simulating the heat exchangers, the most important parameter is the logarithmic mean temperature difference (LMTD) which is denoted in all results by "corrected delta T." The value substituted for the coefficient of heat transfer (300 $MJ/hr.m^2 \cong 83.33\ W/m^2$) was not determined in advance; It is only an assumed value. The target, here, is to estimate the product value of the overall coefficient of heat transfer, U, times the heat transfer area, A, i.e. "UA" corresponding to a specified LMTD and presumed heat duty, Q, for each heat exchanger.

Values of pressure viewed in all results refer to the absolute pressures.

5.1.2 Evaluation of the heat exchanger network

The question that should be answered in this discussion is whether the heat transfer area used in the heat exchanger network is minimum. To answer this question, one should consider the process flowsheet which has been predicted by the energy integration analysis, Figure 4.12. The total area of heat transfer calculated for this network is then compared with that already exists within the actual design of the plant assuming that the coefficients of heat transfer are kept the same.

The scheme to be applied is as follows:

1. The "UA" product of all actual heat exchanger network are are estimated using the general equation of heat transfer,

$$Q = U * A * LMTD \quad ....(5.2)$$

where,

Q : Load of the exchanger, kW,

U : Overall coefficient of heat transfer of the exchanger, $W/m^2.^\circ C$,

A : Heat-transfer area of the tube side , m^2 and

LMTD : Logarithmic mean temperature difference across the heat exchanger, $^\circ C$.

LMTD is known for any heat-exchanging section and Q is obtained from the results of the program calculations. Then, the product "UA" is determined by the equation (5.2). See Table 5.1.

2. Using the same equation, the corresponding "UA" products for the predicted flowsheet in Figure 4.11 can be evaluated using results found in Appendix B. See Table 5.2.

3. The values of the overall coefficient of heat transfer for the actual design are evaluated as follows

$$U_{actual} = \frac{\text{"UA"}_{actual}}{A_{actual}} \quad ....(5.3)$$

where A_{actual} is recalled from the technical data given for the plant. See Table 5.3.

4. Then the resulting values of U in step 3 and the corresponding "UA"'s in Table 5.2 are substituted in the

following equation to find the predicted area,

$$A_{predicted} = \frac{\text{"UA"}_{predicted}}{U_{actual}} \quad \ldots\ldots\ldots\ldots \quad (5.4)$$

See Table 5.4.

TABLE 5.1 : "UA" FOR ACTUAL DESIGN

Section	Simulating Module	Q (kW)	LMTD (°C)	"UA" (W/°C)
Heat Exchanger/				
- upper half :				
* Air - nitrogen	HXER # 11	39.58	30.11	1314
* Air - oxygen	HXER # 12	17.90	33.76	530
- lower half :				
* Air - nitrogen	HXER # 20	3.41	37.11	92
* Air - oxygen	HXER # 21	1.40	41.59	34
Preliminary Heat-Exchanger/				
* Air - nitrogen	HXER # 9	2.35	18.32	128
* nitrogen - oxygen	HXER # 15	- 2.52†	1.45	1737
* Air - nitrogen	HXER # 10	2.72	7.37	370
Σ =				4205

---

† the negative sign is imposed because at this section of heat exchanger, the nitrogen works as a hot stream which is opposite to the nitrogen function thoughout the rest of sections.

TABLE 5.2 : "UA" FOR PREDICTED FLOWSHEET

Section	Simulating Module	Q (kW)	LMTD (°C)	"UA" (W/°C)
Heat Exchanger/				
- upper half :				
* Air - nitrogen	HXER # 2	40.00	23.20	1724
* Air - oxygen	HXER # 1	9.87	36.01	274
- lower half :				
* Air - nitrogen	HXER # 3	5.10	32.58	157
Preliminary Heat-Exchanger/				
* Air - nitrogen	HXER # 11	2.38	15.51	153
* Air - oxygen	HXER # 10	1.96	19.04	103
Σ				2411

TABLE 5.3 : "U" FOR ACTUAL DESIGN

Section	"UA" ($W/^{\circ}C$)	A (m^2)	U ($W/m^2.^{\circ}C$)
Heat Exchanger/			
- upper half :			
* Air - nitrogen	1314	4.58	286.9
* Air - oxygen	530	2.29	231.4
- lower half :			
* Air - nitrogen	92	4.58	20.1
* Air - oxygen	34	2.29	14.8
Preliminary Heat-Exchanger/			
* Air - nitrogen	128 + 370		
	= 498	7.1	70.1
* nitrogen - oxygen	1737	1.4	1240.7

TABLE 5.4 : HEAT TRANSFER AREA FOR THE PREDICTED DESIGN

Section	U $(W/m^2.^\circ C)$	"UA" $(W/^\circ C)$	A (m^2)
Heat Exchanger/			
- upper half :			
* Air - nitrogen	286.9	1724	6.0
* Air - oxygen	231.4	274	1.18
- lower half :			
* Air - nitrogen	20.1	157	7.8
* Air - oxygen	14.8	0.0	0.0
Preliminary Heat-Exchanger/			
* Air - nitrogen	70.1	153	2.18
* Air - oxygen	x†	103	x
Σ =			17.16 + x

---

† x stands for the unknown value of the heat-transfer coefficient between air and oxygen since in the actual design of the plant there is no match between these two streams.

For air-oxygen match suggested within the preliminary heat-exchanger, a coefficient of heat transfer similar to that of air-oxygen match within the upper half of the actual heat exchanger is employed ($U = 231.4\ W/m^2.{}^\circ C.$) Also, the geometry of tubes is suggested to remain invariant i.e. tube-in-tube. It is now desired to evaluate the dimensions of these tubes which will suit both the coefficient of heat transfer and the suggested geometry.

When two different fluids, say F and G, flow according to the pattern shown in Figure 5.1, the coefficient of heat transfer U ruling the process of heat transfer between these fluids is estimated as follows(31),assuming that thermal resistance of the tube wall is negligible when compared to the thermal resistance of the fluid film,

$$U = \frac{h_{io} * h_o}{h_{io} + h_o} \qquad \text{.........} \quad (5.5)$$

where,

h_o : film coefficient of heat transfer for fluid F and

h_{io} : film coefficient of heat transfer for fluid G.

Actually h_{io} is the modified value of the coefficient (h_i) which is based on the inside diameter of the inner tube such that,

$$h_{io} = h_i * \frac{d_i}{d_o} \qquad (5.6)$$

where, referring to Figure 5.1,

h_{io} : Modified film coefficient of heat transfer, $W/m^2.°C$,

h_i : Film coefficient of heat transfer based on the inside diameter of the inner tube, $W/m^2.°C$,

d_i : Inside diameter of the inner tube, m and

d_o : Outside diameter of the inner tube, m.

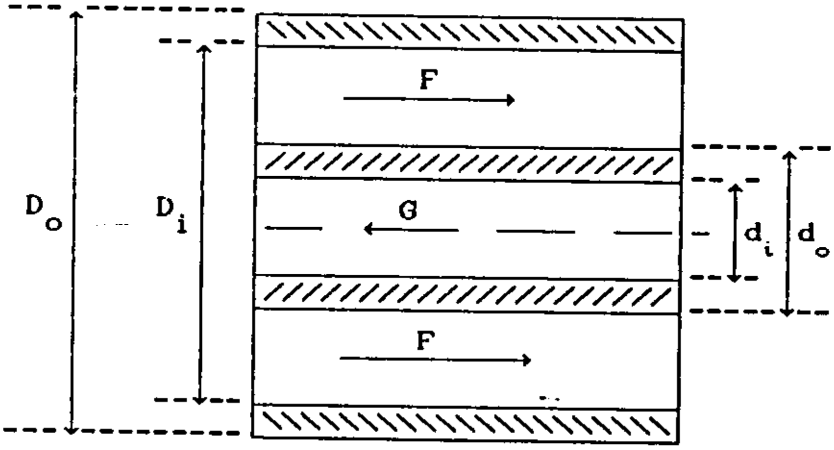


Figure 5.1 Tube-in-tube section

For turbulent flow of gases inside tubes , the film coefficient of heat transfer h can be expressed as a function of both Prandtl and Reynolds numbers as follows$^{(32)}$

$$h = 0.022 * Pr^{0.6} * Re^{0.8} \tag{5.7}$$

To obtain the required value of U (231.4 $W/m^2.°C$), equation (5.5) is used. To determine the appropriate heat transfer coefficients h_o and h_{io} resulting from the suggested geometry (tube-in-tube), one can use equation (5.7) whereby the Prandtl number is known at the corresponding range of temperature. The Reynolds number in the predicted section can be now found. As the Reynolds number is known, one can choose a combination of flow conditions and geometry to satisfy the calculated Reynolds number.

Let's denote the parameters related to the upper half of heat exchanger A4 by "1" and those related to the preliminary heat exchanger A3 by "2".

Then, recalling the necessary values from Table 5.5 and substituting into equation 5.6 will give

$$Pr_1^{0.6} * Re_1^{0.8} = Pr_2^{0.6} * Re_2^{0.8}$$

For air,

$$(1.141)^{0.6} * (6.60866E4)^{0.8} = (0.759)^{0.6} * (Re_2)^{0.8}$$

$$\therefore \quad Re_{2,air} = 8.97 \ E4$$

TABLE 5.5 : Pr & Re NUMBERS FOR AIR AND OXYGEN

Heat Exchanger/ Upper Half

Stream	Prandtle Number	Reynolds Number
Air	1.141	6.60866 E4
O_2	1.010	1.94540 E4

Preliminary Heat-Exchanger

Stream	Prandtl Number
Air	0.759
O_2	1.107

For O_2,

$$(1.010)^{0.6} * (1.9454E4)^{0.8} = (1.107)^{0.6} * (Re_2)^{0.8}$$

$$\therefore \quad Re_{2,O_2} = 1.811E4$$

For the flow inside tube, the Reynolds number is expressed as follows

$$Re = \frac{\rho . v . d}{\mu} \qquad ....(5.8)$$

where,

Re : Reynolds number,

v : Flow velocity, m/s,

d : Tube diameter, m and

μ : Dynamic viscosity of the flowing fluid Pa.s.

But for the flow inside annular space (tube-in-tube), an equivalent diameter, De, is substituted instead of tube diameter, d. For heat transfer, De may be given as in Reference 32,

$$De = \frac{D_i^2 - d_o^2}{d_o^2} \qquad .... (5.9)$$

in terms of the dimensions shown in Figure 5.1, where

D_i : The inside diameter of the outer tube, m.

Now,

$$Re_{2,air} = \frac{\rho \ v \ De}{\mu} = \frac{(53.1).(v).(De)}{1.811E-5} = 8.97 \ E4$$

$\therefore$ $(v.De)_{air}$ = 0.030 and,

$$Re_{2,o_2} = \frac{(304.35).(v).(d_i)}{1.98E-5} = 1.811E4$$

$\therefore$ $(vd_i)_o$ = 1.1782E-3

Let's have for oxygen, 19 tubes of 5x1 mm diametor (similar to the upper-half section within the heat exchanger A4). This will yield a flow velocity of

$$v = \frac{1.1782E-3}{d_i (= 3E-3)} = 0.39 \quad m/s.$$

This value is less than that of the actual design (0.5 m/s). It is noted that oxygen tubes are selected to have the same thickness as in the heat exchanger since the working pressure is assumed similar to the actual design.

To maintain air velocity as in the actual design (5.0 m/s),

$$De = \frac{0.030}{5.0} = 6.0\ E-3\ m = 6.0 \quad mm.$$

Recall that $De = \frac{D_i^2 - d_o^2}{d_o^2}$ where d_o , here, is the outside diameter of the inner (oxygen) tube i.e. 5 mm.

$$\therefore 5.64 = \frac{D_i^2 - 5^2}{5^2} \quad \text{then,}$$

$$D_i = 13.22 \cong 13 \text{ mm}$$

In order to calculate the thickness of the outer (air) tube, the equation of hoop stresses has been used (33). The necessary properties of copper were obtained (34). The thickness was calculated to be 1.0mm. This means that the diameter of the air tube is 15x1 mm.

Since U_{air-O_2} has already been assumed to be 231.4 W/ m². °C and the product of "UA" was determined as 103 W/ °C, then the heat-transfer area required for air-O_2 section will be

$$A_{air-O_2} = \frac{103}{231.4} = 0.445 \ m^2.$$

Hence, the length of the air tube should be

$$L = \frac{0.445}{(19).(\pi).(5.E-3)} = 1.491 \cong 1.5 \ m \ .$$

Finally a bundle of straight, copper tube-in-tube arrangement would be necessary. This will result in a total area of heat transfer pointing to 17.16 + 0.445 = 17.605 m². This resembles a reduction in heat transfer area of about 21% of the existing design (22.24 m².)

5.1.3 Inspection of the air-separation unit/ rectifying columns

Using the program phase named "Tray Sizing Input", it has been possible to investigate the maximum rectification capacity of the two columns within the air-separation unit.

The sizing of a column is based on the *flooding diameter*. It is the maximum diameter beyond which flooding occurs i.e. the column will function improperly.

The lower and upper column diameters needed to rectify the nominal flow r8ate of the incoming air have been calculated to be 0.3 m and 0.4 m, respectively. These diameters are less than those within the existing design. The flow rate of air has then been incrementally raised until both lower and upper columns approach their actual diameters (0.4 m and 0.5 m for the lower and upper columns, respectively). The corresponding value of air flow-rate amounts to 70% above the nominal flow rate.

Through plant details, the maximum tolerance provided for design capacities of equipment was noticed to be less than or equal to 10%. If a similar tolerance is assumed for the air-separation unit, it will have a capacity allowance of 60%. This availability indicates the possibility of increasing the plant productivity. Of course, the plant equipment will respond to the new productivity according to the rated capacity of each. Tracking the plant circuit, the following steps are needed for increasing the productivity of the plant by 60% :

1. Installing another air compressor which is able to deliver 60% of the air flow-rate suggested for the existing compressor at the same outlet pressure. The

resulting two outputs could then join each other in a final single line.

2. Replacement of the air purifier with a new one whose cylinders can accommodate the purification of the extra amount of air flow-rate.

3. Replacement of the expansion turbine with a new one whose liquefaction (refrigeration) duty is high enough to fit the running target.

4. Replacement of the liquid-oxygen pump with a new one capable to pump 60% over the rated capacity of the present pump.

5. Replacement of the existing pipe-network with a new one which is capable to withstand 1.6 times the nominal flow rates.

6. Instruments will be independent of any variation. This is due to the constancy of the properties being measured.

7. A reserve of 21% in the heat transfer area has been estimated to exist within the heat-exchanger network if operated according to the configuration predicted before.

Along with these steps, neither new nor additional civil work will be needed.

5.2. Economical Comparison of the Existing and the Predicted Designs

Table 5.6 illustrates the elements of capital cost of a new oxygen plant based on 1988 prices[1]. The Table also shows the extra capacity for the major equipment within the plant over that given by the manufacturer. This capacity has been evaluated such that the production capacity of the existing plant could be expanded by 60%.

Table 5.7 illustrates the cost of expanding the production capacity of the existing plant by 60% of its nominal value and regarding to the steps listed in section 5.1.4.

TABLE 5.6 : COST ELEMENTS OF A NEW OXYGEN PLANT OF TYPE K-0.15 AND THE EXTRA CAPACITY WITH RESPECT RESPECT TO 60% EXPANSION

Cost element	Cost	Extra Capacity
* Air compressor	$ 100,000	0.0%
* Air purifier	$ 10,000	0.0%
* preliminary heat exchanger,A3	$ 15,000	35.0%
* Heat exchanger,A4	$ 20,000	0.0%
* Turbo-expander	$ 10,000	0.0%
* Liquid-oxygen pump	$ 15,000	0.0%
* Rectifying columns	$ 50,000	100.0%
* Two subcoolers	$ 15,000	0.0%
* Electric system	$ 9,000	100.0%
* Piping system	$ 16,000	0.0%
* Civil construction	$ 75,000	100.0%
Σ Cost	$ 335,000	

TABLE 5.7 : COST OF EXPANDING THE PRODUCTION CAPACITY OF THE EXISTING PLANT BY 60%

Cost element	Cost
* Air compressor	$ 85,000
* Air purifier	$ 12,000
* preliminary heat exchanger,A3	$ 16,000
* Heat exchanger,A4	$ 23,000
* Turbo-expander	$ 12,000
* Liquid-oxygen pump	$ 18,000
* Rectifying columns	$ 0,000
* Two subcoolers	$ 18,000
* Electric system	$ 0,000
* Piping system	$ 25,000
* Civil construction	$ 0,000
Σ Cost	$ 209,000

Table 5.8 shows the annual costs for both the existing and expanded plants(1) .

Now, if JISICO has a future plan demanding more oxygen gas but, less than or equal 1.6 times the production capacity of the existing plant, then two alternatives will rise.

TABLE 5.8 : ANNUAL COST FOR THE EXISTING AND EXPANDED PLANTS

Cost item	Cost value	
	Existing plant	Expanded plant
Electric power	$ 10,000	$ 16,000
Man-power	$ 12,000	$ 12,000
Maintenance	$ 8,000	$ 12,800
Σ	$ 30,000	$ 40,000

These are,

- Alternative 1 : To expand the production capacity of the existing plant by 60%
- Alternative 2 : To install a new plant similar to the existing one.

Upon having a decision to choose either of the two alternatives, lets assume that the company will adopt a simple aggressive policy, and choose a plan for the optimistic sales forecast. This level of analysis is of the least order of complexity(35).

The analysis can be summarized as follows :

(1) The annual costs are estimated for both alternatives 1 & 2.

(2) The cash necessary to start each alternative is annualized. The calcualations are based on 10% interest rate and 20 years life time.

(3) The summation of values estimated in (1) and (2) is divided by the annual amount of production to estimate cost of unit production as expected along the plant life time.

Table 5.9 illustrates this analysis.

TABLE 5.9 : ALTERNATIVE - DECISION ANALYSIS

Description	Alternative (1)	Alternative (2)
(a) Annual cost :		
- Electric power	$ 16,000	$ 20,000
- Man-power	$ 12,000	$ 24,000
- Maintenance	$ 12,800	$ 16,000
Σ	$ 40,000	$ 50,000
(b) Cash for starting	$ 209,000	$ 335,000
(c) Annualized cash	$ 24,549	$ 39,349
(d) Σ (a) & (c)	$ 64,549	$ 89,349
(e) Annual production of oxygen, m^3	(1.6)(1.23E6)*	(2.0)(1.23E6)
(f) Cost of unit production	$ 0.0327	$ 0.0363

Alternative 1 is noticed to cost about 94.5% of the alternative 2 cost.

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* The annual production of the plant is 1,230,000 m^3 of gaseous oxygen(1) .

The estimated cost of unit production does not consider the deterioration factor for either equipment or currency. It only indicates the alternatives costs relative to each other.

Chapter Six

CONCLUSION

The following statements constitue the conclusion of the research :

(1) The oxygen plant under consideration satisfies the condition of the minimum energy requirements by 91.8%. Recall that the rated capacity of the turboexpander is 6.4 kW while the minimum cold requirement has been estimated to be 5.8788 kW.

(2) The heat exchanger network employed within the plant slightly deviates from the optimuum configuration. The heat transfer area of the preliminary heat exchanger A3, could be reduced by 21% if a stream configuration similar to that within the heat exchanger A4 was applied.

(3) The air-separation unit/rectifying columns are capable to handle 60% more flow rate of air than the nominal flow rate. This extra capacity does not consider the (evaporation) losses within practice, it stands for ideal process.

(4) The existing instrumentation of the plant will need few

modifications to accommodate the additional rates.

(5) The cost of equipment replacement has been estimated to be $ 209,000 based on the 1988 prices. While erecting a new similar plant will cost $ 335,000.

(6) The cost analysis presented shows that the cost of unit production if the existing plant is expanded is about 90.0% of the cost if a new similar plant is installed next to the existing one. If the alternative of plant expansion was decided upon, the operation of the existing plant would be stalled to implement the necessary equipment replacement. This may impose additional cost such that expansion becomes not profitable.

(7) The results obtained in this work indicate that expanding the existing plant may not afterall be favourable.

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APPENDIXES

Appendix A

Appendix B

Appendix C

Appendix D

Appendix E

Appendix A

Temperature interval analysis

$\Delta T = 0.0°C$

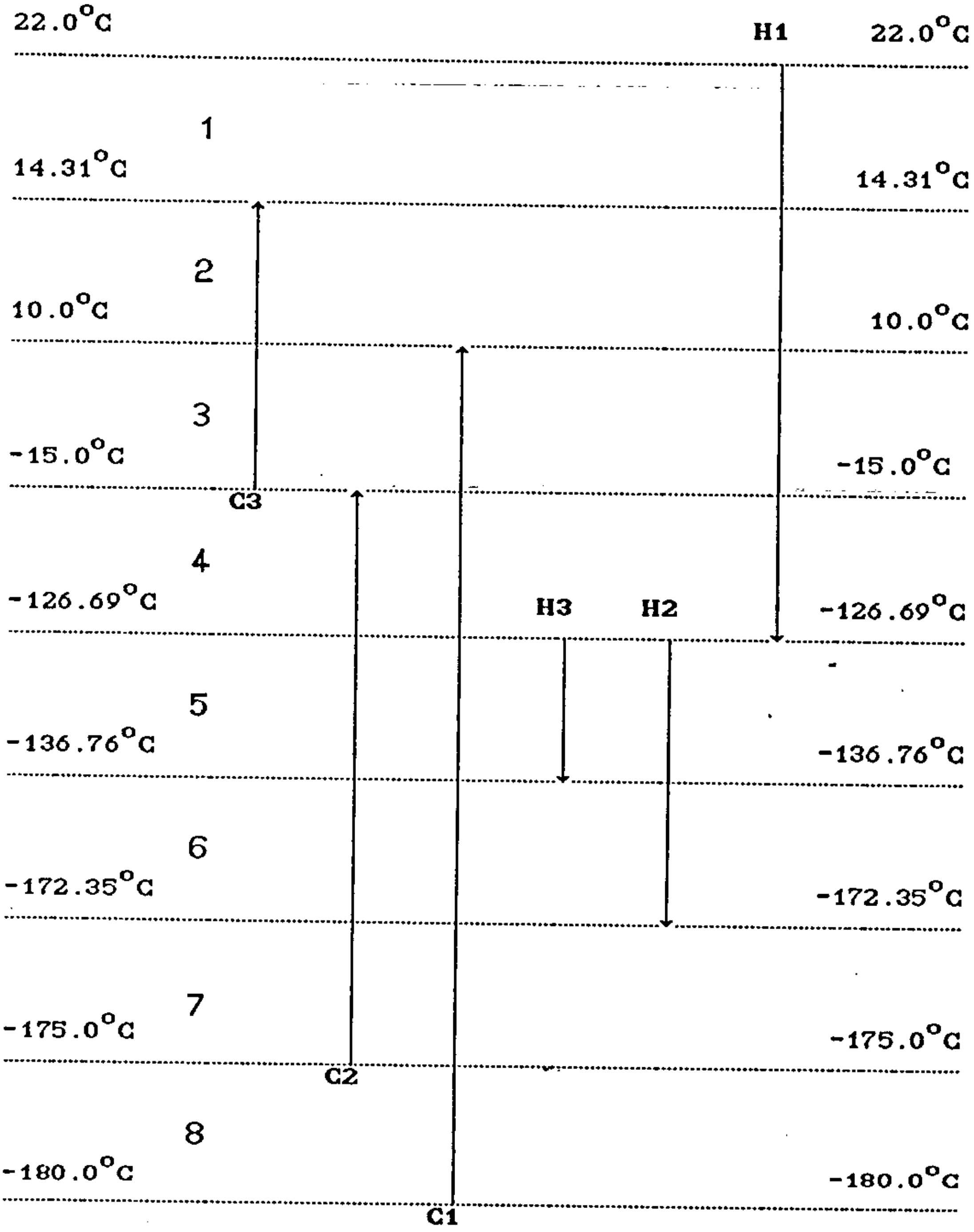

Figure A.1 : Temperature interval analysis

TABLE A.1 : TEMPERATURE-INTERVAL ANALYSIS, $\Delta T = 0.0^{o}C$

^{o}C	Interval No. (i)	$T_i - T_{i+1}$ (^{o}C)	$\Sigma CP_{cold} - \Sigma CP_{hot}$ ($kW/^{o}C$)	ΔH_i (kW)	Surplus or Deficit
22.0					
	1	7.69	- 0.4151	-3.1921	Surplus
14.31					
	2	4.31	- 0.3281	-1.4141	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	111.69	- 0.0315	-3.5182	Surplus
-126.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-136.76					
	6	35.59	+ 0.2364	+8.4135	Deficit
-172.35					
	7	2.65	+ 0.3836	+1.0165	Deficit
-175.0					
	8	5.0	+ 0.1149	+0.5745	Deficit
-180.0					
			$E_{min} = \Sigma$	5.8788	

$\Delta T = 1.0^{\circ}C$

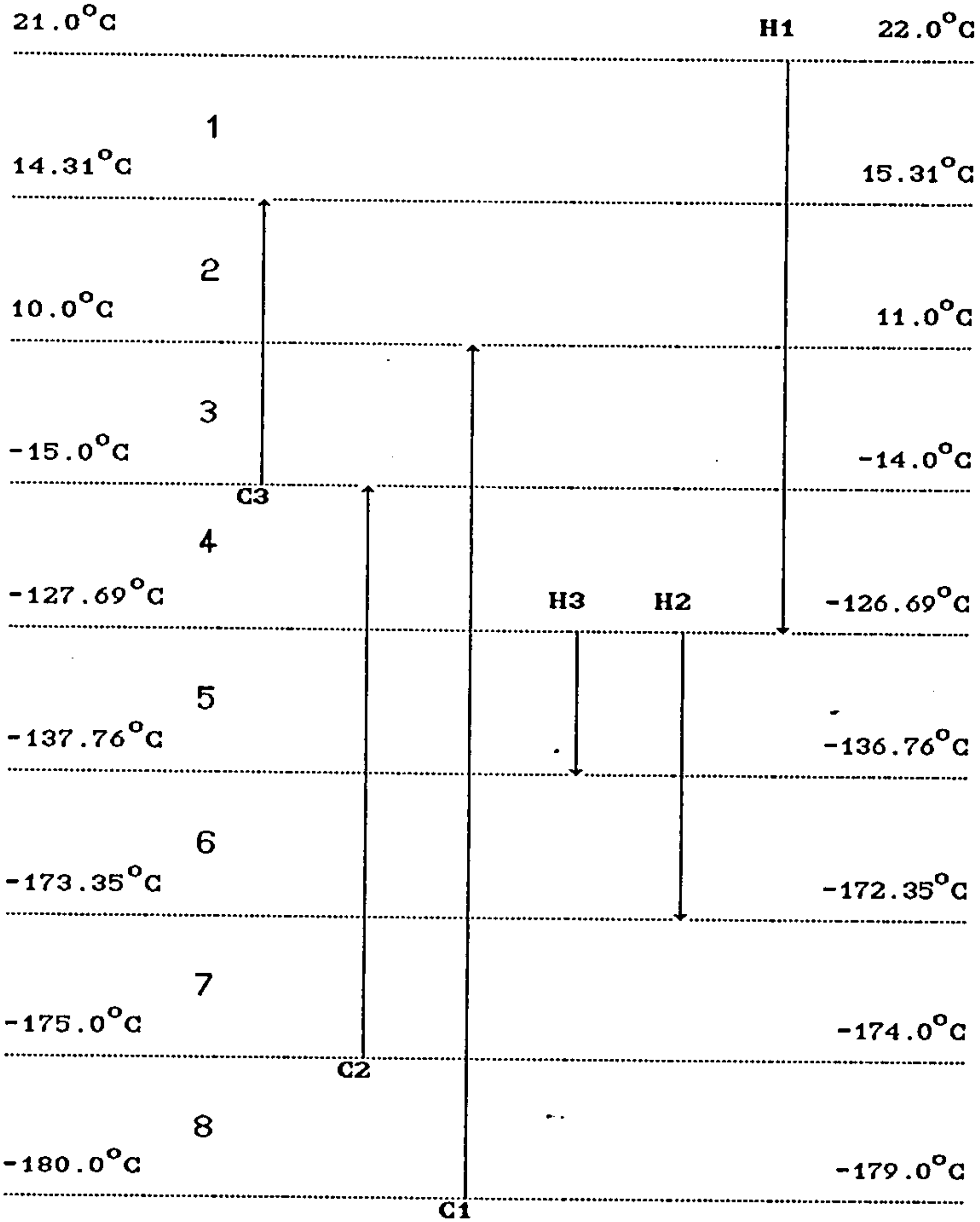

Figure A.2 : Temperature interval analysis

TABLE A.2 : TEMPERATURE-INTERVAL ANALYSIS, $\Delta T = 1.0^{\circ}C$

$^{\circ}C$	Interval No. (i)	$T_i - T_{i+1}$ ($^{\circ}C$)	$\Sigma CP_{cold} - \Sigma CP_{hot}$ (kW/$^{\circ}C$)	ΔH_i (kW)	Surplus or Deficit
21.0					
	1	6.69	- 0.4151	-2.7770	Surplus
14.31					
	2	4.31	- 0.3281	-1.4141	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	111.69	- 0.0315	-3.5497	Surplus
-127.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-137.76					
	6	35.59	+ 0.2364	+8.4135	Deficit
-173.35					
	7	2.65	+ 0.3836	+0.6329	Deficit
-175.0					
	8	5.0	+ 0.1149	+0.5745	Deficit
-180.0					
			$E_{min} = \Sigma$	5.8788	

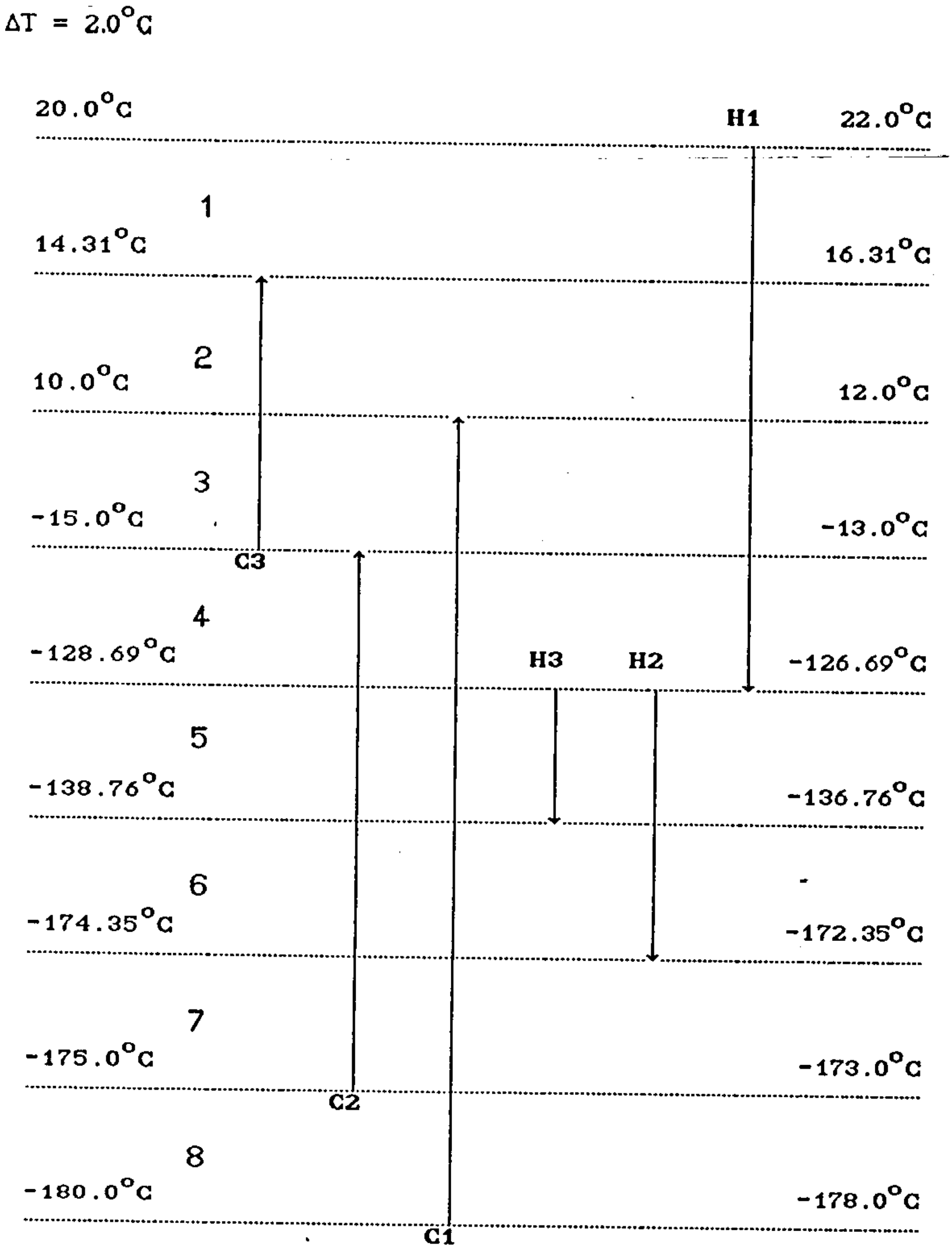

Figure A.3 : Temperature interval analysis

TABLE A.3 : TEMPERATURE-INTERVAL ANALYSIS, ΔT= 2.0°C

°C	Interval No. (i)	$T_i - T_{i+1}$ (°C)	$\Sigma\ CP_{cold} - \Sigma\ CP_{hot}$ (kW/°C)	ΔH_i (kW)	Surplus or Deficit
20.0					
	1	5.69	- 0.4151	-2.3619	Surplus
14.31					
	2	4.31	- 0.3281	-1.4141	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	113.69	- 0.0315	-3.5182	Surplus
-128.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-138.76					
	6	35.59	+ 0.2364	+8.4135	Deficit
-174.35					
	7	0.65	+ 0.3836	+0.2647	Deficit
-175.0					
	8	5.0	+ 0.1149	+0.5745	Deficit
-180.0					
			$E_{min} = \Sigma$	5.8634	

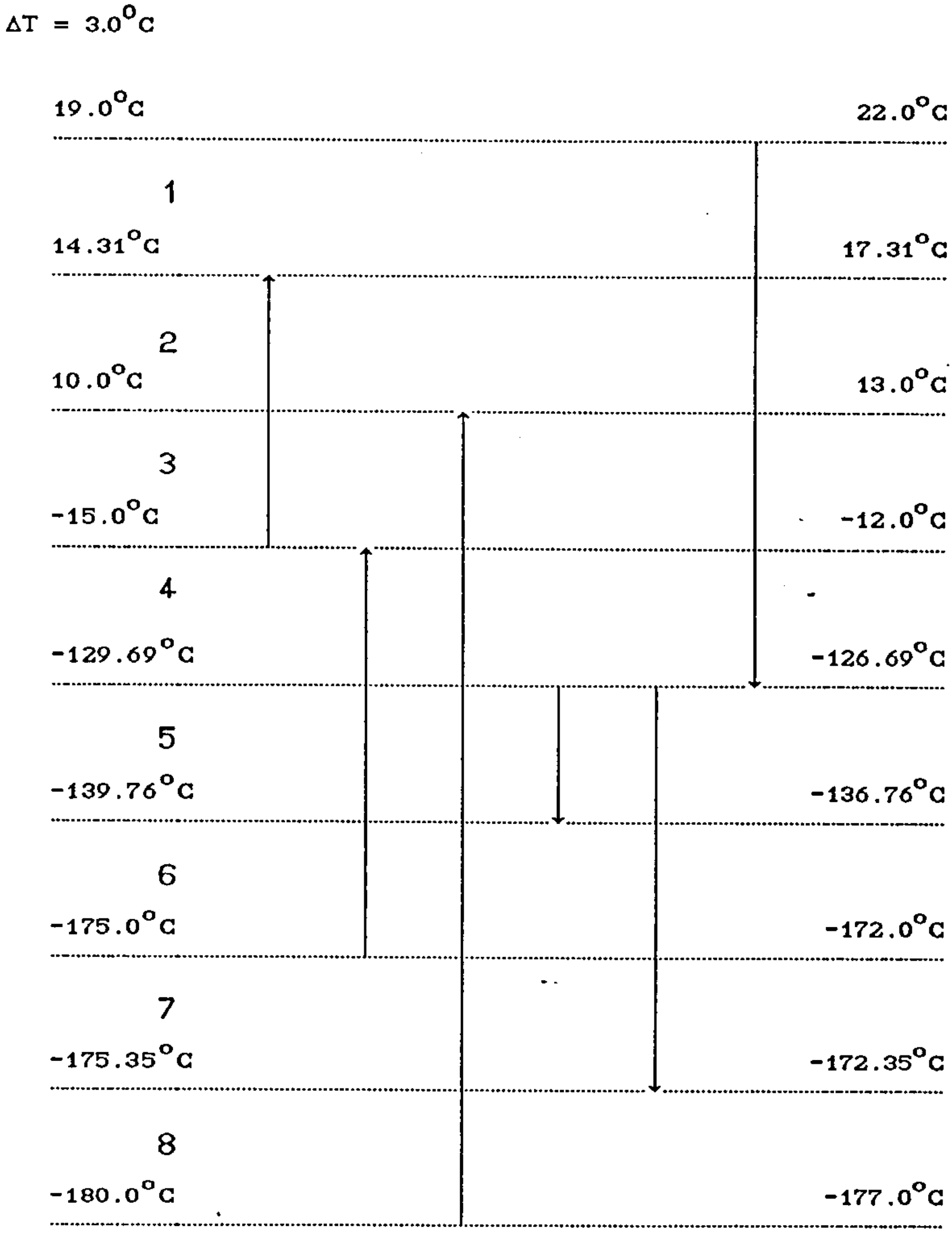

Figure A.4 : Temperature interval analysis

TABLE A.4 : TEMPERATURE-INTERVAL ANALYSIS, $\Delta T = 3.0^{o}C$

^{o}C	Interval No. (i)	$T_i - T_{i+1}$ (^{o}C)	$\Sigma CP_{cold} - \Sigma CP_{hot}$ ($kW/^{o}C$)	ΔH_i (kW)	Surplus or Deficit
19.0					
	1	4.69	- 0.4151	-1.9468	Surplus
14.31					
	2	4.31	- 0.3281	-1.4141	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	114.69	- 0.0315	-3.6127	Surplus
-129.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-139.76					
	6	35.24	+ 0.2364	+8.3307	Deficit
-175.0					
	7	0.35	- 0.0323	-0.0113	Surplus
-175.35					
	8	4.65	+ 0.1149	+0.5343	Deficit
-180.0					
			$E_{min} = \Sigma$	5.8788	

