COMPARISON OF ENERGY INTENSITIES AT THE GHACEM CEMENT FACTORIES AT TEMA AND TAKORADI

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BY

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NYANSAPƆ WƆ SANE NO BADWENMA

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DECLARATION

I hereby declare that this thesis is the result of my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

I dedicate this thesis to my mother, the late Abena Serwa.

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ABSTRACT

Cement factories at Tema and Takoradi were among the number of industries that were established after the nation attained independence in 1957. They were intended to provide cement for the infrastructure developments that were going on at that time, reduce importation bills on cement and create employment. This was intended to support the government policy of changing the agrarian society into industrialized one. As the nation industrialized and increased its Gross National Product (GNP), there was a clear trend towards higher consumption of energy.

There was a rapid increase in the demand for electricity which the Electricity Company of Ghana, the supply authority, could not meet. It became necessary, therefore, to look at demand-side management of the power sector.

This research has studied the production of cement at Ghacem cement factories at Tema and Takoradi. Major energy consuming items were identified and listed. Electric energy consumption data documented at the two factories, from the year 2000 to 2005, were obtained. The load factor was computed, on monthly basis, for the six-year period, for the two factories and graphs drawn to show the variations. Power factor at the two factories were found to be low so causes of the low levels of power factor were identified and ways of improving the power factor were suggested. Lists, showing the currents which would have been drawn by the two plants, had the power factor been improved to unity had been provided. Finally, electric energy intensities were also computed on monthly basis, graphs were drawn to depict the differences. The results were compared and discussed. The maximum difference of the energy intensity was found to be 10% in favour of Takoradi factory. The research identified this outcome to the installation of extra powerful dust plants at the Tema

factory to control environmental pollution and the occasional use of concrete plant and shortcrete mortar plant which are not available at the Takoradi factory.

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NOMENCLATURE

A	Amperes
a. c	Alternating current
¢	Cedi
ECG	Electricity Company of Ghana
GNP	Gross National Product
h	hour
h.p.	horse power
I	current
kVA	Kilovolt Amperes
KVAC	Kilovolt-ampere capacitive
KVAR	Reactive Kilovolt Ampere
kW	Kilowatt

kWh	Kilowatt-hour
LF	Load factor
m	meter
MD	Maximum demand
Mt	metric tons
P	Power
P.f	power factor
PURC	Public Utilities Regulatory Commission
V	Volts
VALCO	Volta Aluminium Company
W	Watts

CHAPTER 1

INTRODUCTION

1.1 Background

After attaining independence in 1957, the government of Ghana made concerted efforts to foster energy intensive industries. This was intended to change the agrarian society into industrialized nation. This led to the construction of the hydropower plant at Akosombo, followed by the establishment of industries such as, the Volta Aluminium Company (VALCO), Tema Oil Refinery, Tema Cement Works, Tema Steel Works, Akosombo Textiles Limited, Nsawam Food Cannery, Kade Match Factory, State Gold Mining Companies, Oda Wood Complex, and the Asutuare Sugar Factory, among others.

The cement factories were established to provide cement for infrastructure development such as the construction of the Tema harbour, Accra – Tema motorway, the State House and also reduce importation bills on cement. The Tema cement works was commissioned in January, 1965 and had a yearly output of approximately 115 000 tons of cement with one mill. The Takoradi plant started production in September 1967 with an annual capacity of 500 000 tons of Portland cement with three mills. Ghana Cement Works limited took over the ownership and management of the Tema plant on 1st September, 1967 and the Takoradi plant on 17th June, 1968, (Ghacem Information Brochure, 1969). The cement plant at Tema currently produces an average of 900 000 metric tons of cement per year and the Takoradi plant produces 720 000 metric tons. In 1967, the Tema factory directly employed one hundred and eight (108) workers while Takoradi plant employed two hundred and seventy six (276). Currently, the two factories directly employ about 900 personnel, (30th Anniversary Brochure, 1999).

1.2 Objectives

The aim of the study is to provide information that could be used in assessing the possibility of improving the rate of production at Ghacem Cement factories at Tema and Takoradi.

Specifically, the objectives of this study are:

- To study production of cement at Tema and Takoradi factories.
- To monitor electricity consumed.
- To obtain energy bills over a given period.
- To compute energy intensities for the two factories.
- To identify causes of difference in energy intensities and suggest measures to improve them.

1.3 Scope

The study focuses only on the Ghacem Cement Works factories at Tema and Takoradi. The focus has been mainly on electric energy consumed compared with tons of cement produced at the two factories.

1.4 Methodology

The methodology involved study visits made to the two Ghacem factories at Tema and Takoradi. The manufacturing process of cement at the factories was studied and relevant production data as well as information, such as the brief history of the two plants already documented were collected. Some Engineers and Technicians were interviewed.

Sources of information used were obtained from literature available at the Tema and Takoradi factories as well as information on the internet.

The analyses made were based on the data collected and those measured during the study visits. Table of major energy consuming items, with their power rating, at the cement factories at Tema and Takoradi was compiled. The load factor was calculated on monthly basis and comparison made. Power factor improvement was also discussed and electric currents at improved power factor computed. Finally, monthly energy intensities were computed, and graphs drawn to illustrate the variation of the energy intensities, comparisons were made and the results discussed.

1.5 Significance of Research

This thesis is the comparison of energy intensities of the Ghacem Cement factories at Tema and Takoradi. It is measuring how much electrical energy would be consumed to produce one ton of cement at the two factories. The energy involved here is the total electrical energy. This includes the energy used directly for the production of cement, lighting, environmental pollution control, machine tools drives, air conditioning, office equipment, recreational facilities, etc. (industries that ignore any of these operates under an overhead that escalates along with electric rates). The energy intensity assessment gives an indication of the economy of production. It should prompt manufactures of the need for efficient use of electricity or any other source of energy they might be using. Electrical energy had been identified to be a factor of production whose cost directly affects the price of the cement.

Cement factories at Tema and Takoradi are under one management. The assessment would give an indication to them as to which of them would need to improve in order to be ahead of their competitor, which is Diamond Cement.

Another thing which should call for energy intensity assessment is the tariff structure. The tariff structure being used in Ghana now is the increasing or inverted block tariff, where the kilowatt price increases as consumption rises. It means that the higher the consumption the higher the consumer would pay for incremental blocks. (The decreasing block is where the initial slab of consumption has the highest price followed by successively cheaper blocks). This accounts for high electric energy charges. Manufacturing industries are again charged for maximum demand and low power factor penalty. These charges are higher than the normal kilowatthour consumption charges. Therefore certain energy intensity values should serve as "gauge" for prompt energy efficient use action.

Energy intensity assessment would be more beneficial to industries that produce similar items for the same market. For example, Tema Textiles Limited and Akosombo Textiles Limited, both of them produce textiles for the Ghanaian market under different management. If one of them is able to improve his energy intensity, his production cost would be lower and his competitiveness would be enhanced.

Improving energy intensity calls for improving demand –side efficiency, i.e. the efficiency with which electricity is used by the consumer, (Turkson, 2000). If losses in energy consumption, especially with large consumers, are recovered, it could be supplied to other consumers without expansion in the generating capacity.

In summary, energy intensity compares the energy consumed to produce unit quantity. In cement production, the unit quantity is the ton of cement produced.

Energy intensity assessment gives an indication of the economy of production and calls for prompt action to be taken when the values are high.

1.6 Structure of Thesis

The following chapters present the work done to meet the objective of the work. The research focuses on the comparison of energy intensities of Ghacem Cement Factories at Tema and Takoradi. Chapter two reviews the literature on how cement is produced and the major energy consuming items in the cement production. It highlights on some motors which account for major electrical energy consumption. Chapter three presents an overview of types of methodology available for conducting research and why survey method was used for this research. The electrical energy consumption and cement production data collected at the cement factories at Tema and Takoradi are also presented. Chapter four involves electrical energy assessment where relevant parameters including load factor and energy intensities are analysed. Chapter five discusses and compare the calculated values for the two factories.

Chapter six presents concluding remarks and recommendations for further work.

CHAPTER 2

LITERATURE REVIEW

2.1 Production of Cement

Cement is a hydraulic binder and is defined as a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes which, after hardening retains its strength and stability even under water, (http://www.cima.com.my).

Typical Portland cements are mixtures of tricalcium silicate ($3CaO.\ SiO_2$), tricalcium aluminate ($3\ CaO.Al_2O_3$), and dicalcium silicate ($2\ CaO.\ SiO_2$), in varying proportions, together with small amounts of magnesium and iron compounds. Gypsum ($CaSO_4.2H_2O$) is added to regulate the settling time of the cement,(www.encarta.msn.com/encyclopedia). The Ghacem Cement factories in Ghana use clinker, limestone and gypsum. The clinker is a limestone which has been chemically treated and heated to a temperature of about 1500 ^oC. The heating is usually accomplished in rotary kilns more than 150 m long and 3.7 m or more in diameter. Ghacem imports its main raw materials, clinker, limestone and gypsum, from Norway. At the Takoradi plant, the raw materials were transported on conveyor belts for a distance of about 700 m before they get to the storage sheds, but at Tema, trucks conveyed the raw materials from the quay to the intake feeder, a distance of about 600 m, and by means of a short conveyor belt, the materials were transported to their sheds.

The second stage of the manufacturing process is the grinding. Accurately measured quantities of the clinker and the limestone were fed into the mills from a feed table and, as they passed through the mill, they were ground by steel balls in the mill. A definite proportion of the gypsum is added to control the settling time of the cement. The milling was done in two stages. The first grinding, using bigger steel balls of 60 mm diameter, break up the materials, and the second, using smaller steel balls of 30 mm diameter, ground the materials into fine powder. The particle size is measured by laser diffraction analysis at the quality control unit of the factories. The measure of fineness usually used is the "specific surface", which is the total particle surface area of a unit mass of cement. Typical values are 320 – 380 m^2kg^{-1} for general purpose cements, and 450 – 650 m^2kg^{-1} for "rapid hardening" cements (www.en.wikpedia.org/wiki/image). After grinding, the cement is discharged from the mill through a vibrating screen to the cement pump from where it is blown by compressed air into silos. The silos at the Tema plant have a total storage capacity of 6 200 tons and those at Takoradi, 7000 tons.

The final stage of the production of cement is the packing. The processed cement was shifted from the bottom of the silo to the top of the packing department with the aid of bucket elevators. There were three rotating packing machines at each factory. Each machine had eight spouts on which the bags were placed and through which the filling took place. The packed cement bags were conveyed on belts to the "lorry side" or "rail side" of the loading bay for dispatch.

The cement was delivered in 50 kg paper bags, 1.5 tons big bags or dispatched to the consumer's doorsteps by company operated bulk trucks, with capacity ranging from 12 tons to 40 tons.

The Tema factory had a ready-mixed concrete plant on the site, complete with mixer-trucks available for distribution of concrete in the Tema-Accra area. Again, Ghacem had equipment that is used to produce shortcrete mortar, a product used to stabilize blasted sulphur, also used for major rehabilitation of buildings and structures. Figure 2.1 depicts the flow diagram for cement, concrete and shotcrete

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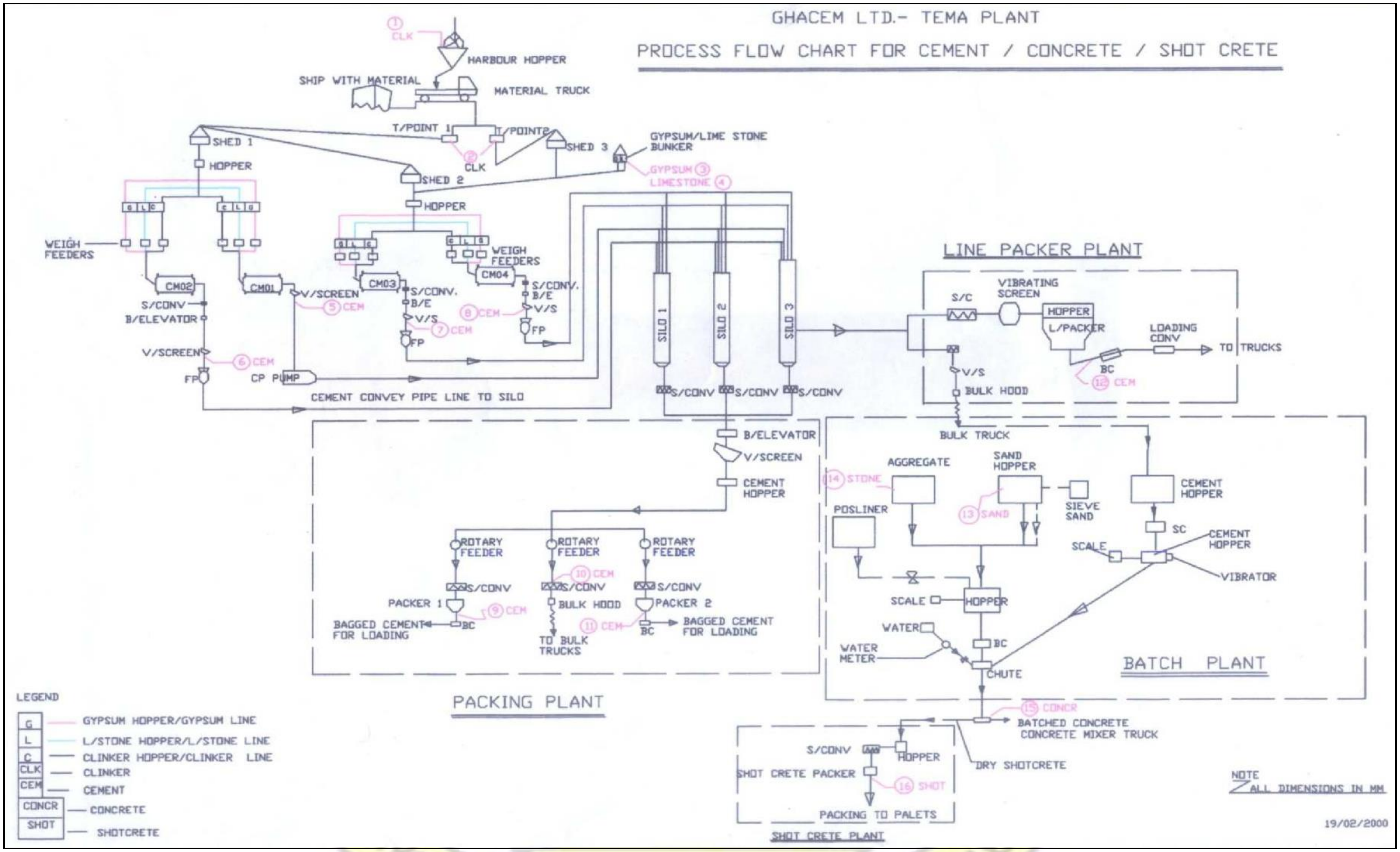

Figure 2.1 Process Flow Chart for Cement, Concrete and Shotcrete at Tema

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2.2 Use of Electricity

Electricity is used for the following operations in the production of cement at the two Ghacem factories at Tema and Takoradi:

- Milling
- Materials transportation
- Packaging
- Environmental control
- Lighting
- Machine tool drives
- Heating, ventilation and air conditioning
- Computers and other controls

2.2.1 Milling

Cement grinding process is highly energy intensive. Figure 2.2 shows a typical mill (arrowed), used for the grinding of the clinker, limestone and gypsum. Two of the four mills at Tema factory are each 11.40 m in length and 3.66 m in diameter and revolve at 15 rev/min. Each was driven by 2 400 kW motor, running at 988 rev/min through a reduction gear box. The other two were each driven by 1 000 kW motor running at 740 rev/min. Each of the 2400 kW driven mills produced cement at the rate of about 80 ton/h while the 1000 kW driven mills produced about 25 ton/h. At Takoradi factory, three of the four mills were driven by 1000 kW and one by 3500 kW motor. Each of the 1000 kW driven mills at Takoradi produced cement at the rate of about 25 ton/h and the 3500 kW driven motor produced about 90 ton/h. The total capacity of the mill motors makes the major difference between the two plants. While Tema was using a total capacity of 6800 kW, Takoradi was using 6500 kW.

Figure 2.2 Typical Cement Mill

(Adapted from http://en.wikpedia.org/wiki/image)

2.2.2 Material Transport

Material transport associated with cement milling process is accomplished by a variety of mechanisms including screw conveyors, belt conveyors, drag conveyors, bucket elevators, air slide conveyors and pneumatic conveying system.

2.2.3 Packaging

Packaging is the last stage of the cement manufacturing process. In advanced countries, the cement is supplied to costumers in bulk haulage trucks or direct under pressure to the costumer's silo. In Ghana and other developing countries, the cement is supplied mostly in 50 kg bags.

From the silos, (where the cement could be stored to prevent moisture from reacting with the cement), cement is conveyed to the top of the packing plant using bucket elevators. The rotating packing machines had eight spouts each on which the empty paper bags were placed. It took one revolution of the packing machine to fill and seal the bags.

At the Tema factory, 3000 to 4000 bags of cement were produced per hour; while 2000 to 2500 bags of cement were also produced per hour at the Takoradi factory.

2.2.4 Environmental Control

The manufacture of cement generates large quantities of dust which are potentially environmentally damaging. Cement dust causes lung function impairment, chronic obstructive lung disease, restrictive lung disease, pneumoconiosis and carcinoma of the lungs, stomach and colon, (www.ncbi.nlm.gov/core/jig). These are prevented from escaping to the atmosphere.

The two areas where dust has the potential to escape are via air streams that have been used to carry the cement (e.g. the raw materials sheds, the mills) and directly from equipment used to transport cement (e.g. the various conveyor belts). Thus to prevent dust emissions all transport equipment are enclosed, and the air from these enclosures was treated in an electrostatic precipitator to remove its load of dust. Here dust-laden air passes between an electrode carrying 50 000 volts and an earthed collection plate. The electrostatic discharge between the electrode and the plate forces the dust out of the plates, from which it was removed. Eighteen of such dust plants are installed at the Tema factory and thirteen at the Takoradi factory.

2.2.5 Lighting

The lighting need in the plants is significant. To promote safety and industrial efficiency, adequate illumination was provided at the mills, the packing bay, the loading bay, the stores, the workshops, administration, the compound, canteen, and clinic. At Tema for instance, it was made up of:

- 56 Mercury lamps, each 1000 W, totalling 56 kW
- 48 Sodium vapour, each 400 W, totalling 19.2 kW
- 932 Fluorescent tubes, each 40 W, totalling 37.28 kW

In all the lamps consume 112.48 kW.

2.2.6 Machine Tools

Machine tools provide the means for cutting to shape a workpiece to required dimensions; the machine supports the tool and the workpiece in a controlled relationship through the functioning of its basic members (Lissaman, 1991).

To ensure uninterrupted production with little downtime, the two cement factories at Tema and Takoradi had well equipped workshops where all repair works were undertaken. The machine tools available in each of the workshops were; centre lathe, pillar drilling machine, sensitive drilling machine, off-hand grinding machine, milling machine, power hacksaw, pedestal grinding machine and arc welding plant. All these machines are electric power driven.

2.2.7 Heating, Ventilation and Air-Conditioning

Not much heating was seen on the plants because they had no operation in the manufacturing process which involved direct heating. The electrical appliances at the kitchens had been replaced with gas operated ones. Ventilation, which is the process of supplying or removing air, by natural or mechanical means, to or from any space was given serious attention at the factories. Areas that were adequately ventilated include, the packing hall, the sheds where the raw materials were off loaded, the workshops and the loading bay. Air conditioning was also given serious consideration at the factories. Almost every office at the factories and the staff bungalows had air conditioners. Induced draught cooling towers were also found on the plants, they were used to cool and circulate the compressor cooling water.

2.2.8 Computers and Other Controls

Information and communication technology played a vital role in the administration of the factories. Computer equipped with printer and photocopying machine were found in almost every office. Also, the percentage of each raw material, namely, clinker, limestone and gypsum, entering each mill at any time, were monitored with computers. The computer and its accessories are minor electric energy consuming items but as they were used for a longer period of time, their cumulative effect became appreciable.

2.2.9 Major Energy Consuming Items

The preceding sections explained how electrical energy was used in the production of cement at Ghacem Cement factories at Tema and Takoradi. Table 2.1 below, is a list of some of the major energy consuming items, with their power ratings in kilowatts, at the two cement factories.

