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ENERGETICS IN THE EGYPTIAN METAL INDUSTRIES

REPORT NO. 3

PERFORMANCE ANALYSIS AND ENERGY CINSERVATION MEASURES IN THE IRON AND STEEL COMPLEX, HELWAN

[BLAST FURNACES AND ELECTRIC DRIVES]

CAIRO UNIVERSITY_- MASSACHUSETTS INSTITUTE OF TECHNOLOGY

TECHNOLOGICAL PLANNING PROGRAM 000761

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SUMMARY

THE PRESENT REPORT IS THE THIRD IN A SERIES OF RESEARCH DOCUMENTS THAT AIM AT THE ANALYSIS AND CONSERVATION OF ENERGY CONSUMPTION IN THE EGYPTIAN METAL INDUSTRIES. THIS REPORT IS DEVOTED, FIRSTLY, TO THE ANALYSIS OF THE PERFORMANCE OF THE BLAST FURNACE SHOP AND THE BLAST AIR STOVES AT HADISOLB IN TERMS OF DAILY AND MONTHLY ENERGY CONSUMPTIONS & PRODUCTIVITY DURING 1985. SECONDLY, THE REPORT DESCRIBES A DEVELOPED TECHNIQUE FOR ENERGY CONSERVATION MEASURES IN ELECTRIC DRIVES WITH PARTICULAR REFERENCE TO THE SINTERING SHOP AT HADISOLB IN HELWAN.

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CHAPTER 1

INTRODUCTION

1.1 Background

In the last decade, nations became strongly aware of the accute problem of fossil fuel depletion, their souring prices and the political and economical factors encountered. Two distinct routes for survival were brought to surface, firstly the rationalization of fossil fuel consumption, and secondly seeking and developing new and renewable sources of energy.

Egypt, albeit its severe development problems, has started a national program for energy rationalization in major consuming sectors and particularly those in metal industries and transportation. In an earlier publication [1], it was shown that the metal industry in Egypt consumes more than 10% of the total energy consumption. Such high figure promoted several studies in attempt to reduce such consumption and to develop the means for an efficient utilization of available fossil fuels. Among the studies are those of references 2,3 and 4.

The present report is the second in a series of research documents that aim at the analysis of the energy status at the Egyptian Iron and Steel Company at Helwan. The final goals of the study can be identified as:

1. To represent the present energy status, in a systematic and a parametric mannar.
2. To analyse these information in terms of input/output data and to build overall material and energy balances.
3. To pin-point locations where more effort should be done to improve productivity and hence improve energy utilization efficiency.
4. To construct an energy management master plan based on the collected data from the different shops and those measured through the course of this study.

The first report[1] described the energy status in the following major shops;

1. Sintering shop
2. Blast furnace shop
3. Steel making shop
4. Utilities

It concluded that there were basic differences in both the material and energy balances between the actual 1980/1981 performance and those of the design norms. The report stated briefly the main causes of such divergence in performance.

1.2 The Plan

Following this preliminary stage, a guide line working plan was designed and constructed after a thorough investigation and general and technical meetings and seminars with the HADISOLB Team, and the American counterpart team. This working plan included field measurements, computer analysis and statistics. The details of this work plan are given here.

I. Blast Furnace Shop

* Detailed investigation of the aerodynamic characteristics of the flow in the BF.
* Detailed investigation of the temperature and flow patterns.
* Optimum utilization of BF gases.

* Monitoring of alkalies in slag and BF gases. Overall material balance for the alkalies.
* Laboratory work: Sample preparation and testing for both chemical and physical properties.

II. Sintering Plants

* Thermal modelling of the sintering bed.
* Calculation of bed temperature profile in both vertical and longitudinal directions.

* Sinter characterization; chemical, physical and mechanical.
* Experimental investigations to determine the distribution of alkalies in both solid and gas phases.

III. Electric Drive Systems

* Measurement of electric power consumption, power factor and daily load curves for the different shops.
* Measurement of duty-cycle, all-day efficiency and power factor for large drive systems and selected typical medium and small systems.
* Development of an integrated power factor improvement system.
* Investigation of the feasibility of introducing thyristor control circuits for variable speed drives.

IV. Steel Making Shops

* Survey of the present status of measurement and control facilities.
* Calibration of available instruments and compiling of specifications for complimentary equipment.
* Data collection, measurements and data analyses to work out detailed material and energy balances.
* Detailed investigation of the metallic efficiency of the continuous casting unit.

- Chemical composition
- Rate of cooling
- Drawing speed of soildified casting
- Size effect of cast slabs and billets.

V. Slab Reheating Furnace

* Furnace body
  - Insulation of furnace roof
  - Reduction of diffusion heat loss at furnace openings.
* Operational Improvement
  - Reduction of stock discharge temperature
  - Appropriate furnace heat pattern
  - Hot charging of the stock
  - Evaporative cooling
  - Modification of combustion burners.

1.3 The Way Forward

The present report makes use of the most recent available data and particularly those of the blast furnace area and electric drives.

Observations made in the sintering plant showed that the quality of sinter should be improved. The ore is being toasted rather than sintered. Such observations, combined with the

excessively large amount of return fines per ton sinter and ton productivity, called for more concrete evidence in a form of experimentation and laboratory analysis.

Experimentation at the sintering plant were planned to take place on one of the large machines. This, of course, requires a full study of the machine parameters, working order, firing system and cooling system. Samples of sintered ore from different shifts were collected and sent for laboratory analysis. In addition, work is underway on a laboratory scale sintering machine at Cairo Univesity. It would be, however, too early to report any of the findings of the work as its analysis and statistical level of confidence are under investigation now.

A major problem in the steelmaking shops is the lack of proper instrumentation that facilitates the control of operations. A comprehensive survey was carried out by the team to determine the present condition of the instruments used for measurements and control in the mixer, oxygen converter and continuous casting shops. Difficulties were also encountered in obtaining quantitative information regarding the weight of slag, weight and analysis of waste gas, and weight and analysis of fine dust. Effort is now directed to obtain reliable data from which accurate material and energy balances could be deduced.

The work carried out at the iron making shop comprised two major areas, namely;

1. Blast air cowper stoves
2. Blast furnace performance

Real progress is showing in field experimentation and office calculations. The second chapter of this report describes the analysis of the cowper stoves and presents an overall aerodynamic and heat transfer pattern. The third chapter is devoted to blast furnace performance at different times and loading conditions. This includes measurements of the aerodynamic, metallurgical and thermal characteristics. Analysis of the 1982 production and energy consumption rates is also presented. Chapter 3 also includes comparisons of energy consumption in blast furnace area through the years 1977 to 1983 and with design norms and international figures.

Chapter 4 describes the work carried out on the electric drive systems. Such work is diversified by nature, and covers most of the production sectors. However, this chapter is devoted to field work carried out for the drives at the sintering shop.

As a result of the instrument survey carried out by the team, tables specifying these instruments, their status, range of operation and accuracy were constructed and were handed over to HADISOLB team to make use of them in repair and replacement schedules.

1.4 References

1. M.G. El Maghraby et al, Energetics in the Egyptian Metal Industries, Report No. 1, Analysis of the Present Status in the Iron and Steel Complex, Helwan, CU-MIT Project, Nov. 1982.

2. G.M. El Raghy and A.A. Mourad, Energetics in Iron and Steel Industry with Reference to the Egyptian Case, 2nd Metallurgical conference in A.R.E., El Tabbin, Dec. 1978.

3. G. Taher and A. Helmy, An Investigation into Energy Consumption for Steel in Egypt Using BF/BOF and DR/EAR Routes, Int. Symposium on State of the Art of Production and Uses of DRI, El Tabbin, 1981.

4. Proceedings of the Seminar on Energetics in the Egyptian Metal Industries, Cairo University, Jan. 1983.

CHAPTER 2

BLAST AIR STOVES

2.1 General

This chapter is devoted to the analysis and assessment of the blast air stoves (cowper stoves). The prime objective of the stoves is to heat up the blast air to be injected into the blast furnace. At HADISOLB, three stoves are connected to blast furnaces 3 and 4. Each of these stoves consists mainly of a gas burner and two passages (chambers):

1. gas burner
2. combustion chamber and tunnel
3. checkers chamber.

These are shown in fig.2.1. The two chambers are separated by partition wall. The gas burner supplies the stove with hot products of combustion. The prime objective of the combustion chamber is to generate high temperatures effectively and efficiently. Heat is stored in the refractory walls and is then exchanged to the cold blast air when the gas burners are stopped and cold air is admitted. A major factor in the heating cycle is the dome temperature which should not exceed a certain value in order to preserve the refractory material.

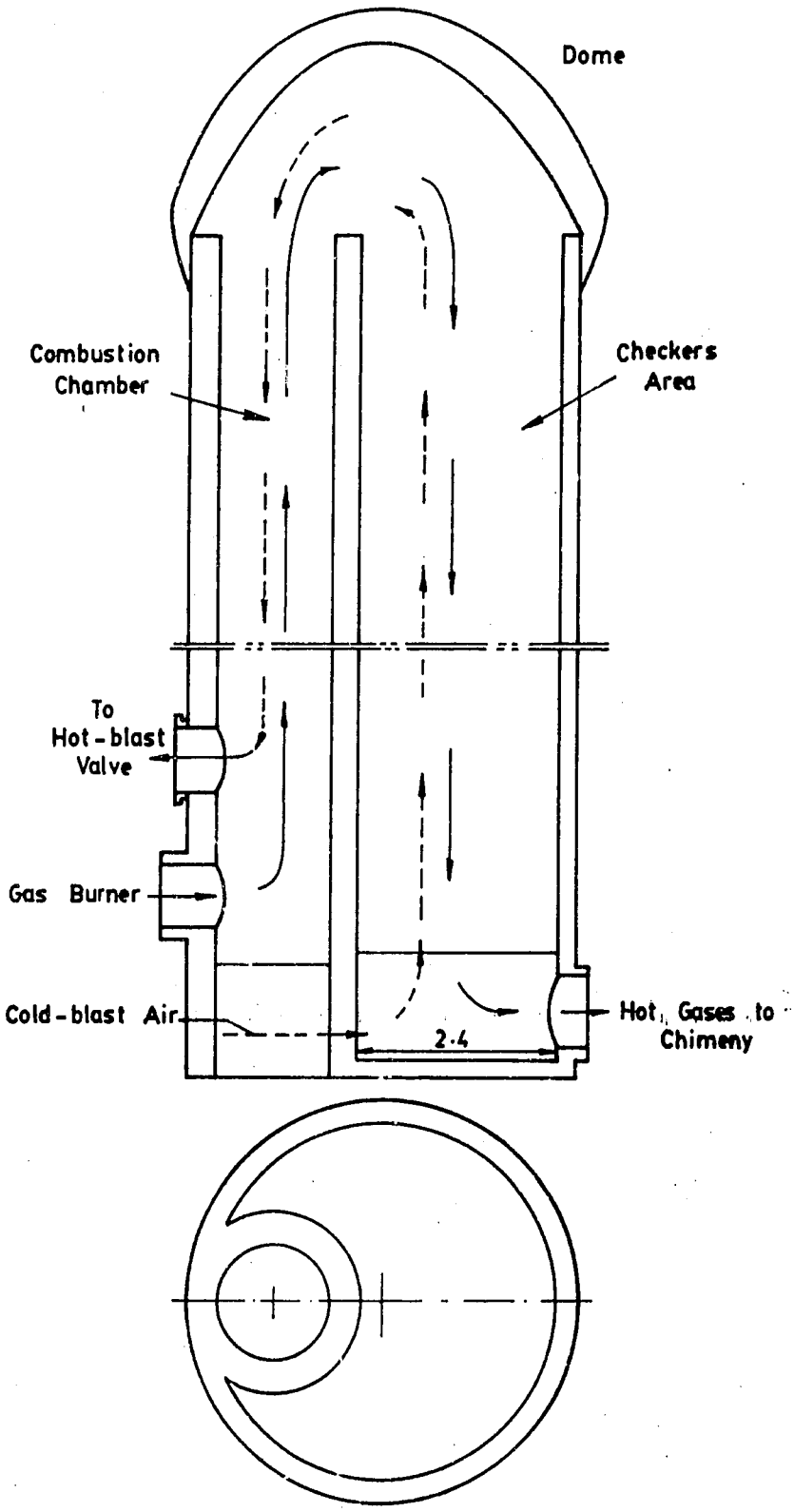

Figure 2.1: Schematic Representation of a Cowper Stove

The basic design features of the cowper stove are that they are cylindrical in shape and the length-to-diameter ratio is about 5. Such length (about 33 m) is required to allow for large heat transfer areas between the flowing media (gas/air) and the refractory walls (1).

In the following sections, each of the components of the stove is analysed.

2.2 Gas-Burning System

The gas burner is an integral part of the stove and is supplied with blast-furnace gas for its operation. It consists of a welded body in the form of a T-pipe. The combustion air is blown through with the aid of a centrifugal fan driven by an electric motor. The compressed air flows through a pipe centrally located through the T pipe as shown in Fig.2.2. In the top portion of the burner body, the blast-furnace gas pipe is provided and supplies the B.F. gas that flows in an annular space concentric with the central air pipe. The flow rate of the air to the burner is regulated through the automatic adjustment of guide vanes at the blower intake.

The sequence of operation of the stoves follows the following steps:

1. Heating-gas period during which the walls of the stove are all heated by the hot products of combustion and the gas burner is in operation during this period.