ΔT = 4.0°C

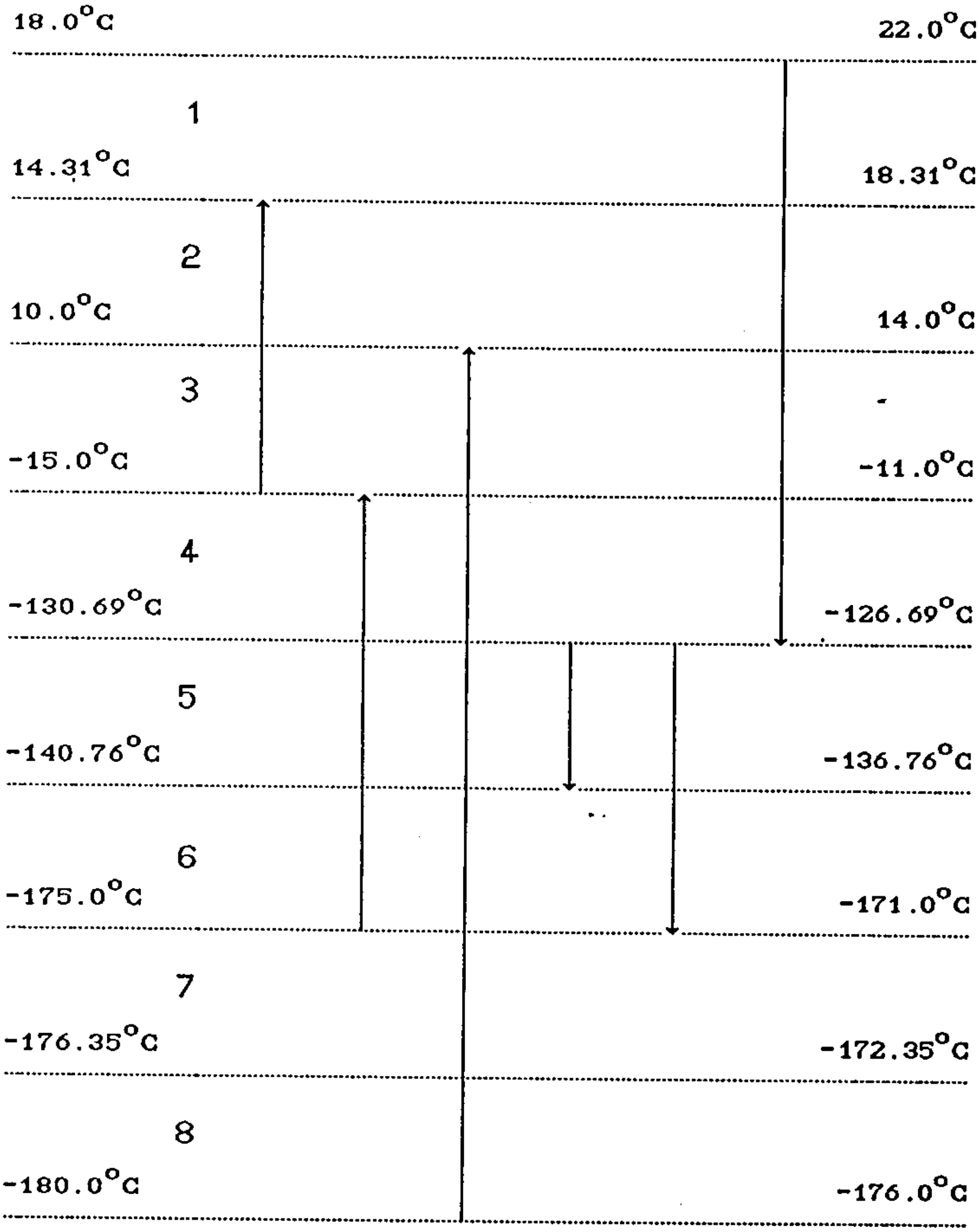

Figure A.5 : Temperature interval analysis

TABLE A.5 : TEMPERATURE-INTERVAL ANALYSIS, $\Delta T = 4.0^{\circ}C$

°C	Interval No. (i)	$T_i - T_{i+1}$ (°C)	$\Sigma CP_{cold} - \Sigma CP_{hot}$ (kW/°C)	ΔH_i (kW)	Surplus or Deficit
18.0					
	1	3.69	- 0.4151	-1.5317	Surplus
14.31					
	2	4.31	- 0.3281	-1.4141	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	115.69	- 0.0315	-3.6442	Surplus
-130.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-140.76					
	6	34.24	+ 0.2364	+8.0943	Deficit
-175.0					
	7	1.35	- 0.0323	-0.0436	Surplus
-176.35					
	8	3.65	+ 0.1149	+0.4194	Deficit
-180.0					
			$E_{min} = \Sigma$	5.8788	

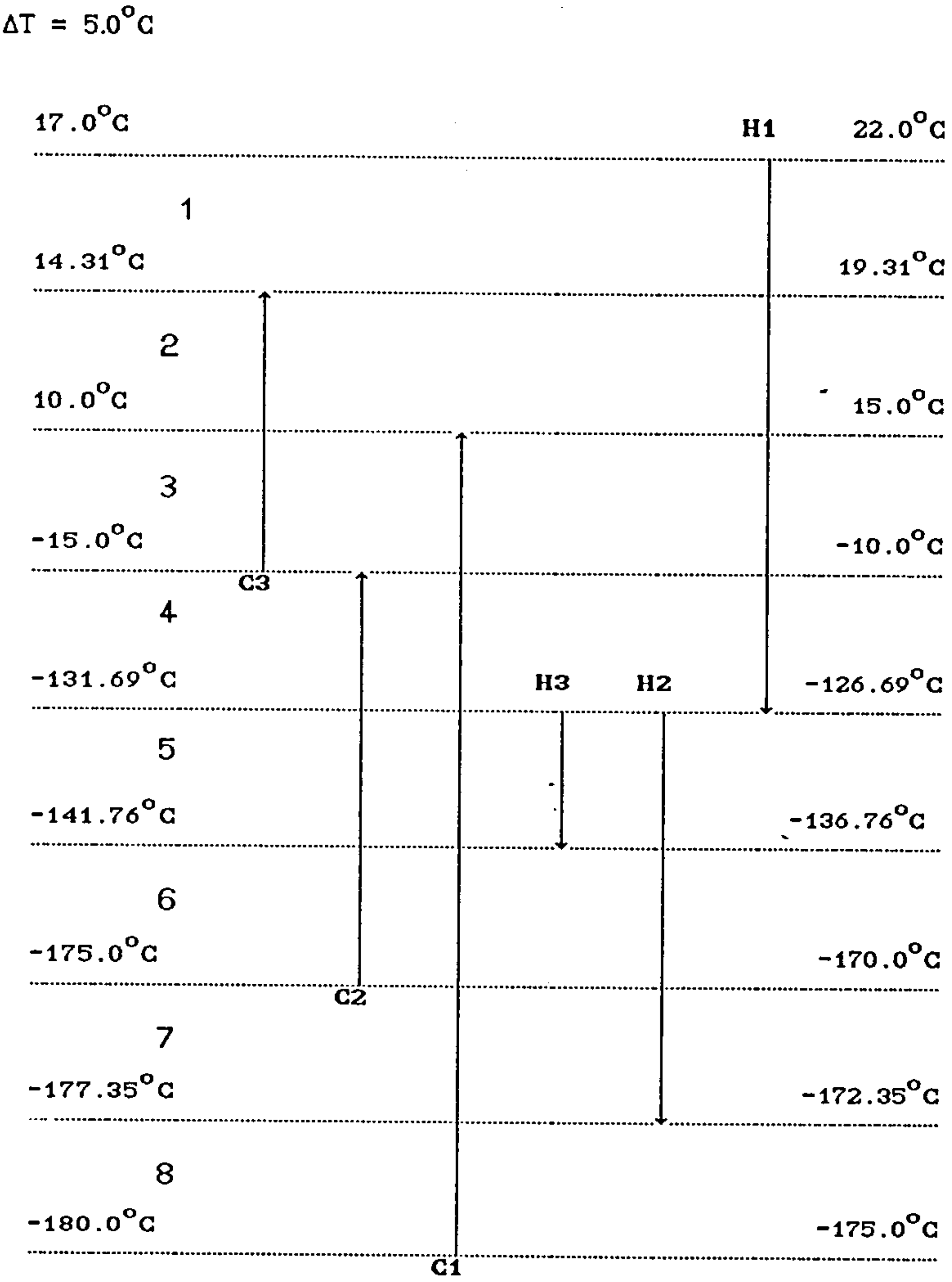

Figure A.6 : Temperature interval analysis

TABLE A.6 : TEMPERATURE-INTERVAL ANALYSIS, $\Delta T = 5.0^{o}C$

^{o}C	Interval No. (i)	$T_i - T_{i+1}$ (^{o}C)	$\Sigma CP_{cold} - \Sigma CP_{hot}$ (kW/^{o}C)	ΔH_i (kW)	Surplus or Deficit
17.0					
	1	2.69	- 0.4151	-1.1166	Surplus
14.31					
	2	4.31	- 0.3281	-1.4141	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	116.69	- 0.0315	-3.6757	Surplus
-131.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-141.76					
	6	33.24	+ 0.2364	+7.8579	Deficit
-175.0					
	7	2.35	- 0.0323	-0.0759	Surplus
-177.35					
	8	2.65	+ 0.1149	+0.3045	Deficit
-180.0					
			$E_{min} = \Sigma$	5.8788	

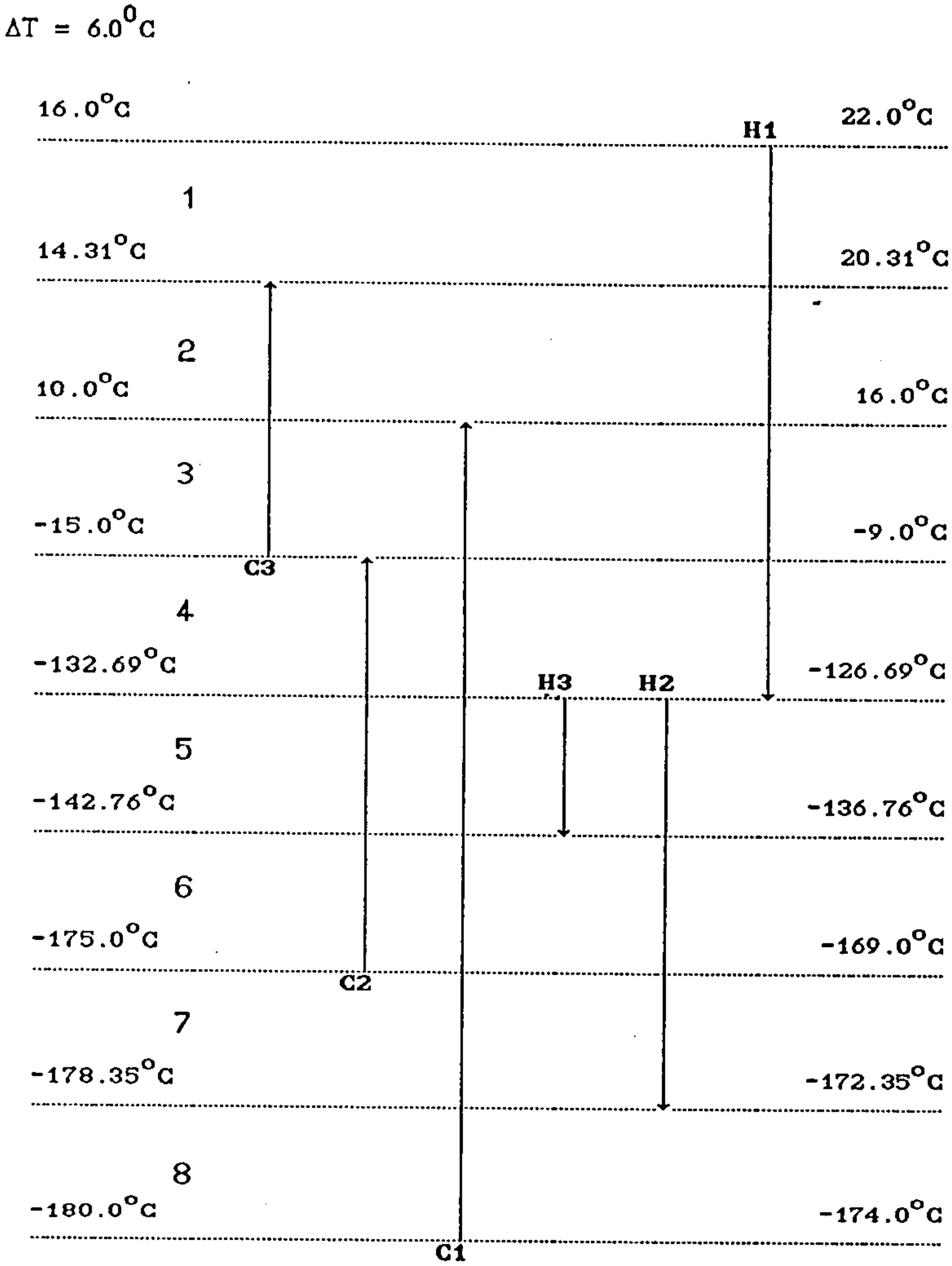

Figure A.7 : Temperature interval analysis

TABLE A.7 : TEMPERATURE-INTERVAL ANALYSIS, $\Delta T = 6.0^oC$

^oC	Interval No. (i)	$T_i - T_{i+1}$ (^oC)	$\Sigma CP_{cold} - \Sigma CP_{hot}$ ($kW/^oC$)	ΔH_i (kW)	Surplus or Deficit
16.0					
	1	1.69	- 0.4151	-0.7015	Surplus
14.31					
	2	4.31	- 0.3281	-1.4141	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	117.69	- 0.0315	-3.7072	Surplus
-132.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-142.76					
	6	32.24	+ 0.2364	+7.6215	Deficit
-175.0					
	7	3.35	- 0.0323	-0.1082	Surplus
-178.35					
	8	1.65	+ 0.1149	+0.1896	Deficit
-180.0					
			$E_{min} = \Sigma$	5.8788	

$\Delta T = 7.0^{o}C$

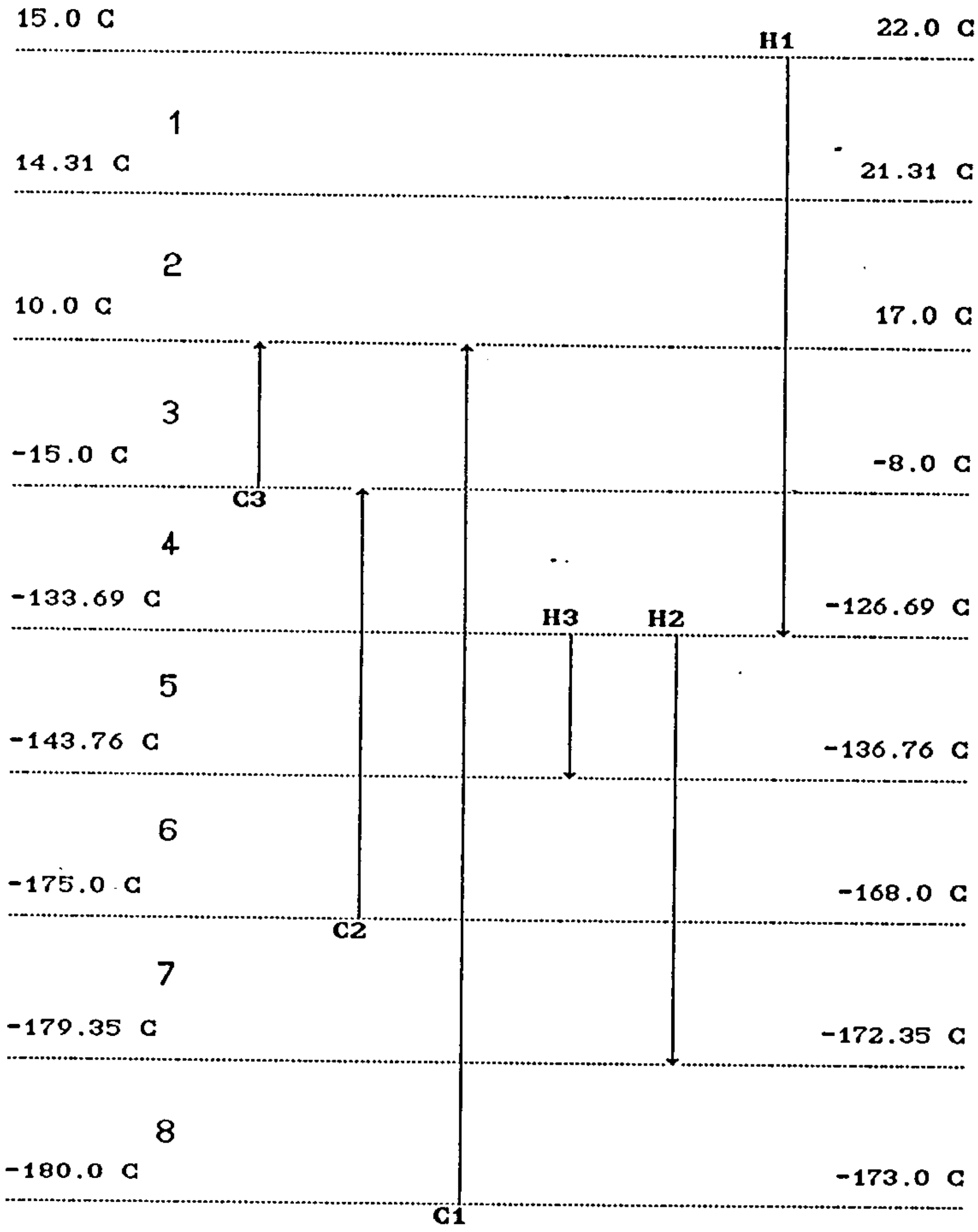

Figure A.8 : Temperature interval analysis

TABLE A.8 : TEMPERATURE-INTERVAL ANALYSIS, $\Delta T = 7.0^{o}C$

^{o}C	Interval No. (i)	$T_i - T_{i+1}$ (^{o}C)	$\Sigma CP_{cold} - \Sigma CP_{hot}$ ($kW/^{o}C$)	ΔH_i (kW)	Surplus or Deficit
15.0					
	1	0.69	- 0.4151	-0.2864	Surplus
14.31					
	2	4.31	- 0.3281	-1.4141	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	118.69	- 0.0315	-3.7387	Surplus
-133.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-143.76					
	6	31.24	+ 0.2364	+7.3851	Deficit
-175.0					
	7	4.35	- 0.0323	-0.1405	Surplus
-179.35					
	8	0.65	+ 0.1149	+0.0747	Deficit
-180.0					
			$E_{min} = \Sigma$	5.8788	

ΔT = 8.0°C

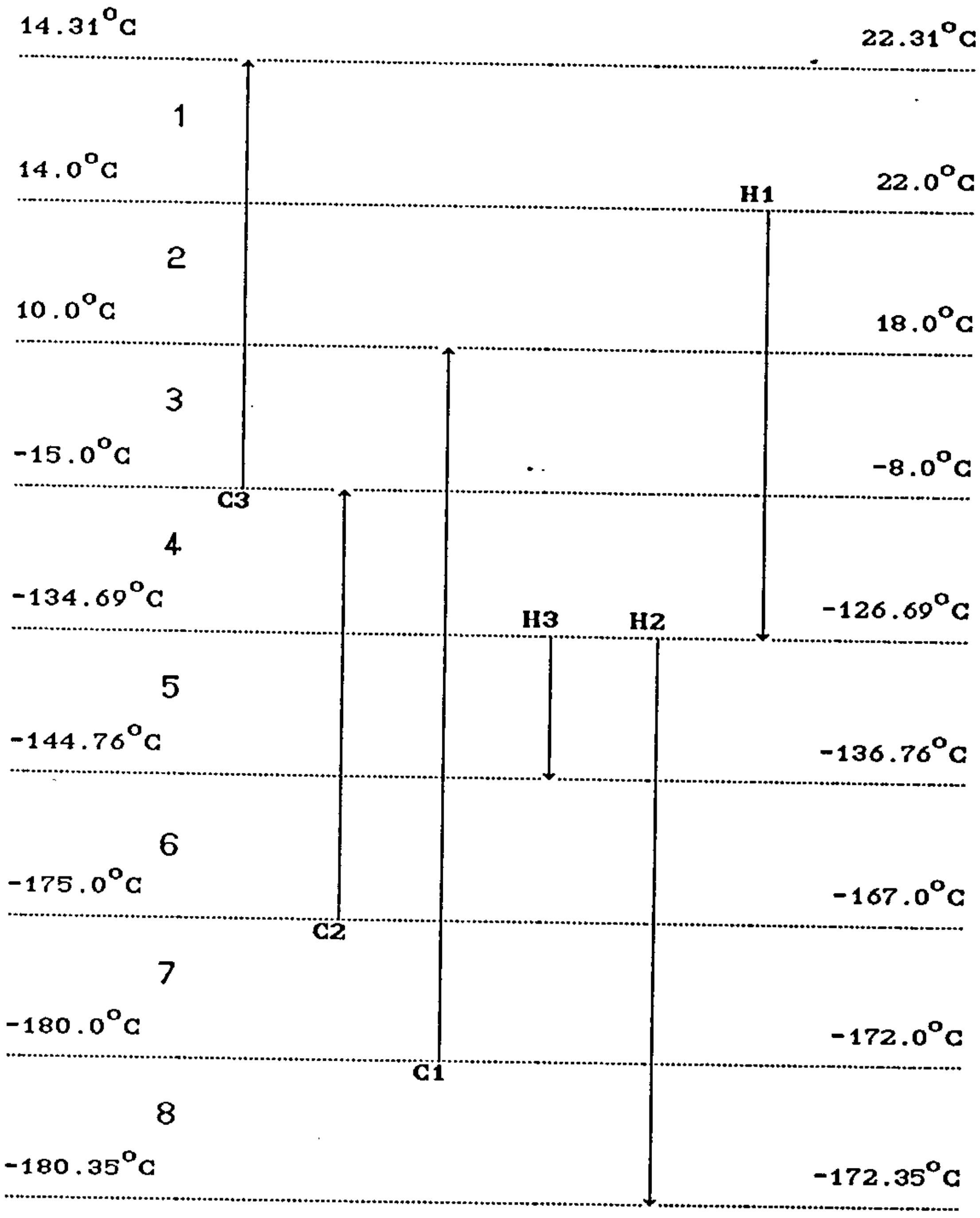

Figure A-9 : Temperature - interval analysis

TABLE A.9 : TEMPERATURE-INTERVAL ANALYSIS, ΔT= 8.0°C

°C	Interval No. (i)	$T_i - T_{i+1}$ (°C)	$\Sigma CP_{cold} - \Sigma CP_{hot}$ (kW/°C)	ΔH_i (kW)	Surplus or Deficit
14.31					
	1	0.31	+ 0.0870	+0.0270	Deficit
14.0					
	2	4.0	- 0.3281	-1.3124	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	119.69	- 0.0315	-3.7702	Surplus
-134.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-144.76					
	6	30.24	+ 0.2364	+7.1487	Deficit
-175.0					
	7	5.0	- 0.0323	-0.1615	Surplus
-180.0					
	8	0.35	- 0.4151	-0.1453	Surplus
-180.35					
			$E_{min} = \Sigma$	5.9726	

ΔT = 9.0°C

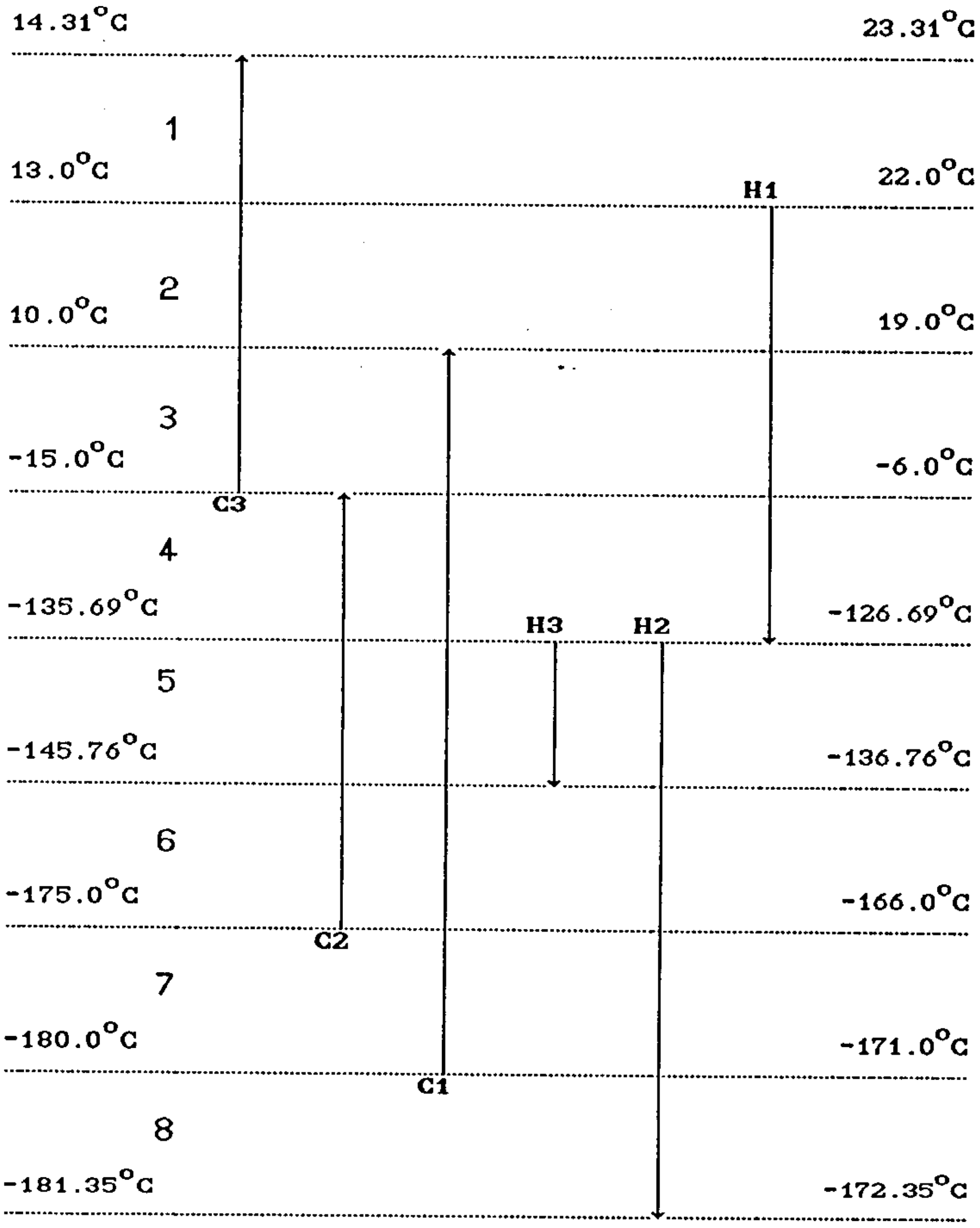

Figure A-10 : Temperature - interval analysis

TABLE A.10: TEMPERATURE-INTERVAL ANALYSIS, $\Delta T = 9.0^{o}C$

^{o}C	Interval No. (i)	$T_i - T_{i+1}$ (^{o}C)	$\Sigma CP_{cold} - \Sigma CP_{hot}$ ($kW/^{o}C$)	ΔH_i (kW)	Surplus or Deficit
14.31					
	1	1.31	+ 0.0870	+0.1140	Deficit
13.0					
	2	3.0	- 0.3281	-0.9843	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	120.69	- 0.0315	-3.8017	Surplus
-135.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-145.76					
	6	29.24	+ 0.2364	+6.9123	Deficit
-175.0					
	7	5.0	- 0.0323	-0.1615	Surplus
-180.0					
	8	1.35	- 0.4151	-0.5604	Surplus
-181.35					
			$E_{min} = \Sigma$	6.2405	

$\Delta T = 10.0^0C$

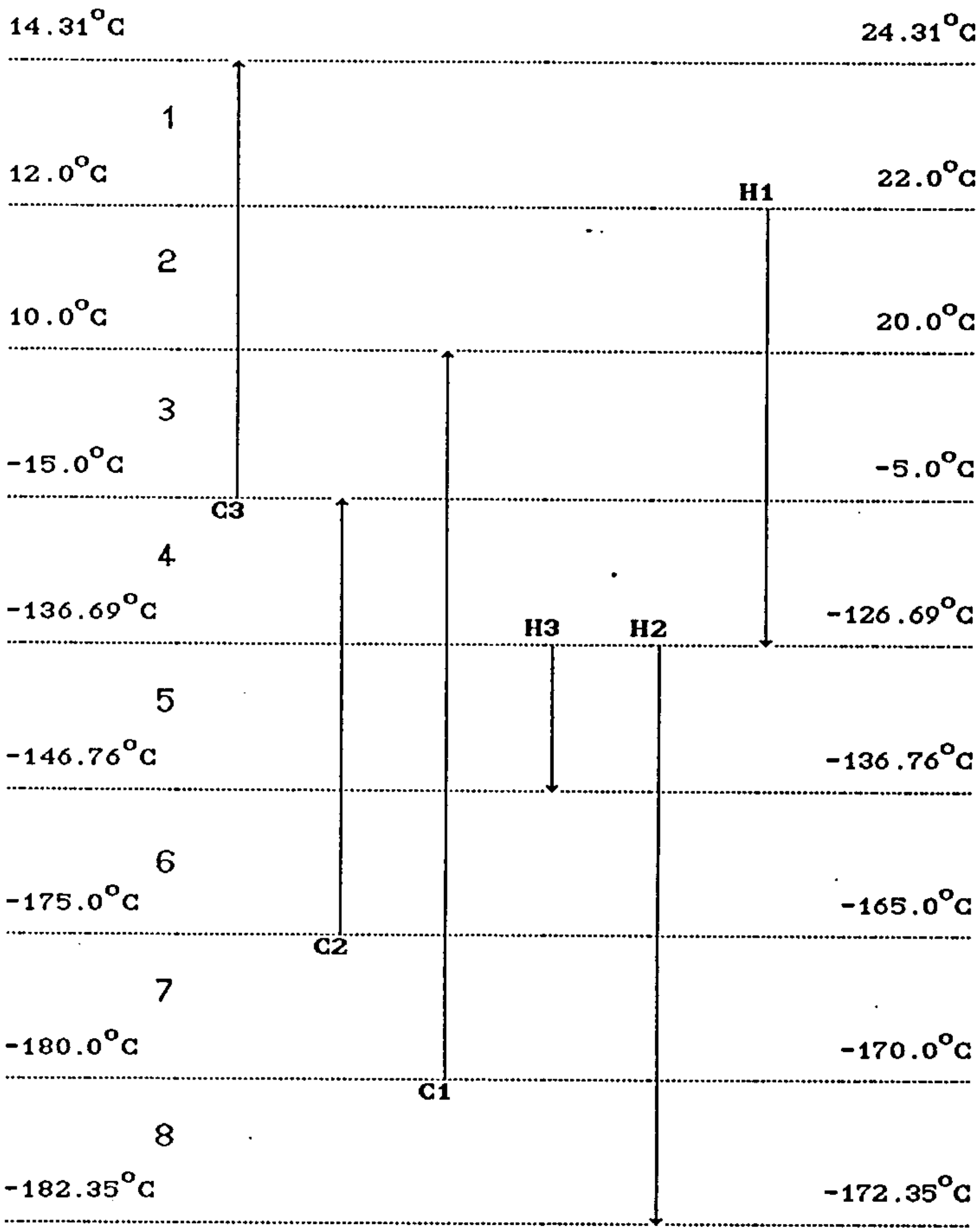

Figure A-11 : Temperature - interval analysis

TABLE A.11: TEMPERATURE-INTERVAL ANALYSIS, $\Delta T=10.0^{\circ}C$

$^{\circ}C$	Interval No. (i)	$T_i - T_{i+1}$ ($^{\circ}C$)	$\Sigma\ CP_{cold} - \Sigma\ CP_{hot}$ ($kW/^{\circ}C$)	ΔH_i (kW)	Surplus or Deficit
14.31					
	1	2.31	+ 0.0870	+0.2010	Deficit
14.0					
	2	2.0	- 0.3281	-0.6562	Surplus
10.0					
	3	25.0	- 0.2132	-5.33	Surplus
-15.0					
	4	121.69	- 0.0315	-3.8332	Surplus
-136.69					
	5	10.07	- 0.2412	-2.4289	Surplus
-146.76					
	6	28.24	+ 0.2364	+6.6759	Deficit
-175.0					
	7	5.0	- 0.0323	-0.1615	Surplus
-180.0					
	8	2.35	- 0.4151	-0.9755	Surplus
-182.35					
			$E_{min} = \Sigma$	6.5084	

Appendix B

Computer results of the simulating flowsheet of the oxygen plant of type K-0.15

PLANT.REP

```
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          TOPOLOGY

Equipment                   Stream Numbers

  1  ENTM                  1  -2    0    0
  2  ENTM                  3  -4    0    0
  3  ENTM                  5  -6    0    0
  4  ENTM                  7  -8    0    0
  5  HXER                  2  -3    0    0
  6  HXER                  4  -5    0    0
  7  HXER                  6  -7    0    0
  8  HXER                  8  -9    0    0
  9  HXER                  9  48  -10  -49
 10  HXER                 10  36  -11  -38
 11  HXER                 13  44  -15  -47
 12  HXER                 14  45  -16  -46
 13  HXER                 11 -12    0    0
 14  DVDR                 12 -13  -14    0
 15  HXER                 46  49  -51  -36
 16  MIXR                 15  16  -17    0
 17  DVDR                 17 -18  -19    0
 18  ENTM                 19 -26    0    0
 19  DVDR                 18 -20  -21    0
 20  HXER                 43  20  -44  -23
 21  HXER                 42  21  -45  -22
 22  MIXR                 23  22  -24    0
 23  VALV                 24 -25    0    0
 24  TOWR                 25  26  -27  -28
 25  HXER                 27  34  -29  -39
 26  HXER                 28  39  -30  -40
 27  HXER                 31  35  -33  -37
 28  VALV                 29 -32    0    0
 29  VALV                 30 -31    0    0
 30  TOWR                 32  33  -34  -35
 31  PUMP                 37 -41    0    0
 32  DVDR                 47 -48  -50    0
 33  HXER                 40 -43    0    0
 34  HXER                 41 -42    0    0
 35  MIXR                 38  50  -52    0

Stream Connections

Stream     Equipment
      From      To
   1      0        1
   2      1        5
   3      5        2
   4      2        6
   5      6        3
   6      3        7
 CODE REPORT
```