Table 2.1 List of Major Electrical Energy Consuming Items at Ghacem cement Factories at Tema and Takoradi (Power rating of Items in kW)

ITEMS	TEMA	TAKORADI
Mill 1 motor	1000	1000
Mill 2 motor	1000	1000
Mill 3 motor	2400	1000
Mill 4 motor	2400	3500
Dust plant fan motors	200	200
Separator fan drive	500	250
Compressor hall motors	200	200
Packing plant suction fan motors	63	63
Bucket elevators	385	385
Screw conveyors	71	71
Cooling water pumps	60	60
Lights	112.48	
Machine tools	35.84	35.84
Air-conditioners	156	

2.3 Electric Motors

Motors represent the largest single use of electricity in most plants. The function of an electric motor is to convert electrical energy into mechanical energy. In a typical a.c. motor, current passes through the motor windings and creates a rotating magnetic field. The magnetic field in turn causes the motor shaft to turn. Motors are designed to perform this function efficiently. The following is a brief summary of the more common types of electric motors in use today in industries.

2.3.1 Wound Rotor Induction Motor

The wound rotor induction motor is sometimes known as the “slip-ring” motor. The wound rotor motor has brass alloy rings mounted on, but insulated from the shaft. Carbon or copper-carbon brushes take current into and out of the rotating secondary winding through these slips rings with which they make sliding contact. The winding is either in star or delta depending on design considerations. The normal operation is with the rings short-circuited, but for starting and speed control, the slip rings permit the insertion of additional impedance or a voltage source, in the rotor circuit.

In general, the slip ring motor is employed for developing a large starting torque with limited starting current and rotor heating; for minimizing rotor heating on a repeated-starting duty; for obtaining limited speed reduction, sometimes with slip power recovery; and for “loss-free” speed control by cascade connection (Hindermarsh, 1995). The applications include high-inertia drives requiring variablespeed control, flywheel machine drives, air- compressors, ram pumps, crushing mills, cranes, hoists winches and lifts. The wound rotor induction motor is used to drive all the cement mills at Tema and Takoradi Ghacem cement factories.

2.3.2 Cage Rotor Induction Motor

The cage rotor motor consists of a set of uniformly spaced bars accommodated in slots and connected at each end to conducting rings. The cage may be built of copper bars brazed on to brass or copper end-rings, or the rotor conducting may be die-cast in aluminium to form the cage and end-rings in one operation. The construction of the cage makes the rotor to be sometimes referred to as squirrel-cage rotor. The squirrel- cage construction is simple, cheap and robust. A further advantage becomes evident when the stator is provided with coils and connections which the number of poles, and therefore the synchronous speed, to be changed. In this case, although the sequence of conductor current reversals round the periphery is altered, the end rings still provide free paths for the currents to flow; the cage winding adapts itself readily to a different number of poles.

One of the disadvantages of the simple cage rotor is its fixed characteristics; no external rotor circuit impedance can be added, to reduce the starting current for example, which might be six times rated value, with full voltage applied. The limitations can be overcome largely, by designing the slot bars with special shapes so that eddy-current effects, are pronounced and cause a high effective resistance at starting when the secondary frequency is high, and a low resistance at normal speed when the slip frequency is very low. Such a resistance variation is beneficial for starting characteristics. The use of simple rectangular bars, if deep enough to enhance the eddy-current effect, will result in considerable improvements over round or square bars.

The cage rotor is always preferred, as it is more robust and much cheaper winding. It is explosion-proof since the absence of the slip-rings and brushes eliminates the risk of sparking. It finds application for most industrial drives where speed control is not required. Some of its starting torque disadvantages can be overcome by use of the double cage or deep-bar cage construction (Chapman, 2005).

Apart from the cement grinding mills, every electric power driven item that can be found at the two Ghacem cement factories at Tema and Takoradi are driven by the cage rotor induction motors.

2.3.3 Synchronous Motor

Three- phase synchronous motor consists essentially of an a. c. armature, normally wound on the stator frame, with a d. c. field winding wound on a salient pole rotor. The a.c. voltage is applied to the armature and a separate d.c. supply, usually110 V, is connected to the rotor through slip rings. As its name implies, the distinctive feature of the synchronous motor is that the rotor revolves in synchronism with the rotating magnetic field of the stator, and its speed is therefore related to the frequency of the a.c. supply to the stator. In itself, the synchronous motor has no starting torque, and special starting arrangements are necessary. For many years, this motor was confined to a power factor improvement duty, most drives being the application of the induction motor. With improvements in design, the synchronous motor is now being used increasingly for many duties because of several useful factors. Starting characteristics of the modern synchronous motor compare favourably with those of the induction motor. Certain types have been designed for direct-on-line staring taking less than three and half times full-load current at start, thus reducing and occasionally eliminating the need for special starting arrangements. Induction motors always operate at a lagging power factor and consequently a synchronous motor of equal output and operating at unity power factor will have a smaller kVA input rating. This means that the synchronous motor can have lower losses and a higher efficiency. It can also be a smaller machine physically, which is an advantage from the point of view of providing foundations and buildings

Typical applications of the synchronous motor include Banbury mixers (used to mix the raw ingredients for rubber products), cement-grinding mills, centrifugal compressors, motor-generator sets, mine ventilating fans, pumps, reciprocating compressor drives and electric ship-propulsion drives.

The speed/torque characteristic is a straight line from no-load to 140 per cent full-load torque. A starting torque is obtained by certain starting arrangements which allow the motor to start as an induction motor before running as a synchronous machine. The salient –pole type of motor runs continuously at synchronous speed regardless of load fluctuations. The power factor can be controlled to suit the load conditions imposed on the installation by associated plant. The power factor can be varied at will by varying the exciter output, and this gives the synchronous machine the advantages over static capacitor, which can only be switched.

The starting method on modern types involves a number of copper bars embedded in the pole faces and connected at their ends. These short-circuited loops form a squirrel-cage winding and the motor behaves like a cage-rotor motor on starting. The machine pulls into synchronism when the d.c. field winding supply is increased to its stated maximum value. During running, these cage windings in the pole faces act as “damping” windings in that they help to smooth out any oscillations that may occur because of sudden fluctuations of load. Because of cage action, the starting current is kept low by reducing the stator voltage to about 60 per cent of the normal value. This is done either by a limiting resistor or reactor; more usually it is done by using an auto-transformer or star-delta starter.

The principal advantages of the synchronous motor are:

- The ease with which the power factor can be controlled.
- The speed is constant and independent of the load.

The principal disadvantages are:

- The cost per kilowatt is generally higher than that of an induction motor.
- A d.c. supply is necessary for the motor excitation. This usually provided by a small d.c. shunt generator carried on an extension of the shaft.
- Some arrangement must be provided for starting and synchronizing the motor (Thompson, 1996)

2.3.4 Synchronous Induction Motor

This type is essentially a wound–rotor induction motor, although the constructional details differ to some degree. The machine starts as an induction motor by cutting out an external rotor resistance. When the rotor is running at speed, a d.c. supply is switched onto the slip rings to provide the rotor with a d.c. field. The motor then pulls into synchronism. The main advantage of this type of motor is that if a heavy overload should occur to force the rotor to drop out of synchronism, the machine will continue to run as an induction motor; and it will pull into synchronism again as soon as the overload condition is removed. The power factor is either leading or unity.

This motor is replacing the usual induction motor for many applications such as large fans, compressors, lineshafts, pumps and generally for machinery where a constant speed is normally required but a small decrease is permissible with overloads. Also it is very often installed along with other induction motors so that it improves the overall power factor of the plant. The leading kVAr capacity is designed to offset the kVAr demand from the induction motors. They have been made for ratings up to 30,000 kW (Hindermarsh, 1995).

In general, three-phase motors are used to drive industrial loads and machinery. The induction motors are commonly used. They are available in two distinct forms: cage machines and slip-ring machines. The cage-rotor is preferred because it is cheaper and robust. It is used mostly where speed control is not required. The main disadvantage of the cage rotor induction motor is its high starting current, which might be six times rated value. Slip-ring induction motor is employed for developing a large starting torque with limited starting current. This makes it suitable for drives such as the cement grinding mills and cranes. Synchronous motor is designed to operate at constant speed and independent of the load. Also, it operates at a leading power factor. For this reason, its application was limited to power factor correction. However, there had been modifications in the design which allow it to be used in the same way as the induction motors and still improve power factor of the plant. The main disadvantage of the synchronous is its higher cost as compared to induction motors. Electrical drive of industrial load and other machinery is more economical, cleaner, more convenient and more flexible than any other type of drive.

2.3.5 High Efficiency Motors

High efficiency of high efficiency motors is obtained by the use of thinner steel laminations in the stator and rotor; use of steel with better electromagnetic properties; addition of more steel; increase of the wire volume on the stator; improved rotor slot design; and the use of smaller more efficient fans. Each of these approaches involve more material, increased material costs, or high manufacturing costs, which accounts for the higher first cost. However, the 25 to 20 per cent higher initial cost is offset by lower operating costs. Other benefits of high-efficiency motors include less effect on performance from variations in voltage phase imbalance, and partial loading. (Muller, 1995)

2.3.6 Variable Frequency a.c. Motors

When centrifugal pumps, compressors, fans, and blowers are operated at constant speed and output is controlled with throttle valves or dampers, the motor operates at close to full load all the time, regardless of the of the delivered output. Substantial energy is dissipated by these closed dampers and valves. Significant energy savings can be realized if the driven unit is operated at only the speed necessary to satisfy the demand. Variable speed drives permit optimum operation of equipment by closely matching the desired system requirements.

Variable-frequency a.c. controllers work with standard a.c. induction motors which allow them to be easily added to an existing drive. Disabling the throttling and by-pass valves and replacing them with an adjustable-speed drive controlled by feedback from a static pressure sensor or flowmeter optimizes control and saves electricity. Many types of pumps (centrifugal, positive displacement, screw, etc.) and fans (air cooler, cooling tower, heating and ventilating, etc.), as well as mixers, conveyors, dryers, colanders, crushers, grinders, certain types of compressors and blowers, agitators and extruders, are driven at varying speeds by adjustable-speed drives. (Muller, 1995)

2.4 Energy Losses in Motors

Energy losses in motors account for high operating cost of manufacturing industries. Motors are designed to perform their function efficiently; opportunity for savings rests primarily in their selection and use. From the book entitled "Modern Industrial Assessments" by Muller et al, identified energy losses in industrial motors to the following:

2.4.1 Idle Running

The most direct power savings can be obtained by shutting off idling motors, thereby eliminating no-load losses. The idle no-load current is frequently about the same as the full-load current, but this is often considered as unimportant.

2.4.2 Efficiency at Low Load

When a motor has a greater rating than the unit it is driving requires, the motor operates at partial load. In this state, the efficiency of the motor is reduced. The use of oversized motors is fairly common because of the following conditions:

- Personnel may not know the actual load; and, to be conservative, select a larger motor than necessary.
- The designer or supplier wants to ensure his unit will have ample power; therefore suggests a driver that is substantially larger than the real requirements.
- When a replacement is needed and a motor with the correct rating is not available, personnel install the next larger motor. Rather than replace the motor when one with the correct rating becomes available, the oversized unit continues in use.

- A larger motor is selected for some unexpected increase in driven equipment load which has not materialized.
- Process requirements have been reduced.
- For some loads, the staring or breakaway torque requirement is substantially greater than the running torque; thus oversizing of the motor is a frequent consequence, with penalties in the running operation.

Replacement of underloaded motors with smaller motors will allow a fully loaded smaller motor to operate at a higher efficiency. This arrangement is generally most economical for larger motors, and only when they are operating at less than one-third to one-half capacity, depending on their size.

2.5 The Energy Charge

The energy charge is the cost which the energy supply authority imposes on consumers for electric energy used. (Hughes, 2008). Traditionally, electric power pricing policy in most countries has been determined mainly on the basis of financial or accounting criteria, e.g., raising sufficient sales revenues to meet operating expenses and debt service requirements while providing a reasonable contribution towards the capital required for future power system expansion. Due to the variety of ways in which electricity is used, the charges may take many forms in order to encourage the best utilization of the generated electricity (Mohan, 1990)

Energy charge is based on the number of kilowatt hours (kWh) used during the billing cycle, which is one month in Ghana. The total kilowatt hours are multiplied by the energy charge for total energy billing. The energy charges vary with the type of service, voltage, and energy consumption. Tariffs contain power factor penalty surcharges in excess of the regular price to encourage consumers whose power factor drops below some acceptable limit (usually 0.95) to install capacitative correction. Fuel surcharge or fuel adjustment clauses are also becoming increasingly common. This permits the utility to quickly pass on to the consumer any unforeseen increases in fuel costs, especially of liquid fuels. The maximum demand charge component is the added cost of supplying energy during peak-load periods and consumers are fully charged for using it at that time. (Mohan, 1990). Examples of energy rate schedules are as follows:

Example 1: General Service schedule which is applied to electrical load demand of up to 8 000 kilowatt hours (kWh) per month. Thus a non- maximum demand charge schedule, there is no measured maximum demand charge and the cost of energy and demand are one charge.

Example 2: Rate schedule A-12 is applied to electrical load demand of 30 to 1 000 kilowatt of demand per month. This schedule has an energy charge, fuel adjustment charge, maximum demand charge, and low power factor penalty.

Example 3: Rate schedule A-22 is applied to electrical load demands of 1 000 to 4 000 kilowatt of demand per month. This schedule has an energy charge, fueladjustment charge, maximum demand charge, and low power factor penalty.

Example 4: Rate schedule A-23 is applied to electrical load demands of 4 000 and above kilowatts (kW) of demand per month

Table 2.2 shows the tariff that is used in Ghana from 1st October, 2003.

Table 2.2 PURC Authorised Tariff – Effective October 1, 2003

Tariff Category		PURC Approved Rates (¢)
SLT-LV		
Maximum Demand	(¢/kVA/Month)	143,100
Energy Charge	(¢/kWh)	403
Service Charge	(¢/Month)	63,600
SLT- MV		
Maximum Demand	(¢/kVA/Month)	97,520
Energy Charge	(¢/kWh)	382
Service Charge	(¢/Month)	63,600
SLT-HV		
Mamimum Demand	(¢/kVA/Month)	89,040
Energy Charge	(¢ /kWh)	371
Service Charge	(¢/Month)	63,600
NON RESIDENTIAL		
0 – 300	(¢/kWh)	848
300+	(¢/kWh)	1,039
Service Charge	(¢/Month)	21,200
RESIDENTIAL		
*0-50 (Exclusive “Lifeline” Block Charge) (¢/Month)		19,080
1 – 300	(¢/kWh)	583
300+	(¢/kWh)	1,018

SOURCE: Electricity Company of Ghana

2.5.1 The Demand Charge

The demand for electrical energy is not constant, but occurs in peaks and valleys. Power companies are obligated to have enough equipment available to meet a customer’s peak demand, even though this equipment is only used during the peak periods and is not in use during most of the working hours. In order to finance the equipment necessary to provide this peak demand service for industrial users, the power demand charge was created. This charge compensates the utility company for the capital investment required to serve peak loads. The demand is measured in kilowatts (kW) or kilovolt amperes (kVA). These units are directly related to the amount consumed in a given time interval of the billing period. The demand periods vary with the type of energy demand; the high fluctuating demand has a short demand period which can be as short as 5 minutes, but generally demand periods are of 15 or 30 minutes. The period with the highest demand is the one used for billing demand. The demand charge is a significant portion of the electric bill (Clark, 1997).

2.5.2 Power Factor Penalty

Power factor quantifies the reaction of alternating current (a.c.) electricity to various types of electrical loads. Inductive loads, as found in motors and fluorescent lamp ballasts, cause the voltage and current to shift out of phase. Electrical utilities must then supply additional power, measured in kilovolt-ampere, to compensate for phase shifting. Power can be considered as a combination of two individual elements. The total power requirement constituents can be broken down into resistive, also known as the real component, and reactive component. Figure 2.3 shows the components of the electric power. Useful work performance comes from the resistive component, measured in kilowatts (kW) by watt meter. The reactive component, measured in reactive kilovolt-amps (kVAR), represents the current needed to produce the magnetic field for the operation of the motor, drive or other inductive device but performs no useful work, does not register on any measurement equipment such as a watt meter. The reactive component significantly contributes to the undesirable heating of electrical generation and transmission equipment formulating real power losses to the utility.

Power factor is defined as the ratio of real, usable power (kW), to apparent power (kVA). A reduction in power factor indicates a reduction in inductive losses. To accomplish this goal, the industrial electricity user must improve the power factor to a value as close to unity as practical for the entire facility. Power factor can also be defined as the mathematical factor by which the apparent power is multiplied in order to obtain active power.

$$\text{Power factor} = \frac{\text{Active power (kW)}}{\text{Apparent power (kVA)}}$$

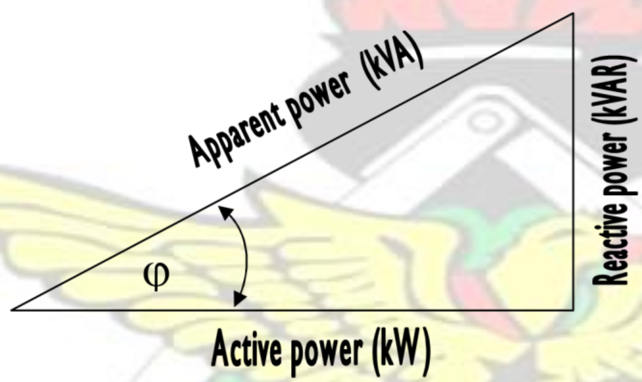

Figure 2.3: Components of Electrical Power

The supply authorities penalize low power factor by charging so much for each point below a certain power factor or by charging so much per kilovolt-ampere (kVA). The reason being that, for a given power, the lower the power factor, the larger must be the size of the alternator to generate that power and the greater must be the cross-sectional area of the conductor to transmit it; in other words, the greater is the cost of generation and transmission of the of the electric energy (Hughes, 2008)

There should be Government involvement for the realisation of the potential for efficient use of energy. For example, in the Republic of Korea, those companies whose annual electricity consumption is greater than 4 million kWh are termed as Energy Management Required Users (EMRUs). They report to the Government their annual production, energy facilities, equipment, annual energy use, and corporate energy conservation plan along with the results of implementing the previous year's plan (Mi-Chung, 2002).

CHAPTER 3

METHODOLOGY AND DATA

This chapter discusses how to get the information or data needed for the research

3.1 Introduction

Methodology is the set of methods used for study or action in a particular subject, as in science or education. Types of methodology available for research of this kind include experiments, quasi experiments, survey method and observation method. Below is brief description of the various types of methodology after which the more suitable one was chosen.

3.2 Using Experiments

An experiment is a means of testing the effect of one thing on another, or others. The variable being tested for its influence on the other one is called the independent variable. The other is dependent variable because its value is dependent on the one being tested.

Advantages of the experimental method are; its suitability for testing causality and the degree of confidence that can be obtained that the effect observed was caused by the thing tested.

The main disadvantage of the experimental method is that the behaviour of the phenomena observed takes place in very false circumstances. It is therefore said that the experimental method has low external validity, which means it is not very generalisable to situations in the real world (Marshall, 1997).

3.3 Quasi Experiments

Quasi experiments are methods which approximate to experiment but do not fit all the requirements of that definition. Usually the experimenter has no control in respect of exposing the target group to the independent variable. Invariably this occurs as a chance of fate.

Some of the effects observed may not be due to the independent variable focused upon. Sometimes it is possible to approximate quite closely to experimental conditions. At times it may be possible to randomize the allocation of participants into the target and control group.

One of the main advantages of this method is that it avoids testing effects. The other is that it is artificial as experimentation and therefore offers higher external validity. The disadvantages are that it has low internal validity and also it lacks control over independent variables and significant control can only be achieved by means of expensive design (Marshall, 1997).

3.4 Survey Method

Surveys attempt to gather information from an entire group, or more usually a sample, which can be used to make inferences or generates policy or reveal unsuspected facts.

The information may be gathered in several ways, for example, interviews; which are face-to-face exchanges with participants, and questionnaires, or structured lists of written inquires, but it is easily invalidated by poor sampling and ambiguities. Surveys can be purely descriptive or explanatory. They can be purely for the collection of factual information or for decision-making. In the later case there are some fairly complex mathematics used for determining sample size measurement error and analysis of data.

The advantages of the surveys are:

- A lot of data can be collected.
- The data comes ready structured and therefore needs less analysis.
- The findings have high external validity.