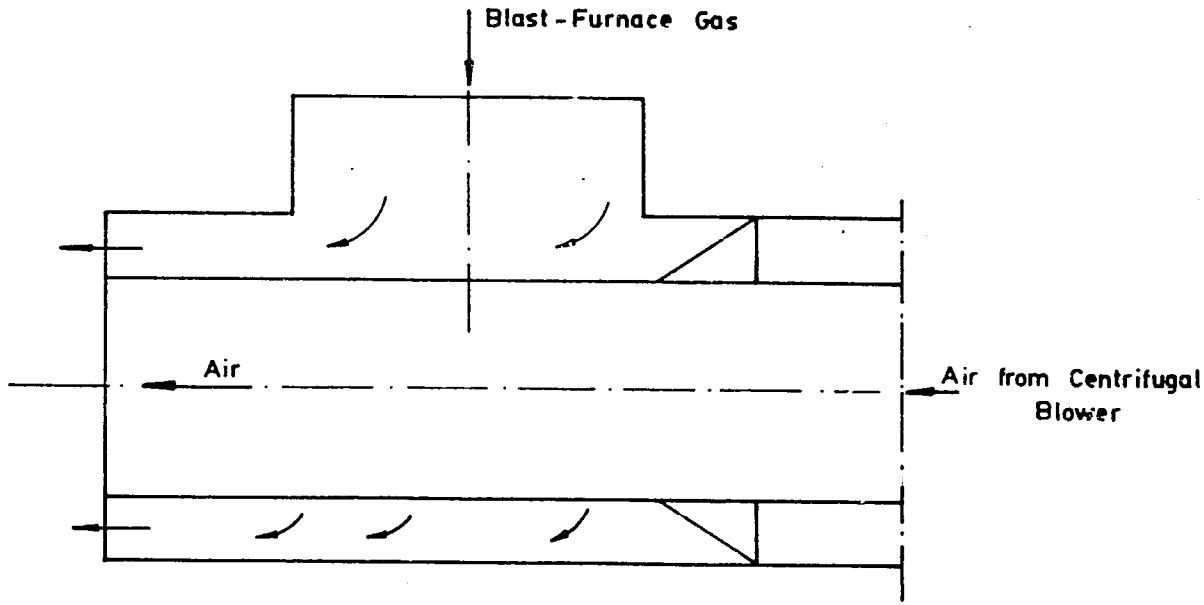

Figure 2.2 The T Section and Burner

2. Blasting-air period during which the blast air is being blown and heated inside the stoves from the hot refractory walls. During this period, the gas burner does not operate.
3. Separation period during which the stove is on standby mode to be heated or under repair. Naturally the gas burner does not operate.

The burner is fed with a nominal rate of 36000 m^3/hr blast-furnace gas whose composition (averaged) is given in table 2.1,[2].

Table 2.1. B.F. Gas Analysis

Gas	CO	CO_2	N_2	CH_4	H_2	O_2
% Volume	27.3	12	57.1	0.4	3.2	0.0

The gas is fed to the burner at room temperature after being cleaned. The outlet of the concentric burner has the air flowing through the central pipe surrounded by the blast-furnace gas in the annular space as shown in figure 2.3. The volume flow rate is

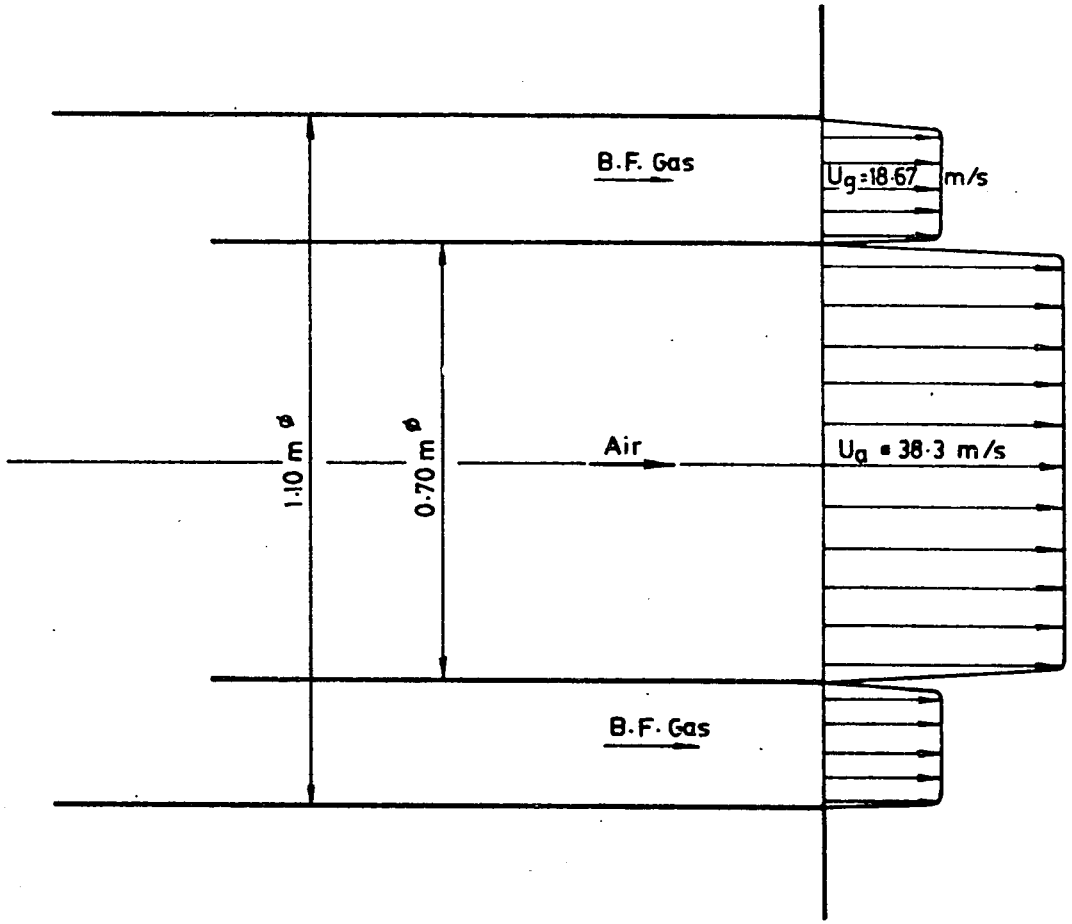

Figure 2.3 Velocity Distribution at Stove Burner Outlet

adjusted according to the temperature of the dome but the air-to-gas volume flow ratio is commonly maintained at 1.3:1. From the volume flow rates and flow areas, the flow velocities can be determined and are shown in figure 2.3 for a particular flow situation on stove 43, on April 10th, 1983.

It can be seen that the central flow has a higher velocity; the flame is stabilized and attached to the end ring upstream of the combustion chamber. This is attributed to the momentum ratio of the two jets. The burner mouth is followed by a refractory tunnel whose length is equal to the thickness of the combustion chamber wall. The consideration of the combustion chamber average diameter and the refractory tunnel length leads to a free flame length of about 3.5 m; the flame length should be less than that value to prevent flame impingement on the front wall (partition wall).

2.3 Combustion Chamber

Combustion of blast-furnace gas is the major event and its efficiency is very important to yield the correct flame length and temperature. The design of the combustion chamber should allow for a stabilized flame with natural draft and the highest temperature that does not damage the refractory walls.

The flame temperature can be obtained from the following considerations:

1. 1st law of thermodynamics;
2. mass continuity; and
3. momentum exchange.

The application of the 1st law of thermodynamics on the burner yields the following balance:

$$m_g \, CP_g \, \Delta t_g + m_g \, (C.V.) + m_a \, CP_a \, \Delta t_a = (m_g + m_a) \, CP_m \, \Delta t_m \quad .... \qquad 2.1$$

The reference temperature is taken as atmospheric and hence equation 2.1 becomes;

$$m_g \, (C.V.) = (m_g + m_a) \, CP_m \, \Delta t \quad ..... \qquad 2.2$$

where:

m_g blast-furnace gas flow rate , kg/s

m_a combustion-air flow rate , kg/s

C.V. calorific value of the blast-furnace gas and is equal to 947 kcal/kg = 3965 kJ/kg

CP_m mean specific heat of the combustion product, kJ/kg ^oC

Δt temperature difference from atmosphere

CP_a, CP_g specific heats of air and gas at constant pressure, kJ/kg ^oC

From equation 2.2 the following equality is obtained,

$$\phi = CP_m \, (t_f - 27)$$

and $\phi = m_g \, (C.V.)/(m_g + m_a)$

The value of CP_m can be taken as a function of temperature and species concentrations as shown in figure 2.4, (see reference 3). The flame temperature was found to be of the order of 1386 ^oC = 1659 ^oK The density of the products of combustion at this temperature was calculated from the equation of state and perfect-gas laws to be $0.217 kg/m^3$. Figure 2.5 shows the temperature distribution along the combustion chamber axis. This distribution was obtained from the following considerations:

1. convected heat transfer through the chamber
2. conducted heat transfer through the chamber walls
3. radiated heat transfer to and from luminous flames
4. mass and energy conservation.

The calculated flow and heat transfer pattern can be readily obtained from the TEACH-T computer code (4) for axisymmetric furnaces. Details of the calculation procedure and its description can be found in reference (5).

The physical and geometrical data of the combustion chamber are necessarily specified, these include:

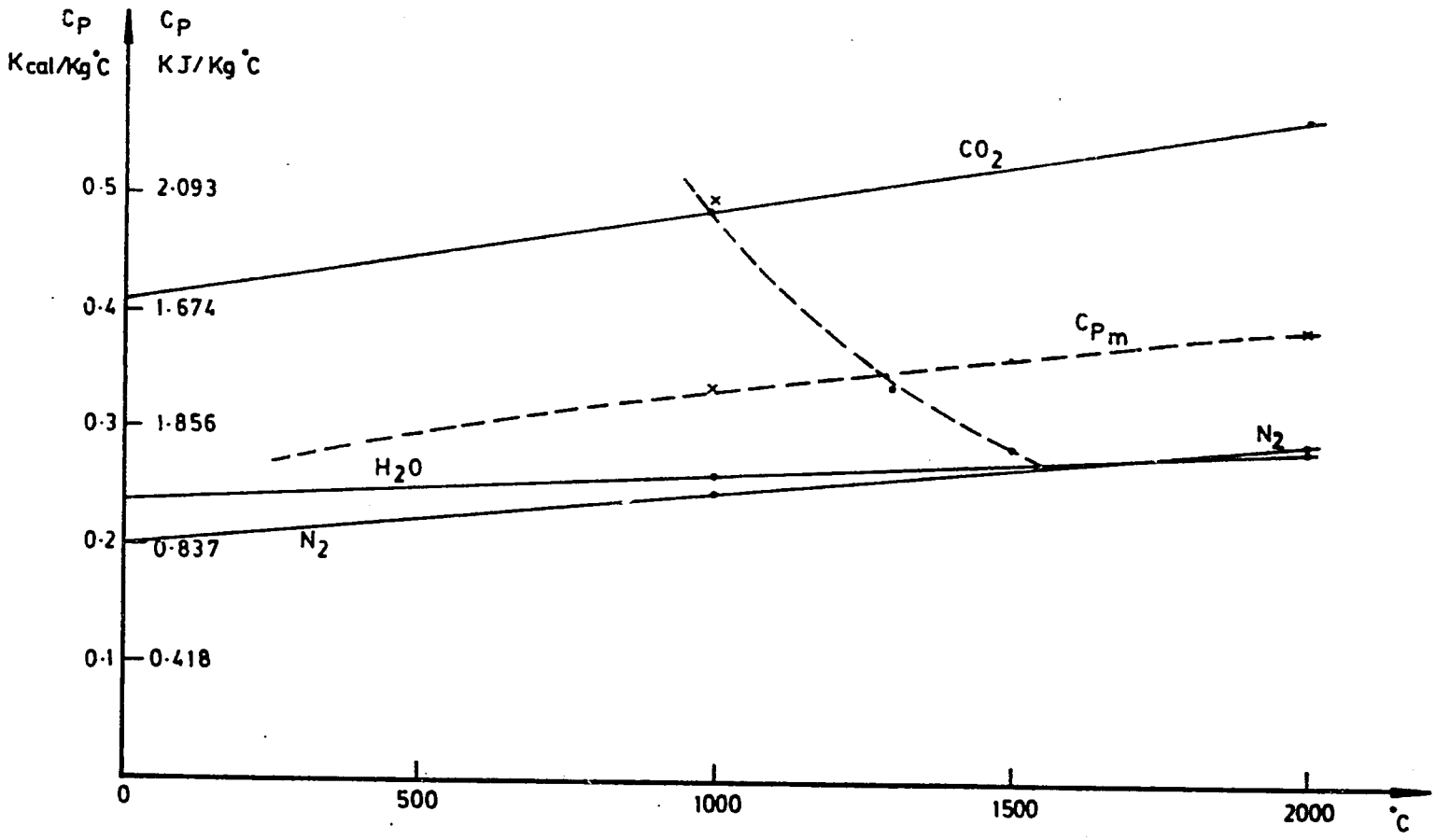

Figure 2.4 Variation of Gas Specific Heat with Temperature

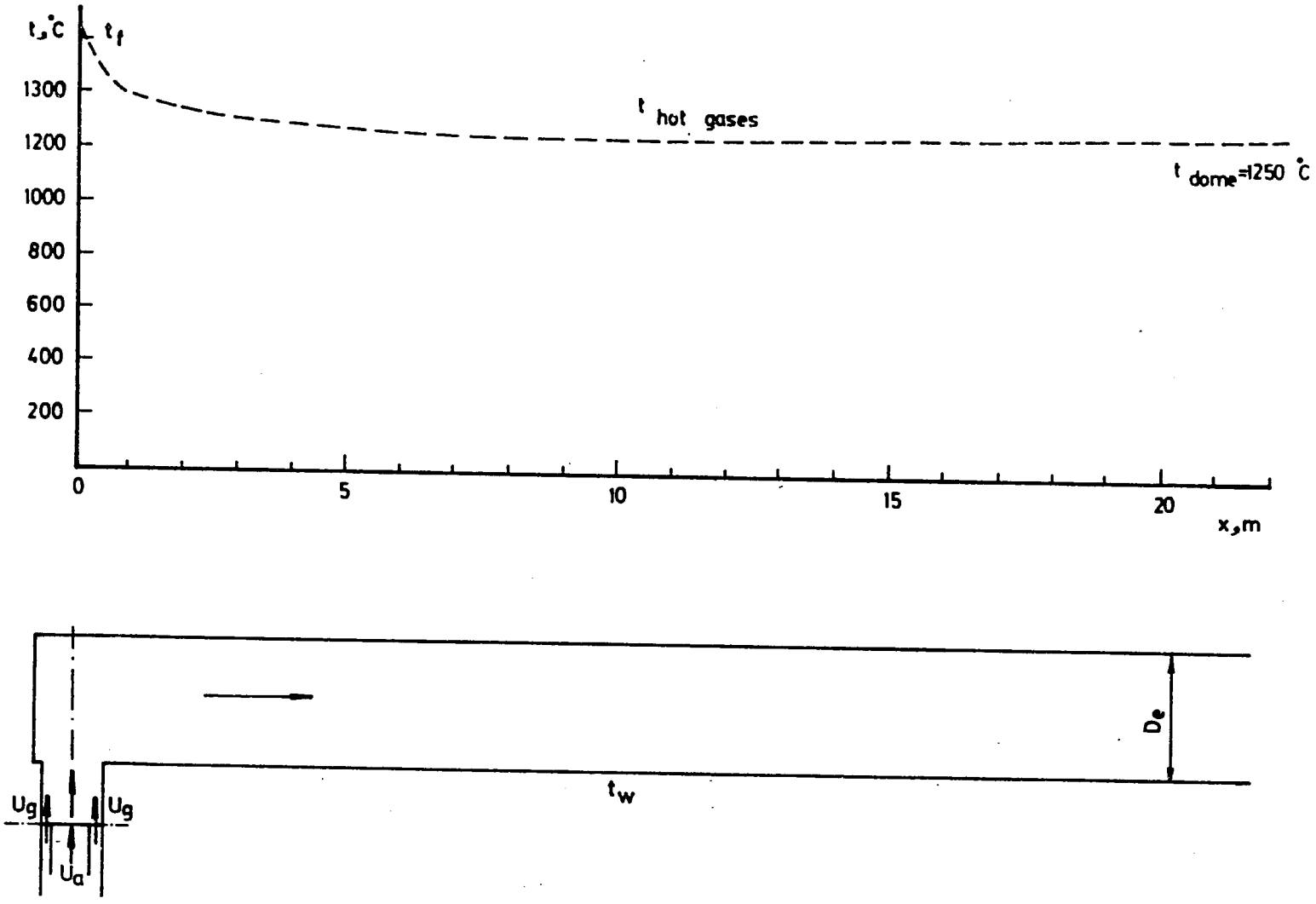

Figure 2.5 Predicted Temperature Variation Along The Centreline of The Combustion Chamber

1. burner dimensions
2. chamber diameter, De
3. chamber length
4. inlet flow rates and temperatures
5. wall temperature distribution
6. physical and chemical properties of flue gases, (table 2.2 shows flue gas composition from stove 43 on April 10th, 1983).

Table 2.2

Flue-Gas Analysis

Gas Sample	CO	CO_2	O_2	CH_4	H_2	V_g
%	3.8	16.6	4.6	0.0	0.0	3300
%	1.4	15.2	7.0	0.0	0.0	3900

V_g = Volume flow rate of flue gas, m^3/hr

The effective laminar viscosity of the flue gases at 1600 ^oK is

calculated to be,

$\mu_f = 5.28 \times 10^{-5}$ kg/ms

The calculation procedure is based on the solution of the conservation equations governing the transport of mass, momentum, species and energy at discrete locations in the flow field. The calculated temperature distribution along the combustion chamber indicated a very slow decay of gas temperature with a temperature of 1280 ^{o}C at the end of the combustion chamber in the vicinity of the dome.

The heat transfer characteristics in the combustion chamber are calculated from the common heat transfer correlations for hot gas flow in a long tube. The Dittus & Boelter (5) equation is expressed as:

$$N_u = 0.023\ R_e^{0.8}\ P_r^{0.4} \qquad 2.3$$

where

R_e is the Reynolds number and is defined as;

$R_e = \rho_f\ u_f\ D_e/\mu_f$

ρ_f = flue gas density = 0.217 kg/m^3

u_f = flue gas average velocity = 31.27 m/s

D_e = equivalent combustion chamber diameter, = 2.35 m

N_u is the Nusselt number and is defined as;

$N_u = h\ D_e/K$

h = average heat transfer coefficient

K = thermal conductivity of products of combustion

P_r is the Prandtl number and is defined as;

$P_r = \mu_g\ CP_m/K$

μ_g = gas viscosity

P_r is assumed to be 0.7 for the flue gases. The error in calculating the transfer with P_r = 0.9 is less than 10%

From equation 2.3, for K = 0.0765 W/m^{o}C, the average heat transfer coefficient is estimated to be 14.8 kcal/hr m^2 ^{o}C (17.2 Wh/m^2 ^{o}C).

Taking the air temperature 20 ^{o}C and the steel shell temperature 80 ^{o}C, the heat losses through the combustion chamber and the stove can be calculated through the conduction analysis of composite walls.

The cowper stoves are designed to sustain high thermal stresses and to resist erosion due to high flow velocity. The refractory walls of the combustion chamber have two functions:

1. to protect the external steel structure from the high temperature generated within the chamber; and
2. together with the checker chamber wall, to carry the load of dome structure in such a manner that the dome remains mechanically stable throughout the life of the stove.

Extreme care is taken in the selection of the refractories to ensure that the temperature of the steel shell is maintained below 80-90 ^{o}C when temperatures of the order of 1400°C are to be generated in the chamber.

The combustion chamber is longitudinally separated from the checkers passage by a partition wall. This central partition wall represents a major constraint in obtaining high dome temperature. Temperature variation is observed vertically upward in the central partition wall as well as horizontally through it. The variation of wall temperature is more severe in the lower sections in the level of the burner. The temperature drop from the combustion chamber has the effect that the hot face expands at a greater rate than the cold, hence there is a tendency of the brick construction to bend towards the checkers.

In order to improve the performance of the stoves, and to achieve a thermally efficient operation, the central partition wall should:

1. incorporate slip joints to ensure that the hot face refractory grades can move independently;
2. incorporate expansion joints to absorb the expansion of the brick work and to assure freedom of movement; and
3. prevent only short circuiting of hot gases through the wall.

2.4. Checkers Chamber

The checkers chamber is constructed of checkers bricks with bores in them to allow the hot gases or cold air to flow and exchange their heat. The main properties of the checkers bricks are:

1. high heat capacity.
2. high coefficient of thermal diffusivity;
3. good resistance to thermal cycling; and
4. high chemcial purity with specific resistance against alkali-vapour attack.

The efficiency of the hot blast stoves depends mainly on the ability of the checker refractory to absorb, retain and give up heat. Stable interlocking is vital to ensure maximum available heating surface area. Checkers in the upper sections of the stove are selected to withstand chemical attack from the gas stream.

Flow and heat transfer simulation can be carried out with the aid of a computational procedure; the checkers can be represented by internal resistances in the momentum and energy conservation equations.

Cowper-Stoves Characteristics

- Dome temperature = 1250 ^{o}C
- Exhaust gas temperature = 330 ^{o}C
- Blast furnace gas flow rate (average) = 40,000 m^3/hr
- Blast furnace gas pressure at network = 800 mm water gauge
- Air pressure at fan inlet = 200 mm water gauge
- Fan motor speed = 750 rpm (DPR)
  980 rpm (1983).

2.5 References

1. Detailed Project Report, Iron & Steel Works in Helwan, 1975

2. M.G. El- Maghraby et al, Energetics in the Egyptian Metal Industries, Report, No. 1, Analysis of the Present Status in the Iron and Steel Complex, Helwan, CU/MIT Project, Nov. 1982.

3. Chemical Energy Data , JANAF, 1971.

4. TEACH-T Computer Code, Imperial College of Seience & Technology, 1976.

5. Khalil, E.E., MSc. Thesis, Cairo University, Cairo, 1973.

CHAPTER 3

BLAST FURNACE SHOP

3.1 Analysis and Equipment

The performance of the blast furnace shop can be viewed through the following considerations:

- Energy requirement per ton product
- Annual production
- Quality of product
- Regular stoppages and scheduled maintenance.

The data on the energy consumptions and production as well as quality of product are collected with the aid of instruments mounted in the control room. Such instruments indicate and record the following entities,

- Blast furnace gas flow rate and analysis
- Blast furnace gas temperature
- Blast air flow rate, temperature and pressure
- Top gas temperature
- Natural gas flow to tuyeres
- Metal temperature
- Natural gas flow to furnace
- Lining temperature at various levels
- Cooling water flow rate
- Air flow rate to stoves

. Blast furnace gas flow rate to cowpers

. Exhaust temperature of stove gases

. Blast furnace gas pressure

. Charge characteristics, basicity, coke humidity, sulphur and carbon content

. Molten metal rate

In order to enable a thorough investigation of the performance of the blast furnace shop, identification of all available instrumentation was carried out with the following instructions in mind:

. identify the measured entity;

. assess the reliability of the instrument;

. identify the status of the instrument (out of order or working); and

. suggest replacement or repair.

The instruments mounted on blast furnaces 3 and 4, with the accompanied stoves, were reviewed and the collected data were handed over to HADISOLB to make use of them in repair and replacement schedules.

3.2 Performance Indications

Data collected from the blast furnace shop for BF3 and BF4 were obtained on daily basis for different months. The data were then processed to yield derived quantities that are of direct

value to energy and material flow and balances. These include:

- total and net production, monthly;
- daily production;
- coke rate;
- sinter to pig iron rate;
- dolomite to pig iron rate;
- fluorospar to pig iron rate;
- total sinter;
- total coke;
- total dolomite;
- total fluorospar;
- blast air : flow rate
  : temperature
  : pressure;
- natural gas : flow rate
  : gas to air ratio;
- CO/CO_2 ratio;
- average basicity of slag;
- average basicity of sinter;
- sulphur, silicon and manganize percent;
- number of pourings;
- stoppages and causes;
- sinter analysis; and
- coke humidity.

Examples of these data are plotted in figures 3.1 to 3.6. These data are considered on the following basis.

1. Monthly variation of consumptions of basic energy sources and materials, for the first three months of 1983.
2. Daily variation of consumptions of basic energy sources and materials for a typical month, March 1983.
3. Comparisons of the obtained energy consumptions with the corresponding values during previous years.
4. Comparisons of energy consumptions with international norms.

Figure 3.1 illustrates the variation of the monthly average consumptions and production rates during the first quarter of 1983 for blast furnace No.3. The charged sinter to the blast furnace increased from 1.776 t/ton pig iron to 1.809 t/ton pig iron in March 1983. The DPR value is 1.787 t/ton pig iron, the present operation consumes more sinter per ton product and consequently more slag is produced. This can be attributed to many factors; among these are the following:

1. Sinter quality and size distribution; these are quite remote at the moment from design values due to poor quality of ore and low performance of sinter machines.

