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REPORT

ON ENERGY AUDIT

AT THE OPEN JOINT-STOCK COMPANY
"CENTRAL ORE CONCENTRATION COMPLEX"
Kryvyi Rih, UKRAINE

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1 EXECUTIVE SUMMARY

1 1 Introduction

The United States Agency for International Development (USAID) under the Contract #30 has financed energy audits at 24 industrial plants which were selected according to the USAID criteria for implementation of the Industrial Energy Efficiency Project This report describes the findings of the energy audit carried out by the Burns and Roe company at the Open Joint-Stock Company Central Ore Concentration Complex (OJSC COCC) in Kryvyi Rih, Ukraine

According to Sub-Task #3 of this Contract, 24 industrial plants out of 90 possible candidates were selected for the audit Each plant was considered on the basis of criteria set by the USAID for selecting project participants The selection criteria included long-term economic forecast, financial state of the enterprise, the share of income generated from exports, current output/ rated output ratio, energy saving potential, a possibility for project replication at similar plants, and the accessibility of the plant to serve as a demonstrating facility for others The OJSC COCC is not the only Ukrainian plant which belongs to the mining and processing sector Most problems pertaining to the plant are typical for Ukrainian industrial enterprises, and their solution can be applied in mining, metallurgical and other industries

The energy audits had the following objectives

- to conduct unofficial training in energy management practices,
- to explain to the plant management the energy management structure,
- to recommend specific steps to improve energy efficiency, including administrative measures and energy saving measures,
- to recommend investment opportunities and medium-cost measures aimed at large-scale energy saving

A team of energy auditors has conducted an energy audit at the plant during March 16 to 20 and, according to the Project objectives, prepared the following report

1 2 Principal findings

As it was expected, the energy auditors team has revealed a number of opportunities to improve energy efficiency under current energy prices Earlier, when energy prices were ***20-30*** times lower than now, energy efficiency measures were irrelevant Currently, improvement of energy efficiency can be profitable, but is difficult to realise because of high discount rates for bank loans and economic obstacles related to barter settlements and inter-enterprise arrears

- The OJSC COCC is considered to be quite successful according to the Ukrainian standards for enterprises of such a scale, however it has to use barter when selling its products

- Being a large consumer of electricity and natural gas, the integrated plant and its pelletizer-plant have a number of problems related to efficient utilisation of energy resources

  - low efficiency of gas equipment due to the lack of up-to-date automatic systems and use of out-dated fuel combustion devices,

- high rates of faulty products because of shortages in the design of technological equipment, and the complicity of observing temperature parameters,

- low efficiency of electrical equipment due to the lack of up-to-date automatic control systems,

- energy efficiency of the plant is also decreasing because the rated capacities do not correspond to the actual production output

1 3 Recommendations

The recommendations set forth in this report will help improve energy efficiency, decrease costs for energy resources, enhance the quality of products while reducing their cost, and to assure the competitiveness of the enterprise The plant has several energy conservation opportunities (ECOs) with different payback periods

Implementation of the proposed ECOs with a short payback period (ECO #1, #2) will reduce gas consumption by ***7,214,000*** m^3 per year, that of electric power - by ***23,071,000*** kWh/year The cost of ECOs with a short payback period of ***1,18*** years is $***3,700,000,*** and the saving is expected to be $***3,129,857***

The implementation of the proposed ECOs with a medium payback period (ECO #4, ECO #6 and ECO #7) will reduce power consumption by ***12,929,000*** kWh/year The cost of ECOs with a medium payback period of ***2 49*** year is $***1,450,000*** and the saving is expected to be $***581,824***

The enterprise also presents energy conservation opportunities with payback periods more than 3 years (ECO #5)

The assessment and implementation of the above-stated ECOs and searching for other ECOs would require a more detailed energy audit of the plant, elaborating the development plan of the enterprise, and selecting energy conservation strategy

1 4 Operation and maintenance

The specific feature of each industrial enterprise is the management's focusing on production issues and its desire to increase production volumes Owing to this, such important issues for the company's operation as energy resources and their cost are often not dealt with adequately

Similar to most Ukrainian industrial enterprises in the past, energy expenses of this plant were substantially subsidised, making energy conservation a low priority issue in the plant's activity

In the last few years, energy expenses increased dramatically due to the growing energy prices Currently, energy cost makes up ***40%*** of the price of plant's products

Most Ukrainian industrial enterprises have an expert or a group of experts - energy engineers Typically, these experts are responsible for reliable energy supply to the plant rather than improving its energy efficiency Due to growing energy prices and the uncertainties in the supply of all types of fuel, energy management is becoming an important activity Each enterprise should properly consider introduction of the position of energy manager or, in case with huge industrial facilities, energy management groups

Such services should regularly monitor all processes and, in particular, estimate monthly energy consumption volumes The data on monthly energy consumption should then be presented graphically and compared with relevant indices in preceding months or years in order to detect

changes in energy consumption volumes If such changes have really occurred, the energy management group should identify their cause and make a decision on whether some measures should be implemented in this regard For instance, if monthly figures show an increase in energy consumption, the cause should be detected

In addition to this, the energy management group should systematically study all processes to identify energy conservation opportunities The experts should assure the implementation of energy efficiency proposals at the plant, beginning from the recommendations listed in this report The energy conservation group should consider all changes proposed to the plant to check their energy efficiency

An energy management group at the plant of the size of COCC should consist of several persons Preferably, such group should include thermal (gas-supply and gas-operated and hot water supply systems, heating and heat-operated equipment, etc) and power engineers (transformers, motors, etc) The group leader should report directly to the top management of the plant

Many enterprises assign to their energy management groups such tasks as "to reduce total annual energy consumption by *5%*" Of course, the planned percentage may change, but such approach, when a task is set, can be serve as a criterion to assess the work of the group itself The above percentage of energy saving could be much higher at Ukrainian industrial enterprises, where energy conservation reserves are substantial Incentive schemes for specialists in charge of efficient utilisation of energy resources should be implemented at plants

1 5 Energy Conservation Opportunities (ECOs)

Table 1 1 List of Energy Conservation Opportunities

# ECO	NAME	Power savings (ths kW•h)	Natural gas savings (ths M^3)	Annual savings ($/year)	Cost of proposed measures ($)	Simple payback period (year)	Item refer
1	Introduction of energy management	23,071	3,514	1,329,857	1,100,000	0 83	7 2
2	Application of the gas-turbine, replacement of injector burners and heating of primary combustion air	0	3,700	1,800,000	2,600,000	1 44	7 3 2
3	Up-grading of the electric drive system for the plant of circulating water supply	3,000	0	1,350,000	320,000	2 37	7 4
4	Installation of a variable-speed drive to the *D1* Fan at the pelletizer - plant	5,929	0	266,824	630,000	2 36	7 3 3 1
5	Installation of a variable-speed drive to the *D2* Fan at the pelletizer - plant	2,353	0	105,882	400,000	3 78	7 3 3 2
6	Installation of a variable-speed drive to the *D3* Fan at the pelletizer - plant	2,000	0	90,000	250,000	2 78	7 3 3 3
7	Installation of a variable-speed drive to the *D4* Fan at the pelletizer - plant	2,000	0	90,000	250,000	2 78	7 3 3 3
	Total	**38,353**	**7,214**	**3,817,563**	**5,550,000**	**1 45**	

2 GENERAL INFORMATION

Name – Open Joint-Stock Company "Central Ore Concentration Complex" (COCC), City of Kryvyi Rih

Director General – Vladimir P Movchan
Chief Energy Engineer – Yury P Cherchel

Tel – (0564) 51-83-01, 51-83-30
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Legal Address and Bank Information

"Central Ore Concentration Complex",
Dnipropetrovsk Oblast, Kryvyi Rih, 324510, Ukraine
Bank Account # 263802 in Zhovtnevy Division of *PROMINVESTBANK* in Kryvyi Rih City
MFO - 305631
OKPO Code - 00190977

2 1 Enterprise history

The first stage of the Kryvyi Rih State Central Ore Concentration Complex was put into operation in 1961 In 1992, the cycle-line technological workshop was put out of operation, which resulted in considerable raise of mining work cost

Despite huge financial problems, in 1996 a new machine (*OK-324*) for pellets production was commissioned, that strengthened the enterprise position on the market

2 2 Production output

The enterprise is engaged in open-pit mining of magnesite, ferruginous quartzite, processes it and produces the following

- iron ore concentrate,
- fluxed iron ore pellets,
- construction crushed stone

The rated capacity of the processing complex of the enterprise was designed for processing ***28*** million tonnes of crude ore, resulted in ***10 2*** million tons of concentrate, and production of ***6 8*** millions tonnes of pellets

2 3 Number of personnel

At present, over *7,000* employees work for the Central Ore Concentration Complex Plant (COCC)

2 4 Similar enterprises in Ukraine

There are dozens of enterprises in Ukraine, producing iron ore raw materials the most similar, in terms of the technological level and types of production, are the Northern COCC (Kryvyi Rih City) and Poltava COCC (Komsomolsk Town)

3 CURRENT STATUS OF PRODUCTION

3 1 Export opportunities

At present, almost all iron ore concentrate is exported from Ukraine, while almost all pellets are supplied to the national metallurgical plants