Stream Connections

```
Stream     Equipment
       From     To
    7       7       4
    8       4       8
    9       8       9
   10       9      10
   11      10      13
   12      13      14
   13      14      11
   14      14      12
   15      11      16
   16      12      16
   17      16      17
   18      17      19
   19      17      18
   20      19      20
   21      19      21
   22      21      22
   23      20      22
   24      22      23
   25      23      24
   26      18      24
   27      24      25
   28      24      26
   29      25      28
   30      26      29
   31      29      27
   32      28      30
   33      27      30
   34      30      25
   35      30      27
   36      15      10
   37      27      31
   38      10      35
   39      25      26
   40      26      33
   41      31      34
   42      34      21
   43      33      20
   44      20      11
   45      21      12
   46      12      15
   47      11      32
   48      32       9
   49       9      15
   50      32      35
   51      15       0
   52      35       0

COMPONENTS . . . . . .        2

ID numbers ...........        46,   47,
 CODE REPORT

        THERMODYNAMICS

  Kvalue option: Peng-Robinson
  Enthalpy option: Peng-Robinson
```

```
Density option: API method

     MISCELLANEOUS


Recycle calculations are converged.

Recycle equipment list (KE2):        13, 14, 17, 18, 19, 33, 20, 11,
                                     31, 34, 21, 22, 23, 24, 12, 15,
                                     25, 26, 28, 29, 27, 30,

Streams used in conv. routine (KE4):( 0)
     ()=Delay factor

Preferred cut stream list (KE3):     11, 17, 40, 37, 34, 35,

Convergence tolerances,        Error
        Flowrates:            .00100000
        Vapor fraction:       .00100000
        Temperature:          .00100000
        Pressure:             .00100000
        Enthalpy:             .00100000
        Flash calcs:          .00005000

Max. loops in recycle calc.:    30
          in flash calcs:       75


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***    DIVIDERS          ***
Equipment no.               14          17          19          3
External name
Fraction/flow  1        .68750      .40000      .71000      .33000
               2        .31250      .60000      .29000      .67000
               3        .00000      .00000      .00000      .00000
               4        .00000      .00000      .00000      .00000
               5        .00000      .00000      .00000      .00000
               6        .00000      .00000      .00000      .00000
Mode                        .0          .0          .0          .0
Stream #                    .0          .0          .0          .0
Comp. ID #                  .0          .0          .0          .0
Comp. ID #                  .0          .0          .0          .0
Comp. ID #                  .0          .0          .0          .0
Comp. ID #                  .0          .0          .0          .0
Comp. ID #                  .0          .0          .0          .0
Comp. ID #                  .0          .0          .0          .0
Comp. ID #                  .0          .0          .0          .0
Comp. ID #                  .0          .0          .0          .0
Comp. ID #                  .0          .0          .0          .0
Comp. ID #                  .0          .0          .0          .0
.......................................................................

***   MIXERS-W/FLASH    ***
Equipment no.               16          22          35
External name
.......................................................................

***       VALVES        ***
```

```
Equipment no.                23             28             29
External name
Outlet pressure bars      6.6132         1.4006         1.4572
.......................................................................

***EXCHANGER/CONDENSERS***
Equipment no.                  5              6              7              8
External name
Heat transfer coeff.      .00000         .00000         .00000         .00000
Area                      .00000         .00000         .00000         .00000
Number of shells              .0             .0             .0             .0
Shell passes                  .0             .0             .0             .0
Tube passes                   .0             .0             .0             .0
Mode                         5.0            5.0            5.0            5.0
Min. delta T or T-out      20.00          20.00          20.00          22.00
Delta P, stream 1         .00000         .00000         .00000         .00000
Delta P, stream 2         .00000         .00000         .00000         .00000
Q, stream 1    MJ/hr     -158.52        -183.56        -164.72        -106.13
Water usage, DM3/hr       .00000         .00000         .00000         .00000
Corrected delta T            .00            .00            .00            .00
Equipment no.                  9             10             11             12
External name
Heat transfer coeff.      300.00         300.00         300.00         300.00
Area                      1.5385         4.4356         15.772         6.3643
Number of shells              .0             .0             .0             .0
Shell passes                  .0             .0             .0             .0
Tube passes                   .0             .0             .0             .0
Mode                         3.0            3.0            3.0            3.0
Min. delta T or T-out      10.00           1.00          25.00          28.00
Delta P, stream 1         .00000         .00000         .00000         .00000
Delta P, stream 2         .00000         .00000         .00000         .00000
Q, stream 1    MJ/hr     -8.4539        -9.8046        -142.49        -64.454
Water usage, DM3/hr       .00000         .00000         .00000         .00000
Corrected delta T          18.32           7.37          30.11          33.76
Equipment no.                 13             15             20             21
External name
Heat transfer coeff.      .00000         300.00         300.00         300.00
Area                      .00000         20.847         1.1028         .40436
Number of shells              .0             .0             .0             .0
Shell passes                  .0             .0             .0             .0
Tube passes                   .0             .0             .0             .0
Mode                         5.0            3.0            3.0            3.0
Min. delta T or T-out      10.00           1.00          36.00          40.00
Delta P, stream 1         .00000         .00000         .00000         .00000
Delta P, stream 2         .00000         .00000         .00000         .00000
Q, stream 1    MJ/hr      3.0318         9.0809         12.279         5.0450
Water usage, DM3/hr       .00000         .00000         .00000         .00000
Corrected delta T           8.63           1.45          37.11          41.59
Equipment no.                 25             26             27             33
External name
Heat transfer coeff.      300.00         300.00         300.00         .00000
Area                      5.7545         5.8885         .53237         .00000
Number of shells              .0             .0             .0             .0
Shell passes                  .0             .0             .0             .0
Tube passes                   .0             .0             .0             .0
Mode                         3.0            3.0            3.0            5.0
Min. delta T or T-out       6.00           3.00           7.00        -175.00
Delta P, stream 1         .00000         .00000         .00000         .00000
Delta P, stream 2         .00000         .00000         .00000         .00000
Q, stream 1    MJ/hr     -10.610        -7.1362         1.3775         .15206
```

```
Water usage, DM3/hr     .00000           .00000            .00000            .00000
Corrected delta T         6.15             4.04              8.63              8.63
Equipment no.               34
External name
Heat transfer coeff.    .00000
Area                    .00000
Number of shells            .0
Shell passes                .0
Tube passes                 .0
Mode                       5.0
Min. delta T or T-out  -180.00
Delta P, stream 1       .00000
Delta P, stream 2       .00000
Q, stream 1   MJ/hr     1.1303
Water usage, DM3/hr     .00000
Corrected delta T        18.32
.............................................................................


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*** PUMPS/COMPRESSORS   ***
Equipment no.                31
External name
Number of stages            .0
Work capacity   MJ/hr   .00000
Outlet pressure bars    190.00
Power type:                 .0
   (+) steam
   (0) electricity
   (-) fuel gas
H, steam out KJ / kg    .00000
Fuel usage, M3   /hr    .00000
Water usage, DM3/hr     .00000
Steam usage Tonnes/hr   .00000
Kilowatt usage          1.1632
.............................................................................

***  ENTROPY MACHINES   ***
Equipment no.                1             2             3             4
External name
Mode                        .0            .0            .0            .0
Outlet pressure bars    2.7100        8.2300        22.300        43.600
Adiabatic efficiency    .70000        .70000        .70000        .70000
Theoretical hp          41.181        47.389        41.786        26.671
Actual horsepower       58.831        67.699        59.694        38.101
Entropy in   KJ/deg C   1140.9        812.34        438.03        94.006
Entropy out, ideal      1140.9        812.33        438.02        93.919
Entropy out, actual     1257.2        940.77        555.43        177.31
Equipment no.               18
External name
Mode                        .0
Outlet pressure bars    6.6065
Adiabatic efficiency    .85000
Theoretical hp         -10.517
Actual horsepower      -8.9396
Entropy in   KJ/deg C  -733.70
Entropy out, ideal     -733.72
```

```
Entropy out, actual   -693.70
...............................................................................


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***  RIGOROUS TOWERS    ***
Equipment no.                  24            30
External name
Number of stages            21.0          57.0
Feed 1, stage #             15.0           1.0
Feed 2, stage #             21.0          17.0
Feed 3, stage #               .0            .0
Feed 4, stage #               .0            .0
Feed 5, stage #               .0            .0
Sidestream # 1 stage          .0            .0
Sidestream # 2 stage          .0            .0
Sidestream # 3 stage          .0            .0
Sidestream # 4 stage          .0            .0
Cond. pressure bars        6.7131        1.4006
Cond. delta P bars         .00000        .00000
Colm. delta P bars         .19400E-01    .19850
Condenser type                .0           1.0
Condenser mode               4.0            .0
Value of cond. spec.       16.000        .00000
Cond comp 1 position         1.0            .0
Cond comp 2 position          .0            .0
Cond. deg. subcooled        1.00           .00
Reboiler mode                 .0           4.0
Val. of reboiler spec      .00000        7.6000
Rebr comp 1 position          .0           2.0
Rebr comp 2 position          .0            .0
Damping ratio              .00000        1.0000
Sidestream 1 mode             .0            .0
Sidestream 2 mode             .0            .0
Sidestream 3 mode             .0            .0
Sidestream 4 mode             .0            .0
Sidestream # 1 spec        .00000        .00000
Sidestream # 2 spec        .00000        .00000
Sidestream # 3 spec        .00000        .00000
Sidestream # 4 spec        .00000        .00000
Sidestrm 1 comp posn          .0            .0
Sidestrm 2 comp posn          .0            .0
Sidestrm 3 comp posn          .0            .0
Sidestrm 4 comp posn          .0            .0
Cond. duty   MJ/hr        -163.51        .00000
Rebr duty   MJ/hr          .00000        153.21
Est dist rate Kgmol/hr     16.000        .00000
Est. reflux Kgmol/hr       .00000        .00000
Est. side draw rate 1      .00000        .00000
Est. side draw rate 2      .00000        .00000
Est. side draw rate 3      .00000        .00000
Est. side draw rate 4      .00000        .00000
Est. temp stg  1  C       -178.00       -193.00
Est. temp stg  N  C       -174.00       -183.00
...............................................................................

CODEREPORT
```

```
*** Stream no.  1 ***
                                   All Vapor
Temperature deg C. . . . . . .       20.0000
Pressure bars. . . . . . . . .       1.01325
Enthalpy MJ/hr   . . . . . . .       812.759
Entropy MJ/hr*K  . . . . . . .       1.14091
Ave. mol. wt.  . . . . . . . .       28.7703
Total flow  kg/hr. . . . . . .       1150.81
        kgmol/hr . . . . . . .       40.0000
Density kg/m3  . . . . . . . .       1.19674
Viscosity centipoise . . . . .       .180405E-01
Thermal cond. cal/cm*s*K . . .       .628029E-04
Specific heat   kJ/kg*K  . . .       1.01667
Z factor . . . . . . . . . . .       .999419
m3/hr (15.6 deg C & 1 atm) . .       947.608
Vol. flowrate m3/hr  . . . . .       961.641
                  Vapor            Vapor
                   mole             flowrate
                  fraction          kgmol/hr
Nitrogen         .810000           32.4000
Oxygen           .190000           7.60000

*** Stream no.  2 ***
                                   All Vapor
Temperature deg C. . . . . . .       154.633
Pressure bars. . . . . . . . .       2.71000
Enthalpy MJ/hr   . . . . . . .       970.718
Entropy MJ/hr*K  . . . . . . .       1.25721
Ave. mol. wt.  . . . . . . . .       28.7703
Total flow  kg/hr. . . . . . .       1150.81
        kgmol/hr . . . . . . .       40.0000
Density kg/m3  . . . . . . . .       2.19114
Viscosity centipoise . . . . .       .239542E-01
Thermal cond. cal/cm*s*K . . .       .907807E-04
Specific heat   kJ/kg*K  . . .       1.02916
Z factor . . . . . . . . . . .       1.00045
m3/hr (15.6 deg C & 1 atm) . .       947.608
Vol. flowrate m3/hr  . . . . .       525.220
                  Vapor            Vapor
                   mole             flowrate
                  fraction          kgmol/hr
Nitrogen         .810000           32.4000
Oxygen           .190000           7.60000
 CODE REPORT

*** Stream no.  3 ***
                                   All Vapor
Temperature deg C. . . . . . .       20.0000
Pressure bars. . . . . . . . .       2.71000
Enthalpy MJ/hr   . . . . . . .       812.202
Entropy MJ/hr*K  . . . . . . .       .812340
Ave. mol. wt.  . . . . . . . .       28.7703
Total flow  kg/hr. . . . . . .       1150.81
        kgmol/hr . . . . . . .       40.0000
Density kg/m3  . . . . . . . .       3.20381
Viscosity centipoise . . . . .       .180405E-01
Thermal cond. cal/cm*s*K . . .       .628029E-04
Specific heat   kJ/kg*K  . . .       1.02047
Z factor . . . . . . . . . . .       .998463
```

```
m3/hr (15.6 deg C & 1 atm) .     947.608
Vol. flowrate m3/hr  . . . .     359.206
                      Vapor      Vapor
                       mole       flowrate
                      fraction   kgmol/hr
Nitrogen            .810000      32.4000
Oxygen              .190000      7.60000

*** Stream no.  4 ***
                                 All Vapor
Temperature deg C. . . . . . .    174.770
Pressure bars. . . . . . . . .    8.23000
Enthalpy MJ/hr   . . . . . . .    993.971
Entropy MJ/hr*K  . . . . . . .    .940765
Ave. mol. wt.  . . . . . . . .    28.7703
Total flow  kg/hr. . . . . . .    1150.81
        kgmol/hr . . . . . . .    40.0000
Density kg/m3  . . . . . . . .    6.34707
Viscosity centipoise . . . . .    .247552E-01
Thermal cond. cal/cm*s*K . . .    .957600E-04
Specific heat   kJ/kg*K  . . .    1.03568
Z factor . . . . . . . . . . .    1.00172
m3/hr (15.6 deg C & 1 atm) . .    947.608
Vol. flowrate m3/hr  . . . . .    181.317
                      Vapor      Vapor
                       mole       flowrate
                      fraction   kgmol/hr
Nitrogen            .810000      32.4000
Oxygen              .190000      7.60000
 CODE REPORT

*** Stream no.  5 ***
                                 All Vapor
Temperature deg C. . . . . . .    20.0000
Pressure bars. . . . . . . . .    8.23000
Enthalpy MJ/hr   . . . . . . .    810.408
Entropy MJ/hr*K  . . . . . . .    .438028
Ave. mol. wt.  . . . . . . . .    28.7703
Total flow  kg/hr. . . . . . .    1150.81
        kgmol/hr . . . . . . .    40.0000
Density kg/m3  . . . . . . . .    9.75871
Viscosity centipoise . . . . .    .180405E-01
Thermal cond. cal/cm*s*K . . .    .628029E-04
Specific heat   kJ/kg*K  . . .    1.03134
Z factor . . . . . . . . . . .    .995489
m3/hr (15.6 deg C & 1 atm) . .    947.608
Vol. flowrate m3/hr  . . . . .    117.928
                      Vapor      Vapor
                       mole       flowrate
                      fraction   kgmol/hr
Nitrogen            .810000      32.4000
Oxygen              .190000      7.60000

*** Stream no.  6 ***
                                 All Vapor
Temperature deg C. . . . . . .    156.639
Pressure bars. . . . . . . . .    22.3000
Enthalpy MJ/hr   . . . . . . .    970.685
Entropy MJ/hr*K  . . . . . . .    .555435
Ave. mol. wt.  . . . . . . . .    28.7703
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```
Total flow  kg/hr. . . . . . .       1150.81
        kgmol/hr . . . . . . .       40.0000
Density kg/m3  . . . . . . . .       17.8789
Viscosity centipoise . . . .         .240468E-01
Thermal cond. cal/cm*s*K . .         .912667E-04
Specific heat   kJ/kg*K   . .        1.04437
Z factor . . . . . . . . . . .       1.00422
m3/hr (15.6 deg C & 1 atm) .         947.608
Vol. flowrate m3/hr  . . . .         64.3682
                     Vapor        Vapor
                      mole         flowrate
                     fraction      kgmol/hr
Nitrogen            .810000       32.4000
Oxygen              .190000       7.60000
 CODE REPORT

*** Stream no.  7 ***
                                  All Vapor
Temperature deg C. . . . . .        20.0000
Pressure bars. . . . . . . .        22.3000
Enthalpy MJ/hr   . . . . . .        805.964
Entropy MJ/hr*K  . . . . . .        .940061E-01
Ave. mol. wt.  . . . . . . .        28.7703
Total flow  kg/hr. . . . . .        1150.81
        kgmol/hr . . . . . .        40.0000
Density kg/m3  . . . . . . .        26.6192
Viscosity centipoise . . . .        .180657E-01
Thermal cond. cal/cm*s*K . .        .628029E-04
Specific heat   kJ/kg*K   . .       1.05903
Z factor . . . . . . . . . .        .988871
m3/hr (15.6 deg C & 1 atm) .        947.608
Vol. flowrate m3/hr  . . . .        43.2331
                     Vapor        Vapor
                      mole         flowrate
                     fraction      kgmol/hr
Nitrogen            .810000       32.4000
Oxygen              .190000       7.60000

*** Stream no.  8 ***
                                  All Vapor
Temperature deg C. . . . . .        107.532
Pressure bars. . . . . . . .        43.6000
Enthalpy MJ/hr   . . . . . .        908.265
Entropy MJ/hr*K  . . . . . .        .177305
Ave. mol. wt.  . . . . . . .        28.7703
Total flow  kg/hr. . . . . .        1150.81
        kgmol/hr . . . . . .        40.0000
Density kg/m3  . . . . . . .        39.4742
Viscosity centipoise . . . .        .220565E-01
Thermal cond. cal/cm*s*K . .        .799859E-04
Specific heat   kJ/kg*K   . .       1.06555
Z factor . . . . . . . . . .        1.00399
m3/hr (15.6 deg C & 1 atm) .        947.608
Vol. flowrate m3/hr  . . . .        29.1540
                     Vapor        Vapor
                      mole         flowrate
                     fraction      kgmol/hr
Nitrogen            .810000       32.4000
Oxygen              .190000       7.60000
 CODE REPORT
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```
*** Stream no.  9 ***
                                      All Vapor
Temperature deg C. . . . . .           22.0000
Pressure bars. . . . . . . .           43.6000
Enthalpy MJ/hr     . . . . . .         802.137
Entropy MJ/hr*K  . . . . . .          -.138655
Ave. mol. wt.  . . . . . . .           28.7703
Total flow  kg/hr. . . . . .           1150.81
          kgmol/hr . . . . . .         40.0000
Density kg/m3  . . . . . . .           52.0371
Viscosity centipoise . . . .           .182234E-01
Thermal cond. cal/cm*s*K . .           .631572E-04
Specific heat    kJ/kg*K   . .         1.09814
Z factor . . . . . . . . . .           .982313
m3/hr (15.6 deg C & 1 atm) .           947.608
Vol. flowrate m3/hr   . . . .          22.1156
                     Vapor           Vapor
                       mole           flowrate
                     fraction         kgmol/hr
Nitrogen           .810000           32.4000
Oxygen             .190000           7.60000

*** Stream no. 10 ***
                                      All Vapor
Temperature deg C. . . . . .           15.3137
Pressure bars. . . . . . . .           43.6000
Enthalpy MJ/hr     . . . . . .         793.683
Entropy MJ/hr*K  . . . . . .          -.167679
Ave. mol. wt.  . . . . . . .           28.7703
Total flow  kg/hr. . . . . .           1150.81
          kgmol/hr . . . . . .         40.0000
Density kg/m3  . . . . . . .           53.4060
Viscosity centipoise . . . .           .179041E-01
Thermal cond. cal/cm*s*K . .           .619794E-04
Specific heat    kJ/kg*K   . .         1.10248
Z factor . . . . . . . . . .           .979320
m3/hr (15.6 deg C & 1 atm) .           947.608
Vol. flowrate m3/hr   . . . .          21.5487
                     Vapor           Vapor
                       mole           flowrate
                     fraction         kgmol/hr
Nitrogen           .810000           32.4000
Oxygen             .190000           7.60000
 CODE REPORT

*** Stream no. 11 ***
                                      All Vapor
Temperature deg C. . . . . .           7.59766
Pressure bars. . . . . . . .           43.6000
Enthalpy MJ/hr     . . . . . .         783.879
Entropy MJ/hr*K  . . . . . .          -.202191
Ave. mol. wt.  . . . . . . .           28.7703
Total flow  kg/hr. . . . . .           1150.81
          kgmol/hr . . . . . .         40.0000
Density kg/m3  . . . . . . .           55.0894
Viscosity centipoise . . . .           .175318E-01
Thermal cond. cal/cm*s*K . .           .606436E-04
Specific heat    kJ/kg*K   . .         1.10845
Z factor . . . . . . . . . .           .975487
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m3/hr (15.6 deg C & 1 atm) .     947.608
Vol. flowrate m3/hr . . . .      20.8902
                  Vapor         Vapor
                   mole          flowrate
                  fraction      kgmol/hr
Nitrogen        .810000         32.4000
Oxygen          .190000         7.60000

*** Stream no. 12 ***
                                All Vapor
Temperature deg C. . . . . . .     10.0000
Pressure bars. . . . . . . . .     43.6000
Enthalpy MJ/hr   . . . . . . .     786.911
Entropy MJ/hr*K  . . . . . . .    -.191324
Ave. mol. wt.  . . . . . . . .     28.7703
Total flow  kg/hr. . . . . . .     1150.81
        kgmol/hr . . . . . . .     40.0000
Density kg/m3  . . . . . . . .     54.5527
Viscosity centipoise . . . . .     .176482E-01
Thermal cond. cal/cm*s*K . . .     .610568E-04
Specific heat   kJ/kg*K  . . .     1.10737
Z factor . . . . . . . . . . .     .976727
m3/hr (15.6 deg C & 1 atm) . .     947.608
Vol. flowrate m3/hr  . . . . .     21.0957
                  Vapor         Vapor
                   mole          flowrate
                  fraction      kgmol/hr
Nitrogen        .810000         32.4000
Oxygen          .190000         7.60000
 CODE REPORT

*** Stream no. 13 ***
                                All Vapor
Temperature deg C. . . . . . .     10.0000
Pressure bars. . . . . . . . .     43.6000
Enthalpy MJ/hr   . . . . . . .     541.001
Entropy MJ/hr*K  . . . . . . .    -.131536
Ave. mol. wt.  . . . . . . . .     28.7703
Total flow  kg/hr. . . . . . .     791.184
        kgmol/hr . . . . . . .     27.5000
Density kg/m3  . . . . . . . .     54.5527
Viscosity centipoise . . . . .     .176482E-01
Thermal cond. cal/cm*s*K . . .     .610568E-04
Specific heat   kJ/kg*K  . . .     1.10752
Z factor . . . . . . . . . . .     .976727
m3/hr (15.6 deg C & 1 atm) . .     651.480
Vol. flowrate m3/hr  . . . . .     14.5033
                  Vapor         Vapor
                   mole          flowrate
                  fraction      kgmol/hr
Nitrogen        .810000         22.2750
Oxygen          .190000         5.22500

*** Stream no. 14 ***
                                All Vapor
Temperature deg C. . . . . . .     10.0000
Pressure bars. . . . . . . . .     43.6000
Enthalpy MJ/hr   . . . . . . .     245.910
Entropy MJ/hr*K  . . . . . . .    -.597889E-01
Ave. mol. wt.  . . . . . . . .     28.7703
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Total flow  kg/hr. . . . . .       359.629
      kgmol/hr . . . . . .         12.5000
Density kg/m3  . . . . . . .       54.5527
Viscosity centipoise . . . .       .176482E-01
Thermal cond. cal/cm*s*K . .       .610568E-04
Specific heat   kJ/kg*K  . .       1.10704
Z factor . . . . . . . . . .       .976727
m3/hr (15.6 deg C & 1 atm) .       296.127
Vol. flowrate m3/hr  . . . .       6.59242
                  Vapor           Vapor
                   mole            flowrate
                  fraction        kgmol/hr
Nitrogen         .810000          10.1250
Oxygen           .190000          2.37500
 CODE REPORT

*** Stream no. 15 ***
                                   All Vapor
Temperature deg C. . . . . .       -126.812
Pressure bars. . . . . . . .        43.6000
Enthalpy MJ/hr  . . . . . . .       398.507
Entropy MJ/hr*K . . . . . . .      -.842187
Ave. mol. wt. . . . . . . . .       28.7703
Total flow  kg/hr. . . . . .        791.184
      kgmol/hr . . . . . .          27.5000
Density kg/m3  . . . . . . .        166.452
Viscosity centipoise . . . .        .106017E-01
Thermal cond. cal/cm*s*K . .        .409996E-04
Specific heat   kJ/kg*K  . .        2.37539
Z factor . . . . . . . . . .        .619385
m3/hr (15.6 deg C & 1 atm) .        651.480
Vol. flowrate m3/hr  . . . .        4.75330
                  Vapor           Vapor
                   mole            flowrate
                  fraction        kgmol/hr
Nitrogen         .810000          22.2750
Oxygen           .190000          5.22500

*** Stream no. 16 ***
                                   All Vapor
Temperature deg C. . . . . .       -126.440
Pressure bars. . . . . . . .        43.6000
Enthalpy MJ/hr  . . . . . . .       181.456
Entropy MJ/hr*K . . . . . . .      -.380657
Ave. mol. wt. . . . . . . . .       28.7703
Total flow  kg/hr. . . . . .        359.629
      kgmol/hr . . . . . .          12.5000
Density kg/m3  . . . . . . .        164.835
Viscosity centipoise . . . .        .106149E-01
Thermal cond. cal/cm*s*K . .        .410453E-04
Specific heat   kJ/kg*K  . .        2.33661
Z factor . . . . . . . . . .        .623874
m3/hr (15.6 deg C & 1 atm) .        296.127
Vol. flowrate m3/hr  . . . .        2.18179
                  Vapor           Vapor
                   mole            flowrate
                  fraction        kgmol/hr
Nitrogen         .810000          10.1250
Oxygen           .190000          2.37500
 CODE REPORT
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*** Stream no. 17 ***
                                    All Vapor
Temperature deg C. . . . . . .      -126.696
Pressure bars. . . . . . . . .       43.6000
Enthalpy MJ/hr    . . . . . .        579.963
Entropy MJ/hr*K   . . . . . .       -1.22284
Ave. mol. wt.  . . . . . . . .       28.7703
Total  flow   kg/hr. . . . . .       1150.81
         kgmol/hr . . . . . .        40.0000
Density kg/m3   . . . . . . .        165.942
Viscosity centipoise . . . .         .106058E-01
Thermal cond. cal/cm*s*K . .         .410139E-04
Specific heat    kJ/kg*K   . .       2.36246
Z factor . . . . . . . . . .         .620796
m3/hr (15.6 deg C & 1 atm) .         947.608
Vol. flowrate m3/hr  . . . . .       6.93515
                    Vapor           Vapor
                     mole            flowrate
                    fraction        kgmol/hr
Nitrogen            .810000         32.4000
Oxygen              .190000         7.60000

*** Stream no. 18 ***
                                    All Vapor
Temperature deg C. . . . . . .      -126.695
Pressure bars. . . . . . . . .       43.6000
Enthalpy MJ/hr    . . . . . .        231.985
Entropy MJ/hr*K   . . . . . .       -.489127
Ave. mol. wt.  . . . . . . . .       28.7703
Total  flow   kg/hr. . . . . .       460.325
         kgmol/hr . . . . . .        16.0000
Density kg/m3   . . . . . . .        165.937
Viscosity centipoise . . . .         .106058E-01
Thermal cond. cal/cm*s*K . .         .410140E-04
Specific heat    kJ/kg*K   . .       2.36314
Z factor . . . . . . . . . .         .620808
m3/hr (15.6 deg C & 1 atm) .         379.043
Vol. flowrate m3/hr  . . . .         2.77413
                    Vapor           Vapor
                     mole            flowrate
                    fraction        kgmol/hr
Nitrogen            .810000         12.9600
Oxygen              .190000         3.04000
 CODE REPORT

*** Stream no. 19 ***
                                    All Vapor
Temperature deg C. . . . . . .      -126.695
Pressure bars. . . . . . . . .       43.6000
Enthalpy MJ/hr    . . . . . .        347.978
Entropy MJ/hr*K   . . . . . .       -.733690
Ave. mol. wt.  . . . . . . . .       28.7703
Total  flow   kg/hr. . . . . .       690.488
         kgmol/hr . . . . . .        24.0000
Density kg/m3   . . . . . . .        165.937
Viscosity centipoise . . . .         .106058E-01
Thermal cond. cal/cm*s*K . .         .410140E-04
Specific heat    kJ/kg*K   . .       2.36291
Z factor . . . . . . . . . .         .620808
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m3/hr (15.6 deg C & 1 atm) .      568.565
Vol. flowrate m3/hr . . . .       4.16120
                  Vapor          Vapor
                   mole           flowrate
                  fraction        kgmol/hr
Nitrogen         .810000         19.4400
Oxygen           .190000         4.56000

*** Stream no. 20 ***
                                 All Vapor
Temperature deg C. . . . . . .    -126.695
Pressure bars. . . . . . . . .     43.6000
Enthalpy MJ/hr   . . . . . . .     164.710
Entropy MJ/hr*K  . . . . . . .    -.347280
Ave. mol. wt.  . . . . . . . .     28.7703
Total flow  kg/hr. . . . . . .     326.831
          kgmol/hr . . . . . .     11.3600
Density kg/m3  . . . . . . . .     165.937
Viscosity centipoise . . . . .     .106058E-01
Thermal cond. cal/cm*s*K . . .     .410140E-04
Specific heat   kJ/kg*K  . . .     2.36313
Z factor . . . . . . . . . . .     .620808
m3/hr (15.6 deg C & 1 atm) . .     269.121
Vol. flowrate m3/hr  . . . . .     1.96963
                  Vapor          Vapor
                   mole           flowrate
                  fraction        kgmol/hr
Nitrogen         .810000         9.20160
Oxygen           .190000         2.15840
 CODE REPORT

*** Stream no. 21 ***
                                 All Vapor
Temperature deg C. . . . . . .    -126.695
Pressure bars. . . . . . . . .     43.6000
Enthalpy MJ/hr   . . . . . . .     67.2758
Entropy MJ/hr*K  . . . . . . .    -.141847
Ave. mol. wt.  . . . . . . . .     28.7703
Total flow  kg/hr. . . . . . .     133.494
          kgmol/hr . . . . . .     4.64000
Density kg/m3  . . . . . . . .     165.937
Viscosity centipoise . . . . .     .106058E-01
Thermal cond. cal/cm*s*K . . .     .410140E-04
Specific heat   kJ/kg*K  . . .     2.36258
Z factor . . . . . . . . . . .     .620808
m3/hr (15.6 deg C & 1 atm) . .     109.922
Vol. flowrate m3/hr  . . . . .     .804498
                  Vapor          Vapor
                   mole           flowrate
                  fraction        kgmol/hr
Nitrogen         .810000         3.75840
Oxygen           .190000         .881600

*** Stream no. 22 ***
                                 All Vapor
Temperature deg C. . . . . . .    -136.781
Pressure bars. . . . . . . . .     43.6000
Enthalpy MJ/hr   . . . . . . .     62.2307
Entropy MJ/hr*K  . . . . . . .    -.177787
Ave. mol. wt.  . . . . . . . .     28.7703
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Total flow  kg/hr. . . . . . .      133.494
         kgmol/hr . . . . . .       4.64000