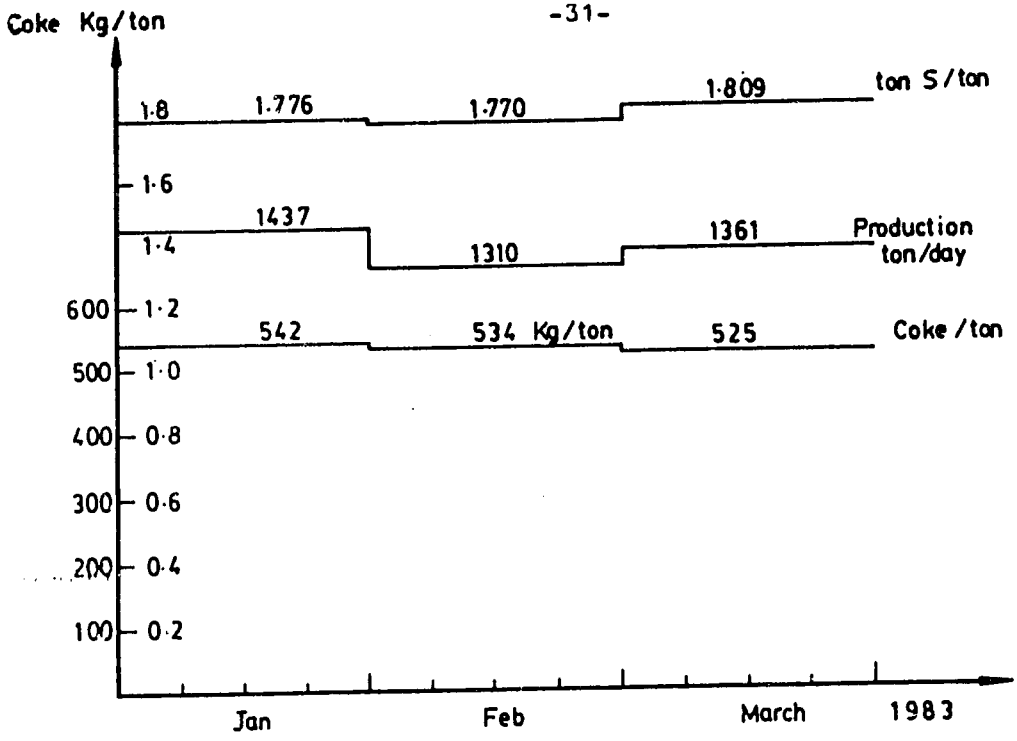

Figure 3.1 Blast Furnace Performance Rates B.F. 3

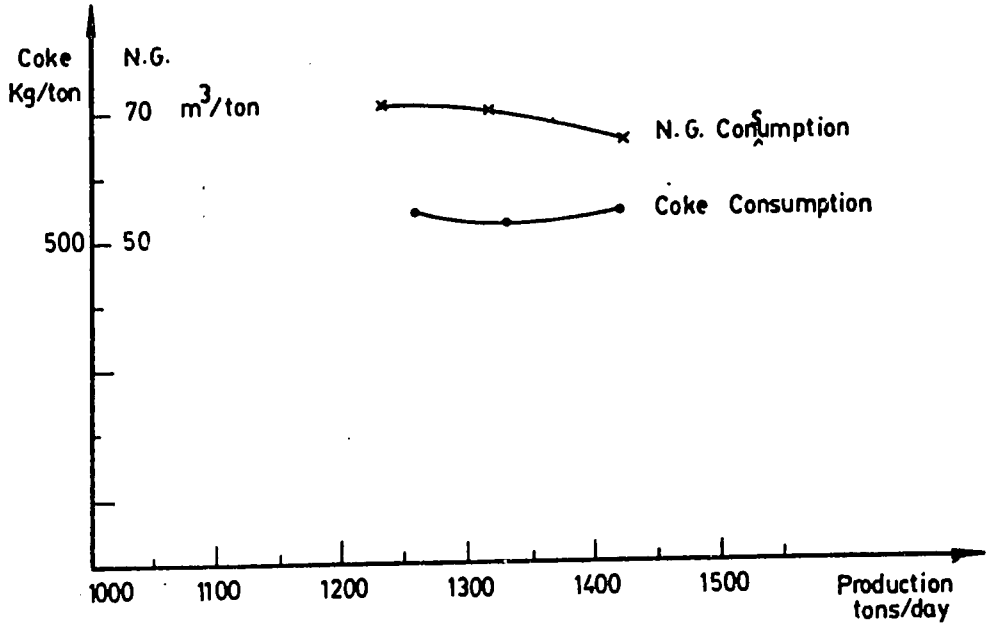

Figure 3.2 Coke and Natural Gas Rates in B.F. 3 at Various Production Rates

2. Low production rates due to formation of scaffolding, repairs or stoppages of the furnace during the month. The daily production rate of the furnace is designed for 1915 tons of pig iron. The corresponding daily production during Jan. 1983 was 1437 while the March values fell to 1361 ton/day.
3. Although the plant is fully instrumented, the charge characteristics and proportions were controlled manually. A new control system was recently installed for that purpose.

It is worth noting that the production rates were lower than the DPR values for unforeseen troubles and maintenance. The experience during March 1983, is shown as an example in the following table:

Total number of pourings	276
Pourings lost due to operation room	3
Pourings lost due to furnace stoppages	31
Furnace stoppages due to operation	22.50 hrs
Furnace stoppages due to steel shop	20.45
Furnace stoppages due to electrical faults	5.40
Furnace stoppages due to mechanical faults	15.45
Furnace stoppages due to instruments	0.05
Total lost time	63.85 hrs
stoppage time %	8.58%

About 30% of the time lost and consequently production is due to steelworks troubles.

An important factor in energy assessment of the blast furnace performance is the coke rate. In figure 3.1. The average coke rates during Jan., Feb., and March 1983 are shown. The average consumption came down from 542 kg/ton pig iron in January to 525 kg/ton during March of the same year. The corresponding natural gas injection rate was 67.6 m^3/ton in Jan. and increased to 69.45 m^3/ton in March 1983. Figure 3.2 indicates the corresponding consumptions of coke and natural gas at various production rates.

The design values of coke rate consumptions given in the DPR (1), were 486 kg/ton pig iron and about 87 kg of liquid fuel oil per ton pig iron was burnt in the blast furnace. The energy consumptions are higher than the design values by up to 3% (on equivalent fuel basis). The 1980/1981 average coke rate consumption for an identical furnace (B.F.4) was 629 kg/ton with the fuel rate of 55 kg/ton.

Before stating the reasons for the improved performance of blast furnaces 3 and 4 from 1980 to date, it is imparative to analyse, closely, the daily variation of furnace loading, sinter, production and energetics.

The daily variation of the coke rate is shown in figure 3.3 for the three months of January, February, and March 1983. The coke rate can be seen to vary between 470 and 590 kg/ton, with the average values during the month as indicated in figure 3.1. The natural gas rate is shown in figure 3.4 for Feb., and March and is shown to fluctuate between 54 and 81 m^3/ton.

Figure 3.5. illustrates the variation of coke rate, natural gas injection rate, CO/CO_2 ratio and production along March 1983 for blast furnace 3. The operation of the furnace is erratic with large fluctuations in coke rate and consequently natural gas injection rate. The daily variations of the coke rate and natural gas are consistent and of a generally similar pattern. The two rates of fossil energy consumption are interactive by virtue of optimization of furnace operation to save energy. Previous investigations, El Ganainy and El-Hussany (2) indicated that the natural gas injection should be related to the coke rate to obtain the optimum furnace performance.

The corresponding production-rate variation and the CO/CO_2 ratio are also shown in figure 3.5 for blast furnace number 3 in March 1983.

The obtained daily variations are fluctuating about an average value of 525 kg/ton of coke and 69.45 m^3/ton of natural gas. The average daily production is 1361 ton/day and the CO/CO_2 ratio varies between 1.76 and 2.35. Lower values of the CO/CO_2 ratio

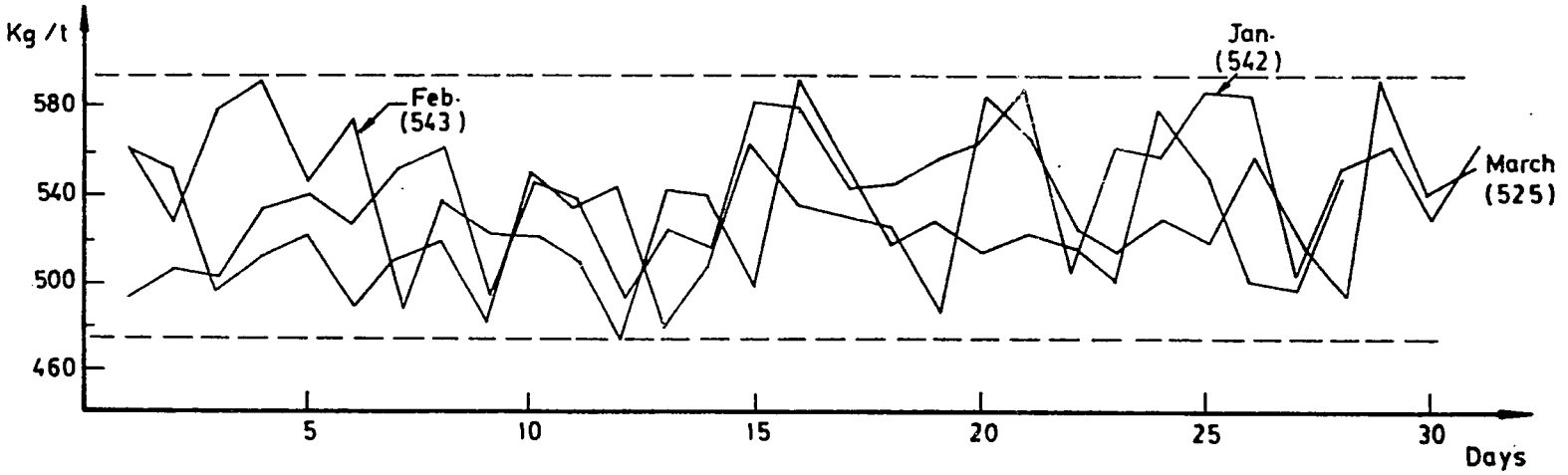

Figure 3.3 Coke Rate Variation in B.F. 3 (Jan., Feb., March 1983)

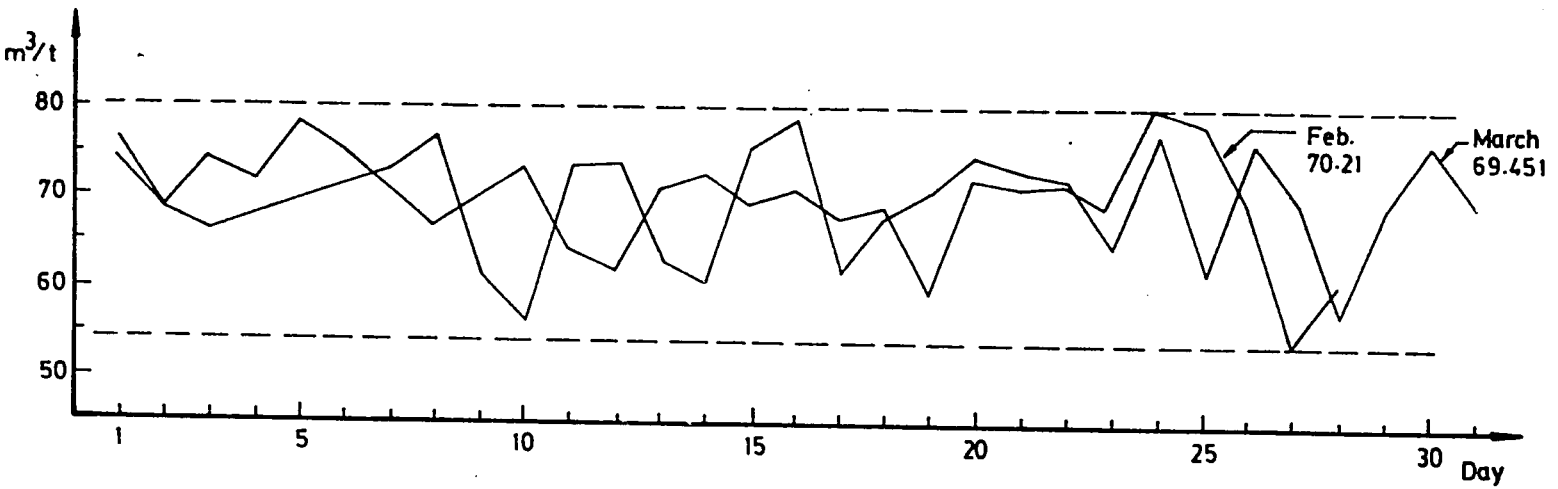

Figure 3.4 Natural Gas Consumption in B F 3 (Feb. and March 1983)

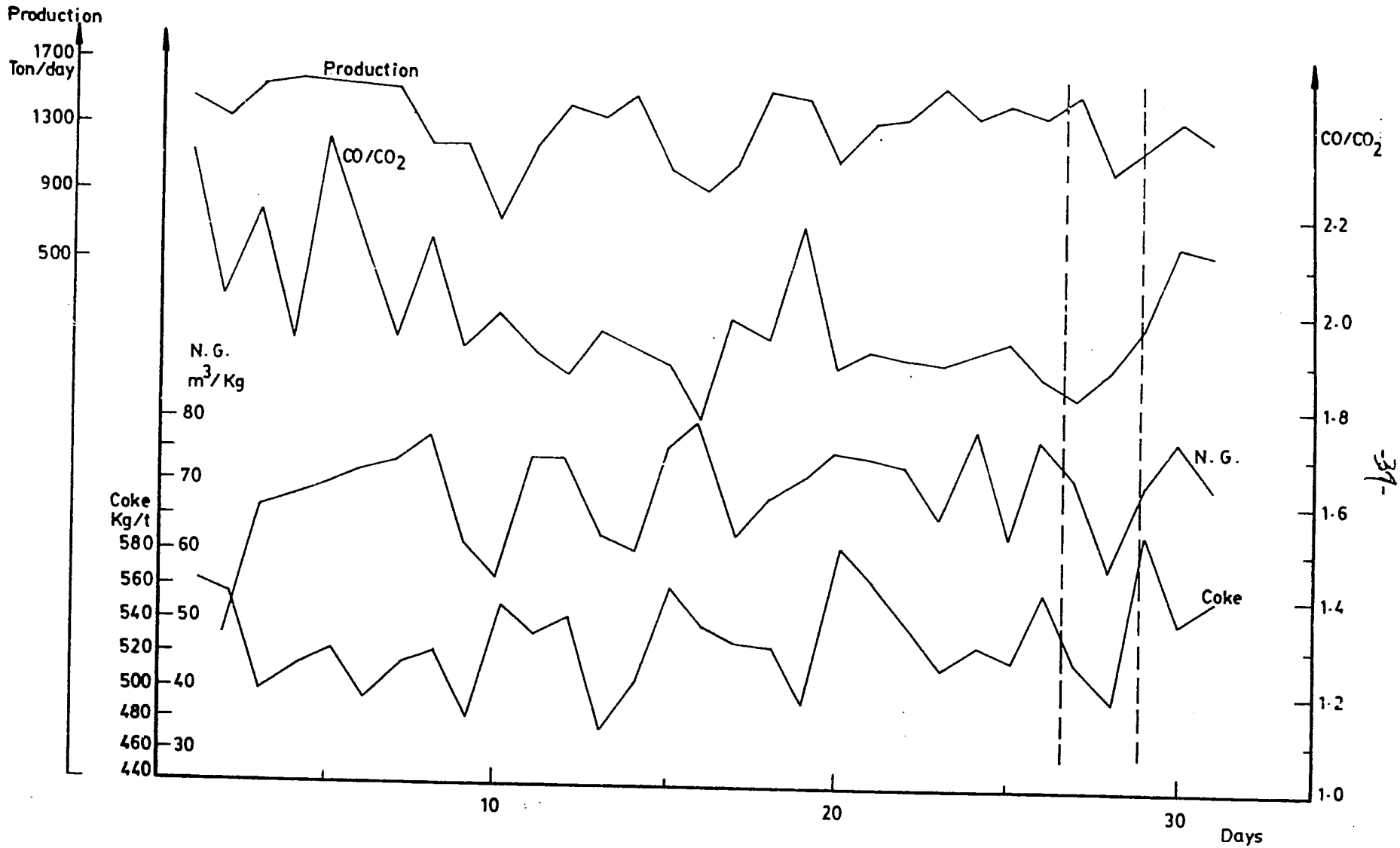

Figure 3.5 Fossil Fuel Consumption Rates and Productivity in B.F. 3 (March 1983)

indicate better utilization of coke and hydrocarbon fuel. Such an observation is consistent during the last few days of March where CO/CO_2 decreased to 1.82 with minimum natural gas and coke consumptions.