3 2 Structure of the enterprise

The enterprise consists of

- four open cuts, one of them is laid-up at present,
- department of railway transport,
- two departments of auto transport for technological process,
- crushing-and-processing complex,
- pelletizer-plant,
- auxiliary departments, providing for the operation of principal workshops

3 3 Consumers of the enterprise's products

Main consumers of the iron ore raw material in Ukraine are steel works of Kryvyi Rih, Dnipropetrovsk, Dniprodzerzhinsk and Yenakiyevo

The products are exported to East European countries Poland, Czechia, Slovakia, Romania

3 4 Importance of the sector to the national economy

Since the Open Joint-Stock Company "Central Ore Concentration Complex" is one of the largest producers of raw materials (iron ore and pellets) for the ferrous metallurgy in Ukraine and other CIS-countries, and its products are competitive, this enterprise has good prospects and is of importance for the Ukrainian economy

4 FINANCIAL STATUS OF THE ENTERPRISE

4 1 Currency versus barter

The marketing of almost all the enterprise's products is carried out through barter transactions

4 2 Viability of the enterprise

Based on the activity results for 1995 the Central Ore Concentration Complex is among the best hundred (i e *#79*) enterprises of Ukraine, according to the rating, held by the "Ukrainian Investment Newspaper" In 1995 the enterprise's income made up US $***60 099*** million, while in 1996 - US $***35 353*** million The "*Deloitte & Touche*" firm served as a consultant for that rating Due to the economic recession, in 1996 the Central Ore Concentration Complex was unprofitable However in 1997, the output increased ***1 5 - 1 7*** times, that enabled the enterprise to approach close to a profitable operation

5 ENERGY CONSUMPTION

5 1 Power

Table 5 1 Power consumption in *1995 – 1996*

	Power consumption (thousands kW•h)	
Month	**1995**	**1996**
January	58 623	49 892
February	52,965	40,062
March	63,389	53,364
April	59,181	49,071
May	63,070	37,505
June	62,507	46,440
July	58,769	45,344
August	62,547	51,247
September	61,916	47,125
October	63,925	48,877
November	56,891	48,911
December	54,622	62,576
Total	718,405	580,414