Density kg/m3 . . . . . . .         267.904
Viscosity centipoise . . . .        .106456E-01
Thermal cond. cal/cm*s*K . .        .397891E-04
Specific heat   kJ/kg*K  . .        7.77801
Z factor . . . . . . . . . .        .412963
m3/hr  (15.6 deg C & 1 atm) .       109.922
Vol. flowrate m3/hr  . . . .        .498299
                     Vapor        Vapor
                      mole         flowrate
                     fraction      kgmol/hr
Nitrogen           .810000        3.75840
Oxygen             .190000        .881600
 CODE REPORT

*** Stream no. 23 ***
                                  All Vapor
Temperature deg C. . . . . .       -136.752
Pressure bars. . . . . . . .        43.6000
Enthalpy MJ/hr   . . . . . .        152.431
Entropy MJ/hr*K  . . . . . .       -.434724
Ave. mol. wt.  . . . . . . .        28.7703
Total flow   kg/hr. . . . . .       326.831
         kgmol/hr . . . . . .       11.3600
Density kg/m3  . . . . . . .        267.071
Viscosity centipoise . . . .        .106420E-01
Thermal cond. cal/cm*s*K . .        .397925E-04
Specific heat   kJ/kg*K  . .        7.70562
Z factor . . . . . . . . . .        .414162
m3/hr  (15.6 deg C & 1 atm) .       269.121
Vol. flowrate m3/hr  . . . .        1.22378
                     Vapor        Vapor
                      mole         flowrate
                     fraction      kgmol/hr
Nitrogen           .810000        9.20160
Oxygen             .190000        2.15840

*** Stream no. 24 ***
                                  All Vapor
Temperature deg C. . . . . .       -136.760
Pressure bars. . . . . . . .        43.6000
Enthalpy MJ/hr   . . . . . .        214.662
Entropy MJ/hr*K  . . . . . .       -.612499
Ave. mol. wt.  . . . . . . .        28.7703
Total flow   kg/hr. . . . . .       460.325
         kgmol/hr . . . . . .       16.0000
Density kg/m3  . . . . . . .        267.300
Viscosity centipoise . . . .        .106430E-01
Thermal cond. cal/cm*s*K . .        .397916E-04
Specific heat   kJ/kg*K  . .        7.72551
Z factor . . . . . . . . . .        .413833
m3/hr  (15.6 deg C & 1 atm) .       379.043
Vol. flowrate m3/hr  . . . .        1.72216
                     Vapor        Vapor
                      mole         flowrate
                     fraction      kgmol/hr
Nitrogen           .810000        12.9600
Oxygen             .190000        3.04000
 CODE REPORT
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*** Stream no. 25 ***
                               Overall            Vapor              Liquid
Temperature deg C.           -172.366
Pressure bars. . .             6.61325
Vapor fraction . .             .817598
Enthalpy MJ/hr    .          214.662     !      187.666       !      27.0110
Entropy MJ/hr*K   .          -.474266    !     -.269560       !     -.204705
Ave. mol. wt.   . .           28.7703    !      28.6655       !      29.2409
Total flow kg/hr .           460.325     !      374.990       !      85.3375
         kgmol/hr .           16.0000    !      13.0816       !      2.91843
Density kg/m3  . . . . . . . . . . .            26.7024       !      1406.48
Viscosity centipoise . . . . . . . .            .690154E-02   !      .103313
Thermal cond. cal/cm*s*K . . . . . .            .357732E-04   !      .505024E-03
Specific heat    kJ/kg*K . . . . . .            1.25170       !      2.17381
Z factor . . . . . . . . . . . . . .            .847052
m3/hr (15.6 deg C & 1 atm) . . . . .            309.974
Vol. flowrate m3/hr  . . . . . . . .            14.0435
Surface tension dyne/cm. . . . . . . . . . . . . . . . . . . .   5.67519
S. G. (60/60)  . . . . . . . . . . . . . . . . . . . . . . . .   .915033
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . . . . . .   .934078E-01
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . . . . . .   .606751E-01
                     Vapor        Liquid           Vapor           Liquid
                     mole         mole             flowrate        flowrate
                   fraction     fraction           kgmol/hr        kgmol/hr
Nitrogen            .83630       .69196            10.9401         2.01943
Oxygen              .16370       .30804            2.14142         .899001

*** Stream no. 26 ***
                               Overall            Vapor              Liquid
Temperature deg C.           -172.347
Pressure bars. . .             6.60647
Vapor fraction . .             .832393
Enthalpy MJ/hr    .          323.794     !      286.507       !      37.2739
Entropy MJ/hr*K   .          -.693828    !     -.411175       !     -.282652
Ave. mol. wt.   . .           28.7703    !      28.6730       !      29.2536
Total flow kg/hr .           690.488     !      572.812       !      117.675
         kgmol/hr .           24.0000    !      19.9774       !      4.02257
Density kg/m3  . . . . . . . . . . .            26.6790       !      1407.54
Viscosity centipoise . . . . . . . .            .690418E-02   !      .103845
Thermal cond. cal/cm*s*K . . . . . .            .357657E-04   !      .504985E-03
Specific heat    kJ/kg*K . . . . . .            1.24986       !      2.17363
Z factor . . . . . . . . . . . . . .            .847282
m3/hr (15.6 deg C & 1 atm) . . . . .            473.210
Vol. flowrate m3/hr  . . . . . . . .            21.4708
Surface tension dyne/cm. . . . . . . . . . . . . . . . . . . .   5.69054
S. G. (60/60)  . . . . . . . . . . . . . . . . . . . . . . . .   .915375
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . . . . . .   .128755
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . . . . . .   .836040E-01
                     Vapor        Liquid           Vapor           Liquid
                     mole         mole             flowrate        flowrate
                   fraction     fraction           kgmol/hr        kgmol/hr
Nitrogen            .83443       .68876            16.6698         2.77060
Oxygen              .16557       .31124            3.30767         1.25197
 CODE REPORT

*** Stream no. 27 ***
                                      All Liquid
Temperature deg C. . . . . .          -175.941
Pressure bars. . . . . . . .           6.71314
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Enthalpy MJ/hr   . . . . . . .      152.101
Entropy MJ/hr*K  . . . . . . .     -1.12251
Ave. mol. wt.  . . . . . . . .      28.0883
Total flow  kg/hr. . . . . . .      449.412
          kgmol/hr . . . . . .      15.9999
Density kg/m3  . . . . . . . .      1329.92
Viscosity centipoise . . . . .      .947307E-01
Thermal cond. cal/cm*s*K . . .      .510531E-03
Specific heat   kJ/kg*K  . . .      2.34647
Surface tension dyne/cm. . . .      4.74317
S. G. (60/60)  . . . . . . . .      .883885
m3/hr (15.6 deg C & 1 atm) . .      .509248
Vol. flowrate m3/hr  . . . . .      .337928
                      Liquid        Liquid
                       mole         flowrate
                     fraction       kgmol/hr
Nitrogen            .981097        15.6975
Oxygen              .189026E-01    .302440

*** Stream no. 28 ***
                                    All Liquid
Temperature deg C. . . . . . .      -172.151
Pressure bars. . . . . . . . .      6.73254
Enthalpy MJ/hr   . . . . . . .      222.843
Entropy MJ/hr*K  . . . . . . .     -1.68107
Ave. mol. wt.  . . . . . . . .      29.2250
Total flow  kg/hr. . . . . . .      701.402
          kgmol/hr . . . . . .      24.0001
Density kg/m3  . . . . . . . .      1402.47
Viscosity centipoise . . . . .      .102868
Thermal cond. cal/cm*s*K . . .      .504666E-03
Specific heat   kJ/kg*K  . . .      2.18357
Surface tension dyne/cm. . . .      5.60304
S. G. (60/60)  . . . . . . . .      .914607
m3/hr (15.6 deg C & 1 atm) . .      .768091
Vol. flowrate m3/hr  . . . . .      .500125
                      Liquid        Liquid
                       mole         flowrate
                     fraction       kgmol/hr
Nitrogen            .695936        16.7025
Oxygen              .304064        7.29756
 CODE REPORT

*** Stream no. 29 ***
                                    All Liquid
Temperature deg C. . . . . . .      -186.647
Pressure bars. . . . . . . . .      6.71314
Enthalpy MJ/hr   . . . . . . .      141.492
Entropy MJ/hr*K  . . . . . . .     -1.23802
Ave. mol. wt.  . . . . . . . .      28.0883
Total flow  kg/hr. . . . . . .      449.412
          kgmol/hr . . . . . .      15.9999
Density kg/m3  . . . . . . . .      1445.97
Viscosity centipoise . . . . .      .123409
Thermal cond. cal/cm*s*K . . .      .527857E-03
Specific heat   kJ/kg*K  . . .      2.09301
Surface tension dyne/cm. . . .      6.98401
S. G. (60/60)  . . . . . . . .      .883885
m3/hr (15.6 deg C & 1 atm) . .      .509248
Vol. flowrate m3/hr  . . . . .      .310805
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                         Liquid        Liquid
                          mole        flowrate
                        fraction      kgmol/hr
Nitrogen             .981097        15.6975
Oxygen               .189026E-01    .302440

*** Stream no. 30 ***
                                    All Liquid
Temperature deg C. . . . . .         -176.939
Pressure bars. . . . . . . .          6.73254
Enthalpy MJ/hr   . . . . . .          215.707
Entropy MJ/hr*K  . . . . . .         -1.75344
Ave. mol. wt.  . . . . . . .          29.2250
Total flow  kg/hr. . . . . .          701.402
        kgmol/hr . . . . . .          24.0001
Density kg/m3  . . . . . . .          1454.69
Viscosity centipoise . . . .          .113785
Thermal cond. cal/cm*s*K . .          .512414E-03
Specific heat   kJ/kg*K  . .          2.07018
Surface tension dyne/cm. . .          6.67743
S. G. (60/60)  . . . . . . .          .914607
m3/hr (15.6 deg C & 1 atm) .          .768091
Vol. flowrate m3/hr  . . . .          .482172
                         Liquid        Liquid
                          mole        flowrate
                        fraction      kgmol/hr
Nitrogen             .695936        16.7025
Oxygen               .304064        7.29756
 CODE REPORT

*** Stream no. 31 ***
                         Overall               Vapor                Liquid
Temperature deg C.      -190.027
Pressure bars. . .       1.45725
Vapor fraction . .       .138541
Enthalpy MJ/hr   .       215.707     !     46.6821        !     168.992
Entropy MJ/hr*K  .      -1.73074     !   -.409657E-01     !    -1.68978
Ave. mol. wt.  . .       29.2250     !     28.5267        !     29.3371
Total flow kg/hr .       701.402     !     94.8512        !     606.546
        kgmol/hr .       24.0001     !     3.32499        !     20.6751
Density kg/m3  . . . . . . . . . .         6.34647        !     1590.31
Viscosity centipoise . . . . . . .         .566974E-02    !     .161615
Thermal cond. cal/cm*s*K . . . . .         .339249E-04    !     .533619E-03
Specific heat   kJ/kg*K  . . . . .         1.10370        !     1.84549
Z factor . . . . . . . . . . . . .         .949507
m3/hr (15.6 deg C & 1 atm) . . . .         78.6264
Vol. flowrate m3/hr  . . . . . . .         14.9457
Surface tension dyne/cm. . . . . . . . . . . . . .              9.92894
S. G. (60/60)  . . . . . . . . . . . . . . . . . .              .917617
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . .              .662037
Vol. flowrate m3/hr  . . . . . . . . . . . . . . .              .381406
                       Vapor      Liquid           Vapor             Liquid
                       mole        mole           flowrate          flowrate
                     fraction    fraction         kgmol/hr          kgmol/hr
Nitrogen             .87111      .66782           2.89644           13.8073
Oxygen               .12889      .33218           .428552           6.86778

*** Stream no. 32 ***
                         Overall               Vapor                Liquid
Temperature deg C.      -192.652
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Pressure bars. . .       1.40055
Vapor fraction . .      .668986E-01
Enthalpy MJ/hr    .      141.492      !    14.7390       !    126.654
Entropy MJ/hr*K   .     -1.23346      !   -.138828E-01   !   -1.21957
Ave. mol. wt.   . .      28.0883      !    28.0396       !    28.0918
Total flow kg/hr .       449.412      !    30.0129       !    419.398
        kgmol/hr .       15.9999      !    1.07037       !    14.9296
Density kg/m3  . . . . . . . . . .         6.29450       !    1503.80
Viscosity centipoise . . . . . . .         .541943E-02   !    .148024
Thermal cond. cal/cm*s*K . . . . .         .336861E-04   !    .537568E-03
Specific heat   kJ/kg*K  . . . . .         1.13005       !    1.97940
Z factor . . . . . . . . . . . . .         .947868
m3/hr (15.6 deg C & 1 atm) . . . .         24.9376
Vol. flowrate m3/hr  . . . . . . .         4.76818
Surface tension dyne/cm. . . . . . . . . . . . .              8.31469
S. G. (60/60)  . . . . . . . . . . . . . . . . .              .883978
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . .              .475188
Vol. flowrate m3/hr  . . . . . . . . . . . . . .              .278895
                    Vapor      Liquid         Vapor           Liquid
                     mole       mole          flowrate        flowrate
                   fraction   fraction        kgmol/hr        kgmol/hr
Nitrogen           .99332     .98024          1.06322         14.6345
Oxygen             .66830E-02 .19763E-01      .715335E-02     .295055
 CODE REPORT

*** Stream no. 33 ***
                        Overall              Vapor               Liquid
Temperature deg C.     -190.008
Pressure bars. . .       1.45725
Vapor fraction . .       .148894
Enthalpy MJ/hr    .      217.084      !    50.2428       !    166.874
Entropy MJ/hr*K   .     -1.71320      !   -.440183E-01   !   -1.66918
Ave. mol. wt.   . .      29.2250      !    28.5310       !    29.3463
Total flow kg/hr .       701.402      !    101.955       !    599.446
         kgmol/hr .      24.0001      !    3.57346       !    20.4266
Density kg/m3  . . . . . . . . . .         6.33689       !    1590.93
Viscosity centipoise . . . . . . .         .567168E-02   !    .161666
Thermal cond. cal/cm*s*K . . . . .         .339457E-04   !    .533592E-03
Specific heat   kJ/kg*K  . . . . .         1.10343       !    1.84441
Z factor . . . . . . . . . . . . .         .949532
m3/hr (15.6 deg C & 1 atm) . . . .         84.6209
Vol. flowrate m3/hr  . . . . . . .         16.0893
Surface tension dyne/cm. . . . . . . . . . . . .              9.94126
S. G. (60/60)  . . . . . . . . . . . . . . . . .              .917866
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . .              .654110
Vol. flowrate m3/hr  . . . . . . . . . . . . . .              .376793
                    Vapor      Liquid         Vapor           Liquid
                     mole       mole          flowrate        flowrate
                   fraction   fraction        kgmol/hr        kgmol/hr
Nitrogen           .87004     .66549          3.10905         13.5938
Oxygen             .12996     .33451          .464419         6.83284

*** Stream no. 34 ***
                              All Vapor
Temperature deg C. . . . . .   -192.647
Pressure bars. . . . . . . .    1.40055
Enthalpy MJ/hr   . . . . . .    453.661
Entropy MJ/hr*K  . . . . . .   -.421952
Ave. mol. wt.  . . . . . . .    28.0407
Total flow  kg/hr. . . . . .    908.518
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         kgmol/hr . . . . . .      32.4000
Density kg/m3  . . . . . . .       6.19011
Viscosity centipoise . . . .       .541992E-02
Thermal cond. cal/cm*s*K . .       .339356E-04
Specific heat   kJ/kg*K  . .       1.13027
Z factor . . . . . . . . . .       .947875
m3/hr (15.6 deg C & 1 atm) .       767.562
Vol. flowrate m3/hr   . . . .      146.771
                      Vapor       Vapor
                       mole        flowrate
                      fraction     kgmol/hr
Nitrogen           .993053        32.1749
Oxygen             .694701E-02    .225083
 CODE REPORT

*** Stream no. 35 ***
                                  All Liquid
Temperature deg C. . . . . .       -179.524
Pressure bars. . . . . . . .        1.59905
Enthalpy MJ/hr   . . . . . .       58.1288
Entropy MJ/hr*K  . . . . . .      -.604788
Ave. mol. wt.  . . . . . . .       31.8810
Total flow  kg/hr. . . . . .       242.295
         kgmol/hr . . . . . .      7.60000
Density kg/m3  . . . . . . .       1708.81
Viscosity centipoise . . . .       .175474
Thermal cond. cal/cm*s*K . .       .517224E-03
Specific heat   kJ/kg*K  . .       1.63250
Surface tension dyne/cm. . .       12.0762
S. G. (60/60)  . . . . . . .       .985094
m3/hr (15.6 deg C & 1 atm) .       .246347
Vol. flowrate m3/hr   . . . .      .141794
                       Liquid      Liquid
                        mole       flowrate
                      fraction     kgmol/hr
Nitrogen           .296160E-01    .225082
Oxygen             .970384        7.37492

*** Stream no. 36 ***
                                  All Vapor
Temperature deg C. . . . . .       -17.0000
Pressure bars. . . . . . . .        1.40055
Enthalpy MJ/hr   . . . . . .       206.062
Entropy MJ/hr*K  . . . . . .       .234685
Ave. mol. wt.  . . . . . . .       28.0407
Total flow  kg/hr. . . . . .       299.812
         kgmol/hr . . . . . .      10.6920
Density kg/m3  . . . . . . .       1.84668
Viscosity centipoise . . . .       .157820E-01
Thermal cond. cal/cm*s*K . .       .571445E-04
Specific heat   kJ/kg*K  . .       1.04649
Z factor . . . . . . . . . .       .998569
m3/hr (15.6 deg C & 1 atm) .       253.296
Vol. flowrate m3/hr   . . . .      162.355
                      Vapor       Vapor
                       mole        flowrate
                      fraction     kgmol/hr
Nitrogen           .993056        10.6178
Oxygen             .694353E-02    .742405E-01
 CODE REPORT
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*** Stream no. 37 ***
                                   All Liquid
Temperature deg C. . . . . . .      -183.027
Pressure bars. . . . . . . . .       1.59905
Enthalpy MJ/hr   . . . . . . .       56.7509
Entropy MJ/hr*K  . . . . . . .      -.619822
Ave. mol. wt.  . . . . . . . .       31.8809
Total flow  kg/hr. . . . . . .       242.295
        kgmol/hr . . . . . . .       7.60000
Density kg/m3  . . . . . . . .       1736.78
Viscosity centipoise . . . . .       .190476
Thermal cond. cal/cm*s*K . . .       .522893E-03
Specific heat   kJ/kg*K  . . .       1.61428
Surface tension dyne/cm. . . .       12.9412
S. G. (60/60)  . . . . . . . .       .985094
m3/hr (15.6 deg C & 1 atm) . .       .246347
Vol. flowrate m3/hr  . . . . .       .139510
                     Liquid          Liquid
                      mole          flowrate
                    fraction        kgmol/hr
Nitrogen          .296180E-01      .225097
Oxygen            .970382          7.37490

*** Stream no. 38 ***
                                   All Vapor
Temperature deg C. . . . . . .       14.3137
Pressure bars. . . . . . . . .       1.40055
Enthalpy MJ/hr   . . . . . . .       215.867
Entropy MJ/hr*K  . . . . . . .       .270798
Ave. mol. wt.  . . . . . . . .       28.0407
Total flow  kg/hr. . . . . . .       299.812
        kgmol/hr . . . . . . .       10.6920
Density kg/m3  . . . . . . . .       1.64442
Viscosity centipoise . . . . .       .172909E-01
Thermal cond. cal/cm*s*K . . .       .624492E-04
Specific heat   kJ/kg*K  . . .       1.04284
Z factor . . . . . . . . . . .       .999233
m3/hr (15.6 deg C & 1 atm) . .       253.296
Vol. flowrate m3/hr  . . . . .       182.323
                    Vapor          Vapor
                     mole           flowrate
                    fraction        kgmol/hr
Nitrogen          .993056          10.6178
Oxygen            .694353E-02      .742405E-01
 CODE REPORT

*** Stream no. 39 ***
                                   All Vapor
Temperature deg C. . . . . . .      -182.235
Pressure bars. . . . . . . . .       1.40055
Enthalpy MJ/hr   . . . . . . .       464.271
Entropy MJ/hr*K  . . . . . . .      -.297990
Ave. mol. wt.  . . . . . . . .       28.0407
Total flow  kg/hr. . . . . . .       908.519
        kgmol/hr . . . . . . .       32.4000
Density kg/m3  . . . . . . . .       5.40076
Viscosity centipoise . . . . .       .612474E-02
Thermal cond. cal/cm*s*K . . .       .350410E-04
Specific heat   kJ/kg*K  . . .       1.11342
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Z factor . . . . . . . . . . .      .961993
m3/hr (15.6 deg C & 1 atm) .      767.562
Vol. flowrate m3/hr  . . . .      168.223
                   Vapor          Vapor
                    mole          flowrate
                   fraction       kgmol/hr
Nitrogen         .993052          32.1749
Oxygen           .694790E-02      .225112

*** Stream no. 40 ***
                                  All Vapor
Temperature deg C. . . . . . .     -175.151
Pressure bars. . . . . . . . .      1.40055
Enthalpy MJ/hr   . . . . . . .      471.407
Entropy MJ/hr*K  . . . . . . .     -.222393
Ave. mol. wt.  . . . . . . . .      28.0407
Total flow  kg/hr. . . . . . .      908.519
          kgmol/hr . . . . . .      32.4000
Density kg/m3  . . . . . . . .      4.97527
Viscosity centipoise . . . . .      .660189E-02
Thermal cond. cal/cm*s*K . . .      .358104E-04
Specific heat   kJ/kg*K  . . .      1.10482
Z factor . . . . . . . . . . .      .968776
m3/hr (15.6 deg C & 1 atm) .      767.562
Vol. flowrate m3/hr  . . . .      182.609
                   Vapor          Vapor
                    mole          flowrate
                   fraction       kgmol/hr
Nitrogen         .993052          32.1749
Oxygen           .694790E-02      .225112
 CODE REPORT

*** Stream no. 41 ***
                                  All Liquid
Temperature deg C. . . . . . .     -183.027
Pressure bars. . . . . . . . .      190.000
Enthalpy MJ/hr   . . . . . . .      59.0735
Entropy MJ/hr*K  . . . . . . .     -.632921
Ave. mol. wt.  . . . . . . . .      31.8810
Total flow  kg/hr. . . . . . .      242.296
          kgmol/hr . . . . . .      7.60001
Density kg/m3  . . . . . . . .      1851.30
Viscosity centipoise . . . . .      .190477
Thermal cond. cal/cm*s*K . . .      .522893E-03
Specific heat   kJ/kg*K  . . .      1.53818
Surface tension dyne/cm. . . .      12.9162
S. G. (60/60)  . . . . . . . .      .985095
m3/hr (15.6 deg C & 1 atm) .      .246348
Vol. flowrate m3/hr  . . . .      .130880
                   Liquid         Liquid
                    mole          flowrate
                   fraction       kgmol/hr
Nitrogen         .296015E-01      .224972
Oxygen           .970398          7.37504

*** Stream no. 42 ***
                                  All Liquid
Temperature deg C. . . . . . .     -180.000
Pressure bars. . . . . . . . .      190.000
Enthalpy MJ/hr   . . . . . . .      60.2039
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Entropy MJ/hr*K . . . . . . .    -.620586
Ave. mol. wt.  . . . . . . . .    31.8810
Total flow  kg/hr. . . . . . .    242.296
        kgmol/hr . . . . . . .    7.60001
Density kg/m3  . . . . . . . .    1832.14
Viscosity centipoise . . . . .    .177378
Thermal cond. cal/cm*s*K . . .    .517994E-03
Specific heat   kJ/kg*K  . . .    1.54479
Surface tension dyne/cm. . . .    12.1671
S. G. (60/60)  . . . . . . . .    .985095
m3/hr (15.6 deg C & 1 atm) . .    .246348
Vol. flowrate m3/hr  . . . . .    .132249
                   Liquid         Liquid
                    mole         flowrate
                  fraction       kgmol/hr
Nitrogen         .296015E-01     .224972
Oxygen           .970398         7.37504
 CODE REPORT

*** Stream no. 43 ***
                                 All Vapor
Temperature deg C. . . . . . .    -175.000
Pressure bars. . . . . . . . .    1.40055
Enthalpy MJ/hr   . . . . . . .    471.559
Entropy MJ/hr*K  . . . . . . .    -.220847
Ave. mol. wt.  . . . . . . . .    28.0407
Total flow  kg/hr. . . . . . .    908.517
        kgmol/hr . . . . . . .    32.4000
Density kg/m3  . . . . . . . .    4.96696
Viscosity centipoise . . . . .    .661203E-02
Thermal cond. cal/cm*s*K . . .    .358270E-04
Specific heat   kJ/kg*K  . . .    1.10413
Z factor . . . . . . . . . . .    .968902
m3/hr (15.6 deg C & 1 atm) . .    767.562
Vol. flowrate m3/hr  . . . . .    182.915
                  Vapor          Vapor
                    mole         flowrate
                  fraction       kgmol/hr
Nitrogen         .993056         32.1750
Oxygen           .694356E-02     .224971

*** Stream no. 44 ***
                                 All Vapor
Temperature deg C. . . . . . .    -162.695
Pressure bars. . . . . . . . .    1.40055
Enthalpy MJ/hr   . . . . . . .    483.838
Entropy MJ/hr*K  . . . . . . .    -.102970
Ave. mol. wt.  . . . . . . . .    28.0407
Total flow  kg/hr. . . . . . .    908.517
        kgmol/hr . . . . . . .    32.4000
Density kg/m3  . . . . . . . .    4.37578
Viscosity centipoise . . . . .    .743164E-02
Thermal cond. cal/cm*s*K . . .    .371982E-04
Specific heat   kJ/kg*K  . . .    1.09313
Z factor . . . . . . . . . . .    .977283
m3/hr (15.6 deg C & 1 atm) . .    767.562
Vol. flowrate m3/hr  . . . . .    207.627
                  Vapor          Vapor
                    mole         flowrate
                  fraction       kgmol/hr
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Nitrogen          .993056         32.1750
Oxygen            .694356E-02     .224971
 CODE REPORT

*** Stream no. 45 ***
                                    All Liquid
Temperature deg C. . . . . . .       -166.695
Pressure bars. . . . . . . . .        190.000
Enthalpy MJ/hr    . . . . . .         65.2489
Entropy MJ/hr*K  . . . . . . .       -.569975
Ave. mol. wt.  . . . . . . . .        31.8810
Total  flow   kg/hr. . . . . .        242.296
          kgmol/hr . . . . . .        7.60001
Density kg/m3   . . . . . . .         1747.94
Viscosity centipoise . . . . .        .136068
Thermal cond. cal/cm*s*K . .          .496463E-03
Specific heat    kJ/kg*K  . .         1.58880
Surface tension dyne/cm. . .          8.96505
S. G. (60/60)  . . . . . . . .        .985095
m3/hr (15.6 deg C & 1 atm) .          .246348
Vol. flowrate m3/hr  . . . .          .138620
                       Liquid        Liquid
                        mole         flowrate
                      fraction       kgmol/hr
Nitrogen            .296015E-01     .224972
Oxygen              .970398         7.37504

*** Stream no. 46 ***
                                    All Vapor
Temperature deg C. . . . . . .       -18.0000
Pressure bars. . . . . . . . .        190.000
Enthalpy MJ/hr    . . . . . .         129.703
Entropy MJ/hr*K  . . . . . . .       -.190834
Ave. mol. wt.  . . . . . . . .        31.8810
Total  flow   kg/hr. . . . . .        242.296
          kgmol/hr . . . . . .        7.60001
Density kg/m3   . . . . . . .         337.460
Viscosity centipoise . . . . .        .189521E-01
Thermal cond. cal/cm*s*K . .          .540524E-04
Specific heat    kJ/kg*K  . .         1.41163
Z factor . . . . . . . . . . .        .846140
m3/hr (15.6 deg C & 1 atm) .          180.046
Vol. flowrate m3/hr  . . . .          .718010
                       Vapor         Vapor
                        mole         flowrate
                      fraction       kgmol/hr
Nitrogen            .296015E-01     .224972
Oxygen              .970398         7.37504
 CODE REPORT

*** Stream no. 47 ***
                                    All Vapor
Temperature deg C. . . . . . .       -15.0000
Pressure bars. . . . . . . . .        1.40055
Enthalpy MJ/hr    . . . . . .         626.332
Entropy MJ/hr*K  . . . . . . .        .718553
Ave. mol. wt.  . . . . . . . .        28.0407
Total  flow   kg/hr. . . . . .        908.517
          kgmol/hr . . . . . .        32.4000
Density kg/m3   . . . . . . .         1.83226
```

```
Viscosity centipoise . . . .     .158808E-01
Thermal cond. cal/cm*s*K . .     .574716E-04
Specific heat   kJ/kg*K  . .     1.04566
Z factor . . . . . . . . . .     .998621
m3/hr (15.6 deg C & 1 atm) .     767.562
Vol. flowrate m3/hr  . . . .     495.851
                    Vapor        Vapor
                     mole        flowrate
                    fraction     kgmol/hr
Nitrogen         .993056         32.1750
Oxygen           .694356E-02     .224971

*** Stream no. 48 ***
                                 All Vapor
Temperature deg C. . . . . .      -15.0000
Pressure bars. . . . . . . .      1.40055
Enthalpy MJ/hr   . . . . . .      206.689
Entropy MJ/hr*K  . . . . . .      .237124
Ave. mol. wt.  . . . . . . .      28.0407
Total flow  kg/hr. . . . . .      299.812
         kgmol/hr . . . . . .     10.6920
Density kg/m3  . . . . . . .      1.83227
Viscosity centipoise . . . .      .158808E-01
Thermal cond. cal/cm*s*K . .      .574715E-04
Specific heat   kJ/kg*K  . .      1.04545
Z factor . . . . . . . . . .      .998621
m3/hr (15.6 deg C & 1 atm) .      253.296
Vol. flowrate m3/hr  . . . .      163.631
                    Vapor        Vapor
                     mole        flowrate
                    fraction     kgmol/hr
Nitrogen         .993056         10.6178
Oxygen           .694353E-02     .742405E-01
 CODE REPORT

*** Stream no. 49 ***
                                 All Vapor
Temperature deg C. . . . . .      12.0000
Pressure bars. . . . . . . .      1.40055
Enthalpy MJ/hr   . . . . . .      215.143
Entropy MJ/hr*K  . . . . . .      .268271
Ave. mol. wt.  . . . . . . .      28.0407
Total flow  kg/hr. . . . . .      299.812
         kgmol/hr . . . . . .     10.6920
Density kg/m3  . . . . . . .      1.65783
Viscosity centipoise . . . .      .171821E-01
Thermal cond. cal/cm*s*K . .      .620435E-04
Specific heat   kJ/kg*K  . .      1.04336
Z factor . . . . . . . . . .      .999193
m3/hr (15.6 deg C & 1 atm) .      253.296
Vol. flowrate m3/hr  . . . .      180.849
                    Vapor        Vapor
                     mole        flowrate
                    fraction     kgmol/hr
Nitrogen         .993056         10.6178
Oxygen           .694353E-02     .742405E-01

*** Stream no. 50 ***
                                 All Vapor
Temperature deg C. . . . . .      -15.0000
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```
Pressure bars. . . . . . . . .      1.40055
Enthalpy MJ/hr   . . . . . . .      419.642
Entropy MJ/hr*K  . . . . . . .      .481432
Ave. mol. wt.  . . . . . . . .      28.0407
Total flow  kg/hr. . . . . . .      608.708
          kgmol/hr . . . . . .      21.7080
Density kg/m3  . . . . . . . .      1.83227
Viscosity centipoise . . . . .      .158808E-01
Thermal cond. cal/cm*s*K . . .      .574715E-04
Specific heat   kJ/kg*K  . . .      1.04576
Z factor . . . . . . . . . . .      .998621
m3/hr (15.6 deg C & 1 atm) . .      514.267
Vol. flowrate m3/hr  . . . . .      332.220
                     Vapor        Vapor
                      mole         flowrate
                     fraction     kgmol/hr
Nitrogen           .993056        21.5573
Oxygen             .694356E-02    .150731
 CODE REPORT

*** Stream no. 51 ***
                                  All Vapor
Temperature deg C. . . . . . .      9.97684
Pressure bars. . . . . . . . .      190.000
Enthalpy MJ/hr   . . . . . . .      138.784
Entropy MJ/hr*K  . . . . . . .     -.157037
Ave. mol. wt.  . . . . . . . .      31.8810
Total flow  kg/hr. . . . . . .      242.296
          kgmol/hr . . . . . .      7.60001
Density kg/m3  . . . . . . . .      284.551
Viscosity centipoise . . . . .      .203259E-01
Thermal cond. cal/cm*s*K . . .      .585559E-04
Specific heat   kJ/kg*K  . . .      1.27814
Z factor . . . . . . . . . . .      .904312
m3/hr (15.6 deg C & 1 atm) . .      180.046
Vol. flowrate m3/hr  . . . . .      .851514
                     Vapor        Vapor
                      mole         flowrate
                     fraction     kgmol/hr
Nitrogen           .296015E-01    .224972
Oxygen             .970398        7.37504

*** Stream no. 52 ***
                                  All Vapor
Temperature deg C. . . . . . .     -5.32648
Pressure bars. . . . . . . . .      1.40055
Enthalpy MJ/hr   . . . . . . .      635.509
Entropy MJ/hr*K  . . . . . . .      .753482
Ave. mol. wt.  . . . . . . . .      28.0407
Total flow  kg/hr. . . . . . .      908.517
          kgmol/hr . . . . . .      32.4000
Density kg/m3  . . . . . . . .      1.76568
Viscosity centipoise . . . . .      .163539E-01
Thermal cond. cal/cm*s*K . . .      .590755E-04
Specific heat   kJ/kg*K  . . .      1.04497
Z factor . . . . . . . . . . .      .998852
m3/hr (15.6 deg C & 1 atm) . .      767.562
Vol. flowrate m3/hr  . . . . .      514.551
                     Vapor        Vapor
                      mole         flowrate
```