The disadvantages are:

- The truth of the answers may be suspect.
- It depends heavily on participant motivation.
- Interviewer and questionnaire can be bias (Marshall, 1997)

3.5 Observation Methods

Observation methods can be passive or involve participation.

- In passive observation researchers just watch and record.
- In active observation researchers get involved in the group behaviour. This is known as participant observation. This may be overt or covert, depending on whether researchers disclose why they have joined the group.

3.5.1 Participant Observation

An advantage of participant observation is that researchers can "get behind the veil". They can become accepted as members of the group being studied, so members cease to show them only the behaviour they wish them to see as researchers. In other words, participant observer is more likely to see people behaving naturally.

This is especially so if their true purpose for joining the group is not disclosed. This is known as covert research. This type of method poses an obvious ethical dilemma.

Nevertheless, many covert research projects are carried out and researchers considering this method will have to handle the ethical question themselves. One way of handling it is by asking themselves whether the behaviour they intend to study is normally displayed publicly, without reservation, so that any one who may read the report could have actually seen for themselves the behaviour on which it is based.

Observational techniques have their advantages. They are useful for a wide range of research problems and the data quality benefits because of the absence of testing effects. There are disadvantages to observational methodology too. First, reliability tends to be lower. (Reliability of findings is the degree to which we can expect other research projects using the same methodology to arrive at the same findings). Secondly, the findings from observational methodology tend to have relatively low validity. (Validity is the degree to which what were recorded or measured were what were set out to record or measure), (Marshall, 1997)

3.6 Selecting Research Methodology

Research falls into two basic styles which are objective and subjective (or nomothetic and idiographic). Objective approaches are concerned with physical characteristics and external world, universally applicable rules and laws, tested through hypothesis, experiment and survey. Subjective approaches deal with the created social lives of groups and individuals through observation and explanation: both are systematically controlled and empirical and may be used by physical or social scientists (Marshall, 1997)

The title of this thesis is the Comparison of Energy Intensities of Ghacem Cement Factories at Tema and Takoradi. Specifically, what is expected is to study the manufacturing process of cement at the two factories, identify energy consuming items, collect energy bills, obtain records of cement production, calculate energy intensities for the two Ghacem cement factories and make comparison of the values obtained. The findings must be applicable to other situations or factories.

The survey methodology discussed in section 3.4 was selected for this research. The survey method allows the information to be collected by interviews and questionnaire. Some of the data received was by interviews and postal questionnaires by e-mail. The people interviewed were the Production Managers, Maintenance Engineers, Electrical Engineers, Maintenance Planning Engineers, Instrumentation Technicians and Store Keepers. What also influenced the choice of the survey method was that a lot of data could be collected. For this research, six years electrical energy and cement production data were obtained readily structured. The external validity of the survey method is high, that makes it more suitable than the other methods.

Experiment methodology was not selected because no two variables were being tested. Moreover, it has low reliability and validity. Quasi experiment was not also selected because it is very useful when the research involves items that are naturally grouped e.g. age, sex, ethnic groups, etc. Observation methods could have been used in that it is adaptable to many research problems. However, its findings also have low reliability and validity.

In effect, the four types of research methodology, namely experiment, quasi experiment, survey and observation; the survey method provides findings which have high reliability and validity. The findings can be generalised to situations in the real world, which made it suitable for this research.

3.7 Electrical Energy and Cement Production Data

Table 3.1 (a) - (f). below is the electrical energy and cement production data that was obtained from the Maintenance Manager at Takoradi Ghacem Cement factory from the year 2000 to 2005 It shows the electric energy consumed, in kWh; maximum demand in kVA; power factor and the tons of cement produced each month. A similar data was collected from the Electrical Engineer at Tema Ghacem Cement factory for the same period is also reproduced in Table 3.2 (a) - (f).

(Production values for the year 2000 for the Takoradi factory were not available)

Table 3.1 Electrical Energy Data for Takoradi Ghacem Cement Factory

(a)

ENERGY ANALYSIS GHACEM-TAKORADI			
2000			
Month	Energy (kWh)	Max Demand (kVA)	Power Factor
January	1,954,896	6,816	0.858604
February	2,217,804	6,816	0.953557
March	2,494,044	6,816	1.022468
April	2,612,208	6,912	1.151886
May	2,658,696	6,672	1.073621
June	2,107,020	6,576	0.910262
July	2,176,464	6,528	0.912017
August	2,780,448	6,576	1.165109
September	2,220,252	6,672	0.917676
October	2,224,728	6,624	0.913087
November	2,057,868	5,952	0.907048
December	2,260,464	6,528	1.00
Total	27,764,892	79,488	

(b)

ENERGY ANALYSIS GHACEM-TAKORADI				
2001				
Month	Energy (kWh)	Max Demand (kVA)	Power Factor	Productions (tons)
January	2,114,425	6,672	1.23836	51836.43
February	2,412,136	6,912	0.885395	59267.60
March	2,510,636	7,728	0.783187	60592.70
April	2,531,244	7,872	0.922419	62681.90
May	2,940,900	7,824	1.057401	72887.77
June	2,153,218	7,248	0.812	52306.49
July	2,094,662	7,680	0.852383	51808.52
August	2,752,032	7,584	1.003328	70566.32
September	1,957,944	7,584	0.900398	48843.68
October	2,437,872	7,584	0.995209	60931.59
November	1,893,699	7,488	0.79	46565.17
December	2,540,868	7,392	1.134703	62853.98
Total	24,296,765.92	89,568		701,142.15

(c)

ENERGY ANALYSIS GHACEM-TAKORADI				
2002				
Month	Energy (kWh)	Max Demand (kVA)	Power Factor	Production (tons)
January	1,667,640	7,392	0.684838	41399.42
February	2,162,120	7,296	0.944377	53883.60
March	2,396,584	7,584	0.839973	61090.92
April	2,635,676	7,584	0.944094	66649.93

May	2,328,160	7,152	0.857358	57677.30
June	2,192,052	7,440	0.930163	55692.87
July	1,872,660	7,200	0.837672	48533.51
August	2,294,388	5,616	0.840871	58295.78
September	2,697,708	5,712	1.017314	66826.52
October	2,339,674	5,712	0.912331	58422.73
November	2,433,974	6,768	0.853562	57235.20
December	3,497,748	6,678	1.105452	79326.76
Total	28,518,384	82,134		705034.54

(d)

ENERGY ANALYSIS GHACEM-)I TAKORA				
2003				
Month	Energy(kWh)	Max Demand (kVA)	Power Factor	Production (tons)
January	2,232,036	6,912	0.68031	48890.21
February	3,368,160	6,768	0.984851	75819.42
March	2,810,796	5,712	0.871198	61157.80
April	2,471,340	5,568	0.85804	54686.59
May	2,827,968	5,616	0.972287	62404.05
June	2,498,784	5,520	1.065	52210.85
July	2,486,832	5,328	0.949239	54789.94
August	2,949,060	7,440	0.961604	61591.92
September	3,109,440	7,440	1.100774	64617.92
October	2,552,088	7,440	0.933238	52818.98
November	2,841,216	5,712	1.099094	60003.51
December	3,168,804	5,760	1.138029	71555.60
Total	33,316,524	75,216		720546.79

(e)

ENERGY ANALYSIS GHACEM-TAKORAD				
2004				
Month	Energy(kWh)	Max Demand (kVA)	Power Factor	Productions (tons)
January	2,270,418	6,336	0.723516	49765.87
February	2,538,916	7,152	0.867198	51353.94
March	3,120,212	7,152	0.890398	66095.44
April	2,806,142	7,248	0.942195	57934.26
May	3,044,362	5,808	0.850538	61258.33
June	2,979,768	6,432	0.970587	61292.27
July	2,874,492	6,528	0.886388	63833.60
August	3,018,324	5,952	0.940196	65729.32
September	2,569,140	5,904	0.943574	55004.42
October	2,506,764	5,760	0.828841	54265.18
November	2,624,604	5,904	0.981784	60003.26
December	3,498,324	5,952	1.039093	76725.38
Total	33,851,466	76,128		723261.27

(f)

ENERGY ANALYSIS GHACEM-TAKORADI				
2005				
Month	Energy (kWh)	Max Demand (kVA)	Power Factor	Production (tons)
January	2,181,036	6,048	0.670386	47879.00
February	3,480,708	7,056	1.021809	76117.85
March	3,015,120	7,104	0.835711	67205.95
April	3,287,964	7,104	0.948851	71024.03
May	2,948,160	6,912	0.850313	62288.00

June	2,807,472	5,808	0.943516	64302.00
July	2,342,916	6,000	0.81046	56937.00
August	2,748,816	5,952	0.940859	67344.85
September	2,656,464	5,952	0.917566	61640.60
October	2,454,492	5,952	0.896532	53588.00
November	2,714,964	6,000	0.940591	61272.22
December	2,832,612	5,712	1.040014	64155.86
Total	33,470,724	75,600		753755.36

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Table 3.2 Electrical Energy Data for Tema Ghacem Cement factory

(a) 2000

Month	Energy (kWh)	Max Demand (kVA)	Power Factor	Production (tons)
January	3,403,000	8,040	0.90	82768.57
February	3,891,730	8,200	0.90	101110.53
March	3,936,530	8,940	0.91	92336.05
April	3,712,210	8,340	0.90	102425.32
May	3,932,010	8,000	0.91	103848.30
June	2,963,660	8,000	0.91	75490.59
July	3,309,320	7,680	0.90	73333.56
August	4,028,920	8,080	0.91	113450.34
September	3,008,090	7,520	0.90	74058.82
October	2,207,940	6,640	0.91	69920.39
November	2,084,140	5,640	0.92	45081.49
December	2,059,730	7,520	0.90	55234.79
Total	38,537,280	92,600		989058.75

(b) 2001

Month	Energy (kWh)	Max Demand (kVA)	Power Factor	Production (tons)
January	3,469,290	7,440	0.91	72,660
February	3,226,030	7,320	0.92	78,129
March	2,494,290	7,600	0.90	70,324
April	2,501,050	7,480	0.89	34,766
May	2,630,340	7,320	0.90	78,813
June	2,270,000	6,800	0.91	51,990
July	2,249,760	8,480	0.90	52,779
August	2,692,740	6,640	0.91	61,265
September	2,524,570	6,520	0.90	58,598
October	2,453,130	6,520	0.91	66949
November	2,418,740	6,640	0.92	45,081
December	2,200,680	6,480	0.92	49,943
Total	31,130,620	85,240		721,297

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(c) 2002

Month	Energy (kWh)	Max Demand (kVA)	Power Factor	Production (tons)
January	2,642,300	6,800	0.91	63,713
February	2,883,640	6,880	0.92	69,335
March	2,721,660	6,720	0.91	68,087
April	2,417,810	6,800	0.91	60,449
May	2,833,320	6,600	0.92	75,104
June	2,305,620	6,400	0.92	56,740
July	2,498,920	6,840	0.92	60,158
August	3,039,630	7,920	0.91	73,579
September	2,877,710	7,280	0.91	60,856
October	2,457,000	6,960	0.92	60,879
November	3,020,020	7,160	0.92	-
December	-	-	-	-
Total	29,697,630	76,360		648,900

(d) 2003

Month	Energy (kWh)	Max Demand (kVA)	Power Factor	Production (tons)
January	3,681,440	8,200	0.92	92,208
February	3,290,280	8,400	0.92	78,909
March	3,488,740	7,120	1.04	79,241
April	2,880,440	7,400	0.91	62,478

May	3,480,230	7,480	0.91	77,621
June	2,848,910	7,480	0.91	69,271
July	3,503,300	7,360	0.91	85,542
August	3,030,170	7,280	0.91	73,551
September	2,672,050	7,160	0.91	68,693
October	3,279,200	7,360	0.91	79,685
November	2,975,060	7,280	0.91	74,848
December	2,818,540	7,120	0.91	70,359
Total	37,948,360	89,640		912,406

(e) 2004

Month	Energy (kWh)	Max Demand (kVA)	Power Factor	Production (tons)
January	3,840,890	7,080	0.92	78,808
February	3,582,540	7,210	0.92	79,666
March	4,101,610	8,240	0.92	85,884
April	3,479,700	8,320	0.92	74,505
May	3,239,620	7,280	0.92	70,612
June	3,627,260	7,280	0.92	73,574
July	3,563,950	7,480	0.92	78,586
August	3,333,820	8,320	0.92	81,782
September	3,333,820	7,480	0.92	60,111
October	3,887,460	7,240	0.93	76,308
November	3,225,310	7,330	0.93	72,167
December	3,479,940	7,220	0.92	68,953
Total	42,695,820	90,480		900,956

(f) 2005

Month	Energy (kWh)	Max Demand (kVA)	Power Factor	Production (tons)
January	3,052,820	7,360	0.92	65,707
February	3,518,210	8,400	0.92	71,818
March	3,777,060	8,420	0.92	78,779
April	4,244,650	8,720	0.92	87,556
May	3,310,270	8,360	0.91	64,393
June	3,439,430	7,370	0.92	73,869
July	3,223,820	7,350	0.92	68,495
August	3,275,240	7,340	0.92	71,993
September	3,174,350	7,450	0.92	63,224
October	3,080,810	7,310	0.92	62,882
November	3,017,720	6,370	0.93	63,445
December	3,269,000	6,350	0.93	70,999
Total	40,388,380	90,800		

CHAPTER 4

ELECTRICAL ENERGY ASSESSMENT

In this chapter, some calculations are done using the information provided in the previous chapter from the Ghacem cement factories at Tema and Takoradi.

4.1 Load Factor

Load factor is the ratio of the average kilowatt load over a billing period to the peak demand. The peak demand is the largest quantity of kilowatts consumed during a time interval prescribed in the contract, typically one month. The peak or maximum demand usually occurs within a short period of the working hours.

It is important, because the size or capacity (and therefore cost) of power system components are determined to a great extent by their capability to handle peak power flows.

Load factor had been analyzed to determine the opportunity for improvement. A load factor nearing unity indicates that less opportunity exist for improvement because the energy consumption pattern is already relatively constant and closer to the energy supplied. A load factor is obtained as follows:

$$\text{Load factor} = \frac{\text{average power consumed (kW)}}{\text{maximum demand (kW)}}$$

$$= \frac{\text{energy consumed (kWh)}}{\text{maximum demand (kW) x time (h)}}$$

Where the time is the number of working hours in a month

Maximum demand in kW = maximum demand (kVA) x power factor

Hence,

$$\text{Load factor} = \frac{\text{energy consumed (kWh)}}{\text{maximum demand (kVA) x p.f. x time (h)}}$$

Sample calculations:

For the Tema plant in January 2000:

Energy consumed = 3 403 000 kWh

Maximum demand = 8040 kVA

Power factor = 0.9

No. of working days = 22

$$\text{Load factor} = \frac{\text{energy consumed (kWh)}}{\text{maximum demand (kVA) x p.f. x time (h)}}$$

$$= \frac{3403000 \text{ (kWh)}}{(8040 \times 0.90) \text{ (kW)} \times (22 \times 24) \text{ (h)}}$$

Load factor = 0.89

For the Tema plant again in January 2002:

Energy consumed	= 2 883 640 kWh
Maximum demand	= 6880 kVA
Power factor	= 0.92
No. of working days	= 20

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$$\text{Load factor} = \frac{\text{energy consumed (kWh)}}{\text{maximum demand (kVA) x p.f. x time(h)}}$$

$$= \frac{28836409 \text{ (kWh)}}{(6880 \text{ x } 0.92) \text{ (kW) x } (20 \text{ x } 24) \text{ (h)}}$$

$$= 0.95$$

Table A-1 (a) – (f) indicates the load factor, computed monthly, for the Tema factory for the years 2000 to 2005. Similarly, Table A-2 (a) – (f) shows the monthly load factor for the Takoradi factory for the years 2000 to 2005. (See Appendix 2)

4.2 Maximum Demand

The utility provider (Electricity Company of Ghana), wants the electricity supplied to its customer base to vary less through the course of the day. The generating facility then operates under a relatively steady loading condition, during which time it can generate electricity most efficiently. A special meter is used to measure the peak demand. It records the highest energy use that happens during the worst 15-min interval during the peak billing hours.

The maximum demand metering devices register the total kWh taken over a predetermined period divided by the period in hours. The maximum demand is in fact the average demand recorded over a short period usually fifteen minutes. The maximum demand pointer has also a slipping pointer. When the recording period is *ON*, the pointer moves over an almost circular scale to register the average demand in kW; it moves the slipping pointer along with it. At the end of the recording period, the pointer is automatically re-set to zero and the slipping pointer remains at the highest kW demand during the recording period just ended. The pointer again moves around the scale and if, during this new recording period, the kW demand is higher than the previous period, the slipping pointer will be moved up to record this new high figure and stays there. Thus the reading on the maximum demand meter is always the highest kilowatt demand (Thompson, 1996).

4.2.1 Maximum Demand Charge

Maximum demand charge is a fee for energy used during peak-use hours. The peak or maximum demand charge is an incentive to try creative ways to lower the peak electrical use at a facility, (Clark, 1997).

Table A5 (a) – (c) in the appendix shows the monthly demand charge for the Tema factory from 2003 to 2005. It is the penalty paid for not having an average consumption closer to the power supplied by Electricity Company of Ghana. The demand charges amount to a monthly average of about 32 % of the electricity bill. The demand charge part of the utility bill can be reduced by smoothing out the peaks in energy demand.

4.2.2 Minimising Maximum Demand

The key to a high load factor and corresponding lower demand charge is to even out the peaks and valleys of energy consumption. The approaches to do these are:

- Stagger Start-Up Loads:

  Ahigh-peak load result from the simultaneous start-up of several loads, such as occur at the beginning of a shift. Staggering start-up of equipment to span two or more demand intervals can reduce high-peak load.

- Rescheduling Loads:

  Peak demands are usually established at particular times during the day shift. A review of the operation shows individual loads can be rescheduled to other times or shifts to even out demand. This technique can provide significant gains at little or no cost.

- Automatic Demand Control

  The power demand controller automatically regulates or limits operation in order to prevent set maximum demands from being exceeded.

- Installing a Generator

  Agenerator, brought on-line by an automatic transfer switch as the power use approaches the anticipated peak value, can take up part of the load.

4.3 Power Factor Improvement

The power factor of an electrical service is the ratio of actual power used to apparent power. Power factor improvement is reducing the angle between the apparent power (measured in kVA) and the active power (measured in kW), as shown in figure 4.1. It results in reduction of the kVA taken from the supply which the consumer is charged for.

Poor power factor penalizes the user in three ways.

- It robs the distribution system of capacity that could be used to handle the work- performing load.
- It results in currents higher than necessary to perform a given job, thereby contributing to higher voltage drop and electrical system losses.
- It can result in electric power billing penalties depending on the schedule terms.

Often no penalty is imposed unless the power factor falls below 0.95. Generally a power factor of 0.95 (based on normal full load) is the economic breakeven point in a power factor improvement program; up to this point, improvements usually show a good return on investment. (Muller, 1995)

With induction motors, which are used to drive all the machinery on the plants, power factor is a function of the mode of operation. Power factor decreases because of the inductive component of current that provides the magnetizing force, necessary for the motor operation. Improving the power factor implies decreasing the power (kVA) drawn from the line.

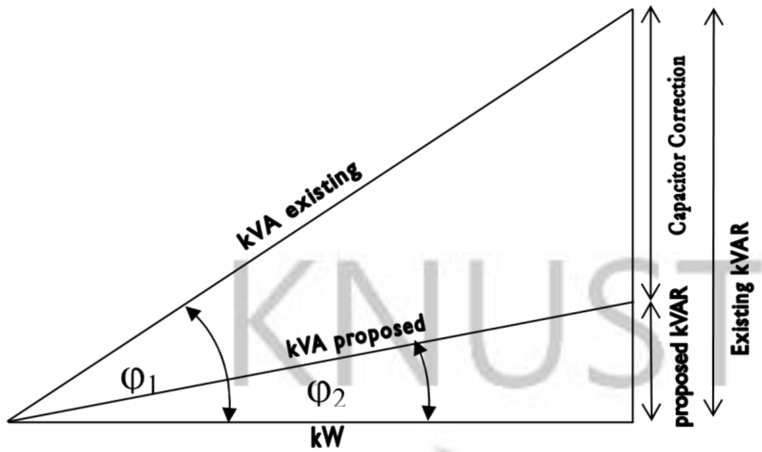


Figure 4.1 Power Factor Correction

4.3.1 Power Factor Improvement Capacitors

The use of power factor improvement capacitors is the simplest and most direct method of power factor improvement. Corrective measures for poor factor involve cancelling the lagging current component with current that leads the applied voltage. Capacitors have the effect of absorbing reactive current on a one-on-one basis, because almost all of the current flowing through a capacitor leads the applied voltage by 90 degrees. A capacitor rated at 100 kilovolt-amperes capacitive (kVAC) will, therefore cancel 100 kilovolt-ampere reactive.