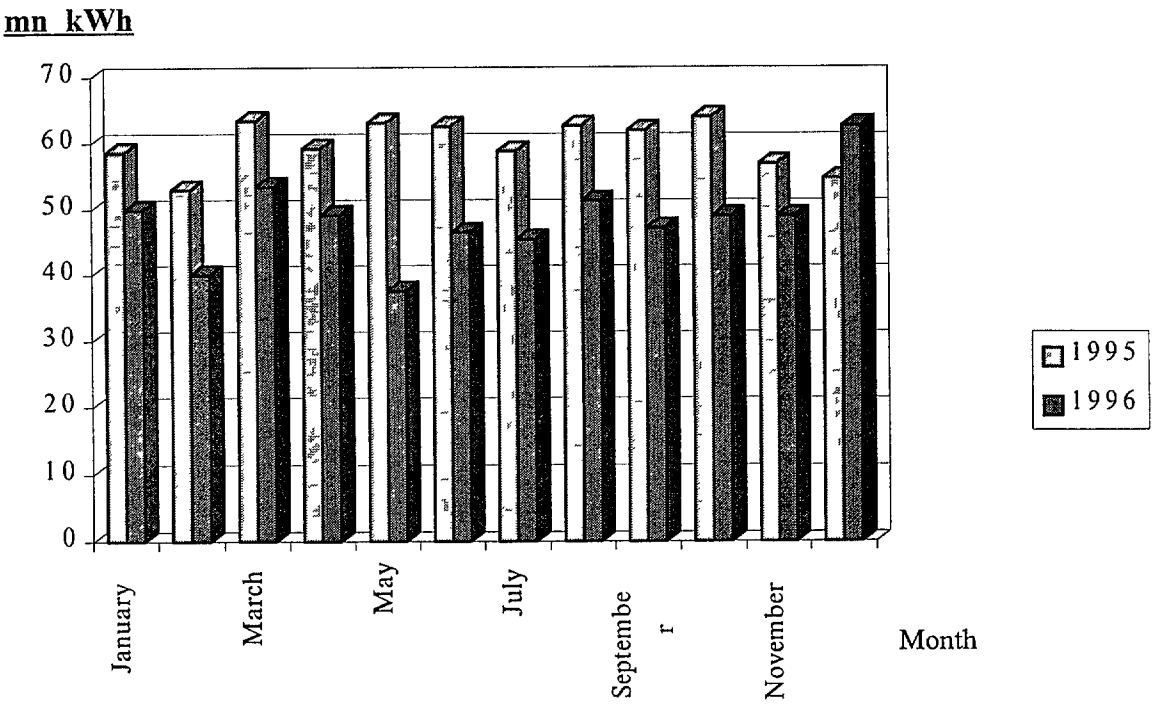


Fig 5 1 Power consumption in 1995 – 1996

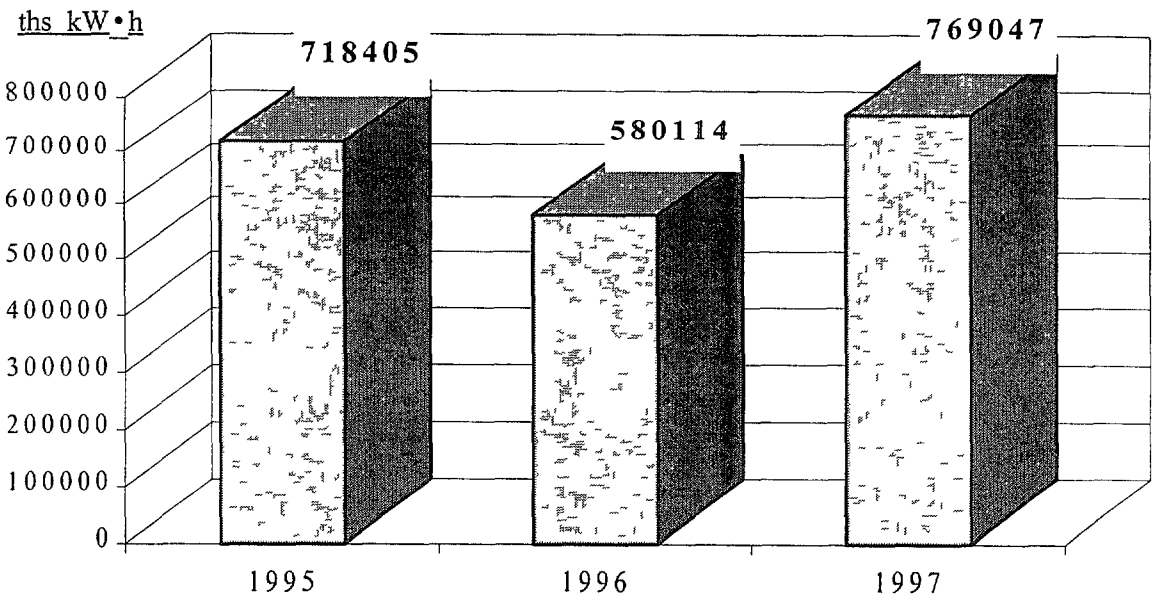


Fig 5 2 Power consumption in 1995 - 1997

Electric power consumption breakdown over main departments of the enterprise

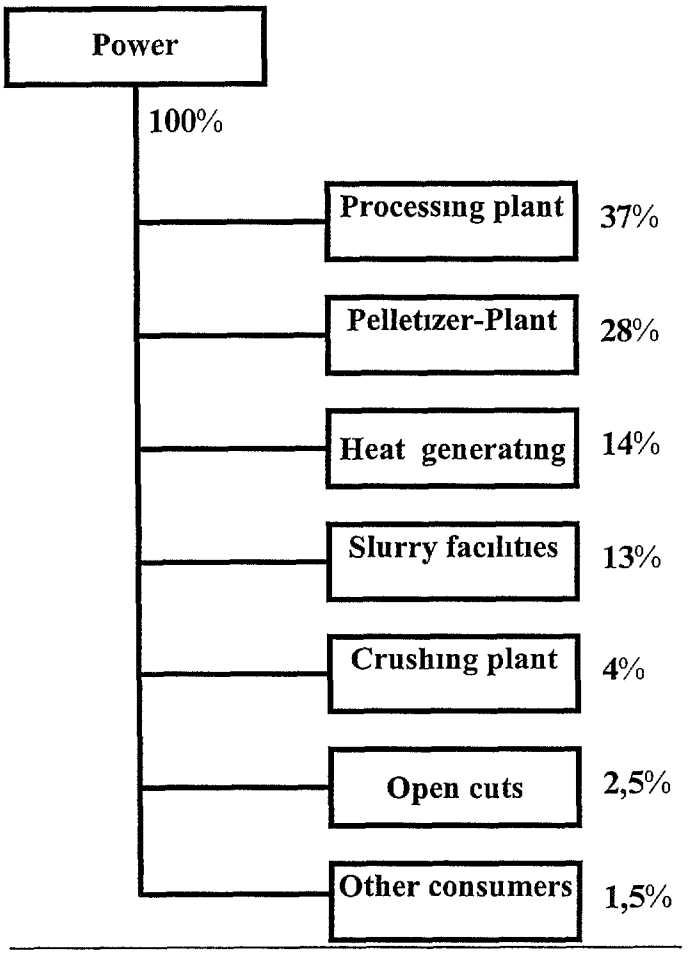


Fig 5 3 Balance of power consumption by the enterprise departments

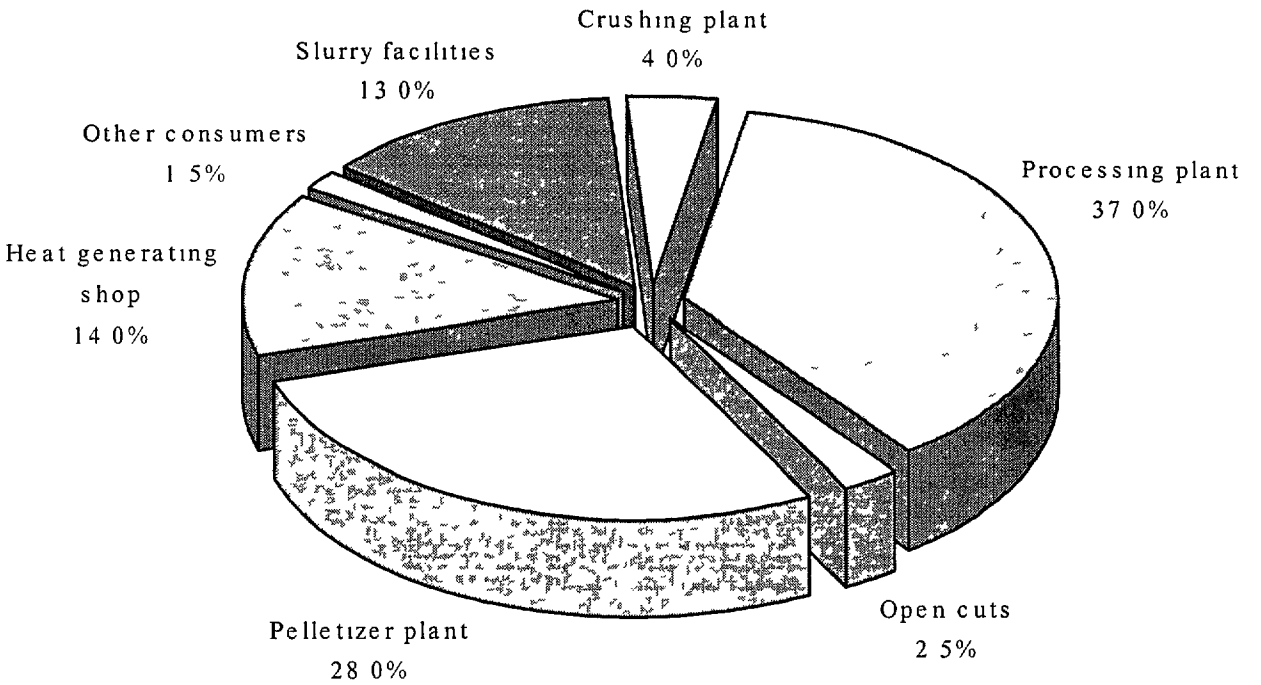


Fig 5 4 Power consumption breakdown over the enterprise's departments

Table 5 2 *Power consumption by pelletizer-plant in 1995 – 1996*

	Power consumption ths kW•h	
Month	**1995**	**1996**
January	15,275	14741
February	16,215	12,965
March	19,533	17,361
April	16,015	15,428
May	20,107	10,545
June	15,726	12,547
July	18,371	13,328
August	18,220	13,498
September	17,132	13,106
October	20,487	12,456
November	16,332	14,683
December	17,753	18,981
Total	211,166	169,639

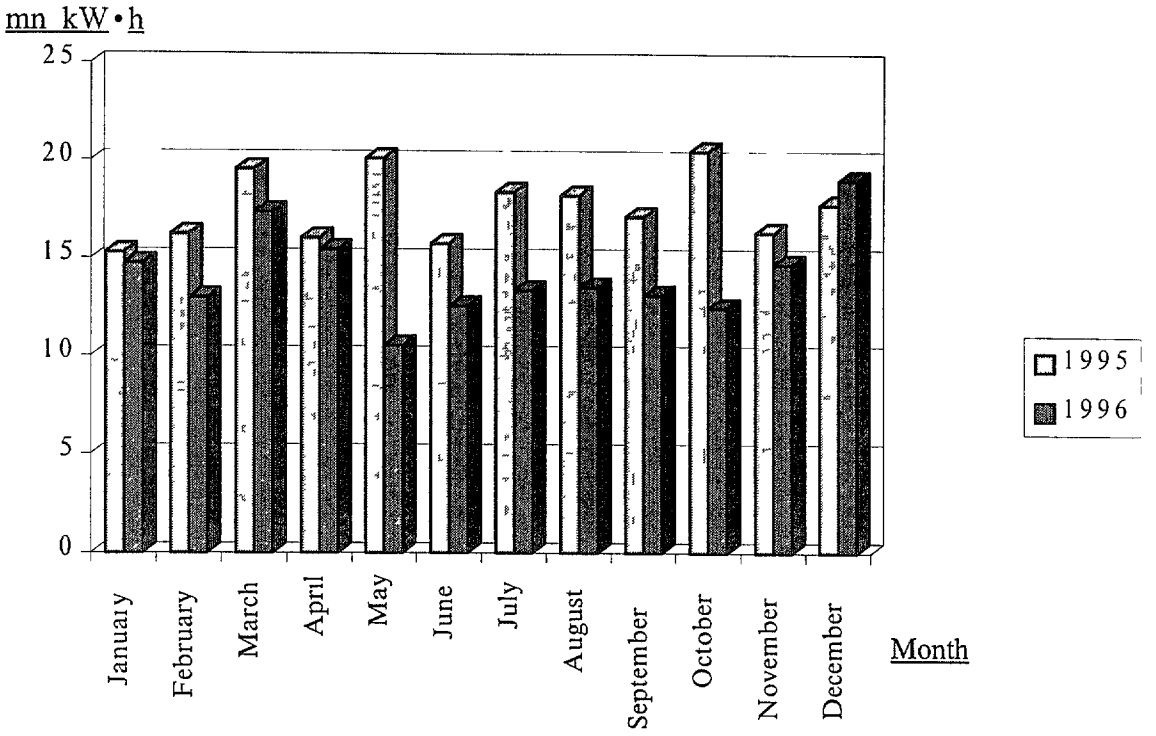
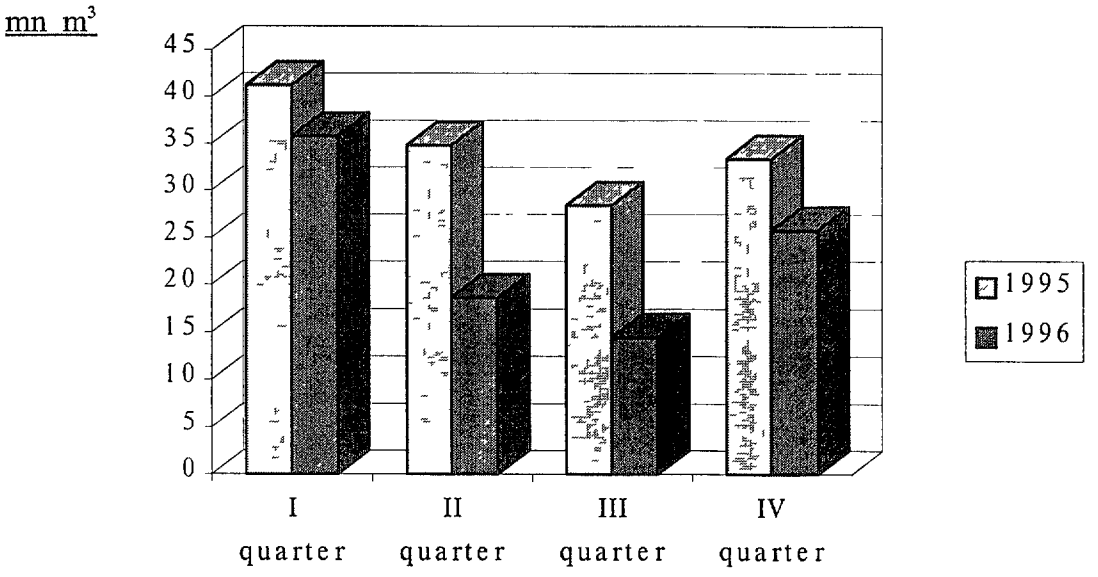


Fig 5 5 Power consumption by pelletizer-plant in 1995 – 1996

5 2 Natural gas

Table 5 3 *Overall natural gas consumption in 1995 – 1996*

	Natural gas consumption (ths m^3)	
Month	**1995**	**1996**
I quarter	41,239	35,822
II quarter	34,878	18,634
III quarter	28,465	14,512
IV quarter	33,403	25,801
Total	137,985	94,769



