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PERFORMANCE OF SOLAR COOLING SYSTEM USING COMPUTER SIMULATION

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To my parents ....

To all the people who are close to my heart .....

ACKNOWLEDGEMENT

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NOMENCLATURE

- COP : Coefficient of performance (dimensionless).
- COP_{sim} : Simulated coefficient of performance (dimensionless) .
- COP_{th} : Theoretical coefficient of performance (dimensionless).
- E_a : Actual electric power input.
- ϵ : Percentage deviation between a listed value and a computed one (dimensionless).
- E.V. : Expansion valve.
- FR : Flow ratio (dimensionless).
- h_6 : Enthalpy of the saturated liquid exit from the condenser (Kj/kg).
- h_8 : Enthalpy of the saturated vapour outlet from the evaporator (Kj/kg).
- h_4 : Enthalpy of saturated vapour outlet from the generator (Kj/kg).
- H_c : Cooling load (kw).

- H_s : Solar power input (kw).
- H_f : Fossil fuel input (kw).
- I : Solar energy ($\frac{wh}{m^2}$).
- m : mass flow rate of water through collector loop (g/s).
- M_{AB} : Mass flow rate of the solution from the absorber to the generator (kg/s) .
- M_{RF} : Mass flow rate of the solution recirculated around the absorber (kg/s).
- P.R.V. : Pressure reducing valve
- Q_e : Heat removed from the refrigerated space (kw).
- Q_g : Heat supplied to the generator (kw).
- $\dot{Q}_c$: Rate of heat rejection from the condenser (kw) .
- $\dot{Q}_e$: Rate of heat absorption in the evaporator (kw).
- $\dot{Q}_g$: Rate of heat addition in the generator (kw).
- REf : Reflux ratio (dimensionless).
- T_2 : Temperature of the water outlet from collectors ($^\circ C$) .
- T_1 : Temperature of the water inlet to collectors ($^\circ C$) .
- T_3 : Temperature of the water outlet from the concentrator ($^\circ C$).
- T_{11} : Temperature of water outlet from the generator ($^\circ C$).
- T_9 : Temperature of the solution outlet from generator ($^\circ C$).

- $T_{4'}$: The temperature of the solution outlet from the absorber (^{o}C) .
- T_5 : Temperature of of the refrigerant inlet to condenser ($^{\circ}C$).
- T_{12} : Temperature of cooling water inlet to condenser ($^{\circ}C$).
- T_6 : Temperature of the refrigerant out from the condenser ($^{\circ}C$).
- T_3 : Temperature of the refrigerant out from the evaporator ($^{\circ}C$).
- $T_{14'}$: Temperature of cooling water out from the absorber ($^{\circ}C$).
- $T_{13'}$: Temperature of cooling water inlet to the absorber ($^{\circ}C$).
- T_{10} : Temperature of the solution out from the pressure reducing valve ($^{\circ}C$) .
- T_a : Absorber temperature ($^{\circ}C$) .
- T_{am} : Ambient temperature ($^{\circ}C$)
- T_c : Condenser temperature ($^{\circ}C$) .
- T_e : Evaporator temperature ($^{\circ}C$).
- T_g : Generator temperature ($^{\circ}C$)
- T_s : Refrigerated space temperature ($^{\circ}C$).
- T_{s1} : Refrigerated space temperature at the first position ($^{\circ}C$).
- T_{s2} : Refrigerated space temperature at the second position ($^{\circ}C$).
- V : wind velocity (m/s) .
- W_c : Energy given to the compressor (kw).

- $\dot{w}_{4'}$: Mass flow rate of the solution out from the absorber (kg/s).
- $\dot{w}_9$: Mass flow rate of the strong solution out from the generator (kg/s).
- $\dot{w}_4$: Mass flow rate of the refrigerant out from the generator (kg/s).
- X : Concentration of lithium bromide in the solution of LiBr - H_2O (dimensionless).
- X_{10} : Concentration of the solution leaving the absorber (dimensionless) .
- X_9 : Concentration of the strong solution leaving the generator (dimensionless).
- $X_{4'}$: Concentration of the solution inlet to the generator (dimensionless) .

ABSTRACT

This thesis presents the results of an experimental and a computer simulation study of an absorption refrigeration cycle. The unit used in the experimental part consists of three flat plate collectors and a concentrator which was used in part of the research. The solution pair selected for this research is water-lithium bromide H_2O-LiBr for its simplicity and ease of handling. For the simulation part of the research a polynomial model with three independent variables was used to predict the temperatures of the various components of the unit, and masses and energy balances of each component of the unit. The results of the experimental research and those produced by the computer model are compared with each other. The simulation results are found to be very close to the experimental ones, as the average percentage deviation between the COP_e and COP_{sim} was 0.031. Also in this research the effects of the solar energy, the generator temperature, the evaporator temperature, the absorber temperature, the condenser temperature, and the mass flow rate of water in the collectors loop on the coefficients of performance are investigated. When the concentrator was made part of the experimental set- up an increase in the generator inlet temperature of an average of about 6 $^{\circ}C$ resulted which lead to about an increase of an average of 6.0% in the coefficient of performance. However, experimental results utilizing a concentrator shows a good achievement in COP, as the maximum COP recorded was 0.83.The performance curves obtained from the simulation programme shows the importance of the absorber, and the condenser temperatures for their ability to be controlled and for their direct effect on COP.

Chapter 1

INTRODUCTION

1.1 General

Refrigeration has become an important supporting technology in the life of people. It is necessary for the preservation of food and medicine, for creating and maintaining comfortable space for people to work in and to live in, and for industrial and surgical processes. Refrigeration is the process of removing heat from cold spaces and dumping it in hot space. Such a process does not occur naturally, otherwise the second law of thermodynamics is violated. It needs power to make it possible.

This power could be either mechanical or thermal. .Both of these forms of energy usually come from fossil fuels. These fuels are being depleted continuously and there is no known way of replenishing them at the rate they are being consumed. The energy resources of the world are limited and the demand for these resources is increasing continuously.

The world energy consumption is likely to double by the year 2020 and triple by the year 2060, [1]. The fossil fuel supply alone will not be adequate to meet the demand. The future supply of energy will rely more and more on nuclear fission and coal, [1]. But, even these resources will not be cheap and may not be available to poor countries. In addition, the burning of coal creates the problems of air pollution and acid rain.

The nuclear energy is having problems of safety. The other sources which do not have any of these problems are renewable energy sources, such as solar energy, wind energy and geothermal energy.Most of these renewable energy sources are available to rich and poor countries. For example most of the Arab countries enjoy some of the maximum solar radiation intensities in the world since most of them lie around the sunny belt of the earth. The total number of sunshine hours in these countries is about 3000 hours of sunshine and the average solar radiation intensity in these countries is about 500 $\frac{W}{m^2}$.[1]

The energy consumption in the Arab world as is the case in the rest of the world will increase with time, [2]. Under these conditions it is necessary that every possible source of energy must be developed to respond as quickly as possible to this growing demand.

Jordan is one of these poor countries which lack adequate conventional energy sources. The energy bill is becoming a heavy burden on the Jordanian economy to the extent that in 1982 oil imports exceeded 110 % of the exports of Jordan which is also equal to 13 % of the gross national product of the country, [3]. It is expected that in the year 2000 the energy bill may exceed 20 % of the GNP, [3]. The bright side for Jordan of this issue, however, is the abundance of solar energy over all of its territory. Jordan has an excellent annual mean solar radiation of 5.5 to 6.0 kwh per m^2 per day compared to that of Europe and most of north America which is about 3.5 kwh per m^2 per day, [3].

Activities in the utilization of renewable energy resources have been reviewed by Audi and Al-Sa'ad, [4]. These started early in the seventies and included solar collectors, desalination, solar heating of houses, and analysis of solar radiation in Jordan. The current research focuses on the use of solar energy in absorption cooling. It is an addition to the activities of the utilization of solar energy in Jordan.

The remainder of this chapter focuses on surveying the literature to indicate activities of this nature in the world, and an outline of theses.

1.2 Literature Review

1.2.1 Historical notes:

Although the vapor compression refrigeration cycle is more popular today, the first attempt of engineers at mechanical refrigeration considered the absorption refrigeration cycle. It was first patented in the USA in 1860 by the French engineer who had worked with absorption refrigeration since 1824. It is believed that the first use of this cycle was in the making of ice during the civil war in the USA.

Soon after that, however, the compression refrigeration cycle was developed and started to replace the absorption cycle since it is more compact and it has high coefficient of performance. But, the absorption cycle remained in demand for places with no electricity because the vapor compression cycle required electric power to drive its compressor.

Recently, the interest in refrigeration and air conditioning by the absorption cycle became great because of the high cost of conventional energy and in some cases because of the unavailability of such sources.

The original absorption refrigeration cycle used low level energy such as by burning kerosine to operate it. The recent interest in such cycles focuses on the use of solar energy in operating such cycle.

A review paper on solar air conditioning was written by Kaushik et. al, [12]. In this paper the authors promote the use of open cycle cooling systems against the traditional closed systems on the basis of studies done by others which show that the performance of the former is better than that of the latter, in addition to being less expensive and simpler in technology. Kaushik also studied both theoretically and experimentally the technical feasibility of these systems.

In a traditional closed cycle the system is bulky because of the separate use of the condenser used to condense the vapor of high temperature and pressure. On the other hand, the open cycle shown in Figure 1.1 has the following advantages;

1. In an open system the solar collector and the regenerator are one which makes the system more compact and efficient.
2. In such system the regeneration temperature is much lower for starting the evaporation and absorption processes. Thus less energy is needed to operate such a system, therefore, the coefficient of performance is better for such systems.
3. The strong solution of the cycle can be stored at atmospheric pressure while in the closed cycle large container are required for storing the solution.

1.2.6 Solar air conditioners

Solar houses and spaces had been constructed to demonstrate and develop the use of solar energy in the cooling of building.

In a solar house that has been tested, Ward et. al [13] describe the design and the construction of a solar heating and cooling project for a 140 m^2 house in Colorado, USA. They also include a cost analysis of the solar energy project under consideration The design calls for the use of $H_2O - LiBr$ absorption system powered by a flat plate collector with an area of 71.3 m^2, and a storage capacity of 1131 gallon. Such a system would provide two thirds of the house heating and cooling loads at a total installed cost of about 6000 US dollars in 1975.

Two other solar house projects in the United States of America were built in Florida. The first one is the cooling of a welcome station using $H_2O - LiBr$ system with hot water heating, [14]. It has a total floor area of about 300 m^2. The capacity of the chiller is 25 tons of refrigeration and the storage is 10000 gallon which were used to provide the thermal energy needed during the short cloudy periods. It was projected that the system would provide 88 percent of the cooling load of the station.

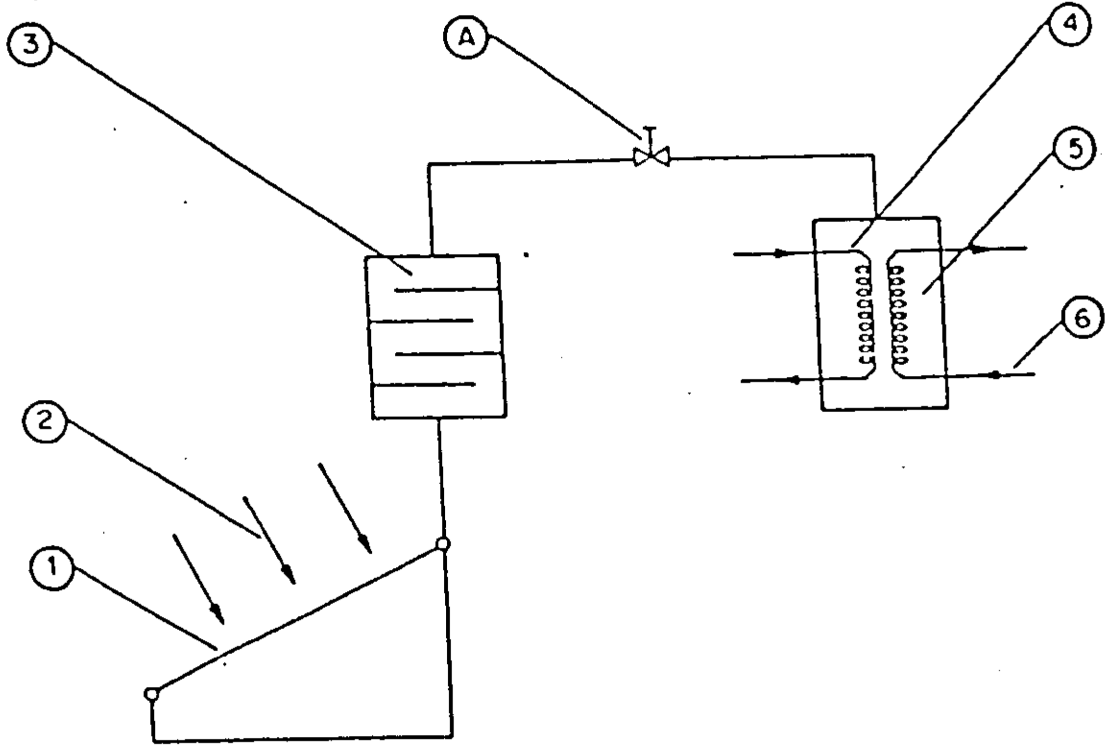
The other Florida solar house project is a large scale application undertaken by Parker et. al, [15]. They designed and built a solar cooling and hot water service supply system for an elementary school building of 6000 m^2, in Florida of the USA. The collector area for this project is 1730 m^2 and the storage capacity is 230 m^3. The project was designed to provide 70 % of the cooling load and 90 percent of the service water load. The expected COP of the system was 0.72.

In Australia an office building of 300 m^2 is cooled by solar.This project was undertaken by Langridge, [16], using $H_2O - LiBr$ working pairs. The outstanding features of this project is the use of concentrators fabricated of plastic. The capacity of the system is 10 tons of refrigeration supported by a collector area of 148 m^2. The performance was reported on the basis of 10 minutes readings. The thermal COP of the chiller was 0.5 and that of the system during three month period in summer had an average of 0.35. The description of a complete system comprised of heating, cooling, and domestic hot water supply of an office building in New Mexico was undertaken by Diamond et. al, [17]. The total floor area was 2370 square meters which used 626 square meters of flat-plate solar collectors. The storage volume consisted of two tanks of a total capacity of 30000 gallon. The total capacity of the machine of this project is 155 ton, but the chiller capacity is 50 tons. The project was built at the New Mexico State University.

More recent projects of cooling houses by solar energy are designed, built and tested in Saudi Arabia, [18], and Kuwait, [19]. The house in Kuwait was upgraded in 1985. Its floor area is 230 m^2. It has a cooling load of 5 tons of refrigeration, which required 91.2 m^2 flat plate collectors with a storage tank capacity of 7.5 m^3. The absorption system is of the $H_2O - LiBr$ type. The test results show an average COP of 0.5. The house built in Saudi Arabia is an extended laboratory with a floor area of 64 m^2. It has a cooling capacity of 3.5 tons and a collector area of 56 m^2 with a storage capacity of 12 m^3. The coefficient of performance of this system was 0.5 during a test period of six months.

1.2.7 Effect of components and parameters

The effect of the condenser and generator temperatures on the performance of an intermittent aqua-ammonia solar refrigerator was analytically investigated by El-Shaarawi et. al, [20, 21]. The intermittent cycle is shown in Figure 1.2. It is mainly designed to collect the intermittent solar energy when it is available and use it for refrigeration when it is not available such as at night. This cycle consists of two major parts: the generator - absorber - rectifier part and the condenser-evaporator part. The two major operations are regeneration and refrigeration. The first part consists of heating the refrigerant-absorbent solution to drive off the refrigerant, while in the second part the refrigerant is condensed and the refrigeration occurs when the liquid refrigerant vaporizes in the evaporator, thus producing the cooling effect.



1	Flat plate collector (generator - cum - absorber)
2	Solar radiation
3	Rectifier
4	Refrigerating load coil
5	Condenser - cum - evaporator
6	Condenser cooling water coil
A	"on - off" valve.

Fig. 1.2: Intermittent solar refrigerator.

The study focused on constant temperature operation. The results show that as the temperature of the condenser is decreased, or increasing the maximum generator temperature, this produces an increase in the effective cooling of the system by reducing the evaporator temperature. Also, for a specified generator temperature the COP of the cycle increases with a decrease in the condenser temperature. However, this relationship is not linear. For every generator temperature there is an optimum condenser temperature beyond which the COP decrease from that optimum at that pair of temperatures.

The major advantages of the intermittent system are its simplicity, its low cost, and its capability of operation at low temperatures.

Nevertheless, the generator and the condenser temperatures are not the only parameters which affect the performance of the refrigeration cycle. In an analytical study by Lazzarine et. al, [22], using $H_2O - LiBr$ pair, they state that not only the temperatures of the condenser, the generator, the evaporator and the absorber, but also cooling water temperature has a direct effect on the COP of the cycle.

For example, at a generator temperature of 80 $°C$ and an evaporator temperature of 4 $°C$ the COP of the cycle is 0.73 while this COP increase to 0.8 when the absorber temperature drops from 35 $°C$ to 30 $°C$. Also, for the effect of the evaporator it is seen than when the temperature of the evaporator drops from 6 $°C$ to 4 $°C$, the COP drops from 0.76 to 0.73 while the generator, absorber, and condenser temperatures were kept at 80 $°C$, 35 $°C$, and 35 $°C$, respectively.

As an illustration of the effect of the cooling water temperature of the condenser and the absorber it is noted that when such temperature is 30 $°C$ and the generator temperature is 91 $°C$ the COP was determined to be 0.70. The COP was also 0.70 when the cooling water temperature was 35 $°C$ and the generator temperature was 105 $°C$.[22]

Similar study focusing on the design of an absorption solar refrigeration system was performed by Ibrahim et. al, [23]. In this study the authors presented a detailed design procedure an performance analysis of an aqua-ammonia system. The results of their work show that the performance depends mainly on the start up conditions, namely, the generator, evaporator, and condenser temperatures. In their conclusion they state that the generator temperature is the major factor influencing the performance. However, the production of a high temperature for the generator cannot be achieved with flat plate collectors. Economic consideration limit the cost of the system to produce higher temperatures.

In another research Audi and Hammad, [24], conducted an experimental investigation on a low cost solar $H_2O-LiBr$ cooling system. The study includes the thermodynamic analysis of the system and the effect of generator temperature, the solar intensity, and the evaporator temperature on the COP of the system. In that research the start up temperature of the generator was 87 $°C$. The maximum hourly COP of this research was 0.75.

A similar research was conducted in Nigeria by Ajakaiye, [25]. In this research the details of the manufacturing of the components of the system using as much as possible materials available in Nigeria are described. The cycle is based on a $H_2O-LiBr$ working pair. The paper indicates that a maximum equilibrium temperature of 92 $°C$ was achieved .

Elsa et, al , [26], study experimentally the effect of absorber reflux on the performance of a water-lithium bromide absorption cooler.
The reflux ratio is defined by the following equation

$$REF = \frac{M_{RF}}{M_{AB}} \tag{1.2}$$

where REF is the reflux ratio, M_{RF} is the mass flow rate of solution recirculated around the absorber and M_{AB} is the mass flow rate of the solution from the absorber to the generator.
However, as the reflux ratio increases the temperature and the concentration of the solution entering the absorber decreases;the decrease in the solution temperature has a positive effect on the COP , whereas the decrease in concentration for the solution enter-

ing the absorber has a negative effect on the *COP*.The interaction of the concentration effect and the temperature effect gives the optimum value for the reflux ratio on the coefficient of performance.However the reflux ratio can be used to decrease both the temperature and the concentration in the generator of an absorption cooler.

1.2.8 Second law analysis

The survey thus far focused on first law analysis on the solar refrigeration systems. Some second law studies have been published. For example, Anand et, al [27], made a second law analysis of a solar powered absorption cooling systems, they identified four main causes of irreversibility in such systems. These are (1) heat transfer among the components and their surroundings through a finite temperature difference, (2) mixing of two fluids at different temperatures, (3) mixing of two fluids at different concentrations, and (4) unrestrained expansion during the throttling process.

For example, in case of single effect the irreversibilities are estimated to be 175.4 $\frac{Btu}{lbref}$ which yields a COP value of 0.83.However, second-order effect yields an additional irreversibilities of 125.0$\frac{Btu}{lbref.}$ which combine with single effect irreversibilities to reduce the value of COP from 0.83 to 0.719 .This is primary due to an increase in generator and absorber irreversibilities.

Another research dealing with system inefficiencies has been carried out by Bremner et, al, [28]. They state that due to high operating temperatures of absorption chillers , solar cooling systems have exhibited low efficiencies .The major reason for this low efficiencies is the heat losses from system loop piping . Another source of system inefficiencies is the thermal capacity of the pipe and fluid which requires a large amount of energy to increase the initial fluid temperatures to the system operating temperatures.These two system effects can total over 13 percent of the collected solar energy in a typical system.

1.2.9 The coefficient of performance

It should be noted that there are absorption refrigeration systems which are designed to use various energy inputs. In particular, solar energy, fossil fuel and electrical energy. Curran, [29], proposes a general expression for the definition of the coefficient of performance of refrigeration as follows.

$$COP = \left(\frac{H_c}{H_s + H_f + E_a}\right) \tag{1.3}$$

where H_c, H_S, H_f, E_a are the cooling load, the solar power input, the fossil fuel input, and the actual eclectic power input, respectively.

However, in this research no fossil fuel nor eclectic power heating were used. The total energy input is limited to solar energy in a continuous mode.

1.3 Objectives of the Research

This research focuses on the study of the a locally manufactured solar absorption cooling system using $H_2O - LiBr$ working pair. The study uses a computer simulation model in which the parameters of the model were determined. The solar source used as the only energy source for the generator of the system was real solar energy (no solar radiation simulator was used).

It is also conducted to determine the optimum operating conditions of the physical system under local climate.

As part of the objective it was planned to study the effect of adding a concentrator to the solar collection flat plates.

The thesis includes the description and the analysis of the system, the experimental set-up and procedures, and the results of the research and the discussion of these results with the main conclusions and recommendations.

Chapter 2

SYSTEM'S DESCRIPTION AND ANALYSIS

2.1 General

In this chapter of the thesis, the absorption refrigeration cycle is introduced and the application of solar energy to power this cycle is also described. Then, thermodynamic analysis of parts of the cycle is employed to define the experimental and theoretical coefficients of performance of the cycle.

This chapter also includes the mathematical and thermodynamic bases of the computer simulation program and a description of the simulation program which was developed and used in this research.

2.2 The Absorption Refrigeration Cycle

As mentioned in chapter 1, the absorption refrigeration cycle was conceived long time ago. It was also shown that a number of working fluid pairs have been tested and analyzed. However, in this section we will focus on the water-lithium bromide ($H_2O - LiBr$) pair which was used in this research.

Figure 2.1 is a schematic of the apparatus which is used to discuss the various processes. Thermal energy is supplied to the generator to help release the refrigerant, water, from the saturated solution of $H_2O - LiBr$. The concentrated (strong) solution is returned to the absorber.

Water vapor leaves the generator at relatively high pressure and high temperature. It passes through the condenser to release some of its thermal energy before it expands through an expansion valve which leads to the evaporator. The evaporator is in the refrigerated space. The refrigerant collects heat from that space and as a result it evaporates. In the absorber the concentrated solution of $H_2O - LiBr$ has great affinity for water, thus it absorbs the incoming vapor easily.

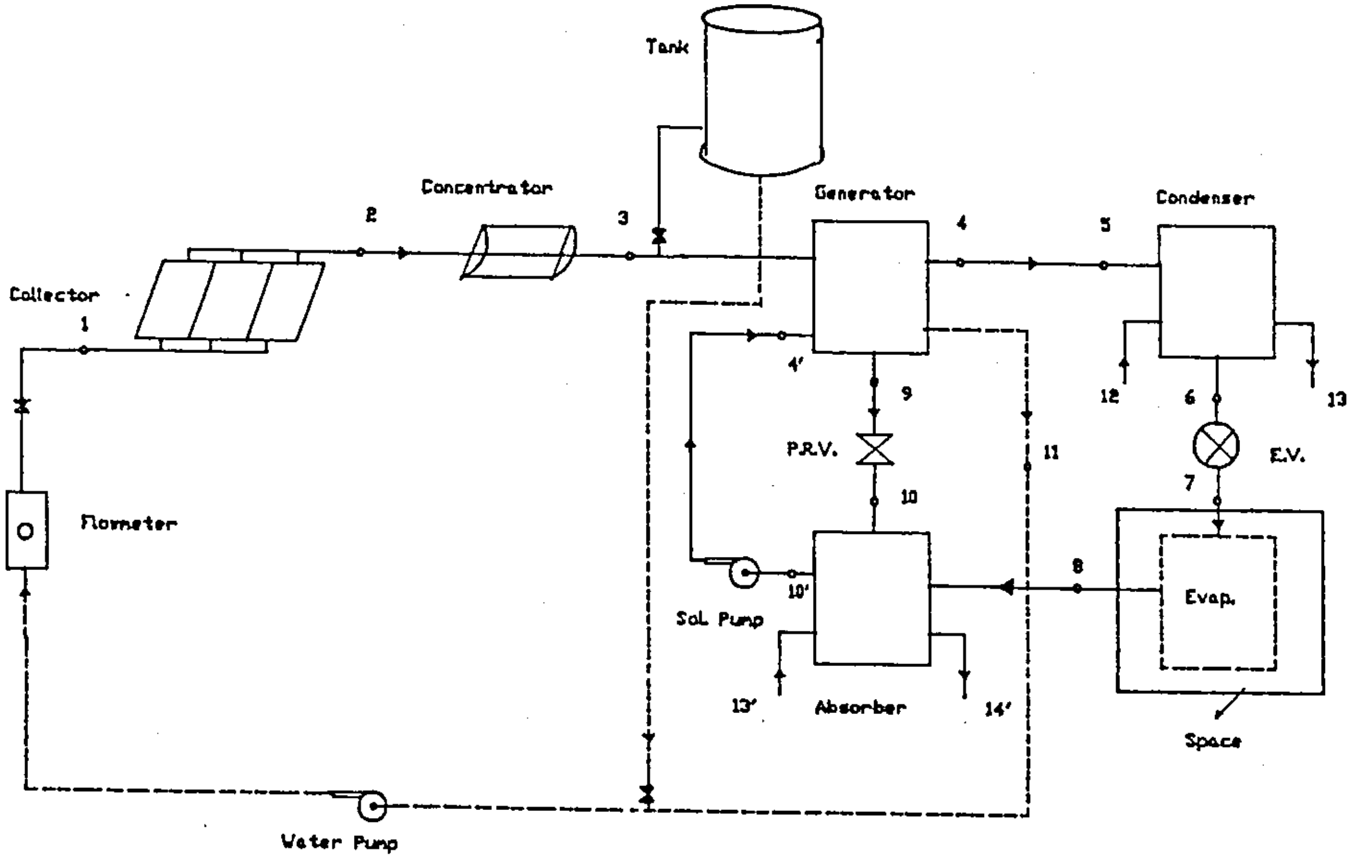


Figure 2.1 :Schematic diagram of the apparatus.

As soon as the solution becomes saturated it is pumped to the generator and the cycle is repeated.

In comparing this cycle with a classical vapor compression cycle, one can see that this cycle has two pressure ends as in the vapor pressure cycle. However, in the vapor compression cycle the compressor raises the pressure of the working fluid and the expansion valve reduces it, but in the absorption refrigeration cycle both the generator and the absorber do the work of the compressor.

As mentioned above, the external source of energy is supplied to the generator. However, heat is rejected in the condenser in an attempt to cool the working fluid as much as it is possible before it goes into the evaporator, and in the absorber because the process of water absorption by lithium bromide is an exothermal process.

It is seen also that there is energy spent in operating a pump to help circulate the solution pair from the absorber to the generator and back. However, this energy is too small compared with the major supply of energy in the thermal form to the generator.

The coefficient of performance of such a cycle is in the range from 0 .6 to about 0.8 ,[7].

This cycle has been modified in a number of ways to improve performance. An additional heat exchanger (some authors call it a solution heat exchanger) is used in the cycle to benefit from the heat in the solution returned from the generator to the absorber to preheat the saturated solution that enters the generator. Such an arrangement is shown in Figure 2.2. The same figure shows an accumulator that collects the liquid from the condenser and controlled release of this liquid is allowed to enter the expansion valve. This arrangement has two advantages: (a) it helps provide the needed cooling load, and (b) it prevents uncondensed vapor from entering the expansion valve.

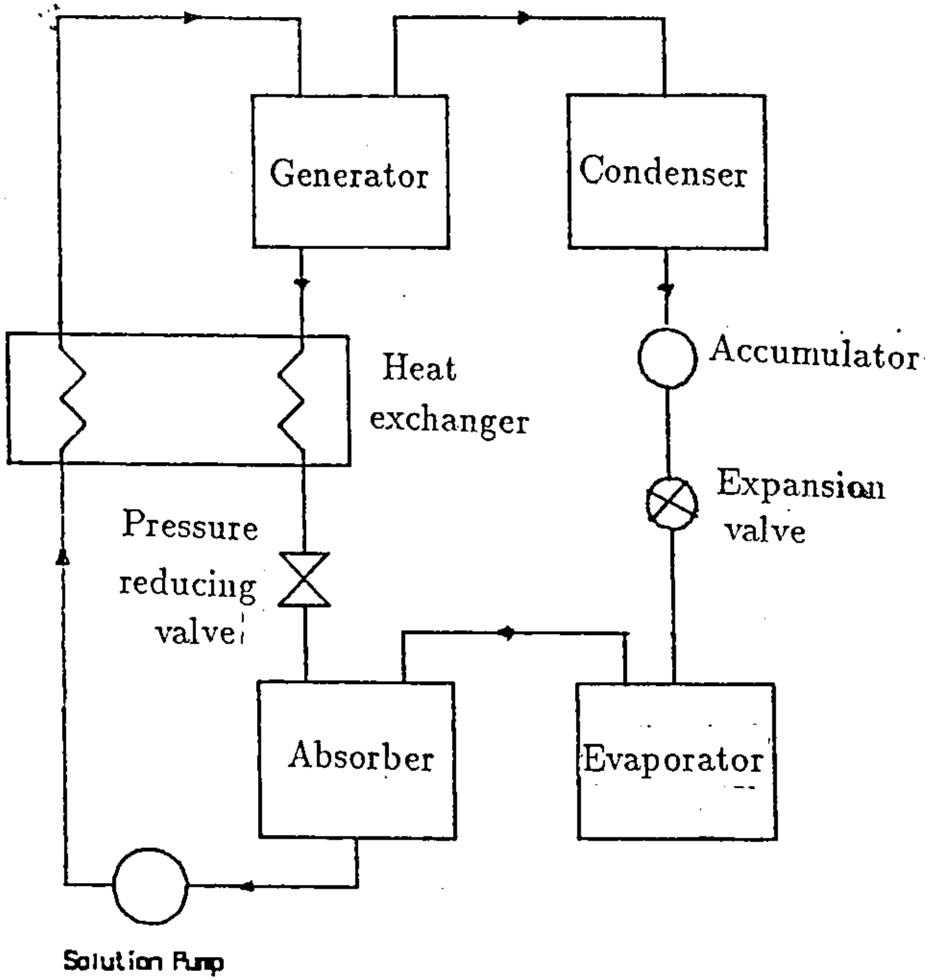


Figure (2.2) Absorption system with heat exchanger and accumulator

A major modification of the cycle is shown in Figure 2.3. This figure shows that two generators instead of one are used. The cycle is generally known as the double effect refrigeration absorption cycle since the traditional generator given a partially strong solution to a second generator. In this generator the vapor which is liberated in the first generator passes through it and rejects part of its heat before it goes to the condenser. The vapor is augmented by the vapor released in the second generator. The strong solution from the second generator goes to the absorber. This modification improvements increase the coefficient of performance to about double that of the single effect system ,[30].

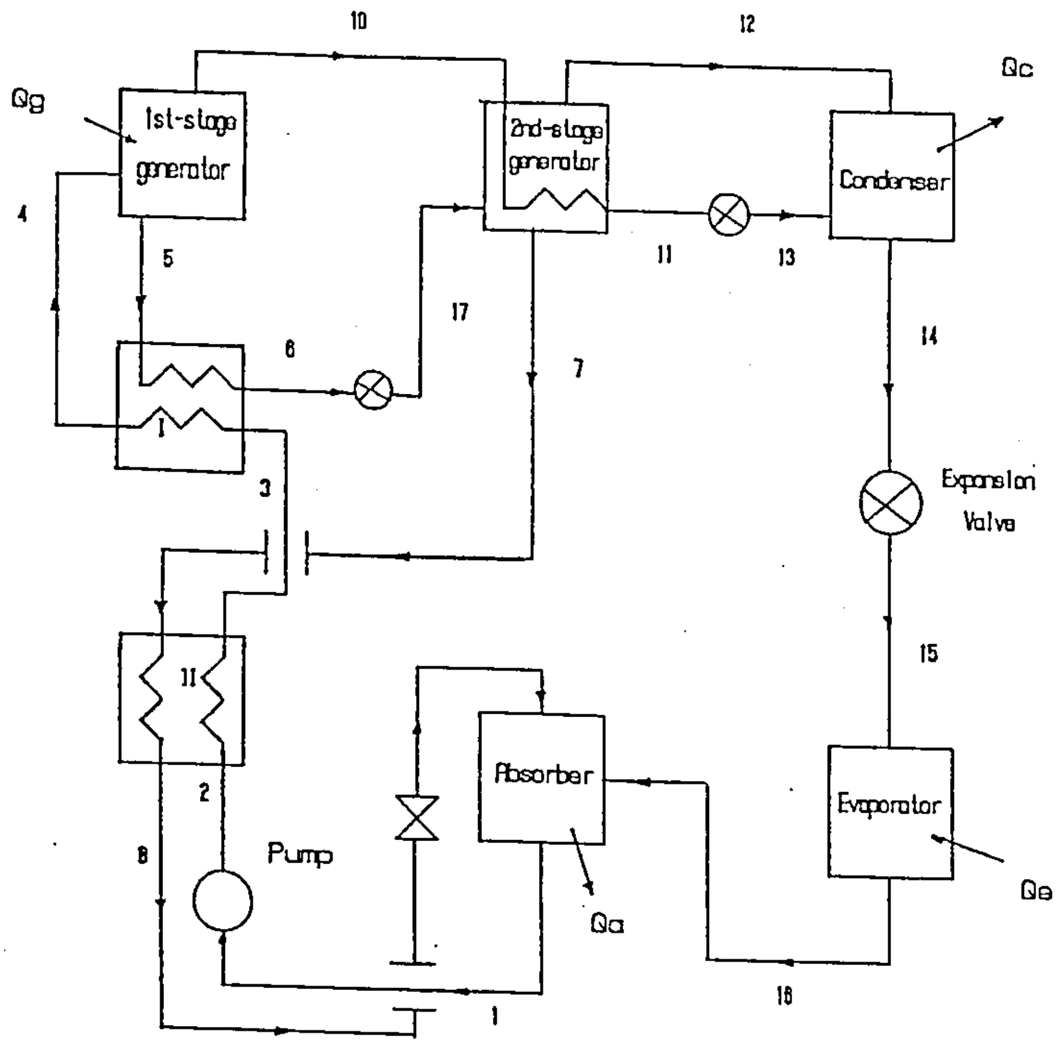


Figure 2.3 : Schematic diagram of a continuous double Effect solar absorption cooling system.

An improvement of the COP is an obvious advantage of this cycle regards the drop in COP as the temperature of the generator increases which is needed to make possible the double effect scheme. Another disadvantage is the capital cost of installing a second generator and its associated heat exchangers and other equipment.

Another major modification of the original cycle is the so called two stage vapor absorption refrigeration system, shown in Figure 2.4, [6]. The evaporator of the first stage is used to cool the absorber of the second stage, lowers the temperature in the evaporator, and thus improving the absorptivity of the solution, thus the COP is improved (as is shown in section 2.4 below.) However, this combination results in a lower overall coefficient of performance. But, the major advantages are lower temperature in the second evaporator, and possible elimination or reduction in size (and cost) of a cooling tower.

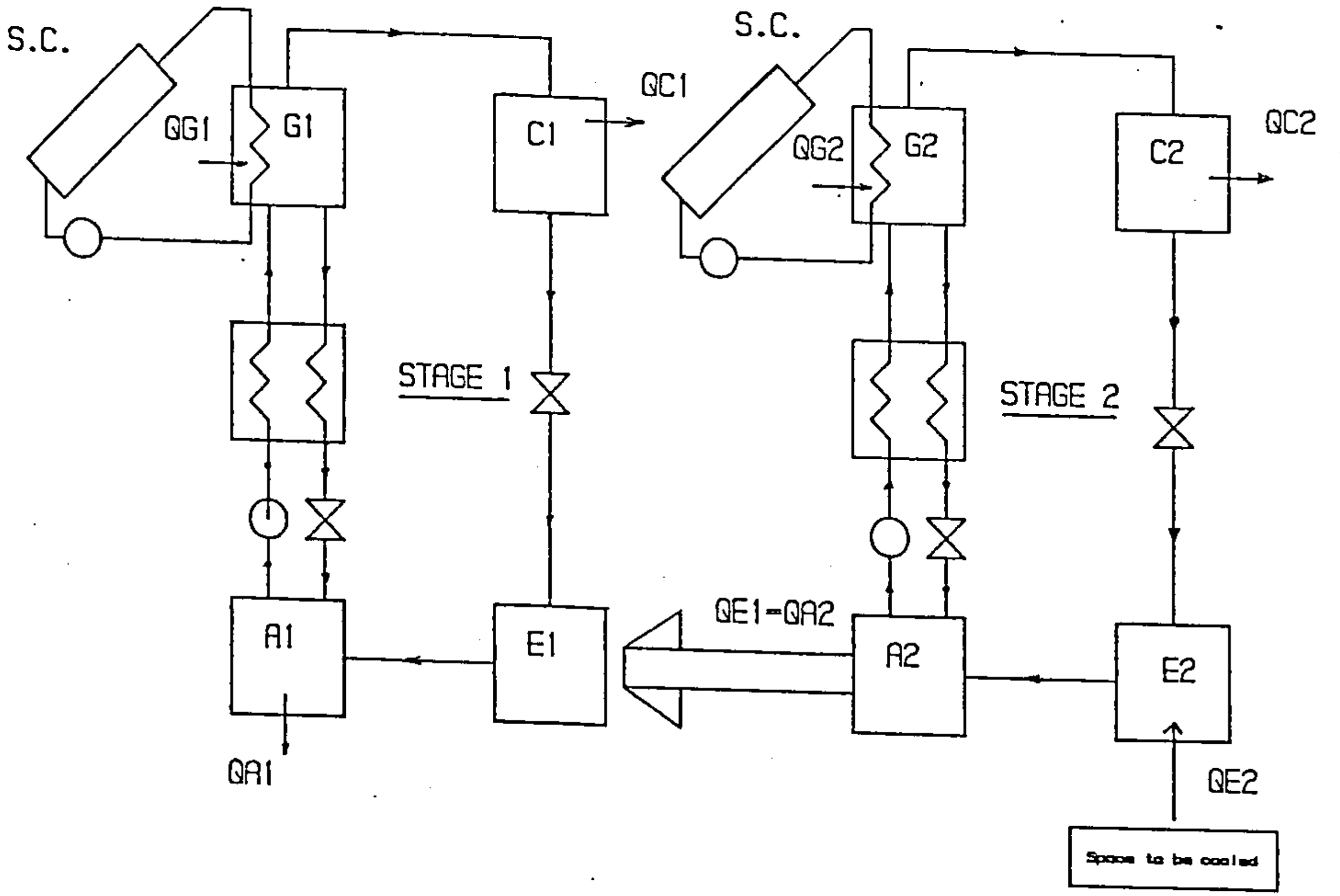


Figure 2.4 : Schematic diagram of two-stage absorption refrigeration and air conditioning cycle.