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                      fraction        kgmol/hr
Nitrogen             .993056         32.1750
Oxygen               .694356E-02     .224971
 CODE REPORT


 TOWR # 1          Data file: PLANT.OUT            Profile file: link.prf


Column Summary

      Temp    Pres                          Net Flow Rates                       Duties
Stg    C      bars                            kgmols/hr                           MJ/hr
                           Liquid        Vapor          Feed       Product
  1 -175.9     6.713 18.302                                          16.000     -163.51
  2 -174.8     6.713 18.437        34.301
  3 -174.6     6.714 18.315        34.437
  4 -174.4     6.715 18.186        34.315
  5 -174.1     6.716 18.053        34.186
  6 -173.9     6.717 17.920        34.053
  7 -173.7     6.718 17.788        33.920
  8 -173.5     6.719 17.664        33.788
  9 -173.2     6.720 17.548        33.664
 10 -173.0     6.721 17.441        33.548
 11 -172.9     6.722 17.345        33.441
 12 -172.7     6.723 17.260        33.345
 13 -172.5     6.724 17.188        33.260
 14 -172.4     6.725 17.125        33.188
 15 -172.3     6.726 20.019        33.125       16.000
 16 -172.3     6.727 20.017        20.019
 17 -172.3     6.728 20.013        20.017
 18 -172.3     6.729 20.007        20.013
 19 -172.2     6.731 19.995        20.006
 20 -172.2     6.732 19.977        19.995
 21 -172.2     6.733               19.977       24.000       24.000

 Stream #  25 fed to Stg  15 is  81.760 % Vapor
 Stream #  26 fed to Stg  21 is  83.239 % Vapor

 Stream #  27 is Liquid Distillate from Stg 1
 Stream #  28 is Liquid Bottoms from Stg  21

 Condenser duty is -163.509        MJ/hr
 Reboiler duty is   .000000        MJ/hr
 CODE REPORT


 TOWR # 1          Data file: PLANT.OUT            Profile file: link.prf
Tray Liquid Properties

                                  Standard         Actual       Actual
      Mass flow      Avg          Vol. flow        Vol. flow    Density   Viscosity
Stg     kg/hr       mol wt          m3/hr            m3/hr       kg/m3    centipoise