Picture 5 6 Natural gas consumption in 1995 – 1996

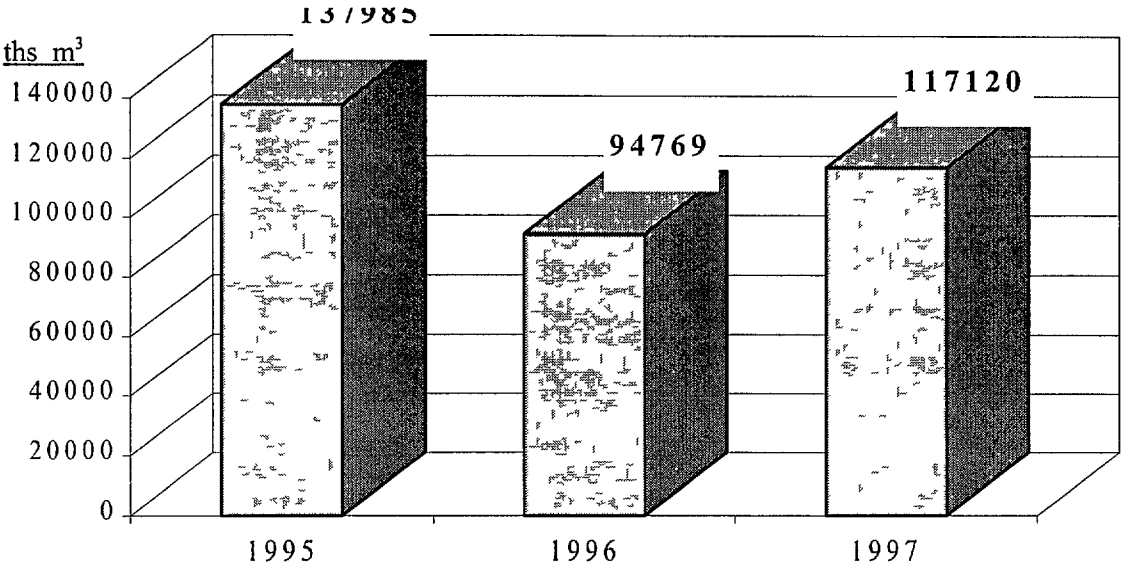


Fig 5 7 Overall natural gas consumption in 1995 – 1997

Except very little amount of gas (*1%*) consumed by the boiler house of the enterprise in cold seasons, all the rest volume of natural gas is consumed by the pelletizer-plant for a technological process Roasting units are the major natural gas consuming equipment

6 PREVIOUS ACTIVITY IN THE FIELD OF ENERGY CONSERVATION

The enterprise focuses considerable attention on energy conservation aspects Thus, the enterprise "Electromechanika" performed an analysis of financial state of the enterprise and grounded the need for reduction of the energy expenses It was also determined, that just organisational no-cost measures would provide an opportunity to reduce the overall energy consumption by the enterprise by more than ***10%***, at the same time reducing the wear-out of equipment Given the lack of necessary measuring instruments (*Combustion Analyzer and Infrared Thermometer*) it was not possible to carry out thorough energy audit at the enterprise

According to recommendations, prepared by the "Electrotechnika", the Central Ore Concentration Complex began the activity aimed at introduction of energy metering systems

7 ENERGY AUDIT

7 1 General

During the energy audit the following energy conservation opportunities have been identified and discussed with the plant management

- erection of a shelter from moisture at the raw materials warehouse,
- adjustment of burners operation,
- observance of the preventive maintenance schedule,
- maintaining optimal and quality load for roasting units and the plant on the whole,
- continuous control over the raw materials and products properties (concentrate, bectonite, limestone, raw and roasted pellets),
- continuous control over faulty production return,
- replacement of existing burners with more efficient ones,
- observance of technological process chart,
- charge components batching,
- protection from overloading in *6 kV* lines,
- extention of the covered warehouse for crushed and dried bectonite, with a supply conveyor and a system of moisture monitoring and control,
- development of a system for the charge preparation control,
- commissioning of a complex for control of technological process of *OK*-324 roasting unit,
- provision of quality binders for the charge (bectonite and limestone),
- introduction of the "bunker-rotor loader" system at the pellets warehouse,
- observance of technological discipline,
- introduction of the energy metering system,
- effective mixing of the components,
- avoidance of emergency downtime,
- charging the unit with raw pellets of required size (*8-18* mm),
- reliable operation of all automated systems and measuring instruments,
- proper classification of the "bed",
- preliminary air heating in the crushing plant,
- transfer of turbo-generator exhausts to the drying zone of roasting units,
- re-calculation of the gas-air mixture supply rate on the basis of thermal balance,
- stabilization of pelletizers and roasting units charging,
- removal of returns from the charge,
- mounting of the transpiration cooling system and utilization of the heat for raw materials drying,
- improvement of the furnace heat insulation,
- installation of the system of automatic control and burners lighting-up,
- improvement of the water supply system

Based on preliminary studies some main lines of activity have been selected

– introduction of energy management,

- modernization of the *OK*-324 roasting unit in the pelletizer-plant,
- improvement of the electric drive system for the circulating water supply plant

7 2 Introduction of energy management

Description of the ECO

Energy Management is the main mechanism of reducing energy consumption and increasing energy efficiency in the industrial enterprises Energy management is a system of management, based upon the serial measurements and tests, thus, providing such type of the enterprise operation, when the exact needed amount of energy is consumed for the production purposes Energy management is an instrument for the enterprise control, which ensures continuous study, therefore providing the knowledge of distribution and consumption of energy both for the production and for heating and other non-production purposes

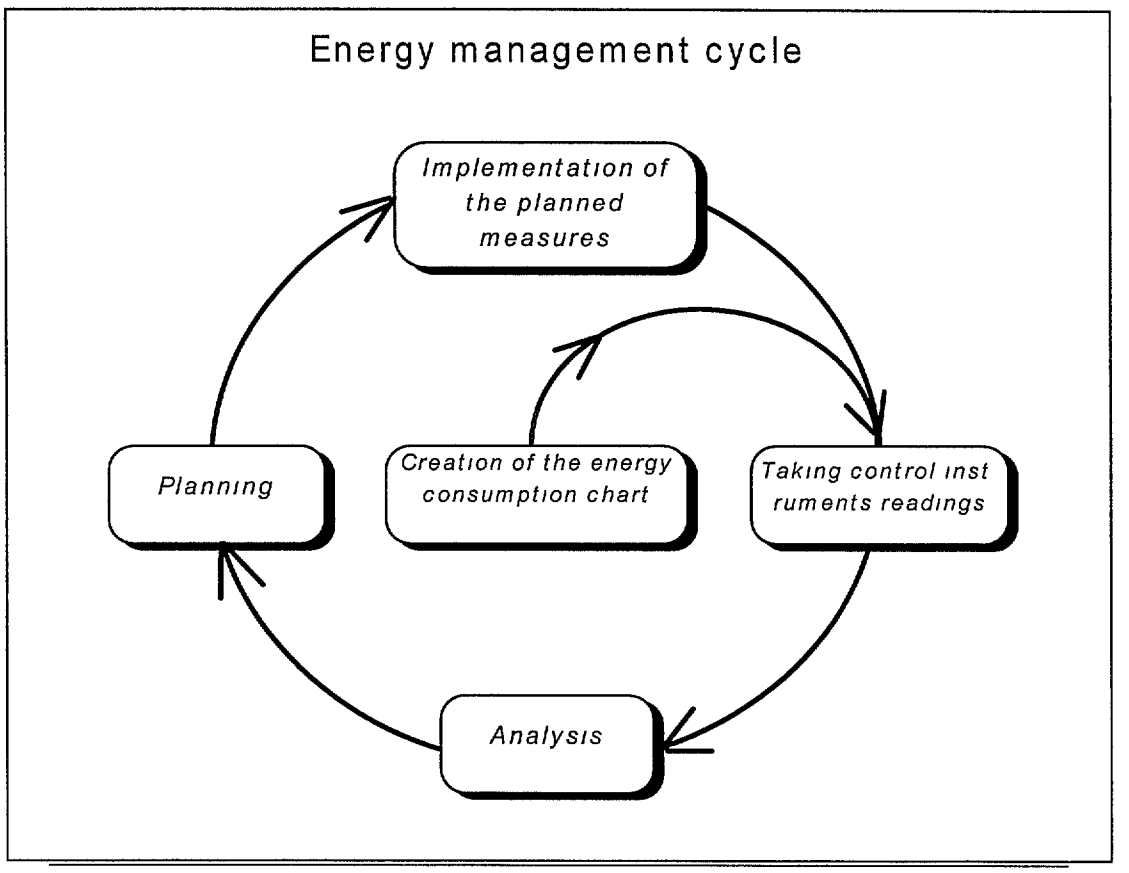


Fig 7 1 Energy Management Cycle

Introduction of the energy management would make it possible to obtain more detailed picture of energy consumption, which would provide a basis to compare consumption levels with those at the other enterprises for the purpose of thorough evaluation of the energy saving projects, planned for the introduction at this plant

Energy Management begins from the appointment of a corresponding employee (energy manager), who would bear responsibility for the introduction of energy management at the enterprise Following are the main duties of the energy manager

- Preparing facility's energy consumption chart (probably in collaboration with an outside consultant - energy auditor),
- Collecting fuel and energy consumption data, using measuring instrumentation,
- Preparing a plan for installation additional meters and measuring equipment,
- Collecting data on raw materials, energy consumption and production output,