2.3 The Solar Powered Cycle

As noted above, the input energy in an absorption refrigeration cycle is a low level (about 90 °C) heat source. This qualifies it for operation using a solar source. In fact, most of current research in this area focuses on using solar energy for this purpose. Figure 2.5 shows a a schematic of $H_2O - LiBr$ cycle operated directly by solar energy. But, such a cycle is dependent on the available solar radiation which varies during the day time. A better arrangement is to have an intermediate storage of thermal energy. If this is the case, a steady cooling effect could be produced during longer hours of the day.

In a practical application of this cycle such as in cooling a house, Figure 2.6, a storage tank is provided to solve the transient problem of the solar system.

When a double effect solar operated system is used the arrangement is shown in Figure 2.3. It is shown that all solar energy is supplied to the first generator. The second generator receives heat from the condensing vapor only. However, the two stage cycle needs two solar collecting systems, as shown in Figure 2.4, because the stages are nearly independent of each other. The first stage helps to lower the temperature in the evaporator of the second stage. The two stages are independent as far as the working pairs are considered. This makes this approach applicable to different working pairs. One pair could be used in the first stage, but a different one is used in the second stage. This approach may be needed in order to optimize the utilization of solar energy.

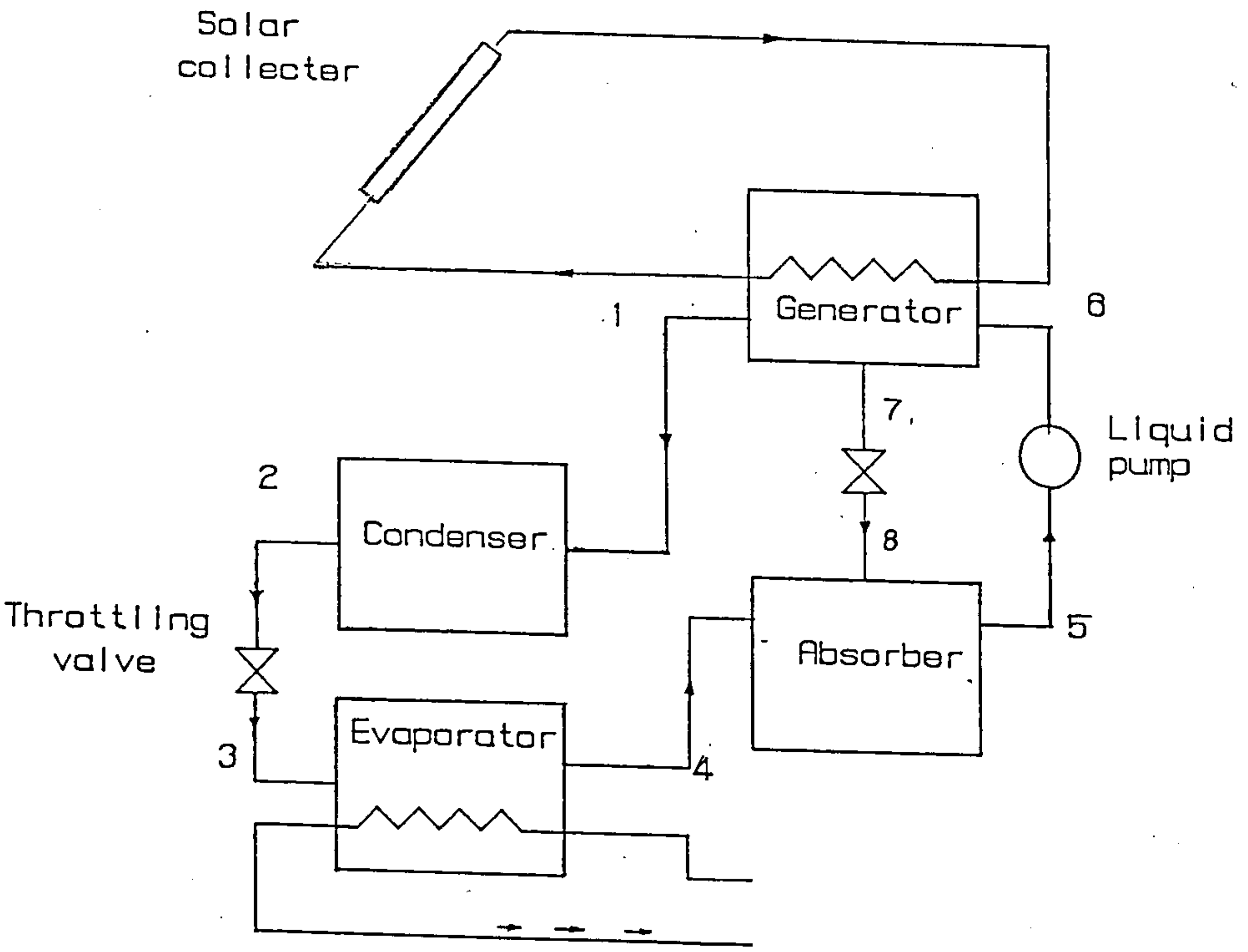


Figure 2.5 : Schematic diagram of a continuous solar absorption cooling system

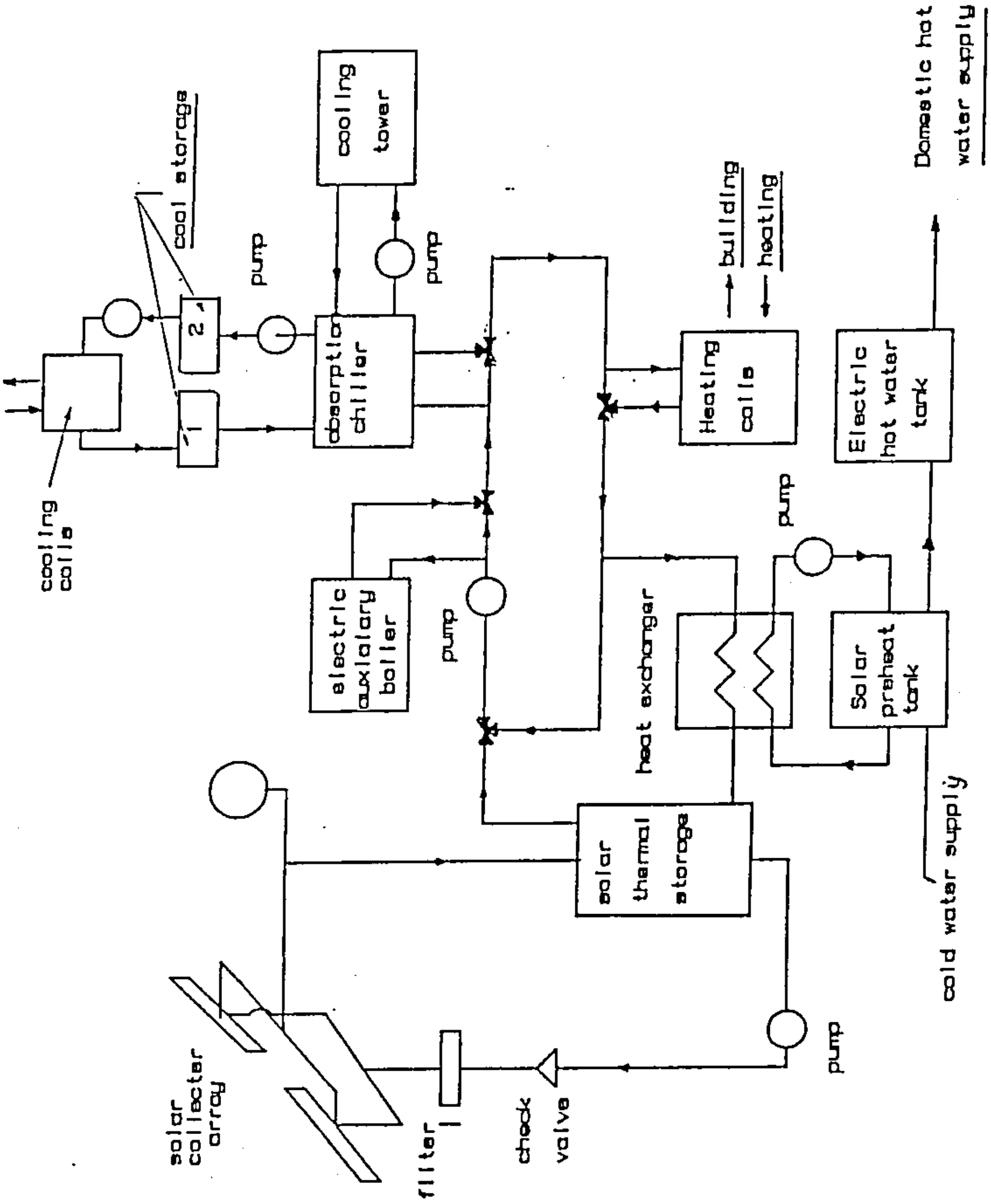


Figure 2.6 :Solar house system schematic.

$$COP = \frac{Q_e}{Q_g} \tag{2.2}$$

where Q_g is the heat supplied to the generator during the time of the removal of Q_e. Both, Q_e and Q_g were calculated using direct measurements of temperatures, mass flow rates, concentration and equilibrium diagrams.

The theoretical coefficient of performance, COP_{th}, was computed on the basis of a Carnot cycle efficiencies. Thus,

$$COP_{th} = \frac{T_e\,(T_g - T_a)}{T_g\,(T_c - T_e)} \tag{2.3}$$

where T_e, T_g, T_a, and T_c are the temperatures of the evaporator, generator, absorber, and condenser, respectively.

This relationship was used in computing COP_{th} of the cycle using the measured temperatures for all the runs.

The computer simulation program was based on constants computed from the experimental temperatures. Therefore, when the COP_{sim}s were computed very small errors were observed between experimental and simulated values.

2.5 Computer Simulation Model

The core of the computer simulation program is based of the following basis. (a) The temperatures of the components of the cycle were computed using a multi-variable polynomial of the second degree and experimental data to determine its coefficients, (b) the computation of the various enthalpies of the refrigerant and carrier were done by simulating the concentration charts by equations, and (c) the use of the energy (the First law of thermodynamics) and the mass balances of the components and the cycle as a whole. All of these are shown in the flow chart figure 2.1.

Furthermore, the analysis is based on the assumption of steady states conditions. This is a normal approximation as outline in reference [27].

2.5.1 The multi-variable polynomial

The computation of the temperature of the various components of the refrigeration cycle was computed by using the following multi-variable polynomial. This is based on similar work by [31].

$$
\begin{aligned}
f(x,y,z) = {} & a_0 + a_1\,x^2 + a_2\,x + a_3\,y^2 + a_4\,y \\
& + a_5\,z^2 + a_6\,z + a_7\,x\,y + a_8\,y\,z + a_9\,x\,z \\
& + a_{10}\,x\,y^2 + a_{11}\,x^2\,y + a_{12}\,y^2\,z + a_{13}\,z^2\,y + a_{14}\,x^2\,z \\
& + a15\,z^2\,x + a_{16}\,x\,y\,z + a_{17}\,x^2\,y\,z + a_{18}\,x\,y^2\,z + a_{19}\,x\,y\,z^2 \\
& + a_{20}\,x^2\,y^2\,z + a_{21}\,x^2\,y\,z^2 + a_{22}\,x\,y^2\,z^2 + a_{23}\,x^2\,y^2\,z^2 \\
& + a_{24}\,x^2\,y^2 + a_{25}\,y^2\,z^2 + a_{26}\,x^2\,z^2
\end{aligned}
\tag{2.4}
$$

where the f(x,y,z) stands for any desired temperature or concentration of the refrigerant in the carrier. The variables x, y, and z represent the measured temperatures. The coefficients a_0 to a_{26} were determined for each of the variables used, such as the generator temperature, the evaporator temperature, etc.

These and other coefficients for various simulation equations are given below.

2.5.2 The enthalpies

The first law (energy balance) application for each of the components of the system was used for the simulation program.

Consider the diagram Figure 2.1. States from 1 to 14 are marked on the diagram. For example, state 5 is the inlet to the condenser and state 6 is the outlet from the condenser. Starting arbitrarily from state 6, the enthalpy, h_6, is given by the following relationship, as suggested by Stoecker,[31].

$$h_6 = h_f(T_C) = A + B\,T_c + C\,T_c^2 \tag{2.5}$$

where A, B, and C are constants determined from the enthalpy tables of saturated water, h_f is the enthalpy of saturated water, in Kj/kg. The temperature of the condenser is T_c in $^\circ C$.

The range of temperature used to compute these constants is from 20 to 40 $^\circ C$. These constants are given as follows.

A=0.1534285

B=4.1956286

C=-0.000257

By using the above equation and the constants as computed above, the deviation between the listed values and the computed ones is given by the following equation

$$\epsilon = \frac{Listed\,value - Computed\,value}{Listed\,value} \tag{2.6}$$

Where ϵ is the deviation.

The maximumϵ using the above mentioned equation is equal to 0.0065695.

The enthalpy at the exit of the evaporator, h_8, is given by the following relation.

$$h_8 = h_v(T_e) = A + B\,T_e + C\,T_e^2 \tag{2.7}$$

where h_v is the enthalpy of saturated vapor at the evaporator temperature, T_e. The range of temperatures covered is from 10 to 20 $^\circ C$.

By using the above equation and the constants as computed above, the maximumϵ is equal to 0.0065695.

The values of the constant for this state are as follows.

A=2501.2114

B=1.8614286

C=-0.00071429

By using the above equation and the constants as computed above, the maximum value of ϵ is equal to 0.0171429.

$$h_4 = h_v(T_g) = A + B\,T_g + C\,T_g^2 \tag{2.8}$$

where h_v is the enthalpy of saturated vapor at the generator temperature, T_g. The range of temperature covered by this equation is from 65 to 85 °C.

A=2533.9966

B=0.97901595

C=0.00493525

By using the above equation and the constants as computed above, the maximum ϵ is equal to 0.036.

These enthalpies, namely, h_6, h_8, and h_4 are for pure water, they were produced using steam tables data. They are used in the computation of $\dot{Q}_g$, $\dot{Q}_c$, $\dot{Q}_e$, and $\dot{Q}_a$.

The enthalpies of the solution of the refrigerant and the carrier ($H_2O - LiBr$) at states 9, and 10 are obtained from the following correlation equation,[32].

$$h = \sum_{0}^{4} A_n X^n + t \sum_{0}^{4} B_n X^n + t^2 \sum_{0}^{4} C_n X^n \tag{2.9}$$

where the constants of this equation are as given as follows:

A_0=-2024.33 B_0=18.2829 C_0=-3.7008214 e-2
A_1=163.309 B_1=-1.1691757 C_1=2.8877666 e-3
A_2=-4.88161 B_2=3.248041e-2 C_2=-8.1313015e-5
A_3=6.302948e-2 B_3=-4.034184e-4 C_3=9.9116628e-7
A_4=-2.913705e-4 B_4=1.8520569e-6 C_4=-4.4441207e-9

2.5.3 The concentrations

The solution concentration, X,is defined as the ratio of the mass of lithium bromide to the mass of the solution of lithium bromide and water. The concentration at state '10 is a function of T_a and T_e which are determined by the multi-variable polynomial described above.

$$X_{10} = f(T_a, T_e) \tag{2.10}$$

The constants of the polynomial are given below.

a_0=116.0094

a_1=5.989273e-3

a_2=-5.64888

a_3=7.356093e-2

a_4=-4.52056

a_7=0.3013122

a_{10}=-3.962865

a_{10}=-3.962865

a_{11}=-1.902175e-3

a_{24}=6.375824e-6

The coefficients which are not listed above came out to be zeros.

The results obtained by using the above simulation equation incur a maximum ϵ of about 0.1 when compared with the values obtained from the ASHRAE concentration charts,[32].

The concentration at state 9, X_9, is given by the following relation.

$$X_9 = f(T_g, T_c). \tag{2.11}$$

The following constants of this simulation equation are obtained as above.

a_0=73.80188

a_1=1.626778e-2

a_2=-.4533701

a_3=-0.0628527

a_4=1.888133

a_7=-4.177556e-3

a_{10}=-1.556-189e-4

a_{11}=-1.014846e-3

a_{24}=2.386577e-5

The coefficients which are not listed came out to be zeroes.

The results obtained by using the above simulation equation incur a maximum ϵ of about 0.02 when compared with the values obtained from the ASHRAE concentration charts,[32].

2.5.4 The temperatures

Finally, the temperatures at the different stations shown in Figure 2.4 are given below as function of the other temperatures shown on the right hand sides of each of the relations. The constants for each of them are listed below it and the maximum deviation between the predicted and the measured values are also given.

The temperature T_3 is given as follows.

The constants which are not listed are came out to be zeroes.

The maximum ϵ as defined above is 0.02335521

$$T_{11} = f(T_3) \tag{2.14}$$

The coefficients of the simulation equation are as follows.

a_0=-7.11547

a_1= -5.913395e-3

a_2=1.515793

The coefficients which are not listed are came out to be zeroes.

The maximum ϵ as defined above 0.03869401

$$T_9 = f(T_{4'}) \tag{2.15}$$

The coefficients of the simulation equation are as follows.

a_0=-305.0764

a_1=-0.2514568

a_2=19.0156

The maximum ϵ as defined above is 0.024

$$T_g = T_4 = f(T_{11}, T_3, T_{4'}, T_a) \tag{2.16}$$

The coefficients are as given in the following list.

a_0=1.480396e-3
a_1=-9.155625e-2
a_2=25.53702
a_3=1.026961e-6
a_4=1.082603e-4
a_5=-4.197122e-7
a_6=-4.442692e-7
a_7=-1.36604
a_8=3.447401e-2
a_9=-3.309341e-5
a_{10}=2.285551e-2
a_{11}=0.3355862
a_{12}=5.231531e-9
a_{13}=2.941949e-8
a_{14}=-0.2166692
a_{15}=-7.863919e-7
a_{16}=1.814134e-2
a_{17}=1.13424e-3
a_{18}=-3.496564e-4
a_{19}=-9.796914e-5
a_{20}=-7.193353e-7
a_{21}=3.805049e-5
a_{22}=-1.125733e-6
a_{23}=-1.610625e-7
a_{24}=-5.644495e-3
a_{25}=-4.932626e-11
a_{26}=4.745068e-4

The maximum ϵ as defined above is 0.0943297.

$$T_b = f(T_4, V, T_{am}) \tag{2.17}$$

The coefficients of the simulation equation are as follows.

a_0=7.730901e-3
a_1=2.126066e-3
a_2=-0.2174519
a_3=-1.023291e-6
a_4=-6.861522e-5
a_5= 9.977443e-6
a_6=2.729824e-4
a_7=1.113278
a_8=9.920663e-4
a_9=8.00873e-6
a_{10}=-1.674268e-2
a_{11}=-7.790711e-3
a_{12}=-4.10151e-8
a_{13}=-5.681425e-8
a_{14}=-7.207324e-4
a_{15}=2.893643e-7
a_{16}=-1.653157e-2
a_{17}=-2.683336e-4
a_{18}=-9.403046e-4
a_{19}=9.597479e-5
a_{20}=5.948959e-7
a_{21}=7.067726e-6
a_{22}=-2.800056e-5
a_{23}=5.902527e-7
a_{24}=4.124185e-4
a_{25}=-1.331292e-9
a_{26}=1.491459e-5

The maximum ϵ as defined above is 0.02475498.

$$T_{13} = f(T_{12}) \tag{2.18}$$

The coefficients are as follows.

a_0=-87.16022

a_1=-0.2135133

a_2=9.793026

The coefficients which are not listed are came out to be zeroes.

The maximum ϵ as defined above is 0.01307686.

$$T_c = T_6 = f(T_{12}, T_{13}, T_b) \tag{2.19}$$

The coefficients are as follows.

a_0=-310.7623

a_1=26.6129

a_2=-46.66857

a_3=-9.282749e-2

a_4=11.29931

a_7=1.428847

a_{10}=-1.015186e-2

a_{11}=-0.7357491

a_{24}=4.528354e-3

The coefficient which are not listed are came out to be zeroes.

The maximum ϵ as defined above is 0.01425491.

$$T_e = T_8 = f(T_6, T_s) \tag{2.20}$$

The coefficients which are not listed are came out to be zeroes.

The maximum ϵ as defined above is 0.1806475

$$T_{14'} = f(T_{13'}) \tag{2.22}$$

The coefficients are as follows.

a_0=-19.28651

a_1=-6.097654e-2

a_2=3.330784

The coefficients which are not listed are came out to be zeroes.

The maximum ϵ as defined above is 0.109668

$$T_{10} = f(T_9) \tag{2.23}$$

The coefficients are as follows.

a_0=-305.0764

a_1=-0.2514568

a_2=19.0156

The coefficient which are not listed are came out to be zeroes.

The maximum ϵ is 0.09831

$$T_a = f(T_{13'}, T_{14'}, T_{10}, T_8) \tag{2.24}$$

The coefficients are as follows.

a_0=-8.944969e-4
a_1=-6.94931
a_2=9.940824
a_3=-9.674193e-7
a_4=-5.245602e-5
a_5=8.629876e-7
a_6=-2.868926e-5
a_7=1.457952
a_8=1.371843e-2
a_9=5.067452e-5
a_{10}=-1.367146e-2
a_{11}=4.616344e-2
a_{12}=-8.674862e-8
a_{13}=-2.482312e-7
a_{14}=0.6447095
a_{15}=4.816122e-6
a_{16}=0.1078114
a_{17}=1.184138e-2
a_{18}=2.721636e-4
a_{19}=3.626276e-3
a_{20}=4.258723e-4
a_{21}=-2.452765e-3
a_{22}=3.731384e-6
a_{23}=8.456794e-6
a_{24}=-5.016348e-3
a_{25}=-5.393894e-9
a_{26}=6.960897e-3

The maximum ϵ is 0.01280713.

2.5.5 Mass and energy balances

The equations for the mass (continuity), and energy balances (first law) based on the simulated and experimental results are computed by using the following equations. The subscripts refer to states shown on apparatus layout, Figure 2.1.

Total mass balance equation of the generator:

$$\dot{w}_4 + \dot{w}_9 = \dot{w}_{4'} \tag{2.25}$$

where $\dot{w}_{4'}$ is the mass flow rate of the solution from the absorber to the generator in Kg/s, $\dot{w}_9$ is the mass flow rate of the strong solution from the generator to the absorber in Kg/s, and $\dot{w}_4$ is the mass flow rate in Kg/s of the refrigerant from the generator to condenser.

The LiBr balance on the generator is as follows:

$$\dot{w}_{4'} X_{4'} = \dot{w}_9 X_9 \tag{2.26}$$

where $X_{4'}$ is the concentration of lithium bromide in the $H_2O - LiBr$ solution inlet to generator, and X_9 is the concentration of lithium bromide in the strong solution leaving the generator. The concentration of lithium bromide in the refrigerant leaving the generator is zero.

Energy balance on the generator:

The rate of heat addition in the generator $\dot{Q}_g$, which is the energy input to the cycle is given by the following equation.

$$\dot{Q}_g = \dot{w}_4 h_4 + \dot{w}_9 h_9 - \dot{w}_{4'} h_{4'} \tag{2.27}$$

where h_4 is the enthalpy in Kj/kg of the refrigerant leaving the generator, h_9 is the enthalpy in Kj/kg of the strong solution leaving the generator, and $h_{4'}$ is the enthalpy of the solution entering the generator in Kj/kg.

All of these enthalpies are computed using the above simulation equation for the simulation program.

The rate of heat rejection out of the condenser, $\dot{Q}_c$, is given by the following equation:

$$\dot{Q}_c = \dot{w}_4 (h_4 - h_6) \tag{2.28}$$

where h_6 is the enthalpy in Kj/kg of the refrigerant leaving the condenser, $\dot{w}_4$ and h_4 are defined after equations 2.5, 2.25 and 2.27.

The rate of heat absorption in the evaporator, $\dot{Q}_e$, is given by the following equation:

$$\dot{Q}_e = \dot{w}_4 \left(h_8 - h_6\right) \tag{2.29}$$

where h_8 is the enthalpy in Kj/kg of the refrigerant leaving the evaporator, h_6 and $\dot{w}_4$ are defined after equations 2.7, 2.5, and 2.27.

The rate of heat rejection by the absorber, $\dot{Q}_a$, has the following equation:

$$\dot{Q}_a = \dot{w}_9 \, h_9 + \dot{w}_4 \, h_8 - \dot{w}_{4'} \, h_{4'} \tag{2.30}$$

where all the terms of this equation are as defined before.

2.5.6 The coefficients of performance

Using the definition of the coefficient of performance, and the parameters which are defined above and computed by the simulation program, the coefficient of performance is computed using equation 2.2
However, the theoretical or Carnot coefficient of performance, COP_{th}, as defined above ,equation 2.3,is used in computing the experimental and the simulated COP_{th} ,[6, 27].

2.6 The Computer code

The simulation code is written in BASIC and it consists of three major subprograms: (a) the main section which accepts the input data for the computation of the coefficients and the error of all the simulation equation, (b) the section which calculates the simulation results on the basis of the computed variables, and (c) the section which calculates

The third section of the program computes(programme B.3) is shown in appendix B of the thesis. It accepts as input the temperatures, and computes the concentrations, the mass flow rates, the enthalpies, the heat interaction, and the coefficients of performance.

The input temperature range for the simulation program for the various components are as follows.

Solar intensity radiation in Wh/m^2 range: 114.5 - 307.6

Wind velocity in m/s range : 0.6 - 4.8

Generator temperature range in $°C$: 67.1 - 4.8

Condenser temperature range in $°C$: 26.0 - 36.4

Evaporator temperature range in $°C$: 12.1 - 17.2

Absorber temperature range in $°C$: 32.1 - 46.2

Ambient temperature range in $°C$: 26.0 - 31.3

Inlet temperature of water entering the collectors range in $°C$: 40.3 - 68

The refrigerated space temperature range in $°C$: 17.6 - 28.0

Temperature of cooling water range in $°C$: 18.9 - 23.1

All of these ranges are based on the collected data.

Chapter 3

EXPERIMENTAL SET-UP AND PROCEDURE

3.1 Apparatus

In this section a brief description of all components of the apparatus used in extracting data. The experimental set-up ,shown in figure 3.1,was installed on the roof of the laboratories of the Department of Mechanical Engineering of the University of Jordan.The experimental apparatus shown in figure 3.1 was already designed .However, some modifications were necessary .These includes the addition of a concentrator and the refrigeration box. The components of the apparatus are described as follows:

3.1.1 Collectors

Three standard flat plate collectors which are connected in series ,the dimension for each collector are as follows:

Depth = 14 cm

Length=173 cm

Width=73 cm

Area=1.26 m^2

Weight=35 kg

Fluid hold-up volume= 2.25 liters

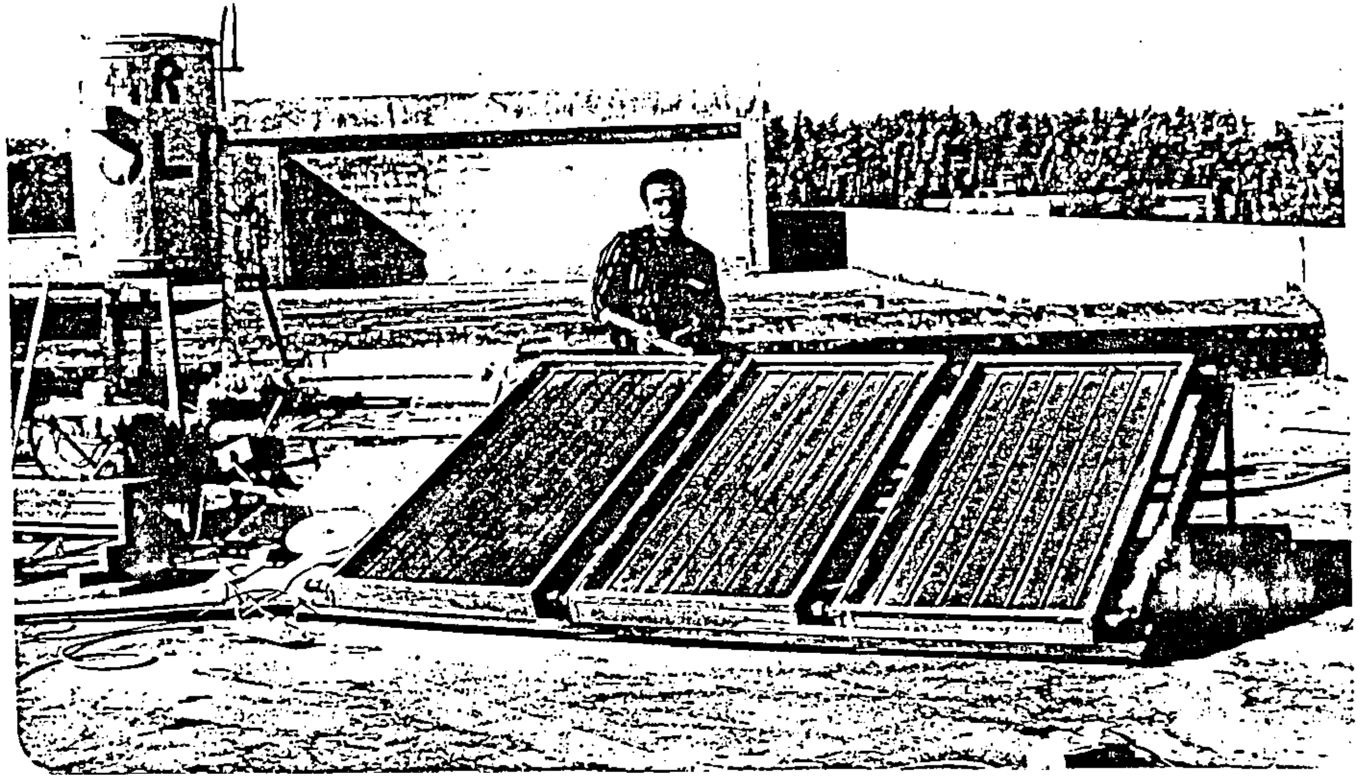


Figure 3.1 : A photograph of the apparatus.

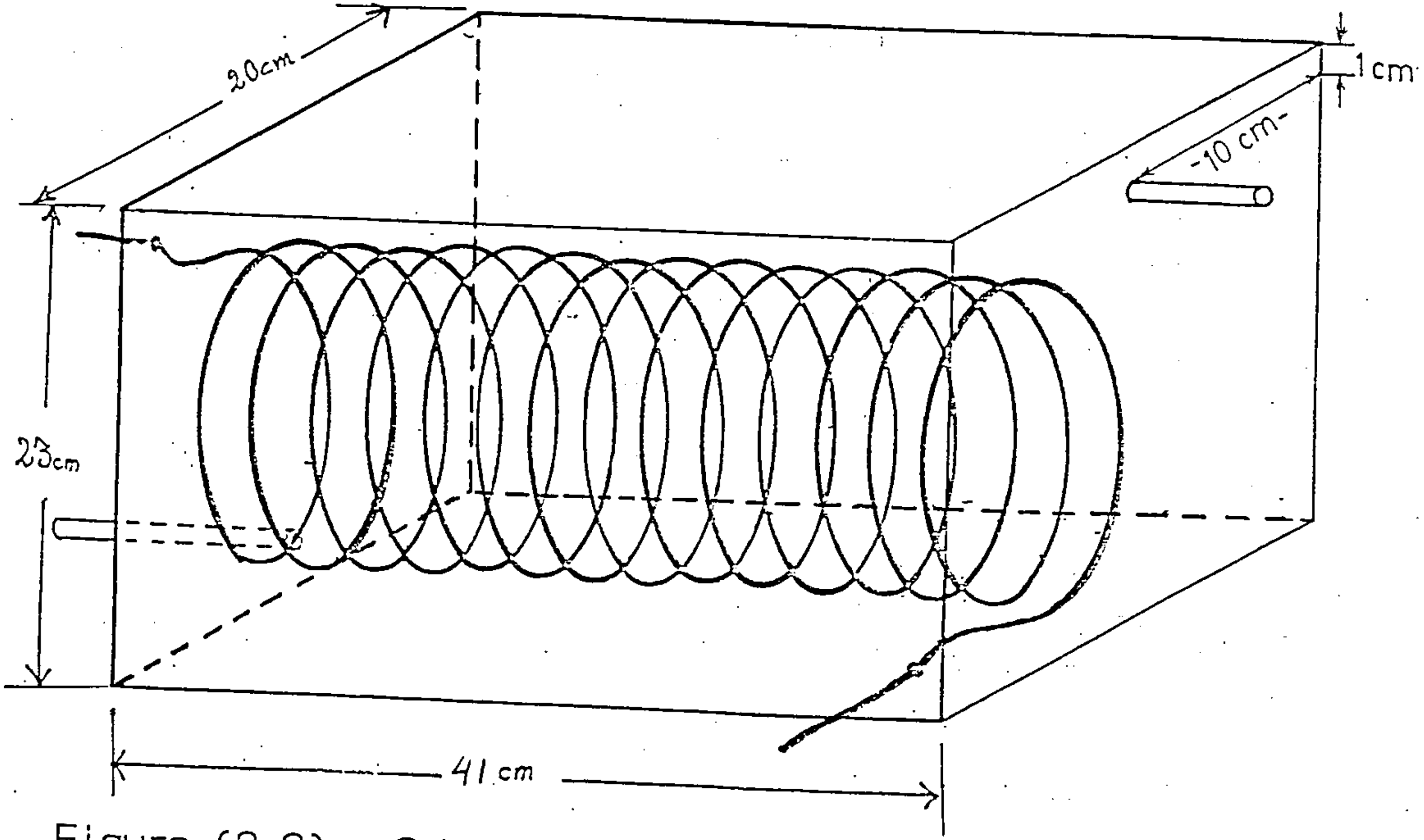


Figure (3.3) : Schematic diagram of the absorber.

3.1.5 The evaporator

The evaporator is the part of the system which is responsible for the cooling effects. The refrigerant coming from the expansion valve has to be evaporated extracting it's latent heat of evaporation from the space to be cooled .The evaporator is an air-cooled type with finned tubes diameter of 1 cm

3.1.6 The refrigerated space

The space to be refrigerated is made of wood ;it consists of two concentric boxes the inner box has the following dimensions: Length = 40 cm
Width=45 cm
Height= 100 cm,
while the outer box has the following dimensions:
length=50 cm width=55cm height=110cm Inside the inner box exist two holes with a space between them of 10 cm. These holes are made so as to record the average refrigerated space temperature

3.1.7 The concentrator

The parabolic concentrator is made of stainless steel with a dimension of 100 cm length and 62 cm width.

The receiver area has the dimensions of 100 cm length and 55 cm width.

The concentrator is covered with a good reflective surface which is chosen to be aluminium foil.The tube enclosed by the concentrator is painted with black, and enveloped by a transparent glass tube so as to minimized convection losses.

3.2 Instrumentation

In this section the instruments used during data collection are to be discussed . There are many measuring parameters as follows:

(1) Temperatures:

The temperatures at different desired positions in the circuit were measured using thermocouples read by multichannel digital meter.Mercury thermometers were also used. The microprooessor thermometers have the following specifications: Type : Ten input thermometers of type 6200

Reading rate : 4 per second.

Working ambient temperature : - 5 to +40 °C.

The thermocouples used are copper- constantant type.

(2) Solar energy:

The solar energy was measured using a solar integrator with the following specifications :

Type : CC10

Temperature range : + 5 to +40 °C.

Irradiation range : 0 to 999.9 e 3 Wh/m^2

(3)Volume flow rate:The volumetric flow rate of the water through collector loop was measured using a standard rotary flow meter meanwhile, the volume flow rate of the cooling water was measured using a baker and a stop watch.

(4)Wind velocity:The wind velocity was measured using wind anemometer with the following specifications:

Type: Edra Five Digital.

Range : 0.3 - 30 m/s.

Accuracy : + 0.01 to - 0.01.

Overall dimensions: 220 mm * 130 mm * 210 mm.

Total weight : 2.5 kg.

3.3 Preparation of Apparatus

In preparation of the apparatus , the following steps were followed:

(a) For the fear that any leak exist,a test was done by operating the system and checking all parts of the system. (b) The concentrator-tube was painted black.It was enclosed in a transparent-cylindrical glass to minimize the losses of convection.

(c) The system is then insulated with rock wool.

(d) Using an evacuation pump for a period 4 hours, the whole system was evacuated.

(e) An amount of 10 kg of LiBr was mixed with 10 liters of water in order to charge the absorption system. The mixture is then poured in the absorber.

(f) The thermocouples are connected at the desired positions.

3.4 Preparation for Collection of Data

The preparation for collection of data consists of the following:

(1) The glass cover of the collectors and concentrator pipe were cleaned.

(2) The reflecting surface of the concentrator was cleaned.

(3) The thermocouples are connected with the microprocessors.

(4) The solar integrator is placed and connected with an electric source.Also the wind anemometer is connected with an electric source.

(5) The solution and the water pump are connected with electric source.

3.5 Data Collected

The data collected are done throughout the following procedure: (i) The water pump is first connected with electric current.

(ii) The air relief valve which is located at the side of the collectors is opened so as to release the air accumulated.This step was done for every reading during the operating period.

(iii) Watching the temperature of the water inlet to the generator as the temperature reaches more than $80°C$; the collecting of data begins.

(iv) Then the solution pump is connected to electric current, and the cooling water is connected to the circuit waiting for the first reading after a minimum time of quarter an hour so as to read steady conditions.

(v) The cooling water flow rate is to be fixed during the whole day.