Similar representation for blast furnace 4 is shown in figure 3.6 for Jan. 1983. Similar trends can be observed with CO/CO_2 ratio arriving at a minimum value at position where the coke rate is minimum. The CO/CO_2 ratio for blast-furnace number 4 is observed to be on average, higher than that of furnace 3. This may be due to the recent over-hauling of furnace 3. The coke rate for furnace 4 during Jan. 1983 is higher than the corresponding value for furnace 3; for furnace 4 the coke rate was 608 kg/ton for Jan. with an average blast-air temperature of 1044 ^{o}C. Furnace 3 was supplied by blast air whose temperature was 1033 ^{o}C, during Jan., 1983.

Table 3.1 represents a comparison of the important operational features of blast-furnaces 3 and 4 during March 1983.

3.3 Assessment of Energy Consumption and Production

Energy consumption and production are strongly inter-related in blast furnace operation. Two of the blast furnaces at HADISOLB, were designed to produce 1915 t/day with an average coke consumption of 486 kg/ton and fuel oil rate of 87 kg/ton. At part loads and with improper operation procedure as well as poor

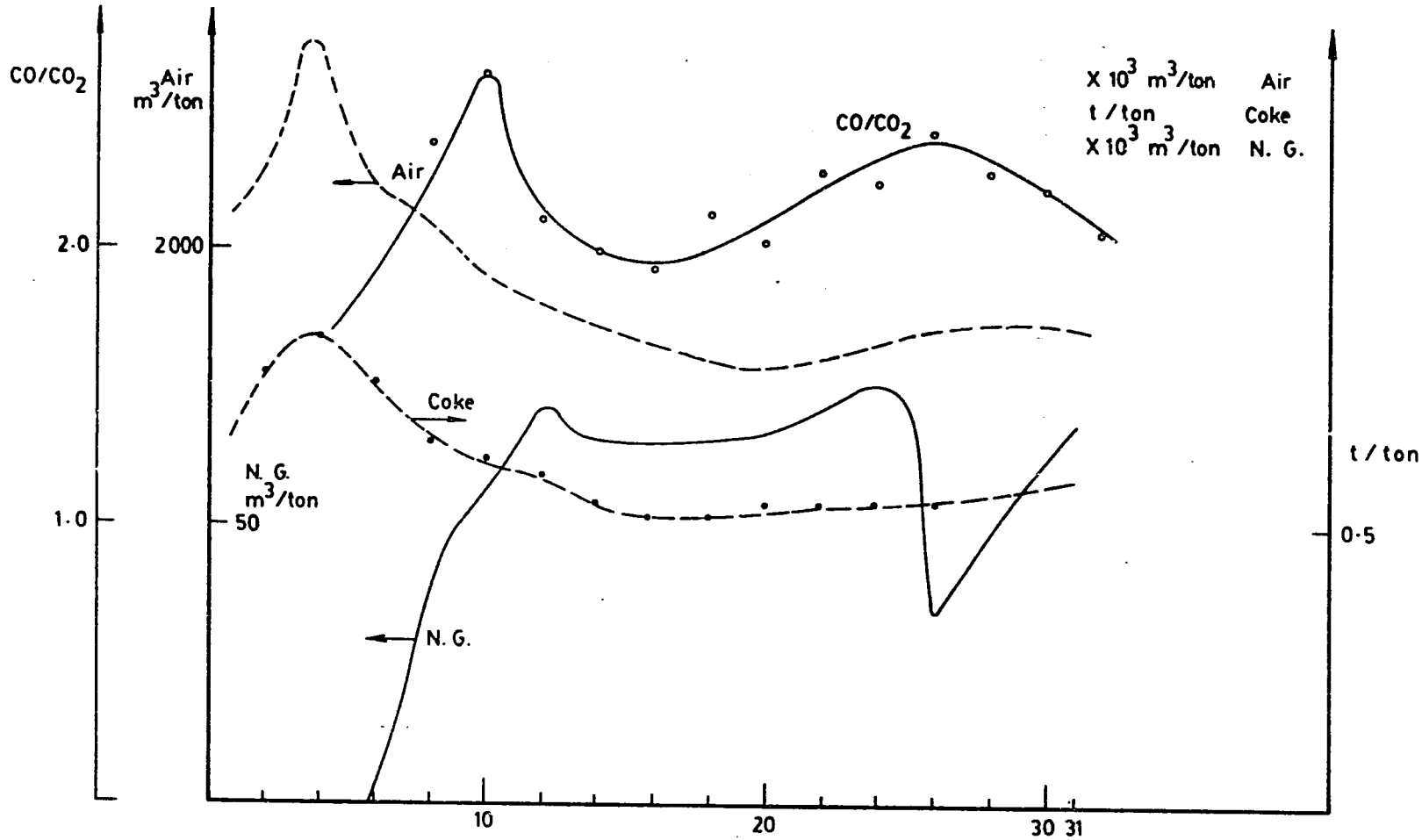

Figure 3.6 : Fossil Fuel Consumption Rates in B.F. 4 (Jan, 1983)

Table 3.1

Operation of Blast Furnaces 3 & 4 During March 1983

	BF 3	BF 4
Total Production Thousand tons	42.210	50.09
Net Production Thousand tons	41.682	49.464
Net daily production, tons	1344.59	1595.62
Coke rate, kg/ton	525.00	549.6
Sinter rate, ton/ton	1.809	1.809
Dolomite rate, ton/ton	0.0536	0.0436
Fluorospar rate, kg/ton	0.6	0.06
Blast air rate m^3/t	1956.35	1973.19
temp. ^oC	1031.0	1068
press; bar	2.097	2.179
Natural gas rate m^3/ton	69.45	93.011
m^3/m^3 air	0.0362	0.0428
Sulphur kg/ton	0.0375	0.0384
Silicon kg/ton	0.670	0.726
Manganese kg/ton	1.0805	1.728
Average basicity		
sinter	0.995	0.995
slag	1.02	1.05

ore and sinter characteristics, the coke rate increases at low production rates.

Blast furnaces 3 and 4, built at HADISOLB, require careful operation and full understanding of the physical, chemical and thermodynamic processes occurring inside the blast furnace. As described earlier in report No.(1) of this project, reference (3) , a series of chemical and metallurgical processes, takes place inside the furnace. These involve reactions between gases, liquids and solids, as well as binary phase changes. These reactions oxidize and reduce various elements with a final pig iron production and the formation of slag. These processes release and absorb energy. The energy obtained from outside sources (purchased), energy from coke and natural gas combustion are used to raise the termperature of the charge and melt the iron. The overall view of the energy consumed (DPR values) for the blast furnace reveals that 68.5% of it comes from coke, while 18.9% of the energy is obtained from the burned fuel. The real consumptions in 1980/1981 indicated that 71.25% of the energy comes from coke while the fuel energy represents 13.76%. The figures for 1982 are shown in figure 3.7, the coke energy represents 70.14% while the natural-gas energy amounts to 10%. Figure 3.8 demonstrates the proportions of energy consumed in blast furnace 4 during the year 1982. It can be seen that the coke energy was successfully reduced to be 67.8% in 1982 relative to the value of 71.25% for the year 1980/1981, see reference (3).

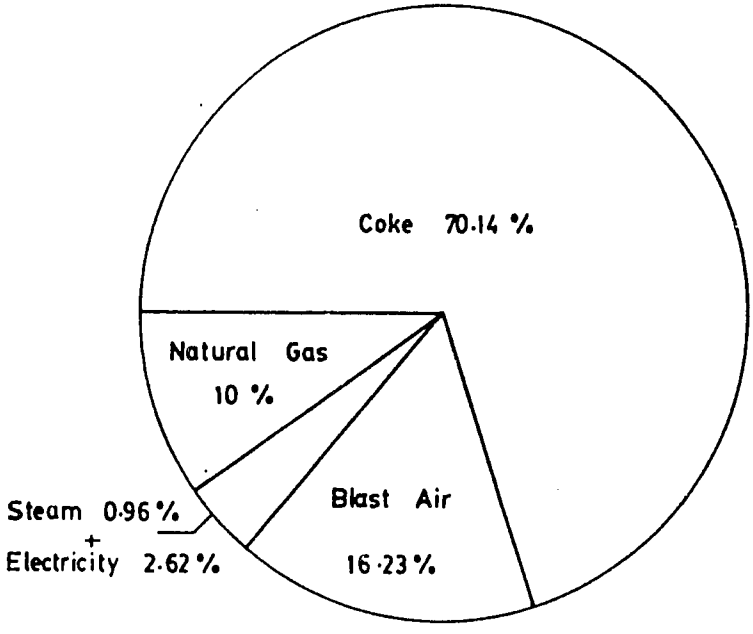

Figure 3.7 Energy Pattern in B.F. 3 (1982)

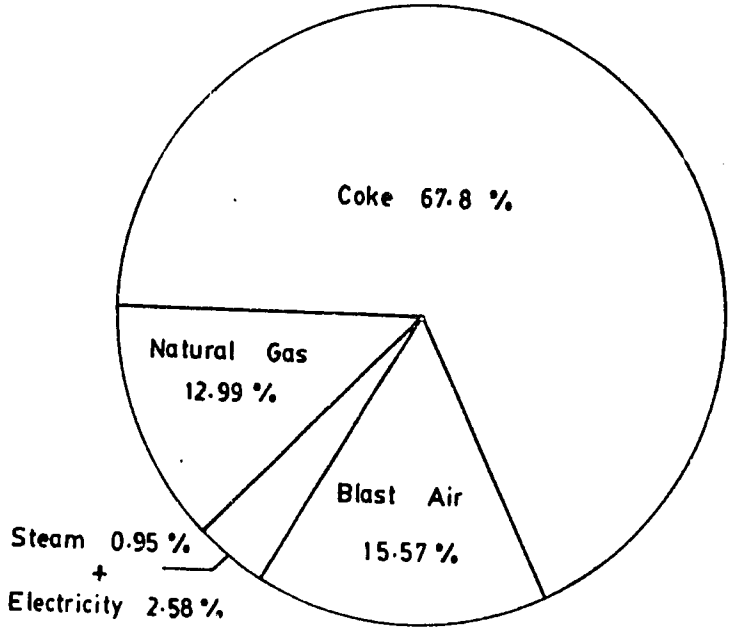

Figure 3.8 Energy Pattern in B.F. 4 (1982)

The corresponding blast-air energy consumed was 15.57% during 1980/1981. The natural-gas consumption represents 13% of the total energy consumed relative to 13.75% during 1980/1981.

The total energy consumed to produce one ton of pig iron was 5.427×10^6 kcal for B.F. 3; the corresponding value for B.F. 4 for the same year (1982) was calculated to be 5.503×10^6 kcal/ton. The energy consumed per ton pig iron was reduced for B.F. 4 by 4.82% . For a total production of 0.527×10^6 tons/year the total energy consumed per year is 2.903×10^{12} kcal. The energy reduction is estimated as 4.82% of 2.9×10^{12} and is equal to 0.14×10^{12} kcal which is equivalent to 21.433×10^3 tons of coke. The corresponding purchase value of this coke is 1.3576 million L.E.

Analysis of the performance of the blast furnace reveals the standard at which it has been managed. The improved performance can be attributed to the following:

1. Selection mining of ore.
2. Experience gained during the operation of the furnaces in handling and diagnozing the various problems that occur during the furnace operation.
3. Improved preventive maintenance schedules due to the afore mentioned experience, and the increased level of engineers, staff and labour training.

4. The optimum utilization of natural-gas injection in the blast furnace in connection to coke rate, see reference (2).
5. The stoppages of the furnace were reduced and hence the furnaces availability was larger.

As an indication of the performance of the furnaces, Figure 3.9 was constructed to indicate the histogram of coke rate, natural gas injection and daily production rate during the years 1978 to 1983. The coke rate was shown to increase due to the operation of the furnace (after overhaul). The rate was then reduced to 525 kg/ton by the year 1983.

The coke rate is reduced with the increased production. The natural gas flow rate was regulated to match the coke. Figure 3.10 demonstrates the coke rate variation which monotonically decreased with time from about 700 kg/ton in 1979 to 535 kg/ton during 1983. The production rate was near the design value and fluctuates around 1600 ton/day. The injected natural gas is correlated to the coke rate.

Figure 3.11 illustrates the variation of the coke rate versus the production rate; the coke rate decreases with the increased production rate.