4.3.2 Synchronous Motors

Synchronous motors provide an effective method of improving power factor because they can be operated at leading power factor. Moreover, power factor of a synchronous motor to serve a load with actual power requirement of 1,000 kW, improves power factor on the load centre from 80 percent to 89 percent. This improvement at the load centre contributes to an improvement in overall plant power factor, thereby reducing the power factor penalty on the plant electric bill. The burden on the load centre, plant distribution system, and entire electric-utility system is 400 kVA less than if an induction motor with a power factor of 85 percent were used.

4.3.3 Phase Advancers

There is another power factor correction device known as phase advancers. In that device, an alternating current exciter, driven from the shaft of a motor or by an auxiliary motor, and electrically coupled to the rotor of a slipring induction motor will improve the power factor of the current drawn from the line. The power absorbed in driving the exciter, however, lowers the overall efficiency of the plant. Thus, unless the rotor and brushgear of the motor are designed to carry the additional excitation currents, the application of the phase advancers is not beneficial.

In summary, therefore, power factor control reduces demand which results in reduced losses, better voltage regulation, and releases generation, transmission, and distribution capacity to serve other existing loads, or saves on investment by delaying the need to add new facilities to load growth.

Computing for currents at improved power factor:

Power of a 3-phase system, $P = \sqrt{3} IV \cos\varphi$

$$\text{Initial current, } I = \frac{P(\text{kW}) \times 1000}{\sqrt{3} \times V \cos\varphi}$$

$$\text{Power} = \frac{\text{energy (kWh)}}{\text{time (h)}}$$

Sample calculation:

January 2000, for Tema plant:

Energy consumed = 3 403 000 kWh

Power factor = 0.90

No. of working days = 22 days

Terminal voltage = 415 V

$$\text{Power} = \frac{3403000}{22x24}\ \text{kW}$$

$$= 6445\ \text{kW}$$

Initial current

$$= \frac{6445x10^3}{\sqrt{3}x0.90x415}$$

$$= 9962A$$

Now, $\sqrt{3}\, I_1 V_1 \cos\varphi_1 = \sqrt{3}\, I_2 V_2 \cos\varphi_2$

Hence, current at improved power factor,

$$I_2 = \frac{I_1 \cos\varphi_1}{\cos\varphi_2}$$

For example, current at a power factor of 0.92, for the Tema plant for January 2000, would be given by:

Initial current, I_1 = 9962 A

Initial power factor, $\cos\varphi_1 = 0.90$

New power factor $\cos\varphi_2 = 0.92$

Therefore,

New current, I_2 =

$$= \frac{9962x0.90}{0.92}$$

$$= 9746A$$

Table A-3 (a) – (f), show the currents that would have been drawn by the Tema plant from 2000 to 2005 if the power factor had been improved successively to unity. Table A-4 (a) – (e) are identical lists for the Takoradi factory for the same period. (Refer to appendix 4 and appendix 5). The dash indicates that the initial power factor was higher than the stated value.

4.4 Energy Intensity

Energy intensity is the energy consumed per unit quantity. The energy involved is the total energy consumed. This includes the energy required to run the plant and machinery, lighting, environmental control, administration and other servicing needs such as the clinic, recreational facilities etc. In cement production, the unit quantity is the ton of cement produced. Energy intensity relates the energy consumed to produce a ton of cement. It is an indication of the economy of production. The energy intensities from the year 2000 to 2005 for the Tema plant is shown in Table A6 (a) – (f) and that for Takoradi plant is also shown in Table A7 (a) – (e) for 2001 to 2005. in appendix

4.5 Electrical Energy Cost

Table 4.1 gives an insight of the total electrical energy cost for 2004 and 2005 for the Tema plant. It confirms the fact that the electrical energy cost is quite substantial and affects the price of cement produced.

Table 4.1 Electrical Energy Cost for Tema Plant

(a) 2004

Month	Energy (kWh)	Energy Cost (Cedis)	Energy Cost/kWh (Cedis/kWh)
January	3,840,890	2,435,890,785	634.20
February	3,582,540	2,338,997,643	652.89
March	4,101,610	2,680,160,790	653.44
April	3,479,700	2,415,915,166	694.29
May	3,239,620	2,198,071,014	678.50
June	3,627,260	2,365,555,217	652.16
July	3,563,950	2,360,150,552	662.23
August	3,333,820	2,405,026,030	721.40

September	3,333,820	2,405,026,030	721.40
October	3,887,460	2,528,338,250	650.38
November	3,225,310	2,246,092,345	696.40
December	3,479,940	2,346,175,210	674.20
Total	42,695,820	28,725,399,032	

(b) 2005

Month	Energy (kWh)	Energy Cost (Cedis)	Energy Cost/kWh (Cedis/kWh)
January	3,052,820	-	-
February	3,518,210	2,495,406,055	709.28
March	3,777,060	2,611,931,290	691.52
April	4,244,650	2,852,016,675	671.91
May	3,310,270	2,399,114,625	724.75
June	3,439,430	2,345,112,245	681.83
July	3,223,820	2,247,677,470	697.21
August	3,275,240	2,269,257,920	692.85
September	3,174,350	2,237,051,265	704.73
October	3,080,810	2,180,052,635	707.62
November	3,017,720	2,096,779,280	694.82
December	3,269,000	2,155,476,440	659.37
Total	40,388,380	25,889,875,900	

CHAPTER 5

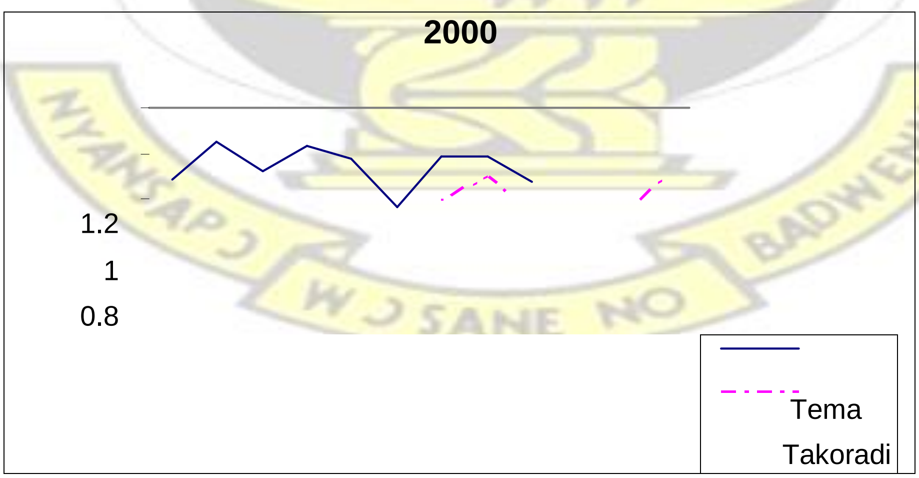
RESULTS AND DISCUSSION

This chapter discusses the results computed from the energy data obtained and the observations made at the two Ghacem cement factories at Tema and Takoradi.

5.1 Load Factor

Figure 5.1 (a) – (f), is the graphical representations of the load factor at the two factories from the year 2000 to 2005. Figure 5.1 (a), shows the load factor for the year 2000. The load factor for the Takoradi plant increased gradually from 0.63 in January to 0.90 in August. It dropped sharply to 0.72 in September and increased again to 0.90 in December. For the Tema plant, the load factor started from 0.89 in January, increased to 1.05 in February, decreased to 0.92 and increased again to 1.03 in April. It dropped to 0.77 in June rose again to 0.99 in August. It dropped to 0.69 in October and finally increased to 0.79 in December. The annual average load factor for the Takoradi plant was 0.72 and that of Tema plant was 0.90.

(a)



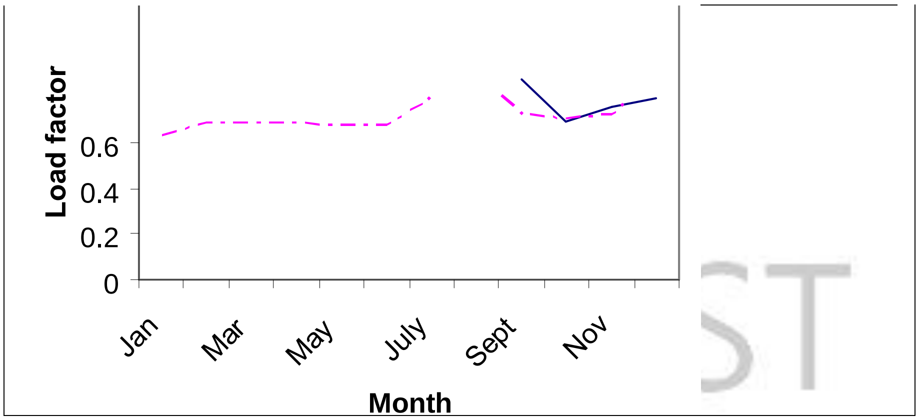


Figure 5.1 (a) Load factor for the year 2000

For the year 2001, from figure 5.1 (b), it can be seen that the Takoradi factory started with a poor load factor of 0.49 in January, increased to 0.83 in March, dropped to 0.69 in April. From then onwards it was fairly constant to November and rose again to 0.79 in December. The Tema factory started with a load factor of 0.97 in January and increased to 0.99 in February. The figure dropped sharply to 0.72 in March. This load factor was maintained until June. It fell to 0.56 in July, rose sharply to 0.9 in October. It reduced to 0.72 in November and finally increased to 0.96 in December. For the year 2001, the annual average load factors recorded at the Takoradi factory and the Tema factory were 0.67 and 0.80, respectively.

(b)

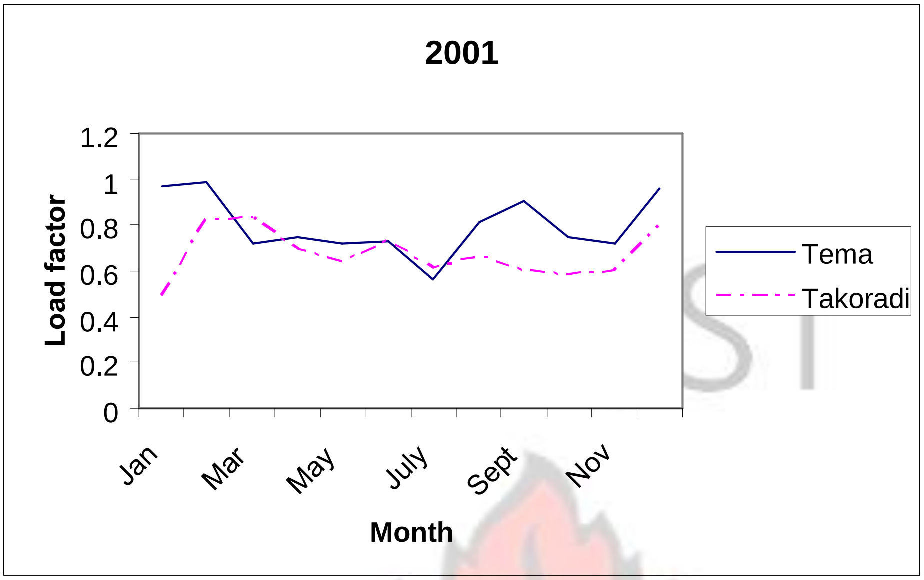


Figure 5.1 (b): Load factor for the year 2001

The load factor variation for the year 2002 is shown in figure 5.1 (c). The Takoradi factory started with a load factor of 0.63 in January and increased uniformly to 0.78 in March. It reduced to 0.72 in May. It remained fairly constant till November when it rose again to 1.10 in December. The Tema factory started the year with a load factor of 0.81 and increased to 0.95 in March. This figure dropped to 0.74 in April. It also remained almost constant till July and rose to 0.88 in August. It dropped again to 0.70 in October and finally rose to 0.96 in November. (Data for the Tema plant for December 2002 was not available). Annual average load factors of 0.75 and 0.83 were recorded at the Takoradi factory and the Tema factory, respectively.

(c)

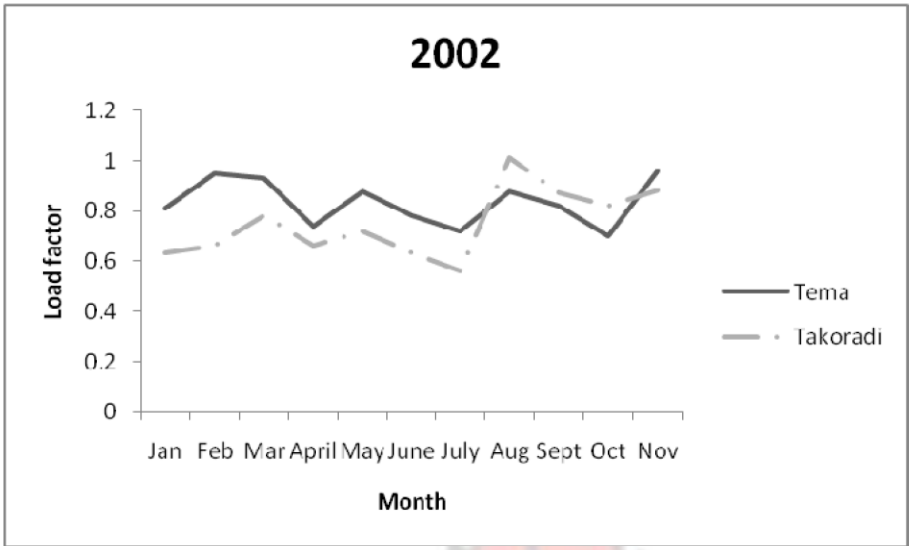


Figure 5.1 (c): Load factor for the year 2002

For the year 2003, the Takoradi plant started with a load factor of 0.94 in January. This is shown in figure 5.1 (d). This value increased to 1.52 in February and dropped gradually to 0.84 in June, it rose to 0.93 in July. It again reduced to 0.67 in October and rose to an appreciable value of 1.00 in December. The load factor for the Tema plant was 0.97 in January, it dropped to 0.89 in February. It rose again to 0.98 in March and reduced to 0.89 in April. This alternating pattern continued till the end of the year. An annual average load factor of 0.91 was recorded at Takoradi factory and 0.92 recorded at the Tema factory.

(d)

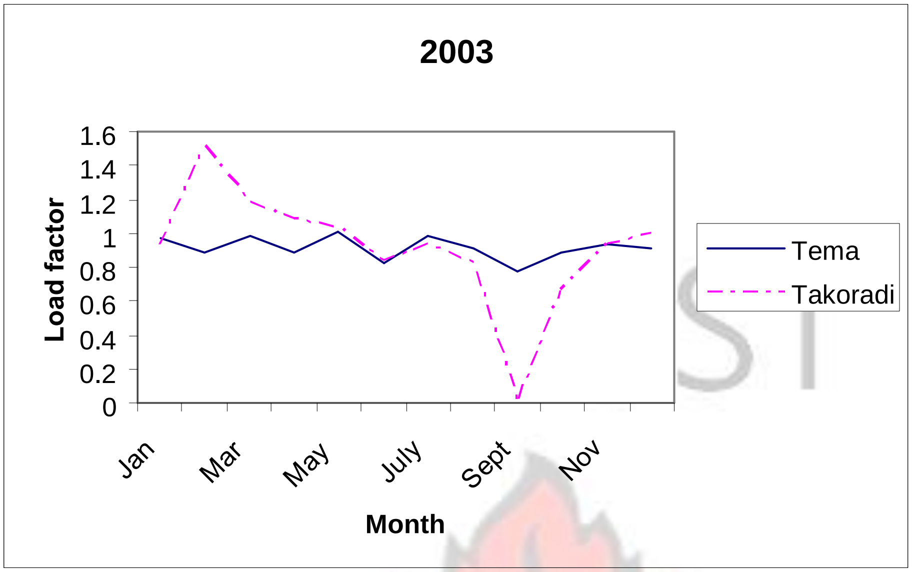


Figure 5.1 (d): Load factor for the year 2003

In the year 2004, the monthly load factor pattern at the Takoradi factory also took alternating form throughout the year as shown in figure 5.1 (e). It was 1.04 in January and dropped to 0.85 in February. It rose to 0.93 in March and dropped again to 0.86 in April, and that continued throughout the year. At the Tema factory, a load factor of 1.23 was recorded in January. This value reduced to 0.95 in April and increased to 1.01 in May. This figure rose slightly to 1.03 in July and dropped to 0.82 in August and rose again to 1.14 in October. It reduced to 0.87 in November and finally rose to 1.04 in December. The second half of the year showed an alternating pattern for the load factor at the two factories. The annual average load factor for the year 2004 registered at the Takoradi plant was 0.97 and that for the Tema plant was 1.02.

(e)

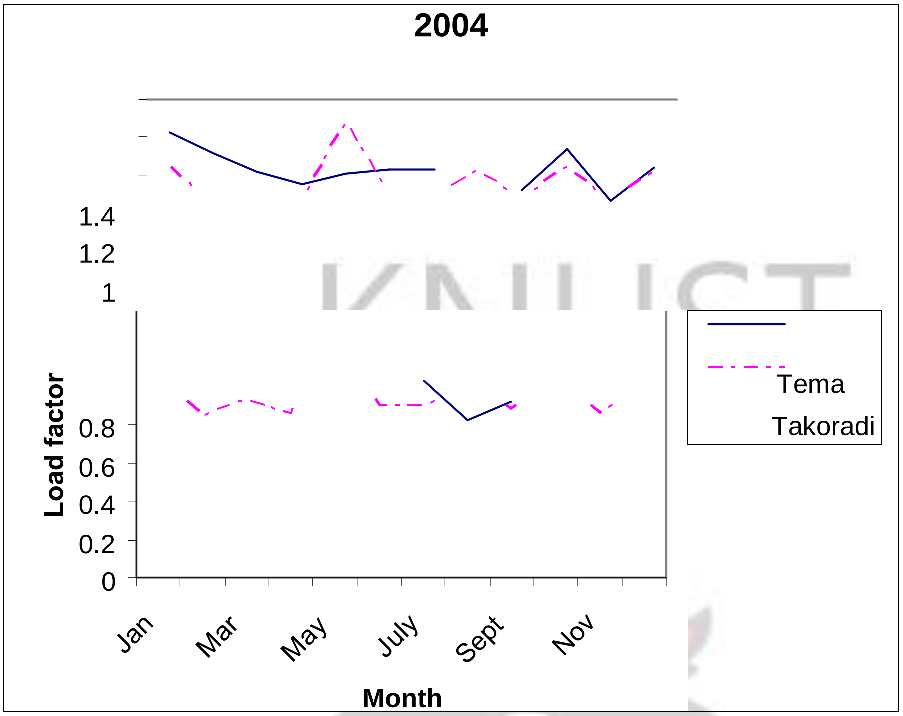


Figure 5.1 (e): Load factor for the year 2004

From figure 5.1 (f), in the year 2005, the Takoradi factory recorded a load factor of 1.07 in January, this figure reduced uniformly to 0.97 in April. This load factor was almost constant until August when it dropped to 0.89. It rose again to 0.92 in September and remained almost constant for three months and rose to 0.99 in December. The Tema factory recorded a load factor of 0.94 in January and this increased uniformly to 1.05 in April. It dropped to 0.86 in May and increased again to 0.99 in July. It again reduced to 0.88 in August, maintained that load factor for another month, i.e. September, and increased uniformly to 1.15 in December. The annual average load factor recorded for the year 2005 at the Takoradi factory was 0.97 and that recorded at Tema plant was 0.96

(f)

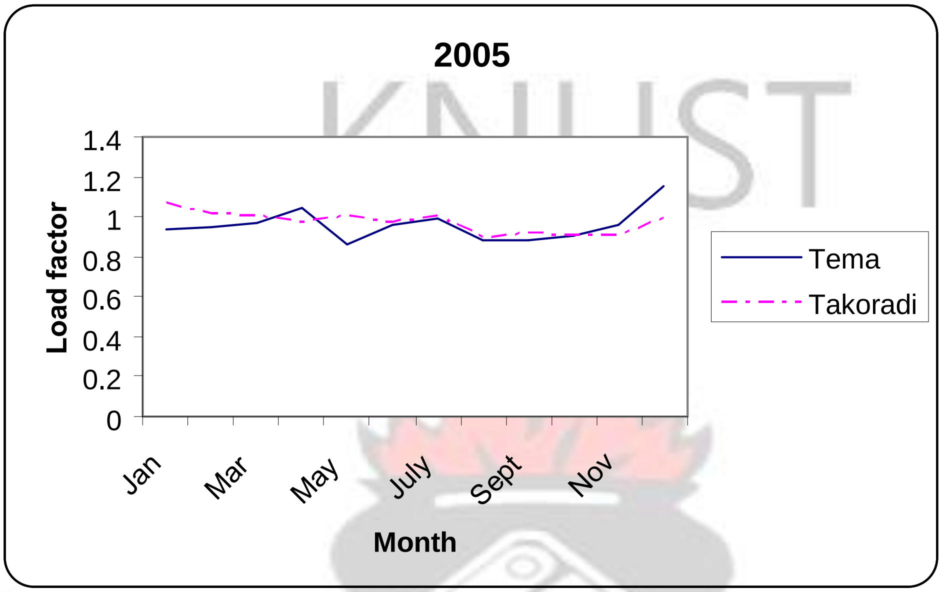


Figure5.1 (f): Load factor for the year 2005

From the information provided above, from the year 2000 to 2002, the annual averages recorded at the Takoradi factory were 0.72, 0.67 and 0.75; as compared to 0.90, 0.80 and 0.85 recorded at the Tema factory. Although, the energy charges for the Takoradi factory were not available, it is obvious that the maximum demand charges for that period would be higher. This is so because Public Utilities Regulatory Commission (PURC) authorised tariff released in October 2003, charges ¢89,040 per kVA per month for high voltage customers such as Ghacem Cement Factories. (Refer to appendix 1). From the year 2003 to 2005, there were improvements in the annual average load factors at the two factories. The figures recorded at the Takoradi factory were 0.92, 0.97 and 0.97; and 0.92, 1.02 and 0.96 for the Tema plant. For the six years under review, i.e. 2000 to 2005, the annual average load factor recorded at the Tema factory was always higher than that recorded at the Takoradi factory. This means that they were taking much power at a time especially when most of the motors are switched at once as it occurs when the morning shift resumes.