  1         514.1   28.09              .58              .39    1329.90        .0947
  2         519.3   28.17              .59              .39    1324.17        .0934
  3         517.4   28.25              .58              .39    1330.77        .0941
  4         515.4   28.34              .58              .39    1337.73        .0949
  5         513.4   28.44              .58              .38    1344.89        .0957
  6         511.3   28.53              .57              .38    1352.12        .0966
```

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  7        509.2  28.63          .57            .37  1359.24     .0974
  8        507.3  28.72          .56            .37  1366.10     .0983
  9        505.5  28.81          .56            .37  1372.55     .0991
 10        503.8  28.89          .56            .37  1378.48     .0998
 11        502.3  28.96          .55            .36  1383.83     .1005
 12        501.0  29.03          .55            .36  1388.54     .1011
 13        499.9  29.08          .55            .36  1392.62     .1016
 14        498.9  29.13          .55            .36  1396.12     .1021
 15        584.0  29.17          .64            .42  1399.05     .1024
 16        584.0  29.18          .64            .42  1399.15     .1024
 17        584.0  29.18          .64            .42  1399.33     .1025
 18        583.9  29.18          .64            .42  1399.65     .1025
 19        583.7  29.19          .64            .42  1400.19     .1026
 20        583.4  29.20          .64            .42  1401.05     .1027
 21        701.4  29.23          .77            .50  1402.45     .1029
Tray Vapor Properties

                          Standard      Actual           Actual
      Mass flow    Avg    Vol. flow    Vol. flow         density
Stg     kg/hr    mol wt     m3/hr        m3/hr      Z     kg/m3

  1    *** Total Condenser : No Vapor Outlet ***
  2      963.5   28.09      812.6       34.93   .8356  27.5836
  3      968.7   28.13      815.8       35.16   .8364  27.5500
  4      966.8   28.18      812.9       35.14   .8372  27.5144
  5      964.8   28.22      809.9       35.11   .8380  27.4771
  6      962.8   28.27      806.7       35.09   .8388  27.4393
  7      960.7   28.32      803.6       35.06   .8397  27.4012
  8      958.6   28.37      800.4       35.03   .8405  27.3650
  9      956.7   28.42      797.5       35.01   .8413  27.3303
 10      954.9   28.46      794.8       34.98   .8420  27.2985
 11      953.2   28.50      792.2       34.96   .8427  27.2699
 12      951.7   28.54      789.9       34.93   .8432  27.2448
 13      950.4   28.58      787.9       34.91   .8438  27.2235
 14      949.3   28.60      786.2       34.89   .8442  27.2061
 15      948.3   28.63      784.7       34.88   .8446  27.1917
 16      573.1   28.63      474.3       21.08   .8446  27.1946
 17      573.1   28.63      474.2       21.07   .8446  27.1974
 18      573.1   28.63      474.1       21.07   .8446  27.1993
 19      573.0   28.64      474.0       21.06   .8446  27.2003
 20      572.8   28.65      473.7       21.06   .8448  27.1985
 21      572.5   28.66      473.3       21.05   .8449  27.1935

CODE: Chemical Engineering Simulation System
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TOWR # 1          Data file: PLANT.TSZ          Profile file: link.prf

 Smith-Dresser-Ohlswager Shortcut Technique

  ***User Provided Input Data***

  Tray spacing (in. or cm)          7.0000
  Downcomer area (ft2 or m2)         .0151
  Weir length (in. or cm)          24.0000
  Weir height (in. or cm)           3.0000

                 Liquid      Vapor        Liquid      Vapor      Flooding  Se
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      Diameter  Vol. flow  Vol. flow    density     density      velocity  height
Stg     meter    m3/min     m3/sec       kg/m3       kg/m3        m/sec      meter

  1   ***Condenser: No tray sizing***
  2      .3051      .01        .01 1324.1680   27.5840          .1673     .0361
  3      .3053      .01        .01 1330.7740   27.5504          .1681     .0361
  4      .3047      .01        .01 1337.7290   27.5148          .1689     .0361
  5      .3041      .01        .01 1344.8930   27.4775          .1696     .0361
  6      .3034      .01        .01 1352.1240   27.4397          .1704     .0362
  7      .3028      .01        .01 1359.2350   27.4016          .1711     .0362
  8      .3022      .01        .01 1366.1010   27.3654          .1718     .0362
  9      .3017      .01        .01 1372.5490   27.3307          .1725     .0362
 10      .3012      .01        .01 1378.4840   27.2989          .1731     .0362
 11      .3007      .01        .01 1383.8270   27.2703          .1736     .0363
 12      .3003      .01        .01 1388.5370   27.2452          .1741     .0363
 13      .3000      .01        .01 1392.6240   27.2239          .1745     .0363
 14      .2997      .01        .01 1396.1170   27.2065          .1749     .0363
 15      .3029      .01        .01 1399.0490   27.1921          .1701     .0359
 16      .2615      .01        .01 1399.1460   27.1950          .1517     .0359
 17      .2615      .01        .01 1399.3340   27.1978          .1517     .0359
 18      .2614      .01        .01 1399.6510   27.1997          .1517     .0359
 19      .2614      .01        .01 1400.1900   27.2007          .1517     .0359
 20      .2613      .01        .01 1401.0490   27.1989          .1518     .0359
 21      .2661      .01        .01 1402.4480   27.1939          .1444     .0354
CODE REPORT


TOWR # 2          Data file: PLANT.OUT          Profile file: pool.prf


Column Summary

     Temp    Pres                      Net Flow Rates                    Duties
Stg   C      bars                        kgmols/hr                        MJ/hr
                      Liquid      Vapor        Feed       Product
  1 -192.6     1.401 14.924                   16.000      32.400
  2 -192.6     1.404 14.920       31.324
  3 -192.6     1.408 14.915       31.320
  4 -192.5     1.411 14.907       31.315
  5 -192.5     1.415 14.896       31.307
  6 -192.5     1.418 14.881       31.296
  7 -192.4     1.422 14.861       31.281
  8 -192.3     1.425 14.832       31.261
  9 -192.2     1.429 14.793       31.232
 10 -192.1     1.432 14.742       31.194
 11 -192.0     1.436 14.674       31.142
 12 -191.8     1.440 14.587       31.074
 13 -191.6     1.443 14.478       30.987
 14 -191.3     1.447 14.348       30.878
 15 -191.0     1.450 14.198       30.748
 16 -190.6     1.454 14.037       30.598
 17 -190.2     1.457 34.459       30.437     24.000
 18 -190.2     1.461 34.464       26.859
 19 -190.2     1.464 34.469       26.864
 20 -190.2     1.468 34.474       26.869
 21 -190.2     1.471 34.479       26.874
 22 -190.1     1.475 34.484       26.879
 23 -190.1     1.479 34.489       26.884
 24 -190.1     1.482 34.494       26.889
 25 -190.1     1.486 34.499       26.894
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26 -190.0      1.489 34.504       26.899
27 -190.0      1.493 34.509       26.904
28 -190.0      1.496 34.514       26.909
29 -190.0      1.500 34.519       26.914
30 -189.9      1.503 34.524       26.919
31 -189.9      1.507 34.529       26.924
32 -189.9      1.510 34.534       26.929
33 -189.9      1.514 34.539       26.934
34 -189.8      1.518 34.544       26.939
35 -189.8      1.521 34.549       26.944
36 -189.8      1.525 34.554       26.949
37 -189.8      1.528 34.559       26.954
38 -189.8      1.532 34.564       26.959
39 -189.7      1.535 34.569       26.964
40 -189.7      1.539 34.574       26.969
41 -189.7      1.542 34.578       26.973
42 -189.7      1.546 34.583       26.978
43 -189.6      1.549 34.588       26.983
44 -189.6      1.553 34.592       26.988
45 -189.6      1.557 34.596       26.992
46 -189.6      1.560 34.599       26.996
47 -189.5      1.564 34.602       26.999
CODE REPORT
                    Liquid       Vapor         Feed       Product

48 -189.5      1.567 34.600       27.002
49 -189.5      1.571 34.589       27.000
50 -189.4      1.574 34.553       26.989
51 -189.3      1.578 34.451       26.953
52 -189.0      1.581 34.183       26.851
53 -188.3      1.585 33.566       26.583
54 -186.7      1.588 32.488       25.966
55 -184.1      1.592 31.382       24.888
56 -181.2      1.596 30.829       23.782
57 -179.5      1.599              23.229                   7.6000      153.21

Stream #  32 fed to Stg   1 is    6.690 % Vapor
Stream #  33 fed to Stg  17 is   14.889 % Vapor

Stream #  34 is Vapor Distillate from Stg 1
Stream #  35 is Liquid Bottoms from Stg  57

Condenser duty is  .000000        MJ/hr
Reboiler duty is   153.215        MJ/hr
CODE REPORT


 TOWR # 2        Data file: PLANT.OUT          Profile file: pool.prf
Tray Liquid Properties

                                Standard        Actual     Actual                Surface
     Mass flow      Avg        Vol. flow      Vol. flow    Density   Viscosity   tension
Stg    kg/hr      mol wt         m3/hr          m3/hr       kg/m3    centipoise  dyne/cm

 1       419.3   28.09             .48            .28     1504.02       .1477      8.32
 2       419.2   28.10             .47            .28     1504.13       .1477      8.32
 3       419.2   28.11             .47            .28     1504.38       .1476      8.32
 4       419.1   28.11             .47            .28     1504.79       .1476      8.33
 5       419.0   28.12             .47            .28     1505.46       .1477      8.34
 6       418.8   28.14             .47            .28     1506.44       .1477      8.36
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  7      418.5  28.16         .47        .28   1507.86    .1479    8.38
  8      418.1  28.19         .47        .28   1509.88    .1482    8.42
  9      417.6  28.23         .47        .28   1512.68    .1485    8.47
 10      417.0  28.28         .47        .27   1516.48    .1491    8.53
 11      416.1  28.35         .47        .27   1521.53    .1499    8.63
 12      414.9  28.45         .47        .27   1528.10    .1509    8.75
 13      413.5  28.56         .46        .27   1536.34    .1522    8.90
 14      411.8  28.70         .46        .27   1546.31    .1539    9.08
 15      409.8  28.86         .45        .26   1557.79    .1558    9.30
 16      407.7  29.04         .45        .26   1570.25    .1580    9.54
 17     1007.2  29.23        1.10        .64   1582.90    .1602    9.78
 18     1007.3  29.23        1.10        .64   1582.70    .1601    9.78
 19     1007.5  29.23        1.10        .64   1582.51    .1600    9.77
 20     1007.6  29.23        1.10        .64   1582.31    .1598    9.77
 21     1007.8  29.23        1.10        .64   1582.10    .1597    9.76
 22     1007.9  29.23        1.10        .64   1581.91    .1596    9.76
 23     1008.1  29.23        1.10        .64   1581.71    .1595    9.75
 24     1008.2  29.23        1.10        .64   1581.51    .1594    9.75
 25     1008.4  29.23        1.10        .64   1581.31    .1593    9.74
 26     1008.5  29.23        1.10        .64   1581.12    .1592    9.74
 27     1008.7  29.23        1.10        .64   1580.92    .1591    9.73
 28     1008.8  29.23        1.10        .64   1580.72    .1590    9.72
 29     1009.0  29.23        1.10        .64   1580.53    .1589    9.72
 30     1009.1  29.23        1.10        .64   1580.33    .1588    9.71
 31     1009.3  29.23        1.11        .64   1580.14    .1587    9.71
 32     1009.4  29.23        1.11        .64   1579.94    .1586    9.70
 33     1009.6  29.23        1.11        .64   1579.75    .1584    9.70
 34     1009.7  29.23        1.11        .64   1579.55    .1583    9.69
 35     1009.9  29.23        1.11        .64   1579.36    .1582    9.69
 36     1010.0  29.23        1.11        .64   1579.16    .1581    9.68
 37     1010.2  29.23        1.11        .64   1578.97    .1580    9.68
 38     1010.3  29.23        1.11        .64   1578.77    .1579    9.67
 39     1010.5  29.23        1.11        .64   1578.58    .1578    9.67
 40     1010.6  29.23        1.11        .64   1578.38    .1577    9.66
 41     1010.8  29.23        1.11        .64   1578.19    .1576    9.66
 42     1010.9  29.23        1.11        .64   1578.00    .1575    9.65
 43     1011.0  29.23        1.11        .64   1577.81    .1574    9.65
 44     1011.2  29.23        1.11        .64   1577.62    .1573    9.64
 45     1011.3  29.23        1.11        .64   1577.44    .1572    9.63
 46     1011.4  29.23        1.11        .64   1577.28    .1571    9.63
 47     1011.5  29.23        1.11        .64   1577.15    .1570    9.63
 48     1011.6  29.24        1.11        .64   1577.13    .1569    9.62
 49     1011.5  29.24        1.11        .64   1577.43    .1569    9.63
 CODE REPORT


 TOWR # 2        Data file: PLANT.OUT          Profile file: pool.prf
Tray Liquid Properties

                             Standard        Actual      Actual                 Surface
       Mass flow    Avg      Vol. flow      Vol. flow    Density    Viscosity   tension
Stg     kg/hr      mol wt      m3/hr          m3/hr       kg/m3    centipoise   dyne/cm

 50     1011.1   29.26         1.11           .64      1578.51      .1571      9.65
 51     1009.8   29.31         1.10           .64      1581.73      .1576      9.71
 52     1006.4   29.44         1.10           .63      1590.22      .1591      9.87
 53      998.6   29.75         1.08           .62      1610.17      .1627     10.26
 54      986.0   30.35         1.05           .60      1646.33      .1692     10.98
 55      976.1   31.10         1.01           .58      1684.68      .1753     11.72
 56      975.4   31.64         1.00           .57      1703.76      .1764     12.04
```

```
 57        242.3  31.88          .25           .14   1708.78      .1755    12.08
 CODE REPORT


 TOWR # 2        Data file: PLANT.OUT          Profile file: pool.prf
Tray Vapor Properties

                                  Standard      Actual               Actual
     Mass flow      Avg          Vol. flow    Vol. flow              density
Stg    kg/hr       mol wt          m3/hr        m3/hr        Z       kg/m3

  1        908.5   28.04            767.6       146.77    .9479     6.1900
  2        878.4   28.04            742.1       141.58    .9478     6.2042
  3        878.3   28.04            742.0       141.25    .9477     6.2183
  4        878.3   28.05            741.8       140.93    .9476     6.2322
  5        878.2   28.05            741.7       140.60    .9476     6.2461
  6        878.1   28.06            741.4       140.28    .9475     6.2595
  7        877.9   28.06            741.1       139.95    .9474     6.2726
  8        877.6   28.07            740.6       139.63    .9474     6.2850
  9        877.2   28.09            739.9       139.31    .9474     6.2969
 10        876.7   28.11            739.0       139.00    .9475     6.3077
 11        876.1   28.13            737.8       138.68    .9475     6.3174
 12        875.2   28.16            736.2       138.36    .9477     6.3256
 13        874.0   28.21            734.1       138.03    .9479     6.3322
 14        872.6   28.26            731.5       137.70    .9481     6.3369
 15        870.9   28.32            728.4       137.36    .9484     6.3399
 16        868.9   28.40            724.9       137.02    .9488     6.3416
 17        866.8   28.48            721.1       136.66    .9492     6.3427
 18        764.9   28.48            636.3       120.33    .9491     6.3569
 19        765.0   28.48            636.4       120.08    .9490     6.3712
 20        765.2   28.48            636.5       119.83    .9489     6.3855
 21        765.3   28.48            636.7       119.59    .9488     6.3997
 22        765.5   28.48            636.8       119.35    .9488     6.4141
 23        765.6   28.48            636.9       119.10    .9487     6.4283
 24        765.8   28.48            637.0       118.86    .9486     6.4426
 25        765.9   28.48            637.1       118.62    .9485     6.4568
 26        766.1   28.48            637.2       118.39    .9484     6.4712
 27        766.2   28.48            637.4       118.15    .9483     6.4854
 28        766.4   28.48            637.5       117.91    .9482     6.4997
 29        766.5   28.48            637.6       117.68    .9481     6.5139
 30        766.7   28.48            637.7       117.44    .9480     6.5282
 31        766.8   28.48            637.8       117.21    .9479     6.5425
 32        767.0   28.48            638.0       116.98    .9478     6.5568
 33        767.1   28.48            638.1       116.74    .9478     6.5710
 34        767.3   28.48            638.2       116.51    .9477     6.5853
 35        767.4   28.48            638.3       116.28    .9476     6.5995
 36        767.6   28.48            638.4       116.06    .9475     6.6138
 37        767.7   28.48            638.5       115.83    .9474     6.6280
 38        767.9   28.48            638.7       115.60    .9473     6.6423
 39        768.0   28.48            638.8       115.38    .9472     6.6565
 40        768.2   28.48            638.9       115.16    .9471     6.6707
 41        768.3   28.48            639.0       114.93    .9470     6.6850
 42        768.5   28.48            639.1       114.71    .9469     6.6992
 43        768.6   28.48            639.2       114.49    .9469     6.7135
 44        768.8   28.49            639.3       114.27    .9468     6.7277
 45        768.9   28.49            639.4       114.04    .9467     6.7419
 46        769.0   28.49            639.5       113.82    .9466     6.7561
 47        769.1   28.49            639.6       113.60    .9465     6.7703
 48        769.2   28.49            639.7       113.39    .9464     6.7842
 49        769.3   28.49            639.6       113.16    .9463     6.7980
```

```
 TOWR # 2         Data file: PLANT.OUT          Profile file: pool.prf
Tray Vapor Properties

                              Standard     Actual                Actual
     Mass flow      Avg      Vol. flow    Vol. flow              density
Stg    kg/hr      mol wt       m3/hr        m3/hr          Z     kg/m3

 50       769.2  28.50         639.4       112.94   .9463    6.8107
 51       768.8  28.52         638.5       112.71   .9464    6.8211
 52       767.5  28.58         636.1       112.45   .9467    6.8252
 53       764.1  28.74         629.8       112.12   .9475    6.8151
 54       756.3  29.13         615.1       111.52   .9494    6.7821
 55       743.7  29.88         589.6       110.28   .9524    6.7435
 56       733.8  30.86         563.4       108.76   .9549    6.7468
 57       733.1  31.56         550.3       108.14   .9562    6.7793

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TOWR # 2         Data file: PLANT.TSZ          Profile file: pool.prf

 Smith-Dresser-Ohlswager Shortcut Technique

  ***User Provided Input Data***

  Tray spacing (in. or cm)        7.0000
  Downcomer area (ft2 or m2)       .0236
  Weir length (in. or cm)        30.0000
  Weir height (in. or cm)         3.0000

                   Liquid     Vapor         Liquid       Vapor      Flooding  Settling
     Diameter   Vol. flow   Vol. flow      density     density     velocity  height
Stg    meter      m3/min      m3/sec        kg/m3       kg/m3       m/sec      meter

  1    .3980        .00         .04 1504.0210     6.1901         .4043    .0373
  2    .3922        .00         .04 1504.1320     6.2043         .4046    .0373
  3    .3920        .00         .04 1504.3760     6.2184         .4042    .0373
  4    .3918        .00         .04 1504.7910     6.2323         .4038    .0373
  5    .3915        .00         .04 1505.4570     6.2462         .4035    .0373
  6    .3913        .00         .04 1506.4410     6.2596         .4032    .0373
  7    .3910        .00         .04 1507.8640     6.2727         .4029    .0373
  8    .3907        .00         .04 1509.8790     6.2851         .4028    .0373
  9    .3904        .00         .04 1512.6780     6.2970         .4028    .0373
 10    .3899        .00         .04 1516.4810     6.3078         .4029    .0373
 11    .3894        .00         .04 1521.5340     6.3175         .4033    .0373
 12    .3889        .00         .04 1528.0950     6.3257         .4038    .0373
 13    .3882        .00         .04 1536.3390     6.3323         .4046    .0374
 14    .3874        .00         .04 1546.3100     6.3370         .4057    .0374
 15    .3865        .00         .04 1557.7890     6.3400         .4070    .0374
 16    .3856        .00         .04 1570.2530     6.3417         .4085    .0374
 17    .3935        .01         .04 1582.9040     6.3428         .3874    .0353
 18    .3775        .01         .03 1582.7020     6.3570         .3785    .0353
 19    .3774        .01         .03 1582.5090     6.3713         .3780    .0353
 20    .3773        .01         .03 1582.3070     6.3856         .3775    .0353
 21    .3772        .01         .03 1582.1040     6.3998         .3769    .0353
```

```
 22      .3771          .01          .03 1581.9110      6.4142           .3764      .0353
 23      .3770          .01          .03 1581.7080      6.4284           .3759      .0353
 24      .3769          .01          .03 1581.5140      6.4427           .3754      .0353
 25      .3768          .01          .03 1581.3120      6.4569           .3748      .0353
 26      .3767          .01          .03 1581.1170      6.4713           .3743      .0353
 27      .3766          .01          .03 1580.9240      6.4855           .3738      .0353
 28      .3765          .01          .03 1580.7210      6.4998           .3733      .0353
CODE REPORT

Smith-Dresser-Ohlswager Shortcut Technique

                    Liquid      Vapor          Liquid        Vapor      Flooding   Settling
        Diameter  Vol. flow   Vol. flow       density       density     velocity   height
Stg       meter     m3/min      m3/sec          kg/m3         kg/m3       m/sec        meter

 29      .3764          .01          .03 1580.5260      6.5140           .3728      .0353
 30      .3763          .01          .03 1580.3320      6.5283           .3723      .0353
 31      .3762          .01          .03 1580.1370      6.5426           .3718      .0353
 32      .3761          .01          .03 1579.9430      6.5569           .3713      .0353
 33      .3761          .01          .03 1579.7490      6.5711           .3708      .0353
 34      .3760          .01          .03 1579.5550      6.5854           .3703      .0353
 35      .3759          .01          .03 1579.3600      6.5996           .3697      .0353
 36      .3758          .01          .03 1579.1650      6.6139           .3692      .0353
 37      .3757          .01          .03 1578.9690      6.6281           .3687      .0353
 38      .3756          .01          .03 1578.7750      6.6423           .3683      .0353
 39      .3755          .01          .03 1578.5800      6.6566           .3678      .0353
 40      .3754          .01          .03 1578.3850      6.6708           .3673      .0353
 41      .3753          .01          .03 1578.1900      6.6851           .3668      .0353
 42      .3752          .01          .03 1578.0040      6.6993           .3663      .0353
 43      .3752          .01          .03 1577.8130      6.7136           .3658      .0353
 44      .3751          .01          .03 1577.6250      6.7278           .3653      .0353
 45      .3750          .01          .03 1577.4420      6.7420           .3648      .0353
 46      .3749          .01          .03 1577.2790      6.7562           .3643      .0353
 47      .3748          .01          .03 1577.1480      6.7704           .3639      .0353
 48      .3747          .01          .03 1577.1340      6.7843           .3634      .0353
 49      .3746          .01          .03 1577.4270      6.7981           .3630      .0353
 50      .3744          .01          .03 1578.5150      6.8108           .3628      .0353
 51      .3740          .01          .03 1581.7290      6.8212           .3630      .0353
 52      .3732          .01          .03 1590.2230      6.8253           .3642      .0353
 53      .3714          .01          .03 1610.1710      6.8152           .3675      .0354
 54      .3682          .01          .03 1646.3300      6.7822           .3738      .0355
 55      .3643          .01          .03 1684.6800      6.7436           .3799      .0356
 56      .3618          .01          .03 1703.7650      6.7469           .3814      .0356
 57     ***Reboiler: No tray sizing***
```

Appendix C

Computer results of the optimized exchanger network of the oxygen plant

ALT2.out

```
CODE: Chemical Engineering Simulation System
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          TOPOLOGY

Equipment                    Stream Numbers

  1   HXER             5  16   -7 -17
  2   HXER             4  15   -6 -18
  3   HXER             9  14  -12 -15
  4   HXER            19  -3    0   0
  5   DVDR             3  -5   -4   0
  6   DVDR             8  -9  -10   0
  7   MIXR             7   6   -8   0
  8   ENTM            10 -11    0   0
  9   VALV            12 -13    0   0
 10   HXER             1  17   -2 -20
 11   HXER             2  18  -19 -21

Stream Connections

Stream     Equipment
       From      To
     1      0      10
     2     10      11
     3      4       5
     4      5       2
     5      5       1
     6      2       7
     7      1       7
     8      7       6
     9      6       3
    10      6       8
    11      8       0
    12      3       9
    13      9       0
    14      0       3
    15      3       2
    16      0       1
    17      1      10
    18      2      11
    19     11       4
    20     10       0
    21     11       0

COMPONENTS . . . . . .        2

ID numbers ...........        46,   47,

         THERMODYNAMICS

  Kvalue option: Peng-Robinson
  Enthalpy option: Peng-Robihson
  Density option: API method
 CODE REPORT
```

```
Recycle calculations are converged.

Recycle equipment list (KE2):          4,   5,   1,  10,   6,   3,   2,   7, 1

Preferred cut stream list (KE3):     19,   8,

Convergence tolerances,          Error
         Flowrates:            .00100000
         Vapor fraction:       .00100000
         Temperature:          .00100000
         Pressure:             .00100000
         Enthalpy:             .00100000
         Flash calcs:          .00005000

Max. loops in recycle calc.:    30
           in flash calcs:      75


CODE: Chemical Engineering Simulation System
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***    DIVIDERS          ***
Equipment no.                 5             6
External name
Fraction/flow  1        .33200        .40000
               2        .66800        .60000
               3        .00000        .00000
               4        .00000        .00000
               5        .00000        .00000
               6        .00000        .00000
Mode                        .0            .0
Stream #                    .0            .0
Comp. ID #                  .0            .0
Comp. ID #                  .0            .0
Comp. ID #                  .0            .0
Comp. ID #                  .0            .0
Comp. ID #                  .0            .0
Comp. ID #                  .0            .0
Comp. ID #                  .0            .0
Comp. ID #                  .0            .0
Comp. ID #                  .0            .0
Comp. ID #                  .0            .0
.........................................................................

***   MIXERS-W/FLASH   ***
Equipment no.                7
External name
.........................................................................

***      VALVES          ***
Equipment no.                9
External name
Outlet pressure bars   6.6132
.........................................................................

***EXCHANGER/CONDENSERS***
```

```
Equipment no.                1            2            3            4
External name
Heat transfer coeff.    300.00       300.00       300.00       .00000
Area                    6.6210       20.686       1.8796       .00000
Number of shells            .0           .0           .0           .0
Shell passes                .0           .0           .0           .0
Tube passes                 .0           .0           .0           .0
Mode                       3.0          3.0          3.0          5.0
Min. delta T or T-out    24.00        19.00        28.00        12.00
Delta P, stream 1       .00000       .00000       .00000       .00000
Delta P, stream 2       .00000       .00000       .00000       .00000
Q, stream 1   MJ/hr    -71.526      -144.00      -18.371       2.9531
Water usage, DM3/hr     .00000       .00000       .00000       .00000
Corrected delta T        36.01        23.20        32.58          .00
Equipment no.               10           11
External name
Heat transfer coeff.    300.00       300.00
Area                    1.2357       1.8388
Number of shells            .0           .0
Shell passes                .0           .0
Tube passes                 .0           .0
Mode                       3.0          3.0
Min. delta T or T-out    12.00        14.40
Delta P, stream 1       .00000       .00000
Delta P, stream 2       .00000       .00000
Q, stream 1   MJ/hr    -7.0601      -8.5576
Water usage, DM3/hr     .00000       .00000
Corrected delta T        19.04        15.51
.................................................................
```

```
CODE: Chemical Engineering Simulation System
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***  ENTROPY MACHINES  ***
Equipment no.                8
External name
Mode                        .0
Outlet pressure bars    6.6065
Adiabatic efficiency    .92000
Theoretical hp         -10.158
Actual horsepower      -9.3453
Entropy in  KJ/deg C   -760.17
Entropy out, ideal     -760.68
Entropy out, actual    -739.87
.................................................................
```

```
 CODE REPORT

*** Stream no.  1 ***
                                 All Vapor
Temperature deg C. . . . . .       22.0000
Pressure bars. . . . . . . .       44.0000
Enthalpy MJ/hr   . . . . . .       802.024
Entropy MJ/hr*K  . . . . . .      -.142020
Ave. mol. wt.  . . . . . . .       28.7703
Total flow  kg/hr. . . . . .       1150.81
        kgmol/hr . . . . . .       40.0000
Density kg/m3  . . . . . . .       52.5200
```

```
Viscosity centipoise . . . .     .182249E-01
Thermal cond. cal/cm*s*K . .     .631572E-04
Specific heat   kJ/kg*K  . .     1.09868
Z factor . . . . . . . . . .     .982210
m3/hr (15.6 deg C & 1 atm) .     947.608
Vol. flowrate m3/hr  . . . .     21.9122
                      Vapor     Vapor
                       mole      flowrate
                      fraction   kgmol/hr
Nitrogen          .810000       32.4000
Oxygen            .190000       7.60000

*** Stream no.  2 ***
                                All Vapor
Temperature deg C. . . . . .      16.4189
Pressure bars. . . . . . . .      44.0000
Enthalpy MJ/hr   . . . . . .      794.964
Entropy MJ/hr*K  . . . . . .     -.166208
Ave. mol. wt.  . . . . . . .      28.7703
Total flow  kg/hr. . . . . .      1150.81
          kgmol/hr . . . . .      40.0000
Density kg/m3  . . . . . . .      53.6688
Viscosity centipoise . . . .      .179587E-01
Thermal cond. cal/cm*s*K . .      .621728E-04
Specific heat   kJ/kg*K  . .      1.10302
Z factor . . . . . . . . . .      .979712
m3/hr (15.6 deg C & 1 atm) .      947.608
Vol. flowrate m3/hr  . . . .      21.4432
                      Vapor     Vapor
                       mole      flowrate
                      fraction   kgmol/hr
Nitrogen          .810000       32.4000
Oxygen            .190000       7.60000
 CODE REPORT

*** Stream no.  3 ***
                                All Vapor
Temperature deg C. . . . . .      12.0000
Pressure bars. . . . . . . .      44.0000
Enthalpy MJ/hr   . . . . . .      789.335
Entropy MJ/hr*K  . . . . . .     -.185758
Ave. mol. wt.  . . . . . . .      28.7703
Total flow  kg/hr. . . . . .      1150.81
          kgmol/hr . . . . .      40.0000
Density kg/m3  . . . . . . .      54.6189
Viscosity centipoise . . . .      .177463E-01
Thermal cond. cal/cm*s*K . .      .614027E-04
Specific heat   kJ/kg*K  . .      1.10628
Z factor . . . . . . . . . .      .977588
m3/hr (15.6 deg C & 1 atm) .      947.608
Vol. flowrate m3/hr  . . . .      21.0702
                      Vapor     Vapor
                       mole      flowrate
                      fraction   kgmol/hr
Nitrogen          .810000       32.4000
Oxygen            .190000       7.60000

*** Stream no.  4 ***
                                All Vapor
Temperature deg C. . . . . .      12.0000
```

```
Pressure bars. . . . . . . . .       44.0000
Enthalpy MJ/hr   . . . . . . .       527.276
Entropy MJ/hr*K  . . . . . . .      -.124086
Ave. mol. wt. . . . . . . . .        28.7703
Total flow  kg/hr. . . . . .         768.743
          kgmol/hr . . . . . .       26.7200
Density kg/m3  . . . . . . . .       54.6189
Viscosity centipoise . . . .         .177463E-01
Thermal cond. cal/cm*s*K . .         .614027E-04
Specific heat   kJ/kg*K  . .         1.10651
Z factor . . . . . . . . . .         .977588
m3/hr (15.6 deg C & 1 atm) .         633.002
Vol. flowrate m3/hr  . . . .         14.0749
                       Vapor        Vapor
                        mole         flowrate
                       fraction      kgmol/hr
Nitrogen             .810000        21.6432
Oxygen               .190000        5.07680
  CODE REPORT

*** Stream no.  5 ***
                                    All Vapor
Temperature deg C. . . . . . .       12.0000
Pressure bars. . . . . . . . .       44.0000
Enthalpy MJ/hr   . . . . . . .       262.059
Entropy MJ/hr*K  . . . . . . .      -.616716E-01
Ave. mol. wt. . . . . . . . .        28.7703
Total flow  kg/hr. . . . . .         382.070
          kgmol/hr . . . . . .       13.2800
Density kg/m3  . . . . . . . .       54.6189
Viscosity centipoise . . . .         .177463E-01
Thermal cond. cal/cm*s*K . .         .614027E-04
Specific heat   kJ/kg*K  . .         1.10704
Z factor . . . . . . . . . .         .977588
m3/hr (15.6 deg C & 1 atm) .         314.606
Vol. flowrate m3/hr  . . . .         6.99530
                       Vapor        Vapor
                        mole         flowrate
                       fraction      kgmol/hr
Nitrogen             .810000        10.7568
Oxygen               .190000        2.52320

*** Stream no.  6 ***
                                    All Vapor
Temperature deg C. . . . . . .      -128.560
Pressure bars. . . . . . . . .       44.0000
Enthalpy MJ/hr   . . . . . . .       383.278
Entropy MJ/hr*K  . . . . . . .      -.846519
Ave. mol. wt. . . . . . . . .        28.7703
Total flow  kg/hr. . . . . .         768.743
          kgmol/hr . . . . . .       26.7200
Density kg/m3  . . . . . . . .       177.787
Viscosity centipoise . . . .         .105647E-01
Thermal cond. cal/cm*s*K . .         .407851E-04
Specific heat   kJ/kg*K  . .         2.63376
Z factor . . . . . . . . . .         .592288
m3/hr (15.6 deg C & 1 atm) .         633.002
Vol. flowrate m3/hr  . . . .         4.32401
                       Vapor        Vapor
                        mole         flowrate
```

```
                   fraction       kgmol/hr
Nitrogen          .810000         21.6432
Oxygen            .190000         5.07680
 CODE REPORT

*** Stream no.  7 ***
                                  All Vapor
Temperature deg C. . . . . . .     -128.519
Pressure bars. . . . . . . . .      44.0000
Enthalpy MJ/hr   . . . . . . .      190.533
Entropy MJ/hr*K  . . . . . . .     -.420439
Ave. mol. wt.  . . . . . . . .      28.7703
Total flow  kg/hr. . . . . . .      382.070
        kgmol/hr . . . . . . .      13.2800
Density kg/m3  . . . . . . . .      177.565
Viscosity centipoise . . . . .      .105659E-01
 Thermal cond. cal/cm*s*K . .        .407901E-04
Specific heat   kJ/kg*K   . .       2.62877
Z factor . . . . . . . . . . .      .592862
m3/hr (15.6 deg C & 1 atm) .        314.606
Vol. flowrate m3/hr   . . . .       2.15175
                   Vapor          Vapor
                    mole           flowrate
                   fraction       kgmol/hr
Nitrogen          .810000         10.7568
Oxygen            .190000         2.52320

*** Stream no.  8 ***
                                  All Vapor
Temperature deg C. . . . . . .     -128.546
Pressure bars. . . . . . . . .      44.0000
Enthalpy MJ/hr   . . . . . . .      573.811
Entropy MJ/hr*K  . . . . . . .     -1.26695
Ave. mol. wt.  . . . . . . . .      28.7703
Total flow  kg/hr. . . . . . .      1150.81
        kgmol/hr . . . . . . .      40.0000
Density kg/m3  . . . . . . . .      177.711
Viscosity centipoise . . . . .      .105651E-01
Thermal cond. cal/cm*s*K . .        .407868E-04
Specific heat   kJ/kg*K   . .       2.63183
Z factor . . . . . . . . . . .      .592484
m3/hr (15.6 deg C & 1 atm) .        947.608
Vol. flowrate m3/hr   . . . .       6.47584
                   Vapor          Vapor
                    mole           flowrate
                   fraction       kgmol/hr
Nitrogen          .810000         32.4000
Oxygen            .190000         7.60000
 CODE REPORT

*** Stream no.  9 ***
                                  All Vapor
Temperature deg C. . . . . . .     -128.546
Pressure bars. . . . . . . . .      44.0000
Enthalpy MJ/hr   . . . . . . .      229.525
Entropy MJ/hr*K  . . . . . . .     -.506780
Ave. mol. wt.  . . . . . . . .      28.7703
Total flow  kg/hr. . . . . . .      460.325
        kgmol/hr . . . . . . .      16.0000
Density kg/m3  . . . . . . . .      177.711
```

```
Viscosity centipoise . . . .       .105651E-01
Thermal cond. cal/cm*s*K . .       .407868E-04
Specific heat   kJ/kg*K  . .       2.63231
Z factor . . . . . . . . . .       .592484
m3/hr (15.6 deg C & 1 atm) .       379.043
Vol. flowrate m3/hr  . . . .       2.59034
                   Vapor          Vapor
                    mole          flowrate
                   fraction       kgmol/hr
Nitrogen         .810000          12.9600
Oxygen           .190000          3.04000

*** Stream no. 10 ***
                                  All Vapor
Temperature deg C. . . . . .       -128.546
Pressure bars. . . . . . . .        44.0000
Enthalpy MJ/hr   . . . . . .        344.287
Entropy MJ/hr*K  . . . . . .       -.760170
Ave. mol. wt.  . . . . . . .        28.7703
Total flow  kg/hr. . . . . .        690.488
        kgmol/hr . . . . . .        24.0000
Density kg/m3  . . . . . . .        177.711
Viscosity centipoise . . . .        .105651E-01
Thermal cond. cal/cm*s*K . .        .407868E-04
Specific heat   kJ/kg*K  . .        2.63220
Z factor . . . . . . . . . .        .592484
m3/hr (15.6 deg C & 1 atm) .        568.565
Vol. flowrate m3/hr  . . . .        3.88550
                   Vapor          Vapor
                    mole          flowrate
                   fraction       kgmol/hr
Nitrogen         .810000          19.4400
Oxygen           .190000          4.56000
 CODE REPORT

*** Stream no. 11 ***
                       Overall              Vapor              Liquid
Temperature deg C.     -172.433
Pressure bars. . .      6.60650
Vapor fraction . .      .794075
Enthalpy MJ/hr   .      319.118      !     273.333      !     45.7936
Entropy MJ/hr*K  .     -.739788      !    -.392903      !    -.346885
Ave. mol. wt.  . .      28.7703      !     28.6535      !     29.2210
Total flow kg/hr .      690.488      !     546.073      !     144.416
       kgmol/hr  .      24.0000      !     19.0578      !     4.94220
Density kg/m3  . . . . . . . . .           26.6876      !     1405.25
Viscosity centipoise . . . . . .           .689482E-02  !     .103319
Thermal cond. cal/cm*s*K . . . .           .357702E-04  !     .505124E-03
Specific heat   kJ/kg*K  . . . .           1.25212      !     2.17687
Z factor . . . . . . . . . . . .           .846983
m3/hr (15.6 deg C & 1 atm) . . .           451.521
Vol. flowrate m3/hr  . . . . . .           20.4619
Surface tension dyne/cm. . . . . . . . . . . . . .            5.65960
S. G. (60/60)  . . . . . . . . . . . . . . . . . .            .914499
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . .            .158166
Vol. flowrate m3/hr  . . . . . . . . . . . . . . .            .102770
                  Vapor       Liquid          Vapor           Liquid
                  mole        mole            flowrate        flowrate
                 fraction    fraction         kgmol/hr        kgmol/hr
Nitrogen         .83931      .69694           15.9954         3.44440
```

```
Oxygen             .16069     .30306          3.06243         1.49780

*** Stream no. 12 ***
                                    All Vapor
Temperature deg C. . . . . . .       -137.366
Pressure bars. . . . . . . . .        44.0000
Enthalpy MJ/hr   . . . . . . .        211.154
Entropy MJ/hr*K  . . . . . . .       -.638783
Ave. mol. wt.  . . . . . . . .        28.7703
Total flow  kg/hr. . . . . . .        460.325
        kgmol/hr . . . . . . .        16.0000
Density kg/m3  . . . . . . . .        297.981
Viscosity centipoise . . . . .       .108017E-01
Thermal cond. cal/cm*s*K . . .       .397190E-04
Specific heat   kJ/kg*K  . . .       9.94371
Z factor . . . . . . . . . . .       .376301
m3/hr (15.6 deg C & 1 atm) . .       379.043
Vol. flowrate m3/hr  . . . . .       1.54484
                   Vapor            Vapor
                    mole             flowrate
                   fraction         kgmol/hr
Nitrogen         .810000            12.9600
Oxygen           .190000            3.04000
 CODE REPORT

*** Stream no. 13 ***
                            Overall              Vapor              Liquid
Temperature deg C.       -172.462
Pressure bars. . .         6.61320
Vapor fraction . .         .774389
Enthalpy MJ/hr    .        211.154     !      177.671      !     33.4807
Entropy MJ/hr*K   .      -.509091      !     -.255681      !    -.253410
Ave. mol. wt.   . .        28.7703     !      28.6438      !     29.2045
Total flow kg/hr  .        460.325     !      354.904      !     105.422
        kgmol/hr  .        16.0000     !      12.3902      !     3.60978
Density kg/m3  . . . . . . . . . . .          26.7247      !     1403.92
Viscosity centipoise . . . . . . . .          .689110E-02  !     .103236
Thermal cond. cal/cm*s*K . . . . . .          .357706E-04  !     .505164E-03
Specific heat   kJ/kg*K  . . . . . .          1.25342      !     2.18061
Z factor . . . . . . . . . . . . . .          .846719
m3/hr (15.6 deg C & 1 atm) . . . . .          293.518
Vol. flowrate m3/hr  . . . . . . . .          13.2802
Surface tension dyne/cm. . . . . . . . . . . . . . . . .         5.64067
S. G. (60/60)  . . . . . . . . . . . . . . . . . . . . .         .914055
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . . .         .115515
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . . .         .750916E-01
                   Vapor      Liquid          Vapor             Liquid
                   mole        mole           flowrate          flowrate
                  fraction    fraction        kgmol/hr          kgmol/hr
Nitrogen          .84174      .70109          10.4293           2.53077
Oxygen            .15826      .29891          1.96094           1.07901

*** Stream no. 14 ***
                                    All Vapor
Temperature deg C. . . . . . .       -175.000
Pressure bars. . . . . . . . .        1.40055
Enthalpy MJ/hr   . . . . . . .        471.559
Entropy MJ/hr*K  . . . . . . .       -.220848
Ave. mol. wt.  . . . . . . . .        28.0407
Total flow  kg/hr. . . . . . .        908.518
```

```
        kgmol/hr . . . . . .      32.4000
Density kg/m3 . . . . . . .       4.96697
Viscosity centipoise . . . .      .661202E-02
Thermal cond. cal/cm*s*K . .      .358270E-04
Specific heat   kJ/kg*K   . .     1.10482
Z factor . . . . . . . . . .      .968902
m3/hr (15.6 deg C & 1 atm) .      767.562
Vol. flowrate m3/hr   . . . .     182.915
                     Vapor       Vapor
                       mole       flowrate
                      fraction    kgmol/hr
Nitrogen          .993061        32.1752
Oxygen            .693858E-02    .224810
 CODE REPORT

*** Stream no. 15 ***
                                 All Vapor
Temperature deg C. . . . . . .   -156.546
Pressure bars. . . . . . . . .    1.40055
Enthalpy MJ/hr   . . . . . . .    489.930
Entropy MJ/hr*K  . . . . . . .   -.492974E-01
Ave. mol. wt.  . . . . . . . .    28.0407
Total flow  kg/hr. . . . . . .    908.518
        kgmol/hr . . . . . . .    32.4000
Density kg/m3  . . . . . . . .    4.13194
Viscosity centipoise . . . . .    .783564E-02
Thermal cond. cal/cm*s*K . . .    .378999E-04
Specific heat   kJ/kg*K   . . .   1.08797
Z factor . . . . . . . . . . .    .980378
m3/hr (15.6 deg C & 1 atm) . .    767.562
Vol. flowrate m3/hr   . . . . .   219.880
                     Vapor       Vapor
                       mole       flowrate
                      fraction    kgmol/hr
Nitrogen          .993061        32.1752
Oxygen            .693858E-02    .224810

*** Stream no. 16 ***
                                 All Liquid
Temperature deg C. . . . . . .   -180.000
Pressure bars. . . . . . . . .    190.000
Enthalpy MJ/hr   . . . . . . .    60.2035
Entropy MJ/hr*K  . . . . . . .   -.620586
Ave. mol. wt.  . . . . . . . .    31.8811
Total flow  kg/hr. . . . . . .    242.296
        kgmol/hr . . . . . . .    7.60000
Density kg/m3  . . . . . . . .    1832.15
Viscosity centipoise . . . . .    .177380
Thermal cond. cal/cm*s*K . . .    .517994E-03
Specific heat   kJ/kg*K   . . .   1.54479
Surface tension dyne/cm. . . .    12.1673
S. G. (60/60)  . . . . . . . .    .985098
m3/hr (15.6 deg C & 1 atm) . .    .246347
Vol. flowrate m3/hr   . . . . .   .132248
                      Liquid      Liquid
                       mole       flowrate
                      fraction    kgmol/hr
Nitrogen          .295803E-01    .224810
Oxygen            .970420        7.37519
 CODE REPORT
```

```
*** Stream no. 17 ***
                                      All Vapor
Temperature deg C. . . . . . .         -12.0000
Pressure bars. . . . . . . . .          190.000
Enthalpy MJ/hr   . . . . . . .          131.730
Entropy MJ/hr*K  . . . . . . .         -.182981
Ave. mol. wt.  . . . . . . . .          31.8811
Total flow  kg/hr. . . . . . .          242.296
        kgmol/hr . . . . . . .          7.60000
Density kg/m3  . . . . . . . .          324.183
Viscosity centipoise . . . . .          .192427E-01
Thermal cond. cal/cm*s*K . . .          .549925E-04
Specific heat   kJ/kg*K  . . .          1.37680
Z factor . . . . . . . . . . .          .860560
m3/hr (15.6 deg C & 1 atm) . .          180.045
Vol. flowrate m3/hr  . . . . .          .747417
                         Vapor         Vapor
                           mole         flowrate
                         fraction       kgmol/hr
Nitrogen               .295803E-01     .224810
Oxygen                 .970420         7.37519

*** Stream no. 18 ***
                                      All Vapor
Temperature deg C. . . . . . .         -7.00000
Pressure bars. . . . . . . . .          1.40055
Enthalpy MJ/hr   . . . . . . .          633.928
Entropy MJ/hr*K  . . . . . . .          .747534
Ave. mol. wt.  . . . . . . . .          28.0407
Total flow  kg/hr. . . . . . .          908.518
        kgmol/hr . . . . . . .          32.4000
Density kg/m3  . . . . . . . .          1.77685
Viscosity centipoise . . . . .          .162726E-01
Thermal cond. cal/cm*s*K . . .          .507952E-04
Specific heat   kJ/kg*K  . . .          1.04497
Z factor . . . . . . . . . . .          .978815
m3/hr (15.6 deg C & 1 atm) . .          767.562
Vol. flowrate m3/hr  . . . . .          511.316
                         Vapor         Vapor
                           mole         flowrate
                         fraction       kgmol/hr
Nitrogen               .993061         32.1752
Oxygen                 .693858E-02     .224810
 CODE REPORT

*** Stream no. 19 ***
                                      All Vapor
Temperature deg C. . . . . . .          9.68271
Pressure bars. . . . . . . . .          44.0000
Enthalpy MJ/hr   . . . . . . .          786.406
Entropy MJ/hr*K  . . . . . . .         -.196156
Ave. mol. wt.  . . . . . . . .          28.7703
Total flow  kg/hr. . . . . . .          1150.81
        kgmol/hr . . . . . . .          40.0000
Density kg/m3  . . . . . . . .          55.1324
Viscosity centipoise . . . . .          .176345E-01
Thermal cond. cal/cm*s*K . . .          .610021E-04
Specific heat   kJ/kg*K  . . .          1.10737
Z factor . . . . . . . . . . .          .976418
```

```
m3/hr (15.6 deg C & 1 atm) .       947.608
Vol. flowrate m3/hr . . . .        20.0739
                        Vapor       Vapor
                          mole       flowrate
                        fraction     kgmol/hr
Nitrogen             .810000       32.4000
Oxygen               .190000       7.60000

*** Stream no. 20 ***
                                   All Vapor
Temperature deg C. . . . . .        10.0000
Pressure bars. . . . . . . .        190.000
Enthalpy MJ/hr   . . . . . .        138.790
Entropy MJ/hr*K  . . . . . .       -.157012
Ave. mol. wt.  . . . . . . .        31.8811
Total flow  kg/hr. . . . . .        242.296
          kgmol/hr . . . . .        7.60000
Density kg/m3  . . . . . . .        284.517
Viscosity centipoise . . . .        .203271E-01
Thermal cond. cal/cm*s*K . .        .585597E-04
Specific heat   kJ/kg*K  . .        1.27878
Z factor . . . . . . . . . .        .904349
m3/hr (15.6 deg C & 1 atm) .        180.045
Vol. flowrate m3/hr  . . . .        .851617
                        Vapor       Vapor
                          mole       flowrate
                        fraction     kgmol/hr
Nitrogen             .295803E-01   .224810
Oxygen               .970420       7.37519
 CODE REPORT

*** Stream no. 21 ***
                                   All Vapor
Temperature deg C. . . . . .        2.01889
Pressure bars. . . . . . . .        1.40055
Enthalpy MJ/hr   . . . . . .        642.486
Entropy MJ/hr*K  . . . . . .        .779154
Ave. mol. wt.  . . . . . . .        28.0407
Total flow  kg/hr. . . . . .        908.518
          kgmol/hr . . . . .        32.4000
Density kg/m3  . . . . . . .        1.71828
Viscosity centipoise . . . .        .167079E-01
Thermal cond. cal/cm*s*K . .        .603186E-04
Specific heat   kJ/kg*K  . .        1.04360
Z factor . . . . . . . . . .        .999007
m3/hr (15.6 deg C & 1 atm) .        767.562
Vol. flowrate m3/hr  . . . .        528.745
                        Vapor       Vapor
                          mole       flowrate
                        fraction     kgmol/hr
Nitrogen             .993061       32.1752
Oxygen               .693858E-02   .224810
```