(vi) After taking the first data, the mass flow rate of the water through collector loop is changed waiting for the second reading.

(vii) For every quarter an hour, the temperatures at the required positions are recorded.

(viii) when the inlet generator temperature decreases below 80 $°C$ the collection of data is stopped.

The data collected are shown in appendix A from this thesis in tables A.1 through table A.9. The temperatures mentioned in the tables are defined in the nomenclature, and shown in Figure 2.1 in chapter 2.

The apparatus also shown in figure 2.2.

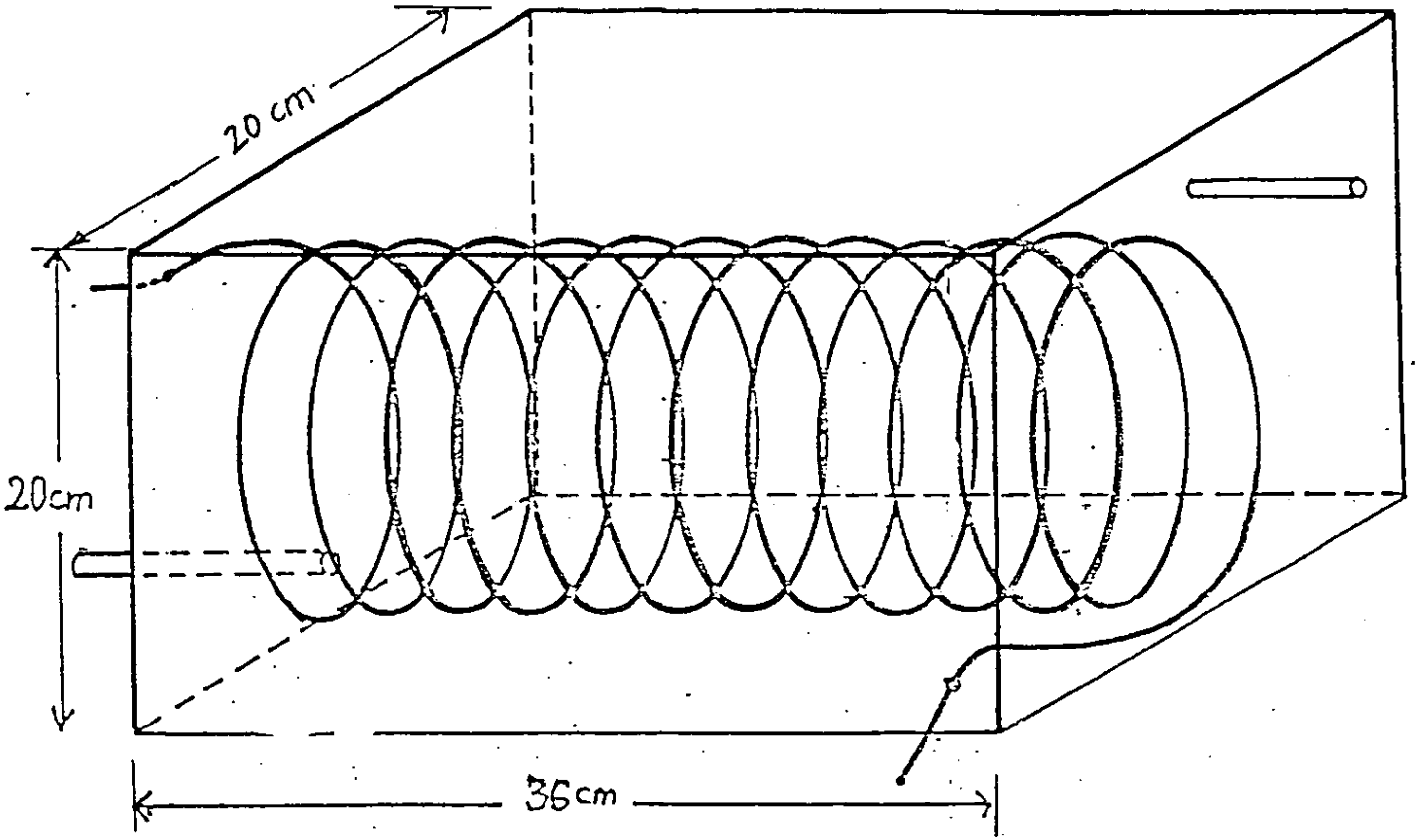


Figure (3.4) : Schematic diagram of the condenser.

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

The data collected experimentally for this research are given in Tables A-1 to A-9 of ,appendix A. This data was used in the computations of results presented and discussed in this chapter. Also, the same data was used in calculating the parameters of the simulation equations which were used in the computer simulation part of this research.

The next section of the chapter explains the method and procedure of the reduction of the data. The results obtained consist of the following: (a) the variation with time of the solar energy, the generator inlet temperature, the generator temperature, the condenser temperature, the evaporator temperature, the absorber temperature, and the refrigerated space temperature during all the test periods; (b) the variation of the experimental coefficient of performance (COP) with the same parameters as in (a); (c) then the results are compared with the published results of other researchers; and (d) the performance curves of the simulation study. These are presented and discussed in details in the next sections.

4.2 Reduction of Data

The first step in the data reduction is the computation of the various heat transfers in the components of the system. These consist of the heat transfer to the generator, $\dot{Q}_g$, the heat from the condenser, $\dot{Q}_c$, the heat transfer in the evaporator, $\dot{Q}_e$, and the heat removed from the absorber, $\dot{Q}_a$. These were computed using the measured temperatures, namely, the generator temperature, T_g, the condenser temperature, T_c, the evaporator temperature, T_e, and the absorber temperature T_a; and the constant mass flow rate of the solution. More details of how these quantities were computed using equations 2.27 through 2.30. After that, all the coefficients of performance for the experimental, simulated and theoretical parts of the research were computed as given by equations 2.4 and 2.5. As an illustration of the computational procedures the data collected on the first of September 1990 for the case when the following data are given:

The generator temperature:

T_g=76.0 $°C$, from Table A.2

The condenser temperature:

T_c=29.1 $°C$, from Table A.2

The evaporator temperature:

T_e=14.7 $°C$, from Table A.2

The absorber temperature:

T_a=39.2 $°C$, from Table A.2

As a result of entering these temperature in equations 2.12 and 2.13 , the following concentrations were obtained.

The concentration of solution leaving the absorber:

$X_{4'}$=51.9%

The concentration of the solution leaving the generator and entering the absorber:

$X_{9'}$=61.9%

The constant mass flow rate of the solution:

$\dot{w}_{4'}$=0.078 kg/s, constant throughout the experiment.

The mass flow rate of the solution leaving the generator is obtained by a mass balance of lithium bromide about the generator, equation 2.28.

$\dot{w}_9$=0.06324 kg/s.

The mass of the refrigerant is obtained by a total mass balance about the generator, equation 2.27 .

$\dot{w}_4$=0.0123 kg/s.

The enthalpy of the solution entering the generator is obtained using equation 2.11.

$h_{4'}$ =74.48 Kj/kg.

The enthalpy of the strong solution leaving the generator is obtained using equation 2.11

.

h_9=158.87 Kj/kg.

The enthalpy of the refrigerant leaving the generator is computed using equation 2.10 .

h_4=2636.9 Kj/kg

The enthalpy of the refrigerant leaving the condenser is computed using equation 2.7 .

h_6=122.0277 Kj/kg.

The enthalpy of the refrigerant leaving the evaporator is obtained using equation 2.9 .

h_8=2528.39 Kj/kg

The rate of heat transfer to the generator is given by equation 2.29 .

Q_g=36.745 Kw.

The rate of heat transfer from the absorber is computed using equation 2.29.

Q_a=29.49 Kw

Then,

The experimental coefficient of performance COP is calculated using equation 2.4:

COP = 0.802699.

The theoretical coefficient of performance is computed using equation 2.5 :

$COP_{th} = 2.1069$.

This sample results are represented in temperature- pressure-concentration diagram see figure 4.0. From this figure, we can notice that we have two cycles, The refrigeration cycle 1-2-3-4, and the solution cycle 1-2-5-6.

The procedure followed in getting the results is shown in figure 4.1 which is the flow chart of program B.3 in Appendix B of this chapter. The results of these and all other computations using the remainder of the data are given in Tables 4.1 through 4.9.

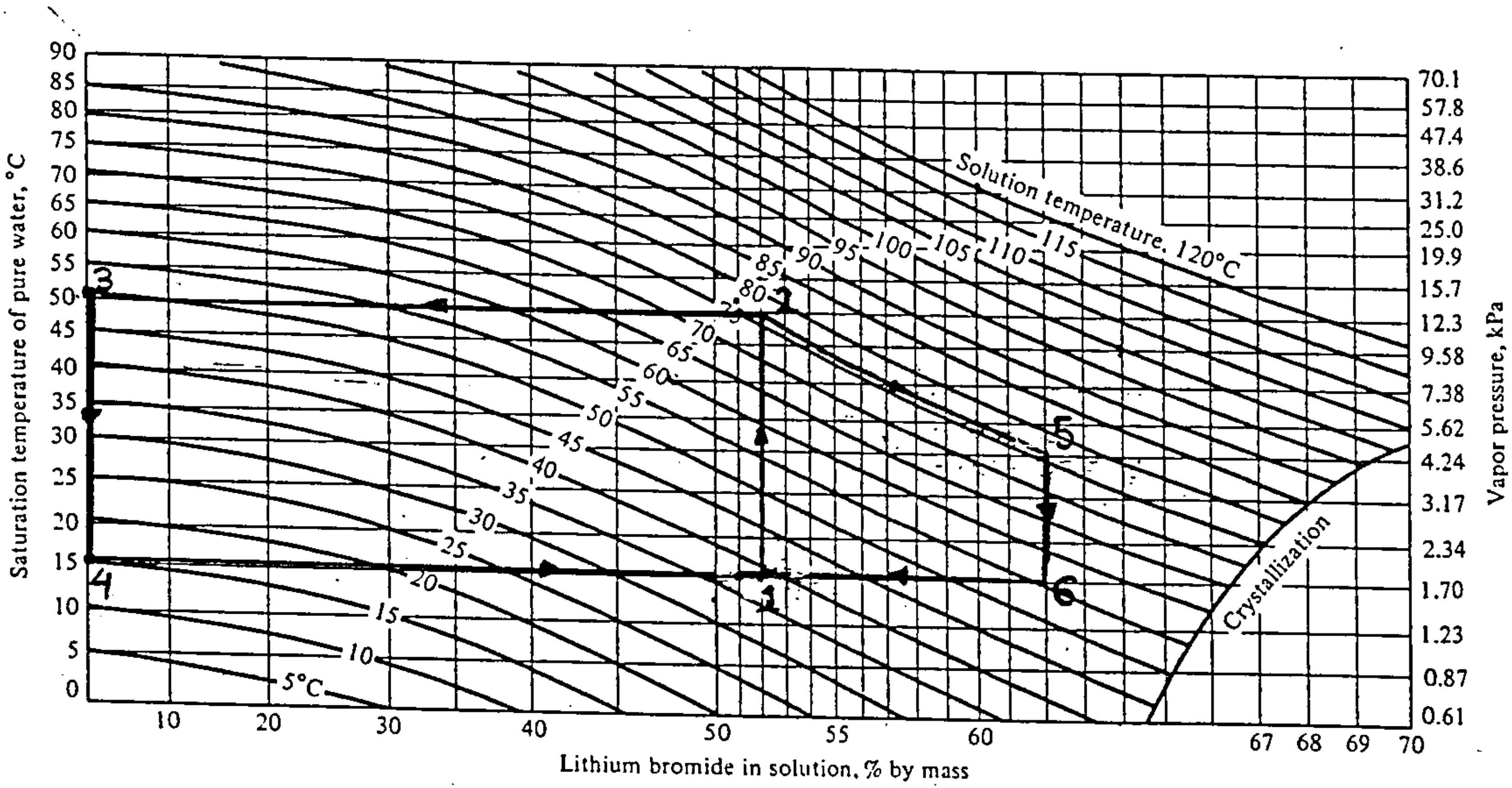


Figure 4.0 : Temperature - Pressure - Concentration of a Typical Cycle.

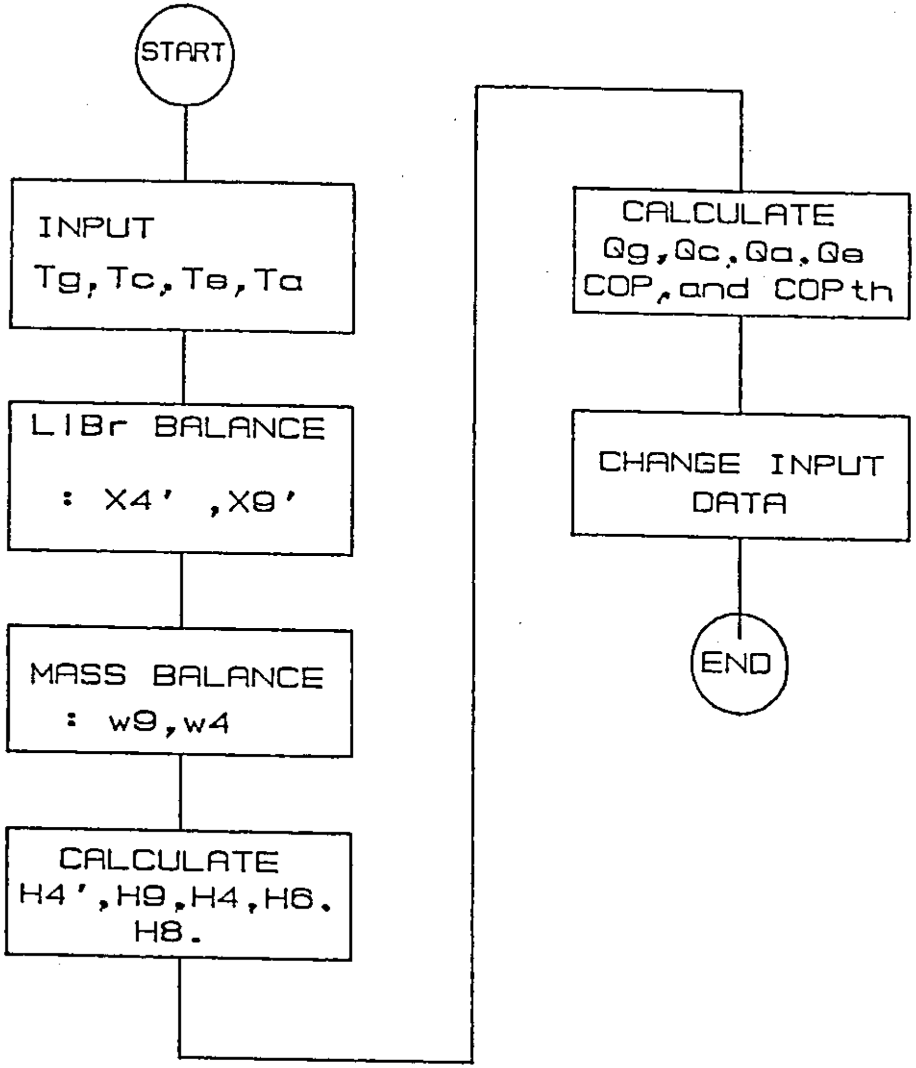


Figure 4.1 : flow chart of calculation procedure.

Table (4.1): Experimental Results

Day:29-8-1990

(with concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP	COP_{th}
11:30	80.2	29.5	16	35.3	0.819	2.72
11:45	79.1	28.1	15.9	35.9	0.823	2.91
12:00	81.9	30.5	16.2	35.4	0.817	2.61
12:15	82.0	30.0	16.8	35.0	0.819	2.91
12:30	80	31.5	16.1	41.0	0.789	2.07
12:45	78.2	31.6	15.1	40.1	0.788	1.89
1:00	78.5	31.5	15.0	40.0	0.790	1.91
1:15	77	31.9	14.9	39.5	0.788	1.82
1:30	76.3	30.0	14.4	38.5	0.801	2.00
1:45	76.0	31.1	14.1	39.0	0.792	1.79
2:00	76.5	31.8	14.9	39.3	0.789	1.81
2:15	73.4	32.1	14.8	39.0	0.782	1.65
2:30	71.3	32.9	14.5	38.6	0.772	1.48
2:45	69.8	33.2	14.3	38.9	0.756	1.37

Table (4.2): Experimental Results

Day:1-9-1990

(with concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP	COP_{th}
11:30	76.0	29.1	14.7	39.2	0.803	2.11
11:45	75.8	29.6	13.1	39.5	0.795	1.81
12:00	84.1	26.1	17.1	40.0	0.830	4.49
12:15	73.1	32.1	13.5	36.3	0.766	1.47
12:30	83.3	26.0	16.9	37.0	0.830	4.20
12:45	82.9	26.8	16.5	37.4	0.825	3.63
1:00	81.9	27.2	16.0	38.3	0.822	3.24
1:15	80.1	28.0	15.5	38.5	0.815	2.73
1:30	79.0	28.3	15.2	38.5	0.813	2.54
1:45	78.6	29.0	14.1	38.2	0.807	2.20
2:00	76.3	29.5	13.0	39.5	0.8049	1.89
2:15	75.1	29.4	13.3	40.0	0.796	1.82
2:30	73.1	30.0	13.4	41.0	0.785	1.65
2:45	72.4	32.5	13.2	41.0	0.740	1.35

Table (4.3): Experimental Results

Day:2-9-1990

(with concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP	COP_{th}
11:30	77.4	32.1	14.9	39.5	0.789	1.81
11:45	78.0	30.4	15.0	39.0	0.799	2.08
12:00	78.9	28.3	16.4	35.3	0.820	2.97
12:15	79.1	27.7	16.1	37.2	0.827	3.35
12:30	80.2	27.9	16.9	33.1	0.832	3.58
12:45	79.0	27.8	17.1	32.1	0.824	3.01
1:00	79.9	28.0	16.8	34.2	0.830	3.52
1:15	78.8	28.7	15.2	38.2	0.811	2.46
1:30	77.3	33.0	14.7	39.9	0.783	1.68
1:45	75.1	32.8	14.5	40.0	0.773	1.58
2:00	73.2	32.8	14.4	40.2	0.760	1.48
2:15	72.3	33.2	14.1	40.5	0.746	1.38
2:30	72.1	32.6	14.0	41.0	0.740	1.39

Table (4.4): Experimental Results

Day:3-9-1990

(with concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP	COP_{th}
11:30	78.2	28.2	15.8	35.2	0.824	2.85
11:45	78.1	31.1	14.8	39.9	0.790	1.92
12:00	80.4	29.0	15.4	37.1	0.820	2.69
12:15	80.2	29.1	15.4	37.0	0.815	2.60
12:30	79.2	28.1	15.9	35.1	0.825	2.97
12:45	76.1	32.9	14.2	41.3	0.762	1.53
1:00	79.7	30.1	15.2	39.5	0.762	1.54
1:15	78.1	28.6	15.8	36.2	0.820	2.69
1:30	77.2	31.7	14.7	40.6	0.780	1.77
1:45	76.3	32.8	14.5	41.2	0.765	1.58
2:00	76.1	32.9	14.2	41.3	0.762	1.53
2:15	75.2	32.1	13.8	41.5	0.720	1.31
2:30	70.1	33.1	13.4	41.8	0.673	1.20
2:45	67.1	33.2	13.2	42.0	0.522	1.05

Table (4.5): Experimental Results

Day:4-9-1990

(with concentrator) / temperatures in $^{\circ}C$

Time	T_g	T_c	T_e	T_a	COP	COP_{th}
11:30	78.1	29.0	14.6	38.5	0.808	2.25
11:45	77.4	29.5	14.5	39.0	0.802	2.10
12:00	77.3	30.0	14.0	39.2	0.798	1.95
12:15	82.1	27.6	15.1	37.4	0.815	2.65
12:30	81.1	28.9	14.7	38.2	0.812	2.53
12:45	79.3	27.2	15.5	36.5	0.825	3.00
1:00	77.0	27.6	15.1	37.4	0.808	2.25
1:15	77.3	30.0	14.0	39.2	0.798	1.95
1:30	75.2	31.1	14.5	39.4	0.788	1.78
1:45	74.2	31.2	14.3	39.6	0.783	1.69
2:00	73.2	32.4	14.0	40.0	0.766	1.50
2:15	73.2	32.6	13.8	40.5	0.761	1.49
2:30	72.1	32.7	13.5	41.2	0.732	1.34

Table (4.6): Experimental Results

Day:8-9-1990

(without concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP	COP_{th}
11:15	78.2	30.0	14.3	37.0	0.811	2.15
11:30	77.3	31.3	13.8	40.9	0.777	1.70
11:45	78.5	30.0	14.5	38.2	0.805	2.13
12:00	76.5	32.0	13.6	40.0	0.796	1.63
12:15	76.9	31.9	13.7	40.6	0.776	1.634
12:30	76.4	32.3	13.6	40.5	0.773	1.58
12:45	75	33.2	13.5	41.2	0.752	1.41
1:00	74	33.7	13.2	42.2	0.714	1.28
1:15	73.9	33.0	12.9	42.4	0.710	1.29
1:30	73.5	34.1	12.7	43.7	0.613	1.15
1:45	73.2	34.1	12.5	44.2	0.529	1.10

Table (4.7): Experimental Results

Day:9-9-1990

(without concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP	COP_{th}
11:15	75.3	33.8	15.0	37.0	0.795	1.68
11:30	77	31.8	14.8	36.9	0.804	1.94
11:45	77.3	31.0	15.0	36.3	0.810	2.11
12:00	76.7	32.0	15.0	37.1	0.802	1.92
12:15	75.0	33.8	14.5	38.0	0.788	1.58
12:30	76.3	33.9	14.9	37.8	0.793	1.67
12:45	75.7	33.3	14.7	37.4	0.795	1.70
1:00	74.3	34.4	14.14.2	38.9	0.775	1.44
1:15	73.1	34.8	14.0	39.0	0.765	1.36
1:30	72.4	35.1	13.7	39.4	0.750	1.28
1:45	68.4	35.4	13.0	39.6	0.672	1.08
2:00	67.3	36.0	12.7	40.1	0.553	0.98
2:15	67.3	36.0	12.7	40.1	0.553	0.98

Table (4.8): Experimental Results

Day:10-9-1990

(without concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP	COP_{th}
11:30	72.9	34.3	14.8	37.2	0.784	1.52
11:45	73.6	34	15.0	37.0	0.790	1.60
12:00	77.2	32.2	16.0	35.4	0.810	2.13
12:15	74.6	33.6	15.1	36.6	0.796	1.70
12:30	76.7	33.0	15.4	36.0	0.805	1.91
12:45	77.4	31.6	16.2	35.0	0.813	2.27
1:00	75.3	33.2	15.2	36.4	0.800	1.79
1:15	72.4	34.5	14.3	37.4	0.778	1.44
1:30	71.2	35.8	14.0	37.8	0.761	1.28
1:45	70.4	35.4	13.8	38.0	0.752	1.25
2:00	69.2	36.4	13.5	38.5	0.715	1.12

Table (4.9): Experimental Results

Day:11-9-1990

(without concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP	COP_{th}
11:15	77.0	29.9	17.1	37.5	0.806	2.54
11:30	77.1	29.3	17.2	35.6	0.819	2.84
11:45	78.0	30.1	17.0	38.2	0.823	2.46
12:00	76.1	30.4	16.9	40.1	0.794	2.22
12:15	75.2	31.0	16.8	41.8	0.775	1.96
12:30	72.4	32.1	16.2	42.5	0.735	1.58
12:45	72.1	33.0	15.0	43.10	0.681	1.35
1:00	75.0	31.8	16.6	42.0	0.765	1.807
1:15	73.4	32.8	15.6	41.5	0.729	1.50
1:30	71.2	33.5	14.8	45.1	0.34	1.17
1:45	70.1	34.1	14.2	46.2	0.33	1.16

The results based of the simulated temperatures were computed using the same procedure and equations as those presented above for the experimental part of the research. These temperatures and the corresponding coefficients of performance are given in Tables 4.10 through 4.19 in the following pages.

Table (4.10): Simulation Results

Day:29-8-1990

(with concentrator) / temperatures in $^{\circ}C$

Time	T_g	T_c	T_e	T_a	COP
11:30	78.0	28.0	15.8	35.0	0.826
11:45	79.4	26.5	16.4	35.7	0.828
12:00	79.3	29.7	15.6	37.5	0.811
12:15	79.4	24.2	16.1	36.6	0.830
12:30	79.1	28.6	15.7	37.2	0.816
12:45	79.9	30.9	15.5	37.6	0.807
1:00	78.3	31.0	15.1	38.1	0.802
1:15	76.9	30.0	15.0	38.1	0.805
1:30	76.8	30.1	14.9	38.4	0.802
1:45	76.8	31.1	14.4	38.9	0.794
2:00	75.9	31.7	14.2	39.2	0.787
2:15	74.8	32.0	14.1	39.4	0.782
2:30	74.1	32.1	14.2	39.4	0.78
2:45	73.2	32.8	14.4	40.2	0.760

Table (4.11): Simulation Results

Day:1-9-1990

(with concentrator) / temperatures in $^{\circ}C$

Time	T_g	T_c	T_e	T_a	COP
11:30	79.3	31.4	14.1	39.7	0.792
11:45	77.6	30.7	14.3	40.0	0.790
12:00	75.5	26.0	14.4	34.9	0.837
12:15	76.5	31.8	14.1	39.6	0.785
12:30	77.6	30.0	14.2	39.5	0.796
12:45	77.4	30.6	14.0	39.6	0.790
1:00	76.8	29.9	14.2	39.4	0.800
1:15	76.7	31.2	14.1	39.5	0.789
1:30	76.5	31.8	14.2	39.4	0.786
1:45	76.4	31.7	14.5	39.1	0.790
2:00	76.4	32.0	14.4	39.1	0.790
2:15	76.3	32.1	14.7	38.8	0.791
2:30	77.3	33.0	14.7	39.9	0.783
2:45	72.1	32.6	14.0	41.0	0.740

Table (4.12): Simulation Results

Day:2-9-1990

(with concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP
11:30	78.9	27.9	15.8	32.1	0.833
11:45	78.1	31.1	14.8	39.9	0.790
12:00	81.0	26.3	14.2	40.7	0.811
12:15	78.2	27.2	14.3	40.0	0.810
12:30	79.0	28.5	14.1	39.7	0.804
12:45	81.2	29.2	14.3	39.4	0.804
1:00	80.2	27.4	15.9	37.3	0.820
1:15	79.7	32.0	15.1	38.2	0.802
1:30	78.5	30.7	15.1	38.1	0.804
1:45	77.4	31.1	15.2	38.1	0.800
2:00	76.3	31.8	15.0	38.3	0.795
2:15	76.1	32.9	14.2	41.3	0.762
2:30	72.4	35.1	13.7	39.4	0.750
2:45	72.1	32.6	14.0	41.0	0.74

Table (4.13): Simulation Results

Day:3-9-1990

(with concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP
11:30	77.6	28.1	15.8	35.1	0.825
11:45	78.7	31.7	15.1	35.939.0	0.796
12:00	80.7	31.3	15.0	38.6	0.802
12:15	79.3	32.0	14.9	38.7	0.798
12:30	80.3	30.8	15.0	38.4	0.804
12:45	79.7	31.6	14.8	38.6	0.800
1:00	77.8	30.9	15.0	38.5	0.799
1:15	75.9	31.9	14.5	38.9	0.789
1:30	74.8	32.1	14.5	38.9	0.786
1:45	74.9	32.0	14.3	39.1	0.785
2:00	73.6	32.2	14.2	39.3	0.780
2:15	72.4	32.5	13.2	41.0	0.740
2:30	72.1	32.6	14.0	41.0	0.740
2:45	73.9	33.0	12.9	42.4	0.710

Table (4.14): Simulation Results

Day:4-9-1990

(with concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP
11:30	78.5	27.1	15.2	36.1	0.827
11:45	76.8	31.3	15.0	38.6	0.796
12:00	77.4	31.5	14.8	38.6	0.797
12:15	80.9	31.3	14.6	38.7	0.802
12:30	80.9	30.3	14.9	38.4	0.804
12:45	79.9	27.8	15.9	37.2	0.820
1:00	79.0	30.3	15.5	37.6	0.808
1:15	79.2	30.9	15.1	38.1	0.804
1:30	79.0	29.0	15.5	37.5	0.813
1:45	78.1	30.0	15.2	38.0	0.806
2:00	75.5	32.1	14.3	39.2	0.785
2:15	77.2	31.7	14.7	40.6	0.780
2:30	75.2	32.1	13.8	41.5	0.720

Table (4.15): Simulation Results

Day:8-9-1990

(without concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP
11:15	74.1	30.0	16.3	38.2	0.804
11:30	74.7	31.8	15.0	38.3	0.792
11:45	76.0	31.9	14.9	38.6	0.792
12:00	76.1	32.0	14.9	38.5	0.793
12:15	76.7	31.9	14.9	38.7	0.794
12:30	75.3	32.2	14.9	38.5	0.790
12:45	73.2	32.8	14.4	40.2	0.760
1:00	72.4	35.1	13.7	39.4	0.750
1:15	72.1	32.6	14.0	41.0	0.740
1:30	75.1	32.1	13.8	41.5	0.720
1:45	75.0	33.2	13.5	41.2	0.750

Table (4.16): Simulation Results

Day:9-9-1990

(without concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP
11:15	74.7	31.0	17.0	36.0	0.810
11:30	77.8	32.0	15.5	38.3	0.798
11:45	80.0	32.0	15.0	38.3	0.796
12:00	76.9	31.5	14.8	38.6	0.795
12:15	75.8	31.8	14.6	38.8	0.790
12:30	76.1	30.1	15.1	38.3	0.800
12:45	75.9	31.6	14.65	38.7	0.792
1:00	75.8	31.7	14.6	38.8	0.790
1:15	74.9	32.0	14.4	39.0	0.785
1:30	74.4	31.4	14.8	38.7	0.790
1:45	76.1	32.9	14.2	41.3	0.762
2:00	72.4	35.1	13.7	39.4	0.750
2:15	72.1	32.6	14.0	41.0	0.740

Table (4.17): Simulation Results

Day:10-9-1990

(without concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP
11:30	70.2	31.6	18.0	35.0	0.807
11:45	75.1	31.8	17.5	37.1	0.812
12:00	77.3	33.1	17.2	37.6	0.800
12:15	76.7	33.2	16.4	37.3	0.790
12:30	77.7	33.0	15.3	37.1	0.802
12:45	78.0	32.0	14.6	37.9	0.800
1:00	77.5	32.3	14.2	37.6	0.790
1:15	75.1	31.6	14.2	38.4	0.796
1:30	75.9	31.9	14.2	38.6	0.791
1:45	73.2	32.8	14.4	40.2	0.7603
2:00	72.4	35.1	13.7	39.4	0.750

Table (4.18): Simulation Results

Day:11-9-1990

(without concentrator) / temperatures in °C

Time	T_g	T_c	T_e	T_a	COP
11:15	75.3	29.3	16.6	35.6	0.819
11:30	78.0	31.3	15.8	38.2	0.801
11:45	77.9	31.2	15.2	38.4	0.800
12:00	77.23	32.0	14.7	38.7	0.790
12:15	76.2	31.7	14.8	38.8	0.780
12:30	75.4	31.7	14.7	38.9	0.782
12:45	75.2	31.7	14.8	38.8	0.7699
1:00	75.1	32.2	14.7	38.8	0.760
1:15	74.2	32.4	14.6	38.9	0.753
1:30	72.3	33.3	14.2	40.5	0.746
1:45	75.2	32.1	13.8	41.5	0.720

The deviation of the simulated coefficient of performance with respect to the experimental value was computed using equation 8 of chapter 2.

The results of computing the deviation of the remainder of the other results are given in Tables 4.19 and 4.20.

Table (4.19):Deviations

(Days with concentrator)

state	29-8 ϵ	1-9 ϵ	2-9 ϵ	3-9 ϵ	4-9 ϵ
1	8.5e-3	1.3e-2	5.5e-2	1.2e-3	2.3e-2
2	6.0e-3	6.4e-3	1.1e0-2	7.6e-3	7.4e-3
3	7.0e-3	7.9e-3	1.1e-2	2.1e-2	1.5e-3
4	1.3e-2	2.5e-2	2.1e-2	2.1e-2	1.7e-2
5	3.4e-2	4.1e-2	3.4e-2	2.5e-2	8.7e-3
6	2.4e-2	4.0e-2	2.4e-2	5.1e-2	1.5e-2
7	1.6e-2	2.6e-2	1.0e-2	5.0e-2	1.2e-4
8	2.2e-2	3.1e-2	1.2e-2	3.8e-2	2.0e-2
9	1.8e-3	2.8e-2	2.6e-2	7.8e-3	3.1e-2
10	2.7e-3	2.1e-2	3.5e-2	2.6e-2	2.9e-2
11	2e-3	1.9e-2	4.6e-2	2.4e-2	2.4e-2
12	3.8e-4	6.3e-3	2.1e-2	2.7e-2	2.4e-2
13	9.3e-3	2.5e-3	1.4e-2	9e-2	1.6e-2
14	5.7e-3	4e-4		3.6e-1	

Table (4.20):Deviations

days without concentrator

state	8-9 ϵ	9-9 ϵ	10-9 ϵ	11-9 ϵ
01	8.2e-3	1.8e-2	2.8e-2	1.6e-2
02	2.0e-2	7.5e-3	1.5e-2	2.2e-2
03	1.6e-2	1.7e-2	1.3e-2	2.8e-2
04	3.9e-3	9.1e-3	4.0e-3	6.2e-4
05	2.3e-2	2.5e-3	3.6e-3	2.2e-2
06	2.2e-2	8.5e-3	1.6e-2	6.9e-2
07	1.1e-2	3.3e-3	6.2e-4	1.4e-1
08	4.8e-2	1.9e-2	2.3e-2	3.0e-2
09	4.1e-2	3.0e-2	3.8e-2	6.9e-2
10	1.5e-1	5.3e-2	1.1e-2	1.20
11	3.0e-1	1.2e-1	4.7e-2	
12		2.6e-1		
13		2.5e-1		

4.3 Variation of Test Parameters with Time

In this section, the variation of the various parameters of the test are discussed as they varied with the time of the day of test. These parameters are the solar radiation energy, the inlet generator temperature, the temperatures of the components of the system.

4.3.1 Solar energy

Jordan is a rich country in solar radiation as mentioned in section 1.1 especially during summer months.. All experimental data for this research were collected at the end of August and the beginning of September. An example of the variation of the solar radiation energy with time of the day is shown in Figures 4.2 and 4.3. Figure 4.2 shows that the solar energy collected during the first test period, namely, at 11:30 was 209.3$\frac{wh}{m^2}$,then it increased to a maximum of 240 $\frac{wh}{m^2}$. at 12:30 and dropped to the minimum of the day of 173 $\frac{wh}{m^2}$ at 2:30 p.m , it is seen that the maximum energy for a period for all days of test occurred during the period between 12:00 and 12:45 pm. The absolute maximum for the solar energy collected during a period of 15 minutes during the days of the test was 307.6 Wh/m^2. Other figures showing the variation of the solar energy during the test periods are given in Figures C.1 and C.2

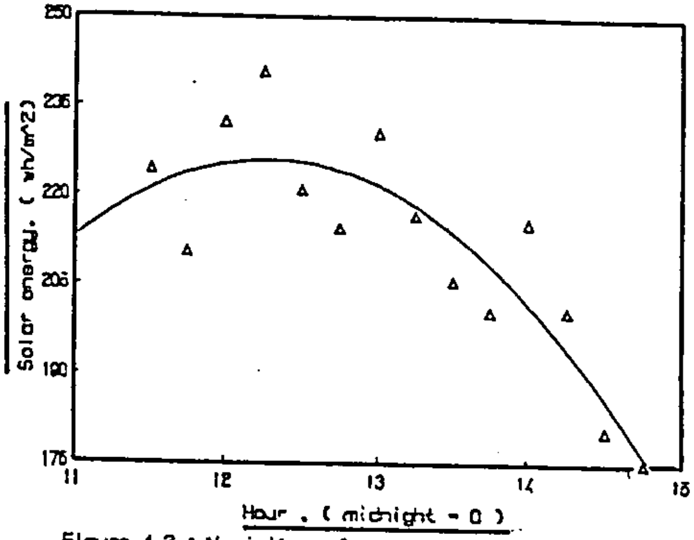


Figure 4.2 : Variation of solar energy with time of the day, ambient temp. = 29.7 °c, initial space temp. = 28.3 °c with concentrator

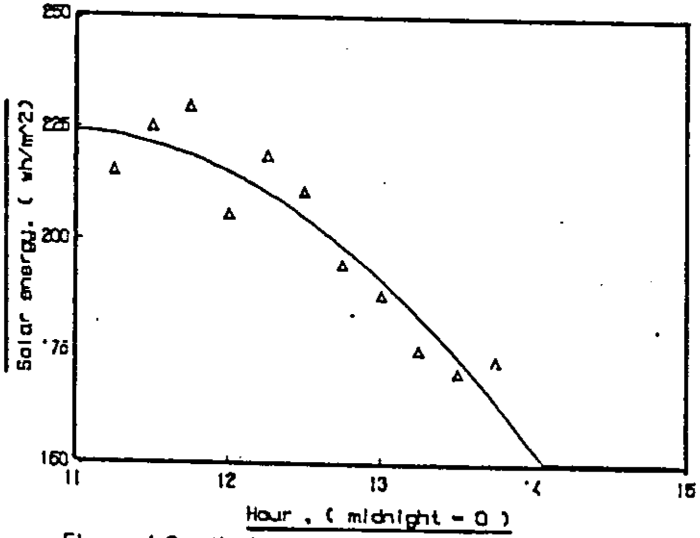


Figure 4.3 : Variation of solar energy with time of the day, ambient temp. = 28.3 °c. Initial space temp. = 28.2 °c without concentrator.

The solar energy collected by three flat plate collector with and without a concentrator as described in chapter 3 was the only source of energy input into the generator. The solar intensity affected directly the inlet generator temperature which affects directly the generator temperature and the the performance of the unit. The dependence of the performance of the system on solar radiation energy is discussed in section 4.3.

