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Characterizing formation dredgeability for clamshell dredge

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CHARACTERIZING FORMATION DREDGEABILITY

FOR CLAMSHELL DREDGE

by

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ABSTRACT

The lack of metrics to assess clamshell dredge formation dredgeability limits the ability of engineers to predict the dredgeability of compact material and increases the risks associated with clamshell selection. Research is, therefore, necessary to increase our understanding of clamshell dredgeability assessment by evaluating possible metrics that will allow the operator to select the optimal clamshell for the operation. Work done and motor energy are possible dredgeability metrics that can be estimated using micro-processor based machine monitoring. The objective of this work is to test the hypotheses that: (i) work done by the pistons during dredging, by a hydraulically actuated dredge, is a better predictor of clamshell dredgeability than motor energy; and (ii) work done during dredging increases with increasing cycle time.

The first objective of this work was achieved by carrying out field data collection and analysis. The field data (motor current, bucket closing pressure and displacement) was sourced from a 16 yd^3 clamshell dredge operating at a mine in Seattle, WA. Work done and motor energy were obtained from the field data. The first research hypothesis was tested by comparing the measure of uncertainty surrounding mean estimates, the coefficient of variation. Kinematics and dynamics models of clamshell dredging were built and validated using the field data. The validated model was then used to test the second research hypothesis.

From this work, it can be concluded that work done is a better predictor of formation dredgeability than motor energy. Also, work done was determined to increase marginally with increasing cycle time. This is a pioneering effort to assess the dredgeability of hydraulically actuated clamshell dredges.

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NOMENCLATURE

Symbol	Description
N	Number of readings
V	Motor voltage
I	Motor current
Δt	Time step
E	Digging energy per cycle
τ	Soil shear strength
c	Soil cohesion
σ_n	Soil normal stress
ϕ	Soil internal friction angle
D_{60}	The grain size at which 60% of the soil is finer
D_{30}	The grain size at which 30% of the soil is finer
D_{10}	The grain size at which 10% of the soil is finer
h_b	Blade height
h_l	Initial layer thickness
W_1	Force resulting from pore under-pressure on the shear plane
W_2	Force resulting from pore under-pressure on the blade
α	Cutting angle
β	Shear angle
δ	Soil/steel angle of friction
F_v	Vertical cutting force
F_h	Horizontal cutting force
P	Pressure (pore pressure)
S_1	Area of the shear surface
S_2	Area of the blade
ρ_w	Desity of water
g	Acceleration due to gravity
v_c	Cutting velocity
e	Volume strain

P_{calc}	Calculated pore pressure
K_{max}	Maximum permeability
m_u	Total mass of upper sheave block
y_u	Vertical position of upper sheave block
F_r	Force in the closing rope (wire)
i	Number of parts of line
W_u	Under water weight of upper sheave block and arms
F_a	Force in one arm
m_l	Total mass of lower sheave block
y_i	Vertical position of lower sheave block
W_b	Under water weight of bucket
m_b	Total mass of bucket
F_{cv}	Vertical force on the cutting edge
F_{ev}	Vertical force on the side edge
F_{ch}	horizontal force on the cutting edge
I_b	Mass moment of inertia of bucket
W_b	Underwater weight of bucket
b_g	Distance between bucket bearing and centre of gravity
b_c	Distance between bucket bearing and arm bearing
a_b	Distance between cutting edge and bucket bearing
M	Moment of side edge forces and bucket bearing
T	Time elapsed, $T_1 = 0$, $T_n = CT$
P_i	Cylinder pressure
A	Cross-sectional area of the cylinder
Δd	Displacement of each of the four cylinders in the time step from (i) to (i+1)
n	Number of readings
φ	Closing (opening) angle of bucket with vertical
θ	Angle between the cutting edge, bucket and arm bearings
θ_1	Angle link r_1 makes with the positive x-axis
θ_2	Angle link r_2 makes with the positive x-axis

θ_3	Angle link r_3 makes with the positive x-axis
r_i	As defined by figure 4.2
ω_2	Velocity of link 2 i.e. $\omega_2 = \frac{d\theta_2}{dt}$
ω_3	Velocity of link 3 i.e. $\omega_3 = \frac{d\theta_3}{dt}$
$\dot{r}_2$	Rate of change of link 2 (r) i.e. $\dot{r}_2 = \frac{d\theta_2}{dt}$
$\ddot{r}_2$	Rate of change of link 2 i.e. $\ddot{r}_2 = \frac{dr_2}{dt}$
α_2	Angular acceleration of link 2 i.e. $\alpha_2 = \frac{d\omega_2}{dt}$
α_3	Angular acceleration of link 3 i.e. $\alpha_3 = \frac{d\omega_3}{dt}$
F_x	Resultant force in x-axis
F_y	Resultant force in y-axis
M_b	Mass of bucket
A_{bx}	Acceleration of the bucket
A_{by}	Acceleration of the bucket
Φ	Angle of between resolved forces F_x and F_y
θ_b	Angle imaginary link makes with the horizontal
r_b	Length of imaginary link between link 3 and center of mass
R_x	Resultant force at pin (point C) in the x-axis
R_y	Resultant force at pin (point C) in the x-axis
B_w	Bucket weight at center of bucket
C_4	cos θ_4 where θ_4 is the angle r4 makes with the point of moment
S_4	sin θ_4 where θ_4 is the angle r4 makes with the point of moment
ω_b	angular velocity of imaginary link θ_b i.e. $r_b = \frac{d\theta_b}{dt}$
r_4	Length that cutting resistance forces make with the point of moment.
r_5	Length that weight of the bucket makes with the point of moment.

1. INTRODUCTION

1.1. BACKGROUND

The United States, and the World, are increasingly, using up the most easily available natural resources, such as fossil fuels, metal ores and minerals that are critical to its commercial progress. Construction aggregate (sand, gravel, crushed stone) is one of these natural resources that are demanded globally (rising nearly 4% annually through 2011 to over 26 billion metric tons (Nair, 2007)). As a result, it is becoming necessary to develop those resources that lie at greater depth in the earth, and where the costs of production are concomitantly higher. In the United States, the impacts of higher production costs can be seen in all avenues of life, from the rising costs of food and fuel, to the constraints that these prices put on the American lifestyle. The increased difficulty in finding economic resources to mine extends to even the most basic of the minerals needed in industry. This includes the aggregate that is used to produce construction materials (concrete, hot mix asphalt, base rock etc.), a critical component of the American infrastructure. This aggregate must be mined from the earth in increasing quantities, straining the available supply of material in the process, and requiring that deposits be worked that lie deeper within the earth.

'Dry' mining methods allow aggregate companies to mine only up to the water table. Companies, therefore, disturb the more land (by creating more pits) in order to meet the demands for aggregate products. However, the use of dredging technology allows aggregate companies to obtain permits that will allow them to mine at depths below the water table, and maximize the extracted resource per unit area of disturbed land. Dredge lakes can be put to useful use after mining (fishing, recreational lakes, water reservoirs etc.), just like conventional dry mining pits. Dredging is, arguably more environmentally friendly as it ensures lower land-use impacts per ton of aggregate.

This good environmental stewardship requires maximum extraction to minimize the impacts. Thus, there is considerable merit in using a dredging process to extract deeper beds of sand and gravel that lie below the water table. Unfortunately, as the water depth increases the technical problems in mining this material also increase. This leads to lower rates of recovery, and higher costs to the consumer. One of the main methods for extracting the deposits at depths greater than 150 ft is to use a clamshell dredge, where a remotely operated bucket is lowered to the deposit. Through its weight and remote action, a clamshell bucket can extract the material and bring it to surface (Figure 1.1). The use of this technology has been found to be environmentally friendly and economic. It is widely used in the production of aggregate in the US and elsewhere.

Figure 1.1 Clamshell dredge on site

1.2. STATEMENT OF PROBLEM

The use of hydraulic clamshell dredge to mine deposits that lie below the water table (especially in excess of 150 ft) causes production to be constrained, particularly since it becomes more difficult to assess the dredging resistance of the deposit being mined. At the same time, the tools that are available to the dredge operator to assess the dredgeability of the deposit are limited. The lack of visibility under muddy water inhibits the dredge operator's ability to judge the dredging effort of the clamshell dredge. This significantly affects productivity, if the ability of the clamshell to adequately dredge the material is misjudged during dredge selection. In addition, remedial action to deal with difficult digging is expensive and difficult since the usual ground fragmentation techniques (e.g. blasting and ripping) cannot be applied in dredging. The lack of tools that relate formation properties to dredgeability significantly increases the risk associated with purchasing a clamshell dredge.

Existing metrics have been found to be inadequate in predicting the dredgeability of a deposit, particularly for compact deposits (in excess of 35 blows/ft standard penetration test) when using clamshell dredges. This increases the operator's risk of acquiring a non-performing asset (a dredge can cost upwards of $4 million). There is, therefore, the need to investigate possible metrics that will allow the operator to select the best clamshell for the operation to assure optimum performance.

Dredging below the water table, coupled with environmental constraints has ensured the advancement of new techniques. Cutter suction dredges and hydraulic clamshell dredges are some of the specialized machines developed to mine underwater. Cutter suction dredges (not the sea going ones) are limited to about 65 ft underwater and significantly less compact aggregates. The market of aggregates (now at around 26 billion tons, annually) considerably exceeds this smaller niche market of the cutter suction dredge. Increasingly, hydraulic clamshell dredges are used to exploit underwater sand and gravel deposits. By understanding the metrics for predicting the dredgeability of compact aggregates using hydraulic clamshell dredges operating at depth underwater, the supply of cheap aggregates in the United States can be increased. Also, such work will improve the capabilities and knowledge base of engineers and reduce the risk of acquiring non-performing assets.

1.3. OBJECTIVES AND SCOPE OF THE RESEARCH

The overarching aim of this research was to increase our understanding of clamshell dredgeability assessment by evaluating possible metrics for measuring it. The specific objectives of this work were to:

1. Test the hypothesis that work done by the pistons during dredging, by a hydraulically actuated dredge, is a better predictor of clamshell dredgeability than motor energy; and
2. Test the hypothesis that work done during dredging increases with increasing cycle time.

The work is limited to dredgeability assessment of hydraulically actuated clamshell dredges. The kinematics and dynamics modeling was restricted to the bucket closing process. Given the nature of this process (only two-dimensional motion), the models are 2-D models.

1.4. RATIONALE OF STUDY

This work deals with clamshell dredging for sand and gravel mining which is very different from river or sea (mostly cutter suction dredges) dredging. Previously, extraction of compact sand and gravel deposits below the water table has been limited to backhoe excavators with maximum reach of approximately 25 feet. Clamshell dredges are capable of mining at depths in excess of 150 feet and hydraulic clamshells can handle significantly more compact material and more boulders than cutter suction dredges. However, the lack of metrics to assess formation dredgeability limits the operator's ability to predict clamshell dredgeability of compact aggregates. This increases the risk of investing in non-performing clamshell dredges.

Metrics based on energy expended during excavation have been used as measures of the difficulty of digging (Hendricks et al., 1989; Hendricks and Scoble, 1990 and Karpuz et al., 1992). For instance, Patnayak et al. (2008) computed energy and power consumption from voltage and current signals for both hoist and crowd motors of electric shovels. Their work showed that hoist motor power is less sensitive to digging trajectory and hence is a useful parameter for determining ground diggability. Awuah-Offei and Frimpong (2005 and 2007), showed that energy per unit loading rate consumed by a shovel is a superior measure of diggability. Work done and motor energy (possible dredgeability metrics) were calculated from the field data and used as a measure of the difficulty of dredging, in this research.

It is important to understand the correlation between any dredgeability metric and operating variables, so that changes in the metric are not wrongly attributed to changes in material properties (density, cohesion, internal friction angle, etc). This is because soil-cutting effort is known to be a function of tool geometry and soil properties as well as operating conditions (Suministrado, et al., 1990b and Abo-Elnora et al., 2003). For a hydraulic clamshell, the operating variables are depth below water, rate of bucket drop, bucket tilt, and bucket closing cycle time. Modern hydraulic clamshells have an autonomous bucket closing cycle. The cycle time is set prior to digging. Preliminary analysis in this work showed a weak correlation between work done and cycle time (Osei and Awuah-Offei, 2009). There is, therefore, the need to test the hypothesis that work done during dredging increases with increasing cycle time.

Once the possible metrics have been identified, further work will build this into an industrial tool that can be used in ever broadening applications. This will help the success of mining operations, thereby lowering the cost of aggregates, and thus holding down the national costs of construction. This research is a pioneering effort in modeling clamshell dredgeability in mining applications, in particular, sand, and gravel deposits. It combines excavation science, kinematics and dynamics modeling, and micro-processor based instrumentation and data acquisition to understand dredgeability. This work will allow industry to take full advantage of dredging technology to exploit compact reserves, deep underwater. The increased exploitation of underwater aggregate reserves will increase the aggregate reserves in the US. In 2008, about 1 billion metric tons of construction aggregates (sand and gravel) were produced in the US. This was produced from 6,192 operations, 10% of which were dredging operations (Wallace, 2008). By facilitating the easy exploitation of reserves underwater through clamshell dredging, this research program will contribute to the supply of lower-cost of aggregates in the US.

1.5. METHODOLOGY

The first section of the research involved field data collection and analysis. The field data (motor current, bucket closing pressure, and displacement) were collected from a Rohr Corp 16 yd^3 clamshell dredge operating at a mine in Seattle, Washington. Dredgeability metrics (work done and motor energy) were obtained from the field data. The sensitivity of the metrics to independent variables (mean bucket tilt and cycle time) were evaluated using statistical correlation analysis. The first research hypothesis was tested by comparing the measure of the uncertainty surrounding mean estimates (coefficient of variation). The second section involved dynamics and kinematics modeling and implementation using MATLAB's Simulink® toolbox. The model was validated using the field data. The validated model was then used to test the second research hypothesis.

1.6. STRUCTURE OF THE THESIS

Literature survey is covered under Chapter 2, which is in five (5) main sections covering clamshell dredge operations, measurement of dredgeability, factors affecting dredgeability, soil properties and cutting resistance, kinematics and dynamics modeling, simulation, and validation. The field experiments, data collection and analysis are discussed in Chapter 3. Chapter 4 covers the kinematics and dynamics modeling, the set up for the simulation in Simulink® (MATLAB), the validation of the model using the field data and simulation experimentation. The research results are presented and discussed in Chapter 5. Finally, the conclusions and relevant recommendations for future work are covered in Chapter 6.

2. LITERATURE SURVEY

This chapter reviews the relevant literature on hydraulic clamshell dredging in compact aggregate mining. The review covers clamshell dredge operation, measurement of dredgeability, factors affecting dredgeability, soil properties and cutting resistance, kinematics and dynamics of the dredging process as well as simulation and validation.

2.1. CLAMSHELL DREDGE OPERATIONS

The clamshell dredge (Figure 2.1) is a fully automated dredge, which is operated at the operator's cabin. For a working cycle, the dumping point of the grab is always the starting point. The dredge operates by lowering the bucket to bottom of the lake. The operator then manually or automatically operates the closing time of the bucket. For automatic control, the automatic sequences of the working cycles are initiated by the operator using the Programmable Logic Controller (PLC). In the cabin, the operator is able to see the bucket close via the in-cabin screen. The closed bucket is then raised to the surface by the trolley cables on the overhead cranes. The content of the bucket is then emptied to the hoppers, and the required aggregate size is conveyed to the plant after screening and, sometimes, sizing.

During the dredging cycle it is necessary to localize every dredging of the bucket by means of a positioning system. This helps the dredge operator to place the next bite of the bucket after the foregoing, creating a dig well. The dredge under study therefore had a dredging well. The dredging well enables easy formation of the dig well, which aids dredging through the failure of the walls of the well. The size of the bucket determines the digging well, most dredging wells have space for two digging positions. The dredge has four winches at its four corners, which is used to position it (dredge). Motion is achieved by slacking one side of the winch, which is best administered when there is no wind.

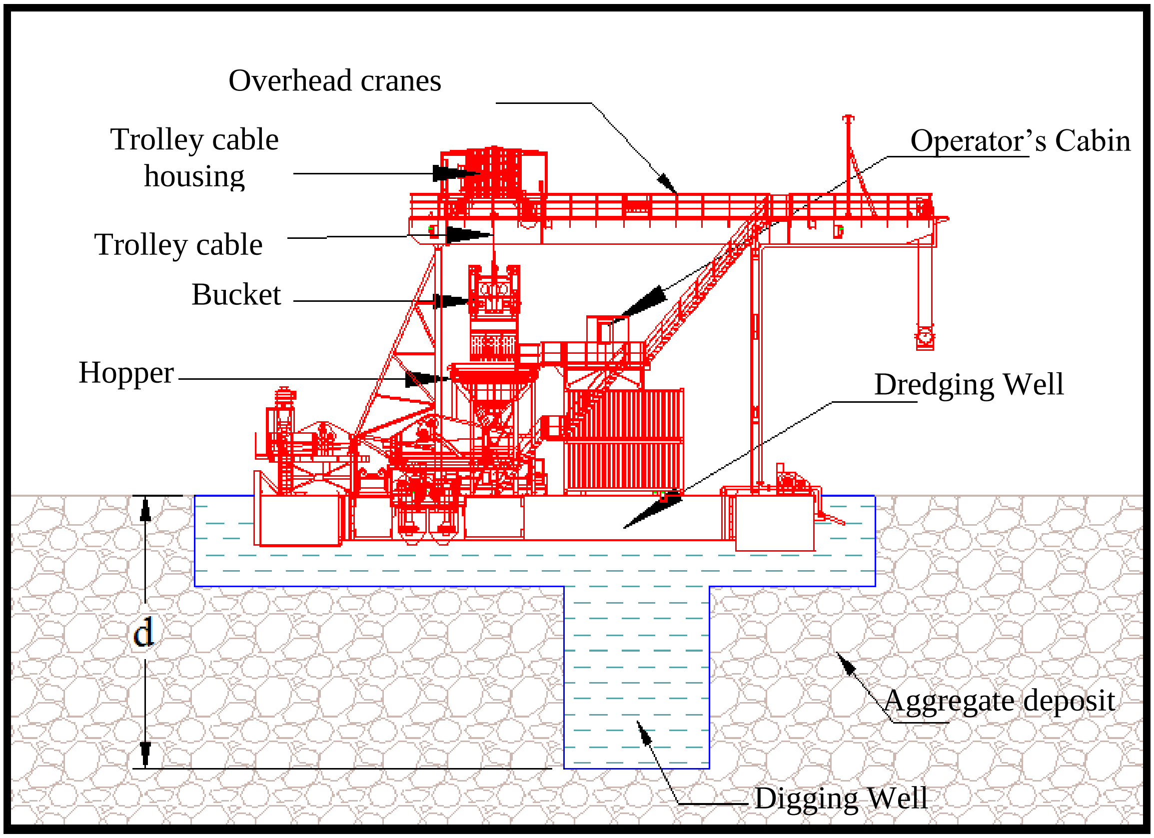

Figure 2.1 Nomenclature of a clamshell dredge

2.2. MEASUREMENT OF DREDGEABILITY

Dredgeability of a formation is defined as the ease of dredging by a dredge. Formation dredgeability depends on the type of dredge used. Dredgeability determines the dredging time, dredging effort and the amount of material excavated. Dredgeability is basically diggability in saturated material. Diggability is defined as the ease of digging by an excavator in dry materials. For a given excavator, the diggability determines the digging time, the digging effort and the amount of material excavated (Awuah-Offei, 2009). The ease/difficulty of excavation (diggability/dredgeability) depends on the excavating tool and the digging environment. For a given excavator, the digging effort is a good measure of the diggability. Many studies have been carried out to investigate the measurement of formation diggability. Since diggability and dredgeability can be measured by digging effort of an excavating tool, understanding the body of knowledge on measuring diggability will pave the way for comprehensive studies in determining dredgeability of saturated formations.

Williamson et al. (1983) pioneered micro-processor monitoring of excavators, which has since become the state-of-the-art for diggability measurement. Their work was aimed at deriving a muck pile diggability index by monitoring DC motors and relays of P&H electric shovels. The investigation was narrowed to digging, and thus limiting the influence of other factors affecting shovel productivity. The ease of digging was judged by using the difference in the signal profiles observed during digging. Williamson et al. (1983) used a P&H 2100BL shovel with a magnetorque control system making it difficult to separate crowd motor responses from hoist motor responses. Mol et al. (1987) monitored the crowd motors of P&H electric shovels. In their study, voltage and current signals observed from the digging cycles were used to generate a diggability index.

Hendricks and Scoble (1990) presented a detailed study based on the techniques of Williamson et al. (1983). Their study monitored signals of a P&H 2800XP electric shovel in different operating environments. Microprocessor-based instrumentation installed aboard the shovel permitted monitoring of hoist armature voltage and current; crowd armature voltage and current; hoist rope position; and crowd arm extension. These permitted the determination of the dipper trajectory for each dig cycle. The behavior of hoist motor and crowd voltage and current signals was used to determine digging conditions (easy or hard). Consequently, they used the ratios of the total signal length to the area under the plot of both the hoist armature voltage and current as measures of diggability (ease of digging). The result of their study suggested hoist motor response to be more sensitive to variation in diggability, and that no relationship between crowd motor responses and fragmentation was apparent. The work carried out indicated that the individual practices of operators regarding the depth of cut of the trajectories significantly affect the nature of the motor signals recorded. This makes it difficult to tell whether the difficulty in digging is due to the material characteristics or the trajectory (depth of cut).

Karpuz et al. (1992) also used monitoring techniques introduced by Williamson et al. (1989) to study the effect of depth of cut and operating environment on diggability. They investigated the essential difference between shovel performances with disturbed material (blasted) and direct digging condition, together with the factors affecting the production rate. In the study, the cycle time, digging time, dipper fill factor, power and energy consumptions of digging were considered to be most significant. P&H 2100 BL electrical shovels (4 and 7 years of study length) at different sites with dipper capacity of 15 yd^3 were monitored during overburden removal. The results of their studies revealed the relative increase of digging power with increasing depth of cut. Subsequently, they concluded that, based on the interpretation of data from numerous monitored dig cycles, the specific energy which depends on power consumption, digging time and amount of excavated material was the most effective parameter that correlates well with depth of cut and formation digging characteristics. Karpuz et al. (1992) explained specific energy to be dependent on cycle time. This is contrary to the definition of specific energy, as specific energy is defined as the ratio of energy to the payload. Energy by unit loading rate as defined by Awuah-Offei and Frimpong (2005 and 2007) is dependent on cycle time. These studies (Hendericks and Scoble (1990) and Karpuz et al. (1992)) showed that it is possible to use microprocessor monitoring of excavators as pioneered by Williamson et al. (1983) to study the digging behavior signals of P&H 2800XP and 2100 electrical shovels.

Patnayak et al. (2008) showed that the performance of electric shovels in the Athabasca oil sands was controlled by the diggability characteristics of the oil sands formations. Oil sands diggability is related to the geology and depositional environment and depends upon geological parameters, such as facies and member, and geotechnical parameters, such as shear strength, density, water content, bitumen content, and particle size. The performance of a shovel was found to be influenced by equipment and geometric parameters, such as operator's practices and skill, bucket and tooth design, digging trajectory (depth of cut), and direction of digging with respect to bedding planes of the oil sands formations.

Current and voltage data from hoist, crowd and swing motors of electric shovels were collected at one-second intervals and analyzed to identify key performance indicators. Performance parameters recorded include date and time, hoist armature voltage and current, hoist field current, crowd armature voltage and current and crowd field current and swing armature voltage and current. Patnayak et al. (2008) estimated the digging energy for each dig cycle by integrating the product of voltage and current values over the dig cycle time as shown in Equation (1). Definitions of symbols are in the nomenclature. Digging power for a dig cycle was determined as the average digging energy per unit dig time. They postulated that since conditions were similar, all variability was due to operator preferences. Consequently, the parameter with the least coefficient of variation is the most appropriate measure of material variability since it is the least sensitive to operator practice. This approach is adopted in testing the first hypothesis in this research.

$$\text{Energy} = \sum_{i=1}^{n} 0.5\left|V_{i+1}I_{i+1} + V_i I_i\right|\Delta t \tag{1}$$

Awuah-Offei and Frimpong (2005 and 2007) used models to simulate the energy per unit loading rate of the P&H 2100BL shovel. Their studies showed that energy per unit loading rate (Equation 2) consumed by a shovel is a superior measure of diggability and shovel performance, since it is directly proportional to digging effort and cycle time but inversely proportional to material payload. Once operator performance and the other operating variables are isolated, the energy per unit loading rate was expected to be a good measure of dredgeability (dredging resistance) as well.

$$\text{Energy per unit loading rate, } \widehat{E} = \frac{E \times \text{Digging Time}}{\text{Payload}} \tag{2}$$

In diggability measurement, the current state-of-the-art employed in the measurement of the digging effort of an excavation tool is the microprocessor monitoring techniques. This technique first developed by Williamson et al. (1983) and successfully employed by Hendricks and Scoble (1990) and Karpuz et al. (1992), in the study of other excavators (P&H 2800XP and 2100 electrical shovels), have helped in deriving diggability indices. Since diggability and dredgeability can be measured by the digging effort of the excavation tool, this state-of-the-art in measuring diggability can be implemented in measuring the digging effort of a dredging tool.

Since the modern clamshell dredge (excavation tool) is fully automated, data can be collected from the sensors that monitor the clamshell dredge. From this data, energy (work done and motor energy) and power consumption can be computed from the pressure, displacement, voltage, current and payload. The specific energy or the energy per unit loading rate can be computed to measure the dredgeability. The dredge used in the field experiments was not equipped with a scale. This prevented researchers from measuring payload, which is important in computing specific energy or energy per unit loading rate.

2.3. FACTORS AFFECTING DREDGEABILITY

Hemami et al. (1994) indicated that the factors that affect excavation effort and diggability includes four major factors; the material, the bucket geometry and size, the bucket motion and environmental effects, like temperature and gravity.

Spigolon (1993) studied the geotechnical factors that affect the dredgeability of sediments. He defined dredgeability as the means with which an underwater soil, sediment or rock can be excavated, removed, transported and deposited with respect to known or assumed equipment methods and in-situ material characteristics. There are several independent variables that affect dredgeability for clamshell dredging: equipment type and rated capacity; physical properties of the soil or rock; geometry of the site and cycle time. Based on excavation, the dredgeability properties of soil sediments are: cuttability, rock hardness, and under water slope instability (flowability).

Also the geotechnical engineering characteristics of sediment needed for the evaluation of its dredgeability properties are:

- In-situ consistency of cohesive soil, compactness of granular soils, or degree of cementation of soils or rock.
- Grain size distribution, including median size, maximum size, uniformity, and amount of fines.
- For granular materials the shape and hardness of the grains.
- For cohesive soils, the plasticity of the 0.42mm screen fraction.
- Presence and amount of organic matter and shells.

For a clamshell dredge bucket, Figure 2.2 shows the factors that affect the dredging effort. Bucket parameters define the digging tool geometry and the available digging force. The size and weight of the bucket are important in defining the added digging force from gravity. The presence and configuration of teeth has been shown to significantly affect the required digging effort (Maciejewski et al; 2004). The size of hydraulic cylinders and the available fluid pressure determines the pressure at the teeth for a hydraulically actuated clamshell dredge. Production variables that affect the digging effort include the state of the material (in-situ or sloughed material), the deposit being mined (virgin material or previously mined tailings) and operator experience and preferences. Depth below water affects the pore pressure, surcharge on the material and the drag on the bucket during dredging.

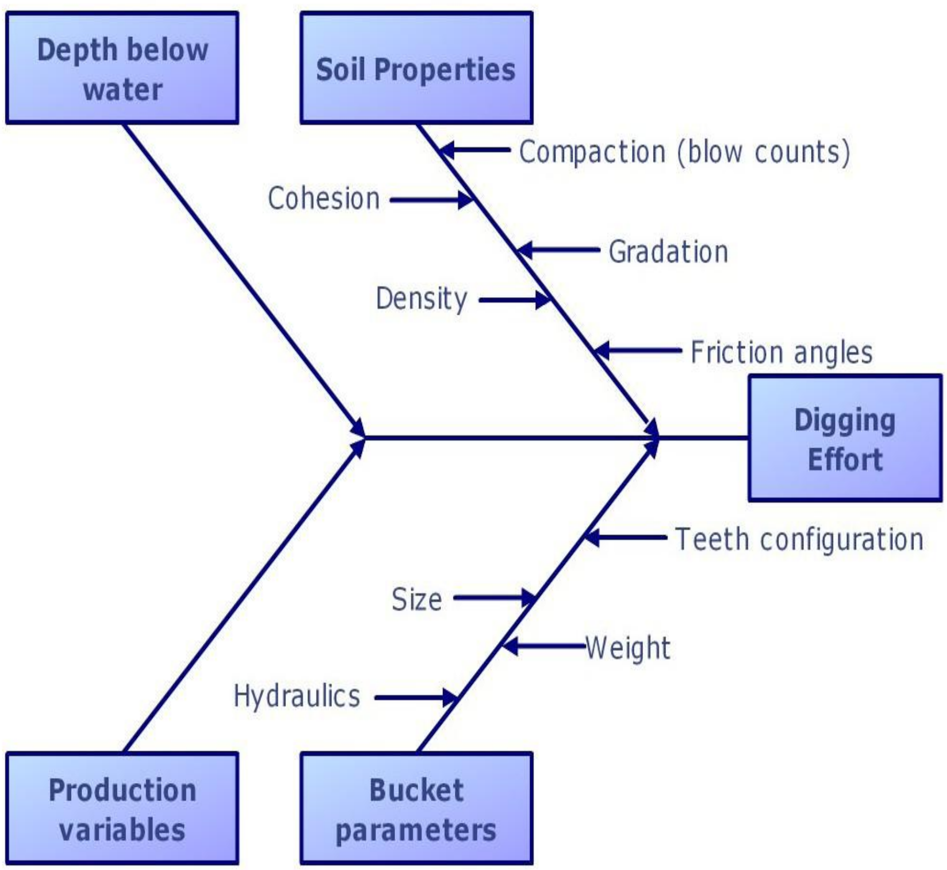

Figure 2.2 Factors affecting dredging effort of a clamshell

2.4. SOIL PROPERTIES AND CUTTING RESISTANCE

2.4.1. Soil Properties. Soils are characterized by strength, compressibility, size and shape, grain size distribution, specific gravity and moisture content (plasticity). According to Wray (1986), moisture content is the most important factor affecting the characteristics of soil. The soil may be saturated (all voids filled with water) or it may be partly saturated. Moisture content influences soils differently, and it may be the greatest implication on the soils behavior when the soil is subjected to loading (Wray, 1986). Knowledge of the strength of soil is necessary for understanding the dredgeability of soils. The strength of soils was expressed by Coulomb (1776) by using the failure model, given by Equation (3).

$$\tau = c + \sigma_n \tan\phi \quad (3)$$

According to Herbich (1992), dredgeability using cutter suction dredge depends on the flow and deformation of in-situ material and disturbance by the mechanical action of the cutter. Soil characteristics are a function of the in-situ density, void ratio, degree of consolidation, layering and cementation. Soils for dredging purposes are usually tested in-situ or in the laboratory. In-situ test can be a simple desk study, which is conducted if there is sufficient historical and local information available to establish geotechnical and geological conditions at the site or field sampling (drilling or SPT (Standard Penetration Test) blow count[1] and boring). It should be noted that the strength of a rock material determined by the uniaxial compression test is dependent on the moisture content of the core specimen, anisotropy, and the adopted test procedure.

The United Soil Classification System (USCS) classifies soil according to texture, plasticity, and engineering behavior. In terms of texture, the shape of the grain size curve has an important effect on the properties of sands and gravels. This can be described with two coefficients, the coefficients of curvature, C_c (Equation 4) and the coefficient of uniformity, C_u (Equation 5) (Herbich, (1992) and all referenced therein).

[1] The SPT blow count is the number of hammer blows needed to drive the sampler a distance of 12 in (30.5 cm).

$$C_c = \frac{(D_{30})^2}{D_{60}D_{10}} \tag{4}$$

$$C_u = \frac{D_{60}}{D_{10}} \tag{5}$$

For plasticity, it is necessary to conduct the liquid limit (LL) and plastic limit (PL) test of Attenberg. The difference between the liquid limit and the plastic limit (Equation 6) is the range of water content over which the remolded clay behaves as a plastic material and is referred to as the plasticity index (PI) (Herbich, 1992).

$$PI = LL - PL \tag{6}$$

Soil cutting effort is known to be a function of soil properties and other factors. The characteristics of soil such as strength, grain size, specific gravity, moisture content, texture and plasticity determines the properties of soil such as density, cohesion, friction angle and external friction angle of a formation. These properties serve as the resistive forces of the soil during cutting by a tool.

2.4.2. Cutting Resistance. The theory of cutting resistance is based on the resistance of soil to cutting by a blade. The dredge bucket cuts soil by the action of the teeth. Knowledge of the theory of cutting tool resistance is key to modeling the total force on a clamshell bucket during dredging. 2-D and 3-D wedge failure theories and finite element methods have been explored in modeling soil cutting resistance.

Early studies were conducted on the failure of soil during cutting beginning in the 1950s (Payne, 1956; Reece, 1965; Osman, 1964; Hettiaratchi et al., 1966 and Hettiaratchi and Reece, 1975), leading to the development of useful models for the calculation of cutting resistance. Soil cutting effort is known to be a function of tool geometry, soil properties (density, ρ; cohesion, c; internal friction angle, φ; and external friction angle, δ) and operating conditions (cutting angle, α_c; cutting depth, d; and surcharge, p_0) (Suministrado et al., 1990b and Abo-Elnora et al., 2003).

Thukar and Godwin (1990) demonstrated the tip-effect phenomenon of rotary tillage tools while cutting a two-dimensional soil slice with a wire under quasi-static conditions and also proposed a force prediction model on the basis of Mohr-Coulomb soil mechanics. Experimental investigations with a 20-guage wire working in a frictional soil showed that there are two modes of soil failure, a passive general shear failure zone towards the free curved face of a previous cut and local shear failure zone towards the undeformed soil, occurring simultaneously. From their study it was realized that the general shear failure plane for most practical cases was at an angle of $45 - \phi/2$ (where ϕ is angle of shearing resistance) with the direction of major principal stress, the direction of which, is a tangent to the cutting path of the wire at the point of incipient soil failure. In cutting a full slice, the orientation of the principal stress changed with the angular position of the tip. They developed a theoretical force prediction model of the wire (tip) tool on the basis of Mohr-Coulomb soil mechanics and this gave good agreement with experimental results. Thukar and Godwin (1990) applied the ultimate bearing capacity theory proposed by Meyerhof (1961) for wedge-shaped foundation with a 90^o included angle at great depth, while cutting purely cohesive media (artificial clay). This showed good correspondence with cutting between observed and predicted results.

Boccafogli et al. (1992) evaluated two different soil cutting methods, both based on the classical wedge method. The target of their work was to verify the cyclic behavior of soil cutting efforts, or failure frequency. The wedge model was chosen, with the horizontal forces calculated. They then carried out numerical simulation using soil values obtained by a small bevameter during soil bin tests. The test was executed at different blade angles and at different operating angles. From their studies, they postulated dynamic models of soil failure can only be used to predict the mean value of soil cutting force.

The development of models by earlier researchers facilitated later studies on the tip-effect phenomenon (Thukar and Godwin, 1990) and cyclic behavior (Boccafogli et al., 1992). This work served as backbone for further studies to be conducted on real tools such as bulldozer blades, moldboard plows and excavator buckets. Some examples of these studies are discussed in the ensuing paragraphs.

Shuren and Qinsen (1994) proposed a 2-D mathematical model of soil-blade interaction for the bulldozer. They analytically solved for the forces acting on the wedge of soil ahead of the blade, the resultant forces were then resolved into their horizontal and vertical components. The result of the model was compared with the experimental model and was found to correlate well.

Sumministrado et al. (1990a) developed a model for predicting the trajectory of soil motion on the moldboard plow surface. They proposed a mathematical model to approximate trajectories of soil furrow subslices and subsequently calculated the forces occurring on the moldboard surface. The soil reaction forces encountered were also determined by a model which used the method of trial wedges to determine the angle of the failure surface with the horizontal. The calculated forces were compared with experiments preformed in the laboratory.

Zeng and Yao (1992) developed a dynamic model for soil cutting resistance prediction by blade and tine. Their model was based on soil flow under cutting, unlike previous models that took soil as a rigid body and were based on empirical failure patterns. They applied the concept of virtual power (in plasticity theory) to calculate the resistance forces to the cutting board. In comparison with previous models, this model included the effects of shear rate and the effects of soil compaction for the first time. Their model can simulate the relation of cutting resistances to major factors, such as cutting depth, cutting width, rake angles and cutting speed. The developed model was a success when the result was compared with experimental results.

The attempt to better predict the cutting resistance by blade led to the application of finite element method (FEM) (Xiang and Saperstein, 1988; Yong and Hanna, 1997). Chi and Kushwaha (1990) developed a non-linear 3D finite element model to study soil failure under loading by a narrow tillage blade. They applied the weighted residual method to formulate the finite element model. The model also takes into account friction at the soil-tool interface, and progressive and continuous cutting. Their results provided soil forces, a progressive developed failure zone, and displacement field and stress distribution along the tool surface. Tillage test conducted in the laboratory soil bin, validated soil forces from the finite element analysis.

In dry material, geotechnical properties such as material strength, material bulk density, specific gravity, moisture content and Attenberg limits, porosity and clay contents exist. Dredging involves cutting saturated soils with all these geotechnical properties, but the most important of these properties is pore water pressure (Krazanowski, 1987).

In the water saturated cutting process, the dilatancy phenomenon plays an important role in determining the cutting forces. As a result of shear in the sand, pore volume changes. The flowing water which fills the increased volume experiences a certain resistance, causing pore water pressure. Based on pore pressure calculations and the equilibrium of horizontal (F_h) and vertical (F_v) forces, equations can be derived to predict the cutting forces (Figure 2.3). Equations (7)-(9) show the forces acting on the blade per unit width (Miedema, 2005). For larger cutting angles (> 60^o), a wedge is formed in front of the cutting blade, which does not move relative to the blade. In dry soil, Hettiaratchi and Reece (1975) found a mechanism called boundary wedges. At large cutting angles, this wedge acts as a blade with a smaller blade angle. The forces that act on the blade during soil cutting are transmitted to the blade through grain stresses and water pressure from the wedge and cut soil (Miedema, 2004).