Table 5.1 shown below is the annual average load factor for the year 2000 to 2005 and figure 5.2 is the graphical representation.

Table 5.1 Annual Average Load Factor

	2000	2001	2002	2003	2004	2005
Tema	0.90	0.80	0.83	0.92	1.02	0.96
Takoradi	0.73	0.67	0.78	1.00	0.97	0.97

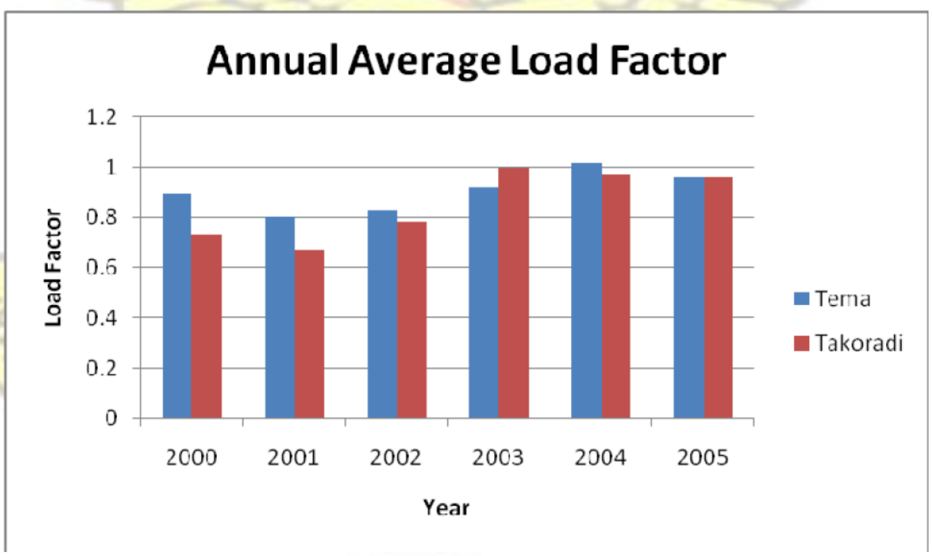


Figure 5.2 Graph of Annual Average Load Factor

The determination of load factor for Ghacem Cement factories is of prime importance in the analysis of demand behaviour because the starting current of the induction motors is about six times the rated current. This leads to higher energy demand, especially when the motors are started at the same time. The monthly electrical energy cost which they pay to Electricity Company of Ghana is greatly due to the low value of the load factor.

5.2 Maximum Demand Charge

Maximum demand charge is the fee which industrial consumers pay for not making maximum use of the electrical energy supplied to them by the Electricity Company of Ghana. This charge is quite higher than the normal charge to provide great impetus to energy demand management and conservation efforts. Traditionally, power systems have been designed and operated to meet forecast demand, at some level of reliability. The Electricity Company of Ghana would like to prevent outage costs, which represent the economic consequences of service curtailment to the customer, when the demand for electricity temporarily exceeds the available supply capability. Therefore, peak load pricing or time of use (TOU) tariff is applied where the added cost of supplying energy during peak load periods is fully charged to the consumer. Ghacem Cement factories at Tema and Takoradi were charged every month for maximum demand penalty.

Figure 5.3 shows the monthly percentage contribution of the maximum demand charge to the total electrical energy charges. For the year 2003, in January, the percentage maximum demand charge was 30.4 %. This figure increased to 33.2 % in February; it reduced to 30.4 % in March and increased again to 35.1 % in April. This alternating pattern continued until July when it rose steadily from 30.9 % to

36.0 % in September. It dropped to 32.3 % in October and finally increased 34.7 % in December.

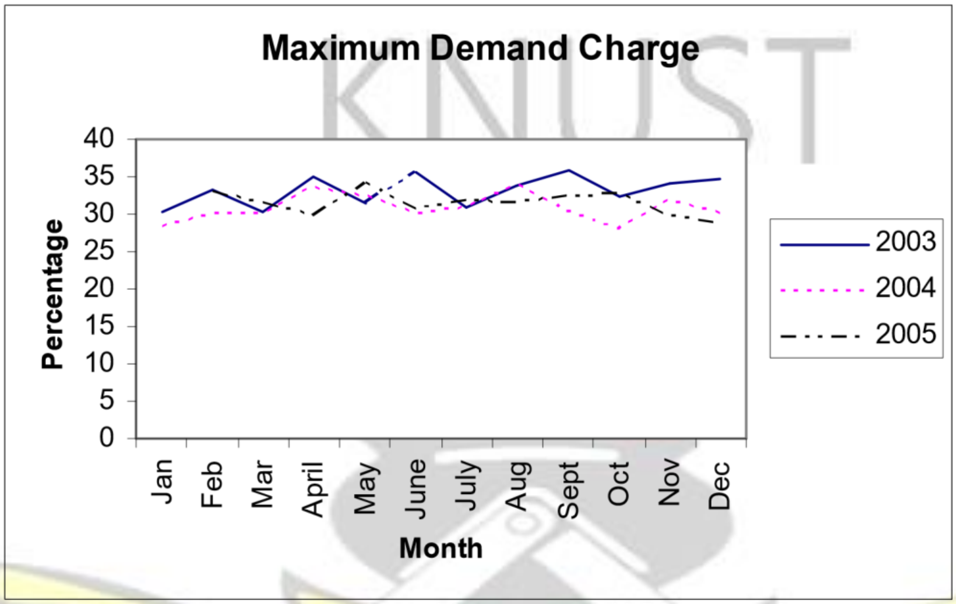


Figure 5.3 Percentage maximum demand charge for the Years 2003 – 2005 for Tema factory

For the year 2004, maximum demand charge contribution to the total electrical energy bill in January was 28.3 %. This figure rose to 33.6 % in April, it dropped uniformly to 30.0 % in June and increased again to 33.7 % in August. There was a sharp drop from 33.7 % to 27.9 % in October, this figure rose to 31.8 % in November and reducing slightly to 30.0 % in December.

The situation for the year 2005 was not very different. In February, (January data was not available), the percentage maximum demand was 32.8 %. That figure reduced uniformly to 29.8 % in April, it increased to 34.0 % in May and dropped again to 30.6 % in June. It increased to 31.9% in July, reduced slightly to 31.5 % in

August. The percentage maximum demand charge increased steadily to 32.7 % in October, and reduced steadily as well to 28.7 % in December. There was an alternating pattern with a maximum of 32.8 % and a minimum of 28.7 %. The annual percentage average of the maximum demand charge for the years 2003, 2004 and 2005 were 33.2 %, 30.8 % and 31.4 %, respectively. (This computation had been done for the Tema factory only because the total energy charges and the maximum demand charge for Takoradi factory were not available). The percentage maximum demand charge for the Takoradi factory would not be very different for the period 2003 to 2005 because the annual average load factor for the two factories were almost the same during that period: i.e., 0.91 and 0.92 for the year 2003, 0.97 and 1.03 for the year 2004 and 0.97 and 0.96 for the year 2005.

As stated earlier in the section, charges for maximum demand penalty are quite high and suggestions made in section 4.2.2 on how maximum demand could be minimised; namely, stagger start-up times, rescheduling loads, installing a generator, and installing automatic demand control, should be employed to reduce the maximum demand and the part of the electrical energy bills which is contributed by the maximum demand charges.

5.3 Power Factor Charges

The power factor of the majority of industrial loads is considerably less than unity. Ghacem cement factories are no exception to this. This is due mostly to the numerous electric motors and discharge lighting, which have a significant inductive element. The result is that a wattless magnetising current is drawn from the supply. Figure 5.4 (a) – (f) compares the power factor for the Takoradi and Tema plants from the year 2000 to 2005.

For the year 2000, as shown as in figure 5.4 (a), the power factor recorded at the Takoradi plant in January was 0.86. This value increased uniformly to 1.15 in April, it dropped to 0.91 in June. The same value was recorded in July; it increased to 1.17 in August and reduced to 0.91 in October, maintained that value the following month and rose to 1.00 in December. At the Tema factory, the power factor recorded was fairly constant through out the year, the minimum value recorded was 0.90 and the maximum 0.92.

(a)

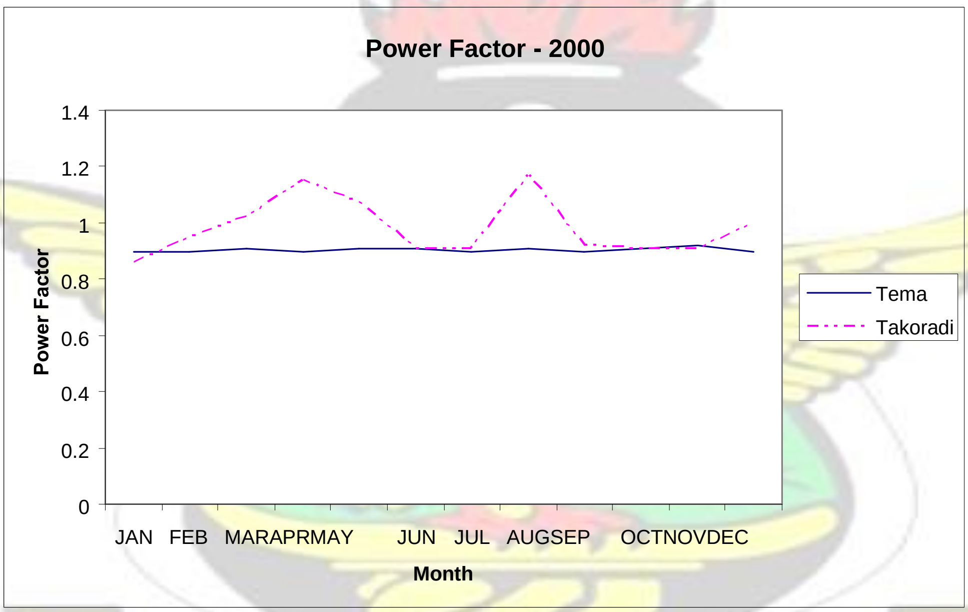


Figure 5.4 (a): Power factor for the year 2000

In the year 2001, as can be seen in figure 5.4 (b), the plant at Takoradi recorded a power factor of 1.23 in January. This value reduced steadily to 0.78 in March and rose to 1.06 in May. It dropped to 0.81 in June and increased again to 1.00 in August. It reduced to 0.90 in September, increased to 1.00 in October, reduced to 0.79 in November and rose again to 1.13 in December. An alternating pattern was thus obtained. At the Tema factory, the power factor was fairly constant. The least value recorded was 0.89 which occurred in April and the maximum value was 0.92 which was recorded in November and December.

(b)

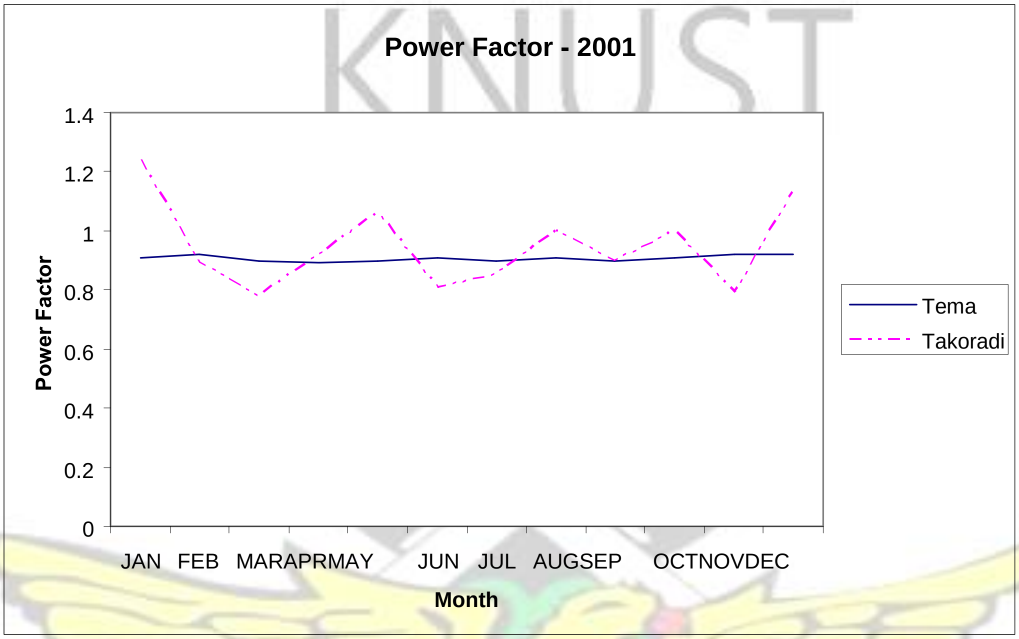


Figure 5.4 (b): Power factor for the year 2001

For the year 2002, the power factor registered at the Takoradi factory was fluctuating. This is shown in figure 5.4 (c). It started from a low value 0.68 in January and rose to 0.94 in February; it dropped to 0.84 in March and increased again to 0.94 in April. The power factor reduced to 0.86 in May, increased to 0.93 in June dropped again to 0.84 in July and increased to 1.02 in September. It dropped steadily to 0.85 in November and increased finally to 1.11 in December. Only two values for the power factor were recorded at the Tema factory for the year 2002. A power factor of 0.91 was recorded in the months of January, March, April, August and September;

for the remaining seven months, a power factor of 0.92 was registered. The power factor was almost constant.

(c)

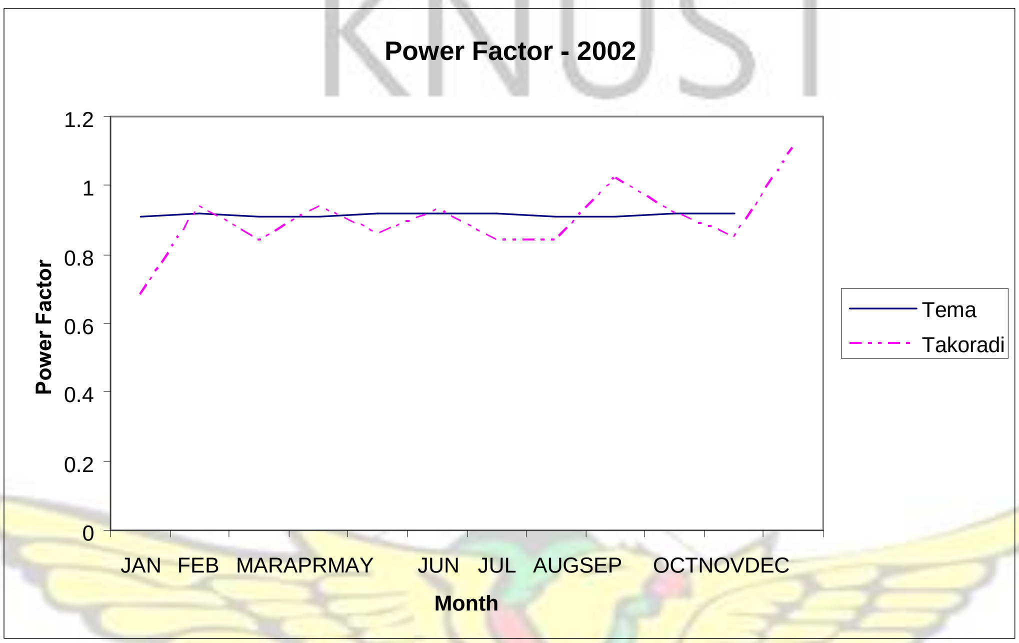


Figure 5.4 (c): Power factor for the year 2002

For the year 2003, as can be seen in figure 5.4 (d), a power factor of 0.72 was recorded in January at the Takoradi factory. This figure rose steadily to 0.94 in April, it reduced to 0.85 in May, increased to again to 0.97 in June and dropped to 0.87 in July. It rose to 0.94 in August, maintained that value in September and rose uniformly to 1.04 in December. At the Tema factory also for the year 2003, a power factor of 0.92 was recorded in January and February; this figure rose to 1.04 in March and dropped to 0.91 in April. The power factor of 0.91 was maintained constant for the rest of the year.

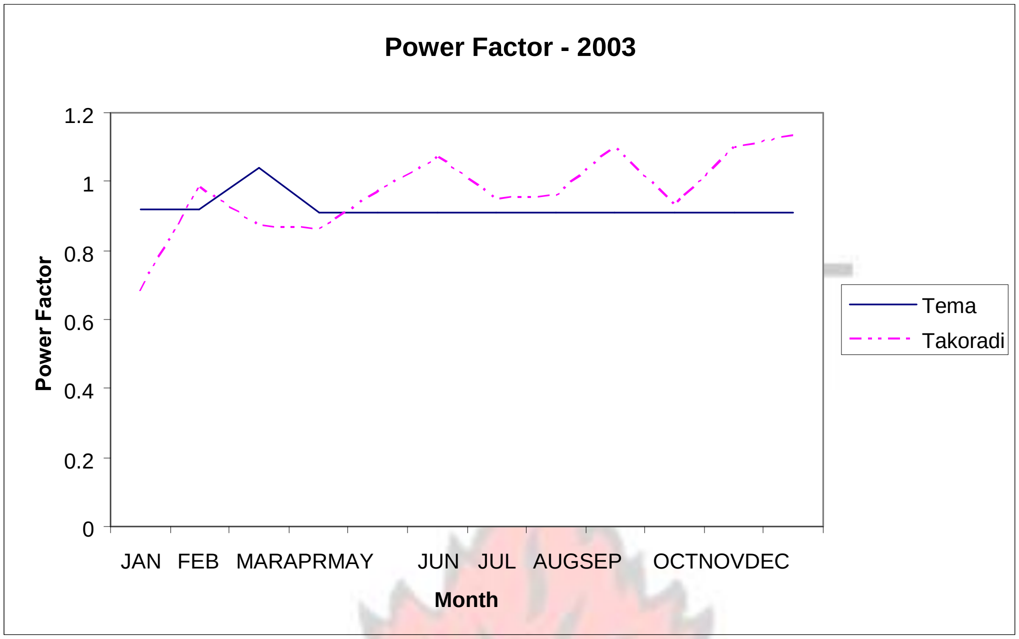


Figure 5.4 (d): Power factor for the year 2003

In the year 2004, as shown in figure 5.4 (e), the power factor registered at the Takoradi factory in January was as low as 0.72, this figure rose steadily to 0.94 in April. It dropped to 0.85 in May, increased to 0.97 in June, reduced to 0.87 in July and it increased again to 0.94 in August. That value of 0.94 was maintained in September. It dropped to 0.83 in October and increased uniformly to 1.03 in December. At the Tema factory, the power factor was almost constant. A value of 0.92 was registered throughout the year except October and November in which a figure of 0.93 was recorded.