4.3.2 Inlet generator temperature

The inlet generator temperature is determined by the solar collector system and weather of the day. Also, in this research two cases were considered. The first case is the one when the flat plate collectors were augmented by a concentrator, the second case excludes the use of the concentrator. More details about the solar radiation collection system is included in chapter 3. Figures 4.4 and 4.5 are examples of the variation of the inlet generator temperature with time of the day. Figure 4.4 shows the effect of the concentrator on the variation of the temperature in comparison with Figure 4.5 which excludes the use of the concentrator. As mentioned in chapter 3, this temperature was used to determine the beginning of the test period as it reaches 80 $^{\circ}C$. This is confirmed as the minimum temperature for a meaningful use of solar energy in absorption refrigeration, [22, 27]. Moreover, the performance of the absorption refrigeration system has found to depend mainly on this temperature, [18, 22]. The two figures show that the maximum inlet generator temperature occurs during the same period of maximum solar energy collected, namely, the period 12:00 to 12:45. The maximum temperature shown by Figure 4.4 is 95 $^{\circ}C$ while that of Figure 4.5 is 90 $^{\circ}C$. These temperatures show that the concentrator helps to increase the generator temperature by about 6 %. Other figures showing the variation of the generator inlet temperature with time of the day with the use of the concentrator and without its use are given in Appendix C, Figures C3 and c4.

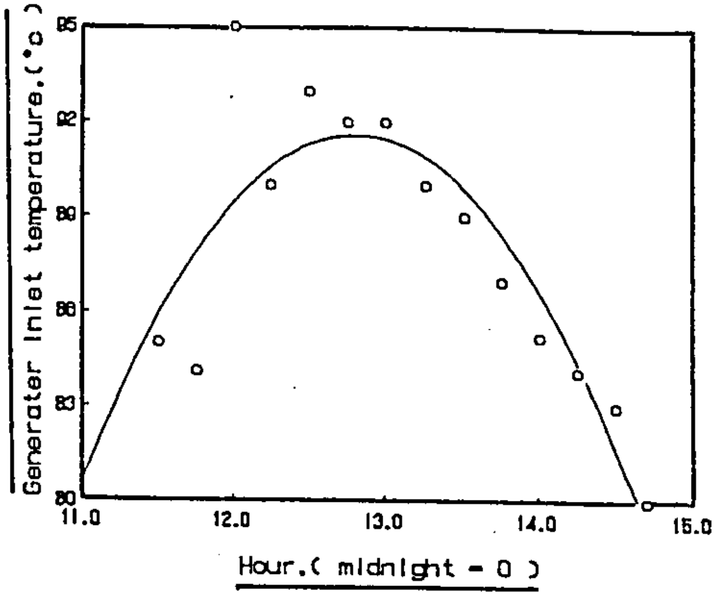


Figure 4.4 :Variation of generator inlet temp. with time in the day ,ambient temp. = 29.69 °c Initial space temp. 28.3 °c, with concentrater

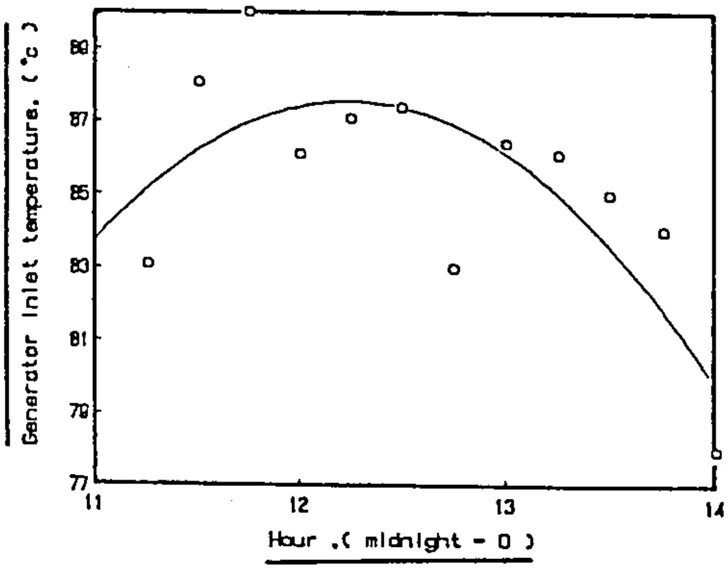


Figure 4.5 :Variation of generator inlet temp. hour in the day , ambient temperature = 27.653 °c Initial space temp. = 27.6 °c . without concent.

4.3.3 Other cycle temperatures

In this section, the variation of the temperatures of the generator, the condenser, the evaporator, the absorber, and the refrigerated space with time of the day are considered. These temperatures are presented for the two test modes: with and without the addition of the concentrator.

The temperature of the generator refers to the temperature of the refrigerant leaving the generator. Figures 4.6 and 4.7 show the variation of this temperature with time. Figure 4.6 shows that at the beginning of the test period this temperature was 80 ^{O}C; it reached a maximum of 84 ^{O}C at the same period of maximum generator inlet temperature, i.e between 12:00 and 12:45, it then dropped to a minimum temperature of 70 $°C$ at the end of operation period. For the case when the concentrator was not used, figure 4.7, these temperatures were 75 $°C$, 76 $°C$, and 68 $°C$, respectively. In this case, the percentage contribution of the concentrator is about 10 %.Other figures showing the variation of space temperature with time of the day are listed in Appendix C in figures C5 and C6.

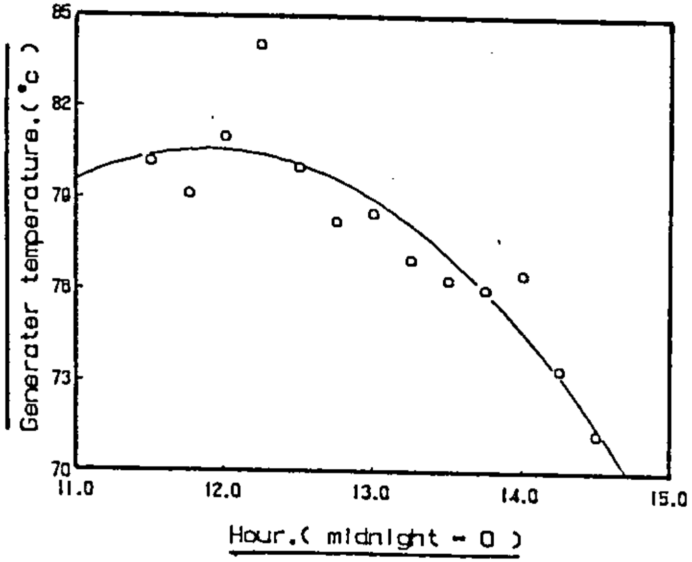


Figure .4.6 :Variation of generator temperature with time in the day ,ambient temp. = 29.69 °c Initial space temp. 28.3 °c. with concentrater

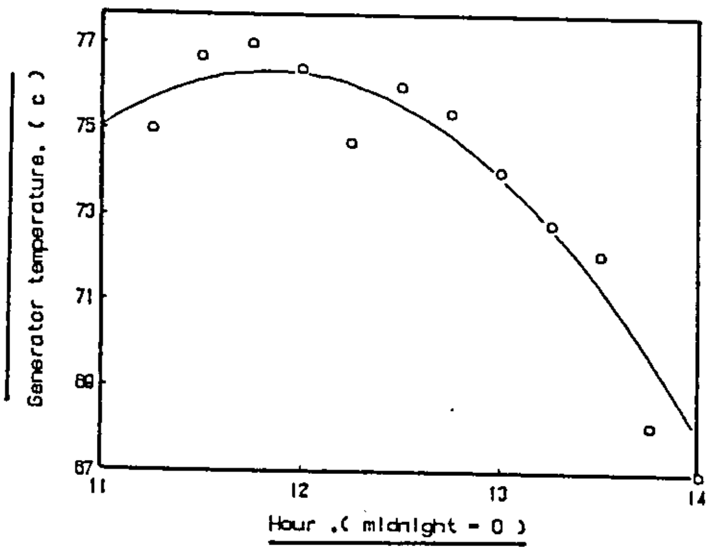


Figure 4.7 :Variation of generator temperature hour in the day , ambient temperature = 27.853 °c Initial space temp. = 27.6 °c , without concent.

On the other hand, the variation of condenser temperature with time of the day depends on three main factors: (a) The temperature of the refrigerant entering the condenser, (b) the difference between the inlet and the outlet temperatures of the cooling water , (c) the ambient temperature and wind speed. These factors were observed to influence the variation of the condenser temperature by the fact that the refrigerant leaving the regenerator is exposed to ambient air before it enters the condenser itself. In the condenser, the exchange with the tap water produces the maximum heat removal from the refrigerant. Moreover, the condenser itself was exposed to ambient air which helped in the rate of cooling of the refrigerant. As noted before, the most important factor is the cooling water temperature since it affects mainly the condenser temperature. As an illustration of the variation of the temperature of the condenser, Figures 4.8 and 4.9 show the data for two cases of concentrator use or its absence. Figure 4.8 shows that the beginning temperature of the condenser is 29.5 $^{\circ}C$ for a difference between the inlet and the outlet cooling water of 4.2 $^{\circ}C$ while at the end of the test run the condenser temperature was 32 $^{\circ}C$ with a difference between inlet and outlet of cooling water of 2.0 $^{\circ}C$.

From figure 4.9, it is seen that the test beginning temperature of the condenser was 32 $^{\circ}C$ with a difference between inlet and outlet of cooling water of 3.1 $^{\circ}C$ while the temperature of the condenser at the end of operation is 36 $^{\circ}C$ with a difference between the inlet and outlet temperatures of cooling water of 1.1 $^{\circ}C$. Other figures shows this variation are listed in Appendix c through figures C7 and C8.

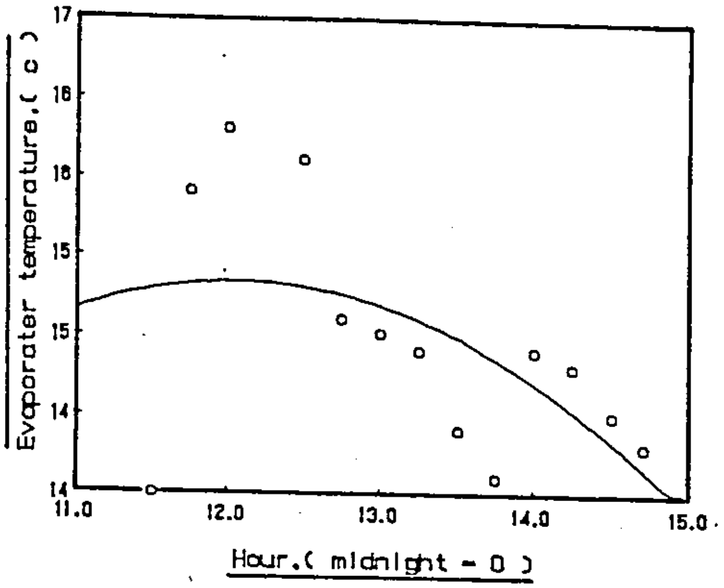


Figure 4.10 :Variation of evaporater temperature with time in the day ,ambient temp. = 29.69 c Initial space temp. 28.3 c, with concentrater

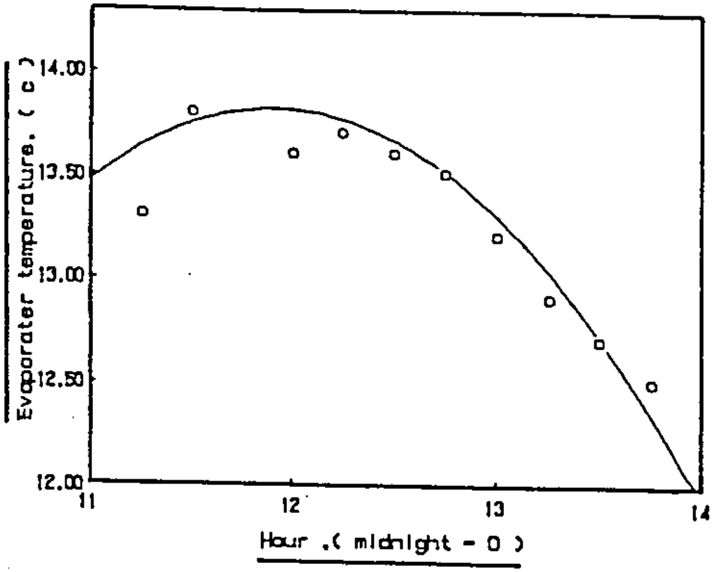


Figure 4.11 :Variation of evaporater temperature hour in the day , ambient temperature = 28.255 c Initial space temp. = 28.2 c , without concent.

The variation of the refrigerated space temperature with time of the day depends on four factors: (a) the starting refrigerated space temperature, (b) the temperature of the refrigerant leaving the evaporator, (c) the operating period, and (d) the value of the coefficient of performance which explained in more details in section 4.4.

From figure 4.12, the case of the presence of the concentrator, the initial refrigerated space temperature is 28.3 $°C$ with evaporator temperature of 16 $°C$ while the minimum refrigerated space temperature is 17.5 $°C$ at the end of the operating period, between 11:30 a.m to 2:45 pm. The other case, figure 4.13, shows that the starting refrigerated space temperature is 26.2$°C$ with initial evaporator temperature of 14.3$°C$ while the minimum refrigerated space temperature is 20$°C$ at an evaporator temperature of 12.5$°C$ at the end of the operating period, from 11:15 am to 1:45 pm. It can be shown that the minimum temperature attained is lower than in the case without the use of the concentrator. The reason for this behaviour, is that the operating period which has the lower limit of 80 $°C$ inlet generator temperature is higher in the case of the concentrator than the other case.Other figures which show the variation of space temperature with time are shown in appendix C,figures C11 and C12.

The average length of test run for the days when the concentrators was used is 3.4 hours, while that for the days without concentrator is 2.63 hours. The gave an additional test time of 0.78 hours.

The last factor, the value of the coefficient of performance of the system, as expected affects mainly the refrigerated space: as the COP increases, the temperature of the refrigerated space drops. It is shown elsewhere in this chapter, section 4.3, that the COP was higher in the case of use of the concentrator than that without the use of the concentrator.

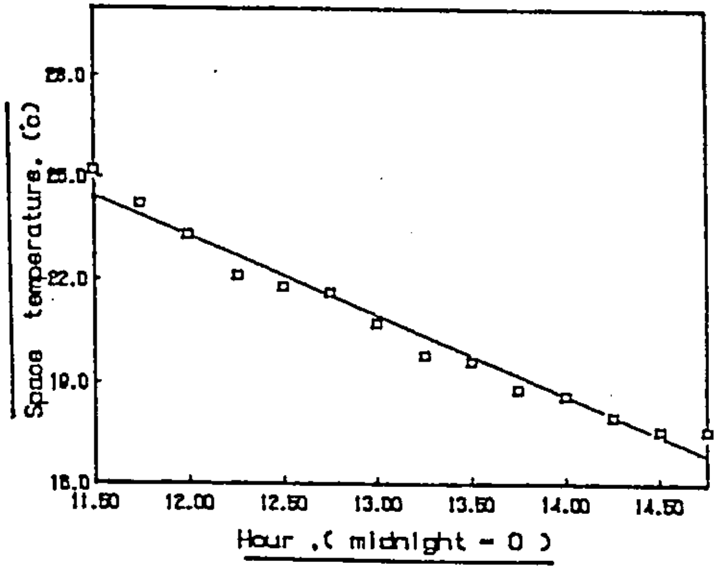


Figure 4.12 : Variation of space temp. with hour in the day, ambient temp. = 29.89°c initial space temp. = 28.3°c, with concen.

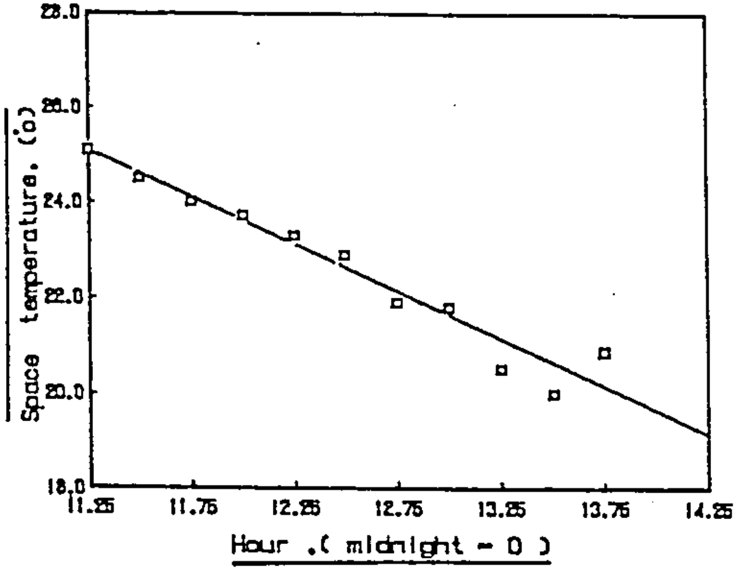


Figure 4.13 : Variation of space temp. with hour in the day, ambient temp. = 28.255 °c initial space temp. = 26.3 °c, without concen.

The absorber temperature ,on the other hand,is affected by many factors:(a) the temperature of the refrigerant coming from the evaporator,(b)the difference between inlet and outlet of cooling water temperature,and (c)the temperature of the strong solution coming from the generator .

For example,figures 4.14 and 4.15 shows the variation of the absorber temperature with time in the day for the two cases.Figure 4.14 shows the variation of absorber temperature with time for the case with the concentrator. The initial absorber temperature is 35.3 ^{o}C with an initial evaporator temperature of $16^{o}C$,difference between inlet and outlet of cooling water of $4.2^{o}C$ and a temperature of strong solution entering the absorber of $43^{o}C$ while the maximum of T_a is 43 ^{o}C at 12:30 with T_e of $16.1^{o}C$ and strong solution temperature is $44^{o}C$ and a difference between inlet and outlet of cooling water of 2.8 ^{o}C .At the end of operating period the absorber temperature is $38.9^{o}C$ with T_e of $14.3^{o}C$, a strong solution temperature of $43.9^{o}C$ and a difference of 2 ^{o}C between inlet and outlet of cooling water.The variation of absorber temperature of the non concentrator case is shown in figure 4.17 .However ,at the begin of the operating period,the absorber temperature is $37.0^{o}C$ with an initial evaporator temperature of 14. $3^{o}C$,strong solution temperature of $50^{o}C$ and a difference between inlet and outlet of cooling water of $3.7^{o}C$.The maximum absorber temperature is $44.5^{o}C$ with evaporator temperature of $13.6^{o}C$, strong solution temperature of $49.8^{o}C$ and a difference between inlet and outlet of cooling water of $2^{o}C$.The end absorber temperature is $40^{o}C$ with evaporator temperature of $12.5^{o}C$,strong solution temperature of $48.5^{o}C$ and a difference in cooling water temperature of $1.7^{o}C$.Other figures which show the variation of absorber temperature with time are shown in appendix C , figures C13 and C14.

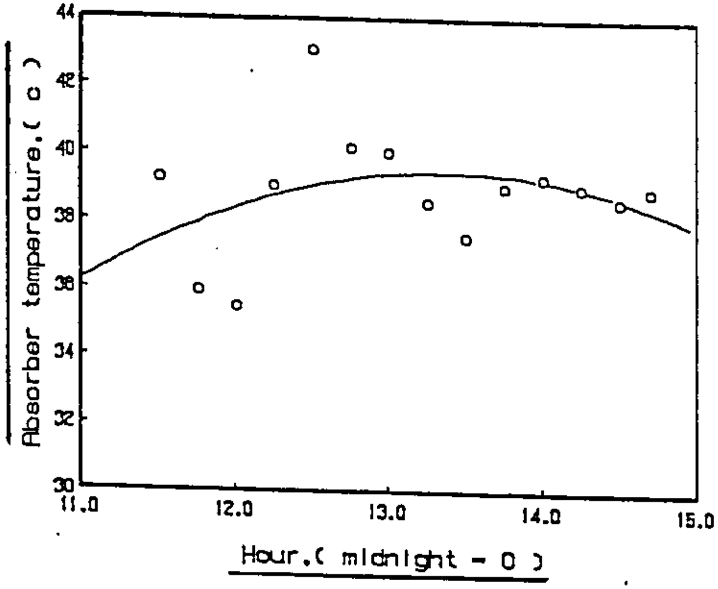


Figure 4.14 : Variation of absorber temp.with hour in the day, ambient temp. = 29.69 °c initial space temp. = 28.3 °c, with concen.

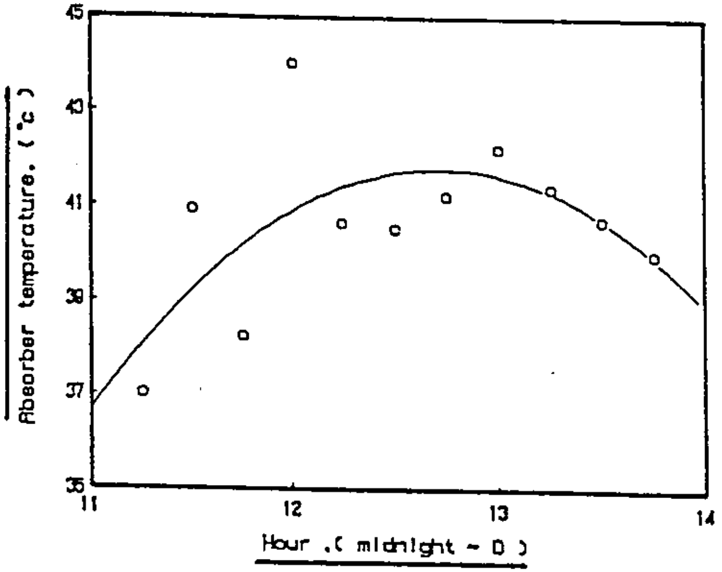


Figure 4.15 : Variation of absorber temp. with hour in the day, ambient temp. = 28.255 °c initial space temp. = 28.2 °c, without concen.

The variation of the above mentioned temperatures with time is shown in figure 4.16. From this figure we can see that the highest of all of these temperatures, as expected, is the generator temperature, T_g. The lowest temperature of the cycle is that of the evaporator, T_e, and intermediate temperatures are the absorber temperature, T_a, and the condenser temperature, T_c.

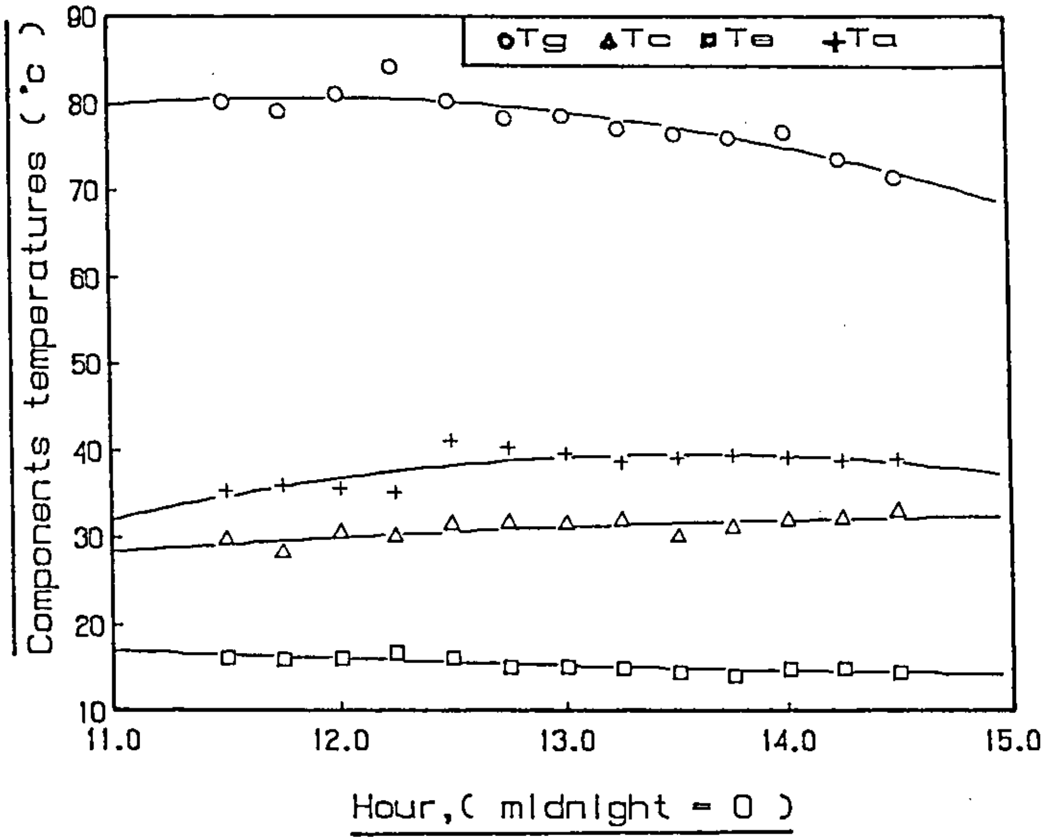


Figure 4.16 :Variation of components temperatures with time in the day ,ambient temp. = 29.69 °c initial space temp. 28.3 °c. with concentrater

4.4 Variation of COP

In this section, the variations of the experimental coefficients of performance, COP's, with other test parameters are discussed. These parameters include the solar energy, the inlet generator temperature, the mass flow rate of the water through the collector loop, the generator temperature, the condenser temperature, the evaporator temperature and the absorber temperature.

4.4.1 Solar energy

Figure 4.17 and 4.18 show the variation of the experimental coefficient of performance, COP_e, and the theoretical coefficient of performance, COP_{th}, with solar energy, these figures show that as the solar energy increases both COP's increase. This is so because an increase in solar energy leads to an increase in the generator temperature, this increases the amount of refrigerant leaving the generator; thus the cooling capacity increases which tends to increase the COP value.[18, 4]. As an illustration figure 4.17 shows that the maximum value of COP_e is 0.83 and the maximum value of COP_{th} attained is 2.9. This took place at a a solar energy of 240 wh/m^2 using the concentrator. Without using the concentrator, figure 4.18, shows that the maximum COP_e is 0.81 and the maximum COP_{th} is 2.6 This again illustrates the significance of the use of the concentrator. In considering all the test runs for the case of using the concentrator and the case without using it the two averages of COP_e were found to be equal 0.79 and 0.745, respectively. This shows that the increase in the COP as a result of adding the concentrator is about 6.0 %. Other figures which show this variation are shown in appendix C, figures C15 and C16.

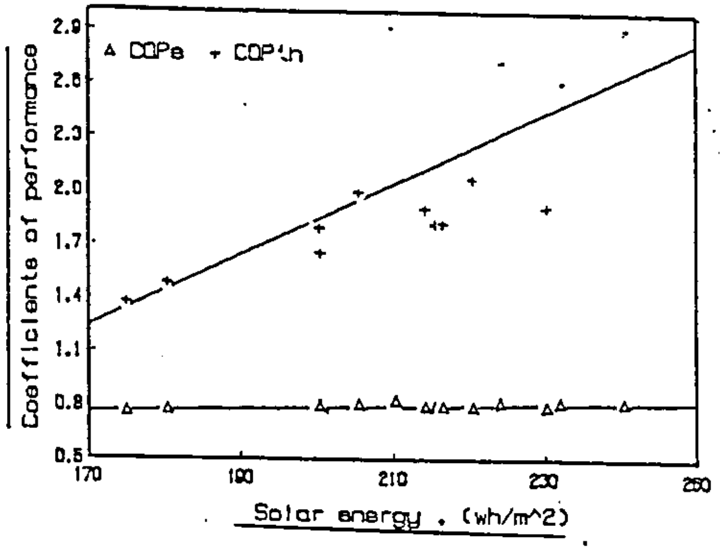


Figure 4.17 : Variation of theoretical and exp COP's with solar energy, ambient temp.= 29.7°C Initial space temp. = 28.3°c, with concen.

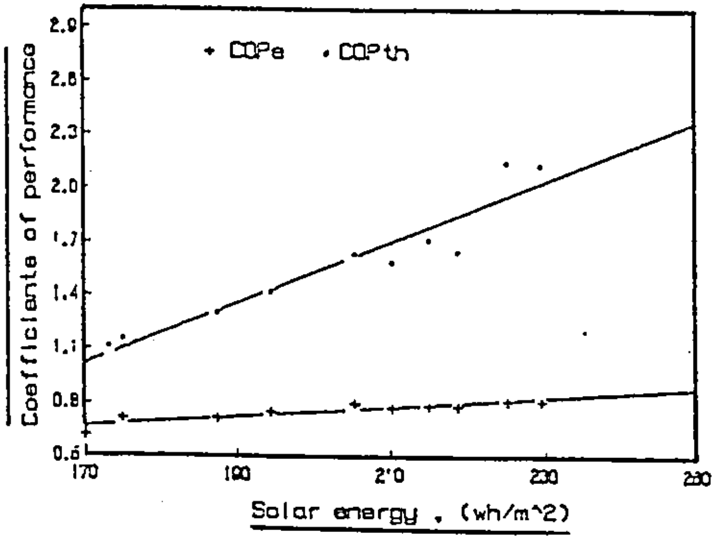


Figure 4.18 : Variation of theoretical and expe COP's with solar energy, ambient temp.=26.3°c, Initial space temp. = 28.3°c, without concen.

4.4.2 Generator inlet temperature

Figures 4.19 and 4.20 show the variation of the COP with generator inlet temperature. For the first case, figure 4.19 shows that as this temperature increases the value of COP_e increases. For example, at a maximum temperature of 95°C the COP_e is 0.83 while at a temperature of 80°C the COP is.79 . Again, figure 4.20 shows that the maximum temperature attained is 87°C with a COP_e of 0.80. However,the reason for the differences between the maximum generator inlet temperature for the two cases is according to the presence of the concentrator and the maximum solar energy recorded during the two days,250 $\frac{wh}{m^2}$ for the first case and 229.4$\frac{wh}{m^2}$ for the other day.It is known also that as the generator inlet temperature increases it means more refrigerant released from the solution which means that high COP occur;[18, 22, 4]

Other figures which show the variation of inlet generator temperature with COP are shown in appendix C,figures C17 and C18.

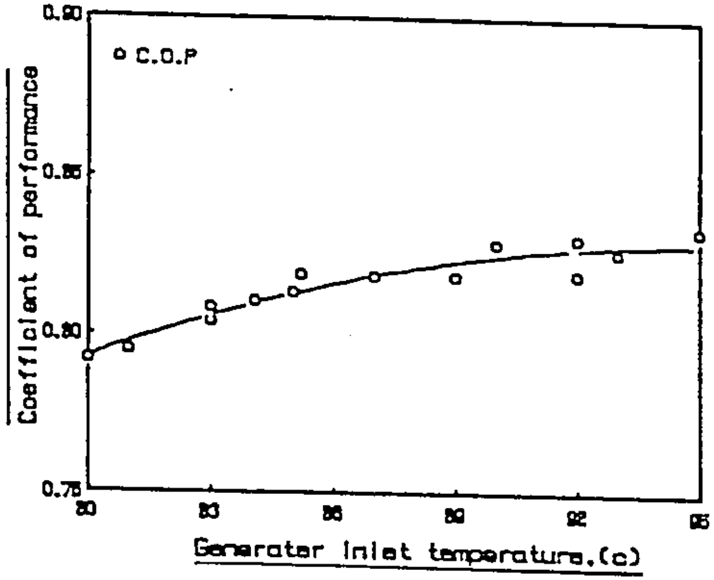


Figure 4.19 : Variation of generator inlet temp. coefficient of performance. ambient temp.=28°C initial space temp. = 28.7 °c, with concen.

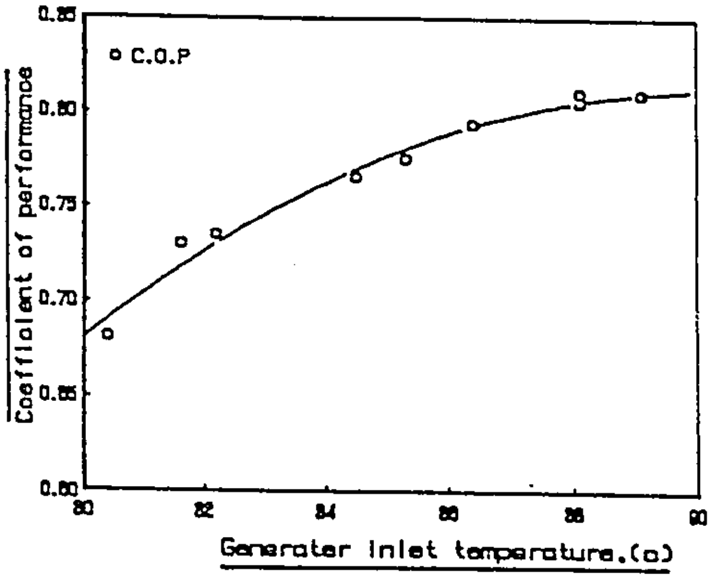


Figure 4.20 : Variation of generator inlet temp. coefficient of performance.ambient temp. =27.92 °C initial space temp. = 28.2 °c, without concen.

4.4.3 Mass flow rate of water

The effect of mass flow rate of water throughout the collectors loop on the value of COP is studied .Figures 4.21 and 4.22 show this variation .From the two figures we can see that the maximum COP recorded is at a flow rate of 30 g/s.Actually ,through the results obtained , the maximum COP recorded for all days lie between 20 g/s and 30 g/s .The explanation for this behaviour is that as the flow rate decreases it means that the time allowed for the water so as to get get more energy from the sun is increased.This increase means that we have high inlet generator temperature which , consequently increase the value of COP recorded. The other figures show the variation of mass flow rate of the water through collector loop with COP are shown in appendix C, figures C19 and C20.

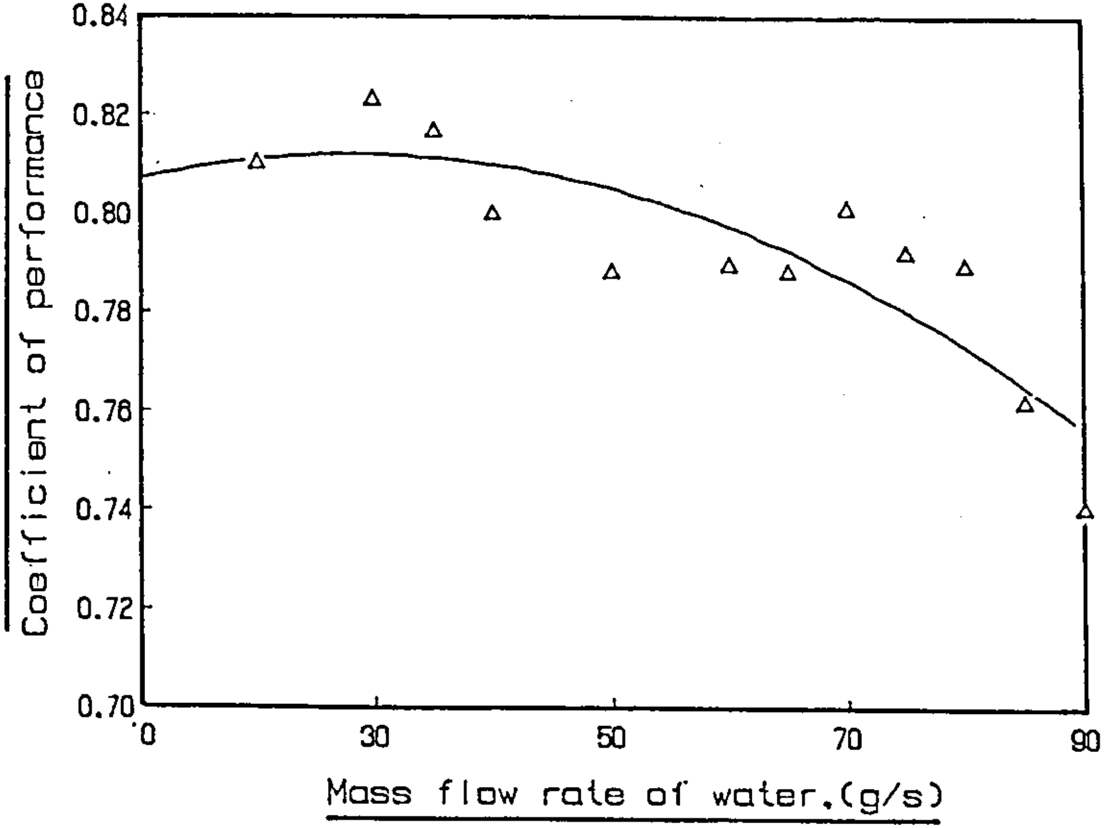


Figure 4.21 :Variation of COP with mass flow rate of water through collecters,ambient temp.=29.7°c , initial space temp. = 28.3,with concentrater

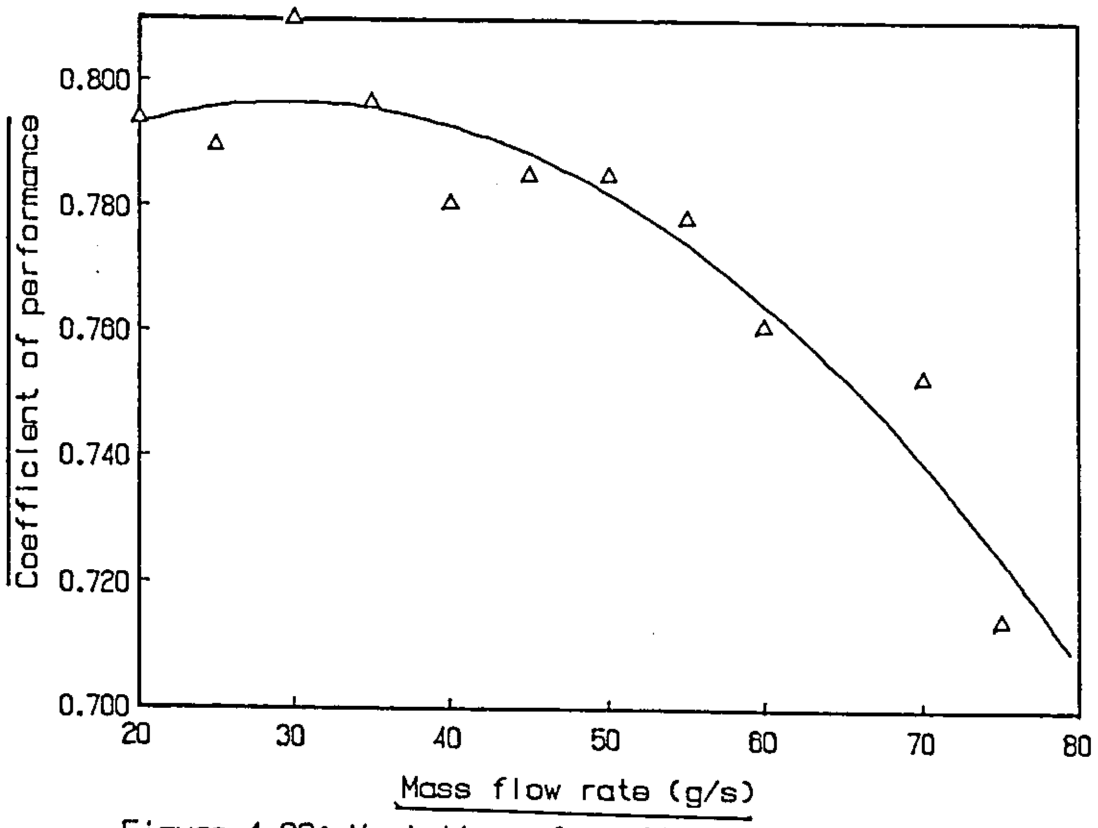


Figure 4.22: Variation of coefficient of performance with mass flow rate of water through collecters. ambient temp. = 29.3 c. initial space temp. = 29.0 c. without Concentrator

4.4.4 Other cycle temperatures

Throughout the rest of this section ,we are going to discuss the effect of components temperatures naimly,the generator temperature,the condenser temperature,the evaporator temperature and the absorber temperature on the value of COP.