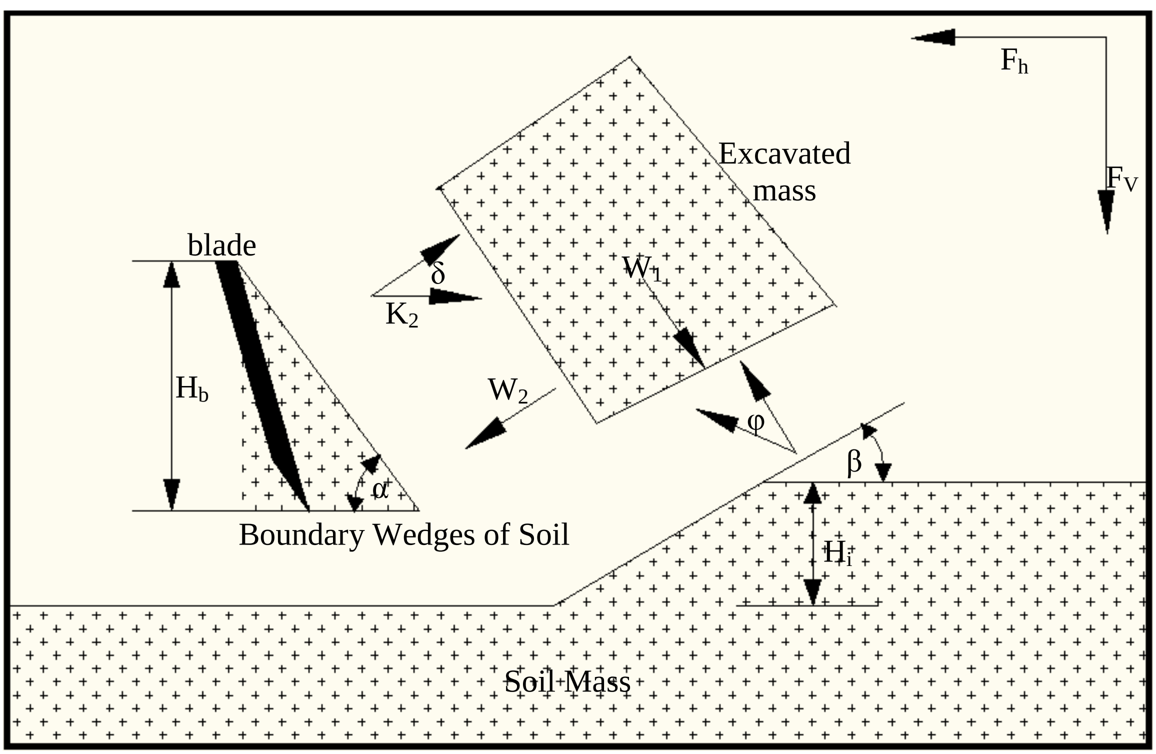

Figure 2.3 The forces on the layer cut (Miedema 2005)

$$F_h = -W_2 \sin(\alpha) + K_2 \sin(\alpha + \delta) \quad (7)$$

$$F_v = -W_2 \cos(\alpha) + K_2 \cos(\alpha + \delta) \quad (8)$$

$$K_2 = \frac{W_2 \cdot \sin(\alpha + \beta + \varphi) + W_1 \sin(\varphi)}{\sin(\alpha + \beta + \delta + \varphi)} \quad (9)$$

Yasheng et al. (2006) studied the interaction between the dredge cutter and the soil. Their study used the 2D cutting theory of Miedema (2004 and 2005) to calculate the pressure distribution and the blade cutting forces for the saturated sand at small cutting angles by using MATLAB. They concluded that the cutting angle of the blade on the cutter head and the shear angle continuously vary. Thus, the cutting angle and the shear angle and other parameters could be easily modified to simulate the different situations in practice. In calculating water pore pressure, the average dimensionless pressures on the blade and shear angle, P_{1m} and $P_{2m,}$ were obtained based on the finite element node pressure. Yasheng et al. (2006) calculated the water pore force (W_1 and W_2) by substituting Equation (10) into (11).

$$Pcalc = \frac{W_i}{S_i}, \quad S_1 = \frac{b \cdot h_l}{\sin\beta}, \quad S_2 = \frac{b \cdot h_p}{\sin\alpha}, \quad for\ i = 1,2 \quad (10)$$

$$P_{real} = \frac{\rho_w \cdot g \cdot v_c \cdot e \cdot h_l}{k_{\max}} P_{calc.} \quad (11)$$

Miedema's (2005) laboratory research has shown that, for cutting velocities in a range from 0.5 to 5 m/s, the cutting process is dominated by the phenomenon of dilatancy so the contributions of gravitational, cohesive, adhesive and inertial forces can be neglected. Yasheng et al. (2006) took the velocity, v_c = 0.5m/s, and simplified the force equilibrium equations on the blade and shear zone equation. The parameters obtained determined the horizontal (Equation 7) and vertical forces (Equation 8). The results were compared with that of Miedema (2005) and they were similar.

In this work, the model by Yasheng et al. (2006), which is based on the 2D theory of Miedema (2004 and 2005), will be employed in modeling the cutting resistance of the soil.

2.5. KINEMATICS AND DYNAMIC MODELING

Miedema and Vlasblom (2006) studied the closing curve of a cable actuated clamshell by modeling the kinematics and dynamics of the clamshell bucket. They calculated the closing curve of the clamshell bucket by solving the equations of motion of the moving parts of the bucket. The type of clamshell dredge they considered had six main bodies that are subject to motions. They assumed that because the arms have small rotational amplitude and translate vertically with the upper sheave block, they can be considered as part of the upper sheave block. Also the clamshell was considered to be symmetrical with respect to its vertical axis; only the equations of motion of one halve of the clamshell have to be solved. The other half is subject to exactly the same motions, but mirrored with respect to the vertical axis. Based on their free body diagram (Figure 2.4), which considered the main bodies, they derived equations of motion. The weights were considered to be submerged weights and masses were considered to be the sum of the steel masses and hydro-mechanically added masses. Figure 2.4 shows the positive directions of motions, forces and moments. Equations (12) and (13) were derived from the equilibrium of forces for the upper sheave and lower sheave block. Equation (14) shows the equilibrium equation of moments around the bucket bearing.

$$m_u \cdot \ddot{y}_u = F_r(i-1) + W_u - F_a \cdot \cos(\alpha) \tag{12}$$

$$\begin{aligned} m_i \cdot \ddot{y}_i = -F_r \cdot i + W_1 + W_b - m_b \cdot \ddot{y}_b + m_b \cdot bg \cdot \cos(\varphi+\beta)\cdot\varphi^2 \\ + F_a \cdot \cos(\alpha) + F_{cv} + F_{ev} \end{aligned} \tag{13}$$

$$\begin{aligned} I_b \cdot \ddot{\varphi} = -W_b \cdot bg \cdot \sin(\varphi + B) + m_b \cdot y_b \cdot bg \cdot \sin(\varphi+\beta) - F_a \cdot \cos(\alpha) \cdot bc \cdot \sin \\ (\varphi+\theta) + F_a \cdot \sin(\alpha) \cdot bc \cdot \cos(\varphi+\theta) + F_{ch} \cdot ab \cdot \cos(\varphi) - F_{cv} \cdot ab \cdot \sin(\varphi) - M_e \end{aligned} \tag{14}$$

Equations (12), (13) and (14) form a system of coupled non-linear equations of motion. Equation (15) shows the relation of the rope force as the summation of all the vertical forces acting on the clamshell.

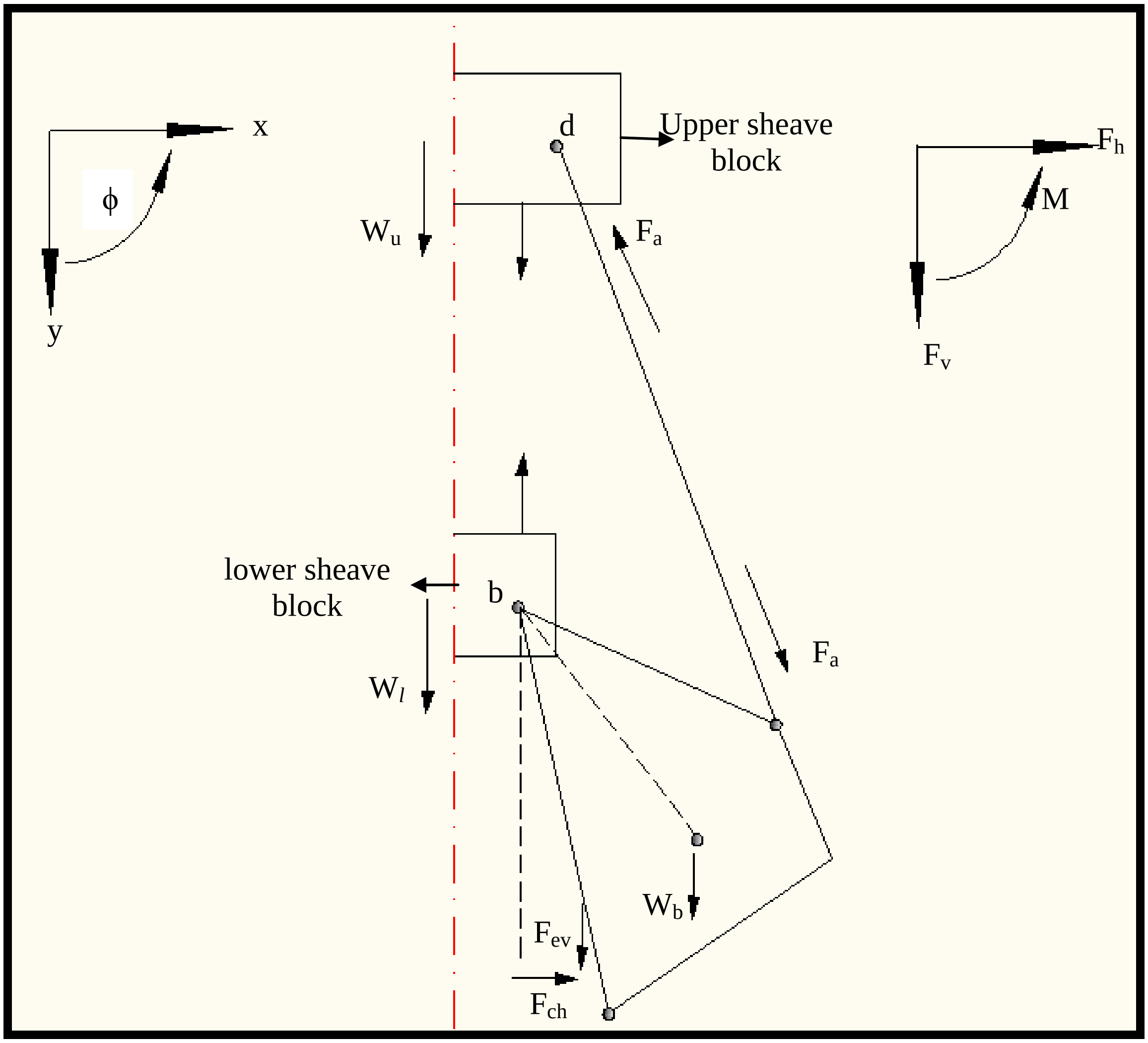

Figure 2.4 Forces distinguished in the clamshell model (Miedema and Vlasbom, 2006)

$$F_r = W_b - m_b \cdot \ddot{y}_b + W_u - m_u \cdot \ddot{y}_u + W_i - m_i \cdot \ddot{y}_i + F_{cv} + F_{ev} + m_b \cdot bg \cdot \cos(\varphi + \beta) \cdot \varphi^2 \qquad (15)$$

From the dynamic equations above, they modeled four degrees of freedom: $\ddot{y}_b$, $\ddot{y}_1$, $\ddot{y}_u$, $\ddot{\varphi}$.

Miedema and Vlasbom (2006) chose φ as the independent degree of freedom for the closing angle of the bucket. For a small time interval (Δt), the length of the closing rope (*l*), and the closing angle (φ) where found to be subjected to small changes, Δ*l* and

Δφ. From this, the vertical position of the upper sheave block and lower sheave were calculated. Dividing the vertical position of the upper and lower sheave block by the time increment, Δt, gives Equations (16) and (17) for the velocities of the blocks.

$$\dot{y}_u = i_r - i \cdot \ddot{\varphi} \cdot \eta(\varphi) \tag{16}$$

$$\dot{y}_I = i_r - (i-1) \cdot \dot{\varphi} \cdot \eta(\varphi) \tag{17}$$

The vertical accelerations of the upper and lower sheave blocks were calculated by taking the derivative of equations (16) and (17) with respect to time, giving Equations (18) and (19). They suggested that since the equations are non-linear, the equations have to be solved numerically, in this case using Newton-Raphson iteration method (Press et al., 1992) and theta integration method (Barclay et al., 2000) to prevent numerical oscillations.

$$\ddot{y}_u = \ddot{i}_r - i \cdot \ddot{\varphi} \cdot \eta(\varphi) - i \cdot \varphi^2 \cdot \frac{d\eta(\varphi)}{d\varphi} \tag{18}$$

$$\ddot{y}_u = \ddot{i}_r - (i-1) \cdot \ddot{\varphi} \cdot \eta(\varphi) - (i-1) \cdot \varphi^2 \cdot \frac{d\eta(\varphi)}{d\varphi} \tag{19}$$

Yasheng et al. (2006) used the simultaneous constraint method in the dynamic analysis of the cutter (Haug, 1989 and 1992; Gardener, 2001). This technique involves developing the Newton’s motion equations that need to be satisfied at any time during the simulation. By solving these equations together with the kinematics equations, the dynamic simulation of any mechanism can be achieved easily. This technique is simple and accurate for solving dynamic problems and offers a means to relate the dynamic solution to the desired inputs. Awuah-Offei (2005) also used this technique to solve the cable shovel kinematics and dynamics problem. The technique results in differential–algebraic equations (DAEs) which can be solved with a combination of ODE and linear solvers.

2.6. NOVELTY OF RESEARCH

This work deals with hydraulic clamshell dredging in compact aggregate mining, which is different from the dredging of river beds or sand. A clamshell dredge is capable of mining at depths in excess of 150 feet. There are two types of clamshell dredges: hydraulic or cable. These dredges can handle significantly more compact material and boulders than cutter suction dredges. They are widely used in the mining of compact aggregates at depth under water. Also, these dredges are distinguished by their remote bucket closing process (operation). The kinematics and dynamics of the closing process of cable clamshell dredges in water-saturated sand have been studied by researchers (Miedema and Vlasblom 2006). A hydraulic clamshell dredge, which provides more closing pressure and is, thus, preferred in mining, has not been researched, extensively. This author is not aware of any work on the kinematics and dynamics of hydraulic clamshells in the literature.

The closing of the bucket of modern hydraulic clamshell dredges at depth under water is autonomous, which limits the operator's ability to better predict the dredgeability of the material. There is a lack of adequate metrics to assess formation dredgeability of hydraulic clamshell dredges at depth under water. In order to identify the metrics necessary for predicting the dredgeability of material, this work employed the current state-of-the-art micro-processor monitoring of excavators in predicting diggability. The monitoring technique helped in acquiring data from existing instrumentation of a modern hydraulic dredge (e.g. Rohr Corporation dredges). Two metrics, work done and motor energy, were identified for data analysis. However, it was necessary to understand the correlation between these metrics (work done and motor energy) and operating variables, so that changes in the metrics are not wrongly attributed to changes in material properties. This work explores the effect of cycle time on the work done, a proposed metric. This work also seeks to model the kinematics and dynamics of the closing process for a hydraulic clamshell dredge using MATLAB Simulink®. Miedema's (2004 and 2005) model was used to model soil cutting resistance.

3. FIELD EXPERIMENT

This section involves the regional and local geology of the study site. It also involves the clamshell dredge description as well as the field experimental setup. The field experiment consists of data collection and data analysis. The objective of this section is to test the hypothesis that work done by the hydraulic actuated piston is a better predictor of formation dredgeability than motor energy.

3.1. STUDY SITE

3.1.1. Regional Geology The site under study is located at Everson, Washington State. The regional geological formations according to Culver (1936) were formed during all four eras: Cenozoic, Mesozoic, Paleozoic and the Pre-Cambrian eras. There are five formations that are illustrative of Washington State geological formation. The formations are the quaternary, tertiary, Mesozoic, Paleozoic and Proterozoic formations. The geology of Everson consists of quaternary formations. These formations can be grouped into alluvial deposits related to glacial deposits, late volcanic rocks such as Tieton andesite, deposits of glacial epoch and other sedimentary formations.

3.1.2. Site Geology The local geology of the site according to Schuster (2005) consists of unconsolidated sediments. These sediments are of the quaternary formations and are mainly alluvial deposits related to glacial deposits. In order to characterize the deposit sixteen holes were drilled on the site. The property is about 61 acres. The first three holes were drilled on the northern part of the site on already dry existing pit floor near the water table. In general, good sand and gravels were encountered in all the holes to depths 100 ft and greater. However, all three of the holes contained shallow clay seams (one to five feet thick), 20-40 ft below surface (elevation 95-70 ft). These clay seams where tan to gray, and very tight and stiff. Two of the holes on the property did not contain these clay seams, which indicate that the clay is laterally discontinuous. Two holes located in the southern part of the property contain significantly shallower resources, and, also, contains similar stiff clay seams. The clay seams, however, tend to be thinner (0.5-2 ft thick). The above water or near surface below water gravel is also quiet dirty. The estimated reserve for the property is 5,820,000 cubic yards. The reserve is classified into upper gravel, clay zone and lower deposit gravels. The lower gravels are classified as potential reserves based on the difficulty of removing the overlying clay seams. Figure 3.1 shows the drill logs for hole ID B-7-92 and B-6-92, which are closest to the site operating during the study.

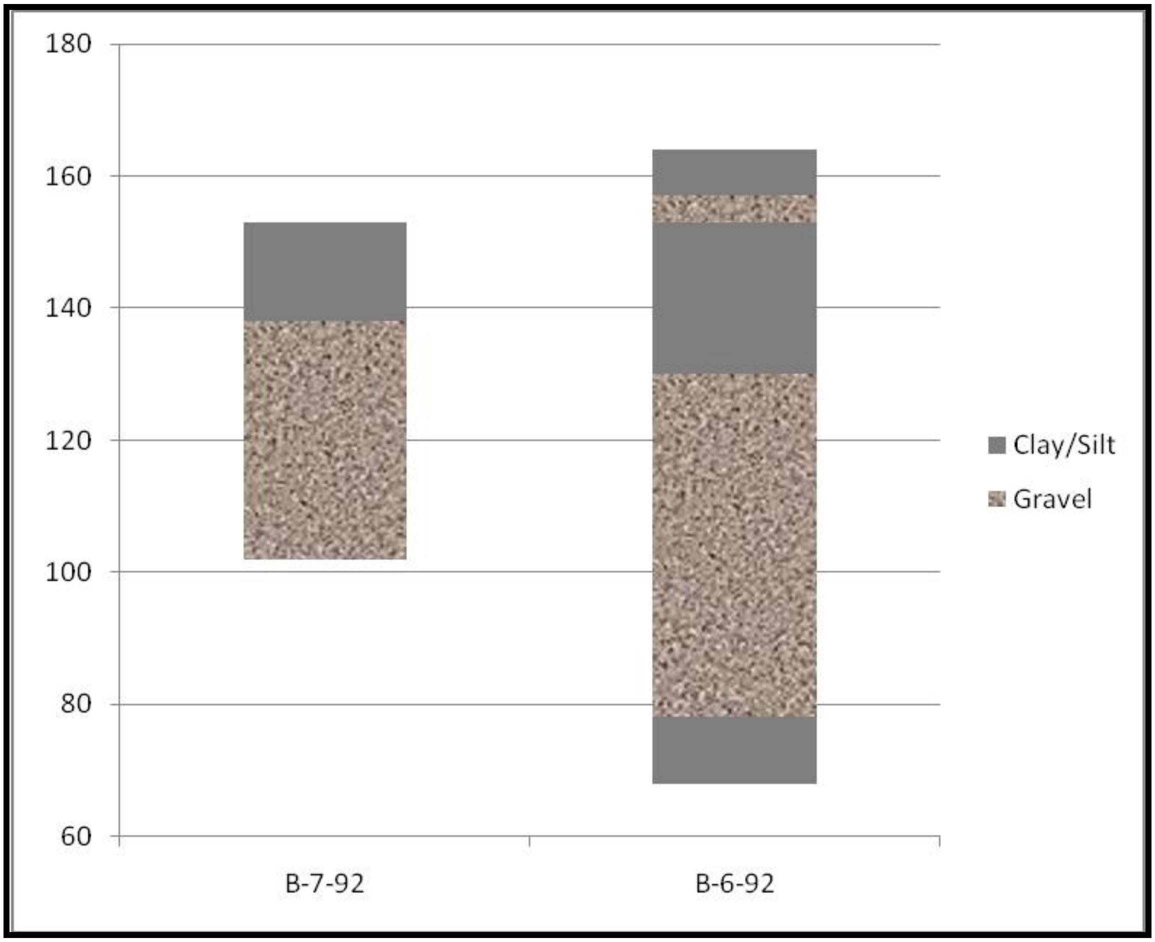

Figure 3.1 Drilling log for hole ID B-7-92 (left) and ID B-6-92 (right)

3.2. CLAMSHELL DREDGE DESCRIPTION

The bucket under study is a 16 yd^3 bucket with a weight of 35.5 tons manufactured by Rohr Corporation of Cleves, Ohio (Figure 3.2). The bucket has a closing pressure of 3,600 psi and opening pressure of 2,200 psi. The hydraulic cylinders and hoses are rated at 5,000 psi. The shells of the bucket are opened and closed by means of right or left handed rotation of the motor. The bucket drive motor is a forward reversing motor, it runs one way to close the shells and reverses to open the shells. The bucket has four hydraulic cylinders.

Figure 3.2 A Clamshell dredge being lowered under water

The power to the bucket is supplied by a specially designed amphibious power cable which is guided by a series of sheaves to allow for the bucket's lifting and lowering actions. Data transmission between the bucket and the industrial PC (IPC) is accomplished by a double cable bus network line (PROFIBUS DP), which is also incorporated in the amphibious power cable. The data transferred by the data bus is evaluated in a programmable control system, then transferred to the IPC where the data is prepared and visually displayed on the screen. The position of the bucket shells is monitored by an angle transmitter (absolute value transmitter). Limits of OPEN and CLOSE can be adjusted via the IPC. The position of the bucket shells is displayed on the screen of the IPC. Due to monitoring of the bucket shells, the shells are automatically stopped at their limit positions. The oil level for the hydraulic system is constantly monitored by an oil level indicator and is displayed on the screen of the IPC. The temperature of the oil is measured by means of PT 100 sensor (Pico Technology) and is shown on the screen of the IPC. The tilting angle of the bucket is monitored by a tilting angle transmitter and is displayed on the screen. The tilt angle has a limit; if the admitted tilting angle is exceeded, the lowering of the bucket is stopped, thus preventing the bucket from rolling over. In turn, damage to the cross beam, hoist ropes, and power cable as a result of the bucket rolling over is limited. The deck of the dredge has continuous level sensors which determines hopper full and dredge overloads (Rohr Corporation, 2008).

3.3. DATA COLLECTION

Data was collected from a 16 yd^3 clamshell dredge in Seattle, WA. The collected data centered on:

- Closing cylinder pressure,
- Bucket drive motor current,
- Percentage change in grab open and close,
- Tilt angle; and
- Hoist current and hoist speed at two-second intervals.

Data was collected over three days using RSLogix 500 software (Rockwell Automation, 2007). Data collected centered on these parameters because the objective was to test the hypothesis that work done by the hydraulic cylinder pistons during dredging, is a better predictor of clamshell dredgeability than bucket drive motor energy. In all, data for 121 digging cycles were collected. The digging cycles were for 18, 20, 22, 24, 26, 28 and 30 seconds (Table 3.1). More data was collected from 18 and 20 second cycles because the closing cycle of the bucket was usually set at 18 or 20 seconds. No data was collected on the payloads because there was no scale on the dredge.

Table 3.1 Shows Experimental design of the data collection

Test Number	Cycle Time (sec)	Number of Cycles
1	18	24
2	20	56
3	22	12
4	24	12
5	26	10
6	28	1
7	30	6
	Total	121

3.4. DATA ANALYSIS

A database was created containing the raw data measured from the site (See Table 3.2 for sample). The database was then checked for obvious errors, gaps and outliers. Motor energy and work done in digging (digging energy) during each cycle were integrated from the motor current, and bucket closing pressure and displacement, respectively (Equations 20 and 21). Average tilt angle over a cycle was also computed. Table 3.2 shows the edited data that incorporate calculated work done, motor energy and average tilt angle. The complete set of data can be found in Appendix A.

Table 3.2 Shows the raw data collection from site (data cycle 1).

Time(sec)	**Closing Cylinder pressure (PSI)**	**Motor Current (A)**	**Change in open or close (%)**	**Tilt Angle (°)**
2	118	1776	82	-12
4	127	2008	71	-15
6	62	2106	62	-17
8	149	2500	52	-18
10	139	2426	44	-18
12	158	2732	36	-17
14	158	2711	27	-15
16	166	2889	20	-11
18	166	2836	12	-9
20	173	2942	5	-5

$$Bucket\ drive\ Motor\ Energy = \frac{V}{2}\sum_{i=1}^{n-1}(I_i + I_{i+1}) \times (T_i - T_{i+1}) \qquad (20)$$

$$Workdone = 4A\sum_{i=1}^{n-1}(\frac{P_i + P_{i+1}}{2})\Delta d \qquad (21)$$

Table 3.3 Shows edited data collected from the field (data cycle 1)

Time(sec)	% Change in piston travel		Cylinder length (ft)	Pressure (psi)	Force (N)	Cylinder Displacement (m)	Work done (J)	Current(A)	Power (W)	Motor Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0	0	0	0	0	0
2	82	18	67.18	118	25567.40	0.14	1744.06	1776	852480	852480
4	71	29	70.46	127	27517.46	0.08	2212.92	2008	963840	1816320
8	52	48	76.13	149	32284.26	0.14	4305.96	2500	1200000	4327680
10	44	56	78.52	139	30117.53	0.06	1891.86	2426	1164480	2364480
12	36	64	80.91	158	34234.32	0.06	1950.98	2732	1311360	2475840
14	27	73	83.59	158	34234.32	0.07	2335.27	2711	1301280	2612640
16	20	80	85.68	166	35967.70	0.05	1862.30	2889	1386720	2688000
18	12	88	88.07	166	35967.70	0.06	2180.90	2836	1361280	2748000
20	5	95	90.16	173	37484.41	0.05	1948.52	2942	1412160	2773440

4. KINEMATICS AND DYNAMICS MODELING

This section involves kinematics and dynamic modeling of the clamshell dredge bucket digging process and implementation using MATLAB's Simulink® toolbox. It also involves the validation of the model using field data. The objective is to use the validated model to test the hypothesis that work done during dredging increases with increasing cycle time.

4.1. KINEMATICS MODELING

The motion of the clamshell bucket during dredging is produced via the paired motion of two hydraulic pistons. The clamshell bucket teeth first cut through the material by the buckets own weight, then the hydraulic motor pumps fluid to the hydraulic cylinders causing the pistons to be displaced with time. The displaced pistons exert force on the bucket, closing it. Figure 4.1 shows the clamshell bucket motion and schematics for the closed position. The motion can be seen to be two-dimensional moving from open position (A) to closed position (B). Since the clamshell bucket is symmetrical, one side was modeled during the closing process (Miedema et al., 2006).

Figure 4.2 is a schematic representation of the clamshell dredge bucket and shows the major coordinate system. All angular displacements (θ_1, θ_2, and θ_3) are prescribed as positive in the counterclockwise direction from the positive x-axis. The linear displacements r_1 and r_3 are fixed; they do not change during the dredging motion. From Figure 4.2, r_2, θ_2 and θ_3 change with time due to the displacement of the piston.

Based on Figure 4.2, the vector loop equation for the clamshell dredge bucket motion is given by Equation (22). Consequently, Equation (23) shows the position equations based on the x- and y- coordinates. Taking derivatives with respect to time yields Equation (24) and further differentiation with respect to time yields Equation (25). These equations then constitute the kinematic equations. From Figure 4.2, the solution to Equation (24) obtained for the velocities (ω_2 and ω_3) can be used to provide initial conditions for solving Equation (25).

$$\overrightarrow{R_2} = \overrightarrow{R_1} + \overrightarrow{R_3} \tag{22}$$

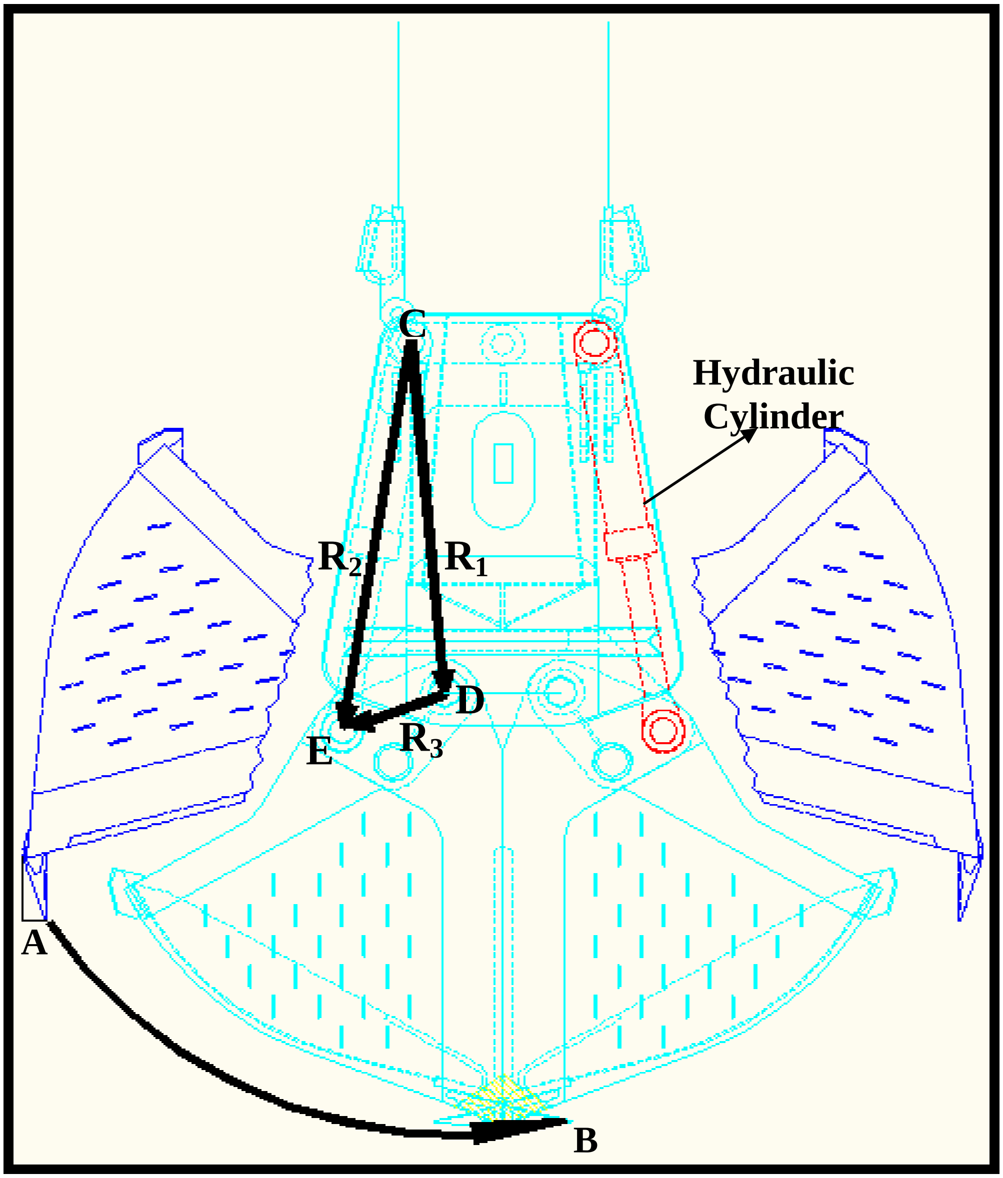

Figure 4.1 The clamshell bucket motion and schematics.

$$\begin{aligned} r_2 \cos\theta_2 &= r_1 \cos\theta_1 + r_3 \cos\theta_3 \\ r_2 \sin\theta_2 &= r_1 \sin\theta_1 + r_3 \sin\theta_3 \end{aligned} \tag{23}$$

$$\begin{bmatrix} -r_2 \sin\theta_2 & r_3 \sin\theta_3 \\ r_2 \cos\theta_2 & -r_3 \cos\theta_3 \end{bmatrix} \begin{bmatrix} \omega_2 \\ \omega_3 \end{bmatrix} = \begin{bmatrix} -\dot{r}_2 \cos\theta_2 \\ -\dot{r}_2 \sin\theta_2 \end{bmatrix} \tag{24}$$

$$\begin{bmatrix} -r_2 \sin\theta_2 & r_3 \sin\theta_3 \\ r_2 \cos\theta_2 & -r_3 \cos\theta_3 \end{bmatrix} \begin{bmatrix} \alpha_2 \\ \alpha_3 \end{bmatrix} = H$$

$$where\ H = \begin{bmatrix} -\ddot{r}_2 \cos\theta_2 - 2\dot{r}_2 \sin\theta_2\omega_2 + r_2 \cos\theta_2 w_2^2 - r_3 \cos\theta_3\omega_3^2 \\ -\ddot{r}_2 \sin\theta_2 - 2\dot{r}_2 \cos\theta_2\omega_2 + r_2 \sin\theta_2\omega_2^2 - r_3 \sin\theta_3\omega_3^2 \end{bmatrix} \tag{25}$$

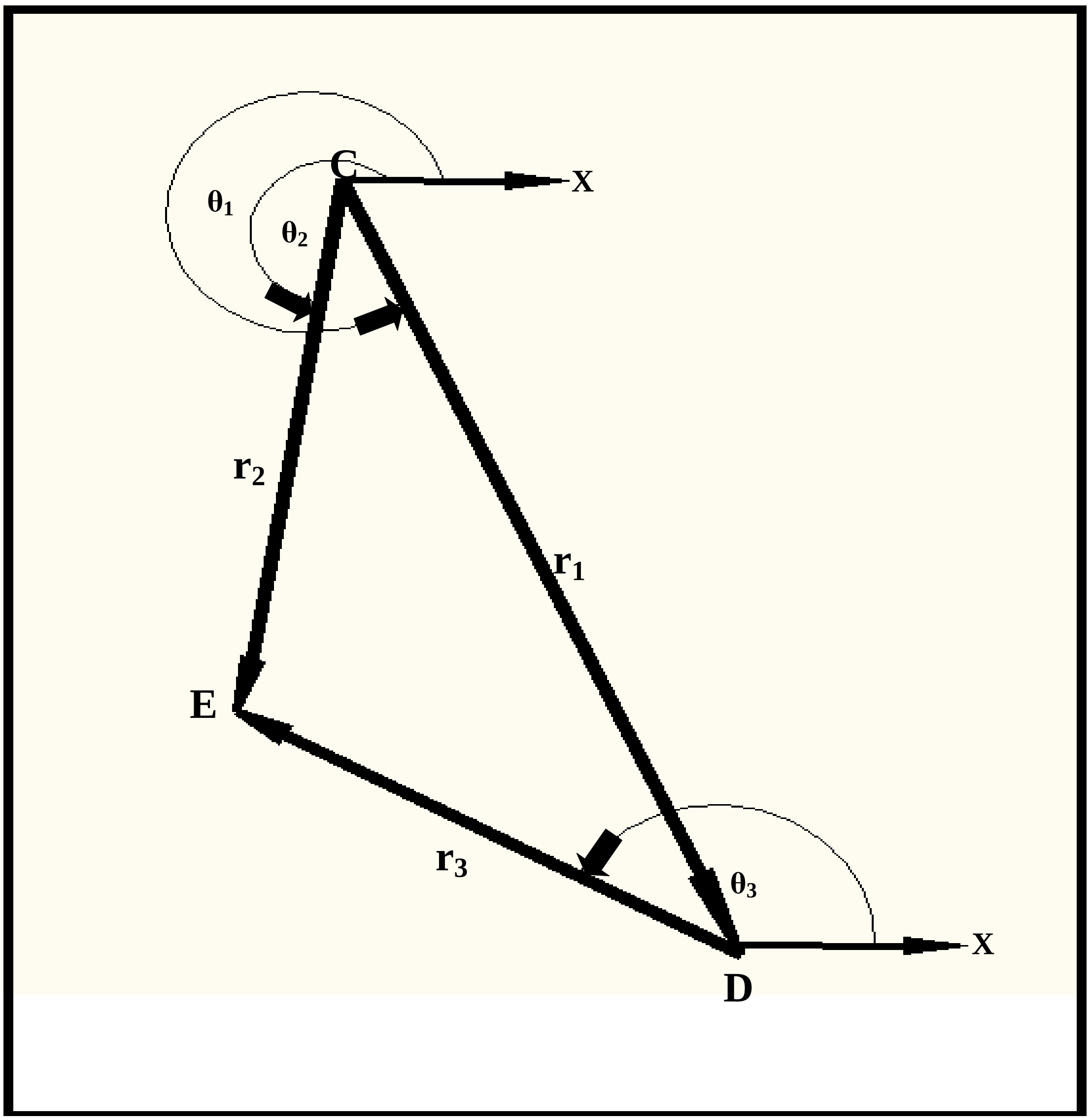

Figure 4.2 Clamshell dredge bucket kinematics

4.2. CLAMSHELL DREDGE DYNAMICS

Figure 4.3 shows the free-body diagram (FBD) of the left hand half of the clamshell bucket shown in Figure 4.1. The FBD does not include the weight of the material in the bucket. The model in this work does not include the weight of the material in the bucket during the simulation. The FBD is used to deduce the constraint equations that need to be satisfied during dredging. The set of constraints are given as Equations (26) – (30).