Appendix D

Computer results of the column-tray sizing under the nominal flow rate of air column.REP

```
CODE: Chemical Engineering Simulation System
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          TOPOLOGY

Equipment                     Stream Numbers

 1  TOWR                  1   2  -3  -4
 2  HXER                  3  10  -5 -13
 3  HXER                  4  13  -6 -15
 4  HXER                  8  11  -9 -12
 5  VALV                  5  -7   0   0
 6  VALV                  6  -8   0   0
 7  TOWR                  7   9 -10 -11
 8  PUMP                 12 -14   0   0
 9  HXER                 15 -16   0   0
10  HXER                 14 -17   0   0

Stream Connections

Stream    Equipment
       From     To
    1       0        1
    2       0        1
    3       1        2
    4       1        3
    5       2        5
    6       3        6
    7       5        7
    8       6        4
    9       4        7
   10       7        2
   11       7        4
   12       4        8
   13       2        3
   14       8       10
   15       3        9
   16       9        0
   17      10        0

COMPONENTS . . . . . .        2

ID numbers ...........        46,   47,

         THERMODYNAMICS

  Kvalue option: Peng-Robinson
  Enthalpy option: Peng-Robinson
  Density option: API method
 CODE REPORT

         MISCELLANEOUS


Recycle calculations are converged.
```

```
column.REP

CODE: Chemical Engineering Simulation System
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        TOPOLOGY

Equipment                   Stream Numbers

  1  TOWR              1   2  -3  -4
  2  HXER              3  10  -5 -13
  3  HXER              4  13  -6 -15
  4  HXER              8  11  -9 -12
  5  VALV              5  -7   0   0
  6  VALV              6  -8   0   0
  7  TOWR              7   9 -10 -11
  8  PUMP             12 -14   0   0
  9  HXER             15 -16   0   0
 10  HXER             14 -17   0   0

Stream Connections

Stream     Equipment
       From      To
    1      0       1
    2      0       1
    3      1       2
    4      1       3
    5      2       5
    6      3       6
    7      5       7
    8      6       4
    9      4       7
   10      7       2
   11      7       4
   12      4       8
   13      2       3
   14      8      10
   15      3       9
   16      9       0
   17     10       0

COMPONENTS . . . . . .        2

ID numbers ...........        46,   47,

        THERMODYNAMICS

  Kvalue option: Peng-Robinson
  Enthalpy option: Peng-Robinson
  Density option: API method
 CODE REPORT

        MISCELLANEOUS

Recycle calculations are converged.
```

```
Recycle equipment list (KE2):          2,   3,   5,   6,   4,   7,

Streams used in conv. routine (KE4):( 0)
      ()=Delay factor

Preferred cut stream list (KE3):     10, 11,

Convergence tolerances,       Error
         Flowrates:          .00100000
         Vapor fraction:     .00100000
         Temperature:        .00100000
         Pressure:           .00100000
         Enthalpy:           .00100000
         Flash calcs:        .00005000

Max. loops in recycle calc.:   30
           in flash calcs:     75


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***      VALVES        ***
Equipment no.                    5            6
External name
Outlet pressure bars   1.4006       1.4572
.......................................................................

***EXCHANGER/CONDENSERS***
Equipment no.                  2            3            4            9
External name
Heat transfer coeff.   300.00       300.00       300.00       .00000
Area                   5.7562       5.8855       .53238       .00000
Number of shells           .0           .0           .0           .0
Shell passes               .0           .0           .0           .0
Tube passes                .0           .0           .0           .0
Mode                      3.0          3.0          3.0          5.0
Min. delta T or T-out    6.00         3.00         7.00      -175.00
Delta P, stream 1      .00000       .00000       .00000       .00000
Delta P, stream 2      .00000       .00000       .00000       .00000
Q, stream 1   MJ/hr   -10.614      -7.1327       1.3775       .15194
Water usage, DM3/hr    .00000       .00000       .00000       .00000
Corrected delta T        6.15         4.04         8.62         8.62
Equipment no.                 10
External name
Heat transfer coeff.   .00000
Area                   .00000
Number of shells           .0
Shell passes               .0
Tube passes                .0
Mode                      5.0
Min. delta T or T-out -180.00
Delta P, stream 1      .00000
Delta P, stream 2      .00000
Q, stream 1   MJ/hr    1.1303
Water usage, DM3/hr    .00000
Corrected delta T        8.62
.......................................................................
```

```
*** PUMPS/COMPRESSORS  ***
Equipment no.                  8
External name
Number of stages              .0
Work capacity   MJ/hr  .00000
Outlet pressure bars   190.00
Power type:                   .0
   (+) steam
   (0) electricity
   (-) fuel gas
H, steam out KJ / kg   .00000
Fuel usage, M3  /hr    .00000
Water usage, DM3/hr    .00000
Steam usage Tonnes/hr  .00000
Kilowatt usage         1.1632
.......................................................................
```

```
CODE: Chemical Engineering Simulation System
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***  RIGOROUS TOWERS    ***
Equipment no.                    1            7
External name
Number of stages             21.0          57.0
Feed 1, stage #              15.0           1.0
Feed 2, stage #              21.0          17.0
Feed 3, stage #                .0            .0
Feed 4, stage #                .0            .0
Feed 5, stage #                .0            .0
Sidestream # 1 stage           .0            .0
Sidestream # 2 stage           .0            .0
Sidestream # 3 stage           .0            .0
Sidestream # 4 stage           .0            .0
Cond. pressure bars        6.7131        1.4006
Cond. delta P bars         .00000        .00000
Colm. delta P bars     .19400E-01        .19850
Condenser type                 .0           1.0
Condenser mode                4.0            .0
Value of cond. spec.       16.000        .00000
Cond comp 1 position          1.0            .0
Cond comp 2 position           .0            .0
Cond. deg. subcooled         1.00           .00
Reboiler mode                  .0           4.0
Val. of reboiler spec      .00000        7.6000
Rebr comp 1 position           .0           2.0
Rebr comp 2 position           .0            .0
Damping ratio              .00000       1.0000
Sidestream 1 mode              .0            .0
Sidestream 2 mode              .0            .0
Sidestream 3 mode              .0            .0
Sidestream 4 mode              .0            .0
Sidestream # 1 spec        .00000        .00000
Sidestream # 2 spec        .00000        .00000
Sidestream # 3 spec        .00000        .00000
Sidestream # 4 spec        .00000        .00000
Sidestrm 1 comp posn           .0            .0
Sidestrm 2 comp posn           .0            .0
Sidestrm 3 comp posn           .0            .0
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Sidestrm 4 comp posn        .0              .0
Cond. duty   MJ/hr     -163.53          .00000
Rebr duty    MJ/hr       .00000         153.21
Est dist rate Kgmol/hr  16.000          .00000
Est. reflux Kgmol/hr     .00000         .00000
Est. side draw rate 1    .00000         .00000
Est. side draw rate 2    .00000         .00000
Est. side draw rate 3    .00000         .00000
Est. side draw rate 4    .00000         .00000
Est. temp stg  1  C    -178.00         -193.00
Est. temp stg  N  C    -174.00         -183.00
.....................................................................

 CODE REPORT

*** Stream no.  1 ***
                         Overall              Vapor                Liquid
Temperature deg C.      -172.366
Pressure bars. . .       6.61325
Vapor fraction . .       .817724
Enthalpy MJ/hr    .      214.671     !      187.651      !      27.0201
Entropy MJ/hr*K   .     -.474310     !     -.269548      !     -.204763
Ave. mol. wt.   . .      28.7704     !      28.6655      !      29.2409
Total flow kg/hr .       460.324     !      375.046      !      85.2782
         kgmol/hr .      15.9999     !      13.0835      !      2.91641
Density kg/m3  . . . . . . . . . . .        26.7085      !      1406.48
Viscosity centipoise . . . . . . . .        .690154E-02  !      .103552
Thermal cond. cal/cm*s*K . . . . . .        .357696E-04  !      .505017E-03
Specific heat   kJ/kg*K  . . . . . .        1.25193      !      2.17510
Z factor . . . . . . . . . . . . . .        .847052
m3/hr (15.6 deg C & 1 atm) . . . . .        309.950
Vol. flowrate m3/hr  . . . . . . . .        14.0424
Surface tension dyne/cm. . . . . . . . . . . . . . .            5.67519
S. G. (60/60)  . . . . . . . . . . . . . . . . . . .            .915033
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . .            .933430E-01
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . .            .606330E-01
                      Vapor      Liquid          Vapor          Liquid
                       mole       mole           flowrate       flowrate
                     fraction   fraction         kgmol/hr       kgmol/hr
Nitrogen              .83630     .69196          10.9418        2.01803
Oxygen                .16370     .30804          2.14175        .898379

*** Stream no.  2 ***
                         Overall              Vapor                Liquid
Temperature deg C.      -172.347
Pressure bars. . .       6.60647
Vapor fraction . .       .832464
Enthalpy MJ/hr    .      323.802     !      286.566      !      37.2358
Entropy MJ/hr*K   .     -.693623     !     -.411253      !     -.282370
Ave. mol. wt.   . .      28.7702     !      28.6730      !      29.2536
Total flow kg/hr .       690.486     !      572.861      !      117.625
         kgmol/hr .      24.0000     !      19.9791      !      4.02087
Density kg/m3  . . . . . . . . . . .        26.6758      !      1407.54
Viscosity centipoise . . . . . . . .        .690418E-02  !      .103704
Thermal cond. cal/cm*s*K . . . . . .        .357676E-04  !      .504990E-03
Specific heat   kJ/kg*K  . . . . . .        1.25085      !      2.17289
Z factor . . . . . . . . . . . . . .        .847282
m3/hr (15.6 deg C & 1 atm) . . . . .        473.307
Vol. flowrate m3/hr  . . . . . . . .        21.4752
Surface tension dyne/cm. . . . . . . . . . . . . . .            5.69055
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S. G. (60/60) . . . . . . . . . . . . . . . . . . . .           .915375
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . .           .128700
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . .           .835686E-01
                    Vapor        Liquid          Vapor          Liquid
                    mole         mole            flowrate       flowrate
                    fraction     fraction        kgmol/hr       kgmol/hr
Nitrogen            .83443       .68876          16.6712        2.76943
Oxygen              .16557       .31124          3.30796        1.25144
 CODE REPORT

*** Stream no.  3 ***
                                         All Liquid
Temperature deg C. . . . . . .           -175.936
Pressure bars. . . . . . . . .            6.71314
Enthalpy MJ/hr   . . . . . . .            152.106
Entropy MJ/hr*K  . . . . . . .           -1.12246
Ave. mol. wt.  . . . . . . . .            28.0883
Total flow  kg/hr. . . . . . .            449.415
         kgmol/hr . . . . . . .           16.0001
Density kg/m3  . . . . . . . .            1329.85
Viscosity centipoise . . . . .            .947183E-01
Thermal cond. cal/cm*s*K . . .            .510523E-03
Specific heat   kJ/kg*K  . . .            2.34680
Surface tension dyne/cm. . . .            4.74204
S. G. (60/60) . . . . . . . .             .883883
m3/hr (15.6 deg C & 1 atm) . .            .509252
Vol. flowrate m3/hr  . . . . .            .337948
                      Liquid             Liquid
                       mole              flowrate
                     fraction            kgmol/hr
Nitrogen            .981119              15.6980
Oxygen              .188808E-01          .302095

*** Stream no.  4 ***
                                         All Liquid
Temperature deg C. . . . . . .           -172.151
Pressure bars. . . . . . . . .            6.73254
Enthalpy MJ/hr   . . . . . . .            222.844
Entropy MJ/hr*K  . . . . . . .           -1.68106
Ave. mol. wt.  . . . . . . . .            29.2250
Total flow  kg/hr. . . . . . .            701.395
         kgmol/hr . . . . . . .           23.9999
Density kg/m3  . . . . . . . .            1402.47
Viscosity centipoise . . . . .            .102869
Thermal cond. cal/cm*s*K . . .            .504666E-03
Specific heat   kJ/kg*K  . . .            2.18426
Surface tension dyne/cm. . . .            5.60303
S. G. (60/60)  . . . . . . . .            .914606
m3/hr (15.6 deg C & 1 atm) . .            .768084
Vol. flowrate m3/hr  . . . . .            .500121
                      Liquid             Liquid
                       mole              flowrate
                     fraction            kgmol/hr
Nitrogen            .695938              16.7024
Oxygen              .304062              7.29745
 CODE REPORT

*** Stream no.  5 ***
                                         All Liquid
Temperature deg C. . . . . . .           -186.647
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Pressure bars. . . . . . . . .          6.71314
Enthalpy MJ/hr       . . . . . . .     141.493
Entropy MJ/hr*K   . . . . . . .       -1.23802
Ave. mol. wt.  . . . . . . . .         28.0883
Total flow  kg/hr. . . . . .           449.415
         kgmol/hr . . . . . .          16.0001
Density kg/m3  . . . . . . . .         1445.97
Viscosity centipoise . . . .           .123407
Thermal cond. cal/cm*s*K . .           .527857E-03
Specific heat    kJ/kg*K  . .          2.09369
Surface tension dyne/cm. . .           6.98386
S. G. (60/60)  . . . . . . .           .883883
m3/hr (15.6 deg C & 1 atm) .           .509252
Vol. flowrate m3/hr   . . . .          .310809
                        Liquid        Liquid
                         mole        flowrate
                       fraction      kgmol/hr
Nitrogen               .981119       15.6980
Oxygen                 .188808E-01   .302095

*** Stream no.   6 ***
                                    All Liquid
Temperature deg C. . . . . . .       -176.935
Pressure bars. . . . . . . . .        6.73254
Enthalpy MJ/hr    . . . . . . .       215.711
Entropy MJ/hr*K  . . . . . . .       -1.75337
Ave. mol. wt.  . . . . . . . .        29.2250
Total flow   kg/hr. . . . . .         701.395
        kgmol/hr . . . . . .          23.9999
Density kg/m3  . . . . . . . .        1454.64
Viscosity centipoise . . . .          .113776
Thermal cond. cal/cm*s*K . .          .512408E-03
Specific heat    kJ/kg*K  . . .       2.06976
Surface tension dyne/cm. . .          6.67650
S. G. (60/60)  . . . . . . .          .914606
m3/hr (15.6 deg C & 1 atm) .          .768084
Vol. flowrate m3/hr   . . . .         .482182
                        Liquid       Liquid
                         mole       flowrate
                       fraction     kgmol/hr
Nitrogen               .695938      16.7024
Oxygen                 .304062      7.29745
 CODE REPORT

*** Stream no.   7 ***
                         Overall              Vapor                  Liquid
Temperature deg C.      -192.652
Pressure bars. . .        1.40055
Vapor fraction . .        .668986E-01
Enthalpy MJ/hr    .       141.493    !     15.1463       !      126.409
Entropy MJ/hr*K   .      -1.23147    !   -.139799E-01    !     -1.21749
Ave. mol. wt.   . .       28.0883    !     28.0396       !      28.0918
Total flow kg/hr  .       449.415    !     30.0132       !      419.402
        kgmol/hr  .       16.0001    !     1.07038       !      14.9297
Density kg/m3  . . . . . . . . . .         6.12529       !      1503.80
Viscosity centipoise . . . . . . .         .541943E-02   !      .147473
Thermal cond. cal/cm*s*K . . . . .         .340943E-04   !      .537581E-03
Specific heat    kJ/kg*K  . . . . .        1.13199       !      1.97733
Z factor . . . . . . . . . . . . .         .947868
m3/hr (15.6 deg C & 1 atm) . . . .         25.6268
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Vol. flowrate m3/hr  . . . . . . . .         4.89995
Surface tension dyne/cm. . . . . . . . . . . . . . . .              8.31471
S. G. (60/60)  . . . . . . . . . . . . . . . . . . . .              .883978
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . .              .475192
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . .              .278897
                 Vapor     Liquid          Vapor           Liquid
                  mole      mole           flowrate        flowrate
                fraction  fraction         kgmol/hr        kgmol/hr
Nitrogen        .99332    .98023           1.06323         14.6346
Oxygen          .66838E-02 .19765E-01      .715428E-02     .295089

*** Stream no.  8 ***
                     Overall             Vapor              Liquid
Temperature deg C.   -190.027
Pressure bars. . .    1.45725
Vapor fraction . .    .138577
Enthalpy MJ/hr   .    215.711    !    46.6854        !    168.988
Entropy MJ/hr*K  .   -1.73072    !   -.409738E-01 !  -1.68975
Ave. mol. wt.  . .    29.2250    !    28.5267        !    29.3371
Total flow kg/hr .    701.395    !    94.8750        !    606.515
        kgmol/hr .    23.9999    !    3.32583        !    20.6740
Density kg/m3  . . . . . . . . . .    6.34762        !    1590.31
Viscosity centipoise . . . . . . .    .566974E-02 !    .161625
Thermal cond. cal/cm*s*K . . . . .    .339222E-04 !    .533619E-03
Specific heat   kJ/kg*K  . . . . .    1.10301        !    1.84662
Z factor . . . . . . . . . . . . .    .949507
m3/hr (15.6 deg C & 1 atm) . . . .    78.6319
Vol. flowrate m3/hr  . . . . . . .    14.9468
Surface tension dyne/cm. . . . . . . . . . . . . . . .              9.92894
S. G. (60/60)  . . . . . . . . . . . . . . . . . . . .              .917617
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . .              .662004
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . .              .381387
                 Vapor     Liquid          Vapor           Liquid
                  mole      mole           flowrate        flowrate
                fraction  fraction         kgmol/hr        kgmol/hr
Nitrogen        .87111    .66782           2.89717         13.8066
Oxygen          .12889    .33218           .428659         6.86744
 CODE REPORT

*** Stream no.  9 ***
                     Overall             Vapor              Liquid
Temperature deg C.   -190.008
Pressure bars. . .    1.45725
Vapor fraction . .    .148943
Enthalpy MJ/hr   .    217.088    !    50.2454        !    166.870
Entropy MJ/hr*K  .   -1.71318    !   -.440287E-01 !  -1.66915
Ave. mol. wt.  . .    29.2250    !    28.5310        !    29.3463
Total flow kg/hr .    701.395    !    101.987        !    599.406
        kgmol/hr .    23.9999    !    3.57461        !    20.4252
Density kg/m3  . . . . . . . . . .    6.33859        !    1590.93
Viscosity centipoise . . . . . . .    .567168E-02 !    .161681
Thermal cond. cal/cm*s*K . . . . .    .339417E-04 !    .533592E-03
Specific heat   kJ/kg*K  . . . . .    1.10308        !    1.84427
Z factor . . . . . . . . . . . . .    .949532
m3/hr (15.6 deg C & 1 atm) . . . .    84.6253
Vol. flowrate m3/hr  . . . . . . .    16.0901
Surface tension dyne/cm. . . . . . . . . . . . . . . .              9.94126
S. G. (60/60)  . . . . . . . . . . . . . . . . . . . .              .917866
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . .              .654067
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . .              .376768
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                        Vapor       Liquid         Vapor          Liquid
                        mole        mole           flowrate       flowrate
                      fraction     fraction        kgmol/hr       kgmol/hr
Nitrogen              .87004       .66549          3.11004        13.5929
Oxygen                .12996       .33451          .464567        6.83238

*** Stream no. 10 ***
                                     All Vapor
Temperature deg C. . . . . . .       -192.647
Pressure bars. . . . . . . . .        1.40055
Enthalpy MJ/hr   . . . . . . .        453.660
Entropy MJ/hr*K  . . . . . . .       -.421952
Ave. mol. wt.  . . . . . . . .        28.0407
Total flow  kg/hr. . . . . . .        908.515
          kgmol/hr . . . . . .        32.3999
Density kg/m3  . . . . . . . .        6.19011
Viscosity centipoise . . . . .        .541992E-02
Thermal cond. cal/cm*s*K . . .        .339356E-04
Specific heat   kJ/kg*K  . . .        1.13097
Z factor . . . . . . . . . . .        .947875
m3/hr (15.6 deg C & 1 atm) . .        767.560
Vol. flowrate m3/hr  . . . . .        146.771
                    Vapor            Vapor
                     mole            flowrate
                    fraction         kgmol/hr
Nitrogen           .993061           32.1751
Oxygen             .693924E-02       .224831
  CODE REPORT

*** Stream no. 11 ***
                                     All Liquid
Temperature deg C. . . . . . .       -179.524
Pressure bars. . . . . . . . .        1.59905
Enthalpy MJ/hr   . . . . . . .        58.1288
Entropy MJ/hr*K  . . . . . . .       -.604787
Ave. mol. wt.  . . . . . . . .        31.8808
Total flow  kg/hr. . . . . . .        242.295
          kgmol/hr . . . . . .        7.60001
Density kg/m3  . . . . . . . .        1708.80
Viscosity centipoise . . . . .        .175472
Thermal cond. cal/cm*s*K . . .        .517224E-03
Specific heat   kJ/kg*K  . . .        1.63202
Surface tension dyne/cm. . . .        12.0760
S. G. (60/60)  . . . . . . . .        .985091
m3/hr (15.6 deg C & 1 atm) . .        .246347
Vol. flowrate m3/hr  . . . . .        .141794
                    Liquid           Liquid
                     mole            flowrate
                    fraction         kgmol/hr
Nitrogen           .296430E-01      .225287
Oxygen             .970357          7.37472

*** Stream no. 12 ***
                                     All Liquid
Temperature deg C. . . . . . .       -183.027
Pressure bars. . . . . . . . .        1.59905
Enthalpy MJ/hr   . . . . . . .        56.7513
Entropy MJ/hr*K  . . . . . . .       -.619821
Ave. mol. wt.  . . . . . . . .        31.8809
Total flow  kg/hr. . . . . . .        242.294
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        kgmol/hr . . . . . .       7.59999
 Density kg/m3  . . . . . . .      1736.77
 Viscosity centipoise . . . .      .190473
 Thermal cond. cal/cm*s*K . .      .522893E-03
 Specific heat   kJ/kg*K   . .     1.61429
 Surface tension dyne/cm. . .      12.9410
 S. G. (60/60)  . . . . . . .      .985091
 m3/hr (15.6 deg C & 1 atm) .      .246347
 Vol. flowrate m3/hr  . . . .      .139510
                   Liquid          Liquid
                    mole          flowrate
                  fraction        kgmol/hr
 Nitrogen       .296411E-01     .225272
 Oxygen         .970359         7.37472
  CODE REPORT

 *** Stream no. 13 ***
                                  All Vapor
 Temperature deg C. . . . . .      -182.231
 Pressure bars. . . . . . . .       1.40055
 Enthalpy MJ/hr    . . . . . .      464.274
 Entropy MJ/hr*K   . . . . . .     -.297945
 Ave. mol. wt.  . . . . . . .       28.0407
 Total flow  kg/hr. . . . . .       908.515
         kgmol/hr . . . . . .       32.3999
 Density kg/m3  . . . . . . .       5.40047
 Viscosity centipoise . . . .       .612500E-02
 Thermal cond. cal/cm*s*K . .       .350415E-04
 Specific heat   kJ/kg*K   . .      1.11274
 Z factor . . . . . . . . . .       .961997
 m3/hr (15.6 deg C & 1 atm) .       767.562
 Vol. flowrate m3/hr  . . . .       168.231
                   Vapor          Vapor
                    mole          flowrate
                  fraction        kgmol/hr
 Nitrogen       .993061         32.1751
 Oxygen         .693924E-02     .224831

 *** Stream no. 14 ***
                                  All Liquid
 Temperature deg C. . . . . .      -183.027
 Pressure bars. . . . . . . .       190.000
 Enthalpy MJ/hr    . . . . . .      59.0741
 Entropy MJ/hr*K   . . . . . .     -.632918
 Ave. mol. wt.  . . . . . . .       31.8809
 Total flow  kg/hr. . . . . .       242.294
         kgmol/hr . . . . . .       7.59999
 Density kg/m3  . . . . . . .       1851.29
 Viscosity centipoise . . . .       .190473
 Thermal cond. cal/cm*s*K . .       .522893E-03
 Specific heat   kJ/kg*K   . .      1.53771
 Surface tension dyne/cm. . .       12.9159
 S. G. (60/60)  . . . . . . .       .985091
 m3/hr (15.6 deg C & 1 atm) .       .246347
 Vol. flowrate m3/hr  . . . .       .130880
                   Liquid          Liquid
                    mole          flowrate
                  fraction        kgmol/hr
 Nitrogen       .296411E-01     .225272
 Oxygen         .970359         7.37472
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*** Stream no. 15 ***
                                     All Vapor
Temperature deg C. . . . . . .        -175.151
Pressure bars. . . . . . . . .         1.40055
Enthalpy MJ/hr   . . . . . . .         471.407
Entropy MJ/hr*K  . . . . . . .        -.222392
Ave. mol. wt.  . . . . . . . .         28.0407
Total flow  kg/hr. . . . . . .         908.515
        kgmol/hr . . . . . . .         32.3999
Density kg/m3  . . . . . . . .         4.97526
Viscosity centipoise . . . . .         .660189E-02
Thermal cond. cal/cm*s*K . . .         .358105E-04
Specific heat   kJ/kg*K  . . .         1.10448
Z factor . . . . . . . . . . .         .968776
m3/hr (15.6 deg C & 1 atm) . .         767.562
Vol. flowrate m3/hr  . . . . .         182.609
                     Vapor           Vapor
                       mole           flowrate
                     fraction        kgmol/hr
Nitrogen           .993061          32.1751
Oxygen             .693924E-02      .224831

*** Stream no. 16 ***
                                     All Vapor
Temperature deg C. . . . . . .        -175.000
Pressure bars. . . . . . . . .         1.40055
Enthalpy MJ/hr   . . . . . . .         471.558
Entropy MJ/hr*K  . . . . . . .        -.220847
Ave. mol. wt.  . . . . . . . .         28.0407
Total flow  kg/hr. . . . . . .         908.515
        kgmol/hr . . . . . . .         32.3999
Density kg/m3  . . . . . . . .         4.96695
Viscosity centipoise . . . . .         .661202E-02
Thermal cond. cal/cm*s*K . . .         .358270E-04
Specific heat   kJ/kg*K  . . .         1.10414
Z factor . . . . . . . . . . .         .968902
m3/hr (15.6 deg C & 1 atm) . .         767.562
Vol. flowrate m3/hr  . . . . .         182.915
                     Vapor           Vapor
                       mole           flowrate
                     fraction        kgmol/hr
Nitrogen           .993061          32.1751
Oxygen             .693924E-02      .224831
 CODE REPORT

*** Stream no. 17 ***
                                     All Liquid
Temperature deg C. . . . . . .        -180.000
Pressure bars. . . . . . . . .         190.000
Enthalpy MJ/hr   . . . . . . .         60.2043
Entropy MJ/hr*K  . . . . . . .        -.620582
Ave. mol. wt.  . . . . . . . .         31.8809
Total flow  kg/hr. . . . . . .         242.294
        kgmol/hr . . . . . . .         7.59999
Density kg/m3  . . . . . . . .         1832.13
Viscosity centipoise . . . . .         .177374
Thermal cond. cal/cm*s*K . . .         .517994E-03
Specific heat   kJ/kg*K  . . .         1.54416
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Surface tension dyne/cm. . .        12.1667
S. G. (60/60)  . . . . . . .        .985091
m3/hr  (15.6 deg C & 1 atm) .       .246347
Vol. flowrate m3/hr   . . . .       .132248
                     Liquid          Liquid
                      mole          flowrate
                    fraction        kgmol/hr
Nitrogen          .296411E-01      .225272
Oxygen            .970359         7.37472
 CODE REPORT


 TOWR # 1         Data file: column.OUT          Profile file: link.prf


Column Summary
                                                                        Duties
      Temp    Pres                     Net Flow Rates                    MJ/hr
Stg    C      bars                       kgmols/hr
                           Liquid       Vapor        Feed       Product
                                                                16.000      -163.53
  1 -175.9    6.713 18.299
  2 -174.8    6.713 18.440      34.299
  3 -174.6    6.714 18.315      34.440
  4 -174.4    6.715 18.184      34.315
  5 -174.1    6.716 18.051      34.184
  6 -173.9    6.717 17.916      34.051
  7 -173.7    6.718 17.784      33.916
  8 -173.5    6.719 17.644      33.784
  9 -173.2    6.720 17.551      33.644
 10 -173.0    6.721 17.443      33.551
 11 -172.9    6.722 17.345      33.443
 12 -172.7    6.723 17.261      33.346
 13 -172.5    6.724 17.197      33.261
 14 -172.4    6.725 17.132      33.197
 15 -172.3    6.726 20.023      33.132      16.000
 16 -172.3    6.727 20.017      20.023
 17 -172.3    6.728 20.018      20.017
 18 -172.3    6.729 20.011      20.018
 19 -172.2    6.731 19.996      20.011
 20 -172.2    6.732 19.979      19.996
 21 -172.2    6.733             19.979      24.000      24.000

 Stream #    1 fed to Stg  15 is  81.772 % Vapor
 Stream #    2 fed to Stg  21 is  83.246 % Vapor

 Stream #    3 is Liquid Distillate from Stg 1
 Stream #    4 is Liquid Bottoms from Stg  21

 Condenser duty is -163.529        MJ/hr
 Reboiler duty is    .000000       MJ/hr
 CODE REPORT


 TOWR # 1         Data file: column.OUT          Profile file: link.prf
Tray Liquid Properties
                                                                               Surface
                                  Standard     Actual     Actual              tension
        Mass flow      Avg       Vol. flow   Vol. flow   Density   Viscosity  dyne/cm
Stg      kg/hr       mol wt        m3/hr       m3/hr      kg/m3    centipoise
```

```
                                                         .37  1329.83      .0947      4.74
 1        514.0  28.09                  .50
                                                         .39  1324.15      .0934      4.62
 2        519.4  28.17                  .59              .39  1330.76      .0941      4.69
 3        517.4  28.25                  .58              .39  1337.70      .0949      4.78
 4        515.4  28.34                  .58              .38  1344.85      .0957      4.87
 5        513.3  28.44                  .58              .38  1352.06      .0966      4.95
 6        511.2  28.53                  .57              .37  1359.18      .0974      5.04
 7        509.1  28.63                  .57              .37  1366.03      .0983      5.13
 8        506.7  28.72                  .56              .37  1372.47      .0991      5.21
 9        505.6  28.80                  .56              .37  1378.42      .0998      5.29
10        503.8  28.89                  .56              .36  1383.77      .1005      5.36
11        502.3  28.96                  .55              .36  1388.50      .1011      5.42
12        501.0  29.03                  .55              .36  1392.60      .1016      5.47
13        500.1  29.08                  .55              .36  1396.11      .1020      5.52
14        499.1  29.13                  .55              .42  1399.05      .1024      5.56
15        584.2  29.17                  .64              .42  1399.15      .1024      5.56
16        584.0  29.18                  .64              .42  1399.33      .1025      5.56
17        584.1  29.18                  .64              .42  1399.65      .1025      5.57
18        584.0  29.18                  .64              .42  1400.20      .1026      5.57
19        583.7  29.19                  .64              .42  1401.05      .1027      5.58
20        583.5  29.20                  .64              .50  1402.45      .1029      5.60
21        701.4  29.22                  .77
Tray Vapor Properties

                              Standard      Actual                Actual
      Mass flow      Avg      Vol. flow     Vol. flow             density
Stg     kg/hr      mol wt      m3/hr         m3/hr        Z       kg/m3

 1       *** Total Condenser : No Vapor Outlet ***
 2        963.4   28.09        812.5          34.93     .8356   27.5835
 3        968.8   28.13        815.9          35.17     .8364   27.5503
 4        966.8   28.18        812.9          35.14     .8372   27.5146
 5        964.8   28.22        809.8          35.11     .8380   27.4772
 6        962.7   28.27        806.7          35.08     .8388   27.4394
 7        960.6   28.32        803.5          35.06     .8397   27.4016
 8        958.5   28.37        800.4          35.03     .8405   27.3653
 9        956.1   28.42        797.0          34.98     .8413   27.3308
10        955.0   28.46        794.8          34.98     .8420   27.2991
11        953.3   28.50        792.3          34.96     .8426   27.2702
12        951.7   28.54        790.0          34.93     .8432   27.2451
13        950.4   28.57        788.0          34.91     .8437   27.2240
14        949.5   28.60        786.4          34.90     .8442   27.2059
15        948.5   28.63        784.9          34.88     .8446   27.1917
16        573.2   28.63        474.3          21.08     .8446   27.1946
17        573.1   28.63        474.2          21.07     .8446   27.1973
18        573.2   28.63        474.2          21.07     .8446   27.1993
19        573.1   28.64        474.1          21.07     .8446   27.2003
20        572.8   28.65        473.7          21.06     .8448   27.1986
21        572.6   28.66        473.3          21.06     .8449   27.1935
```

```
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TOWR # 1        Data file: column.TSZ          Profile file: link.prf

 Smith-Dresser-Ohlswager Shortcut Technique

  ***User Provided Input Data***
```

```
Tray spacing (in. or cm)            7.0000
Downcomer area (ft2 or m2)          .0151
Weir length (in. or cm)            24.0000
Weir height (in. or cm)             3.0000

                   Liquid     Vapor        Liquid       Vapor       Flooding   Settling
        Diameter  Vol. flow  Vol. flow     density      density     velocity   height
Stg      meter     m3/min     m3/sec        kg/m3        kg/m3       m/sec      meter

  1  ***Condenser: No tray sizing***
  2      .3051       .01         .01 1324.1490     27.5839       .1672     .0361
  3      .3053       .01         .01 1330.7550     27.5507       .1681     .0361
  4      .3047       .01         .01 1337.6980     27.5150       .1689     .0361
  5      .3040       .01         .01 1344.8480     27.4776       .1696     .0361
  6      .3034       .01         .01 1352.0650     27.4397       .1704     .0362
  7      .3028       .01         .01 1359.1760     27.4020       .1711     .0362
  8      .3022       .01         .01 1366.0340     27.3657       .1718     .0362
  9      .3016       .01         .01 1372.4660     27.3312       .1724     .0362
 10      .3012       .01         .01 1378.4210     27.2995       .1731     .0362
 11      .3007       .01         .01 1383.7730     27.2706       .1736     .0363
 12      .3003       .01         .01 1388.5020     27.2455       .1741     .0363
 13      .3000       .01         .01 1392.6050     27.2244       .1745     .0363
 14      .2997       .01         .01 1396.1050     27.2063       .1749     .0363
 15      .3029       .01         .01 1399.0530     27.1921       .1701     .0359
 16      .2615       .01         .01 1399.1530     27.1950       .1517     .0359
 17      .2615       .01         .01 1399.3330     27.1977       .1517     .0359
 18      .2615       .01         .01 1399.6530     27.1997       .1517     .0359
 19      .2614       .01         .01 1400.1980     27.2007       .1517     .0359
 20      .2613       .01         .01 1401.0550     27.1990       .1518     .0359
 21      .2661       .01         .01 1402.4480     27.1939       .1444     .0354
CODE REPORT


TOWR # 2           Data file: column.OUT           Profile file: pool.prf


Column Summary
                                                                      Duties
      Temp    Pres                      Net Flow Rates                 MJ/hr
Stg     C     bars                        kgmols/hr
                         Liquid         Vapor         Feed      Product
                                                      16.000     32.400
  1 -192.6     1.401 14.924
  2 -192.6     1.404 14.920        31.324
  3 -192.6     1.408 14.915        31.320
  4 -192.5     1.411 14.907        31.315
  5 -192.5     1.415 14.896        31.307
  6 -192.5     1.418 14.881        31.296
  7 -192.4     1.422 14.861        31.281
  8 -192.3     1.425 14.832        31.261
  9 -192.2     1.429 14.794        31.232
 10 -192.1     1.432 14.742        31.194
 11 -192.0     1.436 14.674        31.142
 12 -191.8     1.440 14.587        31.074
 13 -191.6     1.443 14.478        30.987
 14 -191.3     1.447 14.348        30.878
 15 -191.0     1.450 14.199        30.748
 16 -190.6     1.454 14.037        30.598
 17 -190.2     1.457 34.458        30.437        24.000
 18 -190.2     1.461 34.463        26.858
 19 -190.2     1.464 34.468        26.863
```

```
20 -190.2      1.468 34.473       26.868
21 -190.2      1.471 34.478       26.873
22 -190.1      1.475 34.483       26.878
23 -190.1      1.479 34.488       26.883
24 -190.1      1.482 34.493       26.888
25 -190.1      1.486 34.498       26.893
26 -190.0      1.489 34.503       26.898
27 -190.0      1.493 34.508       26.903
28 -190.0      1.496 34.513       26.908
29 -190.0      1.500 34.518       26.913
30 -189.9      1.503 34.523       26.918
31 -189.9      1.507 34.528       26.923
32 -189.9      1.510 34.533       26.928
33 -189.9      1.514 34.538       26.933
34 -189.8      1.518 34.542       26.938
35 -189.8      1.521 34.547       26.943
36 -189.8      1.525 34.552       26.947
37 -189.8      1.528 34.557       26.952
38 -189.8      1.532 34.562       26.957
39 -189.7      1.535 34.567       26.962
40 -189.7      1.539 34.572       26.967
41 -189.7      1.542 34.577       26.972
42 -189.7      1.546 34.582       26.977
43 -189.6      1.549 34.587       26.982
44 -189.6      1.553 34.591       26.987
45 -189.6      1.557 34.595       26.991
46 -189.6      1.560 34.600       26.995
47 -189.5      1.564 34.602       27.000
CODE REPORT
                     Liquid       Vapor        Feed       Product


48 -189.5      1.567 34.601       27.002
49 -189.5      1.571 34.590       27.001
50 -189.4      1.574 34.554       26.990
51 -189.3      1.578 34.451       26.954
52 -189.0      1.581 34.183       26.851
53 -188.3      1.585 33.566       26.583
54 -186.7      1.588 32.488       25.966
55 -184.1      1.592 31.381       24.888
56 -181.3      1.596 30.829       23.781
57 -179.5      1.599              23.229            7.6000       153.21

Stream #    7 fed to Stg   1 is    6.690 % Vapor
Stream #    9 fed to Stg  17 is   14.894 % Vapor

Stream #   10 is Vapor Distillate from Stg 1
Stream #   11 is Liquid Bottoms from Stg  57

Condenser duty is  .000000       MJ/hr
Reboiler duty is   153.208       MJ/hr
CODE REPORT


 TOWR # 2          Data file: column.OUT          Profile file: pool.prf
Tray Liquid Properties
                                                                                Surface
                                 Standard       Actual      Actual              tension
       Mass flow      Avg        Vol. flow     Vol. flow    Density  Viscosity  dyne/cm
Stg      kg/hr      mol wt         m3/hr         m3/hr      kg/m3    centipoise
```

```
                                                    .28   1504.01      .1477      8.32
1        419.3   28.09               .48            .28   1504.12      .1477      8.32
2        419.2   28.10               .47            .28   1504.37      .1476      8.32
3        419.2   28.11               .47            .28   1504.79      .1476      8.33
4        419.1   28.11               .47            .28   1505.45      .1477      8.34
5        419.0   28.12               .47            .28   1506.43      .1477      8.36
6        418.8   28.14               .47            .28   1507.85      .1479      8.38
7        418.5   28.16               .47            .28   1509.87      .1482      8.42
8        418.1   28.19               .47            .28   1512.67      .1485      8.47
9        417.6   28.23               .47            .28   1516.47      .1491      8.53
10       417.0   28.28               .47            .27   1521.52      .1499      8.63
11       416.1   28.35               .47            .27   1528.09      .1509      8.75
12       414.9   28.45               .47            .27   1536.33      .1522      8.90
13       413.5   28.56               .46            .27   1546.30      .1539      9.08
14       411.8   28.70               .46            .26   1557.78      .1558      9.30
15       409.8   28.86               .45            .26   1570.25      .1580      9.54
16       407.7   29.04               .45            .64   1582.90      .1602      9.78
17      1007.2   29.23              1.10            .64   1582.70      .1601      9.78
18      1007.3   29.23              1.10            .64   1582.51      .1600      9.77
19      1007.5   29.23              1.10            .64   1582.31      .1598      9.77
20      1007.6   29.23              1.10            .64   1582.10      .1597      9.76
21      1007.8   29.23              1.10            .64   1581.91      .1596      9.76
22      1007.9   29.23              1.10            .64   1581.71      .1595      9.75
23      1008.1   29.23              1.10            .64   1581.51      .1594      9.75
24      1008.2   29.23              1.10            .64   1581.31      .1593      9.74
25      1008.4   29.23              1.10            .64   1581.12      .1592      9.74
26      1008.5   29.23              1.10            .64   1580.92      .1591      9.73
27      1008.6   29.23              1.10            .64   1580.72      .1590      9.72
28      1008.8   29.23              1.10            .64   1580.53      .1589      9.72
29      1008.9   29.23              1.10            .64   1580.33      .1588      9.71
30      1009.1   29.23              1.10            .64   1580.14      .1587      9.71
31      1009.2   29.23              1.11            .64   1579.94      .1586      9.70
32      1009.4   29.23              1.11            .64   1579.75      .1584      9.70
33      1009.5   29.23              1.11            .64   1579.55      .1583      9.69
34      1009.7   29.23              1.11            .64   1579.36      .1582      9.69
35      1009.8   29.23              1.11            .64   1579.16      .1581      9.68
36      1010.0   29.23              1.11            .64   1578.97      .1580      9.68
37      1010.1   29.23              1.11            .64   1578.78      .1579      9.67
38      1010.3   29.23              1.11            .64   1578.58      .1578      9.67
39      1010.4   29.23              1.11            .64   1578.39      .1577      9.66
40      1010.6   29.23              1.11            .64   1578.19      .1576      9.66
41      1010.7   29.23              1.11            .64   1578.01      .1575      9.65
42      1010.9   29.23              1.11            .64   1577.81      .1574      9.65
43      1011.0   29.23              1.11            .64   1577.62      .1573      9.64
44      1011.1   29.23              1.11            .64   1577.44      .1572      9.63
45      1011.3   29.23              1.11            .64   1577.27      .1571      9.63
46      1011.4   29.23              1.11            .64   1577.14      .1570      9.63
47      1011.5   29.23              1.11            .64   1577.14      .1569      9.62
48      1011.6   29.24              1.11            .64   1577.42      .1569      9.63
49      1011.5   29.24              1.11
CODE REPORT


TOWR # 2         Data file: column.OUT             Profile file: pool.prf
Tray Liquid Properties

                                  Standard       Actual      Actual                    Surface
        Mass flow      Avg        Vol. flow     Vol. flow    Density     Viscosity     tension
Stg       kg/hr      mol wt         m3/hr         m3/hr       kg/m3      centipoise    dyne/cm

50        1011.1     29.26          1.11           .64       1578.52       .1571        9.65
```

```
51       1009.8  29.31          1.10          .64   1581.72       .1576     9.71
52       1006.4  29.44          1.10          .63   1590.22       .1591     9.87
53        998.6  29.75          1.08          .62   1610.15       .1627    10.26
54        986.0  30.35          1.05          .60   1646.29       .1692    10.78
55        976.1  31.10          1.01          .58   1684.65       .1753    11.72
56        975.4  31.64          1.00          .57   1703.76       .1764    12.04
57        242.3  31.88           .25          .14   1708.77       .1755    12.08
CODE REPORT


TOWR # 2         Data file: column.OUT          Profile file: pool.prf
Tray Vapor Properties

                               Standard       Actual               Actual
         Mass flow    Avg      Vol. flow      Vol. flow            density
Stg       kg/hr     mol wt      m3/hr          m3/hr        Z      kg/m3

  1         908.5   28.04       767.6         146.77     .9479    6.1900
  2         878.4   28.04       742.1         141.58     .9478    6.2042
  3         878.3   28.04       742.0         141.25     .9477    6.2183
  4         878.3   28.05       741.8         140.92     .9476    6.2323
  5         878.2   28.05       741.7         140.60     .9476    6.2461
  6         878.1   28.06       741.4         140.28     .9475    6.2595
  7         877.9   28.06       741.1         139.95     .9474    6.2726
  8         877.6   28.07       740.6         139.63     .9474    6.2850
  9         877.2   28.09       739.9         139.31     .9474    6.2969
 10         876.7   28.11       739.0         139.00     .9475    6.3077
 11         876.1   28.13       737.8         138.68     .9475    6.3174
 12         875.2   28.16       736.2         138.36     .9477    6.3256
 13         874.0   28.21       734.1         138.03     .9479    6.3322
 14         872.6   28.26       731.5         137.70     .9481    6.3369
 15         870.9   28.32       728.4         137.36     .9484    6.3399
 16         868.9   28.40       724.9         137.02     .9488    6.3416
 17         866.8   28.48       721.1         136.66     .9492    6.3427
 18         764.9   28.48       636.3         120.32     .9491    6.3569
 19         765.0   28.48       636.4         120.07     .9490    6.3712
 20         765.2   28.48       636.5         119.83     .9489    6.3855
 21         765.3   28.48       636.6         119.58     .9488    6.3997
 22         765.5   28.48       636.7         119.34     .9488    6.4141
 23         765.6   28.48       636.9         119.10     .9487    6.4283
 24         765.8   28.48       637.0         118.86     .9486    6.4426
 25         765.9   28.48       637.1         118.62     .9485    6.4568
 26         766.1   28.48       637.2         118.38     .9484    6.4712
 27         766.2   28.48       637.3         118.14     .9483    6.4854
 28         766.4   28.48       637.5         117.91     .9482    6.4997
 29         766.5   28.48       637.6         117.67     .9481    6.5139
 30         766.7   28.48       637.7         117.44     .9480    6.5282
 31         766.8   28.48       637.8         117.20     .9479    6.5425
 32         766.9   28.48       637.9         116.97     .9478    6.5568
 33         767.1   28.48       638.0         116.74     .9478    6.5710
 34         767.2   28.48       638.2         116.51     .9477    6.5853
 35         767.4   28.48       638.3         116.28     .9476    6.5995
 36         767.5   28.48       638.4         116.05     .9475    6.6138
 37         767.7   28.48       638.5         115.82     .9474    6.6280
 38         767.8   28.48       638.6         115.60     .9473    6.6423
 39         768.0   28.48       638.7         115.37     .9472    6.6565
 40         768.1   28.48       638.9         115.15     .9471    6.6707
 41         768.3   28.48       639.0         114.93     .9470    6.6850
 42         768.4   28.48       639.1         114.70     .9469    6.6992
 43         768.6   28.48       639.2         114.48     .9469    6.7135
```

```
 44         768.7  28.49          639.3         114.26  .9468    6.7277
 45         768.9  28.49          639.4         114.04  .9467    6.7419
 46         769.0  28.49          639.5         113.82  .9466    6.7561
 47         769.1  28.49          639.6         113.60  .9465    6.7702
 48         769.2  28.49          639.7         113.38  .9464    6.7843
 49         769.3  28.49          639.7         113.16  .9463    6.7980
 CODE REPORT


 TOWR # 2         Data file: column.OUT          Profile file: pool.prf
Tray Vapor Properties

                                 Standard     Actual              Actual
     Mass flow     Avg         Vol. flow    Vol. flow             density
Stg    kg/hr     mol wt        m3/hr        m3/hr         Z       kg/m3

 50         769.2  28.50          639.4         112.94  .9463    6.8108
 51         768.8  28.52          638.5         112.71  .9464    6.8211
 52         767.5  28.58          636.1         112.46  .9467    6.8253
 53         764.1  28.74          629.8         112.12  .9475    6.8152
 54         756.3  29.13          615.1         111.51  .9494    6.7821
 55         743.7  29.88          589.6         110.28  .9524    6.7434
 56         733.8  30.85          563.4         108.76  .9549    6.7469
 57         733.1  31.56          550.3         108.13  .9562    6.7792


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TOWR # 2         Data file: column.TSZ          Profile file: pool.prf

 Smith-Dresser-Ohlswager Shortcut Technique

  ***User Provided Input Data***

  Tray spacing (in. or cm)        7.0000
  Downcomer area (ft2 or m2)       .0236
  Weir length (in. or cm)        30.0000
  Weir height (in. or cm)         3.0000

                  Liquid     Vapor          Liquid       Vapor      Flooding  Settling
     Diameter   Vol. flow   Vol. flow      density      density    velocity  height
Stg    meter     m3/min      m3/sec         kg/m3        kg/m3      m/sec      meter

 1     .3980        .00        .04 1504.0130     6.1901        .4043     .0373
 2     .3922        .00        .04 1504.1240     6.2043        .4046     .0373
 3     .3920        .00        .04 1504.3670     6.2184        .4042     .0373
 4     .3918        .00        .04 1504.7920     6.2324        .4038     .0373
 5     .3915        .00        .04 1505.4480     6.2462        .4035     .0373
 6     .3913        .00        .04 1506.4320     6.2596        .4032     .0373
 7     .3910        .00        .04 1507.8550     6.2727        .4029     .0373
 8     .3907        .00        .04 1509.8700     6.2851        .4028     .0373
 9     .3904        .00        .04 1512.6680     6.2970        .4028     .0373
10     .3899        .00        .04 1516.4700     6.3078        .4029     .0373
11     .3894        .00        .04 1521.5240     6.3175        .4033     .0373
12     .3889        .00        .04 1528.0850     6.3257        .4038     .0373
13     .3882        .00        .04 1536.3290     6.3323        .4046     .0374
14     .3874        .00        .04 1546.3010     6.3370        .4057     .0374
15     .3865        .00        .04 1557.7830     6.3400        .4070     .0374
```

```
16    .3856      .00     .04 1570.2490   6.3417    .4085   .0374
17    .3935      .01     .04 1582.9050   6.3428    .3874   .0353
18    .3775      .01     .03 1582.7020   6.3570    .3785   .0353
19    .3774      .01     .03 1582.5090   6.3713    .3780   .0353
20    .3773      .01     .03 1582.3070   6.3856    .3775   .0353
21    .3772      .01     .03 1582.1040   6.3998    .3769   .0353
22    .3771      .01     .03 1581.9110   6.4142    .3764   .0353
23    .3770      .01     .03 1581.7080   6.4284    .3759   .0353
24    .3769      .01     .03 1581.5140   6.4427    .3754   .0353
25    .3768      .01     .03 1581.3110   6.4569    .3748   .0353
26    .3767      .01     .03 1581.1170   6.4713    .3743   .0353
27    .3766      .01     .03 1580.9240   6.4855    .3738   .0353
28    .3765      .01     .03 1580.7200   6.4998    .3733    0353
CODE REPORT

Smith-Dresser-Ohlswager Shortcut Technique

                                                 Liquid     Vapor     Flooding  Settling
                    Liquid      Vapor            density    density   velocity  height
       Diameter   Vol. flow   Vol. flow          kg/m3      kg/m3     m/sec       meter
Stg    meter      m3/min       m3/sec

29    .3764      .01         .03 1580.5260      6.5140     .3728     .0353
30    .3763      .01         .03 1580.3320      6.5283     .3723     .0353
31    .3762      .01         .03 1580.1380      6.5426     .3718     .0353
32    .3761      .01         .03 1579.9430      6.5569     .3713     .0353
33    .3760      .01         .03 1579.7490      6.5711     .3708     .0353
34    .3760      .01         .03 1579.5550      6.5854     .3703     .0353
35    .3759      .01         .03 1579.3600      6.5996     .3697     .0353
36    .3758      .01         .03 1579.1650      6.6139     .3692     .0353
37    .3757      .01         .03 1578.9700      6.6281     .3687     .0353
38    .3756      .01         .03 1578.7750      6.6423     .3683     .0353
39    .3755      .01         .03 1578.5810      6.6566     .3678     .0353
40    .3754      .01         .03 1578.3860      6.6708     .3673     .0353
41    .3753      .01         .03 1578.1910      6.6851     .3668     .0353
42    .3752      .01         .03 1578.0060      6.6993     .3663     .0353
43    .3751      .01         .03 1577.8130      6.7136     .3658     .0353
44    .3751      .01         .03 1577.6220      6.7278     .3653     .0353
45    .3750      .01         .03 1577.4390      6.7420     .3648     .0353
46    .3749      .01         .03 1577.2740      6.7562     .3643     .0353
47    .3748      .01         .03 1577.1440      6.7703     .3639     .0353
48    .3747      .01         .03 1577.1360      6.7844     .3634     .0353
49    .3746      .01         .03 1577.4200      6.7981     .3630     .0353
50    .3744      .01         .03 1578.5160      6.8109     .3628     .0353
51    .3740      .01         .03 1581.7190      6.8212     .3630     .0353
52    .3732      .01         .03 1590.2160      6.8254     .3642     .0353
53    .3714      .01         .03 1610.1480      6.8153     .3675     .0354
54    .3682      .01         .03 1646.2870      6.7822     .3738     .0355
55    .3643      .01         .03 1684.6500      6.7435     .3798     .0356
56    .3618      .01         .03 1703.7580      6.7469     .3814     .0356
57    ***Reboiler: No tray sizing***
```