(e)

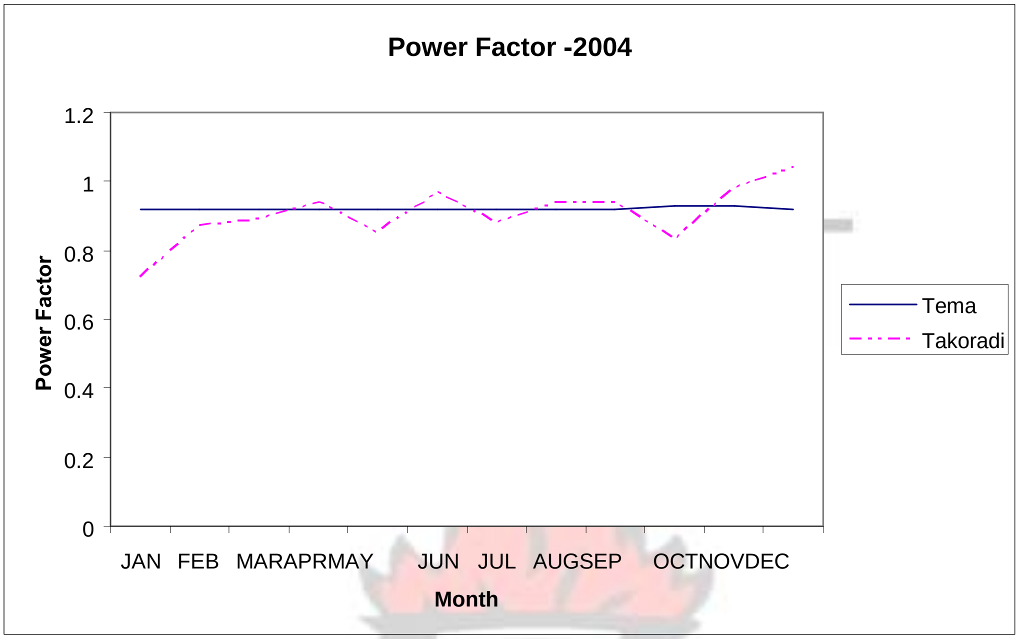


Figure 5.4 (e): Power factor for the year 2004

In the year 2005, as can be seen in figure 5.4 (f), an alternating form was obtained at the Takoradi factory. A power factor as low as 0.67 was recorded in January. This value increased to 1.02 in February, reduced to 0.84 in March and increased again to 0.95 in April. It reduced to 0.85 in May, increased to 0.94 in June and reduced to 0.81 in July. The power factor increased to 0.94 in August, dropped uniformly to 0.89 in October, rose to 0.94 again in November and increased further to 1.04 in December. The Tema factory recorded virtually constant power factor of 0.92 throughout the year. It was in May when 0.91 was recorded and also in November and December when a power factor of 0.93 was registered.

(f)

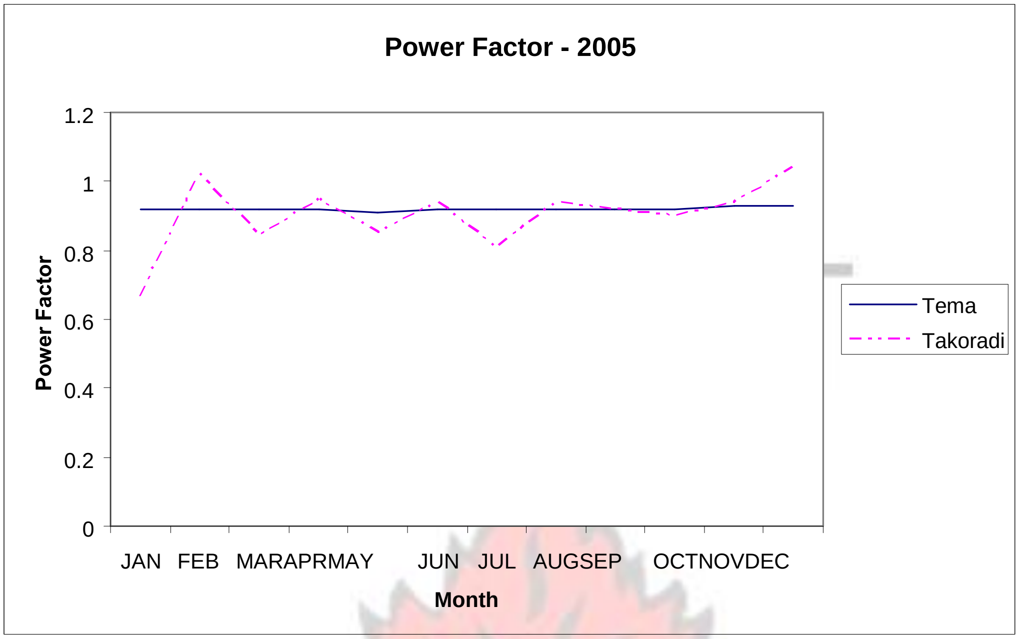


Figure 5.4 (f): Power factor for the year 2005

Tariffs contain power factor penalty surcharges in excess of the regular price to encourage consumers whose power factor drops below some acceptable limit, usually 0.95, to install power factor correction devices such as capacitor and synchronous motor to improve the power factor.

For the six years under review, i.e. 2000 to 2005, the Tema factory could register a power factor greater than 0.95 in just a single month, which was in March 2003, representing 1.4%. At the Takoradi factory, values above 0.95 were recorded twenty-five times, representing 34.7%. A poor power factor is a major source of both losses and voltage drop. Power factor at low levels can be corrected with a very high benefit to cost ratio. Table A-3 and Table A-4 in the appendix show the currents which the two plants at Tema and Takoradi would have drawn from the supply had the power factor been improved increasingly to unity. There could be an appreciable decrease in the current which would have been drawn from the supply, if the power factor had been improved. This would consequently, reduce the kilovolt –ampere demand.

Also, though at the Tema factory low power factor values were recorded, they were fairly constant whereas the power factors at Takoradi were higher they were zig-zag in nature. It calls for proper maintenance such as phase balancing, cleaning and constant lubrication.

5.4 Energy Intensities

Energy intensity compares the total electrical energy consumed by the plant to produce a ton of cement. Figure 5.4 (a) to (e) are the graphical representations of the monthly energy intensities for the Tema cement factory and the Takoradi cement factory from the year 2001 to 2005. (The energy intensity values for the year 2000 are not included because the cement production values for the Takoradi plant were not available).

In the year 2001, as shown in figure 5.5 (a), the Takoradi factory recorded an energy intensity of 51.07 kWh/ton in January. This figure dropped uniformly to 37.98 kWh/ton in April, it rose to 50.99 kWh/ton in May and reduced again to 38.66 kWh/ton in June. This figure increased to 47.21 kWh/ton in August, it reduced to an appreciable level of 29.30 kWh/ton in September and rose to 41.73 kWh/ton in October and finally reduced sharply to 32.03 kWh/ton in December. At the Tema factory, an energy intensity of 47.75 kWh/ton was recorded in January, it reduced uniformly to 35.37 kWh/ton in March. It increased sharply to 71.94 kWh/ton in April, reduced to 33.37 kWh/ton in May and increased again to 43.66 kWh/ton in

June. From June to September it was fairly constant, reduced to 36.64 kWh/ton in October. It rose to 53.65 kWh/ton in November and finally reduced to 44.06 kWh/ton in December.

(a)

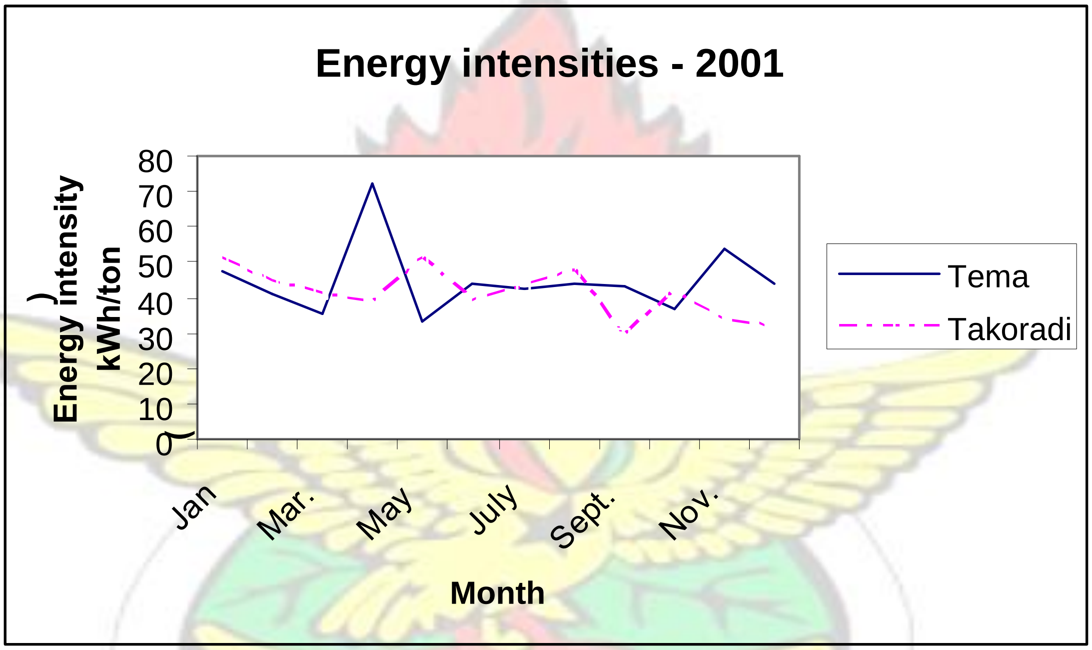


Figure 5.5(a): Energy intensities for the year 2001

From figure 5.5 (b), in the year 2002, the energy intensity registered in January at the Takoradi factory was 40.28 kWh/ton. It reduced to 39.23 kWh/ton in March, this figure increased slightly to 40.37 kWh/ton in May, reduced to 38.58 kWh/ton in July. It increased slightly to 40.37 kWh/ton in September, reduced again to 40.05 kWh/ton in October and increased uniformly to 44.09 kWh/ton in December. At the Tema plant, the energy intensity recorded in January was 41.47

kWh/ton. It increased slightly to 41.59 kWh/ton in February and reduced to 39.9 kWh/ton in March and increased again to 40.00 kWh/ton in April. It reduced to 37.73 kWh/ton in May, increased to 41.54 kWh/ton in July, reduced to 41.31 kWh/ton in August and increased to 47.75 kWh/ton in September. It reduced finally to 40.36 kWh/ton in November. (The values for November and December were not available).

(b)

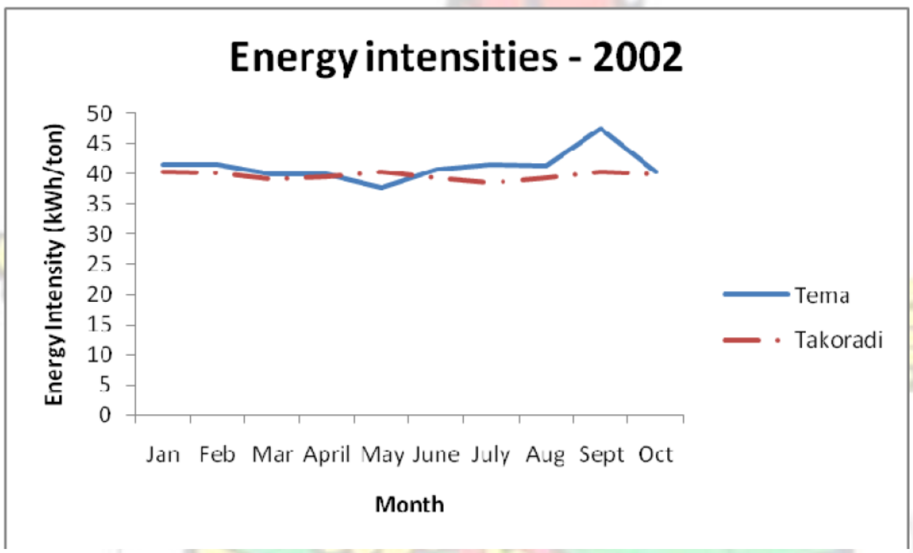


Figure 5.5 (b): Energy intensities for the year 2002

The energy intensities for the year 2003, is shown in figure 5.5(c). At the Takoradi factory an energy intensity of 45.65 kWh/ton was recorded in January. It was reduced to 44.65 kWh/ton in February, increased to 45.96 kWh/ton in March remained fairly constant to May. In June, it rose to 47.86 kWh/ton and reduced to 45.39 kWh/ton in July, increased to 48.32 kWh/ton in October and reduced uniformly to 44.28 kWh/ton in December. At the Tema factory, the energy intensity registered in January was 39.93 kWh/ton, this increased uniformly to 46.10 kWh/ton in April. It reduced to 40.95 kWh/ton in July, increased slightly to 41.20 kWh/ton in August and reduced again to 38.90 kWh/ton in September. It remained fairly constant from then on to December.

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(c)

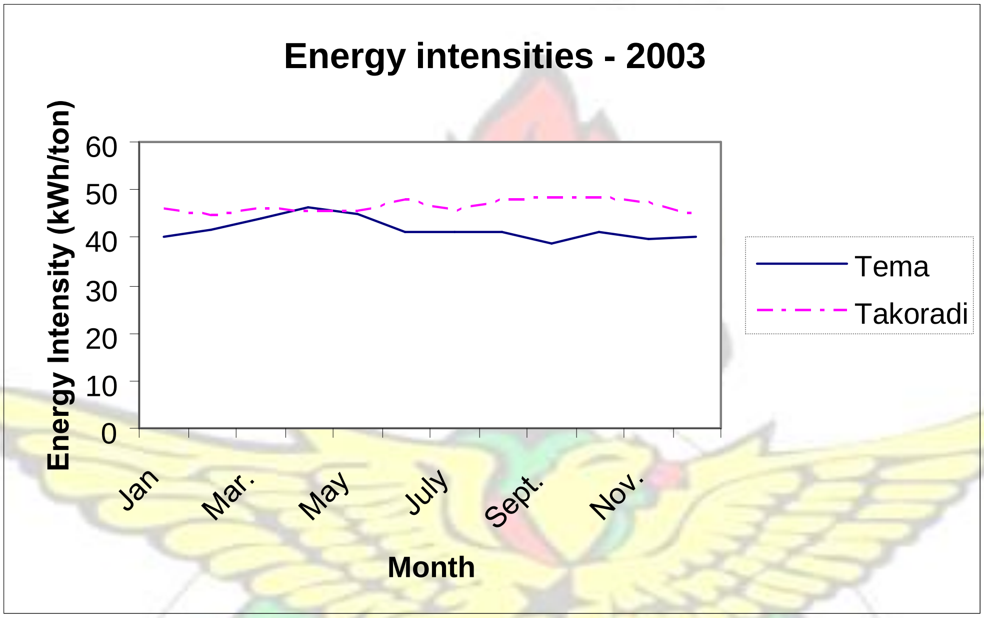

Figure5.5 (c): Energy intensities for the year 2003

From figure 5.5 (d), for the year 2004, the energy intensities recorded at the Takoradi factory had little variations throughout that year, ranging between a maximum of 49.70 kWh/ton, which was recorded in May and a minimum of 43.74 kWh/ton recorded in November. At the Tema factory, an energy intensity of 48.74 kWh/ton was recorded in January. It reduced to 44.97 kWh/ton in February, increased 47.76 kWh/ton in March and reduced uniformly to 45.88 kWh/ton in May. It increased to 49.30 kWh/ton in June, reduced to 45.35 kWh/ton in August and rose again to 55.46 kWh/ton in September. This rose to 50.94 in October, dropped to

44.69 kWh/ton in November and finally rose to 50.47 kWh/ton in December.

(d)

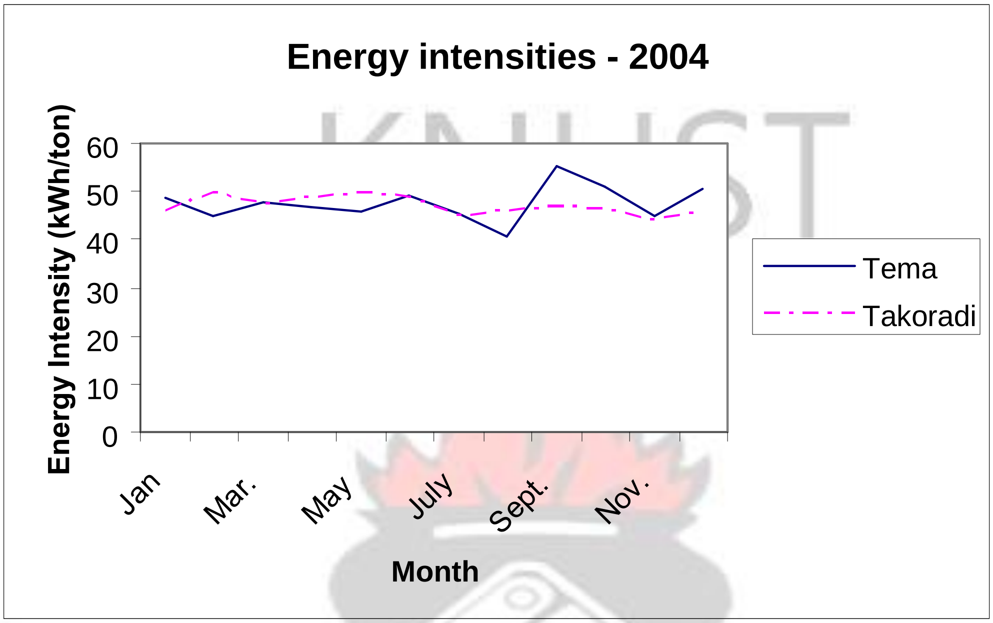

Figure 5.5 (d): Energy intensities for the year 2004

From figure 5.5 (e), for the year 2005, the energy intensity registered at the Takoradi factory was fairly constant from January to March. It rose uniformly from 44.86 kWh/ton in March to 47.33 kWh/ton in May. It dropped to 40.83 kWh/ton in August, increased to 45.80 kWh/ton in October and reduced slightly to 44.15 kWh/ton in December. At the Tema factory, the pattern of the monthly energy intensities was alternating. In January an energy intensity of 46.45 kWh/ton was recorded, it increased to 48.99 kWh/ton in February and decreased slightly to 47.95 kWh/ton in March. It increased uniformly to 51.41 kWh/ton in May, decreased to 45.56 kWh/ton in June and increased again to 47.07 kWh/ton in July. The energy intensity value reduced to 45.49 kWh/ton in August raised to 50.20 kWh/ton in

September and finally reduced uniformly to 46.04 kWh/ton in December.

(e)

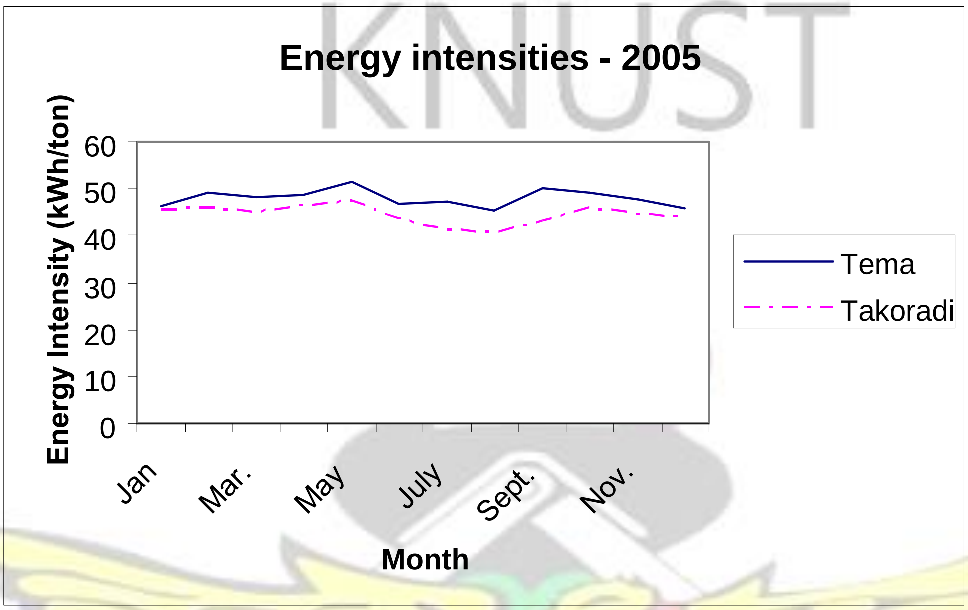

Figure 5.5 (e): Energy intensities for the year 2005

The annual average energy intensities registered from the year 2001 to 2005 is shown in Table 5.2 and figure 5.5 is the graphical representation.