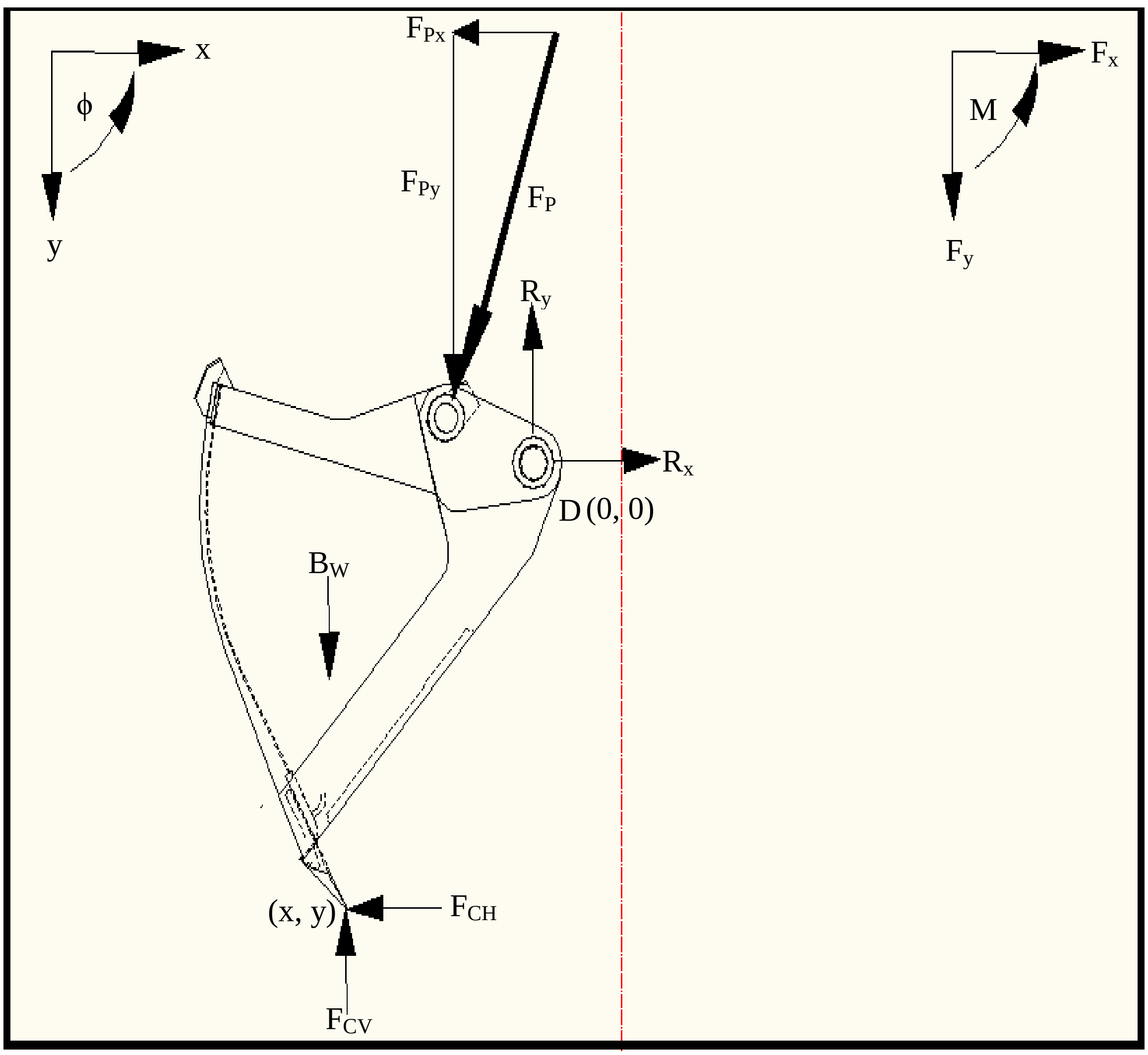

Figure 4.3 Free body diagram of the clamshell dredge

Resolution of forces in both coordinates direction:

$$\sum F_x = M_b A_{bx} \tag{26}$$

$$\sum F_y = M_b A_{by} \tag{27}$$

Moments about the pin joint (revolving pin joint at D):

$$\sum M_D = I\alpha_b \tag{28}$$

Constraining equation due to the piston:

$$\frac{F_{py}}{F_{px}} = \tan\phi \tag{29}$$

Acceleration characteristics of the center of mass of the bucket:

$$\overrightarrow{R_b} = (r_b \cos\phi_b)\hat{i} + (r_b \sin\phi_b)\, j \tag{30}$$

By using the sign convention; forces towards (+) x- and y-axes are positive and forces towards (-) x and y-axes are negative, Equations (26) – (30) become:

$$\begin{aligned} -M_b Ab_x - F_{px} + R_x &= F_{CH} \\ -M_b Ab_y - F_{py} + R_y &= B_w - F_{CV} \end{aligned} \tag{31}$$

$$-F_{CH} r_4 c_4 - F_{CV} r_4 s_4 + B_w r_5 c_5 + F_{py} r_3 c_6 - F_{px} r_3 s_6 = I\alpha_b \tag{32}$$

$$F_{py} = F_{px} \tan\phi \tag{33}$$

$$\begin{aligned} A_{bx} &= -r_b \omega_b^2 \cos\theta_b - (r_b \sin\theta_b)\alpha_b \\ A_{by} &= -r_b \omega_b^2 \sin\theta_b + (r_b \cos\theta_b)\alpha_b \end{aligned} \tag{34}$$

$$\theta_b = [\theta_3 + \frac{47}{180}\pi] \tag{35}$$

From the constraint equations above, it has to be determined which of the variables will be given as inputs and which would be solved for as outputs. For instance, the kinematics parameters can be supplied and the forces solved for as outputs. On the other hand, a particular force could be supplied as an input and the kinematics associated with it derived as an output. For this research, the kinematics parameters, the bucket mass, bucket weight, and inertia were given as inputs and the dynamics forces, reaction and acceleration characteristics of the center of mass were solved as outputs. The resulting system of equations is shown by Equation (36). This is a system of 8 differential algebraic equations (DAEs) (Haug, 1992). Definition of symbols is in the nomenclature.

$$\nabla x = b \tag{36a}$$

$$\nabla = \begin{bmatrix} -M_b & 0 & 0 & 0 & 0 & -1 & 0 & 1 \\ 0 & -M_b & 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & -r_2 \sin\theta_2 & r_3 \sin\theta_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & r_2 \cos\theta_2 & -r_3 \cos\theta_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -I_b & -r_3 \sin\theta_6 & r_3 \cos\theta_6 & 0 & 0 \\ 1 & 0 & 0 & -r_b \cos\theta_b & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & r_b \sin\theta_b & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -\tan\theta_2 & 1 & 0 & 0 \end{bmatrix} \tag{36b}$$

$$x = \begin{bmatrix} A_{by} & A_{bx} & \alpha_2 & \alpha_3 & F_{px} & F_{py} & R_x & R_y \end{bmatrix}^T \tag{36c}$$

$$b = \begin{bmatrix} B_w + F_{cv} \\ F_{CH} \\ -r_2 \cos\theta_2 + 2\dot{r}_2 \sin\theta_2 \omega_2 + r_2 \cos\theta_2 \omega_2^2 - r_3 \cos\theta_3 \omega_3^2 \\ r_2 \sin\theta_2 - 2\dot{r}_2 \cos\theta_2 \omega_2 + r_2 \sin\theta_2 \omega_2^2 - r_3 \sin\theta_3 \omega_3^2 \\ F_{CH} r_4 \cos\theta_4 - F_{CV} r_4 \sin\theta_4 + B_w r_5 \cos\theta_5 \\ -r_b \omega_b^2 \cos\theta_b \\ -r_b \omega_b^2 \sin\theta_b \\ 0 \end{bmatrix} \tag{36d}$$

The clamshell cutting resistance (F_{CH} and F_{CV}) was based on the work by Yasheng et al. (2006). The cutting resistance in the constraint Equations (31) – (35) was modeled using Miedema (2005) in Equations (7) – (9).

4.3. SIMULATION AND NUMERICAL SOLUTION ENVIRONMENT

Matlab 7.2 (Mathworks, 2008) was chosen as the programming platform. The dynamic modeling using Equation (36) was done in MATLAB's dynamic system simulator toolbox, SIMULINK® 7.2 (Mathworks, 2008). The MATLAB/SIMULINK platform was chosen because it offers a vast library of numerical algorithms. Also, SIMULINK is designed for dynamic system simulations of mechanisms. The clamshell dredge simulator consists of MATLAB programs (m-files and scripts) and SIMULINK models. When running the SIMULINK models, the model reads the inputs from the MATLAB programs (m-file and scripts) and passes the output from the simulator to the workspace.

4.3.1. Numerical Modeling. Equation (36), a system of DAE's, is the driving engine of the clamshell bucket simulator. The solution approach is to first obtain the value of the time independent variables from an ODE 2 solver. Concurrently, at each iteration step, the values of these time-dependent variables are used to constitute and solve the linear system in Equation (36). The Dormand-Prince pair embedded algorithm (Dormand and Prince, 1980) with automatic step-size control is used to obtain values for time-dependent variables given initial conditions. This algorithm is known to be an efficient solution procedure for non-stiff ODE's. Figure 4.4 illustrates the solution algorithms. Also, the solution of Equation (36) includes the angular accelerations, which are then passed to the ODE solver to obtain solutions for the angular velocities and displacements. This iterative process goes on till the simulation is terminated by the terminal condition or upon reaching the specified simulation time.

4.3.2. Numerical Accuracy and Stability. ODE solutions are important to the simulation of dynamic systems. Runge-Kutta (R-K) methods are the most known class of ODE solution methods and are used universally for numerical integrations (Cartwright and Piro, 1992). According to Awuah-Offei (2005), for the initial value ODE in Equation (37), the q-stage R-K approximation for y, Yi, for yi = y (xi) is given by Equation (38).

$$\dot{y} = f(y,t) \qquad for \;\; y(a) = y_0, a \le t \tag{37}$$

[2] ODE - ordinary differential equations

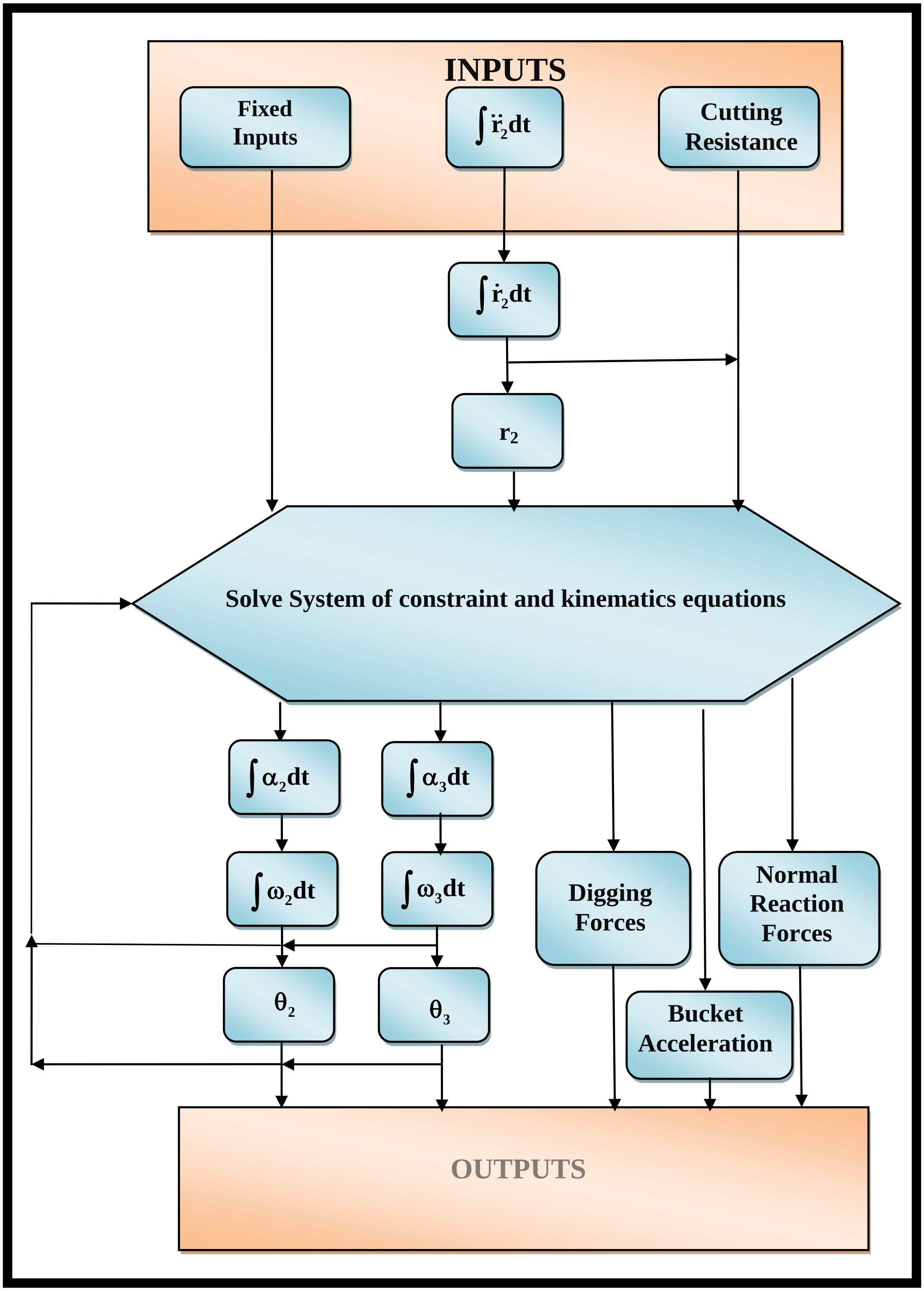

Figure 4.4 Flowcharts of DAE solution algorithm

$$Y_{n+1} = Y_n + h\sum_{i=1}^{q} \varpi_i k_i \tag{38}$$

$$k_i = f\left(x_n + ha_i, Y_n + h\sum_{j=1}^{i-1} \beta_{ij} k_j \right) \tag{38a}$$

Round-off and truncation errors are the two categories of errors encountered with the use of R-K methods. The aspects of the error of a numerical scheme that need to be addressed and evaluated are convergence, consistency and stability (Snyder, 1997). It can be shown that Equation (39) is the necessary and sufficient condition for convergence (Cartwright and Piro, 1992).

$$\sum_{i-1}^{q} \varpi = 1 \tag{39}$$

Since the sufficient condition is satisfied for all R-K methods of order one or higher, all R-K methods are consistent and convergent. Also, the stability horizons for R-K methods are known for linear and nonlinear ODEs (Cartwright and Piro, 1992). Therefore, if used with the right step-sizes, R-K methods produce consistent and stable solutions and are convergent.

The R-K algorithm used in this work is built on a single step, explicit R-K embedded algorithm (4^{th} and 5^{th} order) using the Dormand-Prince pair. The algorithm provides the user the opportunity to specify both relative and absolute error tolerances, which can then be used in step-size control. The step-size control is achieved by embedding the 4^{th} and 5^{th} order algorithms in order to provide dynamic error estimates on which to make the decision to increase or decrease the step-size. The linear part of the DAE is solved with a Gaussian elimination routine with partial pivoting. The algorithm computes a condition estimator of the matrix to determine whether it is badly scaled. A warning is generated if the matrix is badly scaled, and thus, could potentially lead to erroneous results in computing the matrix inverse.

4.4. VERIFICATION AND VALIDATION

4.4.1. Verification. The experiment for verification uses the data given in Tables 4.1 and 4.2. Table 4.1 contains clamshell bucket parameters for the 16 cubic yard bucket at the open position. The initial position is defined by the length of the bucket links (Figure 4.2). In this simulation experiment, the piston was extending at a constant velocity ($\dot{\mathbf{r}}_2$ = distance of piston travel / cycle time). Therefore, the piston had an acceleration of zero ($\ddot{\mathbf{r}}_2 = \mathbf{0}$). This conclusion was based on the analysis of the field data. The piston had a total travel distance of 29.88 inches. Table 4.2 contains the cutting resistance parameters, which includes the field soil properties. The main performance measure in the model verification was to ensure that the vector loop (Equation 22) is closed at all times. This was achieved by ensuring that the error (Equation 40) was acceptable during the clamshell dredge simulation. If the error is less than 10-4 inches, the simulation was considered acceptable. Since most engineering instruments cannot measure length to more than two decimal digits, this was considered acceptable. Figure 4.5 shows the simulation error of the experiment. The maximum error is approximately 7.89×10^{-10} inches, well below the set threshold.

$$E = \begin{bmatrix} \dot{r}_2 \cos\theta_2 & -r_2 \sin\theta_2 \times W_2 & r_3 \sin\theta_3 \times W_3 \\ \dot{r}_2 \sin\theta_2 & r_2 \cos\theta_2 \times W_2 & r_3 \cos\theta_3 \times W \end{bmatrix} \quad (40)$$

Figure 4.5 shows that the error tolerances for the R-K algorithm are small enough to meet the set tolerance. Also, the error increases gradually as the simulation progresses. As the simulation advances, the cumulative effect of round-off errors of the computer and truncation errors of the R-K algorithm passed from one step to the other increases the error. Figure 4.6 shows the clamshell bucket tip trajectory (A). This shows that the bucket tip starts at the coordinate (-94.87, -36.42) and ends at coordinate (10.37, -101.1) in 20 seconds. The fixed point D (Figure 4.3) is used as the origin of the coordinate system. The trajectory is exactly what was expected. Therefore, the model was determined to be working as intended and, thus, verified.

Table 4.1 Clamshell Bucket Parameters

DATA TYPE	PARAMETER	VALUE
Bucket Specifications	Bucket Capacity[yd^3]	16
	Bucket Weight [Pounds]	4,700
	Mass Moment [slugs-in^2]	3,430,501
Initial conditions of bucket	Length of Third Connecting Rod R_3 [in]	24.784
	Length of Imaginary Link [in]	48.46
	Length of piston force to moment point [in]	24.784
	Length of cutting force to moment point [in]	101.62
	Length of Bucket weight to moment point [in]	48.46

Table 4.2 Cutting Resistance Parameters

		Sources
Density of water [kg/m^3]	1000	
Acceleration due to gravity [m/s^2]	9.8	
Velocity [m/s]	0.0738	Simulation Model
Volume Strain [%]	0.0938	Yasheng et al.(2006)
Initial layer thickness [m]	0.2	Field Conditions
Average pore pressure on the shear surface	0.2693	Yasheng et al.(2006)
Average pore pressure on the blade	0.058	Yasheng et al.(2006)
Permeability [m/s]	0.00002	Field Data
Cutting angle [rad]	0.52	Field Data
shear angle [rad]	0.44	Field Conditions
Angle of internal friction angle [rad]	0.56	Field Conditions
Soil/steel angle of friction [rad]	0.52	Field Conditions
Blade height [m]	0.194	Field Data

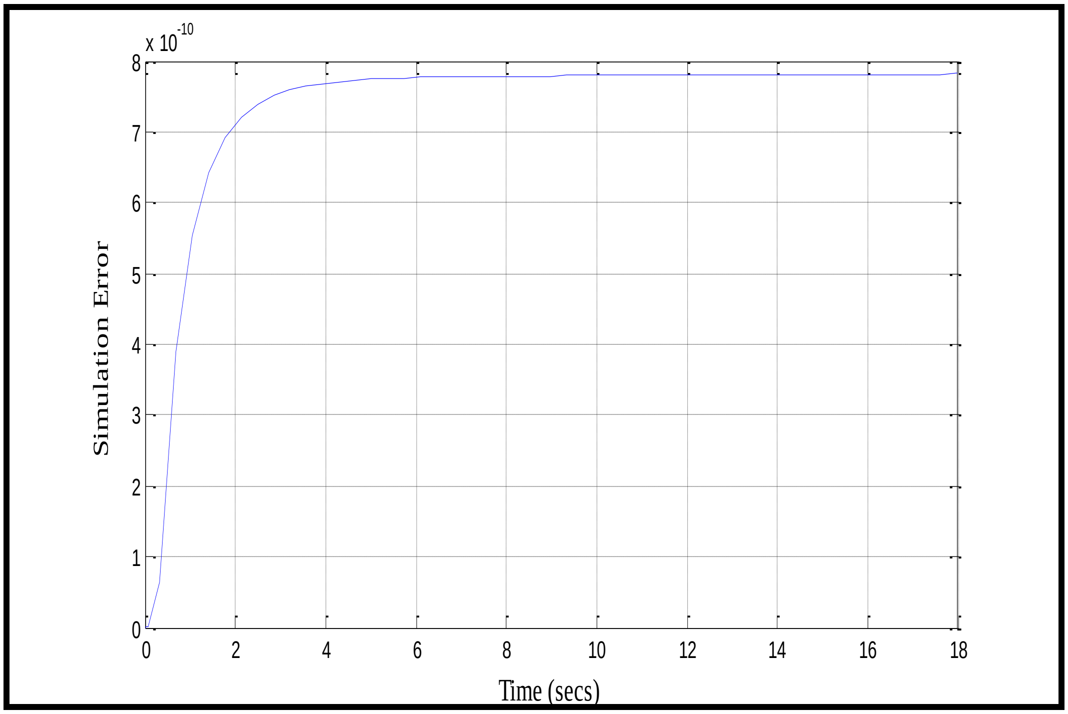

Figure 4.5 Simulator error of the experiment

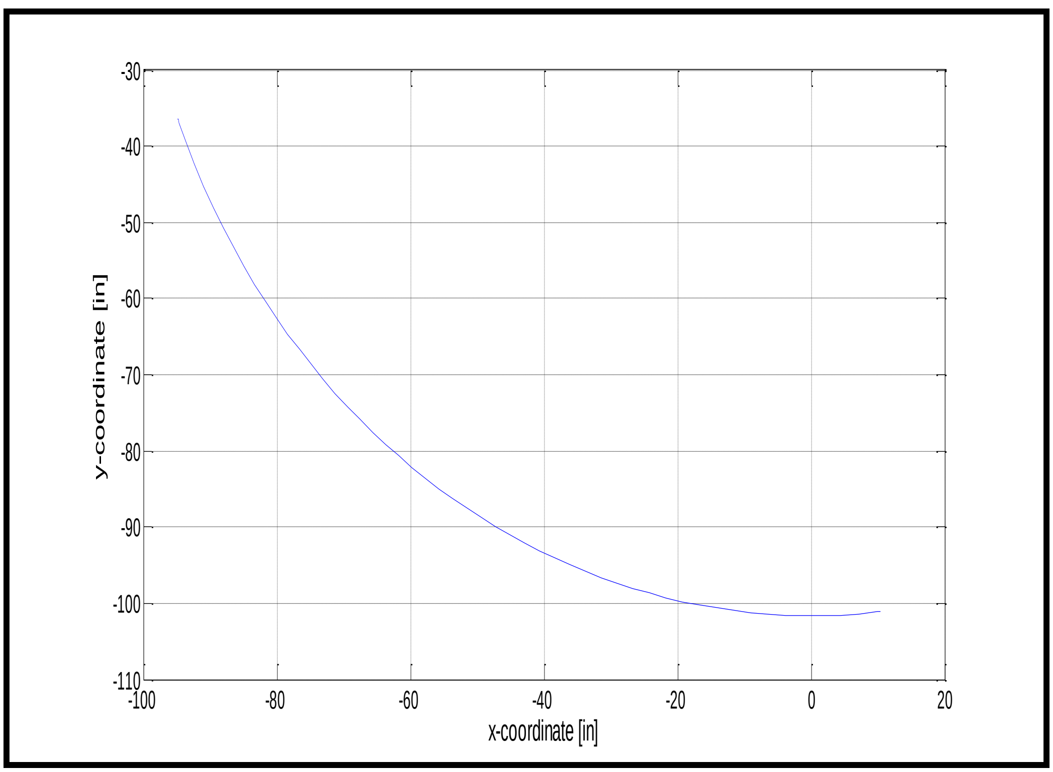

Figure 4.6 Clamshell bucket tip trajectory

4.4.2. Validation of the Model. The inputs for the validation of the model with that of the field are in Table 4.1 and 4.2. The field data collected at 20 seconds cycle time (Table 3.1) was used to validate the model, because that had the largest data set (56 cycles). The simulation was therefore carried out for 20 second cycle time and the results compared to that of the 20 seconds field data. Figure 4.7 shows the force for the simulation of 20 seconds against cycle time. Figure 4.8 shows a plot of pressure against cycle time for the actual (i.e. one of the 56 cycles that had a work done of 71.13 kJ, approximately equal to the mean work done of the data set) and the simulated experiment at 20 seconds. The pressure of the field data is greater than that of the simulated data because the simulated data did not consider the weight of the material in the bucket. Also, other inefficiencies were not factored into the modeling.

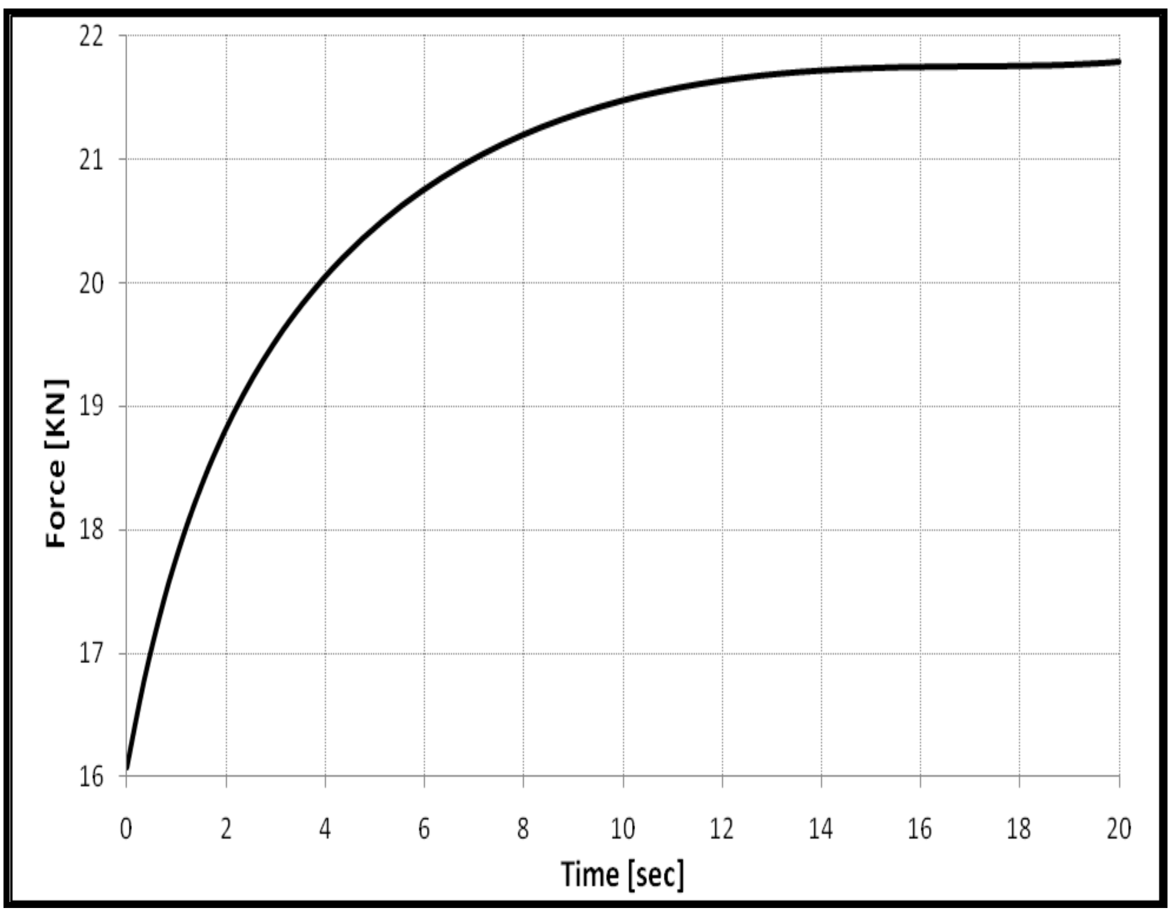

Figure 4.7 Force Output for 20 seconds Cycle Time Simulation

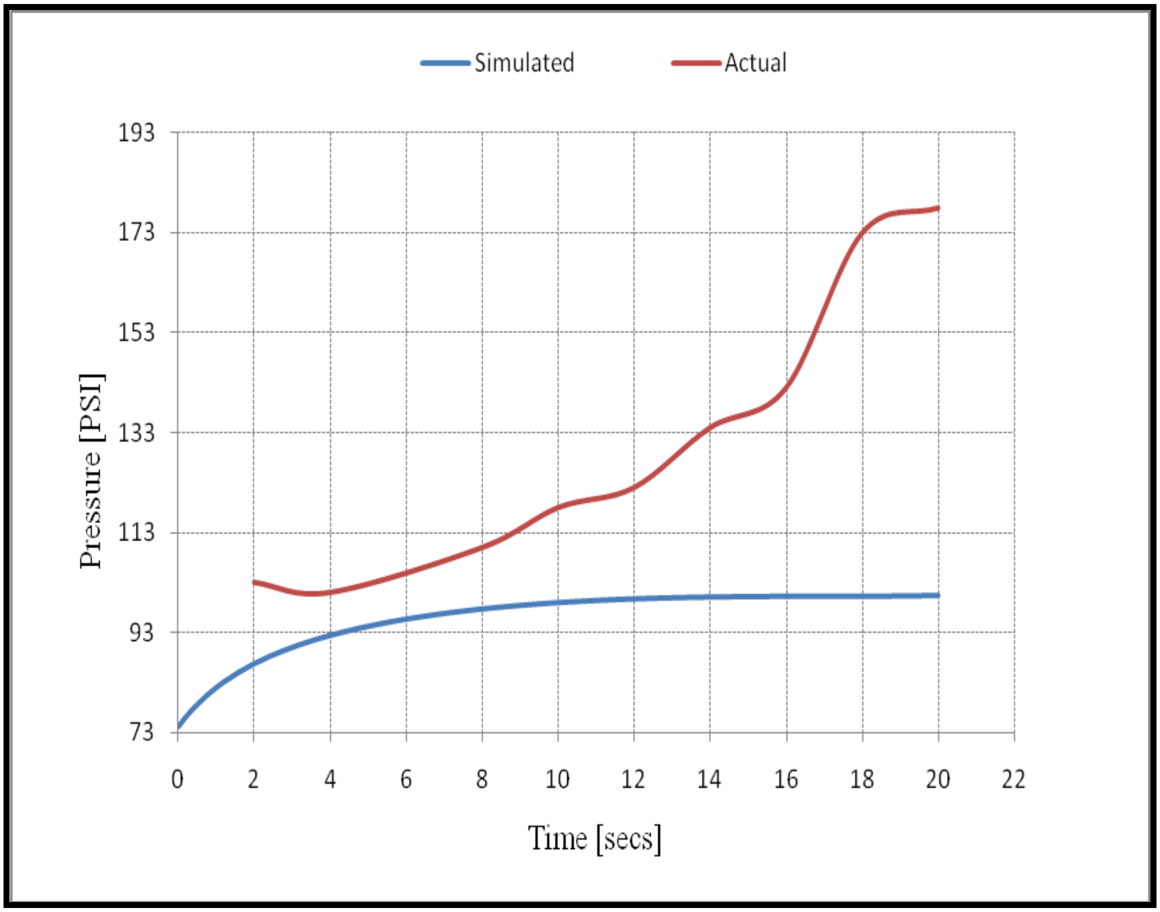

Figure 4.8 Pressure of field data (actual) and simulated against time

Figure 4.9 shows the comparison between the average of the field-measured work done (56 data) and the simulated work done for the 20 second cycle. The simulation gives a work done of 63.22 kJ, which is very close (almost 87%) to the average of the measured work done of approximately 73.02 kJ.

The model can be said to show the expected system behavior during dredging. This is because the simulation results are consistent with expectations from the field data. Every assumption has been justified and explained while the numerical approximation techniques have been adjudged to be sound and to produce accurate results. A real-world clamshell dredge has been simulated successfully to validate the model. The model predicts almost 87% of the work done during dredging by the pistons. The model is, therefore, deemed verified and validated.

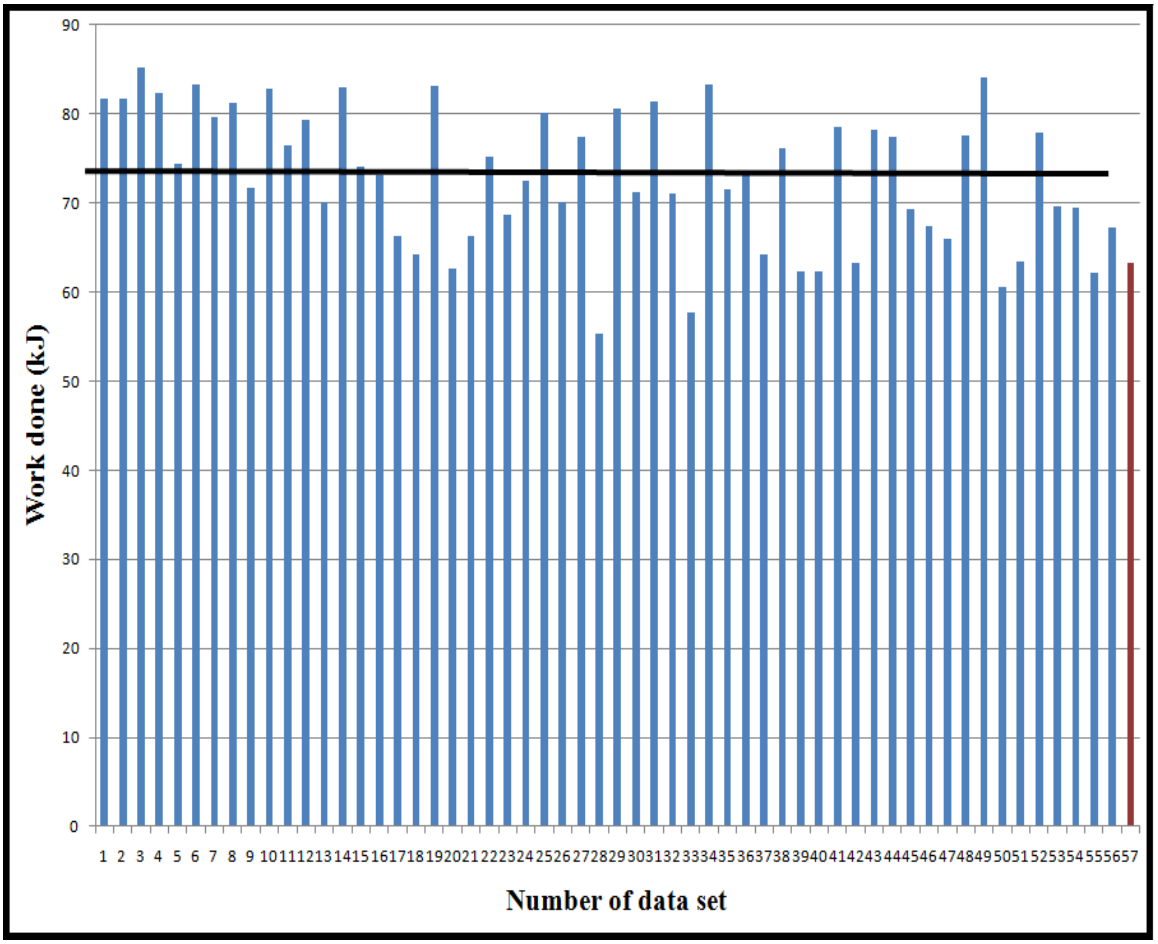

Figure 4.9 Measured work done for 20-second cycle (blue) and simulated work done for the 20-second cycle (red). Black line is the average of the measured data.

4.5. SIMULATION EXPERIMENTATION

The validated model was used to carry out experiments to test the hypothesis that the work done by the pistons increases with increasing cycle time. Table 4.3 shows the piston extension speed and its corresponding cycle time used for the experimentation. The simulation was carried out for cycle time 18, 20, 22, 24, 26, 28 and 30.

Table 4.3 Simulation experimentation setup

Cycle time [sec]	Piston extension speed [in/sec]
18	1.658
20	1.492
22	1.357
24	1.244
26	1.148
28	1.066
30	0.995

5. RESULTS AND DISCUSSIONS

This section contains detailed discussions of results obtained from the field experiments. It also discusses the results of the simulation experiment.

5.1. FIELD EXPERIMENTAL RESULTS

Figure 5.1 shows a plot of work done against cycle time. It can be realized that work done, generally, increases with an increase in digging time. However, for the same cycle time there are different work done values, indicating that the work done in digging by the clamshell does not depend on the cycle time alone. Other factors such as the variability of formation properties, operator effects, depth below water, bucket trajectory, and amount of material dredged also affect the useful work done in dredging. Figure 5.2 also shows a plot of motor energy against cycle time. It can be seen that as the digging time increases, the motor energy, also, tends to increase. Similar to the work done, the same cycle time results in different motor energies. This can be attributed to sources of variability in motor energy

Figure 5.3 and Figure 5.4 show plots of motor energy and work done against average tilt angle over a cycle respectively. The motor energies are higher than the useful work done because the motor expends far more energy to overcome the dredging resistance than necessary to cause the instantaneous displacement of the piston.