- Development of a plan to use low-cost and no-cost energy saving measures,
- Carrying out basic calculations, related to the improvement of energy efficiency, both for overall plant and for individual production lines,
- Implementing new technologies on existing and new energy systems to improve energy efficiency of operation,
- Keeping himself informed on trends in the current energy policy and accompanying issues, (e g , new tax legislation, existing restrictions for energy consumption levels, subsidies, environmental aspects etc)

It is proposed to introduce an energy management system at the enterprise in full volume Implemenation of this proposal will provide an opportunity to reduce energy consumption by *3%*

To introduce energy management system the enterprise should elaborate and install a power metering system with interpretation of the power meters readings from all transformer sub-stations in a time range The existing commercial system of metering monitors only overall power consumption, while all internal consumers are checked sporadically

It is necessary to elaborate a metering system for all kind of energy, employing up-to-date computer devices, which will provide opportunities to assess the energy consumption dynamics in the process of production and to prepare recommendations concerning energy saving

Calculation of the annual energy saving

According to the 1997 records, the plants consumed for a year some *769,047* ths kW•h of power and *117,120* ths m^3 of fuel (natural gas) The world experience and practice confirm that after introduction of the energy management the energy consumption is usually reduced by *3%* The energy saving would make up

1) Power – $769{,}047 \times 0\ 03 = 23{,}071$ ths kW•h
2) Natural Gas – $117{,}120 \times 0\ 03 = 3{,}514$ ths m^3

Calculation of annual savings of energy expenses

At the price of $45 for **1,000** *kW•h* of power the savings will be

$23{,}071 \times 45 = \$1{,}038{,}195$

1 At the price of $83 for *1,000* m^3 of gas the savings will be

$3{,}514 \times 83 = \$291{,}662$

The total savings of energy expenses will make up

$$1{,}038{,}195 + 291{,}662 = \$1{,}329{,}857$$

Costs of setting-up the energy management department

Energy management department wages fund and incentive fund to stimulate production departments to save energy	*$60,000*
Introduction of the energy metering system at the plant (designing, mounting, adjustment)	*$1,000,000*
Purchase of necessary energy audit equipment	*$40,000*
Total costs	*$1,100,000*

Simple payback period

$$\$1{,}100{,}000 / \$1{,}329{,}857 = 0\ 83 \text{ year}$$

7 3 Upgrading the *OK*-1-324/*326Ts* roasting unit at the pelletizer plant

7 3 1 The technological unit description

The *OK-324* roasting unit was modified (by the "Uralmash" research institute) to replace the old roasting unit The rehabilitation of the pelletizer plant provides replacement of the three remaining out-dated units by the *OK-324*

The *OK-324* is a roasting unit of conveyor type, which was designed for thermal treatment and cooling of pellets of ore iron concentrates to attach them necessary physical and chemical properties in order to ensure meeting metallurgical requirements, as well as requirements to their transportation, handling, storage and blast furnace smelting

In a roasting unit iron ore pellets pass over a full cycle of strengthening thermal treatment, including preliminary heating, drying, reheating, roasting and cooling of pellets, resting on the moving grate bar The process employs filtration of heat carrier or cooling air, coming through the layer of pellets

Gas burners are installed in pre-combustion chamber at side walls of roasting area

- in Zone *I* - six burners (three at each side),
- in Zone *II* - eight burners (four at each side)

Burner device with a mixer is installed along the axis of face wall of the pre-combustion chamber (diameter *2* m, length *4* m), an open end of which rests on the cut of a side roasting chamber behind a layer of pellets At the near upper part of the pre-combustion chamber there was made a channel, to which the second stage air is supplied This air is heated up to *880*°C in the recuperation zone and in the roasting unit cooling zone

A jet of gas and air mixture injects hot air from the pre-combustion chamber, supplied through the upper channel of pre-combustion chamber

The fuel is burned in a pre-combustion chamber Combustion products fill the roasting zone chambers and are carried by ID fan down, through the layer of pellets, moved by the conveyor of roasting unit

Natural gas is used as a fuel The gas has the following characteristics

- content of the components of gas fuel, %

CH_4 – *94 926* to *95 920* C_3H_8 – *0 45* to *0 320* C_5H_{12} – *0 035* to *0 024*
C_2H_6 – *1 687* to *1 280* C_4H_{10} – *0 122* to *0 091* CO_2 – *0 020* to *0 045*
N_2 – *2 760* to *2 320*

- density of the natural gas – *0 752* to *0 745* kg/m³
- the lowest calorific value – *35,770* to *35,688* kJ/m³ (*8,543* to *8,524* kcal/nm³)

Table 7 1 Technical specification of the *OK-1-324/336 Ts* roasting unit

№	Name	Units	Quantity
1	Area of active process zones	m²	324
2	Work area (of induced and forced draft)	m²	336
3	Total length of work area	m	84
4	Work width of a unit	m	4
5	Rated output (finished pellets)	t/h	259 2
6	Zones area - preliminary heating - drying, Stage I - drying, Stage II - heating - roasting, Stage I - roasting , Stage II - recuperation - cooling, Stage I - cooling, Stage II - cooling, Stage II	m²	 12 48 18 24 36 48 12 48 24 65
7	Speed of firing trolleys	m/s	0 012 to 0 042
8	The largest thickness of raw pellets layer on the grate bar	mm	400
9	Thickness of the bottom bed layer	mm	100
10	Quantity of burners	piece	14
11	Flow rate of natural gas at 20 °C - Roasting Zone I - Roasting Zone II - total	m³/h	 2,100 2,730 4,830
12	Max rated temperature of heat carrier in the zones - preliminary heating - drying, Stage I - drying, Stage II - heating - roasting , Stage I - roasting, Stage II - recuperation - cooling, Stage I - cooling, Stage II - cooling, Stage III	°C	 350 80 350 600 to 800 1,000 to 1,200 1,300 900 1,020 to 910 780 to 600 440 to 120
13	Capacity of electric motor for trolleys drive	kW	22

7 3 2 Application of the gas-turbine, replacement of injector burners and heating of primary combustion air

Study results

The following parameters have been determined during tests

- composition of gas and air mixtures (O_2, CO, CO_2, NO_x, excess air) – by gas analyser *ENERAC - 2000*, produced by the *Energy Efficiency Systems, Inc* (USA),
- surface temperatures - by the *Heat Spy DHS-24X,* infrared themperature detector/indicator, produced by the *Wahl Instruments, Inc* (USA)

All measurements were carried out at operating unit

The following characteristics have been measured

1) composition of recycled gas, removed by ID fan *D1* out of the cooling Zone III and carried to the drying Zone I and heating zone (Measurement #4),

2) composition of recycled combustion products, removed by ID fan *D3* out of the roasting Zone II and carried to the preliminary heating and drying Zone II (Measurements #2, 6, 15, 17, 18),

3) composition of the gas, exhausted by the ID fan *D2* to the stack out of drying Zone II, heating and roasting Zones I (Measurements #5, 16),

4) composition of the gas, exhausted by the ID fan *D5* to the stack out of drying Zone I, (Measurements #1, 3, 7),

5) gas composition in drying Zones I, II, III (Measurements #8, 9, 10),

6) gas composition in the hood above heating and cooling Zones I, II, III (Measurements #11-14),

7) internal surface temperature of the lining in drying Zone II,

8) external surfaces temperature of roasting unit

Measurements have been carried out at the following ambient conditions

- barometric pressure – **100** to **101** kPa
- ambient temperature – *7* to *15°C*

Measurements, studies and interviews with the plant technicians enabled our audit team to arrive at the forllowing conclusions (concerning unsatisfactory operation of a new unit), namely

- non-correspondence of the process temperature to the rated one, established for pre-roasting zones of the unit, i e temperature of the air, supplied to drying Zone I – *150*°C (the required temperature is *330*°C), temperature of the air, supplied to drying Zone II – *120*°C (the required temperature is *350*°C),
- underheating in drying zones is compensated by excessive consumption of gas in roasting zones, but the temperature chart is not observed any way,
- presence of *CO* in gas and air mixtures, removed from roasting zones, indicates non-efficient combustion of gas by injector burners in pre-combustion chambers, gas after-burning in roasting zones, including at the surface of pellets (this is also confirmed by the fact, that internal lining temperature exceeds the temperature of gas and air mixture by *200* to *250*°C)

Proposal

Given the above mentioned drawbacks, revealed in the process of the *OK-324* roasting unit operation, we propose to carry out detailed study, designing and implementation of the following measures, aimed at improvement of the system

- to use gas-turbine unit (*GTU*) for additional heating of the gas and air mixtures to increase the process temperature in drying zones and in the zone of heating with simultaneous generation of power for the plant's own purposes,
- to replace injector burner with more efficient fish-tail burners (micro-diffusion-flame, flat-flame, disk-flame etc),
- to install contact air heater to ensure adequite temperature of the primary combustion air, supplied to the roasting zones

The above recommendations are aimed at the saving of energy, as well as at the improvement of technological process and reduction of faulty production (increase in the level of products quality) and, thus, reduction of the production costs