As the generator temperature which is the temperature of the refrigerant leaving the generator increases this means that the concentration of the strong solution leaving the generator increase.However,the increase of the concentration of the strong solution has its negative effect on the value of COP.The explanation of this behaviour can be notice if we look at equations 28,27 and 31 of chapter 2.Equation 28 shows that we have a decrease of the flow rate of the strong solution;this decrease tends to increase ,according to mass balance equation 27 of chapter 2,the mass flow rate of the refrigerant leaving the generator so the COP value increase according to equation 31 and 5 of chapter 2.figures 4.23 and 4.24 shows this variation .Other figures which show this variation are listed in appendix C, figures C21 and C22.

At last ,the variation of the absorber temperature with the coefficients of performance are shown if figures 4.29 and 4.30.The absorber temperature has a negative effect on the coefficient of performance since an increase in absorber temperature tends to increase the concentration of the solution out from the absorber which has it's effect to decrease the flow rate of the refrigerant out from the generator thus decrease the coefficients of performance.Other figures show this variation are listed in appendix C, figures C27 and C28.

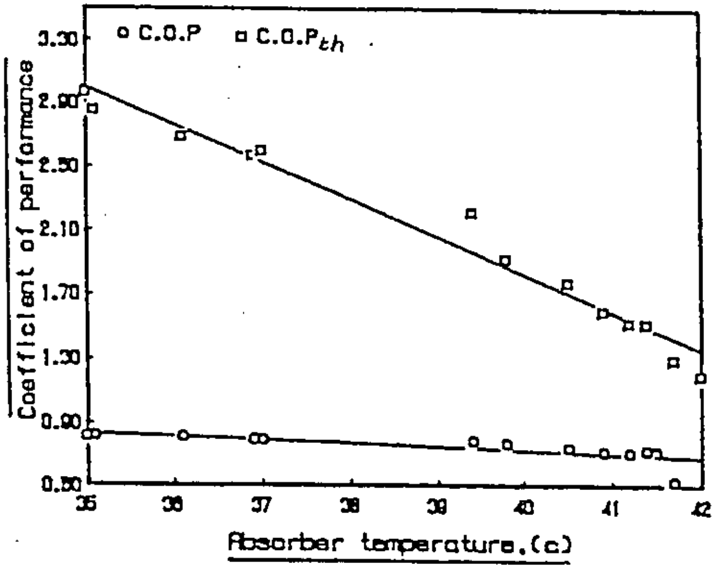


Figure 4.29 : Variation of absorber temp. with coefficient of performance. ambient temp. = 28.8 C initial space temp. = 28.5 °c. with concen.

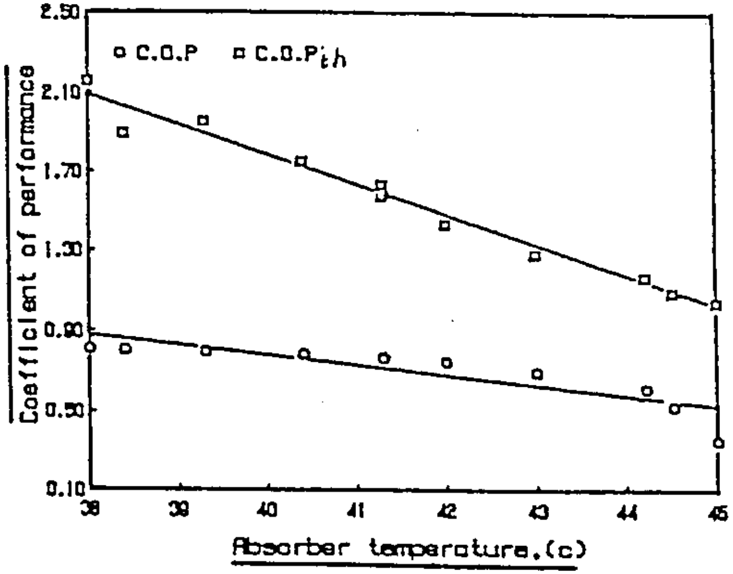


Figure 4.30 : Variation of absorber temp. with coefficient of performance . ambient temp.= 26.3°C initial space temp. = 26.2 °c. without concen.

A comparison between the present results obtained and those obtained by other researchers is presented. According to many researchers, the inlet generator temperature is the predominant factor that affects the other temperatures which in turn affect the the value of the coefficient of performance, [18, 4]. But, the generator inlet temperature is affected mainly by the available solar radiation energy as noted in section 4.2.1. Most researchers used flat plate collectors but noted that desired high temperatures can not be obtained by such collectors, [23, 18]. Accordingly, a concentrator was used with the flat plate collectors throughout this research as higher COP are desired. In addition, the climate of Jordan is known for its abundance with solar energy which helps achieve the desired high temperatures, hence the high COP's.

The average coefficient of performance recorded all the days using the concentrator was 0.789 and the maximum value of 0.83. For example by comparing the results of this research with those of Sayigh, [19], it can be seen from figure 4.31 that the range of the generator inlet temperature of his results occur between $70^{\circ}C$ and $87^{\circ}C$ with a maximum COP of 0.7, in comparison with the range of this research which covers the temperatures from an initial lower limit of $80^{\circ}C$ to a maximum limit of $95^{\circ}C$ with a maximum COP of 0.83. This shows that the COP obtained by this work increase by about 19 % from that of Sayigh.

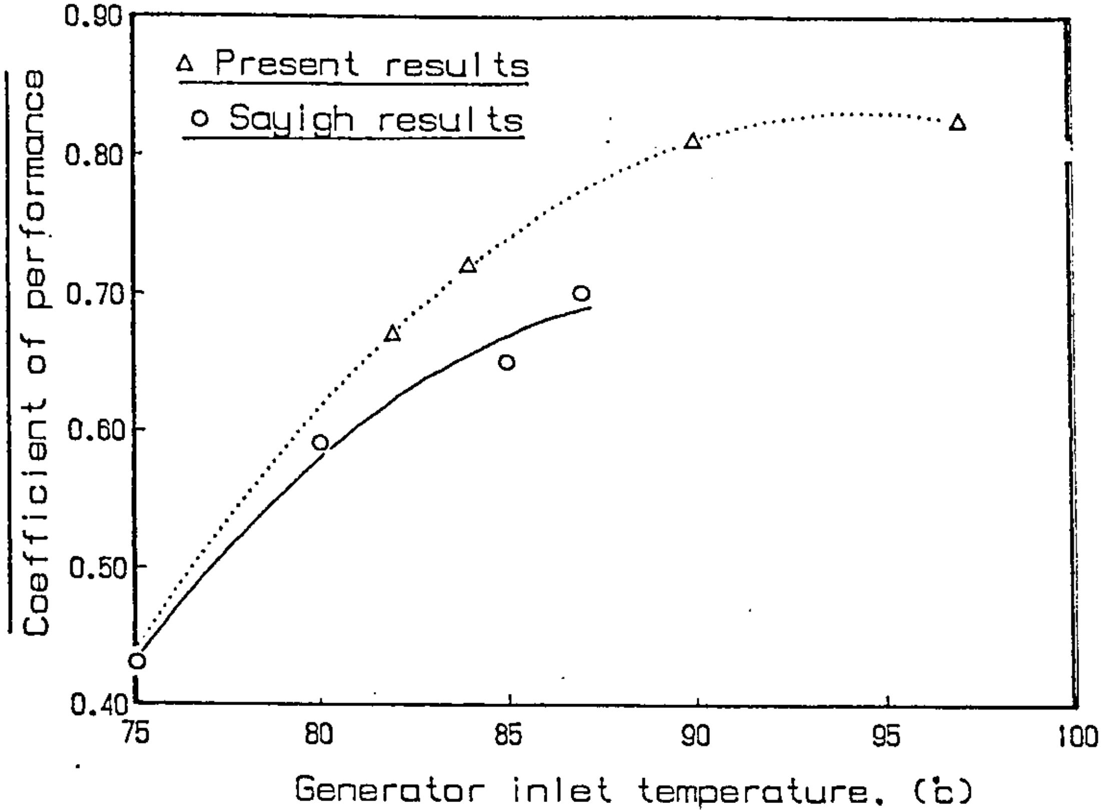


Figure 4.31 : Comparison between Sayigh results and present results .

4.5 Experimental and Simulated COPs

In this section, a comparison between experimental and computer simulated coefficients of performance (COPs) is discussed. From Tables 4.19 and 4.20 we can say that the simulation results and the experimental results are very close to each others. From tables 4.19 and 4.20 the average value of deviation, ϵ, is about 0.031 which shows a good agreement between the simulated and the experimental values of the COPs. This close agreement between these values is also shown in Figures 4.32 and 4.33. These figures show three general trends: (a) the close agreement between the experimental and the simulated COPs is verified by the small value of the deviation, ϵ, as has already been discussed above, (b) both COPs increase with dimensionless temperature difference which is defined as follows:

$$dimensionless\; temp.\, difference = \frac{T_g - T_c}{T_c} \qquad (4.1)$$

where T_g is the generator temperature, and T_c is the condenser temperature.

and (c) the rate of increase of both COPs is greater in the case of the use of the concentrator than the case without the concentrator.

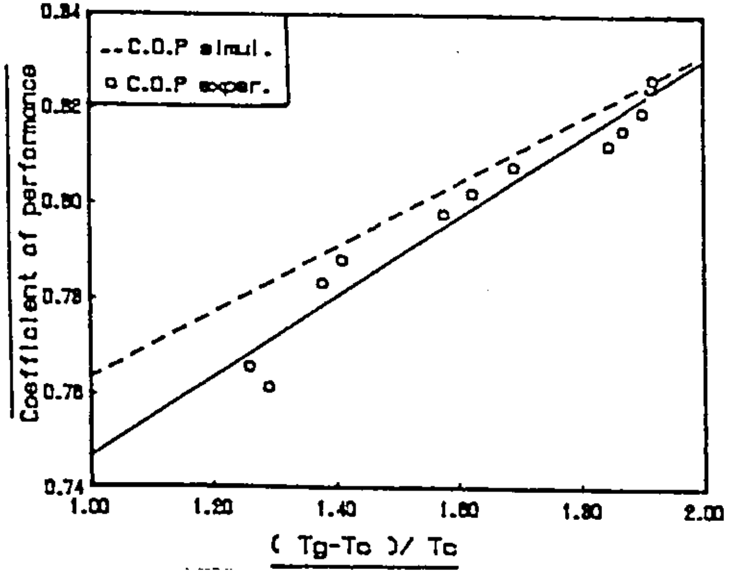


Figure 4.32 : Variation of coefficient of perform. with dimensionless temp. difference. ambient temp. =28.8c̊, initial space temp. = 28.8, with.

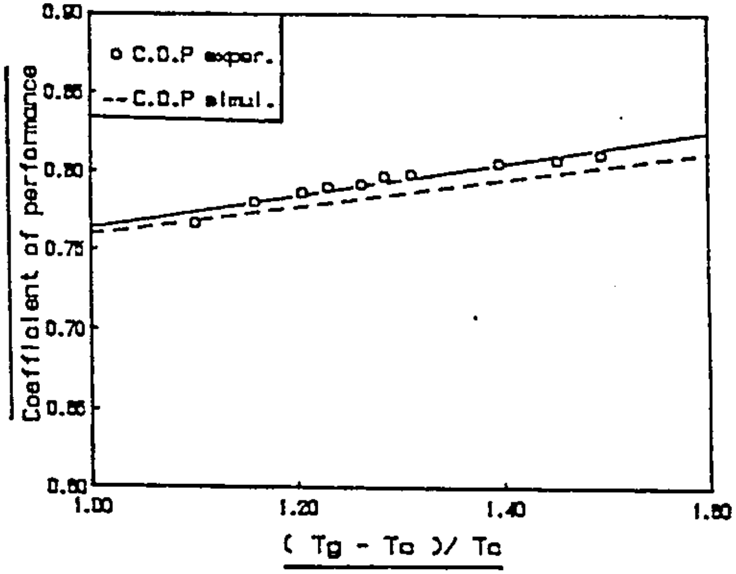


Figure 4.33 : Variation of coefficient of perform. with dimensionless temp. difference . ambient temp. = 27.7c, initial space temp. = 28.5 °c, without.

Figure 4.34 shows an example of the close agreement between the COPs with respect to the mass flow rate of water through the collector loop for all test runs. This figure also shows that the simulated COP is higher than the experimental COP for all the test period. This puts the simulated values between the theoretical and experimental ones although they are closer to the experimental values than the theoretical ones. Figure 4.35 also shows the agreement between the two COPs with respect to time of the day. This shows that the relative relationship between the experimental and the simulated values is independent of the these factors. Moreover, the simulated values as produced by the computer program are good predictions of the results, as demonstrated by the above comparisons.

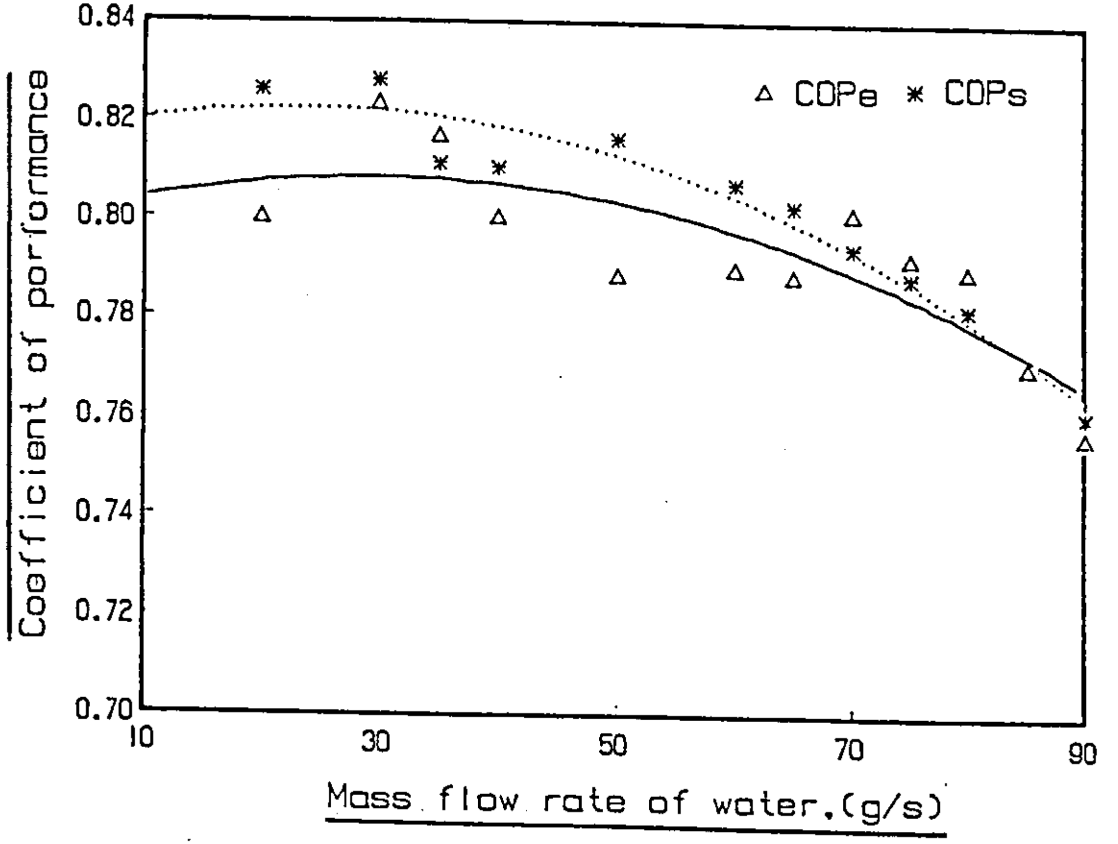


Figure 4.34:Variation of COP 's with mass flow rate of water through collecters.ambient temp.=29.7 . initial space temp. = 28.3.with concentrater

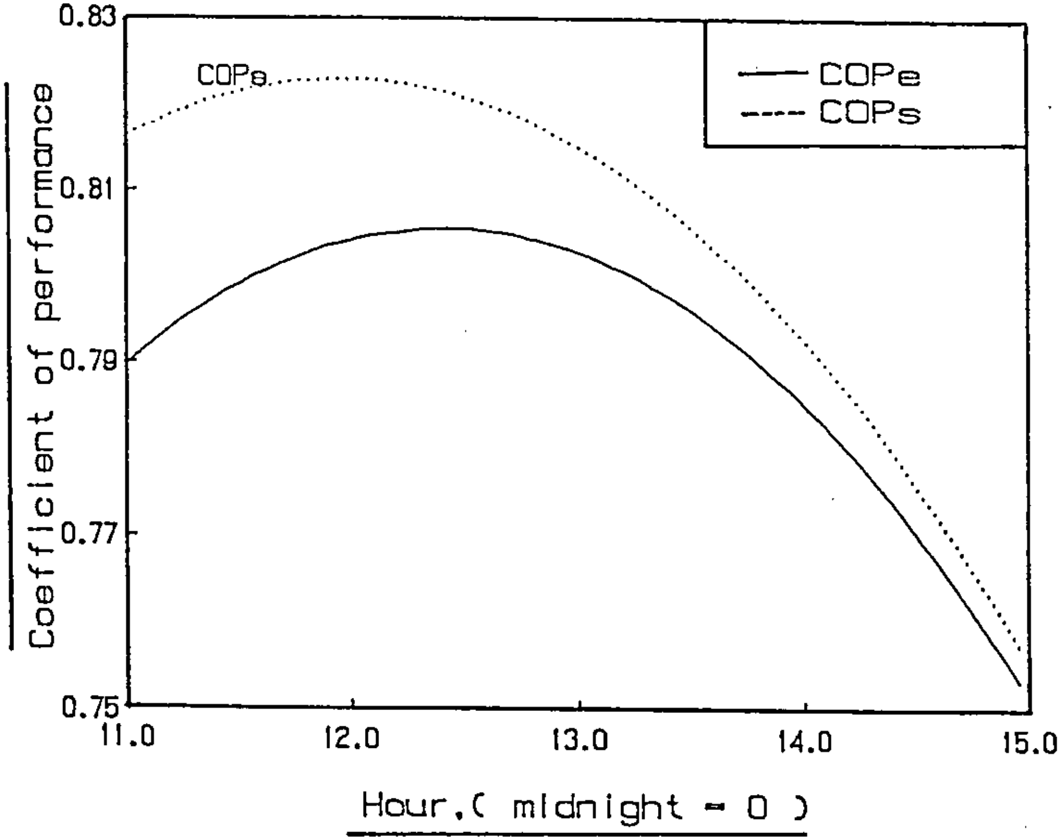


Figure .4.35 :Variation of experimental and simulated COP with time in the day,ambient temp. = 29.69 c initial space temp. 28.3 c. with concentrater

4.6 Performance curves

The experimental results of this research which are discussed above details the variation of the different parameters with COP. Unfortuently, we can not control the ambient conditions, as for example, we cannot keep the ambient temperature fixed and study the other variations with respect to this constant parameter. In order to do so, it is essential to relate all the test parameters with each other . This connection needs actual data which is difficult to obtain experimentally. Thus these were obtained from the various test runs and the simulation program as discussed in chapter 2.

The performance curves discussed below are the curves which predict the performance behaviour of an experimental set-up with the control of varying and fixing different parameters.

The study of the behaviour of the coefficient of performance by fixing the evaporator temperature and varying the inlet generator temperature is first studied. Figure 4.36 shows this behaviour which is consistent with a similar work done by Sayigh,[19]. From this figure we can see that for a fixed evaporator temperature, say $12°C$, as the inlet generator temperature increases the value of COP increase. For example, at an inlet generator temperature of $80°C$ the COP equals 0.76 and for generator temperature of $95°C$ the COP equals 0.81. This shown an increase of about 7.0 %. This figure also shows that as the evaporator temperature increases the value of the coefficient of performance increases. These results show consistency with our experimental results.

As discussed by many researchers, the generator temperature is not the only factor that affects the performance of the refrigeration cycle. The condenser, the evaporator and the absorber temperatures also have direct effect on the COP of the cycle,[22]. However, as a result of this fact, the performance behaviour is now studied by: (a) fixing the evaporator temperature and varying the condenser temperature and by (b) fixing the evaporator and the condenser temperatures and varying the absorber temperature. For case (a) we can notice from figure 4.37 that as the condenser temperature increases the coefficient of performance increases. For example, from the figure 4.37, at evaporator temperature of 12 $^{\circ}C$, condenser temperature of 28$^{\circ}C$, and absorber temperature of 30$^{\circ}C$ the coefficient of performance is 0.83; while for an evaporator temperature of 12$^{\circ}C$, condenser temperature of 34$^{\circ}C$, and an absorber temperature of 30$^{\circ}C$ the coefficient of performance is 0.80. Thus a decrease of condenser temperature of 6$^{\circ}C$ gives an increase of coefficient of performance of 4%. For case (b) we see that as the absorber temperature increases the coefficient of performance decreases. For example, figure 4.37, when evaporator temperature was 12 $^{\circ}C$,condenser temperature was 34 $^{\circ}C$, and absorber temperature was 30 $^{\circ}C$, the coefficient of performance was 0.81; while when the the same evaporator and condenser temperatures were maintained but the absorber temperature increased to be 35 $^{\circ}C$ the coefficient of performance was 0.79. The curve obtained here is consistent with similar work don by Lazzarin et. al, [22].

The last study taking in to consideration the absorber and the condenser temperatures as the parameters to be studied and discussed with constant evaporator temperature of 12 $^{\circ}C$. Figure 4.37 shows this variation. From this figure we can notice two behaviours: (i) The decrease of coefficient of performance with the increase in condenser temperature and (ii) the increase of the coefficient with the decrease in condenser temperature. For the first case, (i), and from the figure, at a condenser temperature of 28$^{\circ}C$, absorber temperature of 40$^{\circ}C$, and evaporator temperature of 12 $^{\circ}C$, the coefficient of performance was 0.80; while for a condenser temperature of 34 °C, absorber temperature of 40°C and evaporator temperature of 12 °C the coefficient of performance was 0.75. This means that a decrease in condenser temperature of 6°C tends to gives an increase in coefficient of performance of 6%. For the other case, from the same figure we can say that when the condenser temperature was 28°C, absorber temperature 40°C, the coefficient of performance was 0.8; while when the condenser temperature was 34 °C and the absorber temperature was 40 °C the coefficient of performance was 0.75.

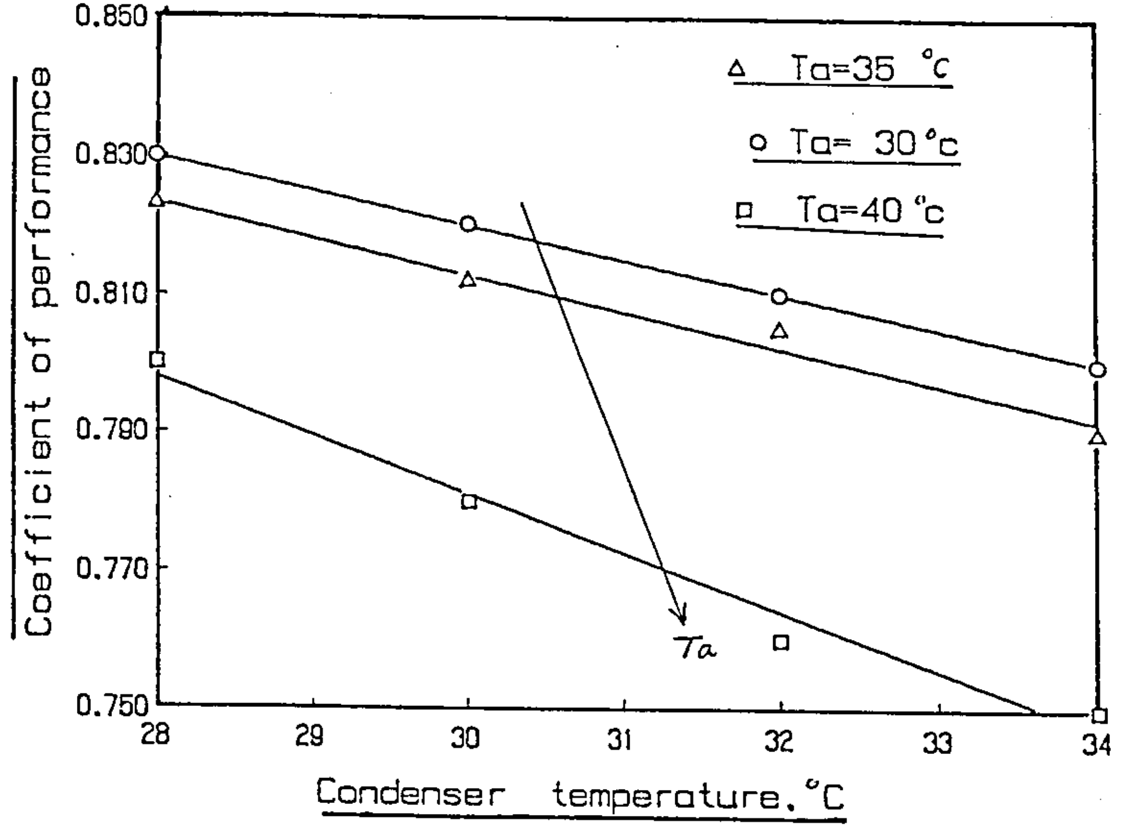


Figure 4.37 : Variation of COP with (Tc, Ta)
Tam = 26.5 °c, cooling water temp. = 20 c, mass
flow rate of water = 20 g/s , Tgi= 90 °C, Te=12 °c

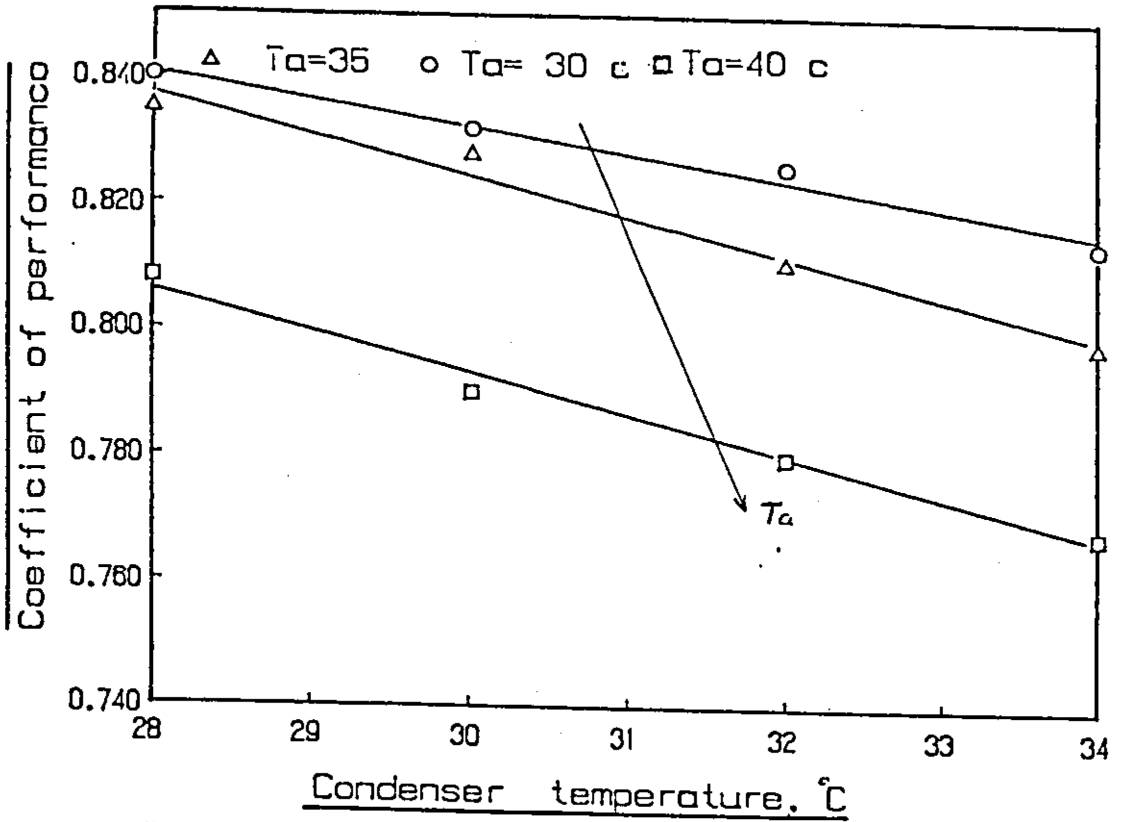


Figure 4.39 : Variation of COP with (Tc, Ta)
Tam = 26.5 °c, cooling water temp. = 20 °c, mass flow rate of water = 20 g/s , Tgi = 90 °C, Te=16 °c

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 General

This chapter contain the main conclusions which are obtained from experimental and simulation results. The results which is obtained using a locally designed and manufactured solar operated lithium bromide water absorption system tested in Amman, Jordan could be divided in to two parts: (a) results from experimental work, and (b) results from simulation work.

5.2 Conclusions from Experimental

There are many conclusions which are extracted from experimental work:

1. The selected range for operation of the cycle shows good coefficients of performance. The selected range is based on the temperature of the water inlet to generator, the lower limit for this temperature was selected to be $80^{\circ}C$.Below this temperature, the cycle is off.

2. the presence of the concentrator increase the temperature of the water entering the generator by an additional $6^{\circ}C$.This tends to increase the value of the coefficient

of performance by a factor of 6%.

3. The coefficient of performance calculated for all days show a good indicated value in comparison to others; this because of climate of Jordan which is rich in solar energy, and the presence of the concentrator enhance in increasing the COP value. For example, the research results shows an increase of 13% of COP compared to Sayigh.

4. The influence of variation the flow rate of water through collector loop on the COP is discussed. It is found that as the high COP occur at a low flow rate (20 g/s to 30 g/s). This is because the lower is the flow rate, the more is the time allowed for the solution in the generator to extract heat from water.

5. The influence of generator inlet temperature on COP shows that an increase in this temperature tends to increase the value of COP which is consistent with previous work done by many researchers.

6. The influence of generator temperature, condenser temperature, evaporator temperature, and absorber temperature on COP were discussed. The generator and the evaporator temperatures have their positive effect on COP while the others have their negative effect.These results are consistent with previous work.

5.3 Conclusions from Simulation

There are many conclusions which concern with simulation, they are as follows:

1. The numerical computer simulation of the system based on the solution of simultaneous heat and mass balances equations is done.The simulation show a good

agreement with the experimental case, this agreement can be shown in chapter 4 of this theses.

2. The simulation results insist on the importance of the inlet generator temperature as a predominant factor that affect first the components temperatures first and the coefficient of performance next.

3. The influence of the generator, the condenser, the evaporator, and the absorber temperatures on the coefficient of performance was discussed. The results obtained by simulation results are consistent with that obtained by experimental .

4. The performance curves as defined in chapter 4 of this thesis are important since they predict the behaviour of the system under the conditions of fixing and varying different parameters. However, Performance curves are obtained for the system under test.These curves are extracted from the simulation programme. The performance curves which are obtained are consistent with other curves obtained by many researchers .

5. The simulation results show that, not only the inlet generator and the evaporator temperature affect the value of COP, but the condenser and the absorber temperatures have their direct effect also.The condenser and the absorber temperatures are an important factors which are to be taken into consideration during the operation of the absorption cycle.Their ability to be controlled through varying the cooling water temperature strengthen their importance.

5.4 Recommendations

Jordan considered as one of the poor countries which lack adequate conventional energy sources.This highlight the urgent need for the country to develop and utilize it's potential indigenous sources of energy in the most appropriate , efficient and accelerated manner. Cooling utilizing solar energy, which is the interest of this research, is needed most when the sunshine is strongest. This may be the primary motivating factor in the continuing development of solar cooling systems. This research deals with an absorption cooling system which is tested in Amman, Jordan. According to present research results, such systems achieve good coefficient of performance. This achievement due, mainly, to the fact that Jordan is rich in solar energy.However, it is recommended to focus on these systems and began to utilize them. Such utilization will be most evident in rural areas.

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Table A.1:data collected

Day:29 -8-1990,with concentrator

initial space temp. = 28.3 °C

flow rate of cooling water = 0.053 l/s

Time	$\dot{m}$ m/s	V m/s	I $\frac{wh}{m_2}$	T_3 °C	T_{11} °C	T_9 °C	T_g °C	T_{12} ° C	T_{13} °C	T_6 °C	T_c °C
11:30	20	1.2	224.0	94.8	84.8	50.2	80.2	19.0	24.0	52.7	29.5
11:45	30	1.3	210.2	95.7	82.1	51.3	79.1	18.5	24.6	52.9	28.1
12:00	35	1.3	232.0	94.0	81.3	50.1	81.0	20.0	24.1	52.9	30.5
12:15	40	2.4	240.4	95.3	87.0	51.0	82.0	20.1	25.1	52.5	30.0
12:30	45	1.5	220.4	94.8	84.4	50.2	80.0	20.5	24.7	52.7	31.5
12:45	50	1.2	214.0	92.2	80.1	50.3	78.2	20.5	23.5	55.1	31.6
01:00	55	2.2	230.2	94.8	80.5	50.9	78.5	20.5	23.8	54.1	31.5
01:15	60	1.8	216.2	91.4	79.9	51.4	77.0	21.3	23.7	56.4	31.9
01:30	65	1.3	205.4	88.7	79.2	52.3	76.3	19.6	22.9	56.7	30.0
01:45	70	1.5	200.2	85.3	78.1	54.0	76.0	20.5	23.7	58.9	31.1
02:00	75	1.2	215.3	87.2	78.3	54.4	76.5	21.6	24.0	57.9	31.8
02:15	80	1.2	200.3	84.2	77.5	54.5	73.4	21.1	24.0	57.6	32.1
02:30	85	2.2	180.4	82.1	76.2	54.3	71.3	21.5	21.0	58.0	32.9
02:45	90	2.2	175.0	80.7	75.1	50.9	69.8	23.0	25.8	57.9	33.2

Table A.1:continued

Time	T_e	$T_{13'}$	$T_{14'}$	T_{10}	$T_{8'}$	T_a	T_{s1}	T_{s2}	T_{am}	T_1	T_2
11:30	16.0	19.0	22.8	43.0	22.1	35.3	25.1	25.3	29.5	58.2	89.2
11:45	15.9	18.5	23.0	44.2	22.6	35.9	24.1	24.4	30.1	57.2	89.1
12:00	16.2	20.0	24.5	42.6	21.9	35.4	23.1	23.7	31.3	53.3	88.2
12:15	16.8	20.1	24.1	41.3	21.5	35.0	21.1	23.3	30.0	54.3	88.7
12.30	16.1	20.8	23.0	44.0	22.1	43.0	21.9	21.7	30.1	51.0	85.7
12.45	15.1	20.5	23.6	43.6	23.0	40.1	21.8	21.3	29.6	58.3	87.2
01:00	15.0	20.5	22.5	44.0	22.8	40.0	20.8	20.6	28.9	57.0	88.1
01:15	14.9	21.3	23.0	45.3	23.6	39.5	19.9	19.7	29.1	48.2	85.3
01:30	14.4	19.6	21.9	46.1	22.8	38.5	19.6	19.5	30.1	41.2	82.2
01:45	14.1	20.5	22.1	43.6	21.3	39.0	18.9	18.7	30.2	43.5	80.3
02:00	14.9	21.6	23.4	45.1	22.7	39.3	18.6	18.5	29.6	43.9	79.1
02:15	14.8	21.1.1	22.4	46.2	20.9	39.0	18.0	17.9	29.5	42.3	78.3
02:30	14.5	21.0	23.1	44.3	20.7	38.6	17.1	18.0	28.9	44.2	75.2
02:45	14.3	23.0	24.0	43.9	20.1	38.9	17.0	18.0	28.7	45.1	74.3

Table A.2:data collected

Day:1-9-1990,with concentrator

initial space temp. = 28.7 °C

flow rate of cooling water = 0.054 l/s

Time	m m/s	V m/s	I $\frac{wh}{m_2}$	T_3 °C	T_{11} °C	T_9 °C	T_g °C	T_{12} °·C	T_{13} °C	T_5 °C	T_c °C
11:30	20	2.2	205.4	85.0	81.4	55.4	76.0	19.3	22.6	54.7	29.1
11:45	25	1.6	208.4	84.1	81.1	56.3	75.8	20.6	23.5	56.4	29.6
12:00	30	2.3	264.3	95.0	86.1	46.2	84.1	18.3	22.1	58.3	26.0
12:15	35	2.8	202.3	84.0	80.9	55.4	73.1	21.0	24.4	54.6	32.1
12:30	40	1.0	240.2	93.0	83.4	49.4	83.3	18.0	21.9	55.1	26.0
12:45	45	1.2	250.4	92.0	85.4	47.3	82.9	18.2	22.1	54.9	26.8
01:00	50	0.8	232.3	92.0	83.9	51.3	81.9	18.5	22.0	54.3	27.2
01:15	55	1.3	228.0	90.0	84.9	47.2	80.1	19.0	23.0	55.3	28.0
01:30	60	1.4	221.2	89.0	82.6	50.7	79.0	19.2	22.9	59.2	28.3
01:45	65	1.9	215.3	87.0	82.1	53.3	78.6	19.4	23.0	57.1	29.0
02:00	70	2.1	210.2	85.2	82.0	50.4	76.3	19.4	23.1	56.3	29.5
02:15	75	2.8	205.3	84.1	81.1	56.3	75.1	19.6	22.5	56.4	29.4
02:30	80	2.3	202.4	83.0	78.1	57.0	73.1	20.0	22.7	56.3	30.0
02:45	85	3.8	185.2	80.0	78.3	56.2	72.4	21.3	24.1	58.9	32.5