Table 5.2 Annual Average Energy Intensity (kWh/ton)

	2001	2002	2003	2004	2005
Tema	44.79	41.21	41.65	47.59	47.93
Takoradi	40.93	40.33	46.31	46.85	44.40

Generally, the energy intensities for Tema factory were slightly higher than Takoradi except the year 2003 as can be seen in the figure 5.5. In the year 2001, it was 9.4% high; 2.2% high in 2002; 10% low in 2003; 1.6% high in 2004, and 8.0% high in 2005. Higher values indicate that more electrical energy was consumed to produce one ton of cement. Although, greater number of tons of cement was produced at Tema, as can be seen in Tables 3.1 and 3.2, the persistent higher energy intensity values recorded was mostly due to the number of high voltage dust plants installed to prevent environmental pollution. The environmental pollution control at Takoradi was not as effective as at Tema owing to the pressure of the neighbours at the Tema plant. In all, eighteen dust plants are installed at the Tema factory. Seven of them are rated 55 kW and the remaining eleven rated 30 kW. So in effect, a total of 715 kW are consumed by dust plants alone. At the Takoradi factory, thirteen dust plants are installed. Seven of them are rated 55 kW and the remaining six also rated 30 kW summing up to 565 kW.

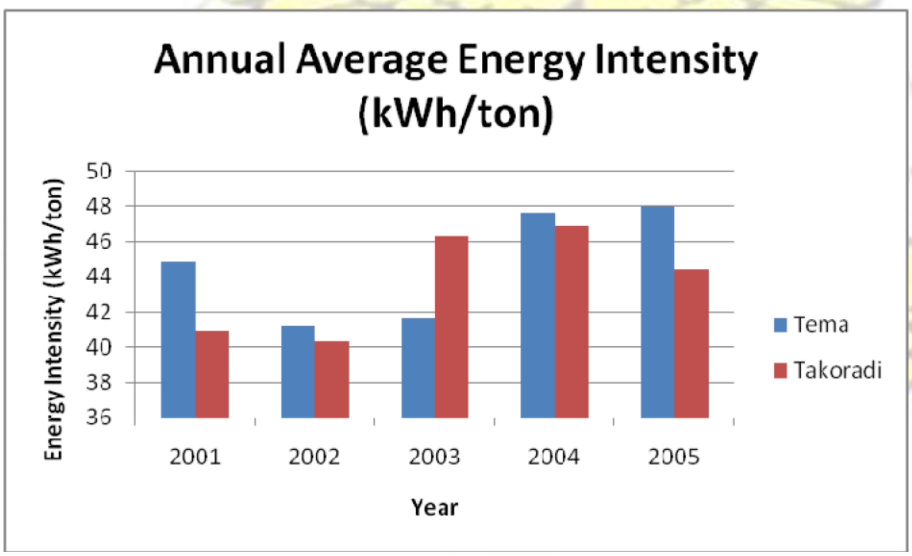

Figure 5.5 Graph of Annual Average Energy Intensity

Another factor that accounts for difference in the energy intensity is the fact that the plant at Tema has additional equipment that could be used to produce readymixed concrete and equipment that is used to produce shortcrete mortar, a product used for major rehabilitation of buildings and structures. These two products are supplied on demand. The operation of those additional plants accounts for extra energy used at the Tema factory at times. The plant at Takoradi does not have those facilities.

In general, the two cement factories at Tema and Takoradi are under the same management, Ghana Cement Works Limited (Ghacem). Their raw materials were from the same source, Norway but technically, there were some differences. At the Tema plant the total capacity of the motors driving the mills was 6800 kW while the total capacity at the Takoradi plant was 6500 kW. At Tema, the raw materials were transported from the jetty to the factory, a distance of 700 m using haulage trucks whereas at Takoradi for the same distance conveyor belt was used. Furthermore, Tema factory has two additional separate plants, one for producing concrete and the other for producing shortcrete mortar. The plant at Takoradi does not have those facilities. At the Tema factory, a total of 80 000 to 100 000 bags of cement were produced in a day of 24 working hours and 70 000 to 90 000 bags produced at the Takoradi factory. Environmental pollution control at Tema was better than at Takoradi because the neighbours of Takoradi factory, Ghana Manganese Company Limited, were not so much concerned in that their operation was equally dusty.

It was observed that apart from the motors driving the mills, identically positioned motors at the two factories had the same power rating. For example, the rating of a motor driving a bucket elevator at Tema had the same rating as the one at Takoradi. Again, in an attempt to reduce the number of spare parts stock, what was known as “standardisation of motors” was instituted. In this regard, motors which were closely rated were allowed to be driven by the largest of them so that a single motor in store could serve as a spare for all those ones. This contributed to oversized motors. Motors become quite inefficient as they experience a less than 100 percent loading condition. (Clark, 1997).

There was efficient energy use attempt, 1000 W high pressure mercury vapour lamps were being replaced with 500 W sodium vapour lamps at the two factories. However, there were instances where a number of fluorescent lamps were left on during day time.

There should be legislative backing to demand–side management in the power sector because it is estimated that about 30% of the electric energy generated in Ghana is wasted (Turkson, 2000). Again, because of the difficulties in securing investment capital for constructing new power supply facilities, energy efficient utilisation of the existing energy resources that ensures the same level of activities with lesser input of energy should be aggressively pursued.

Using a monthly average electrical energy cost of 647.24 ¢/kWh, deduced from Table 4.1, then the electrical energy cost of producing a ton of cement is as presented in Table 5.3. This implies that if there is an increase of 1 kWh/ton of energy intensity, there is an increase in electrical energy cost of ¢647.24.

Table 5.3 Electrical Energy Cost of Cement Production

Energy Intensity (kWh/ton)	Electrical Energy Cost /ton of cement (¢/ton)	Electrical Energy Cost /ton of cement (GH¢/ton)
30	20,228.70	2,022.87
35	23,600.15	2,360.02
40	26,971.60	2,697.16

45	30,343.05	3,034.30
50	33,714.50	3,371.45
55	37,085.95	3,708.60
60	40,457.40	4,045.74

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions and the recommendations for further work.

6.1 Conclusions

The main objective of this research is to compare the energy intensities for Ghacem cement factories at Tema and Takoradi. This was done by studying the cement production process at the two cement factories at Tema and Takoradi, identifying energy consuming items, obtaining previous energy data, cement production data and calculating energy intensities for the two factories. The following are the findings deduced from the study.

- The ideal load factor is 1. This was achieved in few cases (20%) at the two factories. Hence, there is the need to smooth the hills and valleys in the electrical energy demand, especially at Takoradi where low load factors were registered for most of the time.
- The economic power factor is 0.95. The plants were operated below this value for most of the time. A single value above 0.95 was recorded at the Tema factory through out the six years under review representing 1.4%. At the Takoradi factory, power factor values above 0.95 were recorded 23 times,

representing 34.7%. Therefore, the kVA taken from the supply were higher at the two Ghacem Factories. As such, they were charged for low power factor penalty.

- The average monthly maximum demand charge was about 32 % of the energy bills.
- Mill 1 and Mill 2 at the Tema factory were driven by oversized motors. They were previously driven by 1200 hp (895.2 kW) motors and were replaced with 1000 kW motors to produce the same milling capacity of 25 ton/h. As a result of that, an excess power of 104.8 kW for each motor, summing up to 209.6 kW was not utilised.

At Takoradi factory too, Mill 1, Mill 2 and Mill 3 were also driven by oversized motors. These mills were previously driven by 1300 hp (969.8 kW) motors. They had been replaced with 1000 kW motors to produce the same milling capacity of 25 ton/h. Here too, an excess power of 30.3 kW for each motor, totalling 100 kW was not effectively used.

- At Takoradi Ghacem factory, the raw materials were transported a distance of 700 m on conveyor belts. They could adopt the method used at the Tema factory, by using haulage trucks to transport the raw materials from the jetty to the factory.
- There were great numbers of 40 W fluorescent lamps at the production units which contributed to low power factor.

6.2 Anticipated Benefits

Energy intensity analysis gives an indication of the need to consider the study of economics of investments in efficient use of energy. As it has been done for cement factories at Tema and Takoradi, it can be done for other industries, such as Akosombo Textiles Limited and Tema Textiles Limited. They produce similar items for the same market. If the energy intensity of one factory is higher than the other, the production cost is eventually increased and it gives advantage to the other industry. The same thing can be said of competing industries like Juaben Oil Mills in Ashanti Region and Ghana Oil Palm Plantation at Kwae in the Eastern region, who produce palm oil in commercial quantities; Latex Foam Limited and Ash Foam Limited who also produce foam mattresses; Coca Cola Limited and Pepsi Cola Limited who produce soft drinks; Accra Breweries Limited and Ghana Guinness Breweries Limited who produce alcoholic beverages; and Logs and Lumber Limited and Bibiani Logs and Lumber Limited who produce and export lumber.

The energy intensity assessment provides indication for efficient energy use and could guide manufacturing industries as when to cut down on energy consumption

6.3 Recommendations

Energy plays a vital role in the production of cement. It is a factor of production whose cost directly affects the price of the cement. Consequently, it affects the competitiveness of the company, now that it has moved from the monopoly situation to a competitive environment. Improving energy intensities at the Ghacem Cement factories at Tema and Takoradi could ensure reduced production cost. In view of this the following recommendations are made:

- Motors represent the largest single user of electricity in the plants. Purchase of high- efficiency motors should be standard practice with any new purchases.

- Motors should be sized to operate at closely as possible to full load, because power factor of induction motors suffer severely at light loads.
- Synchronous motors should be used to drive some of the conveyors because adjusting the motor's excitation will yield a leading current which could then be used to offset the lagging current taken by the rest of the load.
- There should be education for workers on efficient energy use practices.
- The Government should introduce Energy Management Guidelines which should be adopted by heavy energy users.

For further research work, it is recommended that cost benefit analysis be carried out to show the gains that could be derived by effecting the above recommendations.

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APPENDIX 1

PURC AUTHORISED TARIFF EFFECTIVE OCTOBER 1, 2003

Tariff Category		PURC Approved Rates (¢)
SLT-LV		
Maximum Demand	(¢/kVA/Month)	143,100
Energy Charge	(¢/kWh)	403
Service Charge	(¢/Month)	63,600
SLT- MV		
Maximum Demand	(¢/kVA/Month)	97,520
Energy Charge	(¢/kWh)	382
Service Charge	(¢/Month)	63,600
SLT-HV		
Mamimum Demand	(¢/kVA/Month)	89,040
Energy Charge	(¢ /kWh)	371
Service Charge	(¢/Month)	63,600
NON RESIDENTIAL		
0 – 300	(¢/kWh)	848
300+	(¢/kWh)	1,039
Service Charge	(¢/Month)	21,200
RESIDENTIAL		
*0-50 (Exclusive "Lifeline" Block Charge) (¢/Month)		19,080
1 – 300	(¢/kWh)	583
300+	(¢/kWh)	1,018

*All consumptions above 50 units will not benefit from the subsidized and exclusive "Lifeline" block charge.

Levies

The levies on energy consumed remain as they were for the previous tariff. These are:

Government Special levy **¢1.70 per kWh**
Street Lighting **¢0.50 per kWh**

APPENDIX 2

Table A-1 Load Factor for the Tema Plant

(a)
2000

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	3 403 000	22	8 040	0.90	0.89
Feb	3 891 730	21	8 200	0.90	1.05
Mar	3 936 530	22	8 940	0.91	0.92
April	3 712 210	20	8 340	0.90	1.03
May	3 932 010	23	8 000	0.91	0.98
June	2 963 660	22	8 000	0.91	0.77
July	3 309 320	20	7 680	0.90	0.99
Aug	4 028 920	23	8 080	0.91	0.99
Sept	3 008 090	21	7 520	0.90	0.88
Oct	2 207 940	22	6 640	0.91	0.69
Nov	2 084 140	22	5 640	0.92	0.76
Dec	2 059 730	16	7 520	0.91	0.79

(b)
2001

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	3 469 290	22	7 440	0.91	0.97
Feb	3 226 030	20	7 320	0.92	0.99
March	2 494 290	21	7 600	0.90	0.72
April	2 501 050	21	7 480	0.89	0.75

May	2 630 340	23	7 320	0.90	0.72
June	2 270 000	21	6 800	0.91	0.73
July	2 249 760	22	8 480	0.90	0.56
Aug	2 692 740	23	6 640	0.91	0.81
Sept	2 524 570	20	6 520	0.90	0.90
Oct	2 453 130	23	6 520	0.91	0.75
Nov	2 418 740	23	6 640	0.92	0.72
Dec	2 200 680	16	6 480	0.92	0.96

(c)
2002

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	2 642 300	22	6 880	0.91	0.81
Feb	2 883 640	20	6 880	0.92	0.95
March	2 721 660	20	6 720	0.91	0.93
April	2 417 810	22	6 800	0.91	0.74
May	2 833 320	22	6 600	0.92	0.88
June	2 305 620	21	6 400	0.92	0.78
July	2 498 920	23	6 840	0.92	0.72
Aug	3 039 630	20	7 920	0.91	0.88
Sept	2 877 710	22	7 280	0.91	0.82
Oct	2 457 000	23	6 960	0.92	0.70
Nov	3 020 020	20	7 160	0.92	0.96
Dec	-	18	-	-	-

(d)
2003

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	3 681 440	21	8 200	0.92	0.97

Feb	3 290 280	20	8 400	0.92	0.89
March	3 488 740	20	7 120	1.04	0.98
April	2 880 440	20	7 400	0.91	0.89
May	3 480 230	21	7 480	0.91	1.01
June	2 848 910	21	7 480	0.91	0.83
July	3 503 300	22	7 360	0.91	0.99
Aug	3 030 170	21	7 280	0.91	0.91
Sept	2 672 050	22	7 160	0.91	0.78
Oct	3 279 200	23	7 360	0.91	0.89
Nov	2 975 060	20	7 280	0.91	0.94
Dec	2 818 540	20	7 120	0.91	0.91

(e)

2004

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	3 840 890	20	7 080	0.92	1.23
Feb	3 582 540	20	7 214	0.92	1.12
March	4 101 610	22	8 280	0.92	1.02
April	3 479 700	20	8 320	0.92	0.95
May	3 239 520	20	7 280	0.92	1.01
June	3 627 260	22	7 280	0.92	1.03
July	3 563 950	21	7 480	0.92	1.03
Aug	3 333 820	22	8 320	0.92	0.82
Sept	3 333 820	22	7 480	0.92	0.92
Oct	3 887 460	21	7 240	0.93	1.14
Nov	3 225 310	22	7 330	0.93	0.87
Dec	3 479 940	21	7 220	0.92	1.04

(f)

2005

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	3 052 820	21	7 360	0.92	0.94
Feb	3 518 210	20	8 400	0.92	0.95
March	3 777 060	21	8 420	0.92	0.97
April	4 244 650	21	8 720	0.92	1.05
May	3 310 270	21	8 360	0.91	0.86
June	3 439 430	22	7 370	0.92	0.96
July	3 223 820	20	7 350	0.92	0.99
Aug	3 275 240	23	7 340	0.92	0.88
Sept	3 174 350	22	7 450	0.92	0.88
Oct	3 080 810	21	7 310	0.92	0.91
Nov	3 017 720	22	6 370	0.93	0.96
Dec	3 269 000	20	6 350	0.93	1.15

Table A-2 Load Factor - Takoradi

(a)
2000

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	1954896	22	6816	0.86	0.63
Feb	2217804	21	6816	0.95	0.68
Mar	2494044	22	6816	1.02	0.68
April	2612208	20	6912	1.15	0.68
May	2658696	23	6672	1.07	0.67
June	2107020	22	6576	0.91	0.67
July	2176464	20	6528	0.91	0.76
Aug	2780448	23	6576	1.17	0.90
Sept	2220252	21	6672	0.92	0.72
Oct	2224728	22	6624	0.91	0.70
Nov	2057868	22	5952	0.91	0.72
Dec	2260464	16	6528	1.00	0.90

(b)

2001

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	2114425	22	6672	1.23	0.49
Feb	2412136	20	6912	0.89	0.82
Mar	2510636	21	7728	0.78	0.83
April	2531244	21	7872	0.92	0.69
May	2940900	23	7824	1.06	0.64
June	2153218	21	7248	0.81	0.73
July	2094662	22	7680	0.85	0.61
Aug	2752032	23	7584	1.00	0.66
Sept	1957944	20	7584	0.90	0.60
Oct	2437872	23	7584	1.00	0.58
Nov	1893699	23	7488	0.79	0.60
Dec	2540868	16	7392	1.13	0.79

(c)

2002

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	1667640	22	7392	0.63	0.63
Feb	2162120	20	7296	0.94	0.66
Mar	2396584	20	7584	0.84	0.78
April	2635676	22	7584	0.94	0.66
May	2328160	22	7152	0.86	0.72
June	2192052	21	7440	0.93	0.63
July	1872660	23	7200	0.84	0.56
Aug	2294388	20	5616	0.84	1.01
Sept	2697708	22	5712	1.02	0.87
Oct	2339674	23	5712	0.91	0.82
Nov	2433974	20	6768	0.85	0.88
Dec	3497748	18	6678	1.10	1.10

(d)
2003

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	2232036	21	6912	0.68	0.94
Feb	3 368160	20	6768	0.98	1.52
Mar	2810796	20	5712	0.87	1.18
April	2471340	20	5568	0.86	1.08
May	2827968	21	5616	0.97	1.03
June	2498784	21	5520	1.07	0.84
July	2486832	22	5328	0.95	0.93
Aug	2949060	21	7440	0.96	0.82
Sept	3109440	22	-	1.10	-
Oct	2552088	23	7440	0.93	0.67
Nov	2841216	20	5 712	1.10	0.94
Dec	3168804	20	5760	1.14	1.00

(e)

2004

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	2270418	20	6336	0.72	1.04
Feb	2538916	20	7152	0.87	0.85
Mar	3120212	22	7152	0.89	0.93
April	2806142	20	7248	0.94	0.86
May	3044362	20	5808	0.85	1.28

June	2 979768	22	6432	0.97	0.90
July	2874492	21	6528	0.87	0.90
Aug	3018324	22	5952	0.94	1.02
Sept	2569140	22	5904	0.94	0.88
Oct	2506764	21	5760	0.83	1.04
Nov	2624604	22	5 904	0.98	0.86
Dec	3498324	21	5952	1.04	1.12

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(f)
2005

Month	Energy Consumed (kWh)	No. of Working Days	Max. Demand (kVA)	Power Factor	Load Factor
Jan	2181036	21	6048	0.67	1.07
Feb	3480708	20	7056	1.02	1.01
Mar	3 015120	21	7104	0.84	1.00
April	3 287964	21	7104	0.95	0.97
May	2948160	21	6912	0.85	1.00
June	2807472	22	5808	0.94	0.97
July	2342916	20	6000	0.81	1.00
Aug	2748816	23	5952	0.94	0.89
Sept	2656464	22	5952	0.92	0.92
Oct	2 454492	21	5952	0.90	0.91
Nov	2 714964	22	6000	0.94	0.91
Dec	2 832612	20	5712	1.04	0.99

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APPENDIX 3

Table A-3 CURRENTS AT IMPROVED POWER FACTOR FOR TEMA FACTORY

(a)