Basic calculations

Use of gas-turbine unit

The following technological cycle is proposed

1) Gas turbine unit generates some ***2,500*** to ***3,000*** kW of power to be used for the plant purposes
2) The effluent gas (with temperature of ***450*** to ***500***°C) from gas turbine goes to the distribution device, where it is mixed with the gas and air mixture from roasting Zone II and with air from the cooling Zone III, then it is carried to the drying zones and the heating zone The distribution device should guarantee the required technological temperatures for mixtures

The type and capacity of gas turbine should be finally determined after detailed energy audit and pre-designing study of all peculiarities of the technological process The calculation are based upon assumption, that the *GT-2500* gas turbine, produced by the *"Mashproject"* Works, will be used Its basic characteristics are the following

- electric power – ***2,500*** kW,
- heat capacity – ***4 5*** Gcal/hour,
- electric efficiency – ***27 2*** %,
- effluent gas temperature – ***470***°C

The volume of gas, used for the additional heating of air, is not taken into consideration, since the heat, produced in the process of combustion is transferred to the furnace to heat the raw materials, thus reducing gas consumption in the roasting zone

The cost of ***1*** kW of purchased power is ***$0 045***

The following is a calculation of the cost of power generated by the gas turbine

Calorific value of the gas

$$8{,}200 \text{ kcal/m}^3 = 35{,}333 \text{ kJ/m}^3 = 9\ 8 \text{ kW}\cdot\text{h/m}^3$$

The cost of – ***$0 083*** per ***1***m^3, so the cost of ***1*** kW of the generated power is

$$0\ 083 / 9\ 8 = \$0\ 0085$$

The saving will be

$$\$0\ 045 - \$0\ 0085 = \$0\ 0365$$

At the rated power of gas turbine unit (***2,500*** kW) an annual saving will be

$$2{,}500\ kW \quad \$0\ 0365 \text{ per kW}\cdot\text{h} \quad 8{,}760 \text{ h/year} = \$800{,}000 \text{ per year}$$

Replacement of injector burners with more efficient ones and supply of heated air (as primary air) for the process of combustion in roasting zones

Application of more efficient fish-tail burners (microdiffusion-flame, flat-flame, disk-flame etc) instead of injector burners will improve the quality of gas combustion and reduce the ratio of excessive primary air down to ***1 05***, that, in its turn, will provide a possibility to reduce the gas consumption by ***5*** to ***10***% Besides, these burners have a number of advantages, concerning adjustment, stability of the combustion process, uniformity of the temperature scheme, etc

When the primary air is heated up to *150* to *130*°C the gas consuming equipment saves correspondingly *5* to *10*% of gas Application of efficient burners will give an opportunity to supply preliminary heated air for the combustion process, while gas turbine will allow the primary air get heated by the air from cooling Zone III, through the contact heat exchanger

When calculating the savings we are based upon the rated gas consumption, since it is assumed that the temperature mode in drying and heating zones (with gas turbine application) is maintained, therefore there is no excessive consumption of gas in roasting zones

Rated gas consumption – *4,220* m³/h

Hours of operation in a year – *8,760* h/year

5% of gas saving correspond to

4,220 m³/h *0 05* *8,760* h/year = *1,850,000* nm³/year

At gas price $*83* for *1,000* m³, *5%* of gas saving correspond to $*150,000* a year

Both, burners replacement and supply of heated air will provide minimum *10%* of gas saving, which corresponds to $*300,000* a year

Maintenance of the temperature mode in all zones (thus reducing faulty products and emergency downtime) will save minimum $*500,000* a year

So, the total saving would be

$800,000 year^{1} + $*300,000* year^{1} + $*500,000* year^{1}= $*1,800,000* year^{1}

Implementation costs

Gas Turbine Unit	–	$*1,300,000*
Fish-tail burners *14* units) with a set of gas accessories and automatic control system	–	$*100,000*
Distribution device with automatic control and adjustment system	–	$*50,000*
Contact heat exchanger	–	$*150,000*
Design work	–	$*400,000*
Cost of mounting and putting in operation	–	$*300,000*
Overheads and Contingencies	–	$*300,000*
Total costs	–	$*2,600,000*

Simple payback period

Cost of putting in operation – $*2,600,000*

Annual saving – $*1,800,000* per year

Simple payback period is

$*2,600,000* / $*1,800,000* = *1 44* years

Conclusion The specified set of measures is economically sound It is recommended to use it at a new furnace, and to take into consideration when designing other furnaces

7 3 3 Enhancement of the electric drive systems for IE-324 roasting unit fan

7 3 3 1 Installation of a variable-speed drive to D1 fan

Proposal

For the purpose of efficient control of the operation of *D1* Fan it is recommended that a frequency converter to be installed instead of guiding devices The converter would regulate the frequency of rotation, therefore, the *D1* Fan capacity

Study results

At present, the output of roasting unit is ***60%*** of the design value That is why the required temperature is not observed in many of its zones That results in the fact that air and gas flows do not correspond to the design requirements either
D1 Fan capacity control is carried out by means of guiding device in a range from
176,000 m^3/hour to ***331,096*** m^3/hour The average capacity of *D1* Fan is ***70%*** of open guiding device, that reduces the capacity by ***20%***

If the existing system of *D1* Fan control (with guiding devices) were replaced with a new system with variable speed drive, up to ***20%*** of the power, consumed by the fan, would be saved

Initial data for calculation

- Electric motor capacity – ***3,150*** kW
- Power consumption (of *D1* Fan) – ***2,470,588*** kW • h/month
- Cost of ***1*** kW h of power – ***$0 045***

Savings, resulted from the installation of variable-speed drive

Up to ***20%*** of the electric power consumed by the fan would be saved, if the variable-speed drive were installed at *D1* Fan

The annual saving of power would be

$$2{,}470{,}588 \text{ kW} \cdot \text{h/month} \times 12 \text{ months/year} \times 0\ 2 = 5{,}929{,}411 \text{ kW h/year}$$

in terms of money it is

$$5{,}929{,}411 \text{ kW} \cdot \text{h/year} \times \$0\ 045 \text{ per kW} \cdot \text{h} = \$266{,}824 \text{ per year}$$

The cost of a high-voltage frequency converter for regulation of the rotation speed of *D1* Fan electric motor is ***$630,000***

Calculation of the ECO payback period

Payback period for this ECO is

$$\$630{,}000 \,/\, \$266{,}824 \text{ year}^{1} = 2\ 36 \text{ year}$$

Conclusion In terms of payback period this energy saving measure is a middle-term one, thus it is recommended for its implementation In addition, implementation of

this measure will enhance the level of reliability of the *OK-324* unit, through the elimination of dynamic impacts at the *D1* Fan start-up

7 3 3 2 Installation of a variable-speed drive at D2 Fan

Proposal

For the purpose of efficient control of the *D2* Fan it is recommended that a frequency converter will be installed

Study results

At present, *D2* Fan operates at a reduced capacity - ***281,097*** m^3/hour The rated capacity of *D2* Fan is ***377,998*** m^3/hour

Thus, the relative decrease in the *D2* Fan capacity, compared with the rated value, is

$$(347{,}998 - 281{,}097) / 347{,}998 = 0\ 192 = 19\ 2\%$$

If the existing system of Fan control, based upon guiding devices, were replaced with a new system with variable speed drive, up to *12 5%* of the power, consumed at present by the *D2* Fan, would be saved

Initial data for calculation

- Electric motor capacity – ***2,000*** kW
- Power consumption (of *D2* Fan) – ***1,568,627*** kW • h/month
- Cost of 1 kW/h of power – ***$0 045***

Savings, resulted from the installation of variable-speed drive

Up to **12 5%** of the power, consumed by the fan, would be saved if the variable-speed drive were installed at *D2* Fan

The annual saving of power would be

$$1{,}568{,}627 \text{ kW} \cdot \text{h/month} \times 12 \text{ months/year} \times 0\ 125 = 2{,}352{,}940 \text{ kW} \cdot \text{h/year}$$

in terms of money it is

$$\mathbf{2{,}352{,}940} \text{ kW} \cdot \text{h/year} \times \$\mathbf{0\ 045} \text{ per } 1 \text{ kW} \cdot \text{h} = \$\mathbf{105{,}882\ 3} \text{ per year}$$

The cost of a high-voltage frequency converter for regulation of the rotation speed of *D2* Fan electric motor is ***$400,000***

Calculation of the ECO payback period

Payback period for this ECO is

$$\$400{,}000 / \$105{,}882 \text{ per year} = 3\ 78 \text{ year}$$

Conclusion In terms of payback period this energy saving measure is a middle-term one, thus it is recommended to implement it In addition, implementation of this measure will enhance the level of reliability of the *OK-324* unit, through the elimination of dynamic impacts at the *D2* Fan start-up

7 3 3 3 Installation of a variable-speed drives at the D3 and D4 fans

Proposal

For the purpose of efficient control of the *D3* and *D4* Fans it is recommended that frequency converters will be installed

Study results

At present, the *D3* and *D4* Fans operates at the capacity reduced by ***20%*** to ***30%*** If the existing electric drive system were replaced with a smoothly regulated one, not less than ***17%*** of the power, consumed by the fans, would be saved

Initial data for calculation

- Electric motors capacity – ***1,250*** kW (each)
- Power consumption (of *D3*, *D4* Fans) – ***980,392*** kW • h/month (each)
- Cost of *1* kW/h of power – $***0 045***