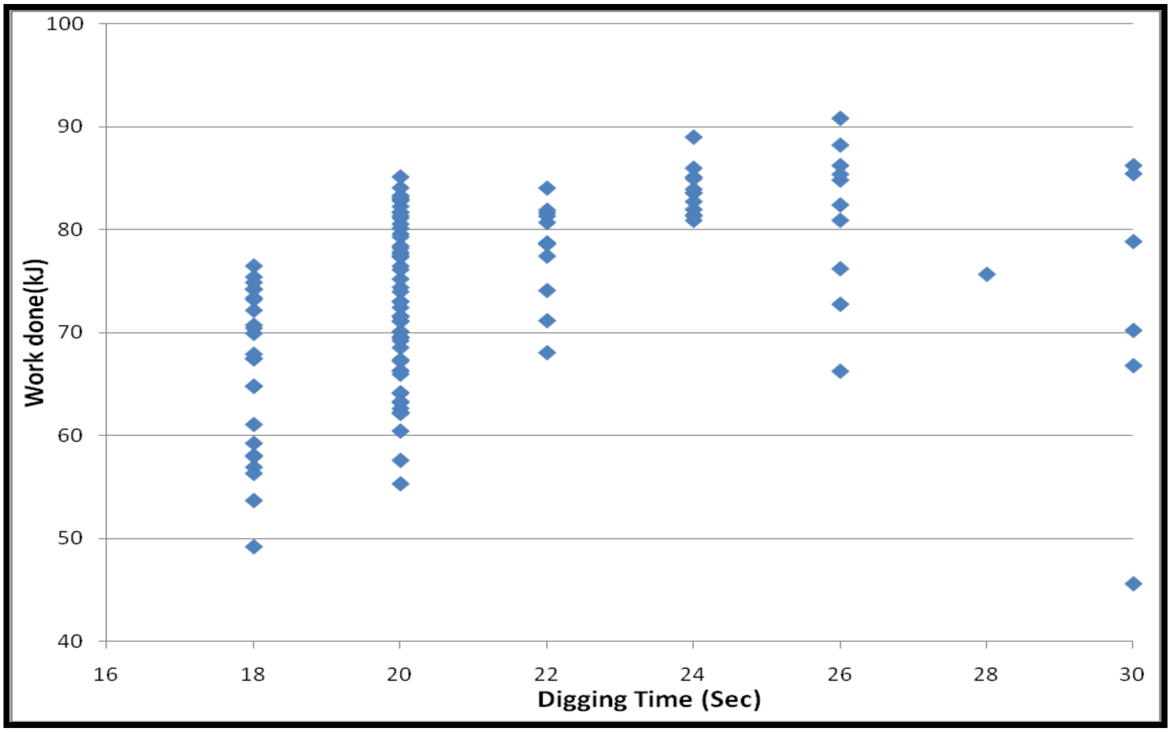

Figure 5.1 Work done (kJ) against the digging time (sec)

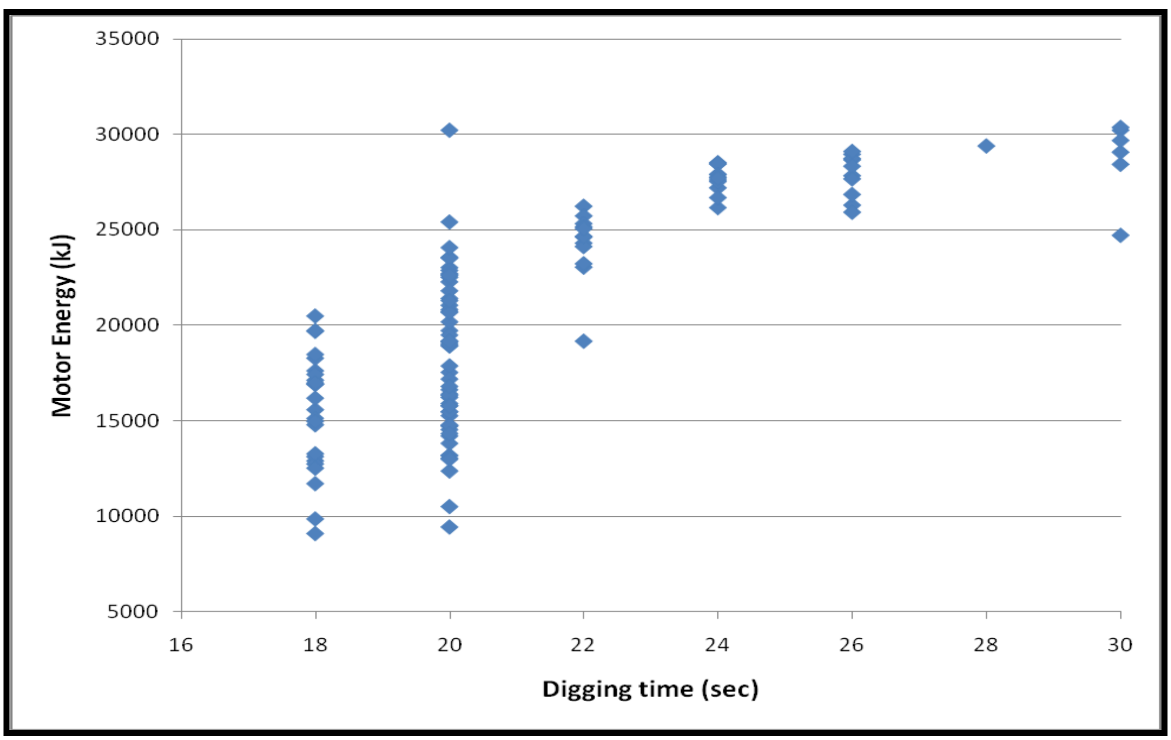

Figure 5.2. Motor energy (kJ) against cycle time (secs)

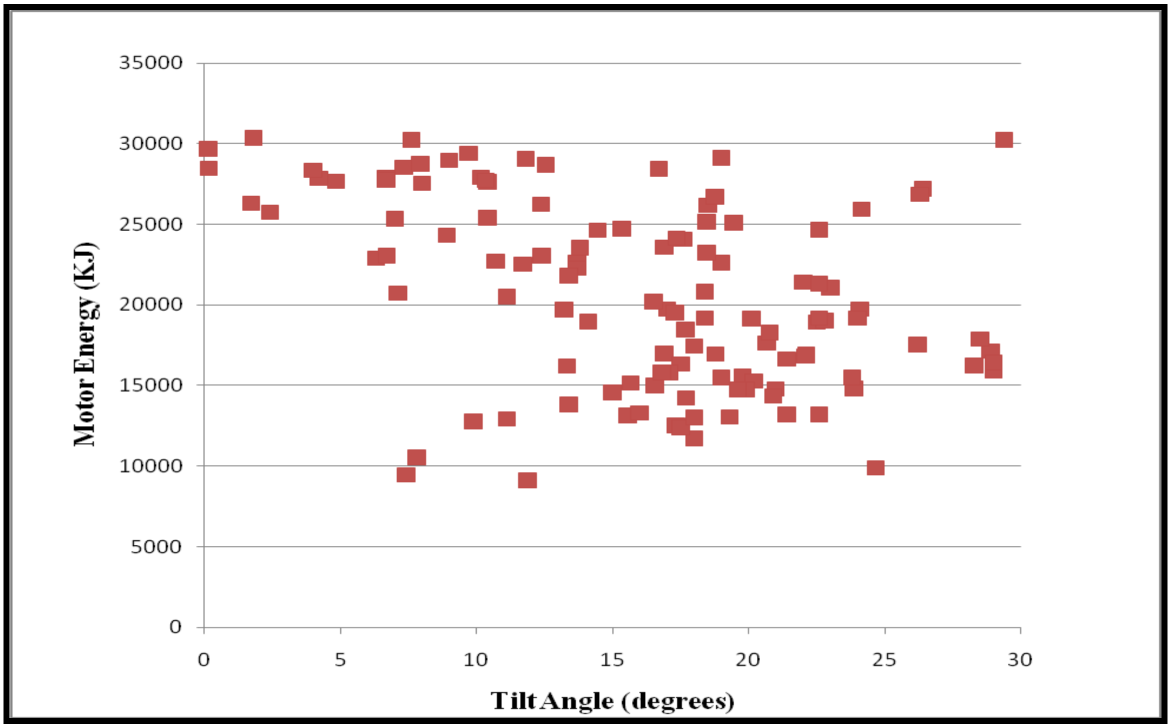

Figure 5.3 Motor energy (kJ) against average tilt angle (degrees)

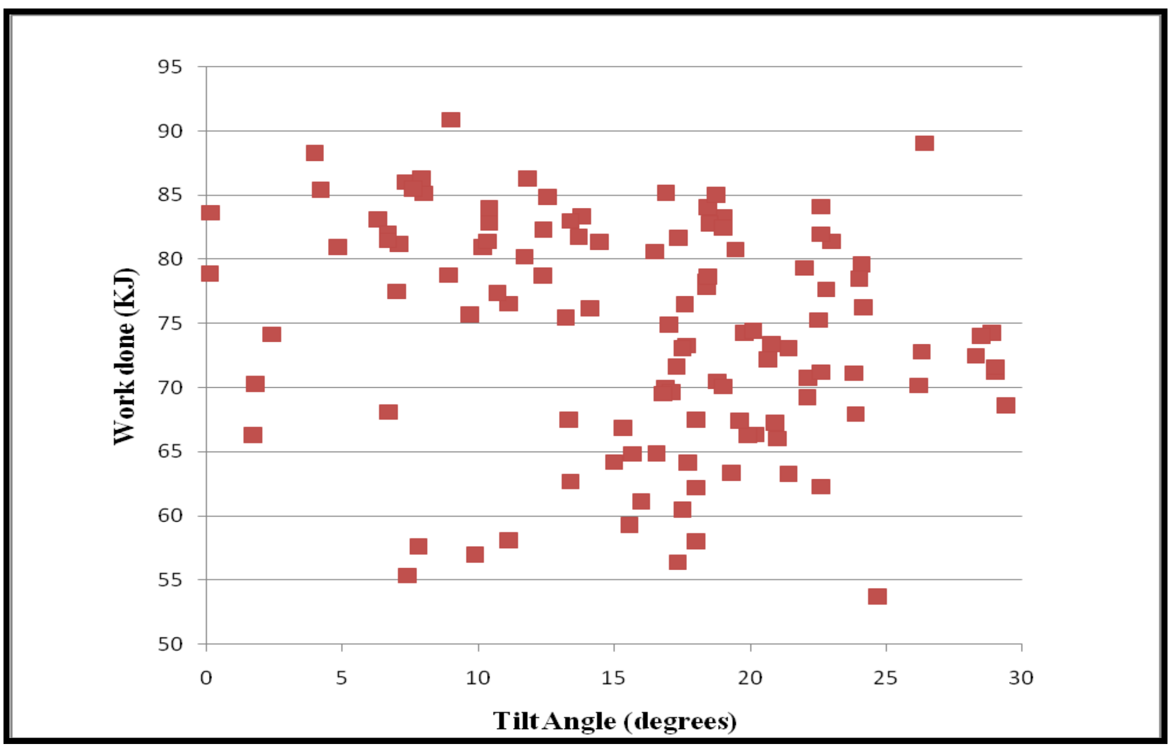

Figure 5.4 Work done (kJ) against average tilt angle (degrees)

Table 5.1 shows summary statistics on the 121 digging cycles, the digging cycles include cycle time 18, 20, 22, 24, 26, 28 and 30 seconds. The work done has a mean of 73.93 kJ and varied over a range of 45.20 kJ. The standard deviation of the work done is 9.18 kJ. Likewise the average tilt angle is varied over a range of 30.87°. The values are varied over a range of 21,255.63 kJ with a standard deviation of 5,712.14 kJ.

Table 5.1 Summary statistics of 121 digging cycles

	Work done(KJ)	Motor Energy(kJ)	Average tilt Angle(Degrees)
Mean	73.93	20635.51	16.14
Standard Error	0.83	519.29	0.65
Median	74.92	20190.24	17.30
Mode	74.26	30220.32	22.60
Standard Deviation	9.18	5712.14	7.14
Sample Variance	84.28	32628529.90	51.02
Range	45.20	21255.36	30.87
Minimum	45.65	9111.36	0.13
Maximum	90.86	30366.72	31.00
Count	121	121	121
Confidence Level (95.0%)	1.65	1028.15	1.29

Table 5.2 shows the summary statistics for the 56 experiments with cycle time of 20 seconds. The work done has a range of 29.81 kJ. The mean (73.02 kJ) of the work done has precision of 1.04 kJ (standard error). The standard deviation is 7.76 kJ. The average tilt angle has a mean of 18.99°. It varies over a range of 24.7° and also has a standard deviation of 6.04°. However, the motor energy is varied over 20,768.64 kJ. It has a mean of 18,250.79 kJ and a standard deviation of 4,111.99 kJ. The summary statistics for the rest of the cycle times (18, 22, 24, 26 and 30) are in Appendix B.

Table 5.2 Summary statistics of 20 seconds digging cycles

	Work done(KJ)	Motor Energy(KJ)	Average tilt Angle(Degrees)
Mean	73.02	18250.79	18.99
Standard Error	1.04	549.49	0.81
Median	73.06	18407.04	19.00
Mode	81.73	#N/A	13.70
Standard Deviation	7.76	4111.99	6.05
Sample Variance	60.20	16908426.25	36.64
Range	29.81	20768.64	24.70
Minimum	55.36	9451.68	6.30
Maximum	85.17	30220.32	31
Count	56	56	56
Confidence Level (95.0%)	2.08	1101.20	1.62

Table 5.3 shows the Pearson Correlation Coefficients (PCC). For two variables to be correlated, the p-value should be equal to or less than the significance level (0.05). If the p-value is greater than the significance level (0.05) then the two variables are not correlated at 95% confidence. There is higher correlation between cycle time and motor energy (PCC = 0.78) than between cycle time and work done (PCC = 0.38). The correlations between cycle time and motor energy, tilt angle and work done are significant because they have p-values (0.0001) which are lower than the significance level (0.05). Likewise, there is lower correlation between tilt angle and work done (PCC = -0.22) than between tilt angle and motor energy (PCC = -0.43). The negative correlation coefficient indicates that as tilt angle increases work done and motor energy decrease. This is likely to be due to reduced payload due to significant tilting of the bucket. The p-values (0.015 and 0.0001) are less than the significance level (0.05) making this negative correlation significant. For work done versus motor energy, the correlation coefficient (0.75) is strong and significant (p-value < 0.0001). This indicates that work done increases as motor energy increases, as would be expected. The correlation analysis shows that motor energy is more sensitive to the operating parameters (higher correlation coefficients) than is work done. Details of Spearman and

Kendall Tau b correlation coefficients, as well as the scatter plot matrix, are in Appendix C. The results are similar to the PCC analysis.

Table 5.3 Pearson correlation coefficients: p-values shown in parenthesis

Number of data = 121 Prob>|r|under Ho: ρ=0				
	Cycle Time	Tilt Angle	Work done	Motor Energy
Cycle Time (secs)	-	-0.43 (< 0.0001)	0.38 (< 0.0001)	0.78 (< 0.0001)
Tilt Angle (°)	-0.43 (<0.0001)	-	-0.22 (<-0.015)	-0.43 (<0.0001)
Work done (kJ)	0.38 (<0.0001)	-0.22 (<0.0150)	-	0.75 (<0.0001)

Table 5.4 shows sensitivity analysis of the work done and the motor energy data. The coefficient of variance (overall, 18, 20 and 22) for work done is lower than for motor energy, indicating lower variability. This is consistent with the correlation results, which show lower correlation between tilt angle and cycle time and work done. For cycle times 24, 26 and 30, the coefficient of variance for motor energy is lower than for work done, which is contrary to the correlation results. This is because the experimental data for these cycle times were few (sparse). Work done may be a better predictor of formation dredgeability than motor energy since it is not as sensitive to the other factors (operator effects, cycle time and tilt angle). However, work done can provide misleading results in difficult digging as illustrated by Figure 5.5. Figure 5.5 shows plots of work done and motor energy for the clamshell working clay. It can be observed that the motor was expending energy throughout the cycle, but not all the energy resulted in useful work

done (say t = 16 secs). Cumulatively, this resulted in a relatively high motor energy but low work done (due to zero cylinder displacement at t = 16 secs).

Table 5.4 Coefficient of variance

Coefficient of Variance (%)		
Cycle Time (secs)	Work done	Motor Energy
Overall	12.31	27.47
18	11.89	19.78
20	10.62	22.53
22	6.05	7.60
24	2.77	2.57
26	9.32	4.08
30	21.05	7.30

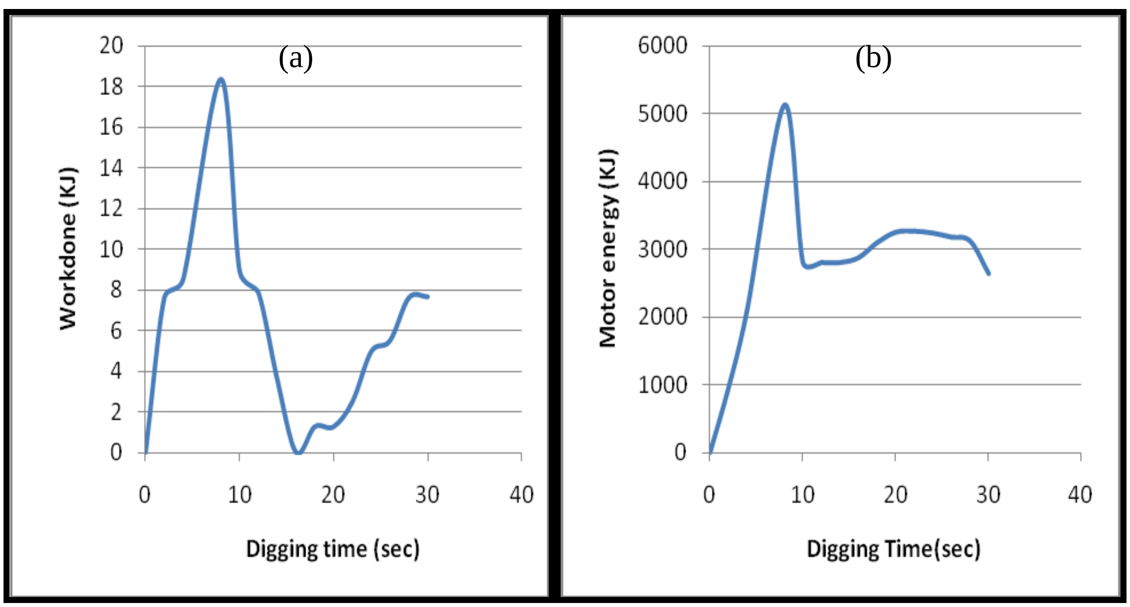

Figure 5.5. A graph of work done (a) and motor energy (b) of clamshell working clay

Work done, though a good measure of formation dredgeability, as seen in Table 5.4, makes it difficult to differentiate between an easy digging formation and a hard digging formation in some instances. This is because an easy to dig formation will have low energy expended by the motor, hence low work done. In light of this, another indicator such as specific energy (energy per ton) or energy per unit loading rate needs to used in conjunction with the work done in order to measure the formation dredgeability accurately (Awuah-Offei, 2005 and 2007; Patnayak et al., 2008). With knowledge of specific energy, it can be ascertained whether the higher energies (work done and motor energy) are really sub-optimal or lead instead to higher productivity. Payload data could not be measured in this study because of the absence of a scale on the dredge. For the Rohr bucket diagnostics system, hoist energy can be used as a proxy for payload. This was not possible in this research because the hoist energy data collected was incomplete. The data collection for the hoist current stopped after the bucket closing cycle was completed.

5.2. SIMULATION RESULTS

Figure 5.6, 5.7 and 5.8 show the sample (20-seconds cycle) results for theta 2 (θ_2), theta 3 (θ_3), omega 2 (ω_2), omega 3 (ω_3), alpha 2 (α_2) and alpha 3 (α_3). It can be seen that, for a constant piston extension speed, θ_2 (angle that link 2 makes with the positive x-axis) decreases (in this example the first 11 seconds) and then increases. This is consistent with ω_2, which is negative (although increasing) till the 11th second, when it turns positive. Likewise, α_2 decreases with increasing cycle time.

It could be seen that θ_3 (angle that link 3 in Figure 4.4 makes with the positive x-axis) increases with time. Also, ω_3 decreases (in this example the first 11 seconds) then it starts to increase. However, the angular acceleration (α_3) can be seen to increase with time.

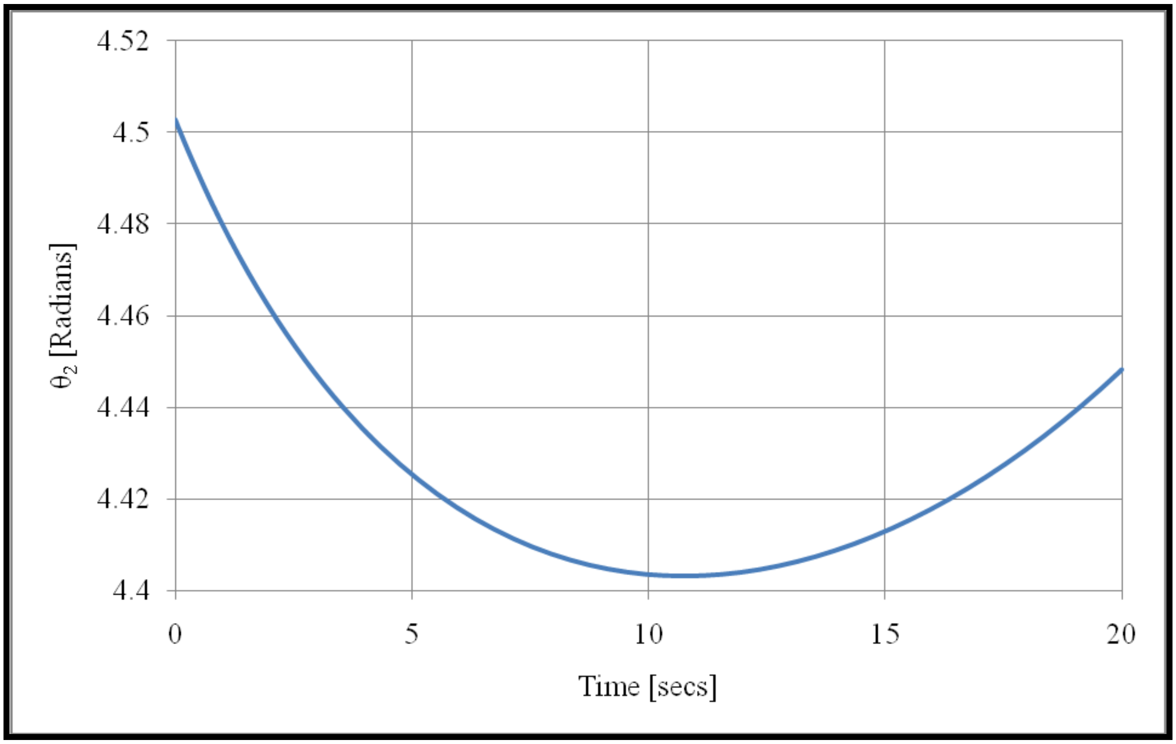

Figure 5.6 Clamshell Dredge Simulation Kinematics Results I

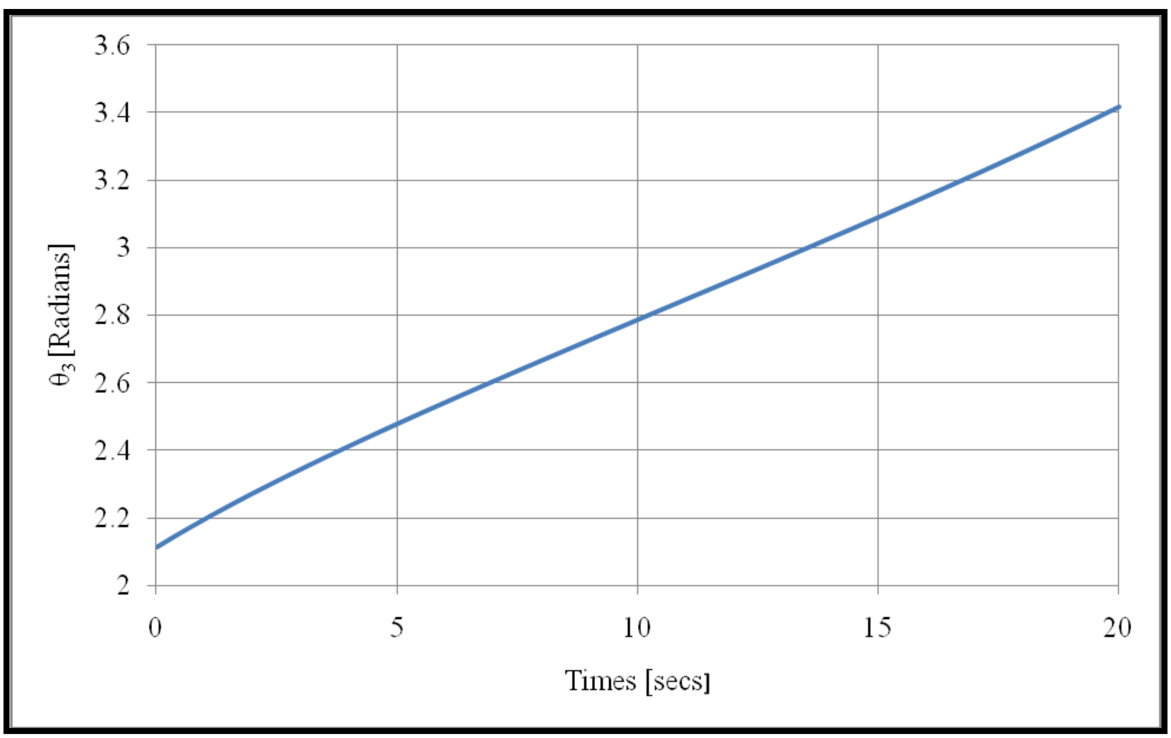

Figure 5.7 Clamshell Dredge Simulation Kinematics Results II

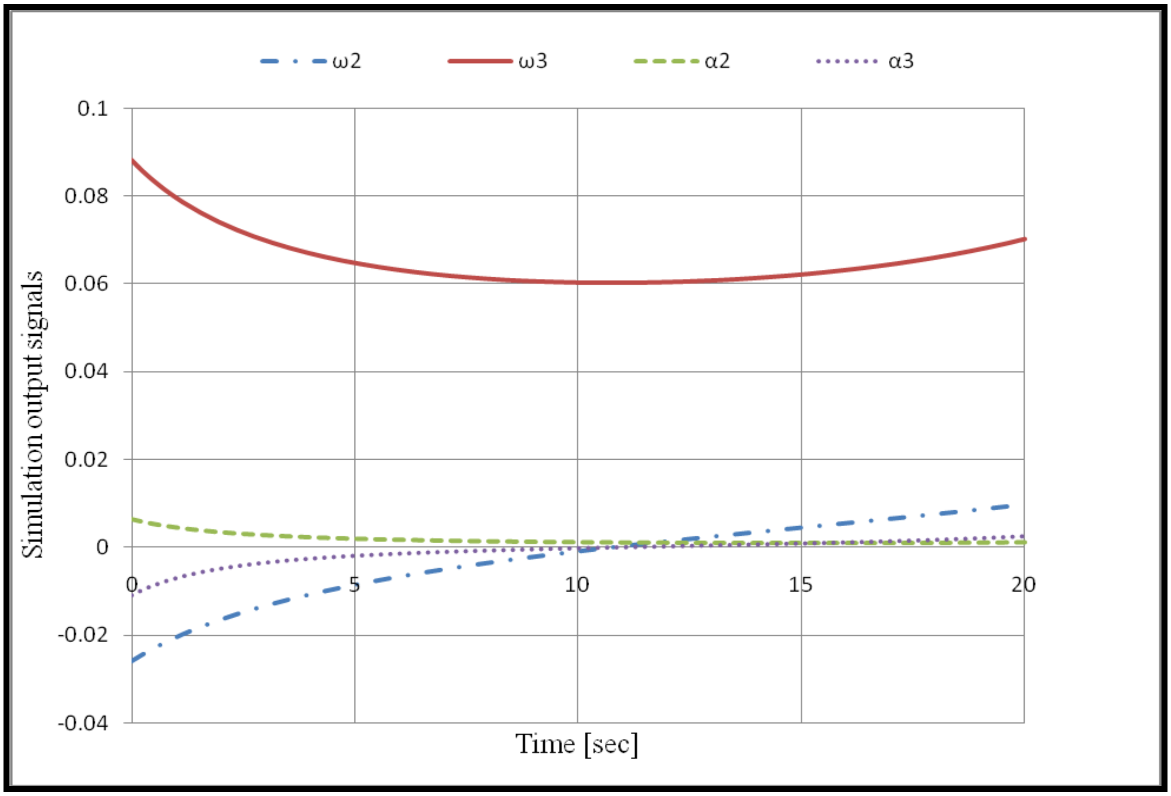

Figure 5.8 Clamshell Kinematics Results III

Figure 5.9 shows the resultant piston force and the normal force. The resultant piston force is low compared to the normal force. This is because it takes the piston force plus the bucket weight to overcome the cutting resistance force of the formation. The bucket weight is hence an important design parameter in ensuring productivity. In very compact aggregate deposits the bucket can be redesigned to be heavier. The only disadvantage is that the increase in weight means a decrease in payload rating of the bucket. This is because the maximum suspended load of the hoist ropes and the overhead cables cannot be exceeded.

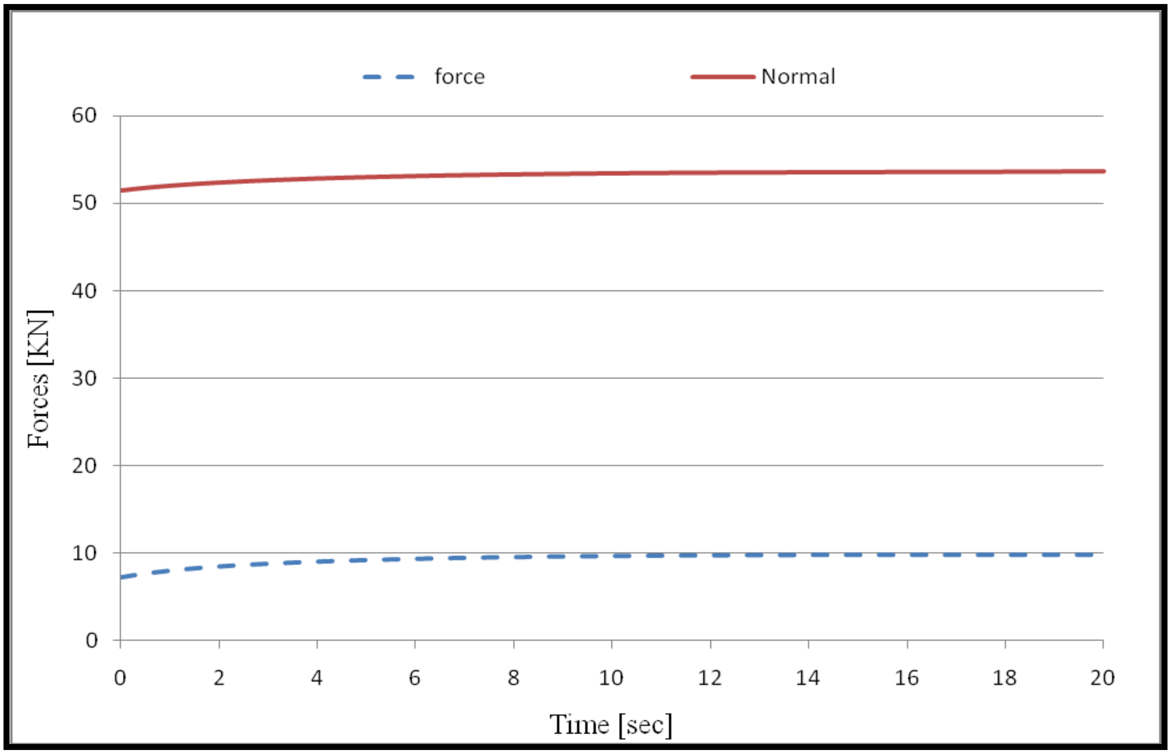

Figure 5.9 Clamshell Dynamic Simulation Results: dynamic forces

The simulation results carried out for cycle times of 18, 20, 22, 24, 26, 28, and 30 are shown by Figures 5.10-5.12. Figure 5.10 shows piston forces against cycle time. The piston forces generally increase as the simulation proceeds. The initial forces are lower for shorter cycles and increase more rapidly compared to longer cycles. The maximum piston force decreases with cycle time. Figure 5.11 shows that the piston speed is significant in determining the power (piston speed is lower for higher cycle times). The power decreases with increasing cycle time. From Figures 5.12 and 5.13, work done (energy) increases with increasing cycle time. Even though the power is lower for the longer cycles, the length of the cycles more than compensates for that, resulting in an overall increase in work done for longer cycles. However, the increase in work done, as a result of increasing cycle time, is only marginal. A polynomial relationship (to the power 3) can be used to explain the relationship between work done and cycle time. This result indicates that though an operator can increase the CT to deal with difficult digging, inputting unduly high CTs results in higher energy consumption during dredging.

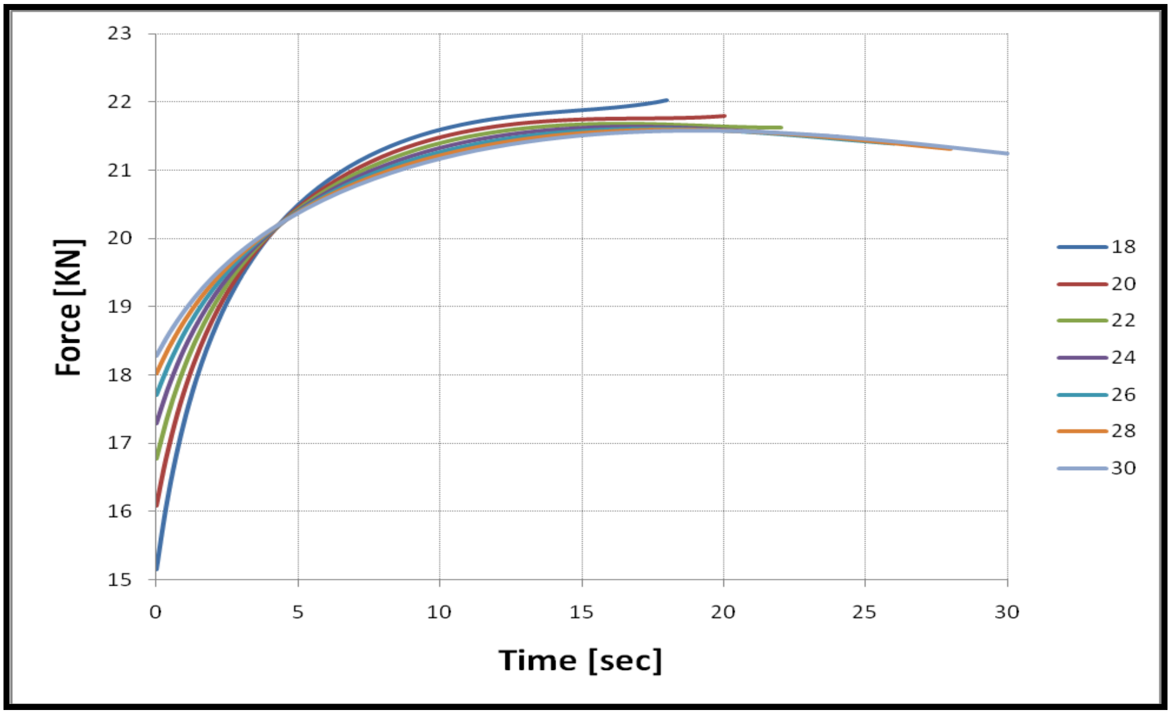

Figure 5.10 Simulation Experimentation Results: Piston Forces

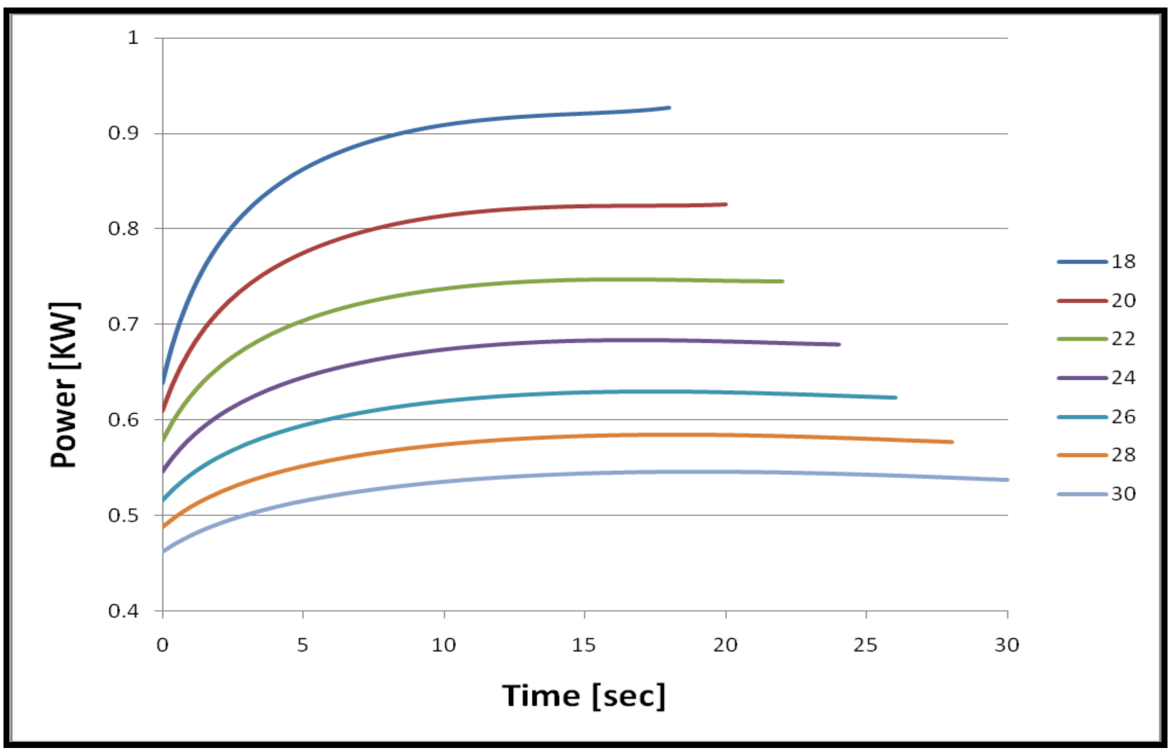

Figure 5.11 Simulation Experimentation Results: Piston Power

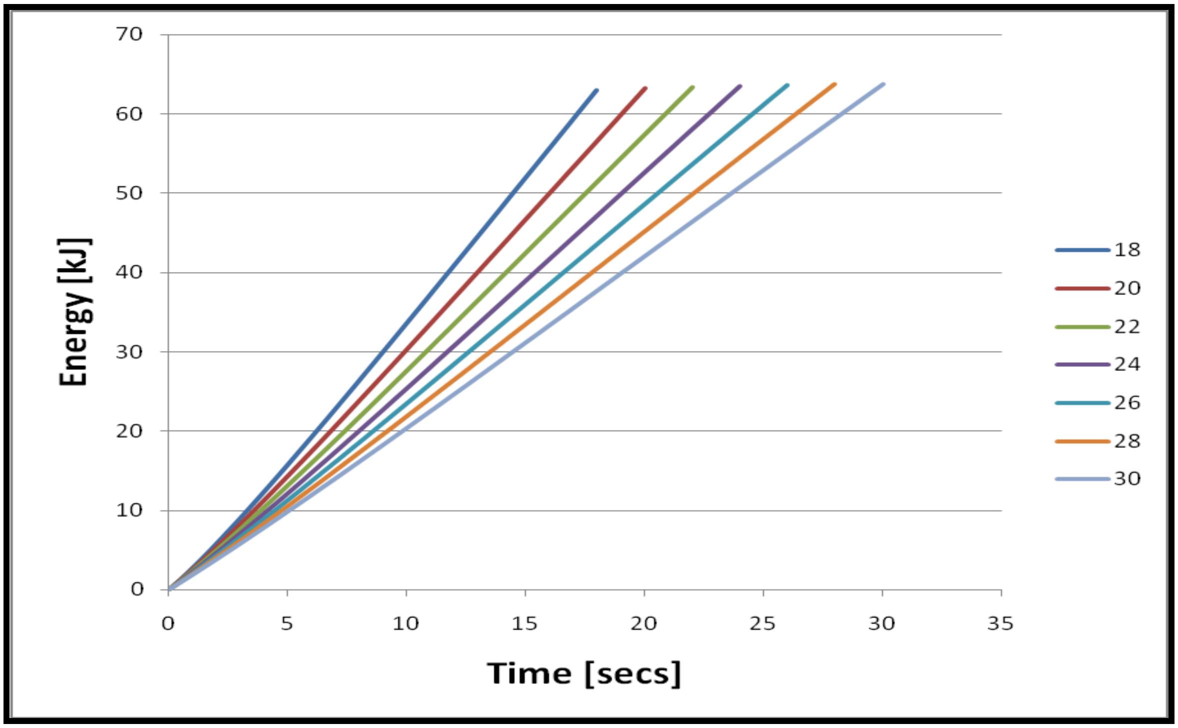

Figure 5.12 Simulation Experimentation Results: Energy

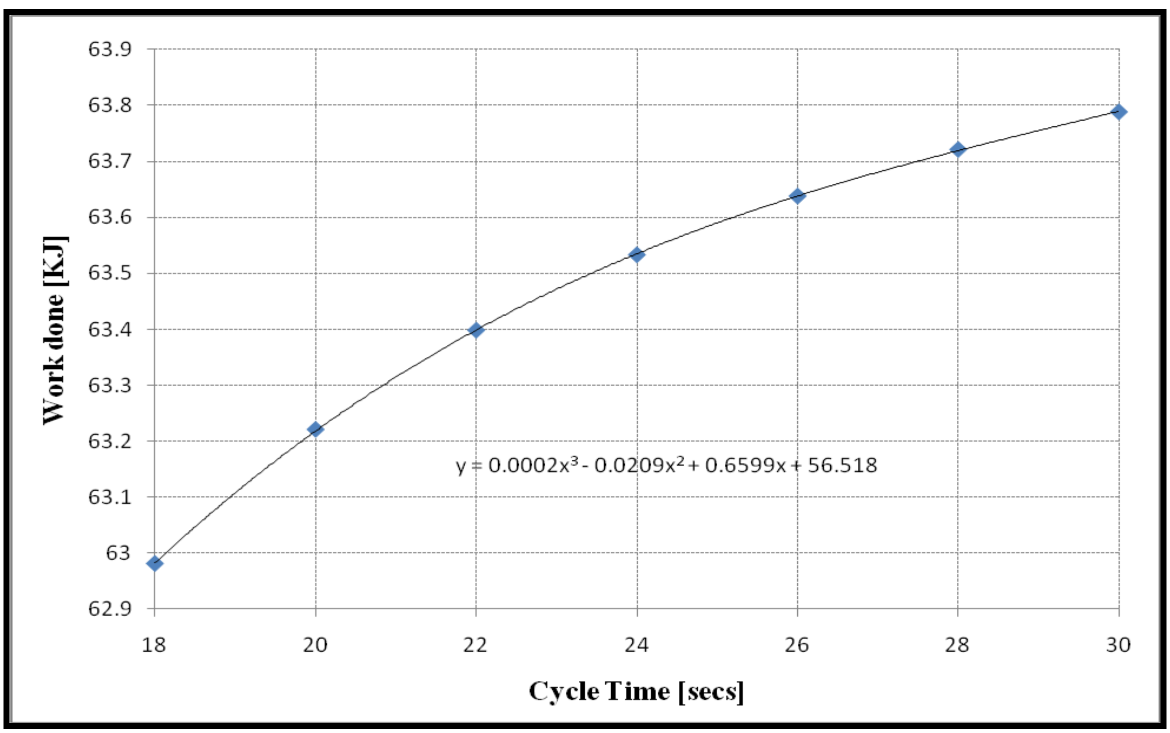

Figure 5.13 Work done against cycle time.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

One of the main methods presently used for extracting under-water deposits at depths greater than 150 ft is a clamshell dredge. The use of a clamshell dredge to mine deposits that lie below the water table causes production to be constrained, particularly, since it becomes more difficult to assess the dredging resistance of the deposit being mined. At the same time, the tools that are available to the dredge operator to assess the dredgeability of the deposits are limited. Remedial action to deal with difficult digging is expensive and difficult since the usual ground fragmentation techniques (blasting and ripping) cannot be applied easily in dredging. Existing metrics have been found to be inadequate in predicting the dredgeability of a deposit, particularly for characterizing the dredgeability of compact deposits with clamshell dredges. This increases the operator's risk of acquiring a non-performing asset (a dredge can cost more than $4 million).