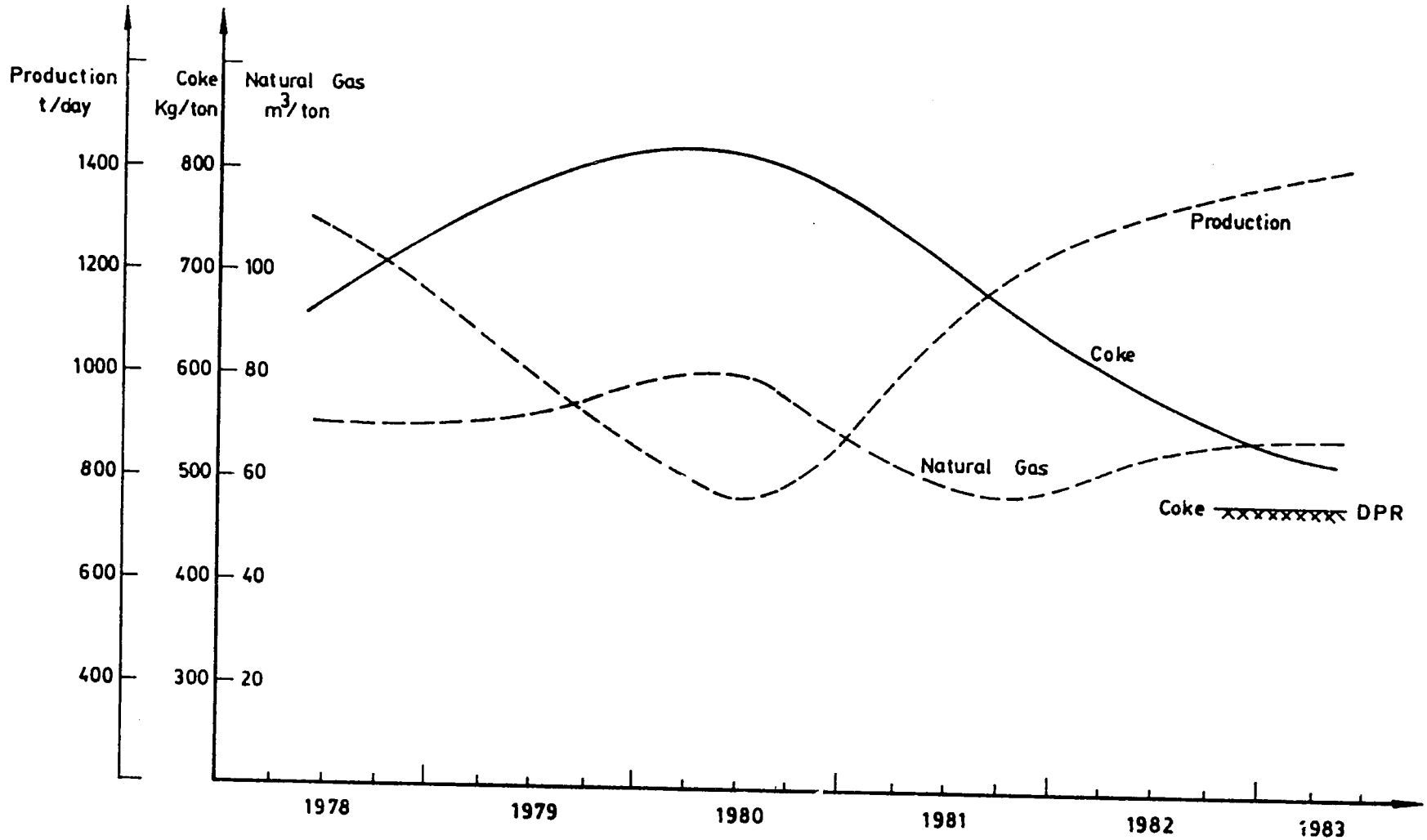

Figure 3.9 Yearly Performance of B.F.3

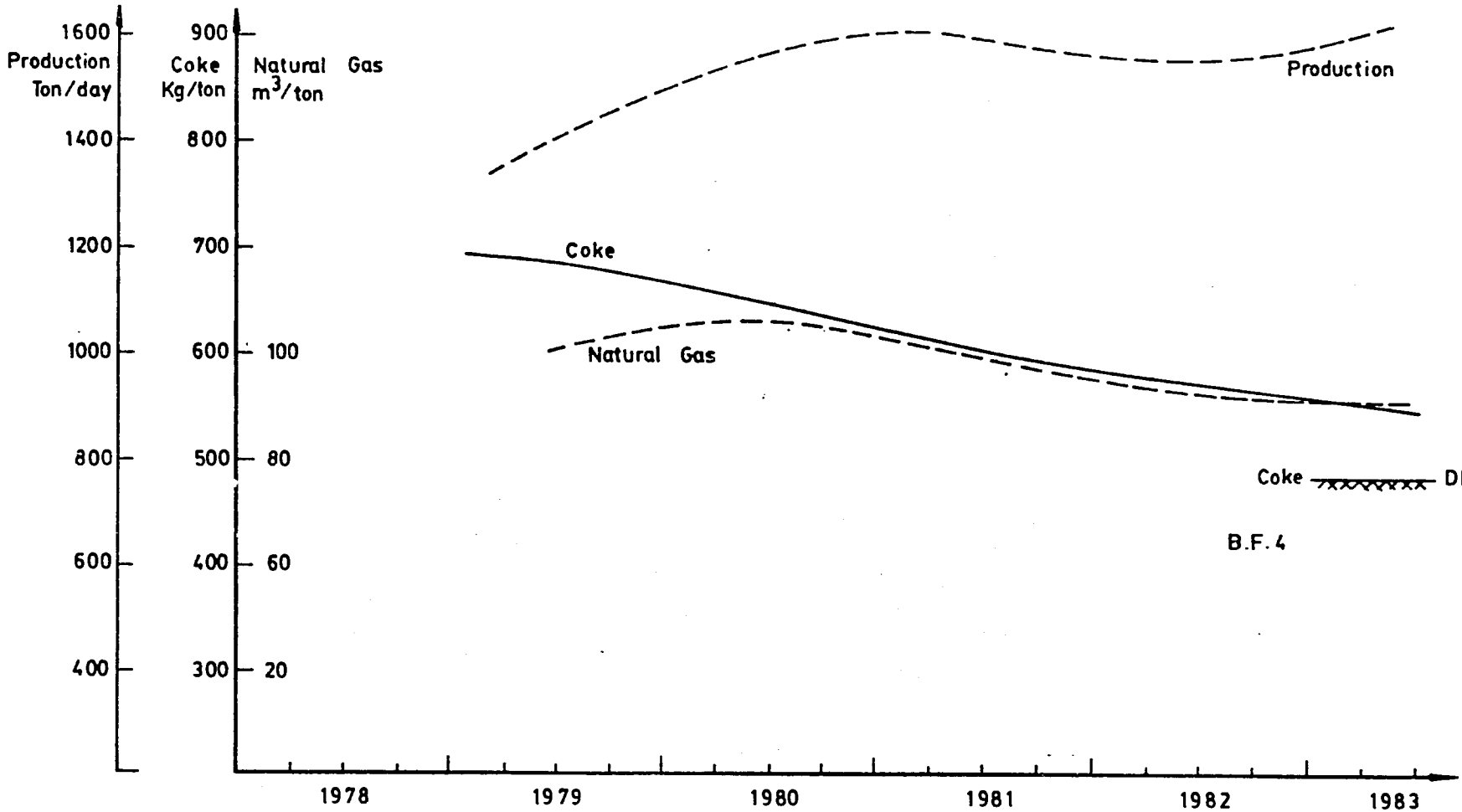

Figure 3·10 Yearly Performance of B.F. 4

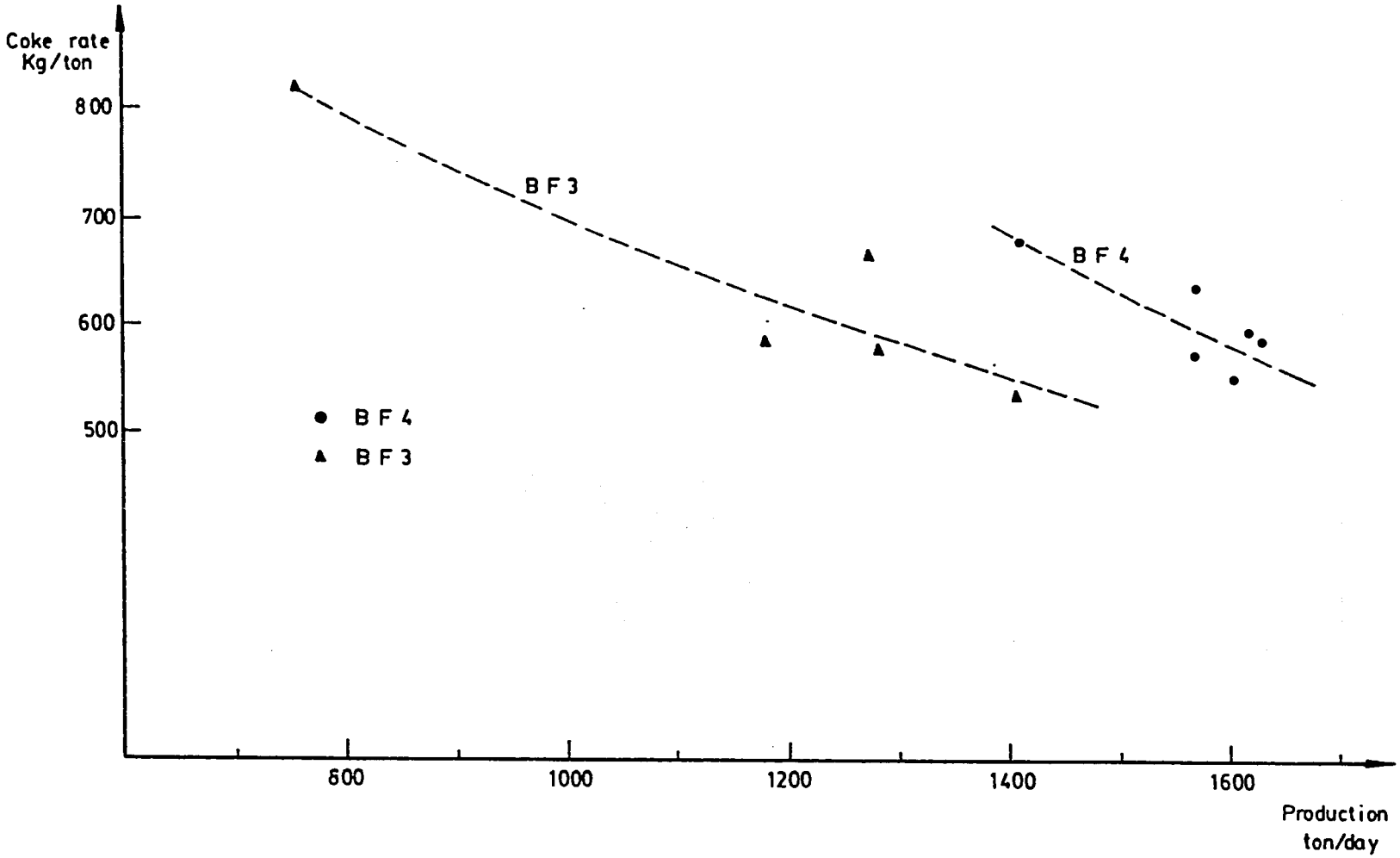

Figure 3.11 Coke Rate Variation with Production Rate

References

1. Detailed Project Report, Iron & Steel Works in Helwan, 1975

2. A. El-Ganainy and M. El-Houssiny, "Energy Saving in Iron Making at Helwan", Seminar on Energetics in the Egyptian Metal Industries, Jan., 17th, 1983, Cairo.

3. M.G. El-Maghraby et al, Energetics in the Egyptian Metal Industries, Report No.1, Analysis of the Present Status in the Iron and Steel Complex, Helwan, CU/MIT Project, Nov. 1982

CHAPTER 4

CONSERVATION OF ELECTRICAL ENERGY

4.1. Introduction

In the Egyptian Iron and Steel Complex, the electrical energy consumption amounts to about 17% of the total energy consumed by the complex as depicted in Fig.4.1. The consumption of electrical energy comes after the coke consumption, which is the largest. In addition, the price of electric energy goes up year after year. Seeking means for reducing electrical energy consumption is , therefore, inevitable.

The main objective of this chapter is to show how the consumption of electrical energy can be reduced with the help of the already existing facilities without adding any hardware. This implies that no extra costs are attributed. The procedure of the approach, suggested to achieve this goal, is described here. The sintering plant, which consumes about 21% of the complex electrical energy as shown in Fig.4.2, is taken as a demonstrative example for applying the approach presented here.