Appendix E

Computer results of the column-tray sizing under 1.7 times the nominal flow rate of air

CO117.REP

```
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        TOPOLOGY

Equipment                  Stream Numbers

 1  TOWR                    1   2  -3  -4
 2  HXER                    3  10  -5 -13
 3  HXER                    4  13  -6 -15
 4  HXER                    8  11  -9 -12
 5  VALV                    5  -7   0   0
 6  VALV                    6  -8   0   0
 7  TOWR                    7   9 -10 -11
 8  PUMP                   12 -14   0   0
 9  HXER                   15 -16   0   0
10  HXER                   14 -17   0   0

Stream Connections

Stream    Equipment
      From      To
   1       0       1
   2       0       1
   3       1       2
   4       1       3
   5       2       5
   6       3       6
   7       5       7
   8       6       4
   9       4       7
  10       7       2
  11       7       4
  12       4       8
  13       2       3
  14       8      10
  15       3       9
  16       9       0
  17      10       0

COMPONENTS . . . . . .         2

ID numbers ...........         46,   47,

        THERMODYNAMICS

  Kvalue option: Peng-Robinson
  Enthalpy option: Peng-Robinson
  Density option: API method
 CODE REPORT

        MISCELLANEOUS


Recycle calculations are converged.
```

```
Recycle equipment list (KE2):            2,   3,   5,   6,   4,   7,

Streams used in conv. routine (KE4):( 0)
      ()=Delay factor

Preferred cut stream list (KE3):      10, 11,

Convergence tolerances,         Error
         Flowrates:            .00100000
         Vapor fraction:       .00100000
         Temperature:          .00100000
         Pressure:             .00100000
         Enthalpy:             .00100000
         Flash calcs:          .00005000

Max. loops in recycle calc.:    30
          in flash calcs:       75


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***       VALVES            ***
Equipment no.                      5            6
External name
Outlet pressure bars     1.4006       1.4572
..............................................................................

***EXCHANGER/CONDENSERS***
Equipment no.                2             3             4             9
External name
Heat transfer coeff.      300.00        300.00        300.00        .00000
Area                      9.7848        10.011        .91125        .00000
Number of shells              .0            .0            .0            .0
Shell passes                  .0            .0            .0            .0
Tube passes                   .0            .0            .0            .0
Mode                         3.0           3.0           3.0           5.0
Min. delta T or T-out       6.00          3.00          7.00       -175.00
Delta P, stream 1         .00000        .00000        .00000        .00000
Delta P, stream 2         .00000        .00000        .00000        .00000
Q, stream 1   MJ/hr      -18.045       -12.132        2.3613        .25606
Water usage, DM3/hr       .00000        .00000        .00000        .00000
Corrected delta T           6.15          4.04          8.64          8.64
Equipment no.                 10
External name
Heat transfer coeff.      .00000
Area                      .00000
Number of shells              .0
Shell passes                  .0
Tube passes                   .0
Mode                         5.0
Min. delta T or T-out    -180.00
Delta P, stream 1         .00000
Delta P, stream 2         .00000
Q, stream 1   MJ/hr       1.9207
Water usage, DM3/hr       .00000
Corrected delta T           8.64
..............................................................................
```

```
*** PUMPS/COMPRESSORS  ***
Equipment no.               8
External name
Number of stages           .0
Work capacity   MJ/hr  .00000
Outlet pressure bars   190.00
Power type:                .0
   (+) steam
   (0) electricity
   (-) fuel gas
H, steam out KJ / kg   .00000
Fuel usage, M3  /hr    .00000
Water usage, DM3/hr    .00000
Steam usage Tonnes/hr  .00000
Kilowatt usage         1.9769
..........................................................................
```

```
CODE: Chemical Engineering Simulation System
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***  RIGOROUS TOWERS   ***
Equipment no.                 1            7
External name
Number of stages            21.0         57.0
Feed 1, stage #             15.0          1.0
Feed 2, stage #             21.0         17.0
Feed 3, stage #               .0           .0
Feed 4, stage #               .0           .0
Feed 5, stage #               .0           .0
Sidestream # 1 stage          .0           .0
Sidestream # 2 stage          .0           .0
Sidestream # 3 stage          .0           .0
Sidestream # 4 stage          .0           .0
Cond. pressure bars       6.7131       1.4006
Cond. delta P bars        .00000       .00000
Colm. delta P bars     .19400E-01      .19850
Condenser type                .0          1.0
Condenser mode               4.0           .0
Value of cond. spec.      27.200       .00000
Cond comp 1 position         1.0           .0
Cond comp 2 position          .0           .0
Cond. deg. subcooled        1.00          .00
Reboiler mode                 .0          4.0
Val. of reboiler spec     .00000       12.920
Rebr comp 1 position          .0          2.0
Rebr comp 2 position          .0           .0
Damping ratio             .00000      1.0000
Sidestream 1 mode             .0           .0
Sidestream 2 mode             .0           .0
Sidestream 3 mode             .0           .0
Sidestream 4 mode             .0           .0
Sidestream # 1 spec       .00000       .00000
Sidestream # 2 spec       .00000       .00000
Sidestream # 3 spec       .00000       .00000
Sidestream # 4 spec       .00000       .00000
Sidestrm 1 comp posn          .0           .0
Sidestrm 2 comp posn          .0           .0
Sidestrm 3 comp posn          .0           .0
```

```
Sidestrm 4 comp posn          .0           .0
Cond. duty   MJ/hr      -277.55        .00000
Rebr duty    MJ/hr       .00000        260.55
Est dist rate Kgmol/hr  16.000         .00000
Est. reflux Kgmol/hr     .00000        .00000
Est. side draw rate 1    .00000        .00000
Est. side draw rate 2    .00000        .00000
Est. side draw rate 3    .00000        .00000
Est. side draw rate 4    .00000        .00000
Est. temp stg  1  C     -178.00       -193.00
Est. temp stg  N  C     -174.00       -183.00
.............................................................................

 CODE REPORT

*** Stream no.   1 ***
                         Overall               Vapor               Liquid
Temperature deg C.      -172.366
Pressure bars. . .       6.61325
Vapor fraction . .       .814077
Enthalpy MJ/hr    .      364.679     !     317.794      !     46.8845
Entropy MJ/hr*K   .     -.811794     !    -.456491      !    -.355303
Ave. mol. wt.   . .      28.7725     !     28.6655      !     29.2409
Total flow kg/hr .       783.129     !     635.157      !     147.972
          kgmol/hr .     27.2180     !     22.1575      !     5.06045
Density kg/m3 . . . . . . . . . . .        26.7085      !     1406.48
Viscosity centipoise . . . . . . .         .690154E-02  !     .103556
Thermal cond. cal/cm*s*K . . . . .         .357696E-04  !     .505017E-03
Specific heat   kJ/kg*K  . . . . .         1.25117      !     2.17498
Z factor . . . . . . . . . . . . .         .847052
m3/hr (15.6 deg C & 1 atm) . . . .         524.913
Vol. flowrate m3/hr  . . . . . . .         23.7814
Surface tension dyne/cm. . . . . . . . . . . . . . . .        5.67517
S. G. (60/60)  . . . . . . . . . . . . . . . . . . . .        .915033
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . .        .161966
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . .        .105208
                     Vapor      Liquid          Vapor          Liquid
                     mole       mole            flowrate       flowrate
                     fraction   fraction        kgmol/hr       kgmol/hr
Nitrogen             .83630     .69196          18.5304        3.50163
Oxygen               .16370     .30804          3.62715        1.55883

*** Stream no.   2 ***
                         Overall               Vapor               Liquid
Temperature deg C.      -172.347
Pressure bars, . .       6.60647
Vapor fraction . .       .832295
Enthalpy MJ/hr    .      550.428     !     487.063      !     63.3645
Entropy MJ/hr*K   .     -1.17950     !    -.698989      !    -.480512
Ave. mol. wt.   . .      28.7703     !     28.6730      !     29.2536
Total flow kg/hr .       1173.83     !     973.666      !     200.164
          kgmol/hr .     40.8000     !     33.9576      !     6.84237
Density kg/m3 . . . . . . . . . . .        26.6758      !     1407.54
Viscosity centipoise . . . . . . .         .690418E-02  !     .103704
Thermal cond. cal/cm*s*K . . . . .         .357676E-04  !     .504990E-03
Specific heat   kJ/kg*K  . . . . .         1.25043      !     2.17322
Z factor . . . . . . . . . . . . .         .847282
m3/hr (15.6 deg C & 1 atm) . . . .         804.459
Vol. flowrate m3/hr  . . . . . . .         36.5005
Surface tension dyne/cm. . . . . . . . . . . . . . . .        5.69054
```

```
S. G. (60/60) . . . . . . . . . . . . . . . . . . . .            .015375
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . .           .219011
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . .           .142210
                      Vapor      Liquid        Vapor             Liquid
                      mole       mole          flowrate          flowrate
                      fraction   fraction      kgmol/hr          kgmol/hr
Nitrogen              .83443     .68876        28.3352           4.71278
Oxygen                .16557     .31124        5.62239           2.12959
 CODE REPORT

*** Stream no.  3 ***
                                      All Liquid
Temperature deg C. . . . . . .         -175.934
Pressure bars. . . . . . . . .          6.71314
Enthalpy MJ/hr   . . . . . . .          258.574
Entropy MJ/hr*K  . . . . . . .         -1.90819
Ave. mol. wt.  . . . . . . . .          28.0894
Total flow  kg/hr. . . . . . .          764.031
          kgmol/hr . . . . . .          27.1999
Density kg/m3  . . . . . . . .          1329.95
Viscosity centipoise . . . . .          .947303E-01
Thermal cond. cal/cm*s*K . . .          .510520E-03
Specific heat   kJ/kg*K  . . .          2.34611
Surface tension dyne/cm. . . .          4.74328
S. G. (60/60)  . . . . . . . .          .883915
m3/hr (15.6 deg C & 1 atm) . .          .865727
Vol. flowrate m3/hr  . . . . .          .574488
                     Liquid            Liquid
                     mole              flowrate
                     fraction          kgmol/hr
Nitrogen            .980825            26.6784
Oxygen              .191745E-01        .521546

*** Stream no.  4 ***
                                      All Liquid
Temperature deg C. . . . . . .         -172.150
Pressure bars. . . . . . . . .          6.73254
Enthalpy MJ/hr   . . . . . . .          378.995
Entropy MJ/hr*K  . . . . . . .         -2.85909
Ave. mol. wt.  . . . . . . . .          29.2255
Total flow  kg/hr. . . . . . .          1192.93
          kgmol/hr . . . . . .          40.8180
Density kg/m3  . . . . . . . .          1402.51
Viscosity centipoise . . . . .          .102874
Thermal cond. cal/cm*s*K . . .          .504664E-03
Specific heat   kJ/kg*K  . . .          2.18318
Surface tension dyne/cm. . . .          5.60360
S. G. (60/60)  . . . . . . . .          .914620
m3/hr (15.6 deg C & 1 atm) . .          1.30633
Vol. flowrate m3/hr  . . . . .          .850576
                     Liquid            Liquid
                     mole              flowrate
                     fraction          kgmol/hr
Nitrogen            .695808            28.4015
Oxygen              .304192            12.4165
 CODE REPORT

*** Stream no.  5 ***
                                      All Liquid
Temperature deg C. . . . . . .         -186.645
```

```
Pressure bars. . . . . . . .       6.71314
Enthalpy MJ/hr    . . . . . .      240.529
Entropy MJ/hr*K  . . . . . . .    -2.10464
Ave. mol. wt.  . . . . . . . .     28.0894
Total flow  kg/hr. . . . . . .     764.031
        kgmol/hr . . . . . . .     27.1999
Density kg/m3  . . . . . . . .     1446.06
Viscosity centipoise . . . . .     .123420
Thermal cond. cal/cm*s*K . . .     .527854E-03
Specific heat   kJ/kg*K   . .      2.09313
Surface tension dyne/cm. . . .     6.98535
S. G. (60/60)  . . . . . . . .     .883915
m3/hr (15.6 deg C & 1 atm) . .     .865727
Vol. flowrate m3/hr   . . . .      .528360
                        Liquid       Liquid
                         mole       flowrate
                       fraction     kgmol/hr
Nitrogen             .980825      26.6784
Oxygen               .191745E-01   .521546

*** Stream no.   6 ***
                                  All Liquid
Temperature deg C. . . . . . .    -176.936
Pressure bars. . . . . . . . .     6.73254
Enthalpy MJ/hr    . . . . . .      366.863
Entropy MJ/hr*K  . . . . . . .    -2.98213
Ave. mol. wt.  . . . . . . . .     29.2255
Total flow  kg/hr. . . . . . .     1192.93
        kgmol/hr . . . . . . .     40.8180
Density kg/m3  . . . . . . . .     1454.70
Viscosity centipoise . . . . .     .113786
Thermal cond. cal/cm*s*K . . .     .512410E-03
Specific heat   kJ/kg*K   . .      2.06949
Surface tension dyne/cm. . . .     6.67757
S. G. (60/60)  . . . . . . . .     .914620
m3/hr (15.6 deg C & 1 atm) . .     1.30633
Vol. flowrate m3/hr   . . . .      .820056
                        Liquid       Liquid
                         mole       flowrate
                       fraction     kgmol/hr
Nitrogen             .695808      28.4015
Oxygen               .304192      12.4165
 CODE REPORT

*** Stream no.   7 ***
                         Overall             Vapor              Liquid
Temperature deg C.     -192.650
Pressure bars. . .      1.40055
Vapor fraction . .      .668756E-01
Enthalpy MJ/hr    .     240.529     !    25.7341      :    214.895
Entropy MJ/hr*K   .    -2.09356     !   -.237600E-01  :   -2.06980
Ave. mol. wt.   . .     28.0894     !    28.0401      !    28.0930
Total flow kg/hr .      764.031     !    51.0205      !    713.011
        kgmol/hr .      27.1999     !    1.81956      !    25.3804
Density kg/m3  . . . . . . . . . . .     6.12840      !    1503.90
Viscosity centipoise . . . . . . . .     .541963E-02  :    .147499
Thermal cond. cal/cm*s*K . . . . . .     .340865E-04  :    .537577E-03
Specific heat   kJ/kg*K  . . . . . .     1.13159      :    1.97731
Z factor . . . . . . . . . . . . . .     .947871
m3/hr (15.6 deg C & 1 atm) . . . . .     43.5406
```

```
Vol. flowrate m3/hr . . . . . . . .        8.32537
Surface tension dyne/cm. . . . . . . . . . . . . . . .          8.31641
S. G. (60/60)  . . . . . . . . . . . . . . . . . . . .          .884012
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . .          .807828
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . .          .474114
                  Vapor      Liquid          Vapor              Liquid
                  mole        mole           flowrate           flowrate
                 fraction    fraction        kgmol/hr           kgmol/hr
Nitrogen         .99321      .97993          1.80720            24.8710
Oxygen           .67883E-02 .20072E-01       .123517E-01        .509438

*** Stream no.   8 ***
                      Overall                Vapor                  Liquid
Temperature deg C.    -190.026
Pressure bars. . .     1.45725
Vapor fraction . .     .138561
Enthalpy MJ/hr   .     366.863     !     79.3547       !     287.431
Entropy MJ/hr*K  .    -2.94376     !    -.696667E-01   !    -2.87410
Ave. mol. wt.  . .     29.2255     !     28.5270       !     29.3375
Total flow kg/hr .     1192.93     !     161.342       !     1031.57
        kgmol/hr .     40.8180     !     5.65578       !     35.1622
Density kg/m3  . . . . . . . . . . .     6.35054       !     1590.34
Viscosity centipoise . . . . . . . .     .566984E-02   !     .161652
Thermal cond. cal/cm*s*K . . . . . .     .339152E-04   !     .533617E-03
Specific heat   kJ/kg*K  . . . . . .     1.10402       !     1.84609
Z factor . . . . . . . . . . . . . .     .949508
m3/hr (15.6 deg C & 1 atm) . . . . .     133.656
Vol. flowrate m3/hr  . . . . . . . .     25.4064
Surface tension dyne/cm. . . . . . . . . . . . . . . .          9.92959
S. G. (60/60)  . . . . . . . . . . . . . . . . . . . .          .917630
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . .          1.12593
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . .          .648657
                  Vapor      Liquid          Vapor              Liquid
                  mole        mole           flowrate           flowrate
                 fraction    fraction        kgmol/hr           kgmol/hr
Nitrogen         .87106      .66770          4.92650            23.4778
Oxygen           .12894      .33230          .729281            11.6844
 CODE REPORT

*** Stream no.   9 ***
                      Overall                Vapor                  Liquid
Temperature deg C.    -190.007
Pressure bars. . .     1.45725
Vapor fraction . .     .149001
Enthalpy MJ/hr   .     369.224     !     85.4078       !     283.830
Entropy MJ/hr*K  .    -2.91394     !    -.748885E-01   !    -2.83905
Ave. mol. wt.  . .     29.2255     !     28.5313       !     29.3468
Total flow kg/hr .     1192.93     !     173.525       !     1019.39
        kgmol/hr .     40.8180     !     6.08192       !     34.7361
Density kg/m3  . . . . . . . . . . .     6.34457       !     1590.97
Viscosity centipoise . . . . . . . .     .567178E-02   !     .161735
Thermal cond. cal/cm*s*K . . . . . .     .339275E-04   !     .533589E-03
Specific heat   kJ/kg*K  . . . . . .     1.10395       !     1.84485
Z factor . . . . . . . . . . . . . .     .949533
m3/hr (15.6 deg C & 1 atm) . . . . .     143.847
Vol. flowrate m3/hr  . . . . . . . .     27.3505
Surface tension dyne/cm. . . . . . . . . . . . . . . .          9.94191
S. G. (60/60)  . . . . . . . . . . . . . . . . . . . .          .917879
m3/hr (15.6 deg C & 1 atm) . . . . . . . . . . . . . .          1.11234
Vol. flowrate m3/hr  . . . . . . . . . . . . . . . . .          .640746
```

```
                     Vapor       Liquid           Vapor             Liquid
                     mole        mole             flowrate          flowrate
                     fraction    fraction         kgmol/hr          kgmol/hr
Nitrogen             .86998      .66537           5.29115           23.1124
Oxygen               .13002      .33463           .790769           11.6237

*** Stream no. 10 ***
                                    All Vapor
Temperature deg C. . . . . . .      -192.645
Pressure bars. . . . . . . . .       1.40055
Enthalpy MJ/hr    . . . . . .        771.479
Entropy MJ/hr*K  . . . . . . .      -.717509
Ave. mol. wt.  . . . . . . . .       28.0411
Total flow  kg/hr. . . . . . .       1545.01
        kgmol/hr . . . . . . .       55.0980
Density kg/m3  . . . . . . . .       6.19003
Viscosity centipoise . . . . .       .542011E-02
Thermal cond. cal/cm*s*K . . .       .339356E-04
Specific heat   kJ/kg*K  . . .       1.13147
Z factor . . . . . . . . . . .       .947878
m3/hr (15.6 deg C & 1 atm) . .       1305.28
Vol. flowrate m3/hr  . . . . .       249.600
                     Vapor        Vapor
                      mole        flowrate
                     fraction     kgmol/hr
Nitrogen             .992954      54.7098
Oxygen               .704628E-02  .388236
 CODE REPORT

*** Stream no. 11 ***
                                    All Liquid
Temperature deg C. . . . . . .      -179.494
Pressure bars. . . . . . . . .       1.59905
Enthalpy MJ/hr    . . . . . .        98.8147
Entropy MJ/hr*K  . . . . . . .      -1.02800
Ave. mol. wt.  . . . . . . . .       31.8848
Total flow  kg/hr. . . . . . .       411.950
        kgmol/hr . . . . . . .       12.9199
Density kg/m3  . . . . . . . .       1708.86
Viscosity centipoise . . . . .       .175450
Thermal cond. cal/cm*s*K . . .       .517176E-03
Specific heat   kJ/kg*K  . . .       1.63153
Surface tension dyne/cm. . . .       12.0763
S. G. (60/60)  . . . . . . . .       .985195
m3/hr (15.6 deg C & 1 atm) . .       .418796
Vol. flowrate m3/hr  . . . . .       .241069
                     Liquid       Liquid
                      mole        flowrate
                     fraction     kgmol/hr
Nitrogen             .286495E-01  .370150
Oxygen               .971351      12.5498

*** Stream no. 12 ***
                                    All Liquid
Temperature deg C. . . . . . .      -183.026
Pressure bars. . . . . . . . .       1.59905
Enthalpy MJ/hr    . . . . . .        96.4537
Entropy MJ/hr*K  . . . . . . .      -1.05378
Ave. mol. wt.  . . . . . . . .       31.8848
Total flow  kg/hr. . . . . . .       411.951
```

```
         kgmol/hr . . . . . .       12.9200
Density kg/m3  . . . . . . .        1737.06
Viscosity centipoise . . . .        .190574
Thermal cond. cal/cm*s*K . .        .522892E-03
Specific heat   kJ/kg*K   . .       1.61370
Surface tension dyne/cm. . .        12.9483
S. G. (60/60)  . . . . . . .        .985194
m3/hr (15.6 deg C & 1 atm) .        .418798
Vol. flowrate m3/hr  . . . .        .237156
                       Liquid       Liquid
                        mole       flowrate
                      fraction     kgmol/hr
Nitrogen          .286528E-01      .370194
Oxygen            .971347          12.5498
 CODE REPORT

*** Stream no. 13 ***
                                   All Vapor
Temperature deg C. . . . . .        -182.231
Pressure bars. . . . . . . .         1.40055
Enthalpy MJ/hr   . . . . . .         789.524
Entropy MJ/hr*K  . . . . . .        -.506673
Ave. mol. wt.  . . . . . . .         28.0411
Total flow  kg/hr. . . . . .         1545.01
         kgmol/hr . . . . . .        55.0980
Density kg/m3  . . . . . . .         5.40057
Viscosity centipoise . . . .         .612507E-02
Thermal cond. cal/cm*s*K . .         .350412E-04
Specific heat   kJ/kg*K   . .        1.11367
Z factor . . . . . . . . . .         .961997
m3/hr (15.6 deg C & 1 atm) .         1305.28
Vol. flowrate m3/hr  . . . .         286.086
                       Vapor        Vapor
                        mole       flowrate
                      fraction     kgmol/hr
Nitrogen          .992954          54.7098
Oxygen            .704622E-02      .388233

*** Stream no. 14 ***
                                   All Liquid
Temperature deg C. . . . . .        -183.026
Pressure bars. . . . . . . .         190.000
Enthalpy MJ/hr   . . . . . .         100.402
Entropy MJ/hr*K  . . . . . .        -1.07603
Ave. mol. wt.  . . . . . . .         31.8848
Total flow  kg/hr. . . . . .         411.951
         kgmol/hr . . . . . .        12.9200
Density kg/m3  . . . . . . .         1851.52
Viscosity centipoise . . . .         .190574
Thermal cond. cal/cm*s*K . .         .522892E-03
Specific heat   kJ/kg*K   . .        1.53708
Surface tension dyne/cm. . .         12.9240
S. G. (60/60)  . . . . . . .         .985194
m3/hr (15.6 deg C & 1 atm) .         .418798
Vol. flowrate m3/hr  . . . .         .222496
                       Liquid       Liquid
                        mole       flowrate
                      fraction     kgmol/hr
Nitrogen          .286528E-01      .370194
Oxygen            .971347          12.5498
```

```
CODE REPORT

*** Stream no. 15 ***
                                      All Vapor
Temperature deg C. . . . . . .        -175.150
Pressure bars. . . . . . . . .         1.40055
Enthalpy MJ/hr   . . . . . . .         801.656
Entropy MJ/hr*K  . . . . . . .        -.378173
Ave. mol. wt.  . . . . . . . .         28.0411
Total flow  kg/hr. . . . . . .         1545.01
         kgmol/hr . . . . . . .        55.0980
Density kg/m3  . . . . . . . .         4.97529
Viscosity centipoise . . . . .         .660203E-02
Thermal cond. cal/cm*s*K . . .         .358103E-04
Specific heat   kJ/kg*K  . . .         1.10436
Z factor . . . . . . . . . . .         .968776
m3/hr (15.6 deg C & 1 atm) . .         1305.28
Vol. flowrate m3/hr  . . . . .         310.541
                       Vapor         Vapor
                        mole          flowrate
                       fraction       kgmol/hr
Nitrogen             .992954         54.7098
Oxygen               .704622E-02     .388233

*** Stream no. 16 ***
                                      All Vapor
Temperature deg C. . . . . . .        -175.000
Pressure bars. . . . . . . . .         1.40055
Enthalpy MJ/hr   . . . . . . .         801.912
Entropy MJ/hr*K  . . . . . . .        -.375563
Ave. mol. wt.  . . . . . . . .         28.0411
Total flow  kg/hr. . . . . . .         1545.01
         kgmol/hr . . . . . . .        55.0980
Density kg/m3  . . . . . . . .         4.96705
Viscosity centipoise . . . . .         .661210E-02
Thermal cond. cal/cm*s*K . . .         .358268E-04
Specific heat   kJ/kg*K  . . .         1.10436
Z factor . . . . . . . . . . .         .968902
m3/hr (15.6 deg C & 1 atm) . .         1305.28
Vol. flowrate m3/hr  . . . . .         311.056
                       Vapor         Vapor
                        mole          flowrate
                       fraction       kgmol/hr
Nitrogen             .992954         54.7098
Oxygen               .704622E-02     .388233
 CODE REPORT

*** Stream no. 17 ***
                                      All Liquid
Temperature deg C. . . . . . .        -180.000
Pressure bars. . . . . . . . .         190.000
Enthalpy MJ/hr   . . . . . . .         102.323
Entropy MJ/hr*K  . . . . . . .        -1.05506
Ave. mol. wt.  . . . . . . . .         31.8848
Total flow  kg/hr. . . . . . .         411.951
         kgmol/hr . . . . . . .        12.9200
Density kg/m3  . . . . . . . .         1832.37
Viscosity centipoise . . . . .         .177473
Thermal cond. cal/cm*s*K . . .         .517995E-03
Specific heat   kJ/kg*K  . . .         1.54391
```

```
Surface tension dyne/cm. . .        12.1752
S. G. (60/60) . . . . . . . .       .985194
m3/hr (15.6 deg C & 1 atm) .        .418798
Vol. flowrate m3/hr  . . . .        .224821
                       Liquid        Liquid
                        mole        flowrate
                      fraction      kgmol/hr
Nitrogen            .286528E-01    .370194
Oxygen              .971347        12.5498
 CODE REPORT


 TOWR # 1          Data file: col17.OUT          Profile file: link.prf


Column Summary

      Temp    Pres                     Net Flow Rates                    Duties
Stg    C       bars                      kgmols/hr                        MJ/hr
                          Liquid        Vapor        Feed      Product
  1 -175.9     6.713 18.299                                     27.200     -277.55
  2 -174.8     6.713 18.440      34.299
  3 -174.6     6.714 18.315      34.440
  4 -174.4     6.715 18.184      34.315
  5 -174.1     6.716 18.051      34.184
  6 -173.9     6.717 17.916      34.051
  7 -173.7     6.718 17.784      33.916
  8 -173.5     6.719 17.644      33.784
  9 -173.2     6.720 17.551      33.644
 10 -173.0     6.721 17.443      33.551
 11 -172.9     6.722 17.345      33.443
 12 -172.7     6.723 17.261      33.346
 13 -172.5     6.724 17.197      33.261
 14 -172.4     6.725 17.132      33.197
 15 -172.3     6.726 20.023      33.132      27.218
 16 -172.3     6.727 20.017      20.023
 17 -172.3     6.728 20.018      20.017
 18 -172.3     6.729 20.011      20.018
 19 -172.2     6.731 19.996      20.011
 20 -172.2     6.732 19.979      19.996
 21 -172.2     6.733             19.979      40.800      24.000

 Stream #   1 fed to Stg  15 is  81.408 % Vapor
 Stream #   2 fed to Stg  21 is  83.229 % Vapor

 Stream #   3 is Liquid Distillate from Stg 1
 Stream #   4 is Liquid Bottoms from Stg  21

 Condenser duty is -277.550        MJ/hr
 Reboiler duty is   .000000        MJ/hr
 CODE REPORT


 TOWR # 1          Data file: col17.OUT          Profile file: link.prf
Tray Liquid Properties

                                  Standard       Actual      Actual                  Surface
       Mass flow       Avg        Vol. flow      Vol. flow   Density    Viscosity    tension
Stg     kg/hr        mol wt        m3/hr          m3/hr      kg/m3      centipoise   dyne/cm
```

```
  1         514.0  28.09             .58              .39   1329.83       .0947      4.74
  2         519.4  28.17             .59              .39   1324.15       .0934      4.62
  3         517.4  28.25             .58              .39   1330.76       .0941      4.69
  4         515.4  28.34             .58              .39   1337.70       .0949      4.78
  5         513.3  28.44             .58              .38   1344.85       .0957      4.87
  6         511.2  28.53             .57              .38   1352.06       .0966      4.95
  7         509.1  28.63             .57              .37   1359.18       .0974      5.04
  8         506.7  28.72             .56              .37   1366.03       .0983      5.13
  9         505.6  28.80             .56              .37   1372.47       .0991      5.21
 10         503.8  28.89             .56              .37   1378.42       .0998      5.29
 11         502.3  28.96             .55              .36   1383.77       .1005      5.36
 12         501.0  29.03             .55              .36   1388.50       .1011      5.42
 13         500.1  29.08             .55              .36   1392.60       .1016      5.47
 14         499.1  29.13             .55              .36   1396.11       .1020      5.52
 15         584.2  29.17             .64              .42   1399.05       .1024      5.56
 16         584.0  29.18             .64              .42   1399.15       .1024      5.56
 17         584.1  29.18             .64              .42   1399.33       .1025      5.56
 18         584.0  29.18             .64              .42   1399.65       .1025      5.57
 19         583.7  29.19             .64              .42   1400.20       .1026      5.57
 20         583.5  29.20             .64              .42   1401.05       .1027      5.58
 21         701.4  29.22             .77              .50   1402.45       .1029      5.60
Tray Vapor Properties

                            Standard     Actual            Actual
     Mass flow     Avg     Vol. flow    Vol. flow          density
Stg    kg/hr     mol wt      m3/hr        m3/hr        Z    kg/m3

  1      *** Total Condenser : No Vapor Outlet ***
  2        963.4  28.09         812.5         34.93  .8356  27.5835
  3        968.8  28.13         815.9         35.17  .8364  27.5503
  4        966.8  28.18         812.9         35.14  .8372  27.5146
  5        964.8  28.22         809.8         35.11  .8380  27.4772
  6        962.7  28.27         806.7         35.08  .8388  27.4394
  7        960.6  28.32         803.5         35.06  .8397  27.4016
  8        958.5  28.37         800.4         35.03  .8405  27.3653
  9        956.1  28.42         797.0         34.98  .8413  27.3308
 10        955.0  28.46         794.8         34.98  .8420  27.2991
 11        953.3  28.50         792.3         34.96  .8426  27.2702
 12        951.7  28.54         790.0         34.93  .8432  27.2451
 13        950.4  28.57         788.0         34.91  .8437  27.2240
 14        949.5  28.60         786.4         34.90  .8442  27.2059
 15        948.5  28.63         784.9         34.88  .8446  27.1917
 16        573.2  28.63         474.3         21.08  .8446  27.1946
 17        573.1  28.63         474.2         21.07  .8446  27.1973
 18        573.2  28.63         474.2         21.07  .8446  27.1993
 19        573.1  28.64         474.1         21.07  .8446  27.2003
 20        572.8  28.65         473.7         21.06  .8448  27.1986
 21        572.6  28.66         473.3         21.06  .8449  27.1935


CODE: Chemical Engineering Simulation System
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TOWR # 1         Data file: col17.TSZ          Profile file: link.prf

 Smith-Dresser-Ohlswager Shortcut Technique

  ***User Provided Input Data***
```

```
Tray spacing (in. or cm)            7.0000
Downcomer area (ft2 or m2)           .0151
Weir length (in. or cm)            24.0000
Weir height (in. or cm)             3.0000

                Liquid      Vapor        Liquid       Vapor       Flooding   Settling
      Diameter  Vol. flow   Vol. flow    density      density     velocity   height
Stg    meter     m3/min      m3/sec      kg/m3        kg/m3       m/sec       meter

  1   ***Condenser: No tray sizing***
  2     .3051       .01          .01 1324.1490    27.5839        .1672     .0361
  3     .3053       .01          .01 1330.7550    27.5507        .1681     .0361
  4     .3047       .01          .01 1337.6980    27.5150        .1687     .0361
  5     .3040       .01          .01 1344.8480    27.4776        .1696     .0361
  6     .3034       .01          .01 1352.0650    27.4397        .1704     .0362
  7     .3028       .01          .01 1359.1760    27.4020        .1711     .0362
  8     .3022       .01          .01 1366.0340    27.3657        .1718     .0362
  9     .3016       .01          .01 1372.4660    27.3312        .1724     .0362
 10     .3012       .01          .01 1378.4210    27.2995        .1731     .0362
 11     .3007       .01          .01 1383.7730    27.2706        .1736     .0363
 12     .3003       .01          .01 1388.5020    27.2455        .1741     .0363
 13     .3000       .01          .01 1392.6050    27.2244        .1745     .0363
 14     .2997       .01          .01 1396.1050    27.2063        .1749     .0363
 15     .3029       .01          .01 1399.0530    27.1921        .1701     .0359
 16     .2615       .01          .01 1399.1530    27.1950        .1517     .0359
 17     .2615       .01          .01 1399.3330    27.1977        .1517     .0359
 18     .2615       .01          .01 1399.6530    27.1997        .1517     .0359
 19     .2614       .01          .01 1400.1980    27.2007        .1517     .0359
 20     .2613       .01          .01 1401.0550    27.1990        .1518     .0359
 21     .2661       .01          .01 1402.4480    27.1939        .1444     .0354
 CODE REPORT


 TOWR # 2          Data file: col17.OUT            Profile file: pool.prf


Column Summary

     Temp    Pres                      Net Flow Rates                        Duties
Stg   C      bars                         kgmols/hr                           MJ/hr
                       Liquid         Vapor        Feed      Product
  1 -192.6     1.401 14.924                       27.200     55.098
  2 -192.6     1.404 14.920      31.324
  3 -192.6     1.408 14.915      31.320
  4 -192.5     1.411 14.907      31.315
  5 -192.5     1.415 14.896      31.307
  6 -192.5     1.418 14.881      31.296
  7 -192.4     1.422 14.861      31.281
  8 -192.3     1.425 14.832      31.261
  9 -192.2     1.429 14.794      31.232
 10 -192.1     1.432 14.742      31.194
 11 -192.0     1.436 14.674      31.142
 12 -191.8     1.440 14.587      31.074
 13 -191.6     1.443 14.478      30.987
 14 -191.3     1.447 14.348      30.878
 15 -191.0     1.450 14.199      30.748
 16 -190.6     1.454 14.037      30.598
 17 -190.2     1.457 34.458      30.437      40.818
 18 -190.2     1.461 34.463      26.858
 19 -190.2     1.464 34.468      26.863
```

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 20 -190.2      1.468 34.473       26.868
 21 -190.2      1.471 34.478       26.873
 22 -190.1      1.475 34.483       26.878
 23 -190.1      1.479 34.488       26.883
 24 -190.1      1.482 34.493       26.888
 25 -190.1      1.486 34.498       26.893
 26 -190.0      1.489 34.503       26.898
 27 -190.0      1.493 34.508       26.903
 28 -190.0      1.496 34.513       26.908
 29 -190.0      1.500 34.518       26.913
 30 -189.9      1.503 34.523       26.918
 31 -189.9      1.507 34.528       26.923
 32 -189.9      1.510 34.533       26.928
 33 -189.9      1.514 34.538       26.933
 34 -189.8      1.518 34.542       26.938
 35 -189.8      1.521 34.547       26.943
 36 -189.8      1.525 34.552       26.947
 37 -189.8      1.528 34.557       26.952
 38 -189.8      1.532 34.562       26.957
 39 -189.7      1.535 34.567       26.962
 40 -189.7      1.539 34.572       26.967
 41 -189.7      1.542 34.577       26.972
 42 -189.7      1.546 34.582       26.977
 43 -189.6      1.549 34.587       26.982
 44 -189.6      1.553 34.591       26.987
 45 -189.6      1.557 34.595       26.991
 46 -189.6      1.560 34.600       26.995
 47 -189.5      1.564 34.602       27.000
CODE REPORT
                      Liquid       Vapor         Feed        Product

 48 -189.5      1.567 34.601       27.002
 49 -189.5      1.571 34.590       27.001
 50 -189.4      1.574 34.554       26.990
 51 -189.3      1.578 34.451       26.954
 52 -189.0      1.581 34.183       26.851
 53 -188.3      1.585 33.566       26.583
 54 -186.7      1.588 32.488       25.966
 55 -184.1      1.592 31.381       24.888
 56 -181.3      1.596 30.829       23.781
 57 -179.5      1.599              23.229                     7.6000      260.55

Stream #   7 fed to Stg   1 is   6.690 % Vapor
Stream #   9 fed to Stg  17 is  14.900 % Vapor

Stream #  10 is Vapor Distillate from Stg 1
Stream #  11 is Liquid Bottoms from Stg  57

Condenser duty is  .000000       MJ/hr
Reboiler duty is   260.549       MJ/hr
CODE REPORT


 TOWR # 2        Data file: col17.OUT         Profile file: pool.prf
Tray Liquid Properties

                                Standard      Actual     Actual                 Surface
       Mass flow     Avg        Vol. flow     Vol. flow  Density    Viscosity   tension
Stg     kg/hr      mol wt        m3/hr         m3/hr     kg/m3      centipoise  dyne/cm
```

```
  1       419.3  28.09          .48          .28   1504.01     .1477     8.32
  2       419.2  28.10          .47          .28   1504.12     .1477     8.32
  3       419.2  28.11          .47          .28   1504.37     .1476     8.32
  4       419.1  28.11          .47          .28   1504.79     .1476     8.33
  5       419.0  28.12          .47          .28   1505.45     .1477     8.34
  6       418.8  28.14          .47          .28   1506.43     .1477     8.36
  7       418.5  28.16          .47          .28   1507.85     .1479     8.38
  8       418.1  28.19          .47          .28   1509.87     .1482     8.42
  9       417.6  28.23          .47          .28   1512.67     .1485     8.47
 10       417.0  28.28          .47          .27   1516.47     .1491     8.53
 11       416.1  28.35          .47          .27   1521.52     .1499     8.63
 12       414.9  28.45          .47          .27   1528.09     .1509     8.75
 13       413.5  28.56          .46          .27   1536.33     .1522     8.90
 14       411.8  28.70          .46          .27   1546.30     .1539     9.08
 15       409.8  28.86          .45          .26   1557.78     .1558     9.30
 16       407.7  29.04          .45          .26   1570.25     .1580     9.54
 17      1007.2  29.23         1.10          .64   1582.90     .1602     9.78
 18      1007.3  29.23         1.10          .64   1582.70     .1601     9.78
 19      1007.5  29.23         1.10          .64   1582.51     .1600     9.77
 20      1007.6  29.23         1.10          .64   1582.31     .1598     9.77
 21      1007.8  29.23         1.10          .64   1582.10     .1597     9.76
 22      1007.9  29.23         1.10          .64   1581.91     .1596     9.76
 23      1008.1  29.23         1.10          .64   1581.71     .1595     9.75
 24      1008.2  29.23         1.10          .64   1581.51     .1594     9.75
 25      1008.4  29.23         1.10          .64   1581.31     .1593     9.74
 26      1008.5  29.23         1.10          .64   1581.12     .1592     9.74
 27      1008.6  29.23         1.10          .64   1580.92     .1591     9.73
 28      1008.8  29.23         1.10          .64   1580.72     .1590     9.72
 29      1008.9  29.23         1.10          .64   1580.53     .1589     9.72
 30      1009.1  29.23         1.10          .64   1580.33     .1588     9.71
 31      1009.2  29.23         1.11          .64   1580.14     .1587     9.71
 32      1009.4  29.23         1.11          .64   1579.94     .1586     9.70
 33      1009.5  29.23         1.11          .64   1579.75     .1584     9.70
 34      1009.7  29.23         1.11          .64   1579.55     .1583     9.69
 35      1009.8  29.23         1.11          .64   1579.36     .1582     9.69
 36      1010.0  29.23         1.11          .64   1579.16     .1581     9.68
 37      1010.1  29.23         1.11          .64   1578.97     .1580     9.68
 38      1010.3  29.23         1.11          .64   1578.78     .1579     9.67
 39      1010.4  29.23         1.11          .64   1578.58     .1578     9.67
 40      1010.6  29.23         1.11          .64   1578.39     .1577     9.66
 41      1010.7  29.23         1.11          .64   1578.19     .1576     9.66
 42      1010.9  29.23         1.11          .64   1578.01     .1575     9.65
 43      1011.0  29.23         1.11          .64   1577.81     .1574     9.65
 44      1011.1  29.23         1.11          .64   1577.62     .1573     9.64
 45      1011.3  29.23         1.11          .64   1577.44     .1572     9.63
 46      1011.4  29.23         1.11          .64   1577.27     .1571     9.63
 47      1011.5  29.23         1.11          .64   1577.14     .1570     9.63
 48      1011.6  29.24         1.11          .64   1577.14     .1569     9.62
 49      1011.5  29.24         1.11          .64   1577.42     .1569     9.63
 CODE REPORT


 TOWR # 2        Data file: col17.OUT          Profile file: pool.prf
Tray Liquid Properties

                              Standard       Actual      Actual               Surface
      Mass flow     Avg       Vol. flow     Vol. flow    Density   Viscosity   tension
Stg    kg/hr       mol wt       m3/hr         m3/hr       kg/m3    centipoise  dyne/cm

 50      1011.1  29.26         1.11          .64   1578.52     .1571     9.65
```

```
 51       1009.8  29.31            1.10          .64   1581.72        .1576     9.71
 52       1006.4  29.44            1.10          .63   1590.22        .1591     9.87
 53        998.6  29.75            1.08          .62   1610.15        .1627    10.26
 54        986.0  30.35            1.05          .60   1646.29        .1692    10.98
 55        976.1  31.10            1.01          .58   1684.65        .1753    11.72
 56        975.4  31.64            1.00          .57   1703.76        .1764    12.04
 57        242.3  31.88             .25          .14   1708.77        .1755    12.08
 CODE REPORT


 TOWR # 2        Data file: col17.OUT          Profile file: pool.prf
Tray Vapor Properties

                             Standard    Actual              Actual
     Mass flow     Avg      Vol. flow   Vol. flow           density
Stg    kg/hr     mol wt       m3/hr       m3/hr       Z     kg/m3

  1      908.5   28.04        767.6      146.77  .9479    6.1900
  2      878.4   28.04        742.1      141.58  .9478    6.2042
  3      878.3   28.04        742.0      141.25  .9477    6.2183
  4      878.3   28.05        741.8      140.92  .9476    6.2323
  5      878.2   28.05        741.7      140.60  .9476    6.2461
  6      878.1   28.06        741.4      140.28  .9475    6.2595
  7      877.9   28.06        741.1      139.95  .9474    6.2726
  8      877.6   28.07        740.6      139.63  .9474    6.2850
  9      877.2   28.09        739.9      139.31  .9474    6.2969
 10      876.7   28.11        739.0      139.00  .9475    6.3077
 11      876.1   28.13        737.8      138.68  .9475    6.3174
 12      875.2   28.16        736.2      138.36  .9477    6.3256
 13      874.0   28.21        734.1      138.03  .9479    6.3322
 14      872.6   28.26        731.5      137.70  .9481    6.3369
 15      870.9   28.32        728.4      137.36  .9484    6.3399
 16      868.9   28.40        724.9      137.02  .9488    6.3416
 17      866.8   28.48        721.1      136.66  .9492    6.3427
 18      764.9   28.48        636.3      120.32  .9491    6.3569
 19      765.0   28.48        636.4      120.07  .9490    6.3712
 20      765.2   28.48        636.5      119.83  .9489    6.3855
 21      765.3   28.48        636.6      119.58  .9488    6.3997
 22      765.5   28.48        636.7      119.34  .9488    6.4141
 23      765.6   28.48        636.9      119.10  .9487    6.4283
 24      765.8   28.48        637.0      118.86  .9486    6.4426
 25      765.9   28.48        637.1      118.62  .9485    6.4568
 26      766.1   28.48        637.2      118.38  .9484    6.4712
 27      766.2   28.48        637.3      118.14  .9483    6.4854
 28      766.4   28.48        637.5      117.91  .9482    6.4997
 29      766.5   28.48        637.6      117.67  .9481    6.5139
 30      766.7   28.48        637.7      117.44  .9480    6.5282
 31      766.8   28.48        637.8      117.20  .9479    6.5425
 32      766.9   28.48        637.9      116.97  .9478    6.5568
 33      767.1   28.48        638.0      116.74  .9478    6.5710
 34      767.2   28.48        638.2      116.51  .9477    6.5853
 35      767.4   28.48        638.3      116.28  .9476    6.5995
 36      767.5   28.48        638.4      116.05  .9475    6.6138
 37      767.7   28.48        638.5      115.82  .9474    6.6280
 38      767.8   28.48        638.6      115.60  .9473    6.6423
 39      768.0   28.48        638.7      115.37  .9472    6.6565
 40      768.1   28.48        638.9      115.15  .9471    6.6707
 41      768.3   28.48        639.0      114.93  .9470    6.6850
 42      768.4   28.48        639.1      114.70  .9469    6.6992
 43      768.6   28.48        639.2      114.48  .9469    6.7135
```

```
 44         768.7  28.49          639.3         114.26  .9468   6.7277
 45         768.9  28.49          639.4         114.04  .9467   6.7419
 46         769.0  28.49          639.5         113.82  .9466   6.7561
 47         769.1  28.49          639.6         113.60  .9465   6.7702
 48         769.2  28.49          639.7         113.38  .9464   6.7843
 49         769.3  28.49          639.7         113.16  .9463   6.7980
 CODE REPORT


 TOWR # 2         Data file: col17.OUT            Profile file: pool.prf
Tray Vapor Properties

                                 Standard      Actual                Actual
     Mass flow      Avg          Vol. flow    Vol. flow              density
Stg    kg/hr      mol wt          m3/hr        m3/hr          Z      kg/m3

 50        769.2  28.50          639.4        112.94  .9463    6.8108
 51        768.8  28.52          638.5        112.71  .9464    6.8211
 52        767.5  28.58          636.1        112.46  .9467    6.8253
 53        764.1  28.74          629.8        112.12  .9475    6.8152
 54        756.3  29.13          615.1        111.51  .9494    6.7821
 55        743.7  29.88          589.6        110.28  .9524    6.7434
 56        733.8  30.85          563.4        108.76  .9549    6.7469
 57        733.1  31.56          550.3        108.13  .9562    6.7792


CODE: Chemical Engineering Simulation System
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TOWR # 2         Data file: col17.TSZ            Profile file: pool.prf

 Smith-Dresser-Ohlswager Shortcut Technique

  ***User Provided Input Data***

  Tray spacing (in. or cm)          7.0000
  Downcomer area (ft2 or m2)         .0236
  Weir length (in. or cm)          30.0000
  Weir height (in. or cm)           3.0000

                    Liquid      Vapor         Liquid       Vapor      Flooding    Settling
       Diameter   Vol. flow   Vol. flow       density      density    velocity    height
Stg     meter      m3/min      m3/sec          kg/m3        kg/m3      m/sec       meter

  1     .3980         .00         .04 1504.0130      6.1901        .4043      .0373
  2     .3922         .00         .04 1504.1240      6.2043        .4046      .0373
  3     .3920         .00         .04 1504.3670      6.2184        .4042      .0373
  4     .3918         .00         .04 1504.7920      6.2324        .4038      .0373
  5     .3915         .00         .04 1505.4480      6.2462        .4035      .0373
  6     .3913         .00         .04 1506.4320      6.2596        .4032      .0373
  7     .3910         .00         .04 1507.8550      6.2727        .4029      .0373
  8     .3907         .00         .04 1509.8700      6.2851        .4028      .0373
  9     .3904         .00         .04 1512.6680      6.2970        .4028      .0373
 10     .3899         .00         .04 1516.4700      6.3078        .4029      .0373
 11     .3894         .00         .04 1521.5240      6.3175        .4033      .0373
 12     .3889         .00         .04 1528.0850      6.3257        .4038      .0373
 13     .3882         .00         .04 1536.3290      6.3323        .4046      .0374
 14     .3874         .00         .04 1546.3010      6.3370        .4057      .0374
 15     .3865         .00         .04 1557.7830      6.3400        .4070      .0374
```

```
 16      .3856          .00          .04 1570.2490       6.3417          .4085     .0374
 17      .3935          .01          .04 1582.9050       6.3428          .3874     .0353
 18      .3775          .01          .03 1582.7020       6.3570          .3785     .0353
 19      .3774          .01          .03 1582.5090       6.3713          .3780     .0353
 20      .3773          .01          .03 1582.3070       6.3856          .3775     .0353
 21      .3772          .01          .03 1582.1040       6.3998          .3769     .0353
 22      .3771          .01          .03 1581.9110       6.4142          .3764     .0353
 23      .3770          .01          .03 1581.7080       6.4284          .3759     .0353
 24      .3769          .01          .03 1581.5140       6.4427          .3754     .0353
 25      .3768          .01          .03 1581.3110       6.4569          .3748     .0353
 26      .3767          .01          .03 1581.1170       6.4713          .3743     .0353
 27      .3766          .01          .03 1580.9240       6.4855          .3738     .0353
 28      .3765          .01          .03 1580.7200       6.4998          .3733     .0353
 CODE REPORT

 Smith-Dresser-Ohlswager Shortcut Technique

                  Liquid       Vapor          Liquid         Vapor      Flooding  Settling
        Diameter Vol. flow  Vol. flow        density        density     velocity  height
Stg      meter    m3/min     m3/sec           kg/m3          kg/m3       m/sec      meter

 29      .3764          .01          .03 1580.5260       6.5140          .3728     .0353
 30      .3763          .01          .03 1580.3320       6.5283          .3723     .0353
 31      .3762          .01          .03 1580.1380       6.5426          .3718     .0353
 32      .3761          .01          .03 1579.9430       6.5569          .3713     .0353
 33      .3760          .01          .03 1579.7490       6.5711          .3708     .0353
 34      .3760          .01          .03 1579.5550       6.5854          .3703     .0353
 35      .3759          .01          .03 1579.3600       6.5996          .3697     .0353
 36      .3758          .01          .03 1579.1650       6.6139          .3692     .0353
 37      .3757          .01          .03 1578.9700       6.6281          .3687     .0353
 38      .3756          .01          .03 1578.7750       6.6423          .3683     .0353
 39      .3755          .01          .03 1578.5810       6.6566          .3678     .0353
 40      .3754          .01          .03 1578.3860       6.6708          .3673     .0353
 41      .3753          .01          .03 1578.1910       6.6851          .3668     .0353
 42      .3752          .01          .03 1578.0060       6.6993          .3663     .0353
 43      .3751          .01          .03 1577.8130       6.7136          .3658     .0353
 44      .3751          .01          .03 1577.6220       6.7278          .3653     .0353
 45      .3750          .01          .03 1577.4390       6.7420          .3648     .0353
 46      .3749          .01          .03 1577.2740       6.7562          .3643     .0353
 47      .3748          .01          .03 1577.1440       6.7703          .3639     .0353
 48      .3747          .01          .03 1577.1360       6.7844          .3634     .0353
 49      .3746          .01          .03 1577.4200       6.7981          .3630     .0353
 50      .3744          .01          .03 1578.5160       6.8109          .3628     .0353
 51      .3740          .01          .03 1581.7190       6.8212          .3630     .0353
 52      .3732          .01          .03 1590.2160       6.8254          .3642     .0353
 53      .3714          .01          .03 1610.1480       6.8153          .3675     .0354
 54      .3682          .01          .03 1646.2870       6.7822          .3738     .0355
 55      .3643          .01          .03 1684.6500       6.7435          .3798     .0356
 56      .3618          .01          .03 1703.7580       6.7469          .3814     .0356
 57     ***Reboiler: No tray sizing***
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