The objectives of this work were to test the hypotheses that: (i) work done by the hydraulic pistons during dredging is a better predictor of clamshell dredgeability than motor energy; and (ii) work done increases with increasing cycle time.

The first objective of this research was achieved by carrying out field data collection and analysis. The field data (motor current, bucket closing pressure and displacement) was sourced from a Rohr Corp 16 yd^3 clamshell dredge operating at a mine in Seattle, WA. Dredgeability metrics (work done and motor energy) were obtained from the field data. The sensitivity of the metrics to independent variables (mean bucket tilt and cycle time) were evaluated using statistical correlation analysis. The first research hypothesis was tested by comparing the measure of the uncertainty surrounding mean estimates (coefficient of variation) of the dredgeability metrics. The second objective of this work involved kinematics and dynamics modeling and implementation using MATLAB's Simulink® Toolbox. The model was validated using the field data. The validated model was then used to test the second research hypothesis.

From this research, it can be concluded that:

- The work done by the clamshell closure pistons during dredging is a better predictor of formation dredgeability than hoist motor energy. This is because work done has a lower variability than motor energy and is therefore not as sensitive to other operating factors (tilt angle, cycle time and operator effect).

- The work done by the clamshell closure pistons during dredging increases with increasing cycle time, even if tilt angle and material properties are kept constant. The increase in work done was, however, only minimal. For the simulated conditions, this relationship can be described by Equation (41), where "T" is the cycle time.

$$\text{Work done} = 0.0002(T)^3 - 0.0209(T)^2 + 0.6599(T) + 56.518 \qquad (41)$$

In addition to the two main conclusions, the following conclusions were also deduced from the work.

- It is feasible to use the data from the Rohr bucket diagnostic system to study dredgeability. However additional monitoring of hoist energy or payload will help in calculating the specific energy in conjunction with the work done in order to measure formation dredgeability accurately.

- Cycle time and tilt angle are identified as key control parameters for both work done and motor energy. Correlation coefficients, at 95% confidence, were significant.

- Valid kinematics and dynamics models of the clamshell dredging process have been formulated by assuming:
  - Constant soil cutting resistance using the Miedema and Vlasblom (2006) 2D soil cutting model
  - Constant velocity for the hydraulic piston.

- The determination of theta b (θ_b) in reference to theta 3 (θ_3) is a key to modeling the dynamics of the clamshell bucket. This relation can be used to determine the dynamics and hence the digging energies of any clamshell bucket.

6.2. RECOMMENDATIONS FOR FUTURE WORK

The following recommendations are made for future work:

- Collect more data on different clamshells working under different conditions to compare their performance, operator effects, bucket and teeth design, initial bucket penetration, digging trajectory and payload. Also, data should be collected at high resolution in the field.

- Conduct experiments to evaluate other measures of dredgeability (specific energy and energy per unit loading rate).

- Conduct experiments to determine optimal cycle times for different formations. This will help dredge operators to set the dredge at required cycle time to maximize productivity.

- Tilt angle should be included in the kinematic and dynamic model in order to simulate its effect on work done and hoist motor energy. This will help to establish a relationship between tilt angle and cycle time, motor energy and work done.

- Cutting resistance with varying cutting angle should be modeled and used to validate the kinematic and dynamic model, to ascertain the effect of formation (soil) properties on work done and motor energy. This will also help to establish a dredgeability index relating work done to geology.

APPENDIX A

EXPERIMENTAL FIELD DATA (RAW AND EDITED) ON CD ROM

1. INTRODUCTION

Included with this thesis is a CD-ROM, which contains the experimental field data (raw and edited) of all 121 data. The documents have been prepared as Microsoft Excel 2007.

APPENDIX B

SUMMARY STATISTICS ON CD ROM

1. INTRODUCTION

Included with this thesis is a CD-ROM, which contains the summary statistics of all the cycle time. The documents have been prepared as Microsoft Excel 2007.

APPENDIX C

STATISTICAL CORRELATION ANALYSIS ON CD ROM

1. INTRODUCTION

Included with this thesis is a CD-ROM, which contains the summary statistics correlation analysis of all the 121 data. The summary statistics includes the Spearman and Kendall Tau b coefficient of correlation. The documents have been prepared as Microsoft Microsoft Word 2007.

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VITA

Bismark Akwasi Osei was born in Accra, Ghana, on October 17, 1983. In May 2006, he received his B.S. with first class honors in Mining Engineering from Kwame Nkrumah University of Science and Technology's School of Mines (since renamed the University of Science and Technology) Tarkwa, Ghana. He did his professional attachment at Anglogold Ashanti Bibiani Limited during the summer of 2005. In 2006, he did his national service with the Department of Urban Roads, where he worked as an assistant environmental engineer. He then worked at Mantrac Ghana Limited as an assistant service administrator from 2007 to 2008. He was latter on employed by Minerals Commission, Ghana, as an Assistant District Officer.

In January 2009, He joined the MS program in Mining Engineering at Missouri University of Science and Technology (MS&T) Rolla, MO. During his two years stay on campus he worked as a graduate research and teaching assistant under the guidance of Dr Kwame Awuah-Offei. He is expected to receive his MS in Mining Engineering in May 2011.

He has published in a peer-reviewed conference proceeding, Pre-Prints of the 2010 SME Annual Conference. Also, his research poster placed 2nd in the 2010 Missouri University of Science & Technology Graduate Research Showcase. Bismark Akwasi Osei has been a member of the Society of Mining and Metallurgical Engineers (SME) since 2009.

EXPERIMENTAL FIELD DATA FOR OVERALL CYCLE TIME (EDITED)

1

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	120.00	26000.75	0.16	2069.22	1905.00	914400.00	914400.00
4.00	69.00	31.00	71.06	132.00	28600.82	0.08	2069.22	2177.00	1044960.00	1959360.00
8.00	50.00	50.00	76.73	151.00	32717.61	0.14	4415.17	2605.00	1250400.00	4590720.00
10.00	42.00	58.00	79.12	161.00	34884.34	0.06	2049.52	2788.00	1338240.00	2588640.00
12.00	34.00	66.00	81.50	163.00	35317.68	0.06	2128.35	2725.00	1250400.00	2588640.00
14.00	26.00	74.00	83.89	158.00	34234.32	0.06	2108.64	2729.00	1338240.00	2588640.00
16.00	18.00	82.00	86.28	166.00	35967.70	0.06	2128.35	2823.00	1308000.00	2646240.00
18.00	10.00	90.00	88.67	163.00	35317.68	0.06	2161.19	2760.00	1309920.00	2617920.00
							19129.65			20494560.00

2

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	78.00	22.00	68.37	125.00	27084.11	0.17	2258.08	2013.00	966240.00	966240.00
4.00	68.00	32.00	71.36	122.00	26434.09	0.08	2028.17	2003.00	961440.00	1927680.00
8.00	49.00	51.00	77.03	120.00	26000.75	0.14	3775.51	1978.00	949440.00	3821760.00
10.00	40.00	60.00	79.71	115.00	24917.38	0.07	1736.67	1780.00	854400.00	1803840.00
12.00	32.00	68.00	82.10	125.00	27084.11	0.06	1576.55	2099.00	949440.00	1803840.00
14.00	24.00	76.00	84.49	125.00	27084.11	0.06	1642.24	2500.00	854400.00	1803840.00
16.00	15.00	85.00	87.17	154.00	33367.63	0.07	2061.83	1871.00	1007520.00	1861920.00
18.00	7.00	93.00	89.56	120.00	26000.75	0.06	1799.90	2697.00	1200000.00	2207520.00
							16878.96			16196640.00

3

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	78.00	22.00	68.37	125.00	27084.11	0.17	2258.08	1874.00	899520.00	899520.00

4.00	68.00	32.00	71.36	122.00	26434.09	0.08	2028.17	1833.00	879840.00	1779360.00
8.00	49.00	51.00	77.03	120.00	26000.75	0.14	3775.51	2008.00	963840.00	3687360.00
10.00	40.00	60.00	79.71	115.00	24917.38	0.07	1736.67	2204.00	1057920.00	2021760.00
12.00	32.00	68.00	82.10	125.00	27084.11	0.06	1576.55	2639.00	963840.00	2021760.00
14.00	24.00	76.00	84.49	125.00	27084.11	0.06	1642.24	2949.00	1057920.00	2021760.00
16.00	15.00	85.00	87.17	154.00	33367.63	0.07	2061.83	2826.00	1266720.00	2324640.00
18.00	7.00	93.00	89.56	120.00	26000.75	0.06	1799.90	2015.00	1415520.00	2682240.00
							16878.96			17438400.00

4

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	75.00	25.00	69.27	98.00	21233.94	0.19	2011.75	1319.00	633120.00	633120.00
4.00	64.00	36.00	72.55	103.00	22317.31	0.08	1815.50	1483.00	711840.00	1344960.00
8.00	46.00	54.00	77.92	108.00	23400.67	0.14	3118.62	1639.00	786720.00	2997120.00
10.00	37.00	63.00	80.61	108.00	23400.67	0.07	1596.26	1596.00	766080.00	1552800.00
12.00	29.00	71.00	83.00	118.00	25567.40	0.06	1484.59	1796.00	786720.00	1552800.00
14.00	21.00	79.00	85.38	108.00	23400.67	0.06	1484.59	1650.00	766080.00	1552800.00
16.00	12.00	88.00	88.07	101.00	21883.96	0.07	1544.53	1428.00	862080.00	1628160.00
18.00	3.00	97.00	90.75	98.00	21233.94	0.07	1470.63	1407.00	792000.00	1654080.00
							14526.45			12915840.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	125.00	27084.11	0.14	1950.16	2058.00	987840.00	987840.00
4.00	70.00	30.00	70.76	132.00	28600.82	0.08	2321.31	2156.00	1034880.00	2022720.00
8.00	52.00	48.00	76.13	146.00	31634.24	0.14	4108.89	2500.00	1200000.00	4469760.00
10.00	43.00	57.00	78.82	142.00	30767.55	0.07	2128.35	2397.00	1150560.00	2350560.00
12.00	35.00	65.00	81.21	158.00	34234.32	0.06	1970.69	2750.00	1200000.00	2350560.00
14.00	27.00	73.00	83.59	168.00	36401.05	0.06	2141.48	2865.00	1150560.00	2350560.00
16.00	19.00	81.00	85.98	156.00	33800.97	0.06	2128.35	2591.00	1320000.00	2470560.00
18.00	10.00	90.00	88.67	130.00	28167.48	0.07	2113.57	2091.00	1375200.00	2695200.00
							18862.79			19697760.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	77.00	23.00	68.67	113.00	24484.04	0.17	2134.09	1745.00	837600.00	837600.00
4.00	67.00	33.00	71.66	122.00	26434.09	0.08	1929.63	1891.00	907680.00	1745280.00
8.00	48.00	52.00	77.33	125.00	27084.11	0.14	3853.52	2046.00	982080.00	3779520.00
10.00	40.00	60.00	79.71	134.00	29034.17	0.06	1701.36	2197.00	1054560.00	2036640.00
12.00	32.00	68.00	82.10	149.00	32284.26	0.06	1859.02	2450.00	982080.00	2036640.00
14.00	23.00	77.00	84.79	137.00	29684.19	0.07	2113.57	2204.00	1054560.00	2036640.00
16.00	15.00	85.00	87.17	139.00	30117.53	0.06	1813.04	2366.00	1176000.00	2230560.00
18.00	6.00	94.00	89.86	161.00	34884.34	0.07	2217.03	2696.00	1057920.00	2233920.00
							17621.26			16936800.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	77.00	23.00	68.67	122.00	26434.09	0.17	2304.07	1953.00	937440.00	937440.00
4.00	67.00	33.00	71.66	125.00	27084.11	0.08	2028.17	2008.00	963840.00	1901280.00
8.00	49.00	51.00	77.03	132.00	28600.82	0.14	3798.51	2114.00	1014720.00	3957120.00
10.00	41.00	59.00	79.42	144.00	31200.90	0.06	1813.04	2406.00	1154880.00	2169600.00
12.00	33.00	67.00	81.80	154.00	33367.63	0.06	1957.55	2639.00	1014720.00	2169600.00
14.00	24.00	76.00	84.49	158.00	34234.32	0.07	2305.71	2699.00	1154880.00	2169600.00
16.00	16.00	84.00	86.88	158.00	34234.32	0.06	2075.79	2656.00	1266720.00	2421600.00
18.00	7.00	93.00	89.56	122.00	26434.09	0.07	2069.22	1940.00	1295520.00	2562240.00
							18352.05			18288480.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	125.00	27084.11	0.16	2155.44	1935.00	928800.00	928800.00
4.00	69.00	31.00	71.06	125.00	27084.11	0.08	2052.80	2048.00	983040.00	1911840.00
8.00	50.00	50.00	76.73	146.00	31634.24	0.14	4227.95	2450.00	1176000.00	4318080.00
10.00	42.00	58.00	79.12	156.00	33800.97	0.06	1983.83	2681.00	1286880.00	2462880.00

12.00	34.00	66.00	81.50	163.00	35317.68	0.06	2095.50	2787.00	1176000.00	2462880.00
14.00	26.00	74.00	83.89	154.00	33367.63	0.06	2082.36	2542.00	1286880.00	2462880.00
16.00	17.00	83.00	86.58	146.00	31634.24	0.07	2217.03	2457.00	1337760.00	2624640.00
18.00	8.00	92.00	89.26	113.00	24484.04	0.07	1914.03	1728.00	1220160.00	2557920.00
							18728.95			19729920.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	78.00	22.00	68.37	110.00	23834.02	0.17	1987.11	1634.00	784320.00	784320.00
4.00	68.00	32.00	71.36	115.00	24917.38	0.08	1847.52	1738.00	834240.00	1618560.00
8.00	49.00	51.00	77.03	118.00	25567.40	0.14	3635.10	1740.00	835200.00	3338880.00
10.00	41.00	59.00	79.42	130.00	28167.48	0.06	1629.10	1997.00	958560.00	1793760.00
12.00	32.00	68.00	82.10	132.00	28600.82	0.07	1936.20	2137.00	835200.00	1793760.00
14.00	24.00	76.00	84.49	134.00	29034.17	0.06	1747.35	2093.00	958560.00	1793760.00
16.00	16.00	84.00	86.88	125.00	27084.11	0.06	1701.36	1953.00	1025760.00	1984320.00
18.00	7.00	93.00	89.56	108.00	23400.67	0.07	1721.89	1574.00	1004640.00	2030400.00
							16205.64			15137760.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	78.00	22.00	68.37	103.00	22317.31	0.17	1860.66	1438.00	690240.00	690240.00
4.00	68.00	32.00	71.36	110.00	23834.02	0.08	1748.99	1649.00	791520.00	1481760.00
8.00	49.00	51.00	77.03	110.00	23834.02	0.14	3432.29	1574.00	755520.00	3094080.00
10.00	40.00	60.00	79.71	113.00	24484.04	0.07	1647.99	1642.00	788160.00	1543680.00
12.00	32.00	68.00	82.10	115.00	24917.38	0.06	1497.72	1715.00	755520.00	1543680.00
14.00	24.00	76.00	84.49	115.00	24917.38	0.06	1510.86	1679.00	788160.00	1543680.00
16.00	15.00	85.00	87.17	106.00	22967.33	0.07	1633.21	1455.00	823200.00	1611360.00
18.00	6.00	94.00	89.86	96.00	20800.60	0.07	1492.80	1165.00	805920.00	1629120.00
							14824.52			13137600.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								

0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	98.00	21233.94	0.14	1528.93	1314.00	630720.00	630720.00
4.00	71.00	29.00	70.46	106.00	22967.33	0.08	1675.09	1546.00	742080.00	1372800.00
8.00	52.00	48.00	76.13	106.00	22967.33	0.14	3307.48	1510.00	724800.00	2933760.00
10.00	43.00	57.00	78.82	113.00	24484.04	0.07	1618.43	1642.00	788160.00	1512960.00
12.00	34.00	66.00	81.50	115.00	24917.38	0.07	1684.94	1765.00	724800.00	1512960.00
14.00	26.00	74.00	83.89	113.00	24484.04	0.06	1497.72	1660.00	788160.00	1512960.00
16.00	18.00	82.00	86.28	106.00	22967.33	0.06	1438.60	1478.00	847200.00	1635360.00
18.00	9.00	91.00	88.96	96.00	20800.60	0.07	1492.80	1278.00	796800.00	1644000.00
							14243.98			12755520.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	91.00	19717.23	0.16	1569.16	946.00	454080.00	454080.00
4.00	69.00	31.00	71.06	89.00	19283.89	0.08	1478.02	1133.00	543840.00	997920.00
8.00	50.00	50.00	76.73	94.00	20367.25	0.14	2855.04	1127.00	540960.00	2169600.00
10.00	41.00	59.00	79.42	91.00	19717.23	0.07	1367.17	1158.00	555840.00	1096800.00
12.00	33.00	67.00	81.80	94.00	20367.25	0.06	1215.26	1152.00	540960.00	1096800.00
14.00	24.00	76.00	84.49	89.00	19283.89	0.07	1352.39	1120.00	555840.00	1096800.00
16.00	16.00	84.00	86.88	91.00	19717.23	0.06	1182.41	1034.00	552960.00	1108800.00
18.00	7.00	93.00	89.56	84.00	18200.52	0.07	1293.27	955.00	537600.00	1090560.00
							12312.71			9111360.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	106.00	22967.33	0.14	1653.74	1511.00	725280.00	725280.00
4.00	71.00	29.00	70.46	115.00	24917.38	0.08	1814.68	1700.00	816000.00	1541280.00
8.00	52.00	48.00	76.13	113.00	24484.04	0.14	3557.10	1735.00	832800.00	3297600.00
10.00	43.00	57.00	78.82	125.00	27084.11	0.07	1758.84	1896.00	910080.00	1742880.00
12.00	35.00	65.00	81.21	139.00	30117.53	0.06	1734.21	2288.00	832800.00	1742880.00
14.00	26.00	74.00	83.89	139.00	30117.53	0.07	2054.44	2262.00	910080.00	1742880.00
16.00	18.00	82.00	86.28	137.00	29684.19	0.06	1813.04	2189.00	1098240.00	2008320.00

18.00	9.00	91.00	88.96	110.00	23834.02	0.07	1825.35	1622.00	1085760.00	2184000.00
							16211.39			14985120.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	106.00	22967.33	0.14	1653.74	1488.00	714240.00	714240.00
4.00	71.00	29.00	70.46	86.00	18633.87	0.08	1576.55	1014.00	486720.00	1200960.00
8.00	52.00	48.00	76.13	108.00	23400.67	0.14	3026.65	1534.00	736320.00	2446080.00
10.00	43.00	57.00	78.82	110.00	23834.02	0.07	1611.04	1697.00	814560.00	1550880.00
12.00	35.00	65.00	81.21	118.00	25567.40	0.06	1497.72	1874.00	736320.00	1550880.00
14.00	26.00	74.00	83.89	120.00	26000.75	0.07	1758.84	1887.00	814560.00	1550880.00
16.00	18.00	82.00	86.28	108.00	23400.67	0.06	1497.72	1553.00	899520.00	1714080.00
18.00	9.00	91.00	88.96	91.00	19717.23	0.07	1470.63	1125.00	905760.00	1805280.00
							14092.90			12533280.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	108.00	23400.67	0.14	1684.94	1453.00	697440.00	697440.00
4.00	71.00	29.00	70.46	113.00	24484.04	0.08	1814.68	1649.00	791520.00	1488960.00
8.00	52.00	48.00	76.13	127.00	27517.46	0.14	3744.31	2030.00	974400.00	3531840.00
10.00	43.00	57.00	78.82	137.00	29684.19	0.07	1950.98	2238.00	1074240.00	2048640.00
12.00	35.00	65.00	81.21	166.00	35967.70	0.06	1990.40	2820.00	974400.00	2048640.00
14.00	27.00	73.00	83.59	166.00	35967.70	0.06	2180.90	2798.00	1074240.00	2048640.00
16.00	19.00	81.00	85.98	154.00	33367.63	0.06	2102.07	2538.00	1353600.00	2427840.00
18.00	10.00	90.00	88.67	120.00	26000.75	0.07	2024.88	1794.00	1343040.00	2696640.00
							17493.16			16988640.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	82.00	18.00	67.18	108.00	23400.67	0.14	1596.26	1561.00	749280.00	749280.00
4.00	71.00	29.00	70.46	115.00	24917.38	0.08	2014.21	1700.00	816000.00	1565280.00

8.00	52.00	48.00	76.13	106.00	22967.33	0.14	3447.89	1642.00	788160.00	3208320.00
10.00	43.00	57.00	78.82	101.00	21883.96	0.07	1529.75	1339.00	642720.00	1430880.00
12.00	34.00	66.00	81.50	122.00	26434.09	0.07	1647.99	1924.00	788160.00	1430880.00
14.00	26.00	74.00	83.89	130.00	28167.48	0.06	1655.38	2045.00	642720.00	1430880.00
16.00	18.00	82.00	86.28	127.00	27517.46	0.06	1688.22	2040.00	923520.00	1566240.00
18.00	9.00	91.00	88.96	103.00	22317.31	0.07	1699.72	1369.00	981600.00	1905120.00
							15279.42			13286880.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	118.00	25567.40	0.15	1937.85	1756.00	842880.00	842880.00
4.00	70.00	30.00	70.76	122.00	26434.09	0.08	1970.69	1914.00	918720.00	1761600.00
8.00	51.00	49.00	76.43	144.00	31200.90	0.14	4149.95	2310.00	1108800.00	4055040.00
10.00	42.00	58.00	79.12	146.00	31634.24	0.07	2143.13	2432.00	1167360.00	2276160.00
12.00	34.00	66.00	81.50	158.00	34234.32	0.06	1996.97	2651.00	1108800.00	2276160.00
14.00	26.00	74.00	83.89	158.00	34234.32	0.06	2075.79	2671.00	1167360.00	2276160.00
16.00	18.00	82.00	86.28	149.00	32284.26	0.06	2016.67	2502.00	1272480.00	2439840.00
18.00	9.00	91.00	88.96	125.00	27084.11	0.07	2024.88	1896.00	1282080.00	2554560.00
							18315.92			18482400.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	118.00	25567.40	0.15	1937.85	1389.00	666720.00	666720.00
4.00	70.00	30.00	70.76	122.00	26434.09	0.08	1970.69	1568.00	752640.00	1419360.00
8.00	51.00	49.00	76.43	144.00	31200.90	0.14	4149.95	1975.00	948000.00	3401280.00
10.00	42.00	58.00	79.12	146.00	31634.24	0.07	2143.13	2164.00	1038720.00	1986720.00
12.00	33.00	67.00	81.80	158.00	34234.32	0.07	2246.59	2015.00	948000.00	1986720.00
14.00	25.00	75.00	84.19	158.00	34234.32	0.06	2075.79	2441.00	1038720.00	1986720.00
16.00	17.00	83.00	86.58	149.00	32284.26	0.06	2016.67	2754.00	967200.00	2005920.00
18.00	8.00	92.00	89.26	125.00	27084.11	0.07	2024.88	1937.00	1171680.00	2138880.00
							18565.54			15592320.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	118.00	25567.40	0.15	1937.85	1907.00	915360.00	915360.00
4.00	70.00	30.00	70.76	122.00	26434.09	0.08	1970.69	2050.00	984000.00	1899360.00
8.00	51.00	49.00	76.43	144.00	31200.90	0.14	4149.95	2152.00	1032960.00	4033920.00
10.00	42.00	58.00	79.12	146.00	31634.24	0.07	2143.13	2055.00	986400.00	2019360.00
12.00	33.00	67.00	81.80	158.00	34234.32	0.07	2246.59	2265.00	1032960.00	2019360.00
14.00	25.00	75.00	84.19	158.00	34234.32	0.06	2075.79	2227.00	986400.00	2019360.00
16.00	17.00	83.00	86.58	149.00	32284.26	0.06	2016.67	2538.00	1087200.00	2073600.00
18.00	8.00	92.00	89.26	125.00	27084.11	0.07	2024.88	2437.00	1068960.00	2156160.00
							18565.54			17136480.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	110.00	23834.02	0.14	1716.14	1644.00	789120.00	789120.00
4.00	70.00	30.00	70.76	115.00	24917.38	0.08	2032.27	1770.00	849600.00	1638720.00
8.00	51.00	49.00	76.43	130.00	28167.48	0.14	3822.32	2094.00	1005120.00	3709440.00
10.00	42.00	58.00	79.12	132.00	28600.82	0.07	1936.20	2152.00	1032960.00	2038080.00
12.00	34.00	66.00	81.50	146.00	31634.24	0.06	1826.17	2465.00	1005120.00	2038080.00
14.00	26.00	74.00	83.89	158.00	34234.32	0.06	1996.97	2643.00	1032960.00	2038080.00
16.00	18.00	82.00	86.28	170.00	36834.39	0.06	2154.62	2823.00	1183200.00	2216160.00
18.00	10.00	90.00	88.67	166.00	35967.70	0.06	2207.17	2820.00	1268640.00	2451840.00
							17691.87			16919520.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	108.00	23400.67	0.14	1684.94	1619.00	777120.00	777120.00
4.00	70.00	30.00	70.76	122.00	26434.09	0.08	2077.44	1882.00	903360.00	1680480.00
8.00	51.00	49.00	76.43	137.00	29684.19	0.14	4040.74	2243.00	1076640.00	3960000.00
10.00	42.00	58.00	79.12	139.00	30117.53	0.07	2039.66	2248.00	1079040.00	2155680.00
12.00	34.00	66.00	81.50	151.00	32717.61	0.06	1905.00	2528.00	1076640.00	2155680.00

14.00	26.00	74.00	83.89	151.00	32717.61	0.06	1983.83	2581.00	1079040.00	2155680.00
16.00	18.00	82.00	86.28	173.00	37484.41	0.06	2128.35	2866.00	1213440.00	2292480.00
18.00	10.00	90.00	88.67	161.00	34884.34	0.06	2194.04	2772.00	1238880.00	2452320.00
							18053.99			17629440.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	77.00	23.00	68.67	103.00	22317.31	0.17	1945.24	1380.00	662400.00	662400.00
4.00	67.00	33.00	71.66	106.00	22967.33	0.08	1716.14	1485.00	712800.00	1375200.00
8.00	48.00	52.00	77.33	101.00	21883.96	0.14	3229.47	1360.00	652800.00	2731200.00
10.00	39.00	61.00	80.01	103.00	22317.31	0.07	1507.58	1400.00	672000.00	1324800.00
12.00	31.00	69.00	82.40	108.00	23400.67	0.06	1386.05	1612.00	652800.00	1324800.00
14.00	22.00	78.00	85.09	110.00	23834.02	0.07	1611.04	1581.00	672000.00	1324800.00
16.00	14.00	86.00	87.47	110.00	23834.02	0.06	1445.17	1644.00	773760.00	1445760.00
18.00	5.00	95.00	90.16	115.00	24917.38	0.07	1662.77	1788.00	758880.00	1532640.00
							14503.46			11721600.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	78.00	22.00	68.37	94.00	20367.25	0.17	1698.08	1203.00	577440.00	577440.00
4.00	67.00	33.00	71.66	84.00	18200.52	0.08	1607.75	956.00	458880.00	1036320.00
8.00	48.00	52.00	77.33	96.00	20800.60	0.14	2808.23	1193.00	572640.00	2063040.00
10.00	40.00	60.00	79.71	98.00	21233.94	0.06	1274.38	1372.00	658560.00	1231200.00
12.00	31.00	69.00	82.40	96.00	20800.60	0.07	1433.68	1266.00	572640.00	1231200.00
14.00	23.00	77.00	84.79	101.00	21883.96	0.06	1294.09	1312.00	658560.00	1231200.00
16.00	14.00	86.00	87.47	132.00	28600.82	0.07	1721.89	2149.00	607680.00	1266240.00
18.00	5.00	95.00	90.16	84.00	18200.52	0.07	1596.26	968.00	629760.00	1237440.00
							13434.36			9874080.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2.00	74.00	26.00	69.57	103.00	22317.31	0.20	2198.96	1488.00	714240.00	714240.00
4.00	63.00	37.00	72.85	108.00	23400.67	0.08	1905.82	1551.00	744480.00	1458720.00
8.00	45.00	55.00	78.22	120.00	26000.75	0.14	3369.88	1902.00	912960.00	3314880.00
10.00	37.00	63.00	80.61	122.00	26434.09	0.06	1589.69	1891.00	907680.00	1820640.00
12.00	28.00	72.00	83.29	132.00	28600.82	0.07	1877.08	2040.00	912960.00	1820640.00
14.00	20.00	80.00	85.68	125.00	27084.11	0.06	1688.22	2058.00	907680.00	1820640.00
16.00	12.00	88.00	88.07	142.00	30767.55	0.06	1753.91	2426.00	979200.00	1886880.00
18.00	2.00	98.00	91.05	175.00	37917.76	0.08	2602.95	2843.00	987840.00	1967040.00
							16986.53			14803680.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	82.00	18.00	67.18	118.00	25567.40	0.14	1744.06	1776.00	852480.00	852480.00
4.00	71.00	29.00	70.46	127.00	27517.46	0.08	2212.92	2008.00	963840.00	1816320.00
8.00	52.00	48.00	76.13	149.00	32284.26	0.14	4305.96	2500.00	1200000.00	4327680.00
10.00	44.00	56.00	78.52	139.00	30117.53	0.06	1891.86	2426.00	1164480.00	2364480.00
12.00	36.00	64.00	80.91	158.00	34234.32	0.06	1950.98	2732.00	1311360.00	2475840.00
14.00	27.00	73.00	83.59	158.00	34234.32	0.07	2335.27	2711.00	1301280.00	2612640.00
16.00	20.00	80.00	85.68	166.00	35967.70	0.05	1862.30	2889.00	1386720.00	2688000.00
18.00	12.00	88.00	88.07	166.00	35967.70	0.06	2180.90	2836.00	1361280.00	2748000.00
20.00	5.00	95.00	90.16	173.00	37484.41	0.05	1948.52	2942.00	1412160.00	2773440.00
							20432.77			22658880.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	82.00	18.00	67.18	118.00	29684.19	0.14	1744.06	1776.00	852480.00	852480.00
4.00	71.00	29.00	70.46	127.00	30117.53	0.08	2212.92	2008.00	963840.00	1816320.00
8.00	52.00	48.00	76.13	149.00	35967.70	0.14	4305.96	2500.00	1200000.00	4327680.00
10.00	44.00	56.00	78.52	139.00	37917.76	0.06	1891.86	2426.00	1200000.00	2400000.00
12.00	36.00	64.00	80.91	158.00	39001.12	0.06	1950.98	2732.00	1164480.00	2364480.00
14.00	27.00	73.00	83.59	158.00	39001.12	0.07	2335.27	2711.00	1311360.00	2475840.00
16.00	20.00	80.00	85.68	166.00	37917.76	0.05	1862.30	2889.00	1301280.00	2612640.00

18.00	12.00	88.00	88.07	166.00	37484.41	0.06	2180.90	2836.00	1386720.00	2688000.00
20.00	5.00	95.00	90.16	173.00	36834.39	0.05	1948.52	2942.00	1361280.00	2748000.00
							20432.77			22285440.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	132.00	28600.82	0.14	2059.37	2137.00	1025760.00	1025760.00
4.00	70.00	30.00	70.76	137.00	29684.19	0.08	2429.70	2242.00	1076160.00	2101920.00
8.00	52.00	48.00	76.13	156.00	33800.97	0.14	4330.59	2671.00	1282080.00	4716480.00
10.00	43.00	57.00	78.82	154.00	33367.63	0.07	2290.93	2676.00	1284480.00	2566560.00
12.00	35.00	65.00	81.21	161.00	34884.34	0.06	2069.22	2836.00	1282080.00	2566560.00
14.00	27.00	73.00	83.59	161.00	34884.34	0.06	2115.21	2787.00	1284480.00	2566560.00
16.00	19.00	81.00	85.98	163.00	35317.68	0.06	2128.35	2802.00	1361280.00	2645760.00
18.00	12.00	88.00	88.07	166.00	35967.70	0.05	1891.04	2868.00	1337760.00	2699040.00
20.00	5.00	95.00	90.16	178.00	38567.78	0.05	1977.26	3073.00	1344960.00	2682720.00
							21291.67			23571360.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	125.00	27084.11	0.14	1950.16	1972.00	946560.00	946560.00
4.00	70.00	30.00	70.76	125.00	27084.11	0.08	2258.08	2104.00	1009920.00	1956480.00
8.00	51.00	49.00	76.43	156.00	33800.97	0.14	4383.96	2580.00	1238400.00	4496640.00
10.00	44.00	56.00	78.52	170.00	36834.39	0.05	1873.80	2942.00	1412160.00	2650560.00
12.00	36.00	64.00	80.91	168.00	36401.05	0.06	2220.31	2956.00	1238400.00	2650560.00
14.00	28.00	72.00	83.29	142.00	30767.55	0.06	2036.38	2359.00	1412160.00	2650560.00
16.00	20.00	80.00	85.68	146.00	31634.24	0.06	1891.86	2432.00	1418880.00	2831040.00
18.00	11.00	89.00	88.37	132.00	28600.82	0.07	2054.44	2071.00	1132320.00	2551200.00
20.00	3.00	97.00	90.75	158.00	34234.32	0.06	1905.00	2712.00	1167360.00	2299680.00
							20574.01			23033280.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								

0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	68.08	113.00	5504.23	0.16	1948.52	1718.00	824640.00	824640.00
4.00	70.00	30.00	71.06	118.00	5747.78	0.08	1896.79	1826.00	876480.00	1701120.00
8.00	51.00	49.00	76.13	137.00	6673.27	0.13	3559.56	2247.00	1078560.00	3910080.00
10.00	44.00	56.00	78.52	125.00	6088.75	0.06	1721.07	2038.00	978240.00	2056800.00
12.00	36.00	64.00	80.91	134.00	6527.14	0.06	1701.36	2243.00	1078560.00	2056800.00
14.00	28.00	72.00	83.29	134.00	6527.14	0.06	1760.48	2273.00	978240.00	2056800.00
16.00	20.00	80.00	85.98	144.00	7014.24	0.07	2054.44	2520.00	1076640.00	2054880.00
18.00	11.00	89.00	88.37	146.00	7111.66	0.06	1905.00	2326.00	1091040.00	2167680.00
20.00	3.00	97.00	90.75	168.00	8183.28	0.06	2062.66	2775.00	1209600.00	2300640.00
							18609.88			19129440.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	122.00	26434.09	0.14	1903.36	1985.00	952800.00	952800.00
4.00	70.00	30.00	70.76	132.00	28600.82	0.08	2294.21	2195.00	1053600.00	2006400.00
8.00	51.00	49.00	76.43	156.00	33800.97	0.14	4493.17	2606.00	1250880.00	4608960.00
10.00	43.00	57.00	78.82	166.00	35967.70	0.06	2115.21	2936.00	1409280.00	2660160.00
12.00	36.00	64.00	80.91	170.00	36834.39	0.05	1931.28	2918.00	1250880.00	2660160.00
14.00	29.00	71.00	83.00	154.00	33367.63	0.05	1862.30	2571.00	1409280.00	2660160.00
16.00	21.00	79.00	85.38	166.00	35967.70	0.06	2102.07	2714.00	1400640.00	2809920.00
18.00	12.00	88.00	88.07	134.00	29034.17	0.07	2217.03	2192.00	1234080.00	2634720.00
20.00	3.00	97.00	90.75	125.00	27084.11	0.07	1914.03	2013.00	1302720.00	2536800.00
							20832.66			23530080.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	113.00	24484.04	0.15	1855.73	1622.00	778560.00	778560.00
4.00	69.00	31.00	71.06	120.00	26000.75	0.08	2104.53	1808.00	867840.00	1646400.00
8.00	50.00	50.00	76.73	130.00	28167.48	0.14	3900.32	2068.00	992640.00	3720960.00
10.00	42.00	58.00	79.12	142.00	30767.55	0.06	1786.76	2275.00	1092000.00	2084640.00
12.00	33.00	67.00	81.80	146.00	31634.24	0.07	2128.35	2467.00	992640.00	2084640.00