4.2. Main Principles of the Approach

The electrical power consumed by any electric device is given

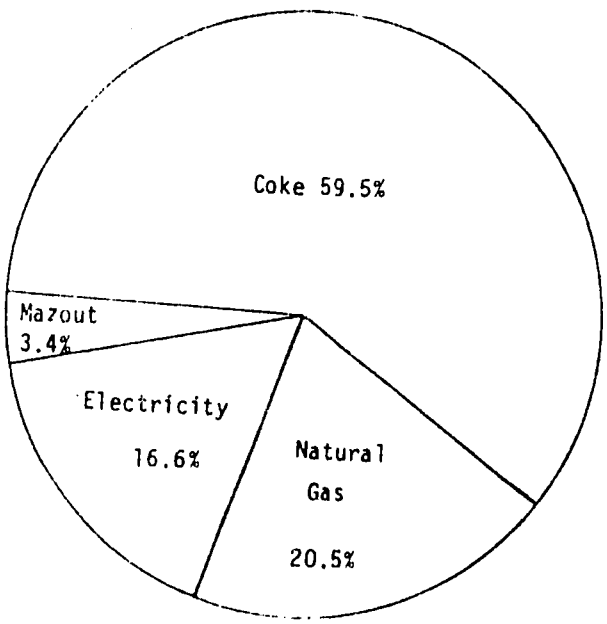

Figure 4.1 : Total Energy Consumption 80/81

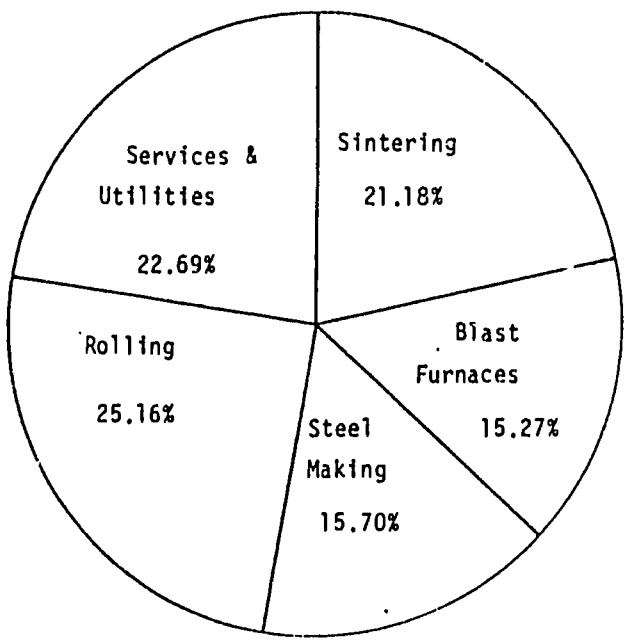

Figure 4.2 : Electrical Energy Consumption(80/81)

by:

$$P = m\ V\ I\ \cos\phi \qquad 4.1$$

where

P is the power consumed by the device,

m is the number of phases,

V is the phase voltage,

I is the phase current,

and ϕ is the phase angle between V & I

In industry, it is usually dealt with constant voltage power supplies. Hence for a given amount of power, increasing ($\cos\phi$) results in reduction of the current, which brings about:

(i) Reduction of voltage drops

(ii) Reduction of feeders and transformer losses, which means conservation of energy, less temperature rise and longer life

(iii) Possibility of increasing the load on the already installed equipment (e.g., feeders and transformers), which means higher reliability

(iv) Less ratings and hence less cost of the equipment to be installed.

In addition, it is a common policy of the electricity authority to penalize low power factor consumers.

Among electrical engineers, increasing the power factor (P.F.) is referred to as "Power Factor Correction".

Although each electrical device has its own power factor that can not be changed, it is the power factor of the supply, which defines its current, to be dealt with. Power factor correction can be accomplished by connecting, in parallel with the device (load), either a capacitor bank (single capacitor in case of single-phase devices) or a synchronous phase modifier, which is a synchronous motor operating at almost zero leading power factor. Installing such equipment may, however, be very expensive. Fortunately, in iron and steel industries, apart from the electrical energy consumed by the electric furnaces, the rest of the electrical energy is mostly consumed by electric drives. For example, in addition to very large number of small electric drives, HADISOLB has about 159 electric drives the ratings of which lies between 100 and 9500 kw. Some of these drives are of the synchronous type and all are of very large capacity; whereas the rest are either of the DC or the induction type. The P.F. of the DC and induction types are determined by the loading conditions and once the load is determined the P.F. is defined & can not be changed. However, the P.F. of a synchronous drive can be changed, at any load, just by changing the excitation current.

This means that if a synchronous motor is connected with some other motors on the same feeder, the feeder P.F. can be improved by changing the P.F. of the synchronous motor (i.e. by varying its excitation). Of course, the increase of the excitation may be accompanied by an increase in the synchronous motor armature current. This results in an increase in the synchronous motor copper losses. A compromise should therefore be accomplished so that the overall losses of the sector or department is minimized. With such a solution, the conservation of electrical energy is attained with no extra cost.

It should be pointed out that, the increase of the synchronous motor field current and the corresponding increase of the armature current are limited by the motor characteristics. It is, therefore, of interest to design a procedure to achieve the goal of energy conservation and at the same time not to cause any harm to the synchronous motors. Such a procedure is visualized by the flow chart illustrated in Fig.4.3.

Now, if each of the sectors has a synchronous motor, the maximization of cost saved in each sector will automatically maximize the cost saved in the whole complex. However, in practice, some of the sectors do not have synchronous motors. In this case, maximization of cost saved in each sector may not be sufficient to minimize the cost of energy of the complex as a whole especially when the complex overall power factor is so low to be penalized. Under such a condition, the overall power factor

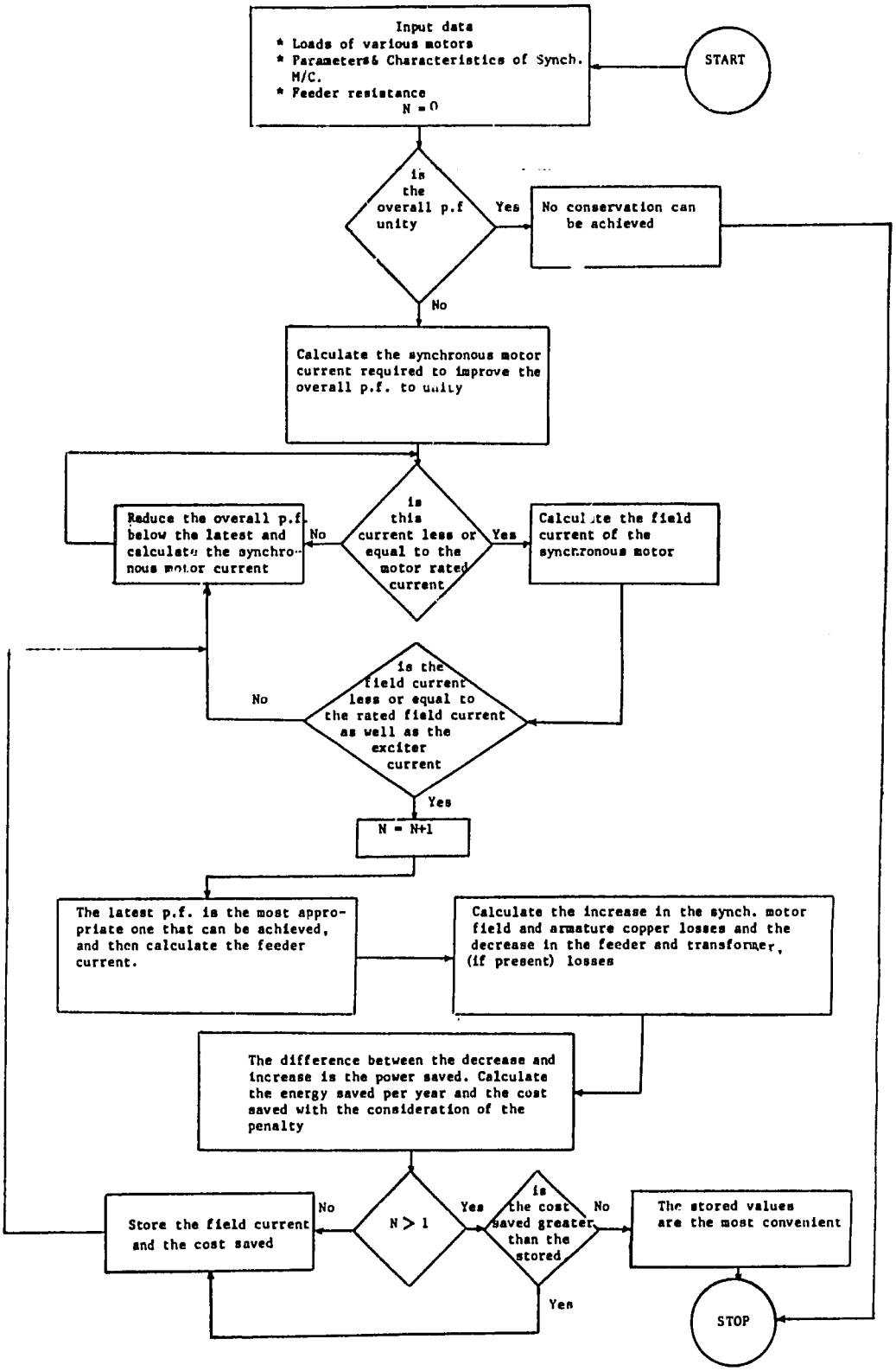

Fig.4.3 : Flow Chart of Electrical Energy Conservation in a sector including a Synchronous Motor.

of the complex must be improved to avoid the penalty which might be costy. This can be achieved by making the sectors having synchronous motors to be of leading power factor to substitute for the lagging power factor sectcrs. An optimization technique may be used to minimize the cost of the electrical energy consumed in the whole complex.

One more point worthy of mentioning is that when the load of the various motors is widely changing, one may follow either of the following two ways:

i. An average load is selected, and the maximization of the cost saved is carried out for this load.

ii. The period of load change is divided into several approximate fixed load intervals. The maximization technique is then applied to each interval and the corresponding adjustments are made accordingly for each loading conditions.

4.3 Case Study

In order to demonstrate the application of the approach described, the sintering plant is taken as an example.

Sintering Plant

As mentioned earlier, the sintering shop consumes about 21% of he electrical energy consumed by the complex. Further more, the sintering plant has very large synchronous motors operating the exhaust fans. The sintering plant comprises four similar units, the single line diagram of each is shown in Fig.4.4. Each unit contains a synchronous motor of 2000 kw, two induction motors of 200 kw each, two induction motors of 630 kw each in addition to a mud pump station and a service substation. The power is fed via a three-phase, 1.75 km long feeder. The resistance of each line of the feeder is 0.226 Ω/km. Our main concern now is the synchronous motor, the parameters of which are:

Armature Winding

Armature resistance (R_a) = .057 Ω (D.C. value)

Armature direct-axis reactance (X_d) = 1.4 p.u.

Armature rated current (I_a) = 214 Amps.

Armature rated voltage (V_a) = 6300 V

Field winding

Field resistance (R_f) = 0.043 Ω

Field rated current (I_f) = 425 Amps.

Field rated Voltage (V_f) = 40V

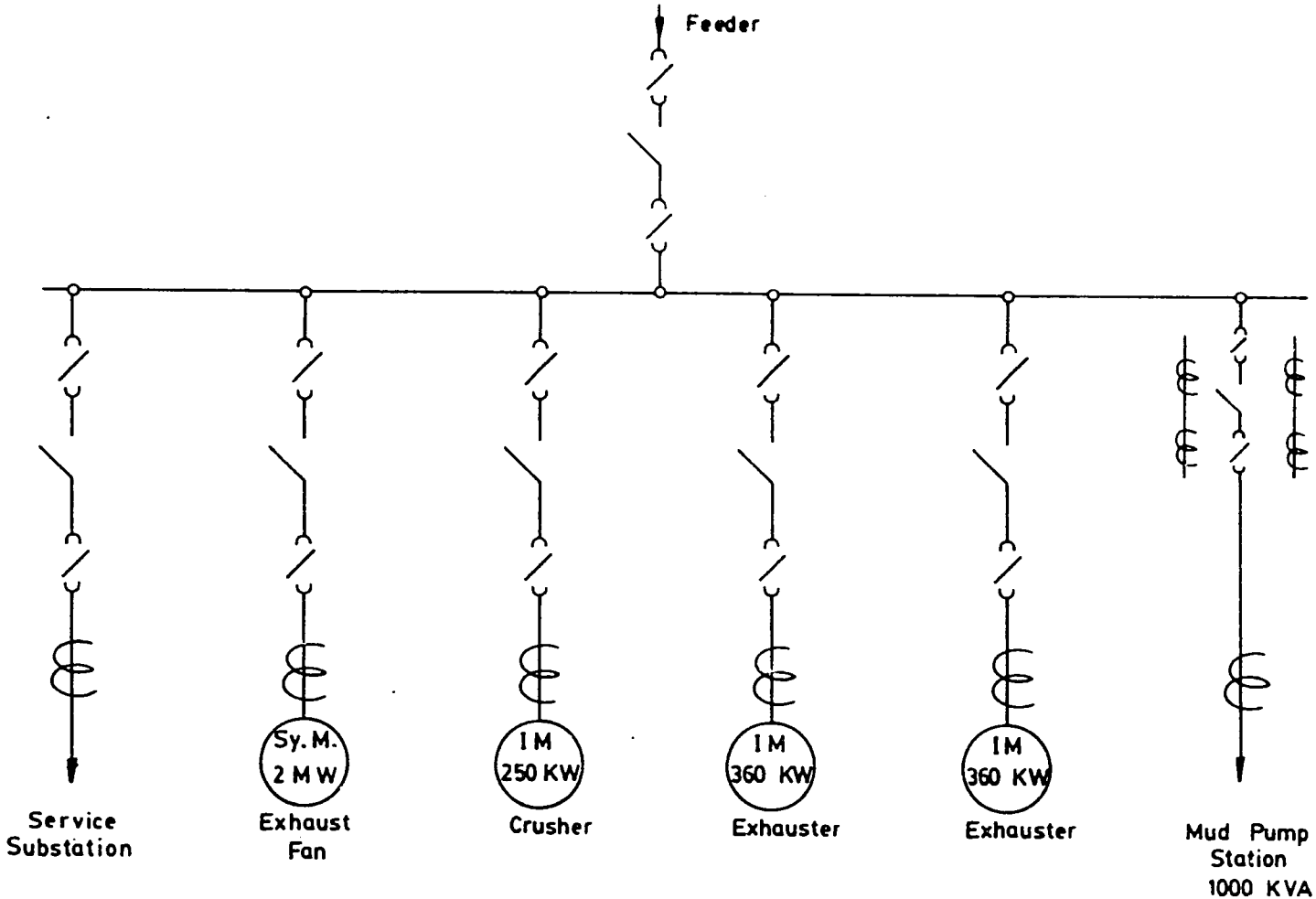

Figure 4.4 Single Line Diagram of One of the Feeders in the Sintering Plant

From the data given and the measurements obtained, the no-load characteristics and the corresponding V curves of the synchronous motor are shown in Fig.4.5 and 4.6, respectively. Further, Fig.4.7 shows the phasor diagram of such a motor with the safe operating boundaries for motor operation shown on it. It should be pointed out, that only the capacitive loading condition (leading power factor) has been considered because the motor will be used to compensate for the inductive reactive power of the other loads. Thus the safe operating region of the motor under consideration is the hatched area.