Table A.2:continued

Time	T_e	$T_{13'}$	$T_{14'}$	T_{10}	$T_{8'}$	T_a	T_{s1}	T_{s2}	T_{am}	T_1	T_2
11:30	14.7	19.3	22.0	45.1	20.9	39.2	26.0	26.9	29.8	53.1	80.3
11:45	13.1	20.6	23.1	45.3	20.4	39.5	25.1	25.0	30.0	52.0	79.3
12:00	17.1	18.3	22.3	40.3	22.3	40.0	25.4	25.3	29.6	53.0	87.2
12:15	13.5	19.6	23.9	44.4	19.7	36.3	24.3	24.1	30.0	49.0	77.2
12.30	16.9	21.0	25.1	44.8	22.5	37.0	23.9	23.0	30.5	45.0	88.0
12.45	16.5	19.2	23.1	45.2	22.3	37.4	23.0	23.2	29.7	43.0	86.3
01:00	16.0	19.0	22.9	45.3	22.0	38.3	22.6	22.7	30.3	42.0	86.1
01:15	15.5	19.0	22.0	44.9	22.4	38.5	22.6	22.0	29.0	41.5	84.0
01:30	15.2	19.2	22.8	46.6	21.7	38.5	21.6	21.7	28.0	41.0	83.4
01:45	14.1	19.3	22.7	47.9	21.6	38.2	21.1	21.0	28.4	40.5	81.3
02:00	13.0	19.4	22.6	46.3	21.3	39.5	21.0	20.5	27.0	40.3	80.2
02:15	13.3	19.6	21.1	45.3	20.4	40.0	20.0	19.5	27.1	41.4	79.3
02:30	13.4	20.0	21.9	41.5	20.3	41.0	19.6	19.0	26.9	42.3	74.2
02:45	13.2	21.5	23.0	42.7	19.7	41.0	18.6	18.0	26.7	43.4	73.2

Table A.3:data collected

Day:2 -9-1990,with concentrator

initial space temp. = 28.0 $^{\circ}C$

flow rate of cooling water = 0.062 l/s

Time	m m/s	V m/s	I $\frac{wh}{m_2}$	T_3 $^{\circ}C$	T_{11} $^{\circ}C$	T_9 $^{\circ}C$	T_g $^{\circ}C$	T_{12} $^{\circ}$ C	T_{13} $^{\circ}C$	T_5 $^{\circ}C$	T_c $^{\circ}C$
11:30	20	1.9	209.3	91.2	78.9	51.3	77.4	21.9	24.0	59.1	32.1
11:45	30	2.0	211.3	95.4	79.0	51.4	78.0	20.1	23.2	56.2	30.4
12:00	35	2.0	217.2	92.5	79.9	45.2	78.9	19.8	23.8	54.1	28.3
12:15	40	1.4	215.0	94.0	80.7	47.3	79.1	18.9	22.7	56.1	27.7
12:30	45	1.8	240.0	97.0	80.4	46.4	80.2	18.9	23.0	51.3	27.9
12:45	50	1.6	230.0	95.1	79.3	47.3	79.0	18.3	23.2	51.2	27.8
01:00	55	1.1	225.0	93.0	80.0	44.4	79.9	18.6	22.9	52.4	28.0
01:15	60	3.1	215.0	92.0	79.2	50.9	78.8	18.6	22.2	55.3	28.7
01:30	65	1.2	205.4	89.0	79.4	54.3	77.3	22.9	24.9	58.1	33.0
01:45	70	1.4	205.2	85.0	79.9	52.2	75.1	22.1	24.9	50.1	32.8
02:00	75	1.6	188.1	82.0	78.3	50.3	73.2	22.1	24.8	51.1	32.8
02:15	80	2.5	175.1	81.0	77.5	54.9	72.3	21.9	24.3	52.1	33.2
02:30	85	3.0	173.8	80.0	76.4	50.2	72.1	21.0	23.0	52.0	32.6

Table A.3:continued

Time	T_e	$T_{13'}$	$T_{14'}$	T_{10}	$T_{8'}$	T_a	T_{s1}	T_{s2}	T_{am}	T_1	T_2
11:30	14.9	21.9	23.9	44.3	22.1	39.5	26.3	26.6	29.8	60.7	82.0
11:45	15.0	20.1	23.0	45.4	22.0	39.0	25.1	25.0	30.2	59.2	84.4
12:00	16.4	19.8	23.0	47.7	21.4	35.4	24.4	24.3	30.9	58.1	87.6
12:15	16.1	18.9	22.8	49.2	21.9	37.2	23.9	23.3	30.9	57.3	86.3
12.30	16.9	18.2	21.5	45.3	20.9	33.1	23.0	22.9	30.1	55.2	90.2
12.45	17.1	18.3	22.0	44.2	20.4	32.1	22.9	22.7	28.1	63.2	89.0
01:00	16.8	19.6	22.9	46.4	20.3	34.2	22.7	22.4	27.9	60.3	88.2
01:15	15.2	18.6	21.3	47.3	22.0	38.2	22.0	21.9	27.9	58.2	85.3
01:30	14.7	19.6	23.6	41.2	22.9	39.9	22.0	21.5	26.2	55.4	81.2
01:45	14.5	22.1	23.5	40.1	23.0	40.0	21.9	21.0	25.3	52.1	80.3
02:00	14.4	21.9	24.1	40.0	23.1	40.2	21.5	21.0	27.1	51.0	79.1
02:15	14.1	22.1	23.2	45.2	23.2	40.5	20.4	20.3	26.3	50.1	75.1
02:30	14.0	21.9	23.0	45.0	22.9	41.0	19.8	19.5	26.2	50.2	75.4

Table A.4:data collected

Day:3-9-1990,with concentrator

initial space temp. = 28.5 °C

flow rate of cooling water = 0.053 l/s

Time	m m/s	V m/s	I $\frac{wh}{m_2}$	T_3 °C	T_{11} °C	T_9 °C	T_g °C	T_{12} °C	T_{13} °C	T_5 °C	T_c °C
11:30	20	2.4	220.3	91.4	79.2	49.1	78.2	19.0	22.3	52.3	28.2
11:45	30	2.7	213.0	90.1	80.4	50.4	78.1	20.5	23.9	63.4	31.1
12:00	40	2.4	252.0	97.0	83.1	50.3	80.4	19.7	22.3	59.3	29.0
12:15	50	3.0	251.0	96.0	82.4	50.3	80.2	19.1	22.3	60.1	29.1
12:30	60	2.3	229.0	93.9	78.3	47.3	79.2	19.1	22.1	50.1	28.1
12:45	65	2.7	209.0	85.4	78.3	53.3	76.1	21.3	23.9	62.4	32.9
01:00	70	2.5	238.0	94.2	81.9	50.4	79.9	20.2	23.6	62.3	30.1
01:15	75	2.6	217.0	90.5	79.0	51.0	78.1	20.6	23.6	56.3	28.6
01:30	80	1.6	216.0	88.3	80.0	50.3	77.2	20.5	22.4	60.3	31.7
01:45	85	2.3	210.0	87.5	79.1	53.4	76.3	22.0	24.1	59.4	32.8
02:00	90	2.1	200.0	85.4	78.3	53.3	76.1	22.3	24.9	62.4	32.9
02:15	95	2.4	190.0	84.8	77.4	54.3	75.2	22.6	24.3	62.1	34.0
02:30	95	1.8	165.0	82.2	75.3	55.0	70.1	22.3	23.3	61.3	33.1
02:45	95	2.0	164.0	82.0	74.3	55.2	67.1	22.3	23.9	61.3	33.2

Table A.4:continued

Time	T_e	$T_{13'}$	$T_{14'}$	T_{10}	$T_{8'}$	T_a	T_{s1}	T_{s2}	T_{am}	T_1	T_2
11:30	15.8	19.0	23.0	50.3	21.6	35.2	26.1	26.0	27.6	53.2	85.2
11:45	14.8	20.5	22.8	46.1	21.5	39.9	25.0	25.1	27.5	50.5	84.9
12:00	15.4	18.7	22.0	50.0	22.2	37.1	24.1	23.9	27.2	59.5	90.1
12:15	15.4	19.1	23.1	49.3	22.1	37.0	23.2	23.3	27.2	52.1	90.3
12.30	15.9	19.1	22.2	50.2	21.5	35.1	22.7	22.5	28.1	63.4	88.7
12.45	14.2	21.3	22.1	44.9	26.0	41.3	22.1	21.9	27.8	60.2	80.0
01:00	15.2	20.2	22.9	48.2	21.3	39.5	21.2	21.6	29.1	60.2	88.3
01:15	15.8	19.7	22.3	50.1	20.6	36.2	21.1	21.0	28.0	68.9	84.3
01:30	14.7	20.5	22.5	45.1	20.3	40.6	20.6	20.3	28.8	62.1	82.3
01:45	14.5	22.0	23.4	44.9	20.4	41.2	20.2	20.0	28.9	50.4	80.2
02:00	14.2	22.3	23.8	44.9	21.0	41.3	19.2	19.0	28.5	52.9	79.3
02:15	13.8	22.6	23.7	45.0	20.5	41.5	18.8	18.3	27.4	50.2	77.3
02:30	13.4	22.3	23.2	43.9	19.6	41.8	18.5	18.6	26.3	50.3	76.3
02:45	13.2	22.3	23.5	43.9	19.2	42.0	18.2	18.3	26.0	50.0	76.0

Table A.5:data collected

Day:4-9-1990,with concentrator

initial space temp. = 28.8 °C

flow rate of cooling water = 0.067 l/s

Time	m m/s	V m/s	I $\frac{wh}{m^2}$	T_3 °C	T_{11} °C	T_9 °C	T_g °C	T_{12} °C	T_{13} °C	T_5 °C	T_c °C
11:30	20	2.1	233.0	90.6	84.3	55.3	78.1	20.1	23.9	54.9	29.0
11:45	25	1.6	211.9	86.3	82.1	55.1	77.4	19.8	22.4	51.7	29.5
12:00	30	2.6	214.1	87.0	80.3	58.1	77.3	20.3	22.5	53.1	30.0
12:15	35	2.7	307.6	96.3	82.2	48.3	82.1	18.8	23.9	62.3	27.6
12:30	40	2.1	283.0	93.8	85.1	54.3	81.1	19.7	22.9	54.1	28.9
12:45	45	1.3	219.0	88.0	80.3	46.1	79.3	18.1	22.0	53.5	27.2
01:00	50	2.0	219.0	87.0	81.4	48.3	77.0	18.8	23.9	52.8	27.6
01:15	55	1.8	224.0	86.3	80.3	58.1	77.3	20.3	22.5	53.1	30.0
01:30	60	1.4	213.0	85.2	79.4	59.3	75.2	20.3	22.5	52.0	31.1
01:45	65	1.2	206.0	84.2	79.6	60.1	74.2	20.2	22.4	51.8	31.2
02:00	70	0.6	198.0	82.1	79.1	62.1	73.2	21.1	23.3	51.9	32.4
02:15	75	1.5	190.0	81.9	78.3	60.1	73.2	21.0	23.0	50.6	32.6
02:30	80	2.3	185.0	80.8	77.3	59.4	72.1	21.9	23.0	50.0	32.7

Table A.5:continued

Time	T_e	$T_{13'}$	$T_{14'}$	T_{10}	$T_{8'}$	T_a	T_{s1}	T_{s2}	T_{am}	T_1	T_2
11:30	14.6	20.1	22.6	55.3	20.1	38.5	27.0	26.9	28.0	49.3	85.3
11:45	14.5	19.8	21.4	51.8	20.1	39.0	25.2	25.9	28.1	42.3	80.1
12:00	14.0	20.3	22.1	50.1	19.9	39.2	24.3	24.7	28.8	52.3	82.9
12:15	15.1	18.8	21.9	56.7	18.3	37.4	23.4	24.0	28.5	60.3	90.2
12.30	14.7	19.7	22.8	55.4	20.0	38.2	22.2	22.2	28.5	60.4	86.1
12.45	15.5	18.1	21.5	54.1	17.3	36.5	21.2	21.4	28.8	55.2	83.9
01:00	15.1	19.8	23.0	56.7	18.3	37.4	21.0	21.0	29.1	50.1	84.4
01:15	14.0	20.3	22.1	50.2	19.9	39.2	20.5	20.7	28.7	52.1	82.9
01:30	14.5	20.3	22.0	49.3	19.3	39.4	20.3	20.7	30.1	54.1	80.2
01:45	14.3	20.2	21.9	48.3	21.5	39.6	19.1	19.9	29.8	50.0	80.2
02:00	14.0	21.1	22.5	43.2	20.4	40.0	19.0	19.3	30.3	45.3	74.9
02:15	13.8	21.0	22.6	41.3	19.7	40.5	18.8	18.9	28.6	44.2	76.3
02:30	13.5	21.9	22.6	41.0	19.6	41.2	18.5	18.3	27.5	43.2	74.9

Table A.6:data collected

Day:8-9-1990,without concentrator

initial space temp. = 26.2 °C

flow rate of cooling water = 0.050 l/s

Time	m m/s	V m/s	I $\frac{wh}{m_2}$	T_3 °C	T_{11} °C	T_9 °C	T_g °C	T_{12} ° C	T_{13} °C	T_5 °C	T_c °C
11:15	20	1.1	225.1	87.2	81.4	53.9	78.2	20.2	26.4	56.1	30.0
11:30	25	3.3	214.9	87.4	82.4	56.9	77.3	20.2	25.4	57.1	30.0
11:45	30	2.9	229.4	88.4	82.1	54.1	78.5	20.0	26.2	55.1	31.4
12:00	35	3.0	205.4	85.6	79.6	56.3	76.5	21.2	25.9	58.0	32.0
12:15	40	3.5	218.6	88.1	83.4	54.9	76.9	21.1	26.3	58.1	31.9
12:30	45	4.6	210.2	86.4	80.6	57.4	76.4	21.1	26.3	57.5	32.3
12:45	50	4.8	194.3	84.1	79.2	55.8	75.0	22.2	26.9	58.1	33.2
01:00	55	4.2	187.4	83.0	78.4	56.9	74.0	22.1	26.1	55.1	33.7
01:15	60	1.5	175.0	82.1	77.3	54.9	73.9	22.2	25.3	56.1	33.0
01:30	65	3.0	170.0	80.1	76.4	53.9	73.5	23.1	25.2	57.1	34.1
01:45	70	4.2	173.1	80.0	76.1	58.9	73.2	23.2	25.2	58.1	34.1

Table A.6:continued

Time	T_e	$T_{13'}$	$T_{14'}$	T_{10}	$T_{8'}$	T_a	T_{s1}	T_{s2}	T_{am}	T_1
11:15	14.3	20.2	24.9	50.0	17.4	37.0	25.2	25.0	26.3	57.2
11:30	13.8	20.2	24.0	51.0	17.9	40.9	24.4	24.6	26.5	54.7
11:45	14.5	20.0	23.6	51.9	18.2	38.2	23.9	24.0	27.0	55.4
12:00	13.6	21.2	24.0	50.2	16.3	40.0	23.6	23.8	26.8	58.2
12:15	13.7	21.1	24.8	50.1	17.9	40.6	23.0	22.5	26.6	57.2
12:30	13.6	21.0	24.0	49.8	17.2	44.5	22.8	23.0	26.0	49.3
12:45	13.5	22.2	24.9	51.3	18.1	41.2	21.0	22.8	26.0	48.0
01:00	13.2	22.1	24.0	50.8	18.4	42.2	21.3	20.2	26.1	49.2
01:15	12.9	22.2	23.9	49.5	18.6	42.4	21.0	20.9	26.1	50.2
01:30	12.7	23.1	24.9	47.5	17.6	43.7	22.2	19.2	26.0	50.6
01:45	12.5	20.2	24.9	48.5	15.7	40.2	20.0	20.0	25.0	50.1

Table A.7:data collected

Day:9-9-1990,without concentrator

initial space temp. = 27.6 °C

flow rate of cooling water = 0.056 l/s

Time	m m/s	V m/s	I $\frac{wh}{m_2}$	T_3 °C	T_{11} °C	T_9 °C	T_g °C	T_{12} ° C	T_{13} °C	T_5 °C	T_c °C
11:15	20	2.0	229.3	83.1	77.3	49.3	75.3	22.7	26.1	55.1	33.8
11:30	25	3.3	257.5	88.1	79.8	49.8	77.0	21.1	26.4	52.1	31.8
11:45	30	3.2	263.8	90.0	79.9	49.3	77.3	20.1	26.3	52.1	31.0
12:00	35	2.2	248.2	86.1	78.3	48.9	76.7	21.0	25.6	53.6	32.0
12:15	40	1.0	215.0	87.1	77.0	48.3	75.0	23.0	26.9	53.7	33.8
12:30	45	0.8	240.0	87.4	79.0	49.0	76.3	22.3	27.4	54.1	33.9
12:45	50	1.3	209.0	83.0	75.1	58.4	75.7	22.9	25.1	57.2	33.3
01:00	55	2.0	238.0	86.4	78.1	49.4	74.3	22.1	25.7	54.7	34.4
01:15	60	3.0	215.0	86.1	76.9	50.4	73.1	22.3	25.9	56.1	34.8
01:30	65	4.2	213.0	85.0	76.1	59.2	72.4	23.1	25.8	56.9	35.1
01:45	70	3.8	210.0	84.0	75.3	60.4	68.4	22.0	25.7	55.3	35.4
02:00	75	3.7	198.2	78.0	74.1	56.4	67.3	23.9	25.5	57.3	36.0
02:15	80	2.6	195.7	77.0	73.1	56.4	67.3	23.9	25.0	58.1	36.1

Table A.7:continued

Time	T_e	$T_{13'}$	$T_{14'}$	T_{10}	$T_{8'}$	T_a	T_{s1}	T_{s2}	T_{am}	T_1
11:15	15.0	22.1	24.9	46.3	18.1	37.0	26.4	26.6	27.8	61.3
11:30	14.8	21.1	24.1	50.4	17.8	36.9	25.6	25.7	27.6	55.1
11:45	15.0	20.1	23.9	50.9	17.9	36.3	24.0	24.0	28.2	51.0
12:00	15.0	21.0	24.3	54.3	18.5	37.1	23.9	23.0	28.3	55.0
12:15	14.5	23.0	25.0	42.3	19.0	38.0	23.6	23.0	27.1	50.1
12:30	14.9	22.3	25.2	51.7	18.1	37.8	23.0	22.8	29.0	52.3
12:45	14.7	22.9	24.1	43.5	18.3	37.4	23.0	22.5	28.1	53.2
01:00	14.2	22.1	24.4	51.2	18.2	38.9	23.2	22.3	28.5	55.1
01:15	14.0	23.3	25.3	43.1	19.1	39.0	23.9	24.0	27.5	50.1
01:30	13.7	23.1	25.4	42.1	18.5	39.4	23.8	23.9	27.0	50.3
01:45	13.0	23.0	25.5	43.9	18.4	39.6	23.4	23.6	26.9	45.0
02:00	12.7	23.9	25.3	44.1	18.4	40.1	23.2	23.0	26.8	42.4
02:15	12.7	23.9	24.5	43.9	19.0	40.1	22.1	23.1	26.7	43.0

Table A.8:data collected

Day:10-9-1990,without concentrator

initial space temp. = 29.0 °C

flow rate of cooling water = 0.056 l/s

Time	m m/s	V m/s	I $\frac{wh}{m^2}$	T_3 °C	T_{11} °C	T_9 °C	T_g °C	T_{12} ° C	T_{13} °C	T_5 °C	T_c °C
11:30	20	1.2	201.8	82.1	78.8	59.4	72.9	23.6	25.3	48.4	34.3
11:45	25	1.1	216.0	83.0	79.2	57.3	73.6	23.5	26.4	49.2	34.0
12:00	30	0.6	243.5	89.4	81.3	47.2	77.0	21.1	25.4	54.2	32.2
12:15	35	0.4	219.2	85.2	79.7	53.4	74.6	23.0	26.1	51.2	33.6
12:30	40	1.2	233.4	80.6	80.2	49.4	76.7	23.1	26.6	52.4	33.0
12:45	45	1.5	264.0	90.0	82.1	43.4	77.4	21.1	25.1	50.2	31.6
01:00	50	1.8	215.2	87.6	80.3	51.6	75.3	23.1	26.4	50.4	33.2
01:15	55	1.4	186.0	80.6	77.5	60.3	72.4	23.1	25.1	49.4	34.5
01:30	60	2.1	141.3	80.4	76.9	61.1	71.2	22.9	24.1	51.7	35.8
01:45	65	2.6	117.0	80.0	76.3	58.4	70.4	22.9	23.3	53.4	35.4
02:00	70	2.0	114.5	79.0	75.3	59.4	69.2	22.9	23.3	53.2	36.4
02:15	75	2.0	114.5	79.0	75.3	59.4	69.2	23.9	24.3	53.2	36.4

Table A.8:continued

Time	T_e	$T_{13'}$	$T_{14'}$	T_{10}	$T_{8'}$	T_a	T_{s1}	T_{s2}	T_{am}	T_1
11:30	14.8	23.6	24.4	49.7	17.8	37.2	27.9	28.0	29.5	60.1
11:45	15.0	23.5	25.7	52.1	17.2	37.0	26.9	27.2	29.9	60.2
12:00	16.0	21.1	24.3	53.3	19.8	35.4	26.2	26.0	29.6	59.4
12:15	15.1	23.0	25.9	54.9	18.4	36.6	25.4	25.0	29.6	57.2
12.30	15.4	23.1	26.1	54.0	20.2	36.0	25.2	25.0	29.8	58.2
12.45	16.2	21.1	23.1	52.4	20.1	35.0	24.6	24.0	29.3	59.2
01:00	15.2	23.1	25.3	55.0	18.9	36.2	23.4	24.0	29.2	58.4
01:15	14.3	23.1	25.3	46.1	15.6	37.4	23.6	24.0	29.0	57.5
01:30	14.0	22.9	23.9	44.3	15.0	37.8	24.0	24.0	28.9	55.2
01:45	13.8	21.9	22.9	43.1	14.4	38.0	24.0	24.2	28.8	54.1
02:00	13.5	23.9	24.3	42.1	14.2	38.5	24.0	24.0	28.7	53.1

Table A.9:data collected

Day:11 -9-1990,without concentrator

initial space temp. = 28.5 °C

flow rate of cooling water = 0.053 l/s

Time	m m/s	V m/s	I $\frac{wh}{m_2}$	T_3 °C	T_{11} °C	T_9 °C	T_g °C	T_{12} ° C	T_{13} °C	T_5 °C	T_c °C
11:15	20	1.2	229.0	88.1	80.4	56.1	77.0	19.2	23.1	49.9	29.9
11:30	25	2.4	242.0	89.1	82.1	52.3	77.1	19.1	23.3	49.3	29.3
11:45	30	2.2	243.2	90.0	83.9	53.2	78.0	20.2	23.3	47.1	30.1
12:00	35	3.4	186.9	86.4	80.1	55.2	76.1	20.9	24.0	46.1	30.4
12:15	40	3.0	186.4	85.3	80.3	55.7	75.2	20.9	23.8	45.1	31.0
12:30	45	3.9	141.0	82.2	78.7	57.4	72.4	21.2	23.1	45.1	32.1
12:45	50	3.9	130.2	80.4	76.3	60.6	72.1	22.0	23.5	44.9	33.0
01:00	55	2.0	145.3	84.5	79.4	56.6	75.0	21.1	23.7	44.2	31.8
01:15	60	0.9	140.4	81.6	76.6	60.3	73.4	22.3	23.6	43.4	32.8
01:30	65	1.2	125.2	80.0	76.2	61.4	71.2	22.1	24.3	48.1	33.5
01:45	70	3.3	115.3	77.0	74.2	62.1	70.1	23.1	25.1	45.1	34.1

Table A.9:continued

Time	T_e	$T_{13'}$	$T_{14'}$	T_{10}	$T_{8'}$	T_a-	T_{s1}	T_{s2}	T_{am}	T_1
11:15	17.1	19.2	23.0	57.3	21.0	37.5	26.1	26.2	28.8	69.0
11:30	17.2	19.1	23.1	58.1	20.4	35.6	25.1	25.0	28.6	68.1
11:45	17.0	20.2	22.1	55.9	22.0	38.2	24.6	24.2	28.5	67.2
12:00	16.9	20.9	23.5	55.2	22.0	40.1	23.9	23.6	27.4	66.4
12:15	16.8	20.9	23.5	49.3	23.6	41.8	22.4	22.6	28.1	58.4
12:30	16.2	21.2	23.0	50.3	23.4	42.5	22.2	22.6	27.3	57.6
12:45	15.0	21.0	23.5	49.3	22.3	43.1	24.9	24.9	27.2	55.4
01:00	16.6	21.1	23.1	50.9	23.4	42.0	24.1	24.4	27.1	52.4
01:15	15.6	22.3	23.8	50.2	21.2	41.5	24.0	24.0	28.2	46.2
01:30	14.8	22.1	23.3	50.1	22.1	45.1	23.3	23.9	28.1	43.2
01:45	14.2	23.1	24.1	48.9	23.0	46.2	21.3	23.9	27.3	44.0

PROGRAMME B.1

```
10 REM ****************************************************************

20 REM  *****      ( MAIN PROGRAMME )     ****************************

25 REM  ****    PREPARED BY :          *****************************

30 REM  *****    M. TARAWNEH         *****************************

40 REM *******************************************************"

60 DIM X(114),Y(114),Z(114),F(114),G(27,27),J1(27,1),R(114),R1(114)

65 DIM M1(114),M2(114),M3(114),M4(114),M5(114),M6(114),M7(114),M8(114),M9(114),M

10(114),M11(114),F1(114),M19(114)

66 DIM M12(114),M13(114),M14(114),M15(114),M16(114),M17(114),M18(114),M20(114),M

21(114)

67 DIM M22(114),M23(114),M24(114),M25(114),M26(114),F1A(114),F2(114),F3(114),F4(

114),F5(114)

70 FOR I=1 TO 114

80 INPUT"inter the value of x,x=";X(I)

90 INPUT"inter the value of y,y=";Y(I)

100 INPUT"inter the value of z,z=";Z(I)

110 INPUT"inter the value of f,f=";F(I)

120 LET S1=S1+(X(I)^2)

130 LET S2=S2+(Y(I)^2)

140 LET S3=S3+(Y(I))

150 LET S4=S4+(X(I))

160 LET S5=S5+(Z(I)^2)

170 LET S6=S6+(Z(I))
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180 LET S7=S7+(X(I)*Y(I))

190 LET S9=S9+(X(I)*Z(I))

200 LET S8=S8+(Y(I)*Z(I))

210 LET S10=S10+(X(I)*Y(I)^2)

220 LET S11=S11+((X(I)^2)*Y(I))

230 LET S12=S12+((Y(I)^2)*Z(I))

240 LET S13=S13+((Z(I)^2)*Y(I))

250 LET S14=S14+((X(I)^2)*Z(I))

260 LET S15=S14+(Z(I)^2*X(I))

270 LET S16=S16+(X(I)*Y(I)*Z(I))

280 LET S17=S17+(X(I)^2*Y(I)*Z(I))

290 LET S18=S18+(X(I)*Y(I)^2*Z(I))

300 LET S19=S19+(X(I)*Y(I)*Z(I)^2)

310 LET S20=S20+(X(I)^2*Y(I)^2*Z(I))

320 LET S21=S21+(X(I)^2*Y(I)*Z(I)^2)

330 LET S22=S22+(X(I)*Y(I)^2*Z(I)^2)

340 LET S23=S23+(X(I)^2*Y(I)^2*Z(I)^2)

350 LET S24=S24+(X(I)^2*Y(I)^2)

360 LET S25=S25+(Y(I)^2*Z(I)^2)

370 LET S26=S26+(X(I)^2*Z(I)^2)

380 LET S27=S27+(X(I)^4)

390 LET S28=S28+(X(I)^3)

400 LET S29=S29+(Y(I)^4)

410 LET S30=S30+(Y(I)^3)
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420 LET S31=S31+(X(I)^3*Y(I))
430 LET S32=S32+(X(I)*Y(I)^3)
440 LET S33=S33+(X(I)^3*Y(I)^3*Z(I)^2)
450 LET S34=S34+(X(I)^2*Y(I)^3*Z(I)^3)
460 LET S35=S35+(X(I)^3*Y(I)^2*Z(I)^3)
470 LET S36=S36+(X(I)^3*Y(I)^2*Z(I)^2)
480 LET S37=S37+(X(I)^3*Y(I)^3*Z(I))
490 LET S38=S38+(X(I)^4*Z(I)^3)
500 LET S39=S39+(X(I)^3*Z(I)^4)
510 LET S40=S40+(X(I)^3*Y(I)*Z(I)^4)
520 LET S41=S41+(X(I)^4*Y(I)^3*Z(I)^3)
530 LET S42=S42+(X(I)^3*Y(I)^4*Z(I)^3)
540 LET S43=S43+(X(I)^3*Y(I)^3*Z(I)^4)
550 LET S44=S44+(X(I)^2*Y(I)^3*Z(I)^4)
560 LET S45=S45+(X(I)^3*Y(I)^2*Z(I)^4)
570 LET S46=S46+(X(I)^4*Y(I)^4*Z(I)^1)
580 LET S47=S47+(X(I)^4*Y(I)^4*Z(I)^3)
590 LET S48=S48+(X(I)^4*Y(I)^3*Z(I)^4)
600 LET S49=S49+(X(I)^4*Y(I)^4*Z(I)^2)
610 LET S50=S50+(X(I)^4*Y(I)^2*Z(I)^4)
620 LET S51=S51+(X(I)^2*Y(I)^4*Z(I)^4)
630 LET S52=S52+(X(I)^3*Y(I)^4*Z(I)^4)
640 LET S53=S53+(X(I)^4*Y(I)^4*Z(I)^4)
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650 LET S54=S54+(X(I)^4*Y(I)^4)

660 LET S55=S55+(Y(I)^4*Z(I)^4)

670 LET S56=S56+(X(I)^4*Z(I)^4)

680 LET S57=S57+(X(I)^2*Y(I)^2*Z(I)^4)

690 LET S58=S58+(X(I)^3*Y(I)^4*Z(I))

700 LET S59=S59+(Z(I)^4)

710 LET S60=S60+(Z(I)^3)

720 LET S61=S61+(X(I)^2*Y(I)*Z(I)^4)

730 LET S62=S62+(Y(I)*Z(I)^3)

740 LET S63=S63+(Y(I)^3*Z(I))

750 LET S64=S64+(X(I)*Y(I)^4)

760 LET S65=S65+(X(I)^2*Y(I)^3)

770 LET S66=S66+(X(I)*Y(I)^2*Z(I))

780 LET S67=S67+(Y(I)^4*Z(I))

790 LET S68=S68+(X(I)*Y(I)*Z(I)^2)

800 LET S69=S69+(X(I)^3*Z(I))

810 LET S70=S79+(Y(I)^3*Z(I)^2)

820 LET S71=S71+(X(I)*Z(I)^3)

830 LET S72=S72+(X(I)^2*Y(I)^3)

840 LET S73=S73+(X(I)*Z(I)^3)

850 LET S74=S74+(X(I)^2*Y(I)*Z(I))

860 LET S75=S75+(X(I)*Y(I)*Z(I)^2)

870 LET S76=S76+(X(I)^2*Y(I)^2*Z(I)^1)

880 LET S77=S77+(X(I)^2*Y(I)*Z(I)^2)
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890 LET S78=S78+(X(I)*Y(I)^2*Z(I)^2)

900 LET S79=S79+(X(I)*Y(I)^3*Z(I))

910 LET S80=S80+(X(I)^3*Y(I)*Z(I))

920 LET S81=S81+(X(I)^2*Y(I)^4)

930 LET S82=S82+(X(I)^3*Y(I)^3)

940 LET S83=S83+(X(I)^2*Y(I)^2*Z(I)^2)

950 LET S84=S84+(Y(I)^2*Z(I)^3)

960 LET S85=S85+(X(I)^4*Y(I))

970 LET S86=S86+(X(I)^3*Z(I))

980 LET S87=S87+(X(I)^3*Y(I)^2)

990 LET S88=S86+(X(I)^4*Z(I))

1000 LET S89=S89+(X(I)^4*Y(I)^2)

1010 LET S90=S90+(X(I)*Z(I)^4)

1020 LET S91=S91+(Y(I)^4*Z(I)^3)

1030 LET S92=S92+(X(I)^3*Z(I)^2)

1040 LET S93=S93+(X(I)*Y(I)^3*Z(I)^3)

1050 LET S94=S94+(X(I)^4*Y(I)^1*Z(I)^4)

1060 LET S95=S95+(X(I)^3*Y(I)^2*Z(I)^4)

1070 LET S96=S96+(X(I)*Y(I)*Z(I)^3)

1080 LET S97=S97+(X(I)^2*Z(I)^3)

1090 LET S98=S98+(X(I)^3*Y(I)^2*Z(I))

1100 LET S99=S99+(X(I)^2*Y(I)*Z(I)^3)

1110 LET S100=S100+(X(I)*Y(I)^2*Z(I)^3)

1120 LET S101=S101+(X(I)^2*Y(I)^3*Z(I))
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1130 LET S102=S102+(X(I)*Y(I)^3*Z(I)^2)

1140 LET S103=S103+(X(I)^2*Y(I)*Z(I)^3)

1150 LET S104=S104+(X(I)*Y(I)^2*Z(I)^3)

1160 LET S105=S105+(X(I)^4*Y(I)^2)

1170 LET S106=S106+(X(I)^3*Y(I)*Z(I)^2)

1180 LET S107=S107+(X(I)^2*Y(I)^3*Z(I))

1190 LET S108=S108+(Y(I)*Z(I)^4)

1200 LET S109=S109+(Y(I)^3*Z(I)^3)

1210 LET S110=S110+(X(I)*Y(I)^4*Z(I))

1220 LET S111=S111+(X(I)^4*Y(I)*Z(I))

1230 LET S112=S112+(Y(I)^4*Z(I)^4)

1240 LET S113=S113+(Y(I)^2*Z(I)^4)

1250 LET S114=S114+(X(I)^4*Z(I)^2)

1260 LET S115=S115+(X(I)^3*Y(I)^3*Z(I))

1270 LET S116=S116+(X(I)*Y(I)*Z(I)^4)

1280 LET S117=S117+(X(I)^2*Y(I)^4*Z(I))

1290 LET S118=S118+(X(I)^2*Y(I)^3*Z(I)^2)

1300 LET S119=S119+(X(I)^2*Y(I)^2*Z(I)^3)

1310 LET S120=S120+(X(I)*Y(I)^3*Z(I)^2)

1320 LET S121=S121+(X(I)^3*Y(I)^2*Z(I)^2)

1330 LET S122=S122+(X(I)^2*Z(I)^4)

1340 LET S123=S123+(X(I)*Y(I)^3*Z(I)^3)

1350 LET S124=S124+(X(I)^3*Y(I)*Z(I)^3)

1360 LET S125=S125+(Y(I)^3*Z(I)^4)
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1370 LET S126=S126+(X(I)*Y(I)^4*Z(I)^3)

1380 LET S127=S127+(X(I)^4*Y(I)^2*Z(I)^2)

1390 LET S128=S128+(X(I)*Y(I)^2*Z(I)^4)

1400 LET S129=S129+(X(I)^2*Y(I)*Z(I)^4)

1410 LET S130=S130+(X(I)^2*Y(I)^4*Z(I)^2)

1420 LET S131=S131+(X(I)^4*Y(I)^3*Z(I))

1430 LET S132=S132+(X(I)^2*Y(I)^4*Z(I))

1440 LET S133=S133+(X(I)^4*Z(I)^2)

1450 LET S134=S134+(Y(I)^4*Z(I)^2)

1460 LET S135=S135+(Y(I)^2*Z(I)^4)

1470 LET S136=S136+(X(I)^3*Y(I)^3)

1480 LET S137=S137+(X(I)^3*Z(I)^3)

1490 LET S138=S138+(X(I)^2*Z(I)^4)

1500 LET S139=S139+(X(I)^2*Y(I)^2*Z(I)^4)

1510 LET S140=S140+(X(I)^4*Y(I)*Z(I)^3)

1520 LET S141=S141+(X(I)^3*Y(I)^3*Z(I)^3)

1530 LET S142=S142+(X(I)^4*Y(I)^2*Z(I)^3)

1540 LET S143=S143+(X(I)^4*Y(I)^3*Z(I)^2)

1550 LET S144=S144+(X(I)^2*Y(I)^3*Z(I)^4)

1560 LET S145=S145+(X(I)^2*Y(I)^4*Z(I)^3)

1570 LET S146=S146+(X(I)*Y(I)^3*Z(I)^4)

1580 LET S147=S147+(X(I)^2*Y(I)^3*Z(I))

1590 LET S148=S148+(X(I)^3*Y(I)^4)

1600 LET S149=S149+(X(I)^4*Y(I)^3)

1610 LET S150=S150+(X(I)*Y(I)^4*Z(I)^2)
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1860 LET S175=S175+(F(I)*X(I)^2*Y(I)^2*Z(I))

1870 LET S176=S176+(F(I)*X(I)^2*Y(I)*Z(I)^2)

1880 LET S177=S177+(F(I)*X(I)*Y(I)^2*Z(I)^2)

1890 LET S178=S178+(F(I)*X(I)^2*Y(I)^2*Z(I)^2)

1900 LET S179=S179+(F(I)*X(I)^2*Y(I)^2)

1910 LET S180=S180+(F(I)*Y(I)^2*Z(I)^2)

1920 LET S181=S181+(F(I)*X(I)^2*Z(I)^2)

1930 S182=S182+(X(I)*Y(I)^2*Z(I)^2)

1940 NEXT I

1950 LET G(1,1) = 114

1960 LET G(1,2)=S1: G(2,1)=S1:G(3,3) = S1

1970 LET G(1,4)=S2:G(4,1)=S2:G(5,5) = S2

1980 LET G(1,5)=S3:G(5,1)=S3

1990 LET G(1,3)=S4:G(3,1)=S4

2000 LET G(1,6)=S5:G(6,1)=S5:G(7,7) = S5

2010 LET G(1,7)=S6:G(7,1)=S6

2020 LET G(1,8)=S7:G(8,1)=S7:G(5,3)=S7:G(3,5)=S7

2030 LET G(1,9)=S8:G(9,1)=S8:G(5,7)=S8:G(7,5)=S8

2040 LET G(1,10)=S9:G(10,1)=S9:G(3,7)=S9:G(7,3)=S9

2050 LET G(1,11)=S10:G(11,1)=S10:G(4,3)=S10:G(3,4)=S10:G(8,5)=S10:G(5,8)=S10

2060 LET G(1,12)=S11:G(12,1)=S11:G(2,5)=S11:G(5,2)=S11:G(3,8)=S11:G(8,3)=S11

2070 LET G(1,13)=S12:G(13,1)=S12:G(4,7)=S12:G(7,4)=S12:G(5,9)=S12:G(9,5)=S12

2080 LET G(1,14)=S13:G(14,1)=S13:G(5,6)=S13:G(6,5)=S13:G(7,9)=S13:G(9,7)=S13

2090 LET G(1,15)=S14:G(15,1)=S14:G(3,10)=S14:G(10,3)=S14:G(7,2)=S14:G(2,7)=S14
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2100 LET G(1,16)=S15:G(16,1)=S15:G(6,3)=S15:G(3,6)=S15:G(7,10)=S15:G(10,7)=S15

2110 LET G(1,17)=S16:G(17,1)=S16:G(3,9)=S16:G(9,3)=S16:G(5,10)=S16:G(10,5)=S16:G
(7,8)=S16:G(8,7)=S16

2120 LET G(1,18)=S17:G(18,1)=S17:G(2,9)=S17:G(9,2)=S17

2130 LET G(1,19)=S18:G(10,4)=S18:G(4,10)=S18:G(19,1)=S18:G(5,17)=S18:G(17,5)=S18
:G(3,13)=S18:G(13,3)=S18

2140 LET G(1,20)=S19:G(20,1)=S19:G(5,16)=S19:G(16,5)=S19:G(17,7)=S19:G(7,17)=S19

2150 LET G(1,21)=S20:G(21,1)=S20:G(3,19)=S20:G(19,3)=S20:G(25,7)=S20:G(7,25)=S20
:G(4,15)=S20:G(15,4)=S20:G(2,13)=S20:G(13,2)=S20

2160 LET G(1,22)=S21:G(22,1)=S21:G(9,15)=S21:G(15,9)=S21:G(10,17)=S21:G(17,10)=S
21:G(27,5)=S21:G(5,27)=S21

2170 LET G(20,3)=S21:G(3,20)=S21:G(2,14)=S21:G(14,2)=S21

2180 LET G(1,23)=S22:G(23,1)=S22:G(4,16)=S22:G(16,4)=S22:G(9,17)=S22:G(17,9)=S22
:G(5,20)=S22:G(20,5)=S22

2190 LET G(3,26)=S22:G(26,3)=S22

2200 LET G(1,24)=S23:G(24,1)=S23:G(10,19)=S23:G(19,10)=S23:G(13,15)=S23:G(15,13)
=S23:G(16,11)=S23

2210 LET G(11,16)=S23:G(8,20)=S23:G(20,8)= S23:G(9,18)=S23:G(18,9)=S23:G(2,26)=S
23:G(26,2)=S23

2220 LET G(4,27)=S23:G(27,4)=S23:G(25,6)=S23:G(6,25)=S23:G(7,21)=S23:G(21,7)=S23

2230 LET G(25,6)=S23:G(6,25)=S23:G(7,21)=S23:G(21,7)=S23:G(5,22)=S23:G(22,5)=S23

2240 LET G(23,3)=S23:G(3,23)=S23:G(17,17)=S23

2250 LET G(1,25)=S24:G(25,1)=S24:G(4,2)=S24:G(2,4)=S24:G(3,11)=S24:G(11,3)=S24:G
(5,12)=S24:G(12,5)=S24:G(8,8)=S24
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2660 LET G(27,26)=S57:G(26,27)=S57

2670 LET G(25,19)=S58:G(19,25)=S58:G(11,21)=S58:G(21,11)=S58

2680 LET G(6,6)=S59

2690 LET G(6,7)=S60:G(7,6)=S60

2700 LET G(22,6)=S61:G(6,22)=S61

2710 LET G(9,6)=S62:G(6,9)=S62:G(14,7)=S62:G(7,14)=S62

2720 LET G(4,9)=S63:G(9,4)=S63:G(5,13)=S63:G(13,5)=S63

2730 LET G(4,11)=S64:G(11,4)=S64

2740 LET G(4,12)=S65:G(12,4)=S65:G(11,8)=S65:G(8,11)=S65

2750 LET G(7,11)=S66:G(11,7)=S66:G(9,8)=S66:G(8,9)=S66

2760 LET G(4,13)=S67:G(13,4)=S67

2770 LET G(3,14)=S68:G(14,3)=S68

2780 LET G(3,15)=S69:G(15,3)=S69

2790 LET G(4,14)= S70:G(14,4)=S70:G(13,9)=S70:G(9,13)=S70:G(26,5)=S70:G(5,26)=S7

0

2800 LET G(6,10)=S71:G(10,6)=S71

2810 LET G(25,5)=S72:G(5,25)=S72

2820 LET G(7,16)=S73:G(16,7)=S73

2830 LET G(8,10)=S74:G(10,8)=S74:G(7,12)=S74:G(12,7)=S74:G(3,17)=S74:G(17,3)=S74

:G(15,5)=S74:G(5,15)=S74

2840 LET G(10,9)=S75:G(9,10)=S75:G(8,6)=S75:G(6,8)=S75

2850 LET G(12,9)=S76:G(9,12)=S76:G(10,11)=S76:G(11,10)=S76:G(8,17)=S76:G(17,8)=S

76:G(5,18)=S76:G(18,5)=S76

2860 LET G(6,12)=S77:G(12,6)=S77:G(16,8)=S77:G(8,16)=S77:G(7,18)=S77:G(18,7)=S77
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2870 LET G(11,6)=S78:G(6,11)=S78:G(13,10)=S78:G(10,13)=S78:G(7,19)=S78:G(19,7)=S
78
2880 LET G(11,9)=S79:G(9,11)=S79:G(8,13)=S79:G(13,8)=S79:G(17,4)=S79:G(4,17)=S79
:G(5,19)=S79:G(19,5)=S79
2890 LET G(8,15)=S80:G(15,8)=S80:G(10,12)=S80:G(12,10)=S80:G(17,2)=S80:G(2,17)=S
80:G(3,18)=S80:G(18,3)=S80
2900 LET G(11,11)=S81:G(25,4)=S81:G(4,25)=S81
2910 LET G(11,12)= S82:G(12,11)=S82
2920 LET G(14,12)=S83:G(12,14)=S83
2930 LET G(2,16)=S92:G(16,2)=S92:G(15,10)=S92:G(10,15)=S92:G(27,3)=S92:G(3,27)=S
92
2940 LET G(8,18)=S98:G(18,8)=S98:G(15,11)=S98:G(11,15)=S98:G(17,12)=S98:G(12,17)
=S98:G(2,19)=S98:G(19,2)=S98:G(3,21)=S98:G(21,3)=S98:G(25,10)=S98:G(10,25)=S98
2950 LET G(19,14)=S93:G(14,19)=S93
2960 LET G(27,22)=S94:G(22,27)=S94
2970 LET G(24,16)=S95:G(16,24)=S95:G(27,23)=S95:G(23,27)=S95
2980 LET G(6,17)=S96:G(17,6)=S96:G(14,10)=S96:G(10,14)=S96:G(9,16)=S96:G(16,9)=S
96:G(7,20)=S96:G(20,7)=S96
2990 LET G(10,16)=S97:G(16,10)=S97:G(27,7)=S97:G(7,27)=S97:G(15,6)=S97:G(6,15)=S
97
3000 LET G(6,18)=S99:G(18,6)=S99:G(14,15)=S99:G(15,14)=S99
3010 LET G(6,19)=S100:G(19,6)=S100:G(16,13)=S100:G(13,16)=S100:G(14,17)=S100:G(1
7,14)=S100:G(7,23)=S100:G(23,7)=S100
3020 LET G(8,19)=S101:G(19,8)=S101:G(12,13)=S101:G(13,12)=S101:G(5,21)=S101:G(21
,5)=S101
```

```
3030 LET G(19,9)=S102:G(9,19)=S102:G(14,11)=S102:G(11,14)=S102:G(17,13)=S102:G(1
3,17)=S102:G(8,26)=S102:G(26,8)=S102
3040 LET G(10,20)=S103:G(20,10)=S103:G(7,22)=S103:G(22,7)=S103:G(16,17)=S103:G(1
7,16)=S103:G(27,9)=S103:G(9,27)=S103
3050 LET G(20,9)=S104:G(9,20)=S104:G(26,10)=S104:G(10,26)=S104
3060 LET G(12,12)=S105
3070 LET G(12,16)= S106:G(16,12)=S106:G(18,10)=S106:G(10,18)=S106:G(17,15)=S106:
G(15,17)=S106:G(20,2)=S106:G(2,20)=S106:G(27,8)=S106:G(8,27)=S106:G(22,3)=S106:G
(3,22)=S106
3080 LET G(11,17)=S107:G(17,11)=S107:G(4,18)=S107:G(18,4)=S107
3090 LET G(6,14)=S108:G(14,6)=S108
3100 LET G(14,13)=S109:G(13,14)=S109:G(26,9)=S109:G(9,26)=S109
3110 LET G(13,11)=S110:G(11,13)=S110:G(19,4)=S110:G(4,19)=S110
3120 LET G(12,15)=S111:G(15,12)=S111:G(18,2)=S111:G(2,18)=S111
3130 LET G(13,13)=S112
3140 LET G(14,14)=S113
3150 LET G(15,15)=S114
3160 LET G(8,21)=S115:G(21,8)=S115:G(18,11)=S115:G(11,18)=S115:G(19,12)=S115:G(1
2,19)=S115
3170 LET G(20,6)=S116:G(6,20)=S116:G(14,16)=S116:G(16,14)=S116
3180 LET G(19,11)=S117:G(11,19)=S117:G(25,13)=S117:G(13,25)=S117
3190 LET G(13,18)=S118:G(18,13)=S118:G(4,22)=S118:G(22,4)=S118:G(20,11)=S118:G(1
1,20)=S118:G(8,23)=S118:G(23,8)=S118:G(19,17)=S118:G(17,19)=S118:G(24,5)=S118:G(
5,24)=S118:G(25,14)=S118:G(14,25)=S118:G(12,26)=S118:G(26,12)=S118:G(21,9)=S118:
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```
G(9,21)=S118

3200 LET G(6,21)=S119:G(21,6)=S119:G(22,9)=S119:G(9,22)=S119:G(18,14)=S119:G(14,

18)=S119:G(16,19)=S119:G(19,16)=S119:G(20,17)=S119:G(17,20)=S119:G(23,10)=S119:G

(10,23)=S119:G(24,7)=S119:G(7,24)=S119:G(13,27)=S119:G(27,13)=S119:G(15,26)=S119

:G(26,15)=S119

3210 LET G(4,20)=S120:G(20,4)=S120:G(23,5)=S120:G(5,23)=S120

3220 LET G(10,21)=S121:G(21,10)=S121:G(8,22)=S121:G(22,8)=S121:G(15,19)=S121:G(1

9,15)=S121:G(17,18)=S121:G(18,17)=S121:G(16,25)=S121:G(25,16)=S121:G(12,20)=S121

:G(20,12)=S121

3230 LET G(16,16)=S122

3240 LET G(13,20)=S123:G(20,13)=S123:G(9,23)=S123:G(23,9)=S123:G(26,17)=S123:G(1

7,26)=S123

3250 LET G(16,18)=S124:G(18,16)=S124:G(15,20)=S124:G(20,15)=S124:G(22,10)=S124:G

(10,22)=S124:G(27,17)=S124:G(17,27)=S124

3260 LET G(26,14)=S125:G(14,26)=S125

3270 LET G(23,13)=S126:G(13,23)=S126:G(26,19)=S126:G(19,26)=S126

3280 LET G(15,21)=S127:G(21,15)=S127:G(12,22)=S127:G(22,12)=S127:G(24,2)=S127:G(

2,24)=S127:G(18,18)=S127:G(27,25)=S127:G(25,27)=S127

3290 LET  G(14,20)=S128:G(20,14)=S128:G(23,6)=S128:G(6,23)=S128:G(26,16)=S128:G(

16,26)=S128

3300 LET G(20,16)=S129:G(16,20)=S129:G(27,14)=S129:G(14,27)=S129

3310 LET G(13,21)=S130:G(21,13)=S130:G(24,4)=S130:G(4,24)=S130:G(26,25)=S130:G(2

5,26)=S130:G(11,23)=S130:G(23,11)=S130:G(19,19)=S130

3320 LET G(21,12)=S131:G(12,21)=S131:G(25,18)=S131:G(18,25)=S131
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```
3330 LET G(21,4)=S132:G(4,21)=S132

3340 LET G(27,2)=S133:G(2,27)=S133

3350 LET G(26,4)=S134:G(4,26)=S134

3360 LET G(6,26)=S135:G(26,6)=S135

3370 LET G(8,25)=S136:G(25,8)=S136

3380 LET G(10,27)=S137:G(27,10)=S137:G(16,15)=S137:G(15,16)=S137

3390 LET G(6,27)=S138:G(27,6)=S138

3400 LET G(16,23)=S139:G(23,16)=S139:G(14,22)=S139:G(22,14)=S139:G(20,20)=S139:G
(24,6)=S139:G(6,24)=S139

3410 LET G(15,22)=S140:G(22,15)=S140:G(27,18)=S140:G(18,27)=S140

3420 LET G(24,17)=S141:G(17,24)=S141:G(23,18)=S141:G(18,23)=S141:G(22,19)=S141:G
(19,22)=S141:G(21,20)=S141:G(20,21)=S141

3430 LET G(24,15)=S142:G(15,24)=S142:G(27,21)=S142:G(21,27)=S142:G(22,18)=S142:G
(18,22)=S142

3440 LET G(21,18)=S143:G(18,21)=S143:G(24,12)=S143:G(12,24)=S143:G(25,22)=S143:G
(22,25)=S143

3450 LET G(26,22)=S144:G(22,26)=S144:G(24,14)=S144:G(14,24)=S144

3460 LET G(26,21)=S145:G(21,26)=S145:G(24,13)=S145:G(13,24)=S145:G(23,19)=S145:G
(19,23)=S145

3470 LET G(26,20)=S146:G(20,26)=S146:G(23,14)=S146:G(14,23)=S146

3480 LET G(25,9)=S147:G(9,25)=S147

3490 LET G(25,11)=S148:G(11,25)=S148

3500 LET G(25,12)=S149:G(12,25)=S149

3510 LET G(26,11)=S150:G(11,26)=S150:G(23,4)=S150:G(4,23)=S150:G(19,13)=S150:G(1
```

```
3,19)=S150

3520 LET G(27,12)=S151:G(12,27)=S151:G(22,2)=S151:G(2,22)=S151:G(18,15)=S151:G(1

5,18)=S151

3530 LET G(21,2)=S152:G(2,21)=S152:G(25,15)=S152:G(15,25)=S152:G(12,18)=S152:G(1

8,12)=S152

3540 LET G(24,11)=S153:G(11,24)=S153:G(25,23)=S153:G(23,25)=S153:G(19,21)=S153:G

(21,19)=S153

3550 LET G(23,26)=S154:G(26,23)=S154

3560 G(14,8)=S162:G(8,14)=S182

3570 LET J1(1,1)=S155

3580 LET J1(2,1)=S156

3590 LET J1(3,1)=S157

3600 LET J1(4,1)=S158

3610 LET J1(5,1)=S159

3620 LET J1(6,1)=S160

3630 LET J1(7,1)=S161

3640 LET J1(8,1)=S162

3650 LET J1(9,1)=S163

3660 LET J1(10,1)=S164

3670 LET J1(11,1)=S165

3680 LET J1(12,1)=S166

3690 LET J1(13,1)=S167

3700 LET J1(14,1)=S168

3710 LET J1(15,1)=S169

3720 LET J1(16,1)=S170
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3730 LET J1(17,1)=S171

3740 LET J1(18,1)=S172

3750 LET J1(19,1)=S173

3760 LET J1(20,1)=S174

3770 LET J1(21,1)=S175

3780 LET J1(22,1)=S176

3790 LET J1(23,1)=S177

3800 LET J1(24,1)=S178

3810 LET J1(25,1)=S179

3820 LET J1(26,1)=S180

3830 LET J1(27,1)=S181

3840 LPRINT

3850 LPRINT

3860 LPRINT CHR$(15)"BEGIN OF DATA":LPRINT CHR$(15)

3870 LPRINT"__________________________________________   "

3880 LPRINT CHR$(14)"PREPARED BY TARAWNEH M.":LPRINT CHR$(14)

3890 LPRINT" ******************************************"

3900 LPRINT TAB(6)" X-DATA";TAB(20)"Y-DATA";TAB(36)"Z-DATA";TAB(50)"F-DATA"

3910 LPRINT TAB(5)"  C";TAB(20)"  C";TAB(36)"  C";TAB(50)"  C"

3920 LPRINT"------------------------------------------------------------"

3930 FOR N=1 TO 114

3940 LPRINT TAB(6);X(N);TAB(20);Y(N);TAB(36);Z(N);TAB(50);F(N)

3950 NEXT N
```

```
3960 LPRINT"--------------------------------------------"
3970 LPRINT" BEGIN OF THE PROCEDURE (LEAST SQUARE ) "
3980 LPRINT "--------------------------------------------"
3990 LPRINT
4000 LPRINT
4010 LPRINT
4020 LPRINT"---------------------------------------------- ----------------
--------------- -"
4030 LPRINT
4040 LPRINT "  ************************************************************ "
4050 LPRINT"   **       the gauss elimination method                     *"
4060 LPRINT"   **   FOR SIMULTANEOUS LINEAR ALGEBRAIC EQUATIOS            *"
4070 LPRINT"  *                  GUASS.BAS                                *"
4080 LPRINT"  ************************************************************"
4090 LPRINT"                     MAIN PROGRAM                             "
4100 LPRINT"***************************************************************"
4110 N=27
4120 DIM A(N,N+1),B(N,N+1),NPIVROW(N,2),NPIVCOL(N,2),X1(N)
4130 FOR K=1 TO N
4140 LPRINT:LPRINT"EQUATION";K:LPRINT
4150 FOR J=1 TO N
4160 LPRINT"  COEFFICIENT(";K;",";J;")=";G(K,J)
4170 B(K,J)=G(K,J)
4180 NEXT J
4190 B(K,N+1)=J1(K,1)
4200 LPRINT:LPRINT"   CONSTANT ";K;"=";B(K,N+1)
```

```
4440 LPRINT"***************************************************************"
4450 FOR K=1 TO N
4460 'APPLY COMPLETE PIVOTING STATEGY
4470 MAXPIVOT=ABS(A(K,K))
4480 NPIVCOL(K,1)=K:NPIVROW(K,2)=K
4490 NPIVCOL(K,1)=K: NPIVCOL(K,2)=K
4500 FOR I=K TO N
4510 FOR J=K TO N
4520  IF MAXPIVOT )=ABS(A(I,J)) GOTO 4560
4530 MAXPIVOT=ABS(A(I,J))
4540 NPIVROW(K,1)=K: NPIVROW(K,2)=I
4550 NPIVCOL(K,1)=K:NPIVCOL(K,2)=J
4560 NEXT J:NEXT I
4570 IF MAXPIVOT)=EPS GOTO 4590
4580 LPRINT"PIVOT ELEMENT SMALLER THAN";EPS;".MATRIX MAY BE SINGULAR.":GOTO 4880
4590 IF NPIVROW(K,2)=K GOTO 4670
4600 IF Q2$="Y" OR Q2$="y" THEN LPRINT"pivoting rows:"
4610 IF Q2$="Y" OR Q2$="y" THEN LPRINT "INTERGHANGE ROWS";NPIVROW(K,2);" AND";K
4620 FOR J = K TO NC
4630 SWAP A(NPIVROW(K,2),J),A(K,J)
4640 NEXT J
4650 DET=DET*(-1)
4660 IF Q2$="Y" OR Q2$="y" THEN GOSUB 6536
4670 IF NPIVCOL(K,2)=K GOTO 4750
4680 IF Q2$="Y" OR Q2$="y" THEN LPRINT"PIVOTING COLUMNS:"
```

```
4210 NEXT K
4220 NC=N+1
4230 LPRINT
4240 EPS=.00001
4250 LPRINT CHR$(12)
4260 DET=1
4270 FOR K=1 TO N
4280 FOR J=1 TO NC
4290 A(K,J)=B(K,J)
4300 NEXT J: NEXT K
4310 LPRINT:LPRINT
4320 LPRINT"**********************************************************************"
4330 LPRINT"AUGMENTED MATRIX:"
4340 GOSUB 6536
4350 LPRINT: INPUT "IS THE AUGMENTED MATRIX CORRECT(Y/N)";Q$:LPRINT
4360 IF Q$="Y" OR Q$="y" THEN 4430
4370 LPRINT "GIVE THE POSITION OF THE ELEMENT TO BE CORRECTED:":LPRINT
4380 INPUT"   ROW NUMBER";NROW:INPUT" COULUMN NUMBER";NCOL
4390 LPRINT:INPUT " CORRECT VALUE OF THE ELEMENT";B(NROW,NCOL):LPRINT
4400 GOTO 4250
4410 '
4420 'BEGINING OF THE GAUSS ELIMINATION PROCEDURE
4430 INPUT"DO YOU WANT TO SEE STEP BY STEP RESULT(Y/N)";Q2$:LPRINT
```

```
4690 IF Q2$="Y" OR Q2$="y" THEN LPRINT "Interghange columns ";NPIVCOL(K,2);"and"
;K
4700 FOR I=1 TO N
4710 SWAP A(I,NPIVCOL(K,2)),A(I,K)
4720 NEXT I
4730 DET=DET*(-1)
4740 IF Q2$="Y" OR Q2$="y" THEN GOSUB 6536
4750 IF K=N THEN GOTO 4860
4760 IF Q2$="Y" OR Q2$="y" THEN LPRINT "PERFORM ELIMINATION:"
4770 FOR I= K+1 TO N
4780 IF Q2$="Y" OR Q2$="y" THEN LPRINT"DIVIDE ROW ";K;"BY ";A(K,K)
4790 IF Q2$="Y" OR Q2$="y" THEN LPRINT"MULTIPLY ROW ";K;"BY";A(I,K);"AND SUBTRAC
T FROM ROW";I
4800 MULT=-A(I,K)/A(K,K)
4810 FOR J=NC TO K STEP -1
4820 A(I,J)=A(I,J)+MULT*A(K,J)
4830 NEXT J
4840 IF Q2$="Y" OR Q2$="y" THEN GOSUB 6536
4850 NEXT I
4860 NEXT K
4870 'APPLY THE BACK-SUBSTITUTION FORMULAS
4880 RANK=K-1 :LPRINT"RANK =";RANK:NNR=N-RANK
```

```
4890 IF RANK=N THEN X1(N) = A(N,N+1) / A(N,N) :NCOUNT=N-1:GOTO 4940

4900 LPRINT" THE PROGRAM SETS";NHR;" UNKNOWN(S) TO UNITY,"

4910 LPRINT"AND REDUCES THE PROBLEM TO FINDING OTHER ";RANK;"UNKNOWN(S)."

4920 FOR JJ=1 TO NHR :X1(N+1-JJ) = 1:NEXT JJ

4930 NCOUNT =RANK

4940 FOR I=NCOUNT TO 1 STEP -1

4950 SUM=0

4960 FOR J =I+1 TO N

4970 SUM =SUM +A(I,J) * X1(J)

4980 NEXT J

4990 X1(I) = (A(I,N+1) -SUM) /A(I,I)

5000 NEXT I

5010 '

5020 ' INTERCHANGE THE ORDER OF THE UNKNOWNS TO CORRECT FOR THE COLUMN PIVOTING

5030 FOR K=N TO 1 STEP -1

5040 SWAP X1(NPIVCOL(K,2)) , X1(NPIVCOL(K,1))

5050 NEXT K

5060 '

5070 ' EVALUATE THE DETERMINANT OF THE MATRIX

5080 FOR I=1 TO N

5090 DET=DET*A(I,I)

5100 NEXT I

5110 LPRINT"*****************************************************************"

5120 LPRINT:LPRINT "RESULTS BY BACK SUBSTITUTION:":LPRINT
```

```
5130 FOR J=1 TO N

5140 LPRINT "X1(";J;") =";X1(J)

5150 NEXT J

5160 LPRINT:LPRINT"VALUE OF DETERMINANT=";DET:LPRINT

5170 LPRINT"******************************************************************"

5180 LPRINT"******************************************************************"

6076 LPRINT:LPRINT "DO YOU WANT TO REPETE THE CALCULATIONS ":LPRINT"WITH MINOR C
HANGES TO THE COEFICIENTS(Y/N)";:INPUT V$

6086 IF V$ = "Y" OR V$ ="y" THEN 6096 ELSE 6106

6096 CLS :GOTO 4250

6106 LPRINT:INPUT "DO YOU WANT TO RESET ALL THE COEFICIENTS(Y/N)";W$

6116 IF W$ ="Y" OR W$ ="y" THEN 6126 ELSE 6156

6126 LPRINT :INPUT "IS THE NEW SET OF THE SAME ORDER AS THE PREVIOUS SET";WW$

6136 IF WW$="N" OR WW$="n" THEN LPRINT CHR$(12):RUN 70

6146 CLS : GOTO 4110

6156 LPRINT" THE RESIDUALS"

6166 LPRINT"____________________ "

6176 FOR J2=1 TO 114

6186 M1(J2)=(X(J2)^2)

6196 M2(J2)=(X(J2))

6206 M3(J2)=(Y(J2)^2)

6216 M4(J2)=(Y(J2))

6226 M5(J2)=(Z(J2)^2)

6236 M6(J2)=(Z(J2))

6246 M7(J2)=(X(J2)*Y(J2))
```

```
6256 H8(J2)=(Y(J2)*Z(J2))

6266 H9(J2)=(X(J2)*Z(J2))

6276 H10(J2) =(X(J2)*Y(J2)^2)

6286 H11(J2)=(X(J2)^2*Y(J2))

6296 H12(J2)=(Y(J2)^2*Z(J2))

6306 H13(J2)=(Z(J2)^2*Y(J2))

6316 H14(J2)=(X(J2)^2*Z(J2))

6326 H15(J2)=(Z(J2)^2*X(J2))

6336 H16(J2)=(X(J2)*Y(J2)*Z(J2))

6346 H17(J2)=(X(J2)^2*Y(J2)*Z(J2))

6356 H18(J2)=(X(J2)*Y(J2)^2*Z(J2))

6366 H19(J2) =(X(J2)*Y(J2)*Z(J2)^2)

6376 H20(J2)  =(X(J2)^2*Y(J2)^2*Z(J2))

6386 H21 (J2) =(X(J2)^2*Y(J2)*Z(J2)^2)

6396 H22 (J2) =(X(J2)*Y(J2)^2*Z(J2)^2)

6406 H23(J2)  =(X(J2)^2*Y(J2)^2*Z(J2)^2)

6416 H24(J2)   =(X(J2)^2*Y(J2)^2)

6426 H25(J2)=(Y(J2)^2*Z(J2)^2)

6436 H26(J2)= (X(J2)^2*Z(J2)^2)

6446 F1(J2)=X1(1)+X1(2)*H1(J2)+X1(3)*H2(J2) +X1(4)*H3(J2) +X1(5)*H4(J2) +X1(6)*H
5(J2) +X1(7)*H6(J2)+X1(8)*H7(J2)+X1(9)*H8(J2)+X1(10)*H9(J2)+X1(11)*H10(J2)

6456 F2(J2)=X1(12)*H11(J2)+X1(13)*H12(J2)+X1(14)*H13(J2)+X1(15)*H14(J2)+X1(16)*H
15(J2) +X1(17)*H16(J2)

6457 F3(J2) =X1(18)*H17(J2) +X1(19)*H18(J2) +X1(20)*H19(J2)

6458 F4(J2) =X1(26)*H25(J2) +X1(27)*H26(J2)+X1(21)*H20(J2)+X1(22)*H21(J2)+X1(23)
```

```
*H22(J2)
6459 F5(J2)=X1(24)*H23(J2) +X1(25)*H24(J2)
6466 F1A(J2)=F2(J2) +F1(J2)+F3(J2)+F4(J2)+  F5 (J2)
6476 R(J2)=(F1A(J2)-F(J2))
6477 R1(J2)=(R(J2)/F(J2))
6486 LPRINT TAB(2)" F-EXPER.";TAB(15)"F-APPROX.";TAB(30)"RESIDUALS";TAB(45)"erro
r"
6496 LPRINT"*********************************************************"
6506 LPRINT TAB(2);F(J2);TAB(15);F1A(J2);TAB(30);R(J2);TAB(45);R1(J2)
6508 NEXT J2
6526 END
6536 '******************* SUBROUTINE 1: LPRINT THE MATRIX*************"
6546 '
6556 FOR KA=1 TO N
6566 LPRINT
6576 FOR J =1 TO NC
6586 LPRINT A(KA,J),
6596 NEXT J:LPRINT: NEXT KA: LPRINT
6616 LPRINT"*********************************************************"
6626 RETURN
```

PROGRAMME B.2

```
10 REM **************************************************************
20 REM ****     COMPUTER SIMULATION  PROGRAMME     ****************
30 REM ****       FOR AN ABSORPTION  COOLING       ****************
40 REM ****             UNIT                       ****************
50 REM  ************************************************************
60 INPUT"INTER NUMBER OF EQUATIONS, N=";N
62 DIM F11(N),F12(N),F13(N),F14(N),F15(N),F16(N),F17(N),F18(N),F19(N),F20(N),F21
(N),F22(N),F23(N),F24(N),F25(N),F26(N),F27(N),F28(N),F29(N),F30(N),F100(N)
70 DIM  T20(N),X1(N),X2(N),W1(N),W2(N),W3(N),H1(N),H2(N),H3(N),H6(N),H7(N)
80 DIM H4(N),H5(N),QG(N),QC(N),QE(N),QA(N),COP(N),A111(N),A222(N),B1(N),B2(N),C2
(N),AM(5),BM(5),CH(5),COOL(N),AB(N),AB1(N),C1(N),COPI(N),A17(27),A18(27)
100 DIM C(N),M(N),I1(N),F(N),B(27),T1(N),T2(N),T3(N),V(N),TA(N),T22(N)
110 DIM T4(N),T5(N),T6(N),T7(N),T8(N),T9(N),T10(N),CC2(N),T21(N)
120 DIM T11(N),T12(N),T13(N),T14(N),T15(N),T16(N),T17(N),T18(N)
130 DIM A1(27),A2(27),A3(27),A4(27),A5(27),A6(27),A7(27),A8(27),T19(N)
140 DIM A9(27),A10(27),A11(27),A12(27),A13(27),A14(27),A15(27),A16(27)
150  A1(1)=.016407:A1(2)=1.915229E-03:A1(3)=.1938627
160  A1(4)=-4.921775E-07:A1(5)=-8.023746E-05:A1(6)=5.426629E-06
170 A1(7)=.0002885514#:A1(8)=5.22605E-03:A1(9)=2.497522E-02 :A1(10)=2.555058E-06
180 A1(11)=.00004406289#:A1(12)=-7.32469E-05:A1(13)=-3.252101E-09
190 A1(14)=-6.750652E-09:A1(15)=-3.534779E-05:A1(16)=.00000004939239#
200 A1(17)=6.126763E-05:A1(18)=.0000005234505#:A1(19)=-5.331174E-06
210 A1(20)=6.858275E-08:A1(21)=1.380144E-08:A1(22)=-2.376168E-09
220 A1(23)=1.69546E-08:A1(24)=-9.11154E-11:A1(25)=2.420463E-07
```

```
230 A1(26)=7.557136E-11:A1(27)=1.720681E-07

240 A2(1)=2.709701E-04:A2(2)=-9.188729E-04:A2(3)=1.149078

250 FOR P=1 TO 24

260 A2(P+3)=0

270 NEXT P

280 A3(1)=1.480396E-03:A3(2)=-9.155625E-02:A3(3)=25.53702:A3(4)=1.026961E-06

281 LPRINT "-----------------------------------------------------"

282 LPRINT" -------      ( DAY:    -   - 1990 )        ---------"

283 LPRINT"  ----   CONCENTRATOR: (__COVERED)         ---------"

284 LPRINT" -------------------------------------------------------"

285 LPRINT" ----------------------------------------------------"

290 A3(5)=1.082603E-04:A3(6)=-4.197122E-07:A3(7)=-4.442692E-07

300 A3(8)=-1.366634: A3(9)=3.447401E-02:A3(10)=-3.309341E-05:A3(11)=2.285551E-02

310 A3(12)=.3355862#:A3(13)=5.231531E-09:A3(14)=2.941949E-08

320 A3(15)=-.2166692:A3(16)=-7.863919E-07:A3(17)=1.814133E-02

330 A3(18)=1.134242E-03:A3(19)=-3.496564E-04:A3(20)=-9.796914E-05

340 A3(21)=-7.193353E-07:A3(22)=3.805049E-05:A3(23)=-1.125733E-06

350 A3(24)=-1.610625E-07: A3(25)=-5.644495E-03:A3(26)=-4.932626E-11

360 A3(27)=4.745068E-04

370 A4(1)=-305.0764:A4(2)=-.2514568:A4(3)=19.0156

380 FOR L=1 TO 24

390 A4(L+3)=0

400 NEXT L

410 A5(1)=-7.11547:A5(2)=-5.913395E-03:A5(3)=1.515793
```

```
420 FOR M=1 TO 24

430 A5(M+3)=0

440 NEXT  M

450 A6(1)=6.184519:A6(2)=-1.288086E-02:A6(3)=1.227925

460 FOR N=1 TO 24

470 A6(N+3)=0

480 NEXT N

490 A7(1)=-.922492:A7(2)=-1.43909E-03:A7(3)=.9918674

500 FOR K=1 TO 24

510 A7(K+3)=0

520  NEXT K

530 A8(1)=7.730901E-03:A8(2)=2.126066E-02:A8(3)=-.2174519# :A8(4)=-1.023291E-06

540 A8(5)=-6.861522E-05:A6(6)=9.977443E-06:A8(7)=2.729824E-04:A8(8)=1.113278#

550 A8(9)=9.920663E-04:A8(10)=8.00873E-06:A8(11)=-1.674268E-02:A8(12)=-7.790711E
-03

560 A8(13)=-4.10151E-08:A8(14)=-5.681425E-08:A8(15)=-7.207324E-04

570 A8(16)=2.893643E-07:A8(17)=-1.653157E-02:A8(18)=-2.663336E-04

580 A8(19)=-9.403046E-04:A6(20)=9.597479E-05:A8(21)=5.948959E-07

590 A8(22)=7.067726E-06:A8(23)=-2.800056E-05:A8(24)=5.902527E-07

600 A8(25)=4.124185E-04:A8(26)=-1.331292E-09:A8(27)=1.491459E-05

610 REM STATION 9

620 A9(1)=-310.7623: A9(2)=26.6129 :A9(3)=-46.66857:A9(4)=-9.282749E-02


630 A9(5)=11.29931#:A9(6)=1.428847#:A9(11)=-1.015186E-02:A9(12)=-.7357491

640 A9(25)=4.528354E-03
```

```
690 REM STATION 10

700 A10(1)=-9.963664:A10(2)=-2.893189E-02:A10(3)=1.691408

710 FOR N=1 TO 24

720 A10(N+3)=0:NEXT N

730 A11(1)=.1120471:A11(2)=.289667:A11(3)=-8.345787:A11(4)=-.5742441#

740 A11(5)=14.48465#:A11(8)=-.1073715:A11(11)=1.920528E-02

760 A11(12)=-1.237774E-02:A11(25)=2.057495E-06

810 REM STATION 12

820 A12(1)=35.42774#:A12(2)=-.1207374:A12(3)=-3.611674:A12(4)=-.1975564

830 A12(5)=3.688181:A12(8)=.2630354:A12(11)=2.085709E-04:A12(12)=-9.721334E-03

840 A12(25)=3.899625E-04

850 REM STATION 13

860 A13(1)=85.5504:A13(2)=2.286305E-02:A13(3)=-2.979104:A13(4)=2.686007E-02

870 A13(5)=-3.940497:A13(8)=.1202973:A13(11)=1.960675E-03:A13(12)=-6.40484E-04

880 A13(25)=-2.790131E-05

890 REM STATION 14

900 A14(1)=-6.944969E-04:A14(2)=-6.94931:A14(3)=9.940824#:A14(4)=-9.674193E-07

910 A14(5)=-5.245602E-05 :A14(6)=8.629876E-07 :A14(7)=-2.868926E-05 :A14(8)=1.45
7952

920 A14(9)=1.371843E-02:A14(10)  =5.067452E-05:A14(11)=-1.367146E-02:A14(12)=4.6
16344E-02

930 A14(13)=-8.674862E-08:A14(14)=-2.482312E-07:A14(15)=.6447095#

940 A14(16)=4.816122E-06:A14(17)=-.1078114#:A14(18)=1.184138E-02

950 A14(19)=2.721636E-04: A14(20)=3.626276E-03 :A14(21)=4.258723E-04
```

```
960 A14(22)=-2.452765E-03:A14(23)=3.731384E-06:A14(24)=8.456794E-06

970 A14(25)=-5.016348E-03:A14(26)=-5.393894E-09:A14(27)=6.960897E-03

980 A15(1) =-19.28651:A15(2)=-6.097654E-02:A15(3)=3.330784#

990 A16(1)=-87.16022:A16(2)=-.2135133#:A16(3)=9.793026#

1000 FOR I=1 TO N

1010 INPUT"MASS FLOW RATE THROUGH COLLECTERS,(KG/S)";M(I)

1020 INPUT" TEMP. OF WATER INLET TO COLLECTERS,(C)";C(I)

1030 INPUT"SOLAR INTENSITY RADIATION (DT),(WH/4M2)";I1(I)

1040 INPUT" WIND VELOCITY, (M/S);V(I)

1050 INPUT" AMBIENT TEMP. , (C)";TA(I)

1051 INPUT" TEMP. OF COOLING WATER T. ( C )";T22(I)

1052 FOR J=1 TO 27:B(J)=A1(J):NEXT J:T1(I)=I1(I):T2(I)=M(I):T3(I)=C(I)

1054 GOSUB 1660:T4(I)=F(I)

1069 FOR J=1 TO 27:B(J)=A2(J):NEXT J:T1(I)=T4(I):T2(I)=0:T3(I)=0

1070 GOSUB 1660:T5(I)=T4(I)

1085 FOR J=1 TO 27:B(J)=A5(J):NEXT J:T1(I)=T5(I):T2(I)=0:T3(I)=0:GOSUB 1660:T6(I
)=F(I)

1090 T7(I)=T5(I)-T6(I):IF I=1 THEN  GOTO 1110 ELSE   GOTO 1100

1100 T8(I)=T20(I-1): GOTO 1120

1110 INPUT"INITIAL TEMP. OF ABSORBER"; T8(I)

1120 FOR J=1 TO 27:B(J)=A4(J):NEXT J:T1(I)=T8(I):T2(I)=0:T3(I)=0:GOSUB 1660:T9(I
)=F(I)

1130 FOR J=1 TO 27:B(J)=A3(J):NEXT J:T1(I)= (T5(I)-T6(I)) :T2(I)=T8(I):T3(I)=T9(
```

```
I):GOSUB 1660:T10(I)=F(I)
1140 FOR N=1 TO 27:B(N)=A8(N):NEXT N:T1(I)=T10(I):T2(I)=V(I):T3(I)=TA(I):GOSUB 1
660:T11(I)=F(I)
1150 FOR J=1 TO 27:B(J)=A16(J):NEXT J:T1(I)=T22(I):T2(I)=0:T3(I)=0:GOSUB 1660:T1
2(I)=F(I)  :IF I=1 THEN GOTO 1152 ELSE GOTO 1160
1152 INPUT"INITIAL TEMP. OF CONDENSER ";T13(I):GOTO 1180
1160 FOR J=1 TO 27:B(J)=A9(J):NEXT J:T1(I)=T12(I)-T22(I):T2(I)=T11(I):GOSUB 1660
:T13(I)=F(I)
1180 IF I=1 THEN  GOTO   1210 ELSE  GOTO  1190
1190 FOR J=1 TO 27 :B(J)=A11(J):NEXT J:T1(I)=T13(I):T2(I)=T17(I-1):T3(I)=0:GOSUB
 1660:T16(I)=F(I)
1200 GOTO 1240
1210 GOTO 1225
1225 FOR J=1 TO 27:B(J)=A11(J):NEXT J:T1(I)=T13(I):INPUT" INITIAL SPACE TEMP.";T
2(I):T3(I)=0:GOSUB 1660:T16(I)=F(I):GOTO 1235
1235 IF I=1 THEN GOTO 1236 ELSE GOTO 1240
1236 GOTO 1240
1240 FOR J=1 TO 27:B(J)=A12(J):NEXT J:T1(I)=T16(I):T2(I)=TA(I):T3(I)=0:GOSUB 166
0:T17(I)=F(I)
1250 FOR J=1 TO 27:B(J)=A15(J):NEXT J:T1(I)= T22(I):T2(I)=0:T3(I)=0:GOSUB 1660:T
19(I)=F(I)
1260 IF I=1 THEN GOTO  1290 ELSE  GOTO 1270
1270 FOR  J=1 TO 27:B(J)=A4(J):NEXT J:T1(I)=T8(I):T2(I)=0:T3(I)=0:GOSUB 1660:T21
(I)=F(I)
1280 GOTO 1292
1290 FOR J=1 TO 27:B(J)=A4(J):NEXT J:T1(I)=35.3:T2(I)=0:T3(I)=0:GOSUB 1660:T21(I
```

```
620 LPRINT TAB(7)"(KW)";TAB(18)"(KW)";TAB(28)"(KW)";TAB(38)"(KW)

630 LPRINT "------------------------------------------------------------------"

640 LPRINT  TAB(5);QG(I);TAB(16);QC(I);TAB(26);QE(I);TAB(38);QA(I);TAB(53);COP(I
)

650 REM  LPRINT "----------------------------------------"

660    LPRINT   TAB(15)"COPI";TAB(26)"(TG-TC)/TC

670 LPRINT   TAB(14)" ( W )"

680 LPRINT "----------------------------------------"

690 LPRINT   TAB(15) ;COPI(I) ;TAB(26);AB1(I)

700 LPRINT"----------------------------------------------------------------------"

710 NEXT I

720 END

730 F11(I)=B(1)+B(2)*T1(I)^2+B(3)*T1(I)+B(4)*T2(I)^2

740 F12(I) =B(5)*T2(I)+B(6)*T3(I)^2+B(7)*T3(I)+B(8)*T1(I)*T2(I)

750 F13(I) =B(9)*T2(I)*T3(I)+B(10)*T1(I)*T3(I)+B(11)*T1(I)*T2(I)^2

760 F14(I) =B(12)*T1(I)^2*T2(I)+B(13)*T2(I)^2*T3(I)+B(14)*T2(I)*T3(I)^2

770 F15(I) =B(15)*T1(I)^2*T3(I)+B(16)*T1(I)*T3(I)^2+B(17)*T1(I)*T2(I)*T3(I)

780 F16(I)=B(18)*T1(I)^2*T2(I)*T3(I)+B(19)*T1(I)*T2(I)^2*T3(I)

790 F17(I)=B(20)*T1(I)*T2(I)*T3(I)^2+B(21)*T1(I)^2*T2(I)^2*T3(I)

800 F18(I)=B(22)*T1(I)^2*T2(I)*T3(I)^2+B(23)*T1(I)*T2(I)^2*T3(I)^2

810 F19(I)=B(24)*T1(I)^2*T2(I)^2*T3(I)^2+B(25)*T1(I)^2*T2(I)^2

820 F20(I)=B(26)*T2(I)^2*T3(I)^2+B(27)*T1(I)^2*T3(I)^2

830 F(I)=F11(I)+F12(I)+F13(I)+F14(I)+F15(I) +F16(I)+F17(I)+F18(I)+F19(I)+F20(I)

840 RETURN
```