14.00	25.00	75.00	84.19	151.00	32717.61	0.06	1950.98	2598.00	1092000.00	2084640.00
16.00	17.00	83.00	86.58	170.00	36834.39	0.06	2108.64	2870.00	1184160.00	2276160.00
18.00	10.00	90.00	88.67	173.00	37484.41	0.05	1971.51	2918.00	1247040.00	2431200.00
20.00	3.00	97.00	90.75	192.00	41601.20	0.05	2097.96	3249.00	1377600.00	2624640.00
							19904.79			19731840.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	125.00	27084.11	0.14	1950.16	1927.00	924960.00	924960.00
4.00	71.00	29.00	70.46	125.00	27084.11	0.08	2052.80	1930.00	926400.00	1851360.00
8.00	52.00	48.00	76.13	130.00	28167.48	0.14	3978.33	2103.00	1009440.00	3871680.00
10.00	43.00	57.00	78.82	146.00	31634.24	0.07	2039.66	2528.00	1213440.00	2222880.00
12.00	35.00	65.00	81.21	158.00	34234.32	0.06	1996.97	2732.00	1009440.00	2222880.00
14.00	27.00	73.00	83.59	144.00	31200.90	0.06	1983.83	2414.00	1213440.00	2222880.00
16.00	18.00	82.00	86.28	156.00	33800.97	0.07	2217.03	2636.00	1311360.00	2524800.00
18.00	10.00	90.00	88.67	166.00	35967.70	0.06	2115.21	2851.00	1158720.00	2470080.00
20.00	3.00	97.00	90.75	175.00	37917.76	0.05	1960.02	3145.00	1265280.00	2424000.00
							20294.00			20735520.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	122.00	26434.09	0.16	2103.71	1955.00	938400.00	938400.00
4.00	69.00	31.00	71.06	127.00	27517.46	0.08	2044.59	2010.00	964800.00	1903200.00
8.00	50.00	50.00	76.73	132.00	28600.82	0.14	4040.74	2156.00	1034880.00	3999360.00
10.00	42.00	58.00	79.12	144.00	31200.90	0.06	1813.04	2394.00	1149120.00	2184000.00
12.00	34.00	66.00	81.50	139.00	30117.53	0.06	1859.02	2336.00	1034880.00	2184000.00
14.00	27.00	73.00	83.59	125.00	27084.11	0.05	1517.43	1881.00	1149120.00	2184000.00
16.00	20.00	80.00	85.68	120.00	26000.75	0.05	1408.22	1897.00	1121280.00	2270400.00
18.00	14.00	86.00	87.47	146.00	31634.24	0.05	1310.51	2479.00	902880.00	2024160.00
20.00	7.00	93.00	89.56	170.00	36834.39	0.05	1816.32	2928.00	910560.00	1813440.00
							17913.57			19500960.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	77.00	23.00	68.67	130.00	28167.48	0.17	2455.15	2043.00	980640.00	980640.00
4.00	67.00	33.00	71.66	142.00	30767.55	0.08	2233.45	2384.00	1144320.00	2124960.00
8.00	49.00	51.00	77.03	170.00	36834.39	0.14	4611.42	2918.00	1400640.00	5089920.00
10.00	42.00	58.00	79.12	175.00	37917.76	0.05	1983.01	3000.00	1440000.00	2840640.00
12.00	36.00	64.00	80.91	175.00	37917.76	0.05	1724.35	3067.00	1400640.00	2840640.00
14.00	30.00	70.00	82.70	173.00	37484.41	0.05	1714.50	2994.00	1440000.00	2840640.00
16.00	23.00	77.00	84.79	178.00	38567.78	0.05	2017.49	3002.00	1472160.00	2912160.00
18.00	16.00	84.00	86.88	173.00	37484.41	0.05	2017.49	2933.00	1437120.00	2909280.00
20.00	9.00	91.00	88.96	168.00	36401.05	0.05	1960.02	2868.00	1440960.00	2878080.00
							20716.88			25416960.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	76.00	24.00	68.97	120.00	26000.75	0.18	2364.83	1912.00	917760.00	917760.00
4.00	66.00	34.00	71.96	122.00	26434.09	0.08	1987.11	1982.00	951360.00	1869120.00
8.00	47.00	53.00	77.63	154.00	33367.63	0.14	4305.96	2638.00	1266240.00	4435200.00
10.00	40.00	60.00	79.71	170.00	36834.39	0.05	1862.30	2951.00	1416480.00	2682720.00
12.00	34.00	66.00	81.50	182.00	39434.47	0.05	1734.21	3128.00	1266240.00	2682720.00
14.00	28.00	72.00	83.29	175.00	37917.76	0.05	1758.84	3025.00	1416480.00	2682720.00
16.00	23.00	77.00	84.79	182.00	39434.47	0.04	1465.70	3095.00	1501440.00	2917920.00
18.00	18.00	82.00	86.28	180.00	39001.12	0.04	1486.23	3073.00	1452000.00	2953440.00
20.00	10.00	90.00	88.67	149.00	32284.26	0.06	2161.19	2510.00	1485600.00	2937600.00
							19126.37			24079200.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	118.00	25567.40	0.16	2034.74	1838.00	882240.00	882240.00
4.00	69.00	31.00	71.06	127.00	27517.46	0.08	2011.75	1982.00	951360.00	1833600.00
8.00	50.00	50.00	76.73	134.00	29034.17	0.14	4071.94	2192.00	1052160.00	4007040.00

10.00	41.00	59.00	79.42	146.00	31634.24	0.07	2069.22	2490.00	1195200.00	2247360.00
12.00	33.00	67.00	81.80	161.00	34884.34	0.06	2016.67	2740.00	1052160.00	2247360.00
14.00	25.00	75.00	84.19	163.00	35317.68	0.06	2128.35	2802.00	1195200.00	2247360.00
16.00	18.00	82.00	86.28	173.00	37484.41	0.05	1931.28	2986.00	1315200.00	2510400.00
18.00	12.00	88.00	88.07	163.00	35317.68	0.05	1655.38	2843.00	1344960.00	2660160.00
20.00	5.00	95.00	90.16	170.00	36834.39	0.05	1914.03	3030.00	1433280.00	2778240.00
							19833.35			21413760.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	77.00	23.00	68.67	96.00	20800.60	0.17	1813.04	1316.00	631680.00	631680.00
4.00	67.00	33.00	71.66	103.00	22317.31	0.08	1634.03	1496.00	718080.00	1349760.00
8.00	48.00	52.00	77.33	118.00	25567.40	0.14	3447.89	1929.00	925920.00	3288000.00
10.00	40.00	60.00	79.71	125.00	27084.11	0.06	1596.26	2046.00	982080.00	1908000.00
12.00	31.00	69.00	82.40	125.00	27084.11	0.07	1847.52	2081.00	925920.00	1908000.00
14.00	23.00	77.00	84.79	142.00	30767.55	0.06	1753.91	2417.00	982080.00	1908000.00
16.00	15.00	85.00	87.17	154.00	33367.63	0.06	1944.41	2611.00	998880.00	1980960.00
18.00	6.00	94.00	89.86	137.00	29684.19	0.07	2150.52	2275.00	1160160.00	2159040.00
20.00	1.00	99.00	91.35	192.00	41601.20	0.04	1350.74	3358.00	1253280.00	2413440.00
							17538.32			17546880.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	110.00	23834.02	0.15	1806.47	1700.00	816000.00	816000.00
4.00	70.00	30.00	70.76	122.00	26434.09	0.08	1905.00	1927.00	924960.00	1740960.00
8.00	51.00	49.00	76.43	146.00	31634.24	0.14	4181.15	2442.00	1172160.00	4194240.00
10.00	42.00	58.00	79.12	158.00	34234.32	0.07	2246.59	2679.00	1285920.00	2458080.00
12.00	34.00	66.00	81.50	163.00	35317.68	0.06	2108.64	2754.00	1172160.00	2458080.00
14.00	26.00	74.00	83.89	156.00	33800.97	0.06	2095.50	2586.00	1285920.00	2458080.00
16.00	18.00	82.00	86.28	158.00	34234.32	0.06	2062.66	2662.00	1321920.00	2607840.00
18.00	10.00	90.00	88.67	154.00	33367.63	0.06	2049.52	2606.00	1241280.00	2563200.00
20.00	1.00	99.00	91.35	156.00	33800.97	0.07	2290.93	2656.00	1277760.00	2519040.00

							20746.44			21815520.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	78.00	22.00	68.37	103.00	22317.31	0.17	1860.66	1563.00	750240.00	750240.00
4.00	68.00	32.00	71.36	115.00	24917.38	0.08	1790.04	1738.00	834240.00	1584480.00
8.00	49.00	51.00	77.03	115.00	24917.38	0.14	3588.30	1823.00	875040.00	3418560.00
10.00	40.00	60.00	79.71	122.00	26434.09	0.07	1751.45	1982.00	951360.00	1826400.00
12.00	32.00	68.00	82.10	134.00	29034.17	0.06	1681.66	2263.00	875040.00	1826400.00
14.00	24.00	76.00	84.49	142.00	30767.55	0.06	1813.04	2368.00	951360.00	1826400.00
16.00	16.00	84.00	86.88	151.00	32717.61	0.06	1924.71	2616.00	1086240.00	2037600.00
18.00	7.00	93.00	89.56	163.00	35317.68	0.07	2320.49	2750.00	1136640.00	2222880.00
20.00	1.00	99.00	91.35	197.00	42684.56	0.05	1773.62	3360.00	1255680.00	2392320.00
							18503.96			17885280.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	108.00	23400.67	0.16	1862.30	1533.00	735840.00	735840.00
4.00	68.00	32.00	71.36	101.00	21883.96	0.08	1887.76	1480.00	710400.00	1446240.00
8.00	50.00	50.00	76.73	113.00	24484.04	0.14	3162.96	1755.00	842400.00	3105600.00
10.00	41.00	59.00	79.42	118.00	25567.40	0.07	1707.11	1788.00	858240.00	1700640.00
12.00	32.00	68.00	82.10	125.00	27084.11	0.07	1795.79	1935.00	842400.00	1700640.00
14.00	24.00	76.00	84.49	142.00	30767.55	0.06	1753.91	2381.00	858240.00	1700640.00
16.00	16.00	84.00	86.88	154.00	33367.63	0.06	1944.41	2598.00	928800.00	1787040.00
18.00	7.00	93.00	89.56	142.00	30767.55	0.07	2187.47	2369.00	1142880.00	2071680.00
20.00	0.00	100.00	91.65	199.00	43117.91	0.05	1960.02	3373.00	1247040.00	2389920.00
							18261.73			16638240.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	96.00	20800.60	0.16	1655.38	1369.00	657120.00	657120.00

4.00	69.00	31.00	71.06	103.00	22317.31	0.08	1634.03	1478.00	709440.00	1366560.00
8.00	50.00	50.00	76.73	106.00	22967.33	0.14	3260.67	1604.00	769920.00	2958720.00
10.00	41.00	59.00	79.42	108.00	23400.67	0.07	1581.48	1647.00	790560.00	1560480.00
12.00	33.00	67.00	81.80	118.00	25567.40	0.06	1484.59	1864.00	769920.00	1560480.00
14.00	25.00	75.00	84.19	127.00	27517.46	0.06	1609.40	2023.00	790560.00	1560480.00
16.00	16.00	84.00	86.88	132.00	28600.82	0.07	1914.03	2275.00	894720.00	1685280.00
18.00	7.00	93.00	89.56	122.00	26434.09	0.07	1877.08	1968.00	971040.00	1865760.00
20.00	1.00	99.00	91.35	197.00	42684.56	0.05	1571.63	3360.00	1092000.00	2063040.00
							16588.29			15277920.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	94.00	20367.25	0.15	1543.71	1297.00	622560.00	622560.00
4.00	70.00	30.00	70.76	96.00	20800.60	0.08	1560.13	1354.00	649920.00	1272480.00
8.00	51.00	49.00	76.43	98.00	21233.94	0.14	3026.65	1450.00	696000.00	2691840.00
10.00	42.00	58.00	79.12	101.00	21883.96	0.07	1470.63	1548.00	743040.00	1439040.00
12.00	33.00	67.00	81.80	115.00	24917.38	0.07	1596.26	1780.00	696000.00	1439040.00
14.00	25.00	75.00	84.19	122.00	26434.09	0.06	1556.85	2010.00	743040.00	1439040.00
16.00	17.00	83.00	86.58	122.00	26434.09	0.06	1602.83	1942.00	854400.00	1597440.00
18.00	8.00	92.00	89.26	110.00	23834.02	0.07	1714.50	1727.00	964800.00	1819200.00
20.00	0.00	100.00	91.65	190.00	41167.85	0.06	1970.69	3342.00	932160.00	1896960.00
							16042.24			14217600.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	82.00	18.00	67.18	115.00	24917.38	0.14	1699.72	1879.00	901920.00	901920.00
4.00	71.00	29.00	70.46	127.00	27517.46	0.08	2185.82	2079.00	997920.00	1899840.00
8.00	52.00	48.00	76.13	156.00	33800.97	0.14	4415.17	2628.00	1261440.00	4518720.00
10.00	43.00	57.00	78.82	154.00	33367.63	0.07	2290.93	2692.00	1292160.00	2553600.00
12.00	35.00	65.00	81.21	166.00	35967.70	0.06	2102.07	2924.00	1261440.00	2553600.00
14.00	28.00	72.00	83.29	151.00	32717.61	0.05	1822.07	2588.00	1292160.00	2553600.00
16.00	19.00	81.00	85.98	161.00	34884.34	0.07	2305.71	2755.00	1403520.00	2695680.00

18.00	11.00	89.00	88.37	132.00	28600.82	0.06	1924.71	2172.00	1242240.00	2645760.00
20.00	2.00	98.00	91.05	142.00	30767.55	0.07	2024.88	2513.00	1322400.00	2564640.00
							20771.08			22887360.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	94.00	20367.25	0.14	1466.52	1220.00	585600.00	585600.00
4.00	70.00	30.00	70.76	98.00	21233.94	0.08	1734.21	1380.00	662400.00	1248000.00
8.00	51.00	49.00	76.43	108.00	23400.67	0.14	3213.87	1627.00	780960.00	2886720.00
10.00	42.00	58.00	79.12	98.00	21233.94	0.07	1522.36	1448.00	695040.00	1476000.00
12.00	34.00	66.00	81.50	106.00	22967.33	0.06	1340.07	1597.00	780960.00	1476000.00
14.00	26.00	74.00	83.89	108.00	23400.67	0.06	1405.76	1736.00	695040.00	1476000.00
16.00	17.00	83.00	86.58	108.00	23400.67	0.07	1596.26	1639.00	766560.00	1461600.00
18.00	8.00	92.00	89.26	101.00	21883.96	0.07	1544.53	1503.00	833280.00	1599840.00
20.00	0.00	100.00	91.65	180.00	39001.12	0.06	1845.88	3328.00	786720.00	1620000.00
							15669.45			13829760.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	101.00	21883.96	0.14	1575.73	1380.00	662400.00	662400.00
4.00	70.00	30.00	70.76	98.00	21233.94	0.08	1797.43	1309.00	628320.00	1290720.00
8.00	51.00	49.00	76.43	106.00	22967.33	0.14	3182.66	1574.00	755520.00	2767680.00
10.00	43.00	57.00	78.82	108.00	23400.67	0.06	1405.76	1574.00	755520.00	1511040.00
12.00	34.00	66.00	81.50	113.00	24484.04	0.07	1633.21	1736.00	755520.00	1511040.00
14.00	26.00	74.00	83.89	127.00	27517.46	0.06	1576.55	2119.00	755520.00	1511040.00
16.00	17.00	83.00	86.58	130.00	28167.48	0.07	1899.25	2136.00	833280.00	1588800.00
18.00	8.00	92.00	89.26	113.00	24484.04	0.07	1795.79	1765.00	1017120.00	1850400.00
20.00	1.00	99.00	91.35	185.00	40084.49	0.05	1712.86	3350.00	1025280.00	2042400.00
							16579.25			14735520.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								

0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	85.00	15.00	66.29	118.00	25567.40	0.11	1453.38	1745.00	837600.00	837600.00
4.00	74.00	26.00	69.57	108.00	23400.67	0.08	2041.31	1516.00	727680.00	1565280.00
8.00	54.00	46.00	75.54	125.00	27084.11	0.15	3826.42	2064.00	990720.00	3436800.00
10.00	45.00	55.00	78.22	134.00	29034.17	0.07	1914.03	2170.00	1041600.00	2032320.00
12.00	37.00	63.00	80.61	137.00	29684.19	0.06	1780.19	2321.00	990720.00	2032320.00
14.00	29.00	71.00	83.00	154.00	33367.63	0.06	1911.57	2649.00	1041600.00	2032320.00
16.00	20.00	80.00	85.68	144.00	31200.90	0.07	2202.25	2457.00	1114080.00	2155680.00
18.00	12.00	88.00	88.07	161.00	34884.34	0.06	2003.54	2808.00	1271520.00	2385600.00
20.00	6.00	94.00	89.86	180.00	39001.12	0.05	1680.01	3121.00	1179360.00	2450880.00
							18812.70			18928800.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	103.00	22317.31	0.14	1606.93	1486.00	713280.00	713280.00
4.00	70.00	30.00	70.76	103.00	22317.31	0.08	1860.66	1506.00	722880.00	1436160.00
8.00	51.00	49.00	76.43	101.00	21883.96	0.14	3182.66	1503.00	721440.00	2888640.00
10.00	42.00	58.00	79.12	120.00	26000.75	0.07	1633.21	1881.00	902880.00	1624320.00
12.00	33.00	67.00	81.80	110.00	23834.02	0.07	1699.72	1735.00	721440.00	1624320.00
14.00	25.00	75.00	84.19	122.00	26434.09	0.06	1524.00	1993.00	902880.00	1624320.00
16.00	17.00	83.00	86.58	134.00	29034.17	0.06	1681.66	2219.00	832800.00	1735680.00
18.00	8.00	92.00	89.26	142.00	30767.55	0.07	2039.66	2295.00	956640.00	1789440.00
20.00	1.00	99.00	91.35	192.00	41601.20	0.05	1919.78	3315.00	1065120.00	2021760.00
							17148.29			15457920.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	106.00	22967.33	0.15	1740.78	1413.00	678240.00	678240.00
4.00	69.00	31.00	71.06	108.00	23400.67	0.08	1932.92	1577.00	756960.00	1435200.00
8.00	50.00	50.00	76.73	110.00	23834.02	0.14	3401.08	1596.00	766080.00	3046080.00
10.00	41.00	59.00	79.42	118.00	25567.40	0.07	1684.94	1766.00	847680.00	1613760.00
12.00	33.00	67.00	81.80	130.00	28167.48	0.06	1629.10	2041.00	766080.00	1613760.00

14.00	25.00	75.00	84.19	139.00	30117.53	0.06	1767.05	2300.00	847680.00	1613760.00
16.00	16.00	84.00	86.88	151.00	32717.61	0.07	2143.13	2543.00	979680.00	1827360.00
18.00	7.00	93.00	89.56	142.00	30767.55	0.07	2165.30	2416.00	1104000.00	2083680.00
20.00	1.00	99.00	91.35	194.00	42034.54	0.05	1655.38	3386.00	1220640.00	2324640.00
							18119.68			16236480.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	122.00	26434.09	0.14	1903.36	1844.00	885120.00	885120.00
4.00	70.00	30.00	70.76	120.00	26000.75	0.08	2185.82	1940.00	931200.00	1816320.00
8.00	51.00	49.00	76.43	144.00	31200.90	0.14	4118.74	2439.00	1170720.00	4203840.00
10.00	43.00	57.00	78.82	161.00	34884.34	0.06	2003.54	2788.00	1338240.00	2508960.00
12.00	34.00	66.00	81.50	149.00	32284.26	0.07	2290.93	2522.00	1170720.00	2508960.00
14.00	28.00	72.00	83.29	170.00	36834.39	0.05	1571.63	3004.00	1338240.00	2508960.00
16.00	22.00	78.00	85.09	170.00	36834.39	0.05	1675.09	3015.00	1210560.00	2548800.00
18.00	14.00	86.00	87.47	158.00	34234.32	0.06	2154.62	2712.00	1441920.00	2652480.00
20.00	6.00	94.00	89.86	168.00	36401.05	0.06	2141.48	2855.00	1447200.00	2889120.00
							20045.20			22522560.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	106.00	22967.33	0.16	1827.82	1475.00	708000.00	708000.00
4.00	68.00	32.00	71.36	110.00	23834.02	0.08	1950.98	1619.00	777120.00	1485120.00
8.00	50.00	50.00	76.73	113.00	24484.04	0.14	3295.98	1599.00	767520.00	3089280.00
10.00	41.00	59.00	79.42	110.00	23834.02	0.07	1647.99	1718.00	824640.00	1592160.00
12.00	32.00	68.00	82.10	122.00	26434.09	0.07	1714.50	1872.00	767520.00	1592160.00
14.00	24.00	76.00	84.49	122.00	26434.09	0.06	1602.83	1899.00	824640.00	1592160.00
16.00	16.00	84.00	86.88	130.00	28167.48	0.06	1655.38	2046.00	898560.00	1723200.00
18.00	7.00	93.00	89.56	132.00	28600.82	0.07	1936.20	2124.00	911520.00	1810080.00
20.00	0.00	100.00	91.65	197.00	42684.56	0.05	1891.04	3383.00	982080.00	1893600.00
							17522.72			15485760.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	115.00	24917.38	0.15	1888.58	1833.00	879840.00	879840.00
4.00	70.00	30.00	70.76	122.00	26434.09	0.08	1946.06	1962.00	941760.00	1821600.00
8.00	51.00	49.00	76.43	144.00	31200.90	0.14	4149.95	2404.00	1153920.00	4191360.00
10.00	42.00	58.00	79.12	156.00	33800.97	0.07	2217.03	2639.00	1266720.00	2420640.00
12.00	34.00	66.00	81.50	168.00	36401.05	0.06	2128.35	2946.00	1153920.00	2420640.00
14.00	28.00	72.00	83.29	175.00	37917.76	0.05	1689.87	3100.00	1266720.00	2420640.00
16.00	23.00	77.00	84.79	178.00	38567.78	0.04	1449.28	3095.00	1414080.00	2680800.00
18.00	17.00	83.00	86.58	168.00	36401.05	0.05	1704.65	2901.00	1488000.00	2902080.00
20.00	9.00	91.00	88.96	163.00	35317.68	0.06	2174.33	2692.00	1485600.00	2973600.00
							19348.07			22711200.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	86.00	18633.87	0.14	1341.71	994.00	477120.00	477120.00
4.00	70.00	30.00	70.76	89.00	19283.89	0.08	1580.66	998.00	479040.00	956160.00
8.00	51.00	49.00	76.43	86.00	18633.87	0.14	2730.23	1011.00	485280.00	1928640.00
10.00	42.00	58.00	79.12	84.00	18200.52	0.07	1256.32	1034.00	496320.00	981600.00
12.00	34.00	66.00	81.50	89.00	19283.89	0.06	1136.43	1054.00	485280.00	981600.00
14.00	25.00	75.00	84.19	91.00	19717.23	0.07	1330.22	1115.00	496320.00	981600.00
16.00	17.00	83.00	86.58	91.00	19717.23	0.06	1195.55	1180.00	505920.00	1002240.00
18.00	8.00	92.00	89.26	98.00	21233.94	0.07	1396.73	1428.00	535200.00	1041120.00
20.00	0.00	100.00	91.65	187.00	40517.83	0.06	1872.16	3358.00	566400.00	1101600.00
							13839.99			9451680.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	118.00	25567.40	0.14	1840.95	1789.00	858720.00	858720.00
4.00	71.00	29.00	70.46	118.00	25567.40	0.08	1937.85	1821.00	874080.00	1732800.00
8.00	52.00	48.00	76.13	137.00	29684.19	0.14	3978.33	2210.00	1060800.00	3869760.00

10.00	43.00	57.00	78.82	142.00	30767.55	0.07	2061.83	2426.00	1164480.00	2225280.00
12.00	35.00	65.00	81.21	139.00	30117.53	0.06	1845.88	2368.00	1060800.00	2225280.00
14.00	26.00	74.00	83.89	144.00	31200.90	0.07	2091.40	2429.00	1164480.00	2225280.00
16.00	18.00	82.00	86.28	158.00	34234.32	0.06	1983.83	2674.00	1136640.00	2301120.00
18.00	9.00	91.00	88.96	168.00	36401.05	0.07	2409.17	2793.00	1165920.00	2302560.00
20.00	2.00	98.00	91.05	180.00	39001.12	0.05	2000.25	3025.00	1283520.00	2449440.00
							20149.49			20190240.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	106.00	22967.33	0.14	1653.74	1458.00	699840.00	699840.00
4.00	70.00	30.00	70.76	106.00	22967.33	0.08	1914.85	1486.00	713280.00	1413120.00
8.00	51.00	49.00	76.43	108.00	23400.67	0.14	3338.68	1569.00	753120.00	2932800.00
10.00	42.00	58.00	79.12	108.00	23400.67	0.07	1596.26	1642.00	788160.00	1541280.00
12.00	34.00	66.00	81.50	142.00	30767.55	0.06	1642.24	2305.00	753120.00	1541280.00
14.00	25.00	75.00	84.19	134.00	29034.17	0.07	2039.66	2175.00	788160.00	1541280.00
16.00	17.00	83.00	86.58	144.00	31200.90	0.06	1826.17	2412.00	1106400.00	1894560.00
18.00	8.00	92.00	89.26	142.00	30767.55	0.07	2113.57	2195.00	1044000.00	2150400.00
20.00	2.00	98.00	91.05	197.00	42684.56	0.05	1670.16	3380.00	1157760.00	2201760.00
							17795.33			15916320.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	115.00	24917.38	0.15	1888.58	1778.00	853440.00	853440.00
4.00	70.00	30.00	70.76	120.00	26000.75	0.08	1929.63	1794.00	861120.00	1714560.00
8.00	51.00	49.00	76.43	137.00	29684.19	0.14	4009.53	2293.00	1100640.00	3923520.00
10.00	42.00	58.00	79.12	154.00	33367.63	0.07	2150.52	2560.00	1228800.00	2329440.00
12.00	34.00	66.00	81.50	158.00	34234.32	0.06	2049.52	2760.00	1100640.00	2329440.00
14.00	26.00	74.00	83.89	151.00	32717.61	0.06	2029.81	2510.00	1228800.00	2329440.00
16.00	17.00	83.00	86.58	161.00	34884.34	0.07	2305.71	2689.00	1324800.00	2553600.00
18.00	9.00	91.00	88.96	170.00	36834.39	0.06	2174.33	2860.00	1204800.00	2529600.00
20.00	3.00	97.00	90.75	197.00	42684.56	0.05	1808.11	3367.00	1290720.00	2495520.00

							Energy(J)			Energy(J)
							20345.73			21058560.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	103.00	22317.31	0.14	1606.93	1395.00	669600.00	669600.00
4.00	70.00	30.00	70.76	101.00	21883.96	0.08	1842.60	1408.00	675840.00	1345440.00
8.00	51.00	49.00	76.43	110.00	23834.02	0.14	3291.87	1579.00	757920.00	2867520.00
10.00	42.00	58.00	79.12	118.00	25567.40	0.07	1684.94	1733.00	831840.00	1589760.00
12.00	33.00	67.00	81.80	122.00	26434.09	0.07	1773.62	1894.00	757920.00	1589760.00
14.00	25.00	75.00	84.19	134.00	29034.17	0.06	1681.66	2170.00	831840.00	1589760.00
16.00	17.00	83.00	86.58	142.00	30767.55	0.06	1813.04	2288.00	909120.00	1740960.00
18.00	9.00	91.00	88.96	173.00	37484.41	0.06	2069.22	3007.00	1041600.00	1950720.00
20.00	2.00	98.00	91.05	178.00	38567.78	0.05	2017.49	2918.00	1098240.00	2139840.00
							17781.37			15483360.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	82.00	17767.18	0.14	1279.31	844.00	405120.00	405120.00
4.00	70.00	30.00	70.76	86.00	18633.87	0.08	1517.43	923.00	443040.00	848160.00
8.00	51.00	49.00	76.43	89.00	19283.89	0.14	2730.23	1061.00	509280.00	1904640.00
10.00	43.00	57.00	78.82	76.00	16467.14	0.06	1083.88	1231.00	590880.00	1100160.00
12.00	34.00	66.00	81.50	98.00	21233.94	0.07	1285.88	1430.00	509280.00	1100160.00
14.00	26.00	74.00	83.89	103.00	22317.31	0.06	1320.36	1443.00	590880.00	1100160.00
16.00	17.00	83.00	86.58	103.00	22317.31	0.07	1522.36	1488.00	686400.00	1277280.00
18.00	8.00	92.00	89.26	127.00	27517.46	0.07	1699.72	2091.00	692640.00	1379040.00
20.00	0.00	100.00	91.65	173.00	37484.41	0.06	1970.69	3214.00	714240.00	1406880.00
							14409.85			10521600.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	127.00	27517.46	0.14	1981.36	2104.00	1009920.00	1009920.00

4.00	70.00	30.00	70.76	130.00	28167.48	0.08	2321.31	2053.00	985440.00	1995360.00
8.00	52.00	48.00	76.13	142.00	30767.55	0.14	4020.21	2368.00	1136640.00	4244160.00
10.00	43.00	57.00	78.82	156.00	33800.97	0.07	2202.25	2629.00	1261920.00	2398560.00
12.00	35.00	65.00	81.21	170.00	36834.39	0.06	2141.48	2863.00	1136640.00	2398560.00
14.00	27.00	73.00	83.59	170.00	36834.39	0.06	2233.45	2865.00	1261920.00	2398560.00
16.00	20.00	80.00	85.68	168.00	36401.05	0.05	1942.77	2923.00	1374240.00	2636160.00
18.00	13.00	87.00	87.77	170.00	36834.39	0.05	1942.77	2908.00	1375200.00	2749440.00
20.00	6.00	94.00	89.86	185.00	40084.49	0.05	2040.49	3159.00	1403040.00	2778240.00
							20826.09			22608960.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	110.00	23834.02	0.16	1896.79	1617.00	776160.00	776160.00
4.00	69.00	31.00	71.06	106.00	22967.33	0.08	1773.62	1518.00	728640.00	1504800.00
8.00	50.00	50.00	76.73	120.00	26000.75	0.14	3525.89	1899.00	911520.00	3280320.00
10.00	41.00	59.00	79.42	108.00	23400.67	0.07	1684.94	1654.00	793920.00	1705440.00
12.00	33.00	67.00	81.80	127.00	27517.46	0.06	1543.71	2033.00	911520.00	1705440.00
14.00	24.00	76.00	84.49	127.00	27517.46	0.07	1877.08	2018.00	793920.00	1705440.00
16.00	16.00	84.00	86.88	132.00	28600.82	0.06	1701.36	2179.00	975840.00	1769760.00
18.00	7.00	93.00	89.56	158.00	34234.32	0.07	2143.13	2765.00	968640.00	1944480.00
20.00	1.00	99.00	91.35	197.00	42684.56	0.05	1748.99	3383.00	1045920.00	2014560.00
							17895.51			16406400.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	77.00	23.00	68.67	98.00	21233.94	0.17	1850.81	1213.00	582240.00	582240.00
4.00	67.00	33.00	71.66	101.00	21883.96	0.08	1634.03	1493.00	716640.00	1298880.00
8.00	48.00	52.00	77.33	120.00	26000.75	0.14	3447.89	1823.00	875040.00	3183360.00
10.00	39.00	61.00	80.01	180.00	39001.12	0.07	2217.03	1529.00	733920.00	1608960.00
12.00	31.00	69.00	82.40	139.00	30117.53	0.06	2095.50	2209.00	875040.00	1608960.00
14.00	23.00	77.00	84.79	161.00	34884.34	0.06	1970.69	2711.00	733920.00	1608960.00
16.00	14.00	86.00	87.47	130.00	28167.48	0.07	2150.52	2048.00	1060320.00	1794240.00

18.00	5.00	95.00	90.16	122.00	26434.09	0.07	1862.30	2116.00	1301280.00	2361600.00
20.00	1.00	99.00	91.35	194.00	42034.54	0.03	1037.90	3270.00	983040.00	2284320.00
							18266.66			16331520.00

61

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	77.00	23.00	68.67	96.00	20800.60	0.17	1813.04	1259.00	604320.00	604320.00
4.00	67.00	33.00	71.66	98.00	21233.94	0.08	1592.97	1360.00	652800.00	1257120.00
8.00	48.00	52.00	77.33	110.00	23834.02	0.14	3245.07	1680.00	806400.00	2918400.00
10.00	40.00	60.00	79.71	106.00	22967.33	0.06	1418.90	1450.00	696000.00	1502400.00
12.00	31.00	69.00	82.40	130.00	28167.48	0.07	1744.06	2040.00	806400.00	1502400.00
14.00	23.00	77.00	84.79	118.00	25567.40	0.06	1629.10	1819.00	696000.00	1502400.00
16.00	14.00	86.00	87.47	115.00	24917.38	0.07	1721.89	1794.00	979200.00	1675200.00
18.00	5.00	95.00	90.16	106.00	22967.33	0.07	1633.21	1523.00	873120.00	1852320.00
20.00	0.00	100.00	91.65	199.00	43117.91	0.04	1252.21	3375.00	861120.00	1734240.00
							16050.45			14548800.00

62

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	118.00	25567.40	0.14	1840.95	1740.00	835200.00	835200.00
4.00	70.00	30.00	70.76	122.00	26434.09	0.08	2167.76	1904.00	913920.00	1749120.00
8.00	52.00	48.00	76.13	134.00	29034.17	0.14	3783.73	2260.00	1084800.00	3997440.00
10.00	43.00	57.00	78.82	132.00	28600.82	0.07	1965.76	2185.00	1048800.00	2133600.00
12.00	35.00	65.00	81.21	130.00	28167.48	0.06	1721.07	2103.00	1084800.00	2133600.00
14.00	26.00	74.00	83.89	127.00	27517.46	0.07	1899.25	1947.00	1048800.00	2133600.00
16.00	18.00	82.00	86.28	132.00	28600.82	0.06	1701.36	2152.00	1009440.00	2058240.00
18.00	10.00	90.00	88.67	130.00	28167.48	0.06	1721.07	1997.00	934560.00	1944000.00
20.00	1.00	99.00	91.35	173.00	37484.41	0.07	2239.20	2802.00	1032960.00	1967520.00
							19040.15			18952320.00

63

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								

0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	84.00	18200.52	0.16	1448.46	1064.00	510720.00	510720.00
4.00	68.00	32.00	71.36	96.00	20800.60	0.08	1625.82	1269.00	609120.00	1119840.00
8.00	50.00	50.00	76.73	106.00	22967.33	0.14	2985.60	1425.00	684000.00	2586240.00
10.00	41.00	59.00	79.42	98.00	21233.94	0.07	1507.58	1359.00	652320.00	1336320.00
12.00	32.00	68.00	82.10	108.00	23400.67	0.07	1522.36	1609.00	684000.00	1336320.00
14.00	24.00	76.00	84.49	115.00	24917.38	0.06	1464.88	1859.00	652320.00	1336320.00
16.00	16.00	84.00	86.88	132.00	28600.82	0.06	1622.53	2073.00	772320.00	1424640.00
18.00	6.00	94.00	89.86	101.00	21883.96	0.08	1913.21	1430.00	892320.00	1664640.00
20.00	0.00	100.00	91.65	199.00	43117.91	0.05	1478.02	3385.00	995040.00	1887360.00
							15568.45			13202400.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	84.00	18200.52	0.16	1448.46	1558.00	747840.00	747840.00
4.00	68.00	32.00	71.36	96.00	20800.60	0.08	1625.82	1442.00	692160.00	1440000.00
8.00	50.00	50.00	76.73	106.00	22967.33	0.14	2985.60	1703.00	817440.00	3019200.00
10.00	41.00	59.00	79.42	98.00	21233.94	0.07	1507.58	1753.00	841440.00	1658880.00
12.00	32.00	68.00	82.10	108.00	23400.67	0.07	1522.36	2058.00	817440.00	1658880.00
14.00	24.00	76.00	84.49	115.00	24917.38	0.06	1464.88	2866.00	841440.00	1658880.00
16.00	16.00	84.00	86.88	132.00	28600.82	0.06	1622.53	3010.00	987840.00	1829280.00
18.00	6.00	94.00	89.86	101.00	21883.96	0.08	1913.21	3004.00	1375680.00	2363520.00
20.00	0.00	100.00	91.65	199.00	43117.91	0.05	1478.02	1924.00	1444800.00	2820480.00
							15568.45			17196960.00

65

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	101.00	21883.96	0.15	1658.66	1413.00	678240.00	678240.00
4.00	70.00	30.00	70.76	110.00	23834.02	0.08	1732.57	1688.00	810240.00	1488480.00
8.00	51.00	49.00	76.43	134.00	29034.17	0.14	3806.72	2154.00	1033920.00	3688320.00
10.00	42.00	58.00	79.12	137.00	29684.19	0.07	2002.71	2242.00	1076160.00	2110080.00
12.00	34.00	66.00	81.50	130.00	28167.48	0.06	1753.91	2089.00	1033920.00	2110080.00

14.00	35.00	65.00	81.21	158.00	34234.32	-0.01	-236.48	2686.00	1076160.00	2110080.00
16.00	17.00	83.00	86.58	161.00	34884.34	0.14	4714.88	2777.00	1002720.00	2078880.00
18.00	8.00	92.00	89.26	125.00	27084.11	0.07	2113.57	1929.00	1289280.00	2292000.00
20.00	0.00	100.00	91.65	190.00	41167.85	0.06	2069.22	3219.00	1332960.00	2622240.00
							19615.76			19178400.00