In order to justify and validate the acceptance of the approach presented, the Cairo University team has visited HADISOLB and tried this approach on site. The results shown in table 4.1 have been obtained from the measurements taken.
From the results shown in table 4.1, one infers that:

i. The variation of the field and armature copper losses is very little compared with that of the feeder copper losses.
ii. A saving of about 38 kw in the total losses can be achieved which means a saving of 12000 Egyptian pounds per year for the four units of the sintering plants.
iii. This method must be applied to the other sectors which have synchronous motors.
iv. The losses of the feeder transformer are not included. Of course, including them will increase the saving.

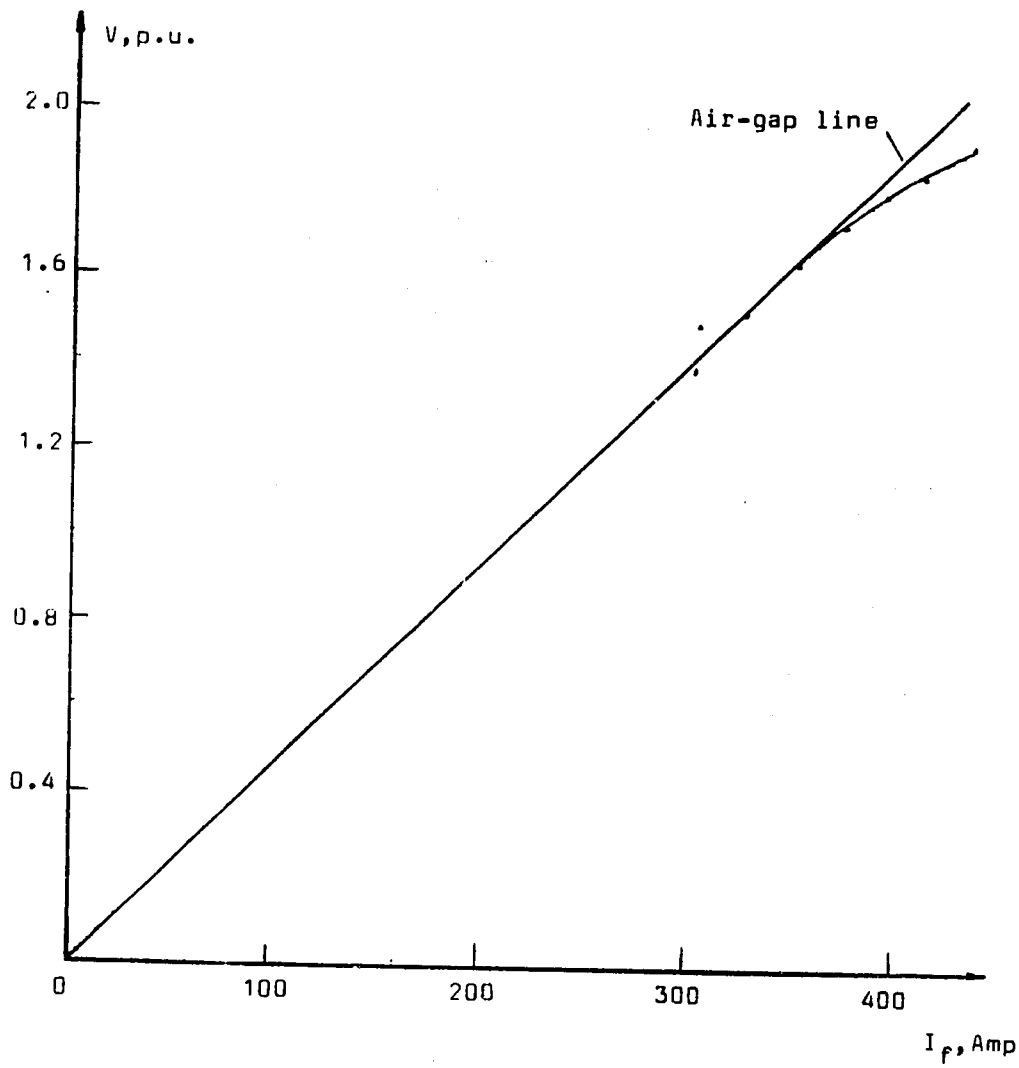

Figure 4.5 : No-Load Characteristics of the Synchronous Motor

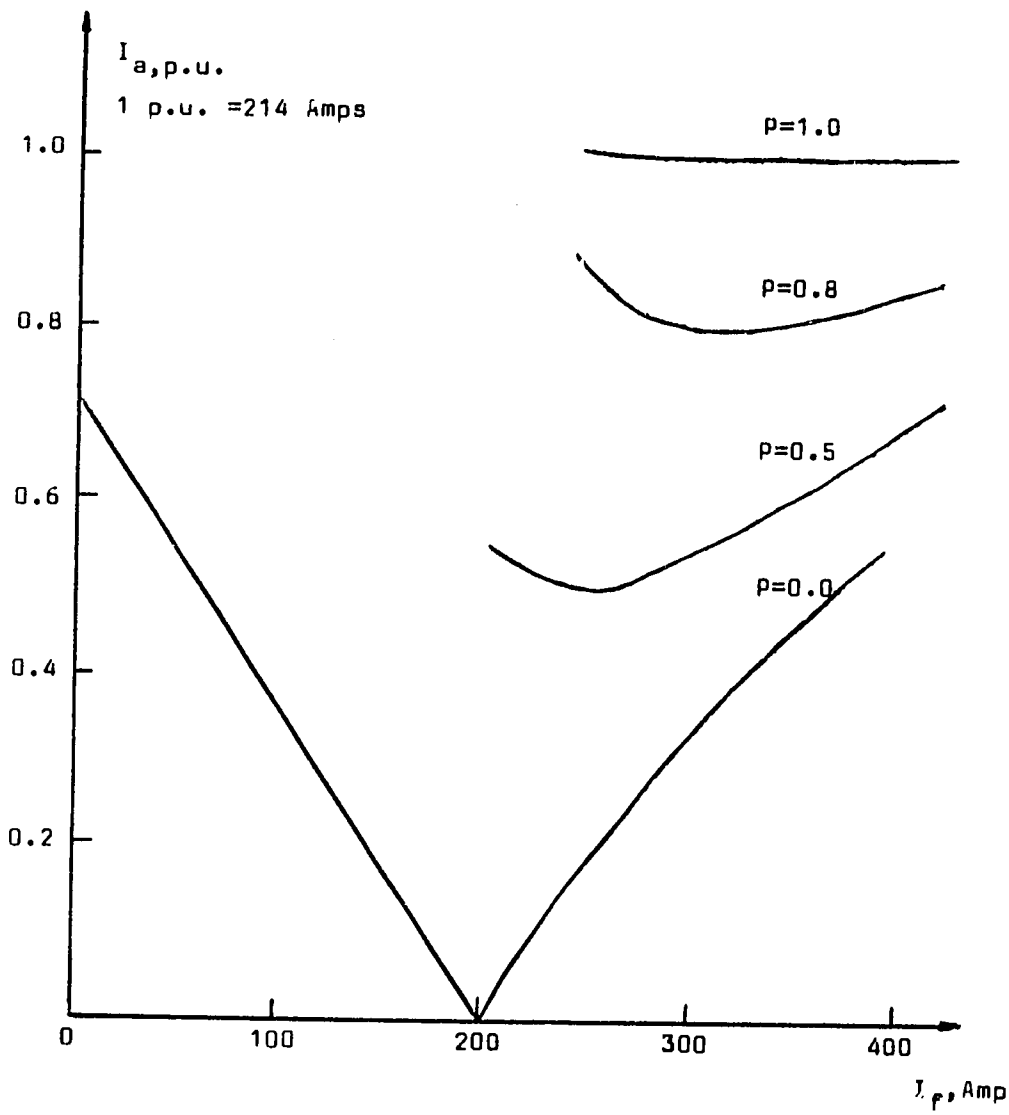

Figure 4.6 : V Curves of the Synchronous Motor

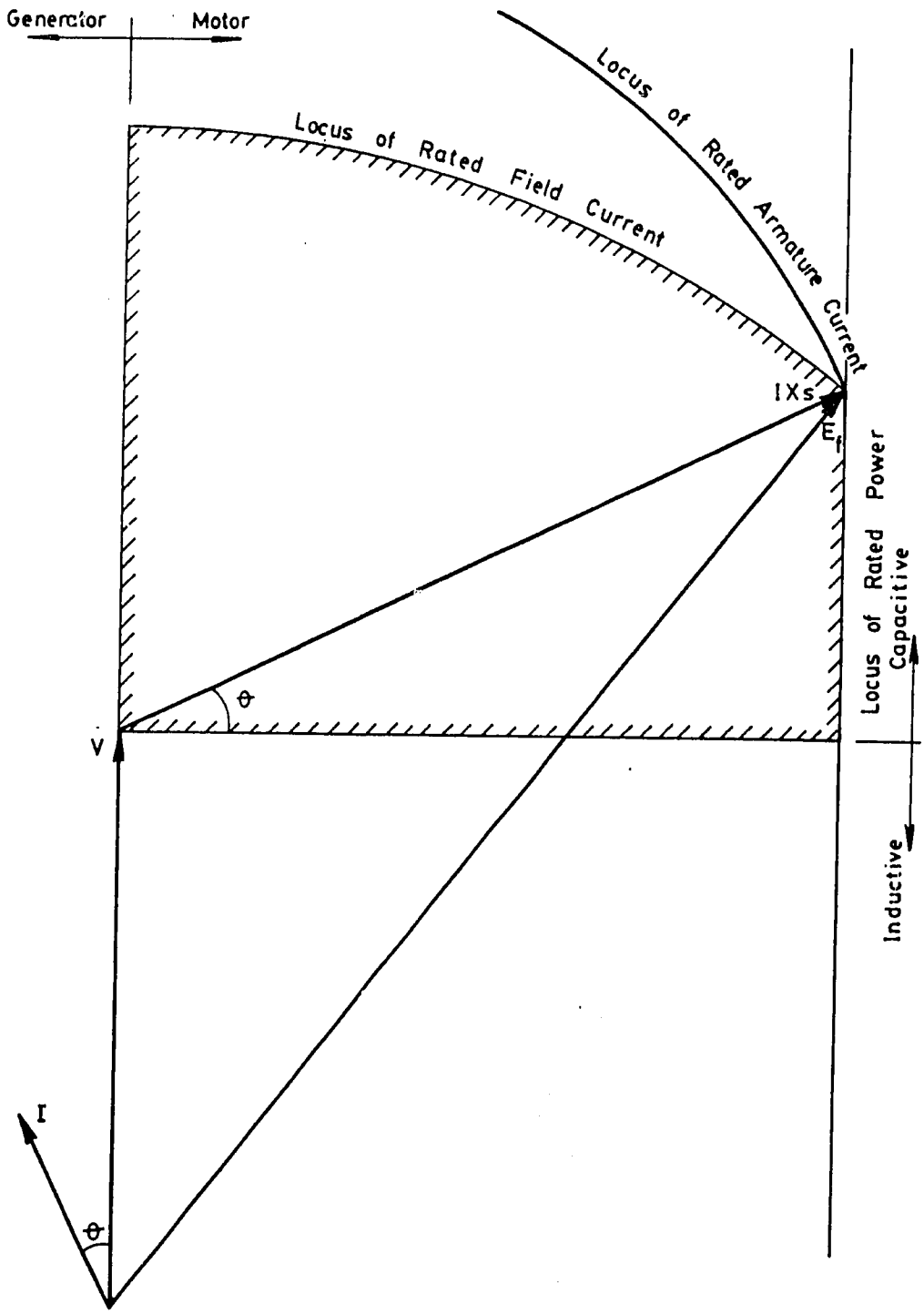

Figure 4.7 :Operating Boundaries of the Synchronous Motor

Table 4.1

Results of Synchronous Motor and Feeder for Various Values of Field Current

I_f(A)	300	320	340	360	380	400	420
I_a(A)	195	192	189	195	201	205.5	207
ϕ(leading)	-3	+3	7	13	16	19	20
I_{fd}(A)	465	457.5	441.75	427.5	438.75	431.25	427.5
ϕ_{fd}(lagging)	32	31	29	27	24	23	23
W_f(kw)	3.87	4.4	4.97	5.57	6.21	6.88	7.59
W_a(kw)	9.62	9.33	9.04	9.62	10.22	10.68	10.84
W_{fd}(kw)	256.55	248.34	231.54	216.84	228.4	220.66	216.84
W_t(kw)	270.06	262.07	245.55	232.03	244.83	238.22	235.2

Where

ϕ Phase angle of the motor

I_{fd} Current of the feeder

ϕ_{fd} Phase angle of the feeder

W_f Field losses

W_a Armature losses

W_{fd} Feeder losses

W_t Total losses.