Savings, resulted from the installation of variable-speed drive

17% of the power consumed by *D3* and *D4* Fans would be saved, if the variable-speed drives were installed on *D3* and *D4* Fans

The annual saving of power would be

$$980{,}392 \text{ kW} \cdot \text{h/month} \times 12 \text{ months/year} \times 0\ 17 = 2{,}000{,}000 \text{ kW} \cdot \text{h/year}$$

in terms of money it is

$$2{,}000{,}000 \text{ kW} \cdot \text{h/year} \times \$0\ 045 \text{ per } 1 \text{ kW} \cdot \text{h} = \$90{,}000 \text{ per year}$$

The cost of high-voltage frequency converter for regulation of rotation speed of *D3* and *D4* Fans electric motors is $***250,000*** per one

Calculation of the ECO payback period

Payback period for this ECO is

$$\$250{,}000 \,/\, \$90{,}000 \text{ year}^{1} = 2\ 78 \text{ year}$$

Conclusion In terms of payback period this energy saving measure is a middle-term one, thus it is recommended to implement it In addition, implementation of this measure will enhance the level of reliability of the *OK-324* unit, through the elimination of dynamic impacts at the *D3* and *D4* Fans start-up

7 4 Upgrading of the electric drive system for the plant of circulating water supply

Proposal

To install frequency converter at one of three pump units in the plant of circulating water supply

Study results

At present, the plant of circulating water supply is equipped with three pumps with driving synchronised motors, ***1,600*** kW each Two or three pumps are usually operating at a time Installation of a variable speed drive would provide a possibility to save ***250,000*** kW • h per month

Power saving

Installation of a variable speed drive would provide a possibility to save

$$250{,}000 \text{ kW} \cdot \text{h/month} \times 12 \text{ months/year} = 3{,}000{,}000 \text{ kW} \cdot \text{h/year}$$

in terms of money it is

$$3{,}000{,}000 \text{ kW} \cdot \text{h/year} \times \$0.045 \text{ per } 1 \text{ kW} \cdot \text{h} = \$135{,}000 \text{ per year}$$

The cost of a frequency converter required to control the motor of one of the pumps is $320,000

Payback period for the ECO is

$$\$320{,}000 / \$135{,}000 \text{ per year} = 2.37 \text{ years}$$

Conclusion In terms of payback period this energy saving measure is economically efficient, and it is recommended for its implementation

8 ENVIRONMENTAL IMPACT OF THE RECOMMENDATIONS

Implementation of energy conservation opportunities results in reduction of harmful exhausts into the atmosphere, due to decrease in fuel and power consumption

According to the Ministry of Energy of Ukraine in 1996 an average quantity of harmful exhausts for each *1,000* kW•h of the generated power was containing

CO – *0 5 kg,*

NO_x – *2 2 kg,*

SO_2 – *9 9 kg,*

Ash – *4 4 kg*

According to the data measured at the enterprise, burning of *1,000* m³ of natural gas entails exhaust of

CO (Carbon monoxide) – *7 5* kg,

NO_x (Oxides of nitrogen) – *80* kg

Implementation of the proposed energy conservation opportunities would reduce the electric power consumption by *38,353* thousand kW h, which is equivalent to the following reduction of harmful exhausts into the atmosphere

CO *38,353* thousand kW•h/year × *0 5* kg/thousand kW•h = *19,176 5* kg/year

NO_x *38,353* thousand kW•h/year × *2 2* kg/thousand kW•h = *84,376 6* kg/year

SO_2 *38,353* thousand kW•h/year × *9 9* kg/thousand kW•h = *379,694 7* kg/year

Ash *38,353* thousand kW•h/year × *4 4* kg/thousand kW•h = *168,753 2* kg/year

Implementation of the proposed energy conservation opportunities would reduce the consumption of natural gas by *7,214* thousand m³/year, which is equivalent to the following reduction of harmful exhausts into the atmosphere

CO *7,214* thousand m³/year × *7 5* kg/thousand m³ = *54,105* kg/year

NO_x *7,214* thousand m³/year × *80* kg/thousand m³= *577,120* kg/year

The overall reduction of harmful exhausts would be as follows

CO *973,281 5* kg/year

NO_x *661,496 6* kg/year

SO_2 *379,694 7* kg/year

Ash *168,753 2* kg/year

APPENDIX A ENERGY CONSERVATION OPPORTUNITIES (ECOs)

Table A 1

List of Energy Conservation Opportunities (ECOs)

# ECO	Measure	Power savings (ths kW•h)	Natural gas savings (ths m³)	Annual savings ($/year)	Cost of proposed measures ($)	Simple payback period (year)	Item refer
1	Introduction of the energy management	23,071	3,514	1,329,857	1,100,000	0 83	7 2
2	Application of the gas-turbine, replacement of injector burners and heating of primary combustion air	0	3,700	1,800,000	2,600,000	1 44	7 3 2
3	Up-grading of the electric drive system for the plant of circulating water supply	30,000	0	135,000	320,000	2 37	7 4
4	Installation of a variable-speed drive to the *D1* Fan at the pelletizer - plant	5,929	0	266,824	630,000	2 36	7 3 3 1
5	Installation of a variable-speed drive to the *D2* Fan at the pelletizer - plant	2,353	0	105,882	400,000	3 78	7 3 3 2
6	Installation of a variable-speed drive to the *D3* Fan at the pelletizer - plant	2,000	0	90,000	250,000	2 78	7 3 3 3
7	Installation of a variable-speed drive to the *D4* Fan at the pelletizer - plant	2,000	0	90,000	250,000	2 78	7 3 3 3
	Total	38,353	7,214	3,817,563	5,550,000	1 45	

APPENDIX B MESURED AND COLLECTED DATA

Following are the results of measurements, carried out at the *OK-324* roasting unit

1 Composition of gas mixtures

Measurement #1
Before gas cleaning *D5*
SERIAL # 11003246
ENERAC MODEL 2000
COMBUSTION TEST REKORD
FOR BURNS & ROE
TIME 11 51 50
DATE 03/17/97
FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	38 7	%
AMBIENT TEMPERATURE	10	°C
STACK TEMPERATURE	66	°C
OXYGEN	20 3	%
CARBON MONOXIDE	0	PPM
CARBON DIOXIDE	00 4	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 3 8	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	16	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #2
After *D3*, drying unit cap II
SERIAL # 11003246
ENERAC MODEL 2000
COMBUSTION TEST REKORD
FOR BURNS & ROE
TIME 12 02 41
DATE 03/17/97
FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	64 1	%
AMBIENT TEMPERATURE	11	°C
STACK TEMPERATURE	103	°C
OXYGEN	18 7	%
CARBON MONOXIDE	18	PPM
CARBON DIOXIDE	01 3	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 6 3	
EXCESS AIR	738	%
OXIDES of NITROGEN	303	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #3

After *D5*

SERIAL # 11003246

ENERAC MODEL 2000

COMBUSTION TEST REKORD

FOR BURNS & ROE

TIME 12 35 48

DATE 03/17/97

FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	73 2	%
AMBIENT TEMPERATURE	12	°C
STACK TEMPERATURE	32	°C
OXYGEN	20 2	%
CARBON MONOXIDE	0	PPM
CARBON DIOXIDE	00 5	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 4 9	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	24	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #4

After *D1*

SERIAL # 11003246

ENERAC MODEL 2000

COMBUSTION TEST REKORD

FOR BURNS & ROE

TIME 12 59 56

DATE 03/17/97

FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	00 0	%
AMBIENT TEMPERATURE	13	°C
STACK TEMPERATURE	160	°C
OXYGEN	21 0	%
CARBON MONOXIDE	0	PPM
CARBON DIOXIDE	00 1	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 2 9	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	0	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #5

After *D2*

SERIAL # 11003246

ENERAC MODEL 2000

COMBUSTION TEST REKORD

FOR BURNS & ROE

TIME 16 05 32

DATE 03/17/97

FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	00 0	%
AMBIENT TEMPERATURE	12	°C
STACK TEMPERATURE	75	°C
OXYGEN	19 7	%
CARBON MONOXIDE	63	PPM
CARBON DIOXIDE	00 8	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 3 7	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	432	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #6

After *D3*, pre-heating zone

SERIAL # 11003246

ENERAC MODEL 2000

COMBUSTION TEST REKORD

FOR BURNS & ROE

TIME 16 22 11

DATE 03/17/97

FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	00 0	%
AMBIENT TEMPERATURE	14	°C
STACK TEMPERATURE	20	°C
OXYGEN	20 7	%
CARBON MONOXIDE	0	PPM
CARBON DIOXIDE	0 2	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 4 7	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	4	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #7

Effluent gas from drying unit Cap I

SERIAL # 11003246

ENERAC MODEL 2000

COMBUSTION TEST REKORD

FOR BURNS & ROE

TIME 16 35 37

DATE 03/17/97

FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	00 0	%
AMBIENT TEMPERATURE	15	°C
STACK TEMPERATURE	51	°C
OXYGEN	20 8	%
CARBON MONOXIDE	0	PPM
CARBON DIOXIDE	00 1	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 7 2	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	0	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #8