66

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	94.00	20367.25	0.15	1543.71	1208.00	579840.00	579840.00
4.00	69.00	31.00	71.06	98.00	21233.94	0.08	1734.21	1279.00	613920.00	1193760.00
8.00	50.00	50.00	76.73	101.00	21883.96	0.14	3104.66	1430.00	686400.00	2600640.00
10.00	42.00	58.00	79.12	98.00	21233.94	0.06	1307.22	1418.00	680640.00	1367040.00
12.00	33.00	67.00	81.80	101.00	21883.96	0.07	1470.63	1508.00	686400.00	1367040.00
14.00	24.00	76.00	84.49	115.00	24917.38	0.07	1596.26	1770.00	680640.00	1367040.00
16.00	16.00	84.00	86.88	118.00	25567.40	0.06	1530.57	1857.00	723840.00	1404480.00
18.00	7.00	93.00	89.56	113.00	24484.04	0.07	1707.11	1647.00	849600.00	1573440.00
20.00	0.00	100.00	91.65	204.00	44201.27	0.05	1822.07	3390.00	891360.00	1740960.00
							15816.43			13194240.00

67

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	108.00	23400.67	0.16	1862.30	1594.00	765120.00	765120.00
4.00	69.00	31.00	71.06	113.00	24484.04	0.08	1814.68	1727.00	828960.00	1594080.00
8.00	50.00	50.00	76.73	127.00	27517.46	0.14	3744.31	2063.00	990240.00	3638400.00
10.00	42.00	58.00	79.12	149.00	32284.26	0.06	1813.04	2537.00	1217760.00	2208000.00
12.00	34.00	66.00	81.50	175.00	37917.76	0.06	2128.35	3009.00	990240.00	2208000.00
14.00	27.00	73.00	83.59	166.00	35967.70	0.05	1960.02	2858.00	1217760.00	2208000.00
16.00	20.00	80.00	85.68	173.00	37484.41	0.05	1948.52	2833.00	1444320.00	2662080.00
18.00	12.00	88.00	88.07	149.00	32284.26	0.06	2115.21	2378.00	1371840.00	2816160.00
20.00	3.00	97.00	90.75	146.00	31634.24	0.07	2180.08	2474.00	1359840.00	2731680.00
							19566.49			20831520.00

68

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	76.00	24.00	68.97	118.00	25567.40	0.18	2325.41	1823.00	875040.00	875040.00
4.00	66.00	34.00	71.96	118.00	25567.40	0.08	1937.85	1823.00	875040.00	1750080.00
8.00	47.00	53.00	77.63	134.00	29034.17	0.14	3931.53	2197.00	1054560.00	3859200.00
10.00	39.00	61.00	80.01	139.00	30117.53	0.06	1793.33	2277.00	1092960.00	2147520.00
12.00	30.00	70.00	82.70	154.00	33367.63	0.07	2165.30	2649.00	1054560.00	2147520.00
14.00	23.00	77.00	84.79	170.00	36834.39	0.05	1862.30	2923.00	1092960.00	2147520.00
16.00	15.00	85.00	87.17	161.00	34884.34	0.06	2174.33	2745.00	1271520.00	2364480.00
18.00	7.00	93.00	89.56	180.00	39001.12	0.06	2240.02	3025.00	1403040.00	2674560.00
20.00	4.00	96.00	90.46	197.00	42684.56	0.02	928.69	3381.00	1317600.00	2720640.00
							19358.75			20686560.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	77.00	23.00	68.67	98.00	21233.94	0.17	1850.81	1362.00	653760.00	653760.00
4.00	67.00	33.00	71.66	103.00	22317.31	0.08	1650.45	1558.00	747840.00	1401600.00
8.00	48.00	52.00	77.33	108.00	23400.67	0.14	3291.87	1524.00	731520.00	2958720.00
10.00	40.00	60.00	79.71	125.00	27084.11	0.06	1530.57	2081.00	998880.00	1730400.00
12.00	31.00	69.00	82.40	142.00	30767.55	0.07	1973.15	2298.00	731520.00	1730400.00
14.00	23.00	77.00	84.79	144.00	31200.90	0.06	1878.72	2407.00	998880.00	1730400.00
16.00	14.00	86.00	87.47	134.00	29034.17	0.07	2054.44	2275.00	1103040.00	2101920.00
18.00	5.00	95.00	90.16	110.00	23834.02	0.07	1803.18	1630.00	1155360.00	2258400.00
20.00	0.00	100.00	91.65	202.00	43767.92	0.04	1280.95	3381.00	1092000.00	2247360.00
							17314.16			16812960.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	96.00	20800.60	0.15	1576.55	1182.00	567360.00	567360.00
4.00	70.00	30.00	70.76	96.00	20800.60	0.08	1576.55	1351.00	648480.00	1215840.00
8.00	51.00	49.00	76.43	113.00	24484.04	0.14	3260.67	1677.00	804960.00	2906880.00

10.00	42.00	58.00	79.12	110.00	23834.02	0.07	1647.99	1674.00	803520.00	1608480.00
12.00	33.00	67.00	81.80	113.00	24484.04	0.07	1647.99	1693.00	804960.00	1608480.00
14.00	25.00	75.00	84.19	122.00	26434.09	0.06	1543.71	1917.00	803520.00	1608480.00
16.00	17.00	83.00	86.58	130.00	28167.48	0.06	1655.38	2026.00	812640.00	1616160.00
18.00	8.00	92.00	89.26	120.00	26000.75	0.07	1847.52	1842.00	920160.00	1732800.00
20.00	0.00	100.00	91.65	199.00	43117.91	0.06	2095.50	3381.00	972480.00	1892640.00
							16851.86			14757120.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	98.00	21233.94	0.16	1689.87	1370.00	657600.00	657600.00
4.00	69.00	31.00	71.06	103.00	22317.31	0.08	1650.45	1500.00	720000.00	1377600.00
8.00	50.00	50.00	76.73	113.00	24484.04	0.14	3369.88	1703.00	817440.00	3074880.00
10.00	41.00	59.00	79.42	113.00	24484.04	0.07	1670.16	1685.00	808800.00	1626240.00
12.00	33.00	67.00	81.80	115.00	24917.38	0.06	1497.72	1495.00	817440.00	1626240.00
14.00	24.00	76.00	84.49	115.00	24917.38	0.07	1699.72	1773.00	808800.00	1626240.00
16.00	16.00	84.00	86.88	115.00	24917.38	0.06	1510.86	1780.00	717600.00	1526400.00
18.00	7.00	93.00	89.56	108.00	23400.67	0.07	1647.99	1490.00	851040.00	1568640.00
20.00	0.00	100.00	91.65	199.00	43117.91	0.05	1764.59	3388.00	854400.00	1705440.00
							16501.25			14789280.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	110.00	23834.02	0.14	1716.14	1683.00	807840.00	807840.00
4.00	70.00	30.00	70.76	113.00	24484.04	0.08	2014.21	1828.00	877440.00	1685280.00
8.00	51.00	49.00	76.43	127.00	27517.46	0.14	3744.31	2063.00	990240.00	3735360.00
10.00	42.00	58.00	79.12	139.00	30117.53	0.07	1965.76	2291.00	1099680.00	2089920.00
12.00	34.00	66.00	81.50	137.00	29684.19	0.06	1813.04	2227.00	990240.00	2089920.00
14.00	26.00	74.00	83.89	137.00	29684.19	0.06	1799.90	2238.00	1099680.00	2089920.00
16.00	17.00	83.00	86.58	146.00	31634.24	0.07	2091.40	2378.00	1068960.00	2168640.00
18.00	8.00	92.00	89.26	137.00	29684.19	0.07	2091.40	2265.00	1074240.00	2143200.00
20.00	0.00	100.00	91.65	194.00	42034.54	0.06	2174.33	3168.00	1141440.00	2215680.00

							19410.48			19025760.00

73

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	83.00	17.00	66.88	122.00	26434.09	0.13	1703.00	1833.00	879840.00	879840.00
4.00	72.00	28.00	70.17	122.00	26434.09	0.08	2203.89	1872.00	898560.00	1778400.00
8.00	52.00	48.00	76.13	139.00	30117.53	0.15	4286.25	2262.00	1085760.00	3968640.00
10.00	43.00	57.00	78.82	146.00	31634.24	0.07	2106.18	2507.00	1203360.00	2289120.00
12.00	35.00	65.00	81.21	161.00	34884.34	0.06	2016.67	2684.00	1085760.00	2289120.00
14.00	27.00	73.00	83.59	166.00	35967.70	0.06	2148.05	2770.00	1203360.00	2289120.00
16.00	20.00	80.00	85.68	168.00	36401.05	0.05	1919.78	2858.00	1288320.00	2491680.00
18.00	12.00	88.00	88.07	161.00	34884.34	0.06	2161.19	2765.00	1329600.00	2617920.00
20.00	3.00	97.00	90.75	175.00	37917.76	0.07	2483.07	2936.00	1371840.00	2701440.00
							21028.09			21305280.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	79.00	21.00	68.08	89.00	19283.89	0.16	1534.68	1072.00	514560.00	514560.00
4.00	69.00	31.00	71.06	91.00	19717.23	0.08	1478.02	1173.00	563040.00	1077600.00
8.00	50.00	50.00	76.73	94.00	20367.25	0.14	2886.24	1233.00	591840.00	2309760.00
10.00	41.00	59.00	79.42	103.00	22317.31	0.07	1455.85	1465.00	703200.00	1295040.00
12.00	33.00	67.00	81.80	106.00	22967.33	0.06	1372.91	1577.00	591840.00	1295040.00
14.00	24.00	76.00	84.49	106.00	22967.33	0.07	1566.70	1607.00	703200.00	1295040.00
16.00	16.00	84.00	86.88	113.00	24484.04	0.06	1438.60	1748.00	756960.00	1460160.00
18.00	7.00	93.00	89.56	106.00	22967.33	0.07	1618.43	1582.00	771360.00	1528320.00
20.00	0.00	100.00	91.65	202.00	43767.92	0.05	1770.34	3391.00	839040.00	1610400.00
							15121.76			12385920.00

75

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	91.00	19717.23	0.15	1494.44	1064.00	510720.00	510720.00

4.00	69.00	31.00	71.06	98.00	21233.94	0.08	1707.11	1297.00	622560.00	1133280.00
8.00	50.00	50.00	76.73	98.00	21233.94	0.14	3057.85	1297.00	622560.00	2490240.00
10.00	42.00	58.00	79.12	101.00	21883.96	0.06	1307.22	1445.00	693600.00	1316160.00
12.00	33.00	67.00	81.80	118.00	25567.40	0.07	1618.43	1828.00	622560.00	1316160.00
14.00	25.00	75.00	84.19	110.00	23834.02	0.06	1497.72	1695.00	693600.00	1316160.00
16.00	16.00	84.00	86.88	115.00	24917.38	0.07	1662.77	1856.00	877440.00	1571040.00
18.00	7.00	93.00	89.56	115.00	24917.38	0.07	1699.72	1652.00	813600.00	1691040.00
20.00	0.00	100.00	91.65	197.00	42684.56	0.05	1793.33	3391.00	890880.00	1704480.00
							15838.60			13049280.00

76

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	113.00	24484.04	0.14	1762.95	1723.00	827040.00	827040.00
4.00	70.00	30.00	70.76	115.00	24917.38	0.08	2059.37	1766.00	847680.00	1674720.00
8.00	51.00	49.00	76.43	122.00	26434.09	0.14	3697.51	1977.00	948960.00	3593280.00
10.00	42.00	58.00	79.12	137.00	29684.19	0.07	1914.03	2288.00	1098240.00	2047200.00
12.00	34.00	66.00	81.50	149.00	32284.26	0.06	1878.72	2472.00	948960.00	2047200.00
14.00	25.00	75.00	84.19	142.00	30767.55	0.07	2150.52	2358.00	1098240.00	2047200.00
16.00	17.00	83.00	86.58	146.00	31634.24	0.06	1891.86	2528.00	1186560.00	2284800.00
18.00	8.00	92.00	89.26	154.00	33367.63	0.07	2217.03	2634.00	1131840.00	2318400.00
20.00	1.00	99.00	91.35	175.00	37917.76	0.05	1891.04	3206.00	1213440.00	2345280.00
							19463.03			19185120.00

77

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	94.00	20367.25	0.15	1543.71	1178.00	565440.00	565440.00
4.00	69.00	31.00	71.06	101.00	21883.96	0.08	1761.30	1351.00	648480.00	1213920.00
8.00	51.00	49.00	76.43	113.00	24484.04	0.14	3162.96	1746.00	838080.00	2973120.00
10.00	42.00	58.00	79.12	113.00	24484.04	0.07	1670.16	1723.00	827040.00	1665120.00
12.00	33.00	67.00	81.80	127.00	27517.46	0.07	1773.62	2046.00	838080.00	1665120.00
14.00	25.00	75.00	84.19	144.00	31200.90	0.06	1780.19	2356.00	827040.00	1665120.00
16.00	17.00	83.00	86.58	130.00	28167.48	0.06	1799.90	2116.00	982080.00	1809120.00

18.00	8.00	92.00	89.26	118.00	25567.40	0.07	1832.74	1864.00	1130880.00	2112960.00
20.00	0.00	100.00	91.65	199.00	43117.91	0.06	2082.36	3388.00	1015680.00	2146560.00
							17406.94			15816480.00

78

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	101.00	21883.96	0.14	1575.73	1254.00	601920.00	601920.00
4.00	70.00	30.00	70.76	98.00	21233.94	0.08	1797.43	1397.00	670560.00	1272480.00
8.00	51.00	49.00	76.43	115.00	24917.38	0.14	3323.08	1794.00	861120.00	3063360.00
10.00	43.00	57.00	78.82	115.00	24917.38	0.06	1510.86	1690.00	811200.00	1672320.00
12.00	34.00	66.00	81.50	132.00	28600.82	0.07	1825.35	2083.00	861120.00	1672320.00
14.00	26.00	74.00	83.89	122.00	26434.09	0.06	1668.52	2011.00	811200.00	1672320.00
16.00	17.00	83.00	86.58	139.00	30117.53	0.07	1928.81	2277.00	999840.00	1811040.00
18.00	8.00	92.00	89.26	113.00	24484.04	0.07	1862.30	1733.00	965280.00	1965120.00
20.00	0.00	100.00	91.65	175.00	37917.76	0.06	1891.86	3294.00	1092960.00	2058240.00
							17383.95			15789120.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	91.00	19717.23	0.15	1494.44	1074.00	515520.00	515520.00
4.00	70.00	30.00	70.76	96.00	20800.60	0.08	1535.50	1251.00	600480.00	1116000.00
8.00	51.00	49.00	76.43	101.00	21883.96	0.14	3073.46	1380.00	662400.00	2525760.00
10.00	42.00	58.00	79.12	103.00	22317.31	0.07	1507.58	1523.00	731040.00	1393440.00
12.00	33.00	67.00	81.80	108.00	23400.67	0.07	1559.31	1564.00	662400.00	1393440.00
14.00	25.00	75.00	84.19	110.00	23834.02	0.06	1432.03	1657.00	731040.00	1393440.00
16.00	16.00	84.00	86.88	110.00	23834.02	0.07	1625.82	1751.00	750720.00	1481760.00
18.00	7.00	93.00	89.56	106.00	22967.33	0.07	1596.26	1657.00	795360.00	1546080.00
20.00	0.00	100.00	91.65	194.00	42034.54	0.05	1724.35	3390.00	840480.00	1635840.00
							15548.75			13001280.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								

0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	84.00	16.00	66.58	98.00	21233.94	0.12	1287.52	1334.00	640320.00	640320.00
4.00	73.00	27.00	69.87	96.00	20800.60	0.08	1752.27	1289.00	618720.00	1259040.00
8.00	54.00	46.00	75.54	110.00	23834.02	0.14	3213.87	1635.00	784800.00	2807040.00
10.00	45.00	55.00	78.22	103.00	22317.31	0.07	1574.09	1468.00	704640.00	1489440.00
12.00	36.00	64.00	80.91	110.00	23834.02	0.07	1574.09	1722.00	784800.00	1489440.00
14.00	28.00	72.00	83.29	113.00	24484.04	0.06	1464.88	1773.00	704640.00	1489440.00
16.00	20.00	80.00	85.68	137.00	29684.19	0.06	1642.24	2305.00	826560.00	1531200.00
18.00	11.00	89.00	88.37	158.00	34234.32	0.07	2180.08	2772.00	851040.00	1677600.00
20.00	3.00	97.00	90.75	166.00	35967.70	0.06	2128.35	2881.00	1106400.00	1957440.00
							16817.38			14340960.00

81

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	75.00	25.00	69.27	137.00	29684.19	0.19	2812.34	2270.00	1089600.00	1089600.00
4.00	65.00	35.00	72.25	139.00	30117.53	0.08	2266.29	2288.00	1098240.00	2187840.00
8.00	47.00	53.00	77.63	166.00	35967.70	0.14	4507.95	2896.00	1390080.00	2488320.00
10.00	41.00	59.00	79.42	175.00	37917.76	0.05	1680.01	3120.00	1390080.00	2780160.00
12.00	37.00	63.00	80.61	180.00	39001.12	0.03	1165.99	3227.00	1497600.00	2887680.00
14.00	33.00	67.00	81.80	180.00	39001.12	0.03	1182.41	3166.00	1548960.00	3046560.00
16.00	29.00	71.00	83.00	175.00	37917.76	0.03	1165.99	3090.00	1519680.00	3068640.00
18.00	23.00	77.00	84.79	173.00	37484.41	0.05	1714.50	2997.00	1483200.00	3002880.00
20.00	16.00	84.00	86.88	170.00	36834.39	0.03	943.85	2825.00	1438560.00	2921760.00
22.00	7.00	93.00	89.56	149.00	32284.26	0.07	2357.44	2467.00	1356000.00	2794560.00
							19796.79			26268000.00

82

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	75.00	25.00	69.27	125.00	27084.11	0.19	2566.00	2002.00	960960.00	960960.00
4.00	65.00	35.00	72.25	139.00	30117.53	0.08	2167.76	2290.00	1099200.00	2060160.00
8.00	46.00	54.00	77.92	170.00	36834.39	0.14	4820.80	2913.00	1398240.00	2497440.00
10.00	42.00	58.00	79.12	180.00	39001.12	0.03	1149.57	3154.00	1398240.00	2796480.00

12.00	37.00	63.00	80.61	180.00	39001.12	0.04	1478.02	3060.00	1513920.00	2912160.00
14.00	31.00	69.00	82.40	178.00	38567.78	0.05	1763.77	3040.00	1468800.00	2982720.00
16.00	26.00	74.00	83.89	187.00	40517.83	0.04	1498.55	3191.00	1459200.00	2928000.00
18.00	22.00	78.00	85.09	190.00	41167.85	0.03	1238.25	3206.00	1531680.00	2990880.00
20.00	18.00	82.00	86.28	190.00	41167.85	0.03	1045.66	3130.00	1538880.00	3070560.00
22.00	11.00	89.00	88.37	149.00	32284.26	0.05	1948.52	2411.00	1502400.00	3041280.00
							19676.90			26240640.00

83

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	132.00	28600.82	0.15	2167.76	2146.00	1030080.00	1030080.00
4.00	69.00	31.00	71.06	139.00	30117.53	0.08	2447.76	2296.00	1102080.00	2132160.00
8.00	50.00	50.00	76.73	158.00	34234.32	0.14	4633.59	2692.00	1292160.00	2394240.00
10.00	42.00	58.00	79.12	166.00	35967.70	0.06	2128.35	2883.00	1292160.00	2584320.00
12.00	37.00	63.00	80.61	187.00	40517.83	0.04	1449.28	3254.00	1383840.00	2676000.00
14.00	35.00	65.00	81.21	190.00	41167.85	0.02	619.13	3362.00	1561920.00	2945760.00
16.00	33.00	67.00	81.80	190.00	41167.85	0.02	624.05	3256.00	1613760.00	3175680.00
18.00	28.00	72.00	83.29	180.00	39001.12	0.04	1519.07	3043.00	1562880.00	3176640.00
20.00	21.00	79.00	85.38	144.00	31200.90	0.03	891.57	2371.00	1460640.00	3023520.00
22.00	12.00	88.00	88.07	134.00	29034.17	0.07	2054.44	2230.00	1138080.00	2598720.00
							18534.99			25737120.00

84

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	85.00	15.00	66.29	132.00	28600.82	0.11	1625.82	2036.00	977280.00	977280.00
4.00	74.00	26.00	69.57	132.00	28600.82	0.08	2384.54	2217.00	1064160.00	2041440.00
8.00	55.00	45.00	75.24	149.00	32284.26	0.14	4383.96	2479.00	1189920.00	2254080.00
10.00	46.00	54.00	77.92	163.00	35317.68	0.07	2305.71	2802.00	1189920.00	2379840.00
12.00	38.00	62.00	80.31	173.00	37484.41	0.06	2207.17	2971.00	1344960.00	2534880.00
14.00	33.00	67.00	81.80	180.00	39001.12	0.04	1449.28	3145.00	1426080.00	2771040.00
16.00	29.00	71.00	83.00	180.00	39001.12	0.03	1182.41	3136.00	1509600.00	2935680.00
18.00	23.00	77.00	84.79	175.00	37917.76	0.05	1748.99	3000.00	1505280.00	3014880.00

Time(sec)	% Change in piston travel Opened	Closed	Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
20.00	16.00	84.00	86.88	166.00	35967.70	0.03	938.35	2787.00	1440000.00	2945280.00
22.00	8.00	92.00	89.26	156.00	33800.97	0.06	2115.21	2614.00	1337760.00	2777760.00
							20341.43			24632160.00

85

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	120.00	26000.75	0.14	1872.16	2018.00	968640.00	968640.00
4.00	70.00	30.00	70.76	132.00	28600.82	0.08	2276.15	2169.00	1041120.00	2009760.00
8.00	52.00	48.00	76.13	151.00	32717.61	0.14	4182.79	2667.00	1280160.00	2321280.00
10.00	44.00	56.00	78.52	170.00	36834.39	0.06	2108.64	2966.00	1280160.00	2560320.00
12.00	37.00	63.00	80.61	173.00	37484.41	0.05	1971.51	3017.00	1423680.00	2703840.00
14.00	32.00	68.00	82.10	185.00	40084.49	0.04	1469.81	3154.00	1448160.00	2871840.00
16.00	28.00	72.00	83.29	190.00	41167.85	0.03	1231.68	3282.00	1513920.00	2962080.00
18.00	24.00	76.00	84.49	175.00	37917.76	0.03	1198.84	3004.00	1575360.00	3089280.00
20.00	18.00	82.00	86.28	170.00	36834.39	0.03	949.35	2881.00	1441920.00	3017280.00
22.00	10.00	90.00	88.67	151.00	32717.61	0.06	2108.64	2590.00	1382880.00	2824800.00
							19369.56			25329120.00

86

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	115.00	24917.38	0.14	1794.15	1794.00	861120.00	861120.00
4.00	71.00	29.00	70.46	130.00	28167.48	0.08	2011.75	2121.00	1018080.00	1879200.00
8.00	52.00	48.00	76.13	144.00	31200.90	0.14	4274.76	2469.00	1185120.00	2203200.00
10.00	43.00	57.00	78.82	161.00	34884.34	0.07	2253.98	2805.00	1185120.00	2370240.00
12.00	36.00	64.00	80.91	170.00	36834.39	0.05	1902.54	3043.00	1346400.00	2531520.00
14.00	31.00	69.00	82.40	180.00	39001.12	0.04	1436.96	3179.00	1460640.00	2807040.00
16.00	26.00	74.00	83.89	180.00	39001.12	0.04	1478.02	3143.00	1525920.00	2986560.00
18.00	21.00	79.00	85.38	173.00	37484.41	0.04	1449.28	3000.00	1508640.00	3034560.00
20.00	13.00	87.00	87.77	154.00	33367.63	0.03	899.82	2603.00	1440000.00	2948640.00
22.00	4.00	96.00	90.46	142.00	30767.55	0.07	2187.47	2356.00	1249440.00	2689440.00
							19688.71			24311520.00

87

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	78.00	22.00	68.37	101.00	21883.96	0.17	1824.53	1437.00	689760.00	689760.00
4.00	67.00	33.00	71.66	103.00	22317.31	0.08	1842.60	1521.00	730080.00	1419840.00
8.00	48.00	52.00	77.33	115.00	24917.38	0.14	3401.08	1770.00	849600.00	1579680.00
10.00	40.00	60.00	79.71	120.00	26000.75	0.06	1543.71	1838.00	849600.00	1699200.00
12.00	31.00	69.00	82.40	130.00	28167.48	0.07	1847.52	2146.00	882240.00	1731840.00
14.00	23.00	77.00	84.79	156.00	33800.97	0.06	1878.72	2651.00	1030080.00	1912320.00
16.00	14.00	86.00	87.47	151.00	32717.61	0.07	2268.76	2547.00	1272480.00	2302560.00
18.00	5.00	95.00	90.16	151.00	32717.61	0.07	2231.81	2608.00	1222560.00	2495040.00
20.00	4.00	96.00	90.46	199.00	43117.91	0.03	963.11	3383.00	1251840.00	2474400.00
22.00	4.00	96.00	90.46	194.00	42034.54	0.00	0.00	3383.00	1623840.00	2875680.00
							17801.84			19180320.00

88

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	125.00	27084.11	0.14	1950.16	2002.00	960960.00	960960.00
4.00	70.00	30.00	70.76	125.00	27084.11	0.08	2258.08	1927.00	924960.00	1885920.00
8.00	51.00	49.00	76.43	142.00	30767.55	0.14	4165.55	2419.00	1161120.00	2086080.00
10.00	43.00	57.00	78.82	158.00	34234.32	0.06	1970.69	2730.00	1161120.00	2322240.00
12.00	35.00	65.00	81.21	170.00	36834.39	0.06	2154.62	2937.00	1310400.00	2471520.00
14.00	28.00	72.00	83.29	175.00	37917.76	0.05	1983.01	3068.00	1409760.00	2720160.00
16.00	23.00	77.00	84.79	170.00	36834.39	0.04	1416.43	2977.00	1472640.00	2882400.00
18.00	17.00	83.00	86.58	187.00	40517.83	0.05	1758.84	3145.00	1428960.00	2901600.00
20.00	12.00	88.00	88.07	178.00	38567.78	0.03	1004.39	3032.00	1509600.00	2938560.00
22.00	6.00	94.00	89.86	178.00	38567.78	0.05	1753.91	3057.00	1455360.00	2964960.00
							20415.69			24134400.00

89

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	82.00	18.00	67.18	127.00	27517.46	0.14	1877.08	2046.00	982080.00	982080.00

4.00	71.00	29.00	70.46	137.00	29684.19	0.08	2384.54	2166.00	1039680.00	2021760.00
8.00	52.00	48.00	76.13	158.00	34234.32	0.14	4602.38	2722.00	1306560.00	2346240.00
10.00	45.00	55.00	78.22	168.00	36401.05	0.05	1873.80	2848.00	1306560.00	2613120.00
12.00	37.00	63.00	80.61	182.00	39434.47	0.06	2299.14	3075.00	1367040.00	2673600.00
14.00	32.00	68.00	82.10	180.00	39001.12	0.04	1486.23	3126.00	1476000.00	2843040.00
16.00	26.00	74.00	83.89	180.00	39001.12	0.05	1773.62	3043.00	1500480.00	2976480.00
18.00	20.00	80.00	85.68	175.00	37917.76	0.05	1748.99	2966.00	1460640.00	2961120.00
20.00	14.00	86.00	87.47	175.00	37917.76	0.03	963.11	2990.00	1423680.00	2884320.00
22.00	7.00	93.00	89.56	175.00	37917.76	0.05	2011.75	2971.00	1435200.00	2858880.00
							21020.63			25160640.00

90

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	82.00	18.00	67.18	127.00	27517.46	0.14	1877.08	2036.00	977280.00	977280.00
4.00	71.00	29.00	70.46	132.00	28600.82	0.08	2339.37	2136.00	1025280.00	2002560.00
8.00	52.00	48.00	76.13	149.00	32284.26	0.14	4383.96	2533.00	1215840.00	2241120.00
10.00	43.00	57.00	78.82	156.00	33800.97	0.07	2253.98	2614.00	1215840.00	2431680.00
12.00	36.00	64.00	80.91	170.00	36834.39	0.05	1873.80	2967.00	1254720.00	2470560.00
14.00	29.00	71.00	83.00	178.00	38567.78	0.05	2000.25	3048.00	1424160.00	2678880.00
16.00	25.00	75.00	84.19	185.00	40084.49	0.03	1192.27	3169.00	1463040.00	2887200.00
18.00	20.00	80.00	85.68	185.00	40084.49	0.04	1519.07	3136.00	1521120.00	2984160.00
20.00	15.00	85.00	87.17	178.00	38567.78	0.03	998.88	3034.00	1505280.00	3026400.00
22.00	8.00	92.00	89.26	178.00	38567.78	0.05	2046.23	3042.00	1456320.00	2961600.00
							20484.90			24661440.00

91

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	127.00	27517.46	0.14	1981.36	2043.00	980640.00	980640.00
4.00	70.00	30.00	70.76	125.00	27084.11	0.08	2276.15	2051.00	984480.00	1965120.00
8.00	52.00	48.00	76.13	154.00	33367.63	0.14	4123.67	2605.00	1250400.00	2234880.00
10.00	43.00	57.00	78.82	166.00	35967.70	0.07	2364.83	2846.00	1250400.00	2500800.00
12.00	36.00	64.00	80.91	173.00	37484.41	0.05	1948.52	3043.00	1366080.00	2616480.00

14.00	30.00	70.00	82.70	175.00	37917.76	0.05	1714.50	3050.00	1460640.00	2826720.00
16.00	25.00	75.00	84.19	180.00	39001.12	0.04	1457.49	3161.00	1464000.00	2924640.00
18.00	20.00	80.00	85.68	185.00	40084.49	0.04	1498.55	3141.00	1517280.00	2981280.00
20.00	15.00	85.00	87.17	187.00	40517.83	0.03	1023.65	3153.00	1507680.00	3024960.00
22.00	9.00	91.00	88.96	178.00	38567.78	0.05	1798.25	2971.00	1513440.00	3021120.00
							20186.97			25076640.00

92

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	115.00	24917.38	0.14	1794.15	1804.00	865920.00	865920.00
4.00	70.00	30.00	70.76	118.00	25567.40	0.08	2104.53	1763.00	846240.00	1712160.00
8.00	51.00	49.00	76.43	19.00	4116.78	0.14	2137.38	2117.00	1016160.00	1862400.00
10.00	43.00	57.00	78.82	158.00	34234.32	0.06	1162.71	2714.00	1016160.00	2032320.00
12.00	34.00	66.00	81.50	154.00	33367.63	0.07	2305.71	2694.00	1302720.00	2318880.00
14.00	28.00	72.00	83.29	182.00	39434.47	0.05	1655.38	3097.00	1293120.00	2595840.00
16.00	23.00	77.00	84.79	182.00	39434.47	0.04	1494.44	3188.00	1486560.00	2779680.00
18.00	19.00	81.00	85.98	175.00	37917.76	0.03	1172.56	3058.00	1530240.00	3016800.00
20.00	12.00	88.00	88.07	173.00	37484.41	0.03	957.61	2924.00	1467840.00	2998080.00
22.00	4.00	96.00	90.46	168.00	36401.05	0.06	2240.02	2886.00	1403520.00	2871360.00
							17024.48			23053440.00

93

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	81.81	122.00	26434.09	0.15	2003.54	1881.00	902880.00	902880.00
4.00	69.00	31.00	92.81	134.00	29034.17	0.08	2312.28	2209.00	1060320.00	1963200.00
8.00	51.00	49.00	110.81	151.00	32717.61	0.14	4212.35	2631.00	1262880.00	2323200.00
10.00	42.00	58.00	119.81	166.00	35967.70	0.07	2342.66	2899.00	1391520.00	2654400.00
12.00	36.00	64.00	125.81	178.00	38567.78	0.05	1694.79	3087.00	1481760.00	2873280.00
14.00	32.00	68.00	129.81	178.00	38567.78	0.03	1169.28	3116.00	1495680.00	2977440.00
16.00	26.00	74.00	135.81	170.00	36834.39	0.05	1714.50	3067.00	1472160.00	2967840.00
18.00	21.00	79.00	140.81	178.00	38567.78	0.04	1428.75	3067.00	1472160.00	2944320.00
20.00	15.00	85.00	146.81	175.00	37917.76	0.03	971.37	3083.00	1479840.00	2952000.00

22.00	11.00	89.00	150.81	182.00	39434.47	0.03	1172.56	3125.00	1500000.00	2979840.00
24.00	5.00	95.00	156.81	175.00	37917.76	0.05	1758.84	2937.00	1409760.00	2909760.00
							20780.91			28448160.00

94

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	75.00	25.00	69.27	134.00	29034.17	0.19	2750.76	2247.00	1078560.00	1078560.00
4.00	65.00	35.00	72.25	146.00	31634.24	0.08	2299.14	2489.00	1194720.00	2273280.00
8.00	48.00	52.00	77.33	178.00	38567.78	0.13	4522.73	3010.00	1444800.00	2639520.00
10.00	42.00	58.00	79.12	178.00	38567.78	0.05	1753.91	3136.00	1505280.00	2950080.00
12.00	38.00	62.00	80.31	185.00	40084.49	0.03	1192.27	3254.00	1561920.00	3067200.00
14.00	35.00	65.00	81.21	190.00	41167.85	0.02	923.76	3242.00	1556160.00	3118080.00
16.00	31.00	69.00	82.40	178.00	38567.78	0.03	1208.69	3085.00	1480800.00	3036960.00
18.00	25.00	75.00	84.19	180.00	39001.12	0.05	1763.77	3075.00	1476000.00	2956800.00
20.00	19.00	81.00	85.98	173.00	37484.41	0.05	1739.13	2985.00	1432800.00	2908800.00
22.00	15.00	85.00	87.17	185.00	40084.49	0.03	1175.85	3105.00	1490400.00	2923200.00
24.00	7.00	93.00	89.56	146.00	31634.24	0.06	2174.33	2416.00	1159680.00	2650080.00
							21504.34			29602560.00

95

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	127.00	27517.46	0.14	1981.36	2069.00	993120.00	993120.00
4.00	71.00	29.00	70.46	137.00	29684.19	0.08	2167.76	2219.00	1065120.00	2058240.00
8.00	52.00	48.00	76.13	156.00	33800.97	0.14	4571.18	2653.00	1273440.00	2338560.00
10.00	43.00	57.00	78.82	158.00	34234.32	0.07	2320.49	2722.00	1306560.00	2580000.00
12.00	35.00	65.00	81.21	166.00	35967.70	0.06	2128.35	2807.00	1347360.00	2653920.00
14.00	28.00	72.00	83.29	168.00	36401.05	0.05	1919.78	2860.00	1372800.00	2720160.00
16.00	21.00	79.00	85.38	182.00	39434.47	0.05	2011.75	3057.00	1467360.00	2840160.00
18.00	16.00	84.00	86.88	182.00	39434.47	0.04	1494.44	3118.00	1496640.00	2964000.00
20.00	12.00	88.00	88.07	185.00	40084.49	0.03	1205.41	3095.00	1485600.00	2982240.00
22.00	6.00	94.00	89.86	187.00	40517.83	0.05	1832.74	3181.00	1526880.00	3012480.00
24.00	4.00	96.00	90.46	194.00	42034.54	0.02	625.69	3191.00	1531680.00	3058560.00

							Energy(J)			Energy(J)
							22258.95			27208320.00

96

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	134.00	29034.17	0.15	2200.60	2225.00	1068000.00	1068000.00
4.00	70.00	30.00	70.76	139.00	30117.53	0.08	2241.66	2333.00	1119840.00	2187840.00
8.00	51.00	49.00	76.43	158.00	34234.32	0.14	4633.59	2717.00	1304160.00	2424000.00
10.00	43.00	57.00	78.82	166.00	35967.70	0.06	2128.35	2836.00	1361280.00	2665440.00
12.00	35.00	65.00	81.21	163.00	35317.68	0.06	2161.19	2871.00	1378080.00	2739360.00
14.00	29.00	71.00	83.00	175.00	37917.76	0.05	1665.23	3068.00	1472640.00	2850720.00
16.00	25.00	75.00	84.19	190.00	41167.85	0.03	1198.84	3268.00	1568640.00	3041280.00
18.00	25.00	75.00	84.19	194.00	42034.54	0.00	0.00	3357.00	1611360.00	3180000.00
20.00	23.00	77.00	84.79	180.00	39001.12	0.02	614.20	3186.00	1529280.00	3140640.00
22.00	18.00	82.00	86.28	173.00	37484.41	0.04	1449.28	2957.00	1419360.00	2948640.00
24.00	10.00	90.00	88.67	163.00	35317.68	0.06	2207.17	2727.00	1308960.00	2728320.00
							20500.11			27906240.00

97

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	76.00	24.00	68.97	130.00	28167.48	0.18	2561.90	2071.00	994080.00	994080.00
4.00	66.00	34.00	71.96	137.00	29684.19	0.08	2192.39	2233.00	1071840.00	2065920.00
8.00	48.00	52.00	77.33	168.00	36401.05	0.14	4507.95	2888.00	1386240.00	2458080.00
10.00	41.00	59.00	79.42	178.00	38567.78	0.05	1988.75	3087.00	1481760.00	2868000.00
12.00	37.00	63.00	80.61	182.00	39434.47	0.03	1182.41	3203.00	1537440.00	3019200.00
14.00	33.00	67.00	81.80	187.00	40517.83	0.03	1211.97	3251.00	1560480.00	3097920.00
16.00	32.00	68.00	82.10	194.00	42034.54	0.01	312.85	3352.00	1608960.00	3169440.00
18.00	27.00	73.00	83.59	182.00	39434.47	0.04	1543.71	3152.00	1512960.00	3121920.00
20.00	22.00	78.00	85.09	173.00	37484.41	0.04	1457.49	3050.00	1464000.00	2976960.00
22.00	16.00	84.00	86.88	173.00	37484.41	0.05	1704.65	3002.00	1440960.00	2904960.00
24.00	8.00	92.00	89.26	168.00	36401.05	0.06	2240.02	2793.00	1340640.00	2781600.00
							20904.10			28464000.00