2000

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00

Jan	9 962	9 746	9 638	9 540	9 441	9 342	9 244	9 145	9 055	8 966
Feb	11 937	11 678	11 549	11 431	11 313	11 195	11 076	10 958	10 851	10 743
March	11 399	11 276	11 151	11 037	10 923	10 809	10 695	10 581	10 477	10 373
April	11 955	11 696	11 566	11 448	11 330	11 211	11 093	10 975	10 867	10 760
May	10 890	10 772	10 653	10 544	10 435	10 326	10 217	10 108	10 009	9 910
June	8 581	8 488	8 394	8 308	8 223	8 137	8 051	7 965	7 887	7 809
July	10 657	10 426	10 311	10 205	10 100	9 994	9 889	9 783	9 687	9 591
Aug	11 159	11 038	10 916	10 805	10 693	10 581	10 469	10 358	10 256	10 155
Sept	9 225	9 025	8 925	8 834	8 743	8 651	8 560	8 469	8 386	8 303
Oct	6 393	6 324	6 254	6 190	6 126	6 062	5 998	5 934	5 876	5 818
Nov	5 969	5 969	5 903	5 843	5 783	5 722	5 662	5 601	5 546	5 491
Dec	8 292	8 112	8 023	7 940	7 858	7 776	7 694	7 612	7 537	7 463

(b)

2001

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00

Jan	10 046	9 937	9 827	9 727	9 626	9 526	9 425	9 325	9 233	9 142 9
Feb	10 163	10 163	10 051	9 948	9 846	9 743	9 640	9 537	9 443	350 6
March	7 650	7 484	7 401	7 326	7 250	7 174	7 098	7 023	6 954	885 6
April	7 756	7 503	7 421	7 345	7 269	7 193	7 117	7 041	6 972	903 6
May	7 366	7 206	7 127	7 054	6 981	6 908	6 835	6 762	6 696	629
June	6 886	6 811	6 736	6 667	6 598	6 529	6 461	6 392	6 329	6 266
July	6 587	6 444	6 373	6 308	6 242	6 177	6 112	6 047	5 988	5 928 6
Aug	7 457	7 376	7 295	7 220	7 146	7 071	6 996	6 922	6 854	786 7 318
Sept	8 131	7 955	7 867	7 786	7 706	7 625	7 545	7 464	7 391	6 183 6
Oct	6 794	6 720	6 646	6 579	6 511	6 443	6 375	6 307	6 245	096
Nov	6 626	6 626	6 553	6 486	6 419	6 352	6 285	6 218	6 157	7 973
Dec	8 666	8 666	8 571	8 483	8 395	8 308	8 220	8 132	8 052	

(c)

2002

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00

Jan	7 650	7 567	7 486	7 406	7 328	7 252	7 177	7 104	7 032	6 962
Feb	9 085	9 085	8 987	8 892	8 798	8 707	8 617	8 529	8 443	8 358
March	8 668	8 574	8 482	8 392	8 303	8 217	8 132	8 049	7 968	7 888
April	7 000	6 924	6 850	6 777	6 706	6 636	6 567	6 500	6 435	6 370
May	8 114	8 114	8 027	7 942	7 858	7 776	7 696	7 618	7 541	7 465
June	6 918	6 918	6 844	6 771	6 700	6 630	6 562	6 495	6 429	6 365
July	6 846	6 846	6 772	6 700	6 629	6 560	6 493	6 427	6 362	6 298
Aug	9 682	9 577	9 474	9 373	9 274	9 178	9 083	8 990	8 899	8 811
Sept	8 332	8 241	8 153	8 066	7 981	7 898	7 817	7 737	7 659	7 582
Oct	6 732	6 732	6 660	6 589	6 520	6 452	6 385	6 320	6 256	6 194
Nov	9 513	9 513	9 411	9 311	9 213	9 117	9 023	8 931	8 840	8 752
Dec	-	-	-	-	-	-	-	-	-	-

(d)

2003

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Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
Jan	11 045	11 045	10 926	10 810	10 696	10 585	10 476	10 369	10 264	10 161
Feb	10 366	10 366	10 255	10 145	10 039	9 934	9 832	9 731	9 633	9 537
March	9 722	-	-	-	-	-	-	-	-	-
April	9 174	9 075	8 977	8 881	8 788	8 696	8 607	8 519	8 433 9	8 349 9
May	10 556	10 442	10 329	10 219	10 112	10 007	9 903	9 802	703	606
June	8 642	8 548	8 456	8 366	8 278	8 192	8 108	8 025	7 944	7 864
July	10 144	10 033	9 925	9 820	9 716	9 615	9 516	9 419	9 324	9 231
Aug Sept Oct Nov Dec	9 191 7 737 9 081 9 475 8 977	9 091 7 653 8 982 9 372 8 879	8 993 7 571 8 886 9 272 8 784	8 898 7 490 8 791 9 173 8 691	8 804 7 411 8 699 9 077 8 599	8 712 7 334 8 608 8 982 8 510	8 623 7 259 8 519 8 889 8 422	8 535 7 185 8 432 8 799 8 336	8 448 7 112 8 347 8 710 8 252	8 364 7 041 8 264 8 623 8 169

(e)

KNUST

2004

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
Jan	12 100	12 100	11 970	11 843	11 718	11 596 10	11 477 10	11 36	11 245	11 132
Feb	11 287	11 287	11 166	11 047	10 930	817 11 257	705 11	10 59	10 489	10 384
March	11 747	11 747	11 620	11 497	11 376	10 505	141	11 02	10 916	10 807
April	10 962	10 962	10 844	10 729	10 616	9 780	10 397	10 29	10 186	10 085
May	10 206	10 206	10 096	9 989	9 883	9 956	9 677	9 581	9 484	9 387
June	10 389	10 389	10 277	10 168	10 061	10 247	9 853	9	9 654	9 558
July	10 693	10 693	10 578	10 465	10 355	9 150 9	10 141	753	9 937	9 837
Aug	9 548	9 548	9 445	9 345	9 246	150	9 056 9	10 03	8 873	8 784
Sept	9 548	9 548	9 445	9 345	9 246	11 177	056	8 963	8 873	8 784
Oct	11 538	-	11 538	11 415	11 295	8 853	11 062	8	10 839	10 730
Nov	9 139	-	9 139	9 041	8 946	10 007	8 762 9 903	963	8 585 9 703	8 499 9 606
Dec	10 442	10 442	10 329	10 219	10 112			10 94		
								8 672 9 802		

(f)

2005

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
Jan	9 159	9 159	9 055	8 964	8 870	8 778	8 687	8 599	8 512	8 427
Feb	11 084	11 084	10 965	10 848	10 734	10 622	10 513	10 406	10 301	10 198
March	11 332	11 332	11 210	11 091	10 974	10 860	10 748	10 638	10 531	10 426
April	12 735	12 735	12 599	12 465	12 333	12 205	12 079	11 956	11 835	11 717
May	10 041	9 932	9 825	97 21	9 618	9 518	9 420	9 324	9 230	9 137
June	9 850	9 850	9 744	9 641	9 539	9 440	9 343	9 247	9 154	9 062
July	10 156	10 156	10 047	9 940	9 835	9 733	9 632	9 534	9 438	9 343
Aug	8 972	8 972	8 875	8 781	8 688	8 598	8 509	8 422	8 337	8 254
Sept	9 091	9 091	8 993	8 898	8 804	8 712	8 623	8 535	8 448	8 364
Oct	9 244	9 244	9 146	9 047	8 952	8 859	8 767	8 678	8 590	8 504
Nov	8 749	- -	8 549	8 458	8 369	8 282	8 197	8 113	8 031	7 951
Dec	10 187		10 187	10 079	9 973	9 869	9 767	9 667	9 570	9 474

KNUST

Table A-4 CURRENTS AT IMPROVED POWER FACTOR FOR TAKORADI FACTORY

(a)

2000

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
Jan	5989	5598	5539	5480	5422	5366	5310	5256	5202	5151
Feb	6444	- -	-	-	-	6377	6311	6247	6183	6122
March	6443	- -	-	-	-	-	-	-	-	-
April	6584	6034	-	-	-	-	-	-	-	-
May	6262	6856	-	-	-	-	-	-	-	-
June	6101	- -	5970	5906	5844	5783	5723	5665	5607	5552
July	6932	6372	6783	6711	6640	6571	6503	6437	6371	6308
Aug	5989	-	-	-	-	-	-	-	-	-
Sept	6662	8901	6591	6520	6451	6385	6318	6254	6190	6129
Oct	6442		6304	6236	6171	6107	6043	5982	5921	5862
Nov	5422		-	-	-	-	-	-	-	-
Dec	9099		8806	8712	8620	8531	8443	8357	8271	8190

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(b)

2001

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00

Jan	4529	-	-	-	-	-	-	-	-	-
Feb	7588	7855	7517	7437	7359	7282	7207	7134	7061	6991
March	8885	7532	7452	7372	7295	7219	7144	7072	6999	6930
April	7595	-	7513	7433	7355	7278	7203	7130	7057	6987
May	6992	-	-	-	-	-	-	-	-	-
June	7338	6460	6391	6323	6256	6192	6127	6065	6003	5944
July	6493	5999	5935	5871	5809	5749	5690	5632	5574	5519
Aug	6934	-	-	-	-	-	-	-	-	-
Sept	6305	6168	6102	6037	5973	5911	5850	5790	5731	5675
Oct	6 144	-	-	-	-	-	-	-	-	-
Nov	6041	5187	5 132	5077	5024	4972	4920	4870	4820	4773
Dec	8146	-	-	-	-	-	-	-	-	

(c)
2002

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00

Jan	6462	4776	4725	4674	4625	4577	4530	4484	4438	4394
Feb	6667	-	-	-	6596	6528	6460	6394	6329	6267
March	8269	7550	7469	7389	7311	7236	7161	7088	7015	6946
April	7388	-	-	-	7310	7234	7159	7086	7014	6945
May	7133	6667	6596	6526	6457	6390	6324	6260	6196	6134
June	6506	-	-	6437	6369	6303	6238	6174	6111	6051
July	5619	5130	5075	5021	4968	4916	4865	4816	4767	4720
Aug	7917	7228	7151	7074	7000	6927	6855	6786	6716	6650
Sept	6969	-	-	-	-	-	-	-	-	-
Oct	6480	6409	6341	6273	6207	6143	6079	6017	5956	5897
Nov	8299	7668	7586	7505	7426	7349	7272	7198	7125	7054
Dec	10240	-	-	-	-	-	-	-	-	-

(d)

2003

KNUST

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
Jan	9061	6696	6625	6554	6485	6418	6351	6287	6223	6161
Feb	9961	-	-	-	-	-	-	-	9860	9762
March	9364	8855	8760	8666	8575	8486	8398	8313	8228	8147
April	8329	7785	7702	7620	7540	7461	7384	7309	7234	7163
May	8048	- -	- -	- -	- -	- -	- -	7965	7884	7806
June	6446	-	-	-	-	6823	6755	-	-	-
July	6897	- -	- -	- -	- -	- -	8392	6686	6618	6552
Aug	8480	- - -	- - -	6842	6770	6700	-	8306	8222	8140
Sept	7448			- -	- -	- -	6631	-	-	-
Oct	6916						- -	6563	6496	6432
Nov	7486							-	-	-
Dec	8056							-	-	-

(e)

2004

KNUST

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
Jan	9 140	7153 7998	7076 7913	7001 7828	6927	6855	6784	6715	6647	6581
Feb	8458	8936	8840	8746	7746	7665	7586	7509	7432	7359
March	9337	-	-	-	8654	8564	8475	8389	8304	8221
April	8652	9590	9488	9387	8561	8472	8384	8299	8214	8133
May	10380	-	-	-	9288	9192	9096	9004	8912	8824
June	8094	8624	8532	8441	-	-	-	8011	7930	7851
July	9120	- -	- -	- -	8352	8265	8180	8096	8014	7935
Aug	8460	7521	7441	7361	8371	8284	8199	8115	8032	7953
Sept	7201 8337	- -	- -	- -	7125	7052	6978	6907	6837	6769
Oct	7057				7283	7208	7133	7061	6989	6919
Nov	9375				-	-	-	-	6985	6915
Dec					-	-	-	-	-	-

(f)

2005

KNUST

Month	Initial Current (A)	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
Jan	8986	6544	6474	6404	6337	6271	6206	6143	6081	6020
Feb	9890	-	-	-	-	-	-	-	-	-
March	9908	9046	8949	8854	8760	8670	8580	8492	8406	8323
April	9554	-	-	-	-	9454	9356	9261	9167	9076
May	9574	8845	8751	8657	8566	8477	8389	8304	8219	8138
June	7869	-	-	-	7786	7706	7626	7 548	7471	7397
July	8383	7381	7302	7224	7148	7074	7000	6929	6858	6791
Aug	7370	- -	-	-	7292	7217	7142	7069	6997	6928
Sept	7680 7528	7364	7526	7446	7368	7291	7216	7142	7069	6999
Oct	7610	- -	7285	7207	7132	7058	6985	6913	6843	6775
Nov	7894		-	-	7530	7452	7375	7299	7225	7154
Dec			-	-	-	-	-	-	-	-

APPENDIX 4

Table A5 Maximum Demand Charge for the Tema Factory

(a) 2003

Month	Energy charge (¢)	Maximum demand charge (¢)	Percentage maximum demand charge
January	2 214 183 668	672 400 000	30.4
February	2 077 753 866	688 800 000	33.2
March	2 157 602 428	655 040 000	30.4
April	1 938 882 668	680 800 000	35.1
May	2 191 397 156	688 160 000	31.4
June	1 934 323 652	688 160 000	35.6
July	2 188 371 260	677 120 000	30.9
August	1 987 432 724	669 760 000	33.7
September	1 829 186 260	658 720 000	36.0
October	2 223 987 590	717 747 200	32.3
November	2 083 837 517	709 945 600	34.1
December	1 998 675 103	694 342 400	34.7

(b) 2004

Month	Energy charge (¢)	Maximum demand charge (¢)	Percentage maximum demand charge
January	2 435 890 785	690 441 600	28.3
February	2 338 997 643	703 509 280	30.1
March	2 680 160 790	807 465 600	30.1
April	2 415 915 166	811 366 400	33.6
May	2 198 071 014	709 945 600	32.3
June	2 365 555 217	709 945 600	30.0
July	2 360 150 552	729 449 600	30.9
August	2 405 026 030	811 366 400	33.7
September	2 405 026 030	729 449 600	30.3
October	2 528 338 250	706 044 800	27.9
November	2 246 092 345	714 821 600	31.8
December	2 346 175 210	704 094 400	30.0

(c) 2005

Month	Energy charge (¢)	Maximum demand charge (¢)	Percentage maximum demand charge

January	-	-	-
February	2 495 406 055	819 168 000	32.8
March	2 611 931 290	821 118 400	31.4
April	2 852 016 675	850 374 400	29.8
May	2 399 114 625	815 267 200	34.0
June	2 345 112 245	718 722 400	30.6
July	2 247 677 470	716 772 000	31.9
August	2 269 257 920	715 796 800	31.5
September	2 237 051 265	7 26 524 000	32.5
October	2 180 052 635	712 871 200	32.7
November	2 096 779 280	621 202 400	29.6
December	2 155 476 440	619 252 000	28.7

APPENDIX 5

Table A 6 Energy Intensity for Ghacem Cement Factory at Tema

(a)

2000

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	3 403 000	82 768.57	41.11
February	3 891 730	101 110.53	38.49
March	3 936 530	92 336.05	42.63
April	3 712 210	102 425.32	36.24
May	3 932 010	103 848.30	37.86
June	2 963 660	75 490.59	39.26
July	3 309 320	73 333.56	45.13
August	4 028 920	113 450.34	35.51
September	3 008 090	74 058.82	40.62
October	2 207 940	69 920.39	31.58
November	2 084 140	45 081.49	46.23
December	2 059 730	55 234.79	37.29

b)

2001

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	3 469 290	72 660	47.75
February	3 226 030	78 129	41.29
March	2 494 290	70 324	35.47
April	2 501 050	34 766	71.94
May	2 630 340	78 813	33.37
June	2 270 000	51 990	43.66
July	2 249 760	52779	42.63
August	2 692 740	61 265	43.95
September	2 524 570	58 598	43.08
October	2 453 130	66 949	36.64
November	2 418 740	45 081	53.65
December	2 200 680	49 943	44.06

(c)
2002

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	2 642 300	63 713	41.47
February	2 883 640	69 335	41.59
March	2 721 660	68 087	39.97
April	2 417 810	60 449	40.00
May	2 833 320	75 104	37.73
June	2 305 620	56 740	40.63
July	2 498 920	60 158	41.54
August	3 039 630	73 579	41.31
September	2 887 710	60 856	47.45
October	2 457 000	60 879	40.36

November	3 020 020	-	-
December	-	-	-

KNUST

(d)
2003

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	3 681 440	92 208	39.93
February	3 290 280	78 909	41.70
March	3 488 740	79 241	44.03
April	2 880 440	62 478	46.10
May	3 480 230	77 621	44.84
June	2 848 910	69 271	41.13
July	3 503 300	85 542	40.95
August	3 030 170	73 551	41.20
September	2 672 050	68 693	38.90
October	3 2 79 200	79 685	41.15
November	2 975 060	74 848	39.75
December	2 818 540	70 359	40.06

NYANSAPɔ WɔSANE NO BADWENMA

(e)
2004

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	3 840 890	78 808	48.74

February	3 582 540	79 666	44.97
March	4 101 610	85 884	47.76
April	3 479 700	74 505	46.70
May	3 239 520	70 612	45.88
June	3 627 260	73 574	49.30
July	3 563 950	78 586	45.35
August	3 333 820	81 782	40.76
September	3 333 820	60 111	55.46
October	3 887 460	76 308	50.94
November	3 225 310	72 167	44.69
December	3 479 940	68 953	50.47

(f)
2005

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	3 052 820	65 707	46.46
February	3 518 210	71 818	48.99
March	3 777 060	78 779	47.95
April	4 244 650	87 556	48.48
May	3 310 270	64 393	51.41
June	3 439 430	73 869	46.56
July	3 223 820	68 495	47.07
August	3 275 240	71 993	45.49
September	3 174 350	63 224	50.20
October	3 080 810	62 882	48.99
November	3 017 720	63 445	47.56
December	3 269 000	70 999	46.04

Table A7 Energy Intensity for Ghacem Cement Factory at

Takoradi

(a)

2001

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	2 114 425	41 399	51.07
February	2 412 136	53 834	44.81
March	2 510 636	61 091	41.10
April	2 531 244	66 650	37.98
May	2 940 900	57 677	50.99
June	2 153 218	55 693	38.66
July	2 094 662	48 534	43.16
August	2 752 032	58 296	47.21
September	1 957 944	66 827	29.30
October	2 437 872	58 423	41.73
November	1 893 699	57 235	33.09
December	2 540 868	79 237	32.03

(b)

2002

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	1 667 640	41 399	40.28
February	2 162 120	53 884	40.13
March	2 396 584	61 091	39.23
April	2 635 676	66 650	39.55
May	2 328 160	57 677	40.37
June	2 192 052	55 693	39.36
July	1 872 660	48 534	38.58
August	2 294 388	58 296	39.36
September	2 697 708	66 827	40.37
October	2 339 674	58 423	40.05
November	2 433 974	57 235	42.53
December	3 497 748	79 327	44.09

(c)

2003

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	2 232 036	48 890	45.65
February	3 368 160	75 819	44.42
March	2 810 796	61 158	45.96
April	2 471 340	54 687	45.19
May	2 827 968	62 404	45.32
June	2 498 784	52 211	47.86
July	2 486 832	54 790	45.39
August	2 949 060	61 592	47.88
September	3 109 440	64 618	48.12
October	2 552 088	52 819	48.32
November	2 841 216	60 004	47.35
December	3 168 804	71 556	44.28

(d)

2004

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	2 270 418	49 766	45.62
February	2 538 916	51 354	49.44
March	3 120 212	66 095	47.21
April	2 806 142	57 934	48.44
May	3 044 362	61 258	49.70
June	2 979 768	61 292	48.62
July	2 874 492	63 834	45.03

August	3 018 324	65 729	45.92
September	2 569 140	55 004	46.71
October	2 506 764	54 265	46.19
November	2 624 604	60 003	43.74
December	3 498 324	76 725	45.60

(e)

2005

Month	Energy Consumed (kWh)	Cement Production (ton)	Energy Intensity (kWh/ton)
January	2 181 036	47 879	45.55
February	3 480 708	76 118	45.73
March	3 015 120	67 206	44.86
April	3 287 964	71 024	46.29
May	2 948 160	62 288	47.33
June	2 807 472	64 302	43.66
July	2 342 916	56 937	41.15
August	2 748 816	67 345	40.82
September	2 656 464	61 641	43.10
October	2 454 492	53 588	45.80
November	2 714 964	61 272	44.31
December	2 832 612	64 156	44.15