Drying unit Cap II

SERIAL # 11003246

ENERAC MODEL 2000

COMBUSTION TEST REKORD

FOR BURNS & ROE

TIME 16 42 09

DATE 03/17/97

FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	34 8	%
AMBIENT TEMPERATURE	16	°C
STACK TEMPERATURE	119	°C
OXYGEN	18 9	%
CARBON MONOXIDE	1950	PPM
CARBON DIOXIDE	01 3	%
COMBUSTIBLE GASES	0 04	%
STACK DRAFT (INCHES H20)	– 6 1	
EXCESS AIR	701	%
OXIDES of NITROGEN	967	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #9

Heating zone, Pre-chamber #6

SERIAL # 11003246
ENERAC MODEL 2000
COMBUSTION TEST REKORD
FOR BURNS & ROE
TIME 16 52 23
DATE 03/17/97
FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	14 0	%
AMBIENT TEMPERATURE	14	°C
STACK TEMPERATURE	298	°C
OXYGEN	21 0	%
CARBON MONOXIDE	49	PPM
CARBON DIOXIDE	00 1	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 35 7	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	5	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #10

Heating zone, Pre-chamber #7

SERIAL # 11003246
ENERAC MODEL 2000
COMBUSTION TEST REKORD
FOR BURNS & ROE
TIME 16 57 14
DATE 03/17/97
FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	00 0	%
AMBIENT TEMPERATURE	13	°C
STACK TEMPERATURE	298	°C
OXYGEN	21 0	%
CARBON MONOXIDE	53	PPM
CARBON DIOXIDE	00 1	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 12 2	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	0	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #11
Cooling zone Cap III

SERIAL # 11003246
ENERAC MODEL 2000
COMBUSTION TEST REKORD
FOR BURNS & ROE
TIME 17 08 54
DATE 03/17/97
FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	00 0	%
AMBIENT TEMPERATURE	13	°C
STACK TEMPERATURE	320	°C
OXYGEN	21 0	%
CARBON MONOXIDE	2	PPM
CARBON DIOXIDE	00 1	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 3 1	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	0	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #12
Cooling zone Cap II

SERIAL # 11003246
ENERAC MODEL 2000
COMBUSTION TEST REKORD
FOR BURNS & ROE
TIME 17 15 22
DATE 03/17/97
FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	00 0	%
AMBIENT TEMPERATURE	13	°C
STACK TEMPERATURE	470	°C
OXYGEN	20 9	%
CARBON MONOXIDE	32	PPM
CARBON DIOXIDE	00 1	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 2 1	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	15	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #13

Cap between roasting Zone II and cooling Zone I

SERIAL # 11003246
ENERAC MODEL 2000
COMBUSTION TEST REKORD
FOR BURNS & ROE
TIME 17 19 57
DATE 03/17/97
FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	60 0	%
AMBIENT TEMPERATURE	13	°C
STACK TEMPERATURE	755	°C
OXYGEN	20 2	%
CARBON MONOXIDE	9	PPM
CARBON DIOXIDE	00 5	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 3 4	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	0	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #14

Heating zone cap

SERIAL # 11003246
ENERAC MODEL 2000
COMBUSTION TEST REKORD
FOR BURNS & ROE
TIME 17 24 32
DATE 03/17/97
FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	90 0	%
AMBIENT TEMPERATURE	14	°C
STACK TEMPERATURE	756	°C
OXYGEN	18 0	%
CARBON MONOXIDE	78	PPM
CARBON DIOXIDE	01 8	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 3 6	
EXCESS AIR	800	%
OXIDES of NITROGEN	15	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #15

Before gas cleaning *D3* (collector)

SERIAL # 11003246
ENERAC MODEL 2000
COMBUSTION TEST REKORD
FOR BURNS & ROE
TIME 17 37 06
DATE 03/17/97
FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	64 2	%
AMBIENT TEMPERATURE	14	°C
STACK TEMPERATURE	144	°C
OXYGEN	17 8	%
CARBON MONOXIDE	15	PPM
CARBON DIOXIDE	01 7	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 17 1	
EXCESS AIR	683	%
OXIDES of NITROGEN	287	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement №16

Before gas cleaning *D2* (collector)

SERIAL # 11003246
ENERAC MODEL 2000
COMBUSTION TEST REKORD
FOR BURNS & ROE
TIME 17 51 18
DATE 03/17/97
FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	50 0	%
AMBIENT TEMPERATURE	14	°C
STACK TEMPERATURE	99	°C
OXYGEN	19 6	%
CARBON MONOXIDE	72	PPM
CARBON DIOXIDE	00 8	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 18 3	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	600	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #17

After *D3*

SERIAL # 11003246

ENERAC MODEL 2000

COMBUSTION TEST REKORD

FOR BURNS & ROE

TIME 18 58 43

DATE 03/17/97

FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	57 0	%
AMBIENT TEMPERATURE	12	°C
STACK TEMPERATURE	123	°C
OXYGEN	18 8	%
CARBON MONOXIDE	0	PPM
CARBON DIOXIDE	01 3	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	+9 0	
EXCESS AIR	783	%
OXIDES of NITROGEN	818	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

Measurement #№18

After *D3*, after gas cleaning

SERIAL # 11003246

ENERAC MODEL 2000

COMBUSTION TEST REKORD

FOR BURNS & ROE

TIME 19 07 44

DATE 03/17/97

FUEL NATURAL GAS 21870 BTU/LB

COMBUSTION EFFICIENCY	59 7	%
AMBIENT TEMPERATURE	12	°C
STACK TEMPERATURE	117	°C
OXYGEN	18 6	%
CARBON MONOXIDE	0	PPM
CARBON DIOXIDE	01 3	%
COMBUSTIBLE GASES	0 00	%
STACK DRAFT (INCHES H20)	– 19 8	
EXCESS AIR	OVER	%
OXIDES of NITROGEN	824	PPM
SULFUR DIOXIDE	0	PPM
CARBON MONOXIDE ALARM	1990	PPM

MODE PPM OXY_REF = 3%

2 Surface Temperature

Temperature of the interior surface of lining in drying zone II	*550* to *570*°C
Temperature of the exterior surface of heat insulation	*35* to *45*°C

APPENDIX C CONVERSION FACTORS

CURRENCY EQUIVALENTS

1 hrn - a Ukrainian money unit
1 hrn = 0,5 x US $1 (the state on April 1998)

CONVERSION FACTORS

HEAT

1 cal = 4 187 J
1 kcal = 4 187 kJ = 3 968 Btu
1 Gcal = 4 187 10^3 MJ = 4 187 GCal
1 Btu = 1,055 J = 1 055 kJ = 1 055 10^{-3} MJ

POWER

1 W = 3 6 10^3 J = 3 6 kJ
1 kW = 3 6 10^3 kJ = 3 6 MJ = 860 kCal
1 MW = 3 6 10^3 MJ = 0 86 GCal
1 kcal = 1 163 10^{-3} kW
1 Gcal = 1163 kW = 1 163 MW
1 kW = 1 36 HP
1 kW = 1 34 hp

PRESSURE

1 kgf/cm^2 = 1 barg
1 barg = 101 325 kPa = 0 1 MPa
1 bar = 10^5 Pa = 100 kPa = 0 1 MPa

LENGTH UNITS

1 mm = 0 0394 in = 0 00328 ft
1 cm = 0 3937 in = 0 0328 ft
1 m = 39 37 in = 3 281 ft

WEIGHT UNITS

1 g = 2 2046 10^{-3} lb
1 kg = 2 2046 lb
1 t = 1000 kg = 2 2046 10^3 lb

AREA UNITS

1 cm^2 = 0 155 in^2 = 1 076 10^{-3} ft^2
1 m^2 = 1 55 10^3 in^2 = 10 76 ft^2

VOLUME UNITS

1 m^3 = 35 31 ft^3 = 1000 l

1 l = 35 31 10^{-3} ft^3
1 l = 0 264 gal (US)

HEAT CONTENT

1 kJ/kg = 0 43 Btu/lb
1 kJ/m^3 = 26 84 10^{-3} Btu/ft^3
1 MJ/m^3 = 26 84 Btu/ft^3
1 kcal/m^3 = 4 187 kJ/m^3 = 0 112 Btu/ft^3

TEMPERATURE

°C = 0 56 (°F – 32)

APPENDIX D ABBREVIATIONS

13

ABBREVIATIONS

ESCO	- energy servicing company
ECO	- energy conservation opportunity,
Fig	- figure,
hrn	- hryvnia,
tel	- telephone,
USAID	- United States Agency for International Development,
VAT	- value-added tax,

barg - atmosphere gauge
BTU - British thermal unit
°C - degrees Celcius
cm^2 - centimeter squares
°F - degrees Fahrenheit
g - gram
Gcal - gigacalorie
GJ - gigajoule
h - hour
kcal - kilocalorie
kg - kilogram
kgf - kilogram-force
kV - kilovolt
kV-A - kilovolt-amper
kW - kilowatt
kW h - kilowatt hour
Lm - lumen
m - meter
m^2 - meter squared
m^3 - meter cubed
min - minute
MJ - megajoule
mm H2O - millimeters of the water column
MW - megawatt
t - tonne
t/h - tonnes per hour
W - watt