98

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	76.00	24.00	68.97	130.00	28167.48	0.18	2561.90	2071.00	994080.00	994080.00
4.00	66.00	34.00	71.96	137.00	29684.19	0.08	2192.39	2233.00	1071840.00	2065920.00
8.00	48.00	52.00	77.33	168.00	36401.05	0.14	4507.95	2888.00	1386240.00	2458080.00
10.00	41.00	59.00	79.42	178.00	38567.78	0.05	1988.75	3087.00	1481760.00	2868000.00
12.00	37.00	63.00	80.61	182.00	39434.47	0.03	1182.41	3203.00	1537440.00	3019200.00
14.00	33.00	67.00	81.80	187.00	40517.83	0.03	1211.97	3251.00	1560480.00	3097920.00
16.00	32.00	68.00	82.10	194.00	42034.54	0.01	312.85	3352.00	1608960.00	3169440.00
18.00	27.00	73.00	83.59	182.00	39434.47	0.04	1543.71	3152.00	1512960.00	3121920.00
20.00	22.00	78.00	85.09	173.00	37484.41	0.04	1457.49	3050.00	1464000.00	2976960.00
22.00	16.00	84.00	86.88	173.00	37484.41	0.05	1704.65	3002.00	1440960.00	2904960.00
24.00	8.00	92.00	89.26	168.00	36401.05	0.06	2240.02	2793.00	1340640.00	2781600.00
							20904.10			28464000.00

99

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	82.00	18.00	67.18	127.00	27517.46	0.14	1877.08	2023.00	971040.00	971040.00
4.00	71.00	29.00	70.46	130.00	28167.48	0.08	2321.31	2114.00	1014720.00	1985760.00
8.00	52.00	48.00	76.13	154.00	33367.63	0.14	4430.77	2638.00	1266240.00	2280960.00
10.00	44.00	56.00	78.52	166.00	35967.70	0.06	2102.07	2886.00	1385280.00	2651520.00
12.00	37.00	63.00	80.61	170.00	36834.39	0.05	1931.28	3005.00	1442400.00	2827680.00
14.00	31.00	69.00	82.40	180.00	39001.12	0.05	1724.35	3156.00	1514880.00	2957280.00
16.00	28.00	72.00	83.29	185.00	40084.49	0.02	899.13	3270.00	1569600.00	3084480.00
18.00	26.00	74.00	83.89	185.00	40084.49	0.02	607.63	3264.00	1566720.00	3136320.00
20.00	22.00	78.00	85.09	180.00	39001.12	0.03	1198.84	3131.00	1502880.00	3069600.00
22.00	16.00	84.00	86.88	173.00	37484.41	0.05	1739.13	2981.00	1430880.00	2933760.00
24.00	8.00	92.00	89.26	156.00	33800.97	0.06	2161.19	2621.00	1258080.00	2688960.00
							20992.78			27616320.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								

0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	122.00	26434.09	0.15	2003.54	1958.00	939840.00	939840.00
4.00	69.00	31.00	71.06	130.00	28167.48	0.08	2276.15	2139.00	1026720.00	1966560.00
8.00	51.00	49.00	76.43	154.00	33367.63	0.14	4197.57	2653.00	1273440.00	2300160.00
10.00	43.00	57.00	78.82	170.00	36834.39	0.06	2128.35	2933.00	1407840.00	2681280.00
12.00	36.00	64.00	80.91	175.00	37917.76	0.05	1983.01	3045.00	1461600.00	2869440.00
14.00	31.00	69.00	82.40	180.00	39001.12	0.04	1457.49	3097.00	1486560.00	2948160.00
16.00	27.00	73.00	83.59	187.00	40517.83	0.03	1205.41	3267.00	1568160.00	3054720.00
18.00	24.00	76.00	84.49	182.00	39434.47	0.02	908.98	3257.00	1563360.00	3131520.00
20.00	21.00	79.00	85.38	182.00	39434.47	0.02	896.66	3159.00	1516320.00	3079680.00
22.00	16.00	84.00	86.88	175.00	37917.76	0.04	1465.70	3042.00	1460160.00	2976480.00
24.00	10.00	90.00	88.67	173.00	37484.41	0.05	1714.50	3004.00	1441920.00	2902080.00
							20237.35			27910080.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	115.00	24917.38	0.15	1888.58	1674.00	803520.00	803520.00
4.00	70.00	30.00	70.76	125.00	27084.11	0.08	1970.69	1847.00	886560.00	1690080.00
8.00	51.00	49.00	76.43	130.00	28167.48	0.14	3978.33	2091.00	1003680.00	1890240.00
10.00	42.00	58.00	79.12	146.00	31634.24	0.07	2039.66	2523.00	1211040.00	2214720.00
12.00	34.00	66.00	81.50	170.00	36834.39	0.06	2075.79	2870.00	1377600.00	2588640.00
14.00	27.00	73.00	83.59	173.00	37484.41	0.05	1971.51	2981.00	1430880.00	2808480.00
16.00	21.00	79.00	85.38	178.00	38567.78	0.05	1729.28	2995.00	1437600.00	2868480.00
18.00	14.00	86.00	87.47	178.00	38567.78	0.05	2046.23	3035.00	1456800.00	2894400.00
20.00	8.00	92.00	89.26	180.00	39001.12	0.05	1763.77	3024.00	1451520.00	2908320.00
22.00	4.00	96.00	90.46	194.00	42034.54	0.03	1228.40	3365.00	1615200.00	3066720.00
24.00	4.00	96.00	90.46	202.00	43767.92	0.00	0.00	3381.00	1622880.00	3238080.00
							20692.25			26168160.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	83.00	17.00	66.88	125.00	27084.11	0.13	1744.88	2041.00	979680.00	979680.00

4.00	73.00	27.00	69.87	134.00	29034.17	0.08	2126.70	2224.00	1067520.00	2047200.00
8.00	53.00	47.00	75.83	142.00	30767.55	0.15	4532.59	2356.00	1130880.00	2198400.00
10.00	45.00	55.00	78.22	134.00	29034.17	0.06	1813.04	2242.00	1076160.00	2207040.00
12.00	36.00	64.00	80.91	161.00	34884.34	0.07	2180.08	2749.00	1319520.00	2395680.00
14.00	29.00	71.00	83.00	173.00	37484.41	0.05	1919.78	2967.00	1424160.00	2743680.00
16.00	23.00	77.00	84.79	180.00	39001.12	0.05	1739.13	3154.00	1513920.00	2938080.00
18.00	20.00	80.00	85.68	194.00	42034.54	0.02	921.30	3279.00	1573920.00	3087840.00
20.00	16.00	84.00	86.88	180.00	39001.12	0.03	1228.40	3020.00	1449600.00	3023520.00
22.00	11.00	89.00	88.37	187.00	40517.83	0.04	1506.76	3188.00	1530240.00	2979840.00
24.00	6.00	94.00	89.86	187.00	40517.83	0.04	1535.50	3214.00	1542720.00	3072960.00
							21248.15			26694240.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	80.00	20.00	67.78	130.00	28167.48	0.15	2134.91	2064.00	990720.00	990720.00
4.00	70.00	30.00	70.76	122.00	26434.09	0.08	2069.22	1963.00	942240.00	1932960.00
8.00	51.00	49.00	76.43	154.00	33367.63	0.14	4305.96	2495.00	1197600.00	2139840.00
10.00	43.00	57.00	78.82	166.00	35967.70	0.06	2102.07	2843.00	1364640.00	2562240.00
12.00	36.00	64.00	80.91	175.00	37917.76	0.05	1960.02	2979.00	1429920.00	2794560.00
14.00	30.00	70.00	82.70	185.00	40084.49	0.05	1773.62	3186.00	1529280.00	2959200.00
16.00	27.00	73.00	83.59	192.00	41601.20	0.02	928.69	3312.00	1589760.00	3119040.00
18.00	23.00	77.00	84.79	185.00	40084.49	0.03	1238.25	3189.00	1530720.00	3120480.00
20.00	19.00	81.00	85.98	185.00	40084.49	0.03	1215.26	3161.00	1517280.00	3048000.00
22.00	14.00	86.00	87.47	182.00	39434.47	0.04	1506.76	3087.00	1481760.00	2999040.00
24.00	7.00	93.00	89.56	175.00	37917.76	0.05	2051.98	2870.00	1377600.00	2859360.00
							21286.74			27534720.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0.00	100.00	0.00	61.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	81.00	19.00	67.48	120.00	26000.75	0.14	1872.16	1852.00	888960.00	888960.00
4.00	70.00	30.00	70.76	125.00	27084.11	0.08	2212.92	1957.00	939360.00	1828320.00
8.00	51.00	49.00	76.43	158.00	34234.32	0.14	4415.17	2689.00	1290720.00	2230080.00

10.00	43.00	57.00	78.82	170.00	36834.39	0.06	2154.62	2913.00	1398240.00	2688960.00
12.00	37.00	63.00	80.61	180.00	39001.12	0.05	1724.35	3111.00	1493280.00	2891520.00
14.00	31.00	69.00	82.40	180.00	39001.12	0.05	1773.62	3136.00	1505280.00	2998560.00
16.00	28.00	72.00	83.29	192.00	41601.20	0.02	916.37	3317.00	1592160.00	3097440.00
18.00	26.00	74.00	83.89	187.00	40517.83	0.02	622.41	3241.00	1555680.00	3147840.00
20.00	22.00	78.00	85.09	180.00	39001.12	0.03	1205.41	3106.00	1490880.00	3046560.00
22.00	17.00	83.00	86.58	178.00	38567.78	0.04	1469.81	3092.00	1484160.00	2975040.00
24.00	10.00	90.00	88.67	170.00	36834.39	0.05	2000.25	2870.00	1377600.00	2861760.00
							20367.08			27766080.00

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0.00	0.00	0.00	0.00	0	0	0
2	77	23	68.67	154.00	7501.34	0.17	2908.41	2623	1259040	1259040
4	67	33	71.66	163.00	7939.73	0.08	2602.95	2855	1370400	2629440
8	53	47	75.83	185.00	9011.35	0.11	4000.50	3201	1536480	2906880
10	50	50	76.73	190.00	9254.90	0.02	923.76	3261	1565280	3101760
12	46	54	77.92	182.00	8865.22	0.03	1221.83	3221	1546080	3111360
14	43	57	78.82	182.00	8865.22	0.02	896.66	3183	1527840	3073920
16	39	61	80.01	182.00	8865.22	0.03	1195.55	3216	1543680	3071520
18	35	65	81.21	185.00	9011.35	0.03	1205.41	3158	1515840	3059520
20	30	70	82.70	180.00	8767.80	0.04	1498.55	3032	1455360	2971200
22	25	75	84.19	163.00	7939.73	0.04	1408.22	2792	1340160	2795520
24	15	85	87.17	158.00	7696.18	0.08	2635.80	2503	1201440	2541600
26	6	94	89.86	142.00	6916.82	0.07	2217.03	2353	1129440	2330880
							22714.67			32852640

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0.00	0.00	0.00	0.00	0	0	0
2	79	21	68.08	127.00	27517.46	0.16	2189.93	2103	1009440	1009440
4	68	32	71.36	132.00	28600.82	0.08	2339.37	2194	1053120	2062560
8	50	50	76.73	161.00	34884.34	0.14	4330.59	2641	1267680	2320800
10	42	58	79.12	173.00	37484.41	0.06	2194.04	2967	1424160	2691840

12	37	63	80.61	187.00	40517.83	0.04	1478.02	3211	1541280	2965440
14	34	66	81.50	190.00	41167.85	0.02	928.69	3246	1558080	3099360
16	31	69	82.40	187.00	40517.83	0.02	928.69	3219	1545120	3103200
18	27	73	83.59	190.00	41167.85	0.03	1238.25	3226	1548480	3093600
20	24	76	84.49	192.00	41601.20	0.02	941.00	3251	1560480	3108960
22	21	79	85.38	194.00	42034.54	0.02	950.86	3231	1550880	3111360
24	16	84	86.88	175.00	37917.76	0.04	1514.97	2884	1384320	2935200
26	7	93	89.56	120.00	26000.75	0.07	2180.08	1789	858720	2243040
							21214.48			31744800

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	79	21	68.08	130	28167.48	0.16	2241.66	2122	1018560	1018560
4	68	32	71.36	144	31200.90	0.08	2474.86	2371	1138080	2156640
8	50	50	76.73	166	35967.70	0.14	4581.85	2790	1339200	2477280
10	42	58	79.12	173	37484.41	0.06	2226.88	2942	1412160	2751360
12	37	63	80.61	178	38567.78	0.04	1441.07	2972	1426560	2838720
14	34	66	81.50	175	37917.76	0.02	869.57	3062	1469760	2896320
16	31	69	82.40	182	39434.47	0.02	879.42	3186	1529280	2999040
18	27	73	83.59	190	41167.85	0.03	1221.83	3280	1574400	3103680
20	24	76	84.49	197	42684.56	0.02	953.32	3360	1612800	3187200
22	21	79	85.38	187	40517.83	0.02	945.93	3199	1535520	3148320
24	16	84	86.88	173	37484.41	0.04	1478.02	2936	1409280	2944800
26	7	93	89.56	132	28600.82	0.07	2253.98	2038	978240	2387520
							21568.38			28734240

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	82	18	67.18	118	25567.40	0.14	1744.06	1834	880320	880320
4	71	29	70.46	122	26434.09	0.08	2167.76	1929	925920	1806240
8	52	48	76.13	151	32717.61	0.14	4259.15	2547	1222560	2148480
10	43	57	78.82	137	29684.19	0.07	2128.35	2293	1100640	2323200

12	35	65	81.21	161	34884.34	0.06	1957.55	2730	1310400	2411040
14	28	72	83.29	173	37484.41	0.05	1919.78	3005	1442400	2752800
16	25	75	84.19	185	40084.49	0.02	881.88	3280	1574400	3016800
18	22	78	85.09	185	40084.49	0.02	911.44	3234	1552320	3126720
20	19	81	85.98	180	39001.12	0.02	899.13	3154	1513920	3066240
22	14	86	87.47	185	40084.49	0.04	1498.55	3176	1524480	3038400
24	10	90	88.67	182	39434.47	0.03	1205.41	3150	1512000	3036480
26	4	96	90.46	180	39001.12	0.05	1783.47	2936	1409280	2921280
							21356.53			27841440

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	83	17	66.88	125	27084.11	0.13	1744.88	1949	935520	935520
4	72	28	70.17	125	27084.11	0.08	2258.08	2016	967680	1903200
8	53	47	75.83	154	33367.63	0.14	4352.76	2565	1231200	2198880
10	45	55	78.22	163	35317.68	0.06	2082.36	2823	1355040	2586240
12	38	62	80.31	170	36834.39	0.05	1914.03	2942	1412160	2767200
14	32	68	82.10	182	39434.47	0.05	1734.21	3070	1473600	2885760
16	27	73	83.59	187	40517.83	0.04	1514.97	3186	1529280	3002880
18	24	76	84.49	187	40517.83	0.02	921.30	3272	1570560	3099840
20	22	78	85.09	187	40517.83	0.02	614.20	3227	1548960	3119520
22	17	83	86.58	175	37917.76	0.04	1486.23	2951	1416480	2965440
24	9	91	88.96	168	36401.05	0.06	2253.16	2903	1393440	2809920
26	5	95	90.16	194	42034.54	0.03	1188.98	3141	1507680	2901120
							22065.16			28336800

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	80	20	67.78	113	24484.04	0.15	1855.73	1693	812640	812640
4	70	30	70.76	115	24917.38	0.08	1872.16	1799	863520	1676160
8	51	49	76.43	127	27517.46	0.14	3775.51	1993	956640	1820160
10	42	58	79.12	125	27084.11	0.07	1862.30	1842	884160	1840800

12	33	67	81.80	134	29034.17	0.07	1914.03	2205	1058400	1942560
14	25	75	84.19	154	33367.63	0.06	1891.86	2651	1272480	2330880
16	19	81	85.98	180	39001.12	0.05	1645.53	3150	1512000	2784480
18	17	83	86.58	194	42034.54	0.02	614.20	3396	1630080	3142080
20	17	83	86.58	194	42034.54	0.00	0.00	3401	1632480	3262560
22	17	83	86.58	194	42034.54	0.00	0.00	3401	1632480	3264960
24	17	83	86.58	197	42684.56	0.00	0.00	3406	1634880	3267360
26	13	87	87.77	151	32717.61	0.03	1143.00	2103	1009440	2644320
							16574.33			26300160

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	80	20	67.78	132	28600.82	0.15	2167.76	2117	1016160	1016160
4	70	30	70.76	130	28167.48	0.08	2151.34	2109	1012320	2028480
8	51	49	76.43	149	32284.26	0.14	4352.76	2477	1188960	2201280
10	42	58	79.12	166	35967.70	0.07	2327.88	2858	1371840	2560800
12	36	64	80.91	175	37917.76	0.05	1680.01	3073	1475040	2846880
14	31	69	82.40	185	40084.49	0.04	1478.02	3183	1527840	3002880
16	27	73	83.59	187	40517.83	0.03	1221.83	3246	1558080	3085920
18	25	75	84.19	190	41167.85	0.02	619.13	3279	1573920	3132000
20	22	78	85.09	190	41167.85	0.02	936.08	3254	1561920	3135840
22	19	81	85.98	192	41601.20	0.02	941.00	3222	1546560	3108480
24	15	85	87.17	185	40084.49	0.03	1238.25	3169	1521120	3067680
26	10	90	88.67	180	39001.12	0.04	1498.55	3022	1450560	2971680
							20612.60			29113440

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	74	26	69.57	115	24917.38	0.20	2455.15	1783	855840	855840
4	64	36	72.55	120	26000.75	0.08	1929.63	1849	887520	1743360
8	45	55	78.22	137	29684.19	0.14	4009.53	2200	1056000	1943520
10	37	63	80.61	142	30767.55	0.06	1832.74	2305	1106400	2162400

12	28	72	83.29	132	28600.82	0.07	2024.88	2126	1020480	2126880
14	20	80	85.68	151	32717.61	0.06	1859.02	2487	1193760	2214240
16	12	88	88.07	161	34884.34	0.06	2049.52	2727	1308960	2502720
18	5	95	90.16	194	42034.54	0.05	2040.49	3350	1608000	2916960
20	5	95	90.16	199	43117.91	0.00	0.00	3383	1623840	3231840
22	5	95	90.16	202	43767.92	0.00	0.00	3385	1624800	3248640
24	5	95	90.16	204	44201.27	0.00	0.00	3391	1627680	3252480
26	5	95	90.16	199	43117.91	0.00	0.00	3396	1630080	3257760
							18200.97			26857440

113

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	81	19	67.48	122	26434.09	0.14	1903.36	1968	944640	944640
4	70	30	70.76	125	27084.11	0.08	2230.99	2035	976800	1921440
8	52	48	76.13	132	28600.82	0.14	3798.51	2217	1064160	2040960
10	43	57	78.82	144	31200.90	0.07	2039.66	2494	1197120	2261280
12	35	65	81.21	158	34234.32	0.06	1983.83	2702	1296960	2494080
14	27	73	83.59	166	35967.70	0.06	2128.35	2916	1399680	2696640
16	21	79	85.38	175	37917.76	0.05	1680.01	3034	1456320	2856000
18	17	83	86.58	185	40084.49	0.03	1182.41	3193	1532640	2988960
20	12	88	88.07	175	37917.76	0.04	1478.02	2999	1439520	2972160
22	9	91	88.96	192	41601.20	0.02	904.05	3383	1623840	3063360
24	9	91	88.96	194	42034.54	0.00	0.00	3371	1618080	3241920
26	6	94	89.86	175	37917.76	0.02	908.98	3004	1441920	3060000
							20238.17			27675360

114

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100.00	0.00	61.81	0	0	0	0	0	0	0
2	82	18.00	67.18	103	22317.31	0.14	1522.36	1538	738240	738240
4	72	28.00	70.17	113	24484.04	0.08	1773.62	1596	766080	1504320
8	52	48.00	76.13	125	27084.11	0.15	3908.54	1982	951360	1717440
10	43	57.00	78.82	132	28600.82	0.07	1899.25	2172	1042560	1993920

12	35	65.00	81.21	137	29684.19	0.06	1767.05	2243	1076640	2119200
14	27	73.00	83.59	149	32284.26	0.06	1878.72	2472	1186560	2263200
16	18	82.00	86.28	158	34234.32	0.07	2268.76	2702	1296960	2483520
18	11	89.00	88.37	173	37484.41	0.05	1902.54	3053	1465440	2762400
20	7	93.00	89.56	192	41601.20	0.03	1198.84	3378	1621440	3086880
22	6	94.00	89.86	187	40517.83	0.01	311.20	3189	1530720	3152160
24	5	95.00	90.16	197	42684.56	0.01	315.31	3381	1622880	3153600
26	4	96.00	90.46	190	41167.85	0.01	317.77	3282	1575360	3198240
							19063.96			25930560

115

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	79	21	68.0764	108	23400.67	0.16	1862.30	1634	784320	784320
4	69	31	71.0604	110	23834.02	0.08	1790.04	1722	826560	1610880
8	50	50	76.73	144	31200.90	0.14	3962.73	2406	1154880	3962880
10	43	57	78.8188	175	37917.76	0.05	1833.56	3012	1445760	2600640
12	37	63	80.6092	170	36834.39	0.05	1699.72	2916	1154880	2600640
14	32	68	82.1012	185	40084.49	0.04	1457.49	3143	1445760	2600640
16	28	72	83.2948	194	42034.54	0.03	1244.82	3328	1399680	2845440
18	27	73	83.5932	194	42034.54	0.01	318.59	3338	1508640	2908320
20	26	74	83.8916	194	42034.54	0.01	318.59	3380	1597440	3106080
22	26	74	83.8916	194	42034.54	0.00	0.00	3363	1602240	3199680
24	23	77	84.7868	182	39434.47	0.02	926.22	3042	1622400	3224640
26	18	82	86.2788	173	37484.41	0.04	1457.49	2883	1614240	3236640
28	11	89	88.3676	185	40084.49	0.05	2057.73	3045	1460160	3074400
							18929.30			29397120

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	22	78	85.0852	202	43767.92	0.59	12937.58	3405	1634400	1634400
4	71	29	70.4636	122	26434.09	-0.37	-13036.12	1905	914400	2548800
8	52	48	76.1332	127	27517.46	0.14	3884.72	2053	985440	3799680

10	43	57	78.8188	139	30117.53	0.07	1965.76	2338	1122240	2107680
12	35	65	81.206	154	33367.63	0.06	1924.71	2578	985440	2107680
14	27	73	83.5932	180	39001.12	0.06	2194.04	2918	1122240	2107680
16	23	77	84.7868	192	41601.20	0.03	1221.83	3289	1237440	2359680
18	22	78	85.0852	199	43117.91	0.01	321.06	3391	1400640	2638080
20	22	78	85.0852	199	43117.91	0.00	0.00	3391	1578720	2979360
22	22	78	85.0852	202	43767.92	0.00	0.00	3398	1627680	3206400
24	22	78	85.0852	197	42684.56	0.00	0.00	3398	1627680	3255360
26	22	78	85.0852	206	44634.62	0.00	0.00	3400	1631040	3258720
28	22	78	85.0852	204	44201.27	0.00	0.00	3401	1631040	3262080
30	22	78	85.0852	202	43767.92	0.00	0.00	3405	1632000	3263040
							11413.58			28438080

117

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	81	19	67.4796	122	26434.09	0.14	7613.43	2005	962400	962400
4	71	29	70.4636	137	29684.19	0.08	8506.81	2389	1146720	2109120
8	53	47	75.8348	173	37484.41	0.14	18327.42	2941	1411680	5116800
10	45	55	78.222	166	35967.70	0.06	8907.52	2888	1386240	2797920
12	38	62	80.3108	175	37917.76	0.05	7840.06	3093	1411680	2797920
14	35	65	81.206	190	41167.85	0.02	3596.51	3352	1386240	2797920
16	35	65	81.206	192	41601.20	0.00	0.00	3408	1484640	2870880
18	34	66	81.5044	192	41601.20	0.01	1261.24	3385	1608960	3093600
20	33	67	81.8028	192	41601.20	0.01	1261.24	3348	1635840	3244800
22	31	69	82.3996	187	40517.83	0.02	2489.64	3262	1624800	3260640
24	27	73	83.5932	190	41167.85	0.03	4953.00	3227	1607040	3231840
26	22	78	85.0852	144	31200.90	0.04	5485.09	2263	1565760	3172800
28	13	87	87.7708	113	24484.04	0.07	7597.01	1725	1548960	3114720
30	5	95	90.158	178	38567.78	0.06	7646.28	3014	1086240	2635200
							85485.26			30220320

118

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								

0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	79	21	68.0764	118	25567.40	0.16	2034.74	1773	851040	851040
4	68	32	71.3588	127	27517.46	0.08	2212.92	2053	985440	1836480
8	50	50	76.73	146	31634.24	0.14	4034.99	2432	1167360	4305600
10	41	59	79.4156	161	34884.34	0.07	2268.76	2725	1308000	2475360
12	33	67	81.8028	168	36401.05	0.06	2161.19	2919	1167360	2475360
14	27	73	83.5932	178	38567.78	0.05	1704.65	3075	1308000	2475360
16	22	78	85.0852	180	39001.12	0.04	1469.81	3077	1401120	2709120
18	17	83	86.5772	180	39001.12	0.04	1478.02	3191	1476000	2877120
20	15	85	87.174	194	42034.54	0.02	614.20	3312	1476960	2952960
22	13	87	87.7708	190	41167.85	0.02	630.62	3246	1531680	3008640
24	10	90	88.666	194	42034.54	0.02	945.93	3261	1589760	3121440
26	8	92	89.2628	209	45284.63	0.02	661.82	3367	1558080	3147840
28	5	95	90.158	204	44201.27	0.02	1017.37	3390	1565280	3123360
30	4	96	90.4564	202	43767.92	0.01	333.38	3393	1616160	3181440
							21568.38			29072640

119

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	80	20	67.778	134	29034.17	0.15	2200.60	2144	1029120	1029120
4	70	30	70.762	103	22317.31	0.08	1946.06	1481	710880	1740000
8	51	49	76.4316	130	28167.48	0.14	3635.10	2157	1035360	3492480
10	43	57	78.8188	178	38567.78	0.06	2023.24	3047	1462560	2497920
12	38	62	80.3108	182	39434.47	0.04	1478.02	3164	1035360	2497920
14	34	66	81.5044	187	40517.83	0.03	1211.97	3282	1462560	2497920
16	32	68	82.1012	190	41167.85	0.02	619.13	3312	1518720	2981280
18	30	70	82.698	192	41601.20	0.02	627.34	3330	1575360	3094080
20	29	71	82.9964	194	42034.54	0.01	316.95	3343	1589760	3165120
22	28	72	83.2948	197	42684.56	0.01	321.06	3390	1598400	3188160
24	28	72	83.2948	194	42034.54	0.00	0.00	3393	1604640	3203040
26	27	73	83.5932	197	42684.56	0.01	321.06	3381	1627200	3231840
28	24	76	84.4884	190	41167.85	0.02	953.32	3193	1628640	3255840
30	16	84	86.8756	101	21883.96	0.06	1911.57	1263	1622880	3251520

							17565.42			30366720

120

Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	81	19	67.4796	127	27517.46	0.14	1981.36	2036	977280	977280
4	70	30	70.762	127	27517.46	0.08	2294.21	2063	990240	1967520
8	52	48	76.1332	134	29034.17	0.14	3857.63	2224	1067520	4115520
10	43	57	78.8188	158	34234.32	0.07	2157.91	2692	1292160	2359680
12	36	64	80.9076	178	38567.78	0.05	1931.28	3029	1067520	2359680
14	30	70	82.698	187	40517.83	0.05	1798.25	3198	1292160	2359680
16	28	72	83.2948	192	41601.20	0.02	622.41	3323	1453920	2746080
18	27	73	83.5932	194	42034.54	0.01	316.95	3368	1535040	2988960
20	26	74	83.8916	194	42034.54	0.01	318.59	3388	1595040	3130080
22	25	75	84.19	199	43117.91	0.01	322.70	3375	1616640	3211680
24	24	76	84.4884	197	42684.56	0.01	325.16	3335	1626240	3242880
26	22	78	85.0852	194	42034.54	0.02	642.12	3290	1620000	3246240
28	19	81	85.9804	187	40517.83	0.02	938.54	3082	1600800	3220800
30	10	90	88.666	113	24484.04	0.07	2217.03	1682	1579200	3180000
							19724.15			29686080

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Time(sec)	% Change in piston travel		Cylinder length(ft)	Pressure(PSI)	Force (N)	Displacement (m)	Energy(J)	Current(A)	Power (W)	Energy(J)
	Opened	Closed								
0	100	0	61.81	0	0.00	0.00	0.00	0	0	0
2	80	20	67.778	89	19283.89	0.15	1461.60	1133	543840	543840
4	69	31	71.0604	94	20367.25	0.08	1652.92	1283	615840	1159680
8	50	50	76.73	101	21883.96	0.14	3042.25	1538	738240	2708160
10	42	58	79.1172	113	24484.04	0.06	1405.76	1708	819840	1558080
12	33	67	81.8028	122	26434.09	0.07	1736.67	1957	738240	1558080
14	25	75	84.19	151	32717.61	0.06	1793.33	2556	819840	1558080
16	17	83	86.5772	166	35967.70	0.06	2082.36	2843	939360	1759200
18	8	92	89.2628	154	33367.63	0.07	2364.83	2469	1226880	2166240
20	4	96	90.4564	202	43767.92	0.03	1169.28	3381	1364640	2591520

22	4	96	90.4564	202	43767.92	0.00	0.00	3381	1185120	2549760
24	4	96	90.4564	199	43117.91	0.00	0.00	3370	1622880	2808000
26	4	96	90.4564	204	44201.27	0.00	0.00	3388	1622880	3245760
28	4	96	90.4564	204	44201.27	0.00	0.00	3395	1617600	3240480
30	4	96	90.4564	204	44201.27	0.00	0.00	3398	1626240	3243840
							16708.99			24720960

SUMMARY STATISTICS FOR 18 SECONDS CYCLE TIME

	Work done(KJ)	*Motor Energy(KJ)*	*Average tilt Angle(Degrees)*
Mean	66.29	15491.42	17.45
Standard Error	1.61	625.54	0.94
Median	67.73	15894.48	17.17
Mode	74.26	#N/A	11.11
Standard Deviation	7.88	3064.53	4.61
Sample Variance	62.17	9391321.36	21.25
Kurtosis	-0.84	-0.52	0.36
Skewness	-0.55	-0.37	0.51
Range	27.27	11383.20	19.00
Minimum	49.25	9111.36	9.89
Maximum	76.52	20494.56	28.89
Count	24.00	24.00	24.00
Confidence Level(95.0%)	3.33	1294.04	1.95

SUMMARY STATISTICS FOR 22 SECONDS CYCLE TIME

	Work done(KJ)	*Motor Energy(KJ)*	*Average tilt Angle(Degrees)*
Mean	78.07	24229.12	14.23
Standard Error	1.36	531.92	1.93
Median	78.73	24646.80	15.91
Mode	#N/A	#N/A	22.60
Standard Deviation	4.73	1842.63	6.70
Sample Variance	22.33	3395295.73	44.87
Kurtosis	0.46	5.22	-1.09
Skewness	-1.03	-2.04	-0.41
Range	15.98	7060.32	20.20
Minimum	68.10	19180.32	2.40
Maximum	84.08	26240.64	22.60
Count	12.00	12.00	12.00
Confidence Level(95.0%)	3.00	1170.75	4.26

SUMMARY STATISTICS FOR 24 SECONDS CYCLE TIME

	Work done(KJ)	*Motor Energy(KJ)*	*Average tilt Angle(Degrees)*
Mean	83.75	27665.08	10.30
Standard Error	0.67	205.19	2.21
Median	83.62	27745.44	9.09
Mode	83.62	28464.00	6.67
Standard Deviation	2.32	710.80	7.65
Sample Variance	5.39	505231.03	58.57
Kurtosis	1.09	0.49	0.50
Skewness	0.97	-0.82	0.76
Range	8.09	2355.84	26.25
Minimum	80.95	26168.16	0.16
Maximum	89.04	28524.00	26.41
Count	12.00	12.00	12.00
Confidence Level (95.0%)	1.48	451.62	4.86

SUMMARY STATISTICS FOR 26 SECONDS CYCLE TIME

	Work done(KJ)	*Motor Energy(KJ)*	*Average tilt Angle(Degrees)*
Mean	81.44	27842.64	11.37
Standard Error	2.40	359.55	2.80
Median	83.65	28089.12	8.46
Mode	#N/A	#N/A	#N/A
Standard Deviation	7.59	1137.00	8.85
Sample Variance	57.58	1292771.96	78.31
Kurtosis	0.26	-1.03	-0.92
Skewness	-0.92	-0.64	0.77
Range	24.56	3182.88	24.58
Minimum	66.30	25930.56	1.72
Maximum	90.86	29113.44	26.30
Count	10.00	10.00	10.00
Confidence Level(95.0%)	5.43	813.36	6.33

SUMMARY STATISTICS FOR 30 SECONDS CYCLE TIME

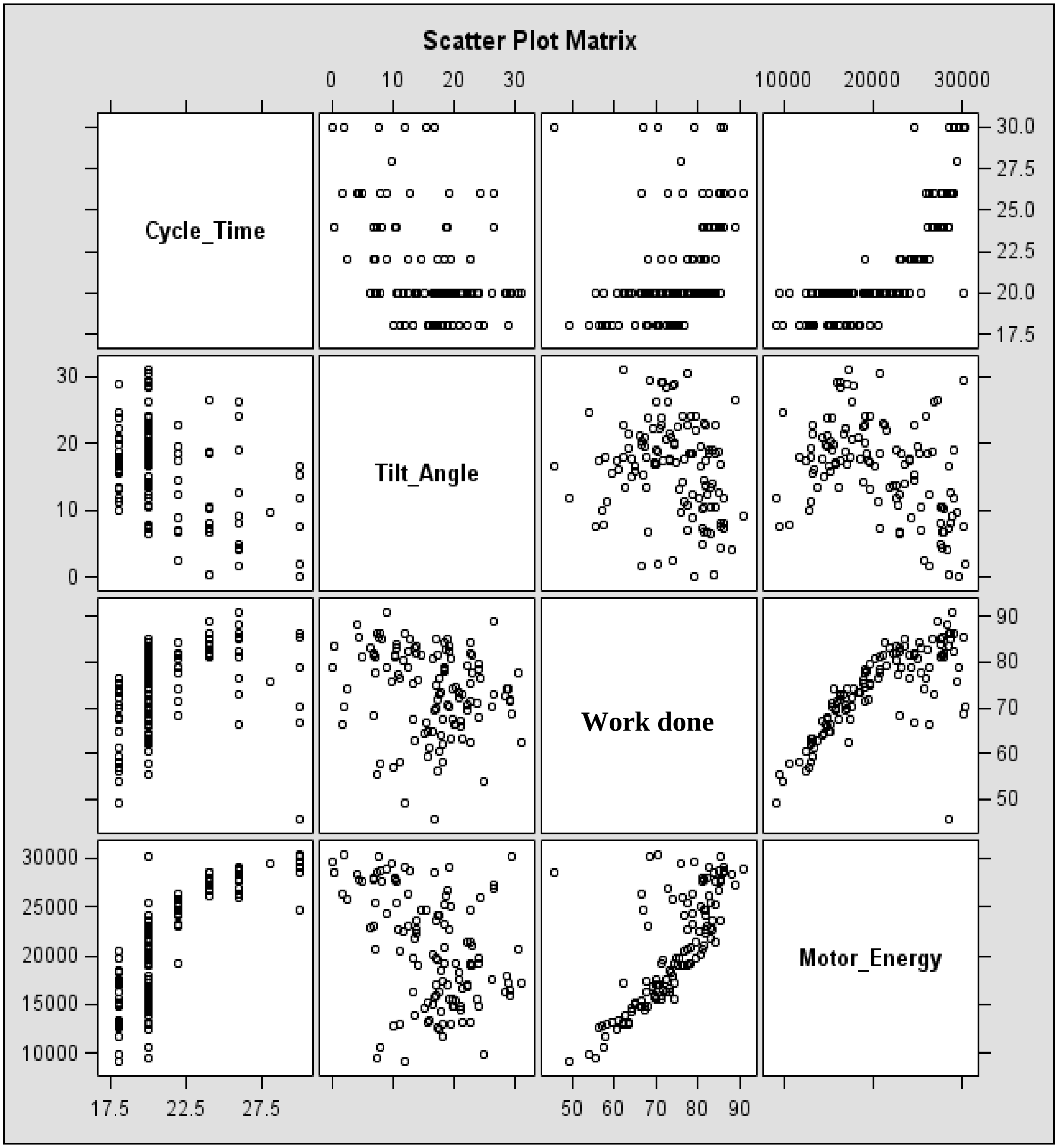
	Work done(KJ)	*Motor Energy(KJ)*	*Average tilt Angle(Degrees)*
Mean	72.23	28750.80	8.89
Standard Error	6.21	858.03	2.83
Median	74.58	29379.36	9.70
Mode	#N/A	#N/A	#N/A
Standard Deviation	15.21	2101.73	6.92
Sample Variance	231.32	4417284.07	47.92
Kurtosis	1.23	3.65	-2.00
Skewness	-1.16	-1.85	-0.24
Range	40.62	5645.76	16.57
Minimum	45.65	24720.96	0.13
Maximum	86.27	30366.72	16.70
Count	6.00	6.00	6.00
Confidence Level(95.0%)	15.96	2205.63	7.26

Spearman correlation coefficients: p-values shown in parenthesis

Number of data = 121 Prob>|r|under Ho: ρ=0				
	Cycle Time	Tilt Angle	Work done	Motor Energy
Cycle Time (secs)	-	-0.35353	0.53498	0.7903
		(< 0.0001)	(< 0.0001)	(< 0.0001)
Tilt Angle (°)	-0.35353	-	-0.26213	-0.40171
	(<0.0001)		(<0.0037)	(<0.0001)
Work done (kJ)	0.53498	-0.26213	-	0.78213
	(<0.0001)	(<0.0037)		(<0.0001)

Kendall Tau b coefficients: p-values shown in parenthesis

Number of data = 121 Prob>|r|under Ho: ρ=0				
	Cycle Time	Tilt Angle	Work done	Motor Energy
Cycle Time (secs)	-	-0.25385	0.42626	0.66034
		(< 0.0002)	(< 0.0001)	(< 0.0001)
Tilt Angle (°)	-0.25385	-	-0.16769	-0.26851
	(<0.0002)		(<0.0065)	(<0.0001)
Work done (kJ)	0.42626	-0.16769	-	0.65229
	(<0.0001)	(<0.0065)		(<0.0001)


Scatter Plot Matrix
Cycle_Time
Tilt_Angle
Work done
Motor_Energy
0
10
20
30
10000
20000
30000
30.0
27.5
25.0
22.5
20.0
17.5
90
80
70
60
50
15000
25000
17.5
22.5
27.5