APPENDIX C

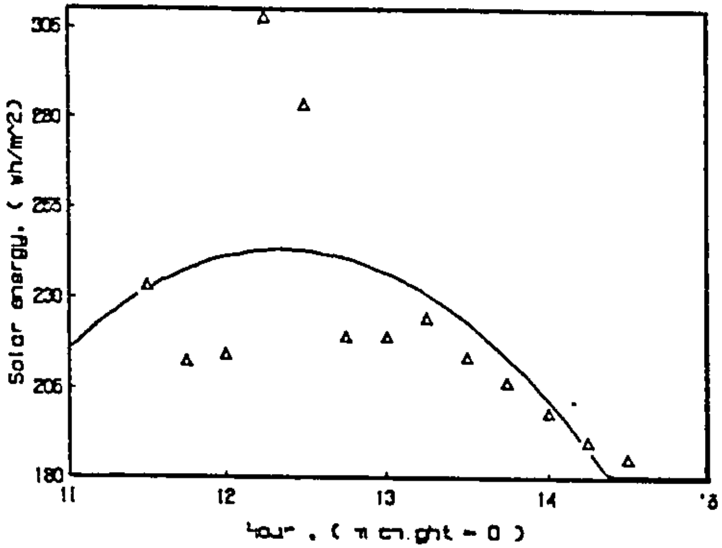


Figure C 1 : Variation of solar energy with time of the day, ambient temp. = 28.8 c. initial space temp. = 28.8 c with concentrator.

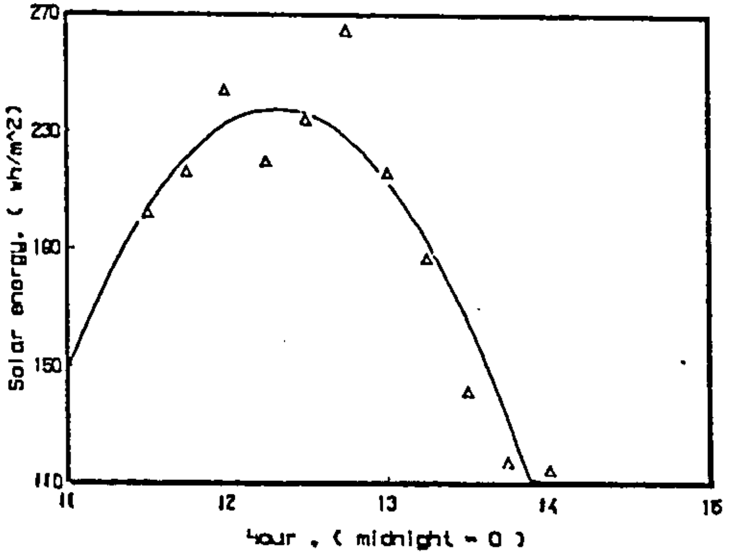


Figure C 2 : Variation of solar energy with time of the day, ambient temp. = 29.3 c. Initial space temp. = 29.0 c without concentrator.

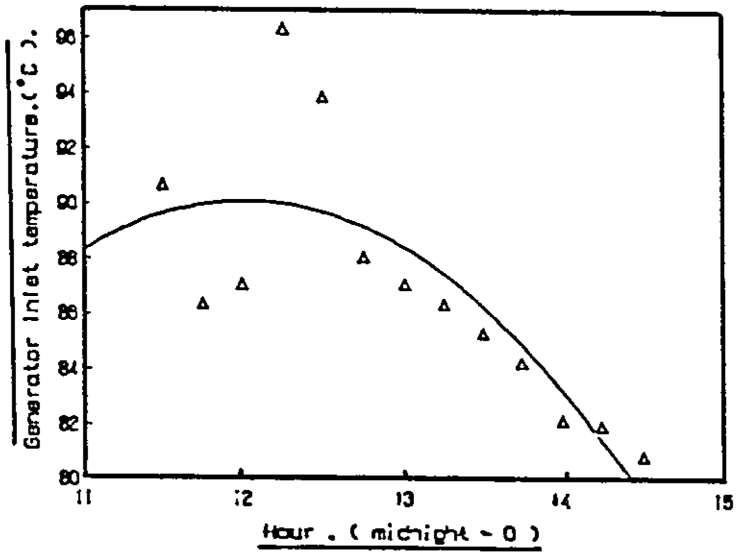


Figure C 3: Variation of generator inlet temperature with time of the day . initial space temperature = 28.8 abient temp. = 28.8 c. with concentrator.

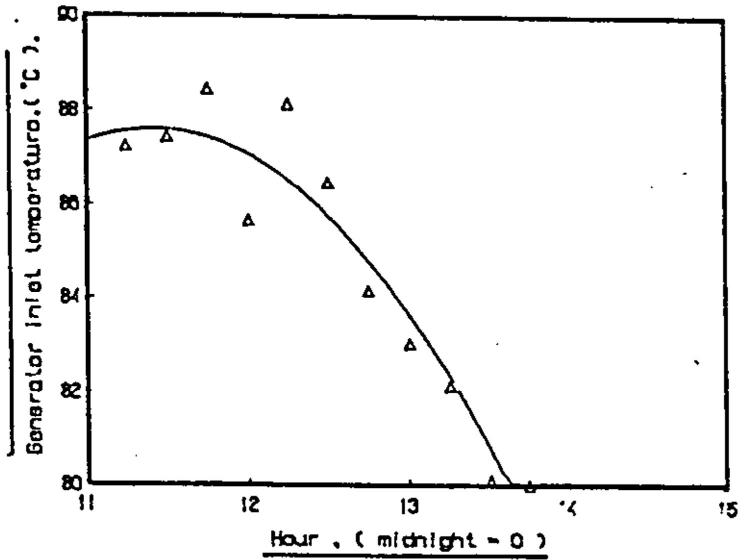


Figure C 4: Variation of generator inlet temperature with time of the day . initial space temperature ≈ 28.2 c abient temp. = 28.3 c. without concentrator.

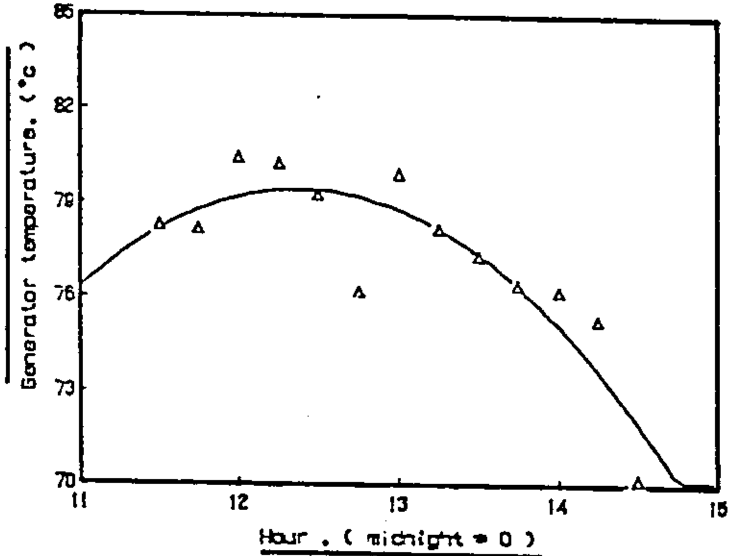


Figure C 5 : Variation of generator temperature with time of the day , ambient temperature = 27.8 c , initial space temp. = 28.5 c. with concentrator.

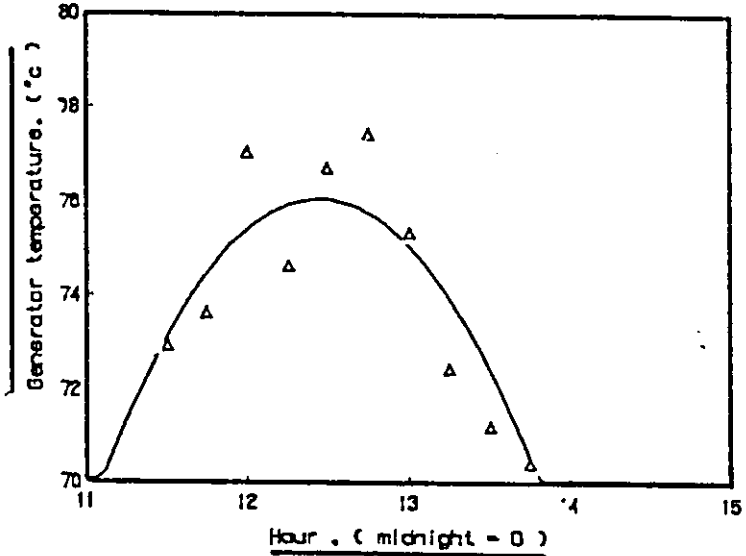


Figure C 6 : Variation of generator temperature with time of the day , ambient temperature = 29.3 c . initial space temp. = 29.0 c. without concentrator.

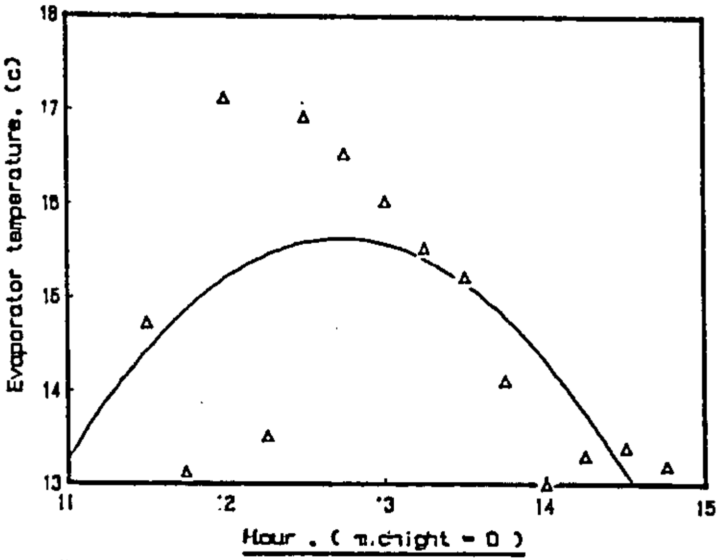


Figure C 9 : Variation of evaporator temp. with hour of the day. ambient temp. = 28.8 °c. initial space temp. = 28.0 °c with concentrator

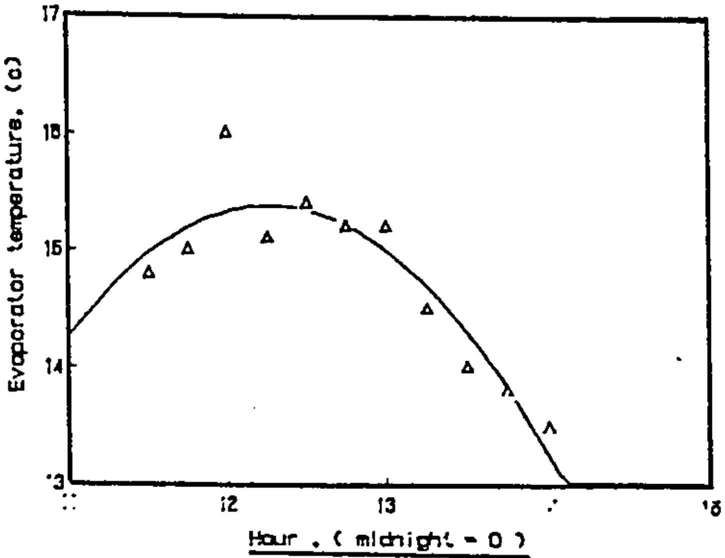


Figure C 10 :Variation of evaporator temp. with hour of the day. ambient temp. = 29.3 c. initial space temp. = 29.0 c without concentrator.

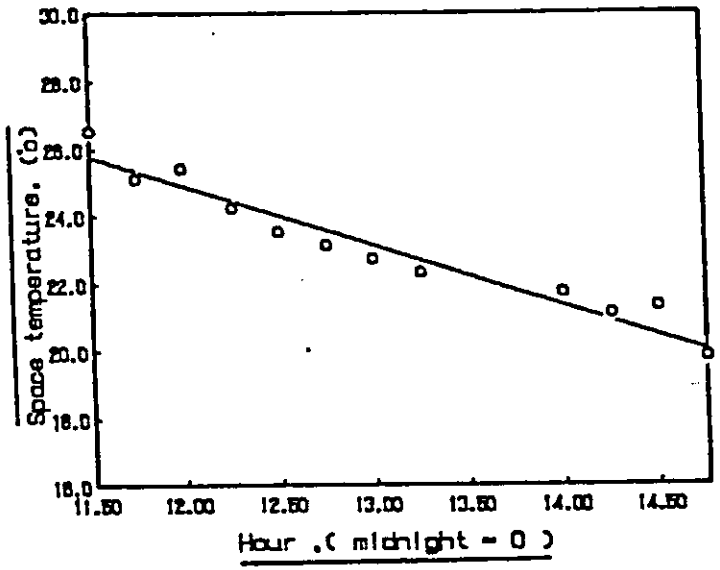


Figure C 11 : Variation of space temp. with hour in the day , ambient temp. = 28.79 °c Initial space temp. = 28.7 °c , with concentrater

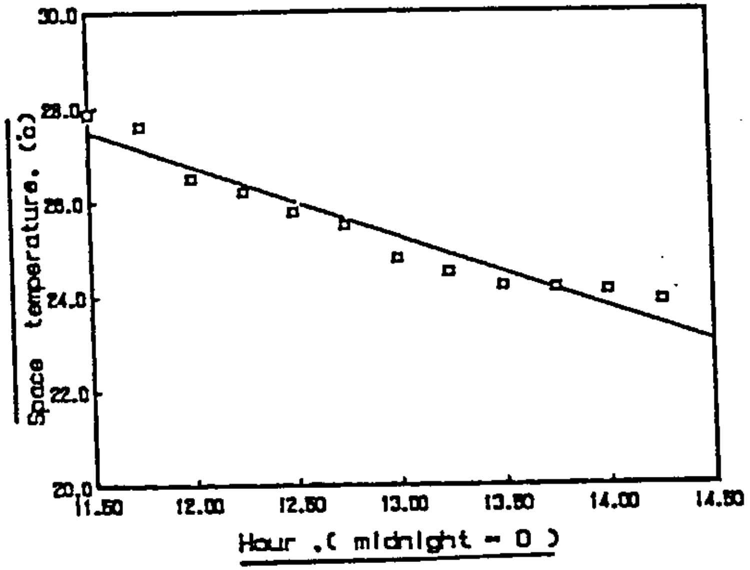


Figure C12 : Variation of space temp. with hour in the day , ambient temp. = 29.3 °c Initial space temp. = 28.0 °c , without concentrater

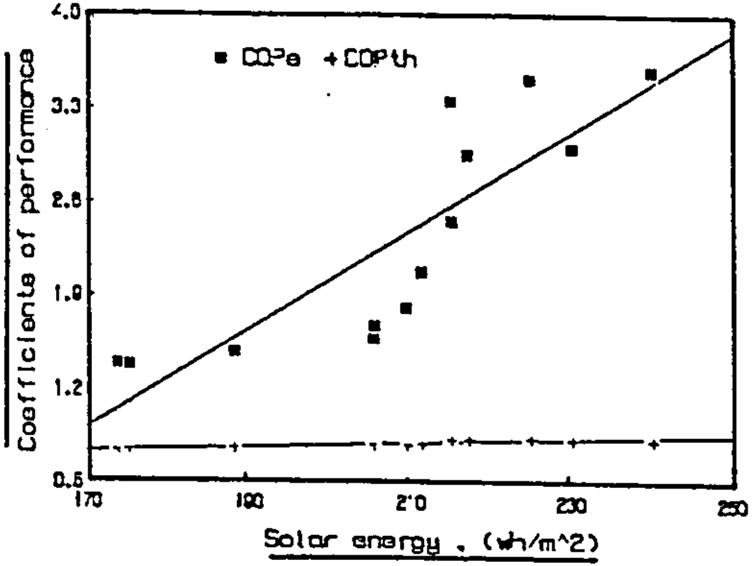


Figure C 15: Variation of theoretical and exper. COPs with solar energy, ambient temp. = 28.2 °c. initial space temp. = 28.2 c. with concentrator

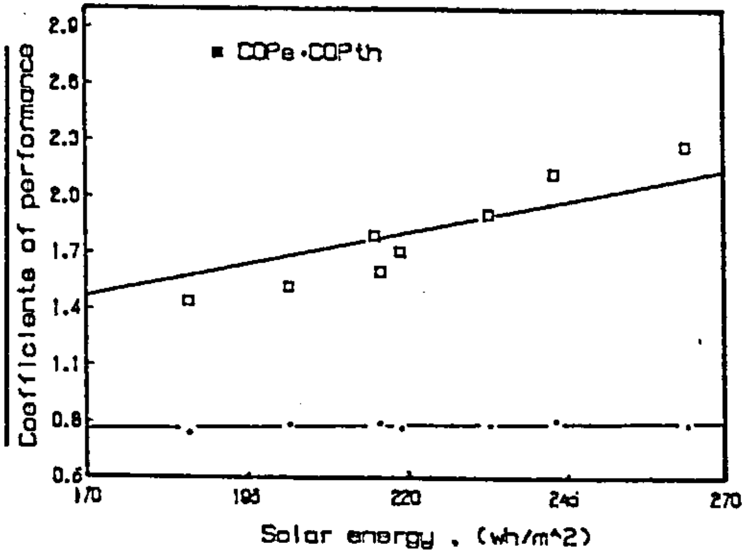


Figure C 16: Variation of theoretical and exper. COPs with solar energy, ambient temp. ≥ 29.3 °c. initial space temp. = 29.0 °c. without concentrator.

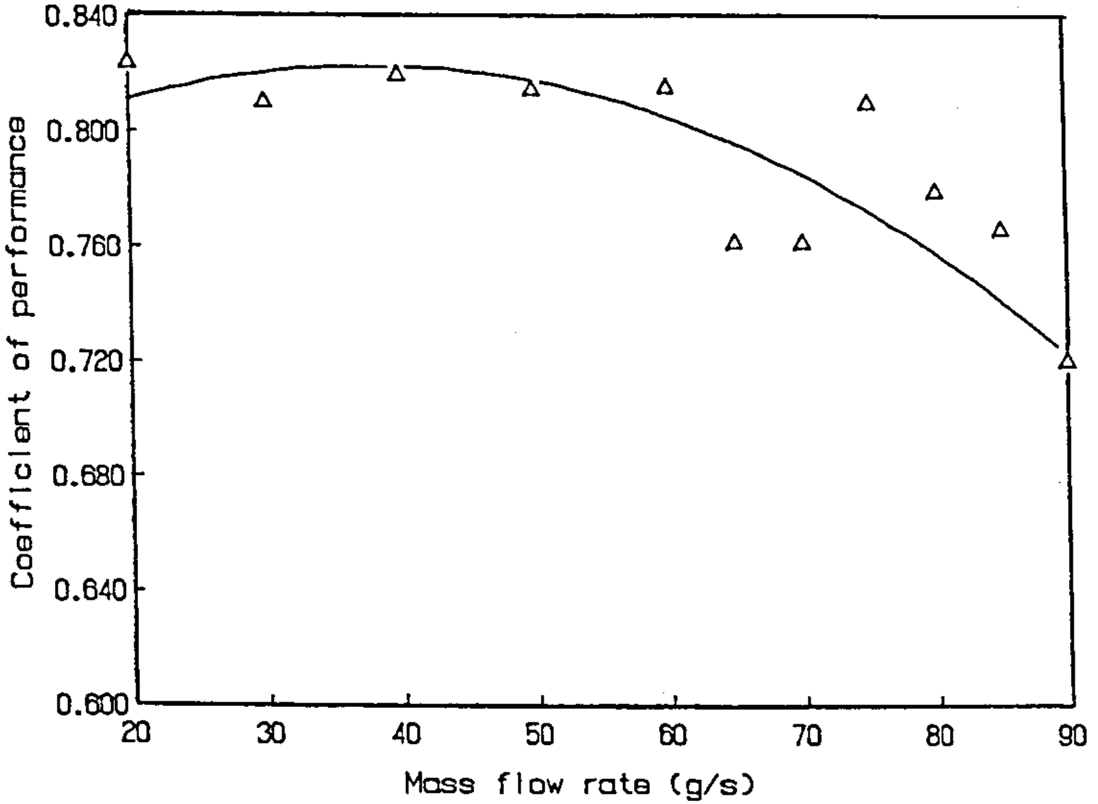


Figure C 19: Variation of coefficient of performance with mass flow rate of water through collecters, ambient temp. = 27.8 c. initial space temp. = 28.5 c.with Concentrator

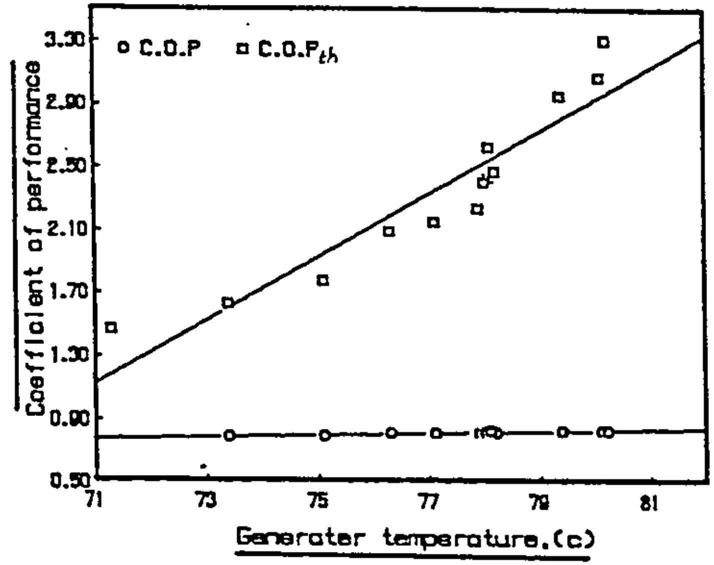


Figure C21 : Variation of generater temp. with coefficient of performance, ambient temp. = 29.7 c Initial space temp. = 28.3 c , with concentrater

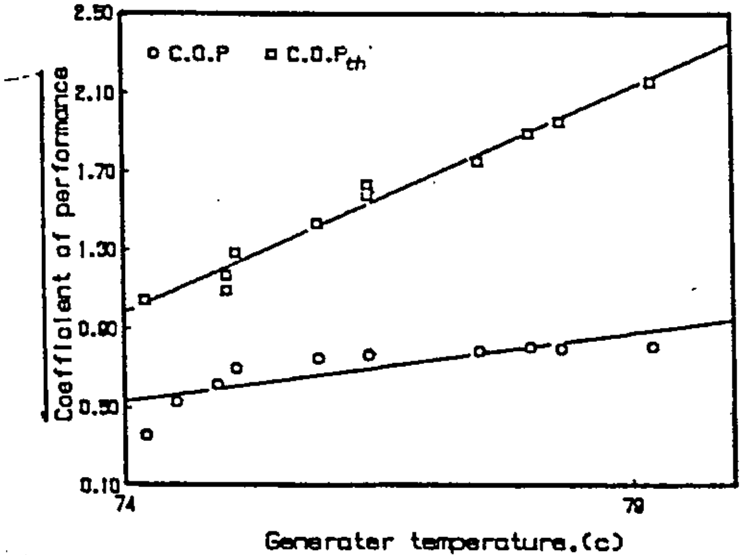


Figure C22 : Variation of generater temp. with coefficient of performance , ambient temp. =26.3 c Initial space temp. = 26.2 c , without concentrater

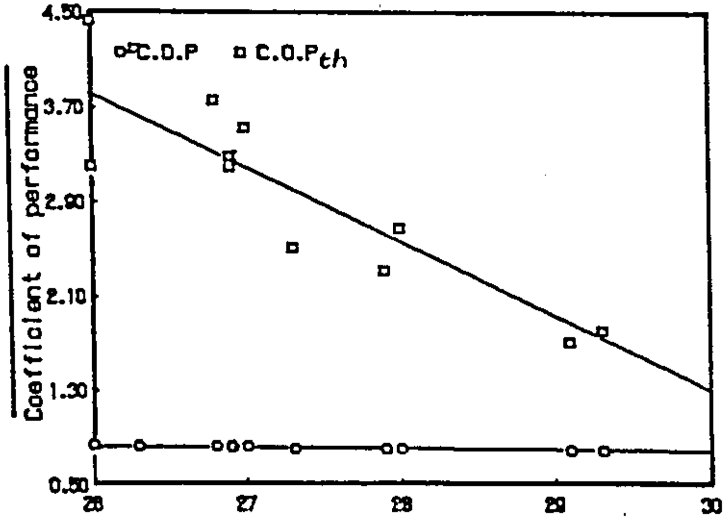


Figure C23 :Variation of condenser temp. with coefficient of performance , ambient temp. = 28.8 c Initial space temp. = 28.7 c , with concentrater

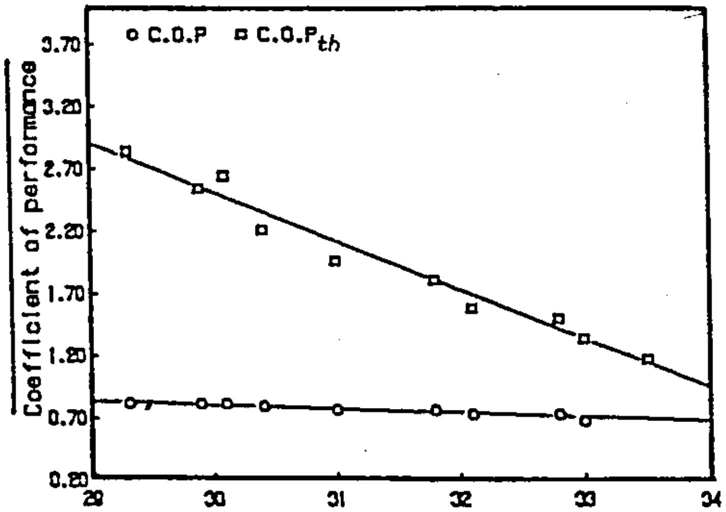


Figure C24 :Variation of condenser temp. with coefficient of performance , ambient temp. = 27.92 c Initial space temp. = 28.2 c , without concentrater

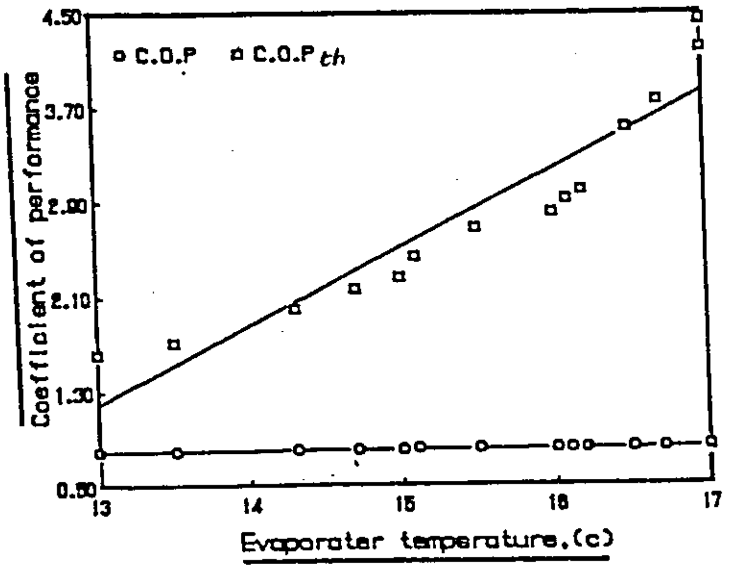


Figure :C25 :Variation of evaporater temp. with coefficient of performance , ambient temp. = 28.8 c initial space temp. = 28.7 c , with concentrater

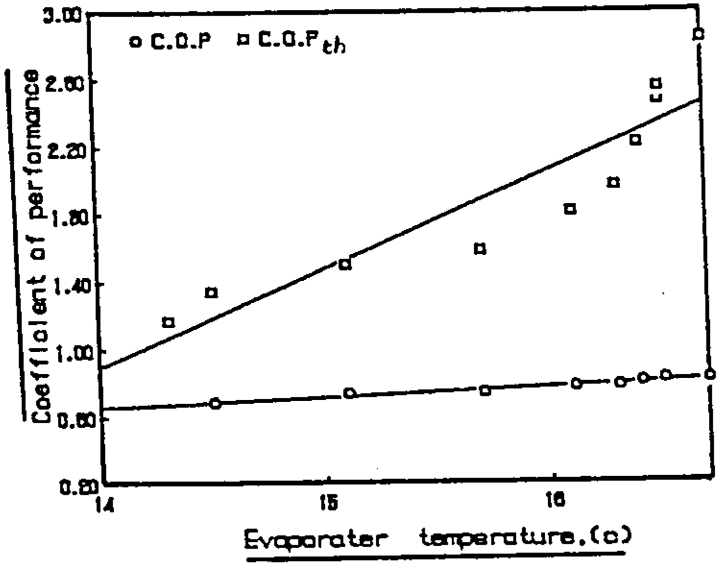
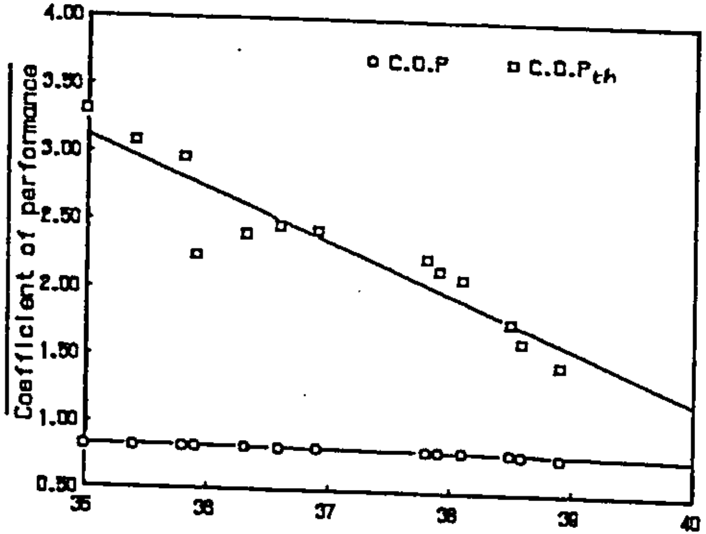
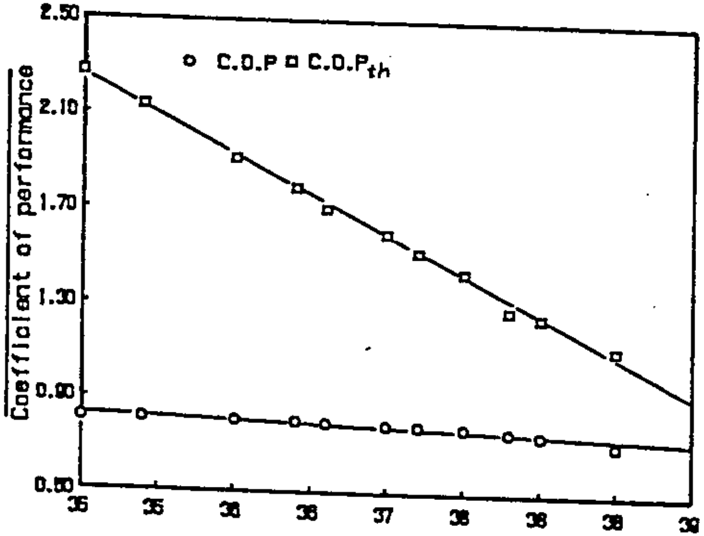


Figure C26 :Variation of evaporater temp. with coefficient of performance , ambient temp. = 27.82 c initial space temp. = 26.2 c , without concentrater



Absorber temperature,(c)

Figure C27 :Variation of absorber temp. with coefficient of performance , ambient temp. =29.7 c initial space temp. = 28.3 c , with concentrater



Absorber temperature,(c)

Figure C28 :Variation of absorber temp. with coefficient of performance , ambient temp. =28.3 c initial space temp. = 28.2 c , without concentrater

الملخص

يتضمن هذا البحث دراسة فعالية جهاز تبريد يعمل بالطاقة الشمسيه . الجهاز التجريبي المستخدم فى هذا البحث يتكون من مولد ، مكثف ، مبخر ، ماص وثلاثة لواقط شمسيه بالاضافه الى مركز شمسى . وكان وسيط التبريد المستخدم فى البحث محلول الماء والليثيوم بروما يد .

تركزت دراسة الفعاليه على المحاكاه الحاسوبيه التى اعتمدت على انموذج حدودي بثلاث متغيرات مستقله والذي استخدمت التجارب الماخوذة من الجهاز التجريبي لتحديد الثوابت المتعدده فى معادلات المحاكاة الحاسوبيه .

يقوم برنامج المحاكاة بايجاد درجات الحرارة المتوقعه عند مواقع مختلفه ويقوم بعمل الحسابات المبنيه على الموازنه الحراريه لايجاد معامل لاداء (الفعاليه). وقد وجد توافقا كبيرا بين النتائج المستخلصه من المحاكاة الحاسوبيه وتلك التى تم التوصل اليها عن طريق النتائج التجريبيه حيث ان الفارق المئوي المتوسط بينهما جميعا كان ٠,٠٣١ .

وباستخدام المحاكاة الحاسوبيه تم رسم منحنيات الاداء للجهاز والتى تبين تغير معامل الاداء مع درجات الحرارة المختلفه حيث تبين من منحنيات الاداء مدى اهمية درجتى حرارة المكثف والماص والتى تعود لتاثيرهما المباشر على معامل الاداء من ناحية ومن ناحية اخرى برزت اهميتها كعاملين يمكن التحكم بهما .

وقد تضمن البحث كذلك دراسة تاثير كلا من الطاقة الشمسيه ، درجة حرارة المولد ، درجة حرارة المكثف ، درجة حرارة المبخر ، درجة حرارة الماص ، معدل تدفق الماء خلال دورة اللاقط ، ووجود المركز على فعالية الجهاز حيث وجد توافقا بين هذه النتائج والنتائج المنشوره . وقد وجد ايضا ان وجود المركز فى الجهاز ادى الى زيادة [illegible] عامل الاداء [illegible] ٦% وقد حقق الجهاز قيمة قصوى