ENERGY ASSESEMENT OF A GLASS FURNACE WITH BETA GLASS PLC-DELTA PLANT AS CASE STUDY

BY

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ABSTRACT

This paper describes the use of the first law of thermodynamics method of analysis (material and energy balance) in analyzing the performance of the Beta glass furnace. Another performance parameter used in analyzing the furnace was the specific energy consumption. After the initial tour of the furnace facilities, relevant data were collected for the period of June 2005 to May 2006. In addition to this and with the assistance of the personnel in the furnace department, detailed performance data were collected for the furnace on July 25th 2006. Using the data, the performance parameters of the furnace were calculated and the Sankey diagram drawn. The work showed that the specific energy consumption of the furnace was 5.78 GJ per ton of glass. This compares favourably with what is obtained in some present day furnaces with values of specific energy consumption ranging from 3.69 GJ- 6.28 GJ per ton of glass. However, there is still vast potential for improvement. The heat balance result highlights clearly the various heat losses in the furnace and the furnace efficiency. The efficiency of the furnace was calculated as 58.08%. A major source of heat loss was identified as that from the furnace stack. The sensible heat in the furnace stack could be recovered by using it to generate steam in a waste heat boiler to drive a turbine. It could also be recovered by using it to preheat one or a combination of the following: Charge (batch), combustion air and primary air for spraying in burners.

Key words: *Glass Furnace, Specific energy consumption. First law analysis, Material balance, Heat balance, Heat losses, Sankey diagram, Energy efficiency, Furnace efficiency.*

1.0 INTRODUCTION

The furnace by definition is a device for heating material (often known as the stock or charge) to a predetermined temperature and enthalpy and therefore it is a user of energy. The primary energy required for heating in furnaces are in the form of furnace oil, natural gas, LDO and electricity (Trinks, 1961).

Energy losses in any industrial heating system are inevitable. However, its economic and environmental impact cannot be taken lightly, thus explaining the growing need for industrial energy efficiency.

The level of energy efficiency a furnace can achieve is inversely proportional to the energy losess that occurs. The higher the energy losses, the lower the efficiency. Overall energy loss can result from losses due to designs that do not incorporate energy efficient specifications such as heat recovery options, operations that run on inefficient methods and poor or non- energy efficiency conscious maintenance programmes. Reducing these losses will substantially increase the system's efficiency but data is needed to identify the losses and subsequently suggest techno-economic solutions to minimize the losses (Hishamudin, 2001). This data can be acquired through an energy assessment.

The more efficient use of industrial process heat represents one of the main areas where industry and commerce can make long lasting effective savings of energy (Turner, 1993).

Periodic evaluation of a furnace's energy efficiency will pay big dividends through reduced energy usage. With significantly higher prices for natural gas, the primary choice of fuel in the glass industry, reducing energy usage will become increasingly important (Brian and Olin, 2003).

Energy Analysis

Energy analysis at the plant or process level normally focuses on two areas. Analysis through the operating facilities, system or cost centers of :

- Material flows
- Energy flows

Material-Energy Balance Method

Most industries are open systems involving mass and energy transfer across their system boundaries. There should be a balance of input and output of both material and energy flows across the plant or process based on the principle of conservation of matter and energy (Lawal , 2006)

The material- energy balance method is based on the first law of thermodynamics and it's corollaries. The method provides a comprehensive audit of energy input, utilization and output (Ughumiakpor , 2002; Ojo , 1995)

Heat Balance of Furnace

Heat balance table is made to numerically understand the present situation of heat loss and efficiency in furnace operation (UNIDO and MITI, 2003). Thus, preparation of heat balance is necessary for assessing energy conservation potential (Bureau of energy efficiency)

The total heat input is provided in the form of fuel or power. The desired output is the heat supplied for heating the material or process. Other heat outputs in the furnaces are undesirable heat losses.

The aims and objectives of this study are as follows:

- To determine the efficiency of the furnace.
- To determine the specific energy consumption of furnace.
- To prepare a material and heat balance of furnace.
- To construct material flow and energy flow diagrams.
- To construct Sankey diagram of furnace.
- To determine where the most significant energy saving potentials are possible.
- To make recommendation toward a more efficient process if necessary.
- To determine where there is need for research and development (R & D)

2.0 LITERATURE REVIEW

The largest energy consumer unit in the glass industry is the furnace. The glass furnace holds the largest opportunity for energy saving in the glass industry. For twelve years, from 1975 to 1986, specific energy consumption has reduced from 14.56

GJ/ton to 10.71 GJ/ton, which is about 26 %. According to recent report, some of the furnaces have reduced the specific energy consumption below 8.73 GJ/ton (UNIDO and MITI, 2003). Presently, depending on the market sector, a glass furnace heated by oxy- fuel burners may use from 3.69 GJ to 6.28 GJ to melt and refine a ton of glass(Brian and Olin, 2003).

The Department of Energy (DOE), Industrial Technology Program (ITP), provided funding for a team comprised of PPG Industries, Eclipse/ combustion Tec and the Diagnostic Instrumentation and Analysis Laboratory at Mississippi State University to develop and demonstrate a set of energy assessment protocol for oxy-fuel fired glass furnaces. The protocol was intended to identify potential opportunities for energy savings, based on a structured evaluation of the operating furnace, and then to confirm the effectiveness of any change made. The development of energy and mass balance for the furnace was a key feature of the protocol, as is identification of localized areas of the furnace where large heat losses occur. The initial application of the protocol was at the PPG Industries fiber glass plant in Shelby NC. The mass and energy balance result for 16th June 2003, showed a furnace efficiency of 46.3 % and the heat loss via the combustion gases leaving the furnace represent 21.3 % of the total heat input to the furnace. It is estimated that energy savings of at least 6 % could result if all of the recommendations arising from use of the protocol are implemented (Brian and Olin,2003).

3.0 DATA COLLECTION AND ANALYSIS

3.1 Furnace specific energy consumption.

The large amount of energy required in the furnace to melt the glass comes from two sources- electricity supplied through a boost electrode and natural gas.

Table 1 gives the furnace monthly boost electricity and natural gas consumption data collected for the period of June 2005- May 2006. Table 1 also includes the monthly melted tonnage for the specified period.

From the monthly fuel and electricity consumption in the furnace, the total annual energy consumption in the furnace was estimated as 300972.10 GJ. The annual melted tonnage was estimated as 52,040 tons of glass.

$$\text{Furnace specific energy consumption} = \frac{\text{Annual energy consumption}}{\text{Annual melted tonnage}}$$

$$= \frac{5117.10 + 295855}{52040}$$

$$= 5.78\ GJ/ton\ glass$$

3.2 Material- Energy balance of furnace

The basic idea is that, if a furnace is operating steadily, the mass flowing out of the furnace is equal to the mass flowing into the furnace. Similarly, the energy flowing out is equal to the energy flowing in. These balances are dependent on the assumption of steady operation, so that the accumulation of mass and energy inside the furnace can be neglected. It is understood however, that an operating industrial glass furnace does not operate under perfectly steady conditions. The glass pull may change and the batch feed may start and stop. In an energy assessment, the steady- state idealization is more accurate when applied to a long- term average of furnace operation, rather than to the instantaneous operation (Brian and Olin, 2003). Thus, daily averages of the glass pull rate, natural gas flow, and combustion air flow rate from the Beta glass furnace instrumentation were used to construct the furnace material - energy balance

Properties of Natural gas, Air and Combustion products

The natural gas entering the furnace was assumed to have the properties given in Table 2. The secondary air (combustion air) and ambient air infiltrating into the furnace were assumed to have the properties given in Table 3. The combustion products exiting the furnace via the exhaust port contain many chemical species. However, only the following combustion product species are considered in this calculation: Oxygen (O_2), Nitrogen (N_2), Carbon dioxide (CO_2), Water Vapour (H_2O) and Argon. The other species are present in very small quantities and so, may not contribute significantly to gross mass and energy balances for the furnace.

3.2.1 Mass balance

Data for the mass balance of the glass furnace collected on 24th July 2005 from the furnace instrument control room is presented in Table 4.

The actual calculation of the mass balance was done using the following control volume.

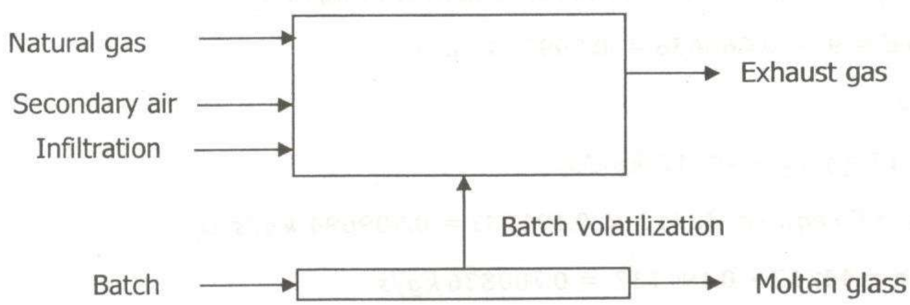

Fig 1 Mass balance control volume

The molar composition of Tables 2 and 3 was used to find the number of moles of carbon, oxygen, hydrogen, nitrogen, and argon atoms entering the furnace per second via natural gas and secondary air.

The glass pull rate from the furnace is known. It is known that for each kilogram (kg) of glass produced, 11.6/100 kg of CO_2 and 8/100 kg of H_2O are generated. Therefore the rate at which these gases are liberated can be easily calculated. These were also converted into molar flow rates of carbon, oxygen, hydrogen, nitrogen and argon.

The value of oxygen percentage by volume calculated initially when infiltration air was neglected gave 0.42%. This value is less than the measured value of 2.71%, thus an infiltration air flow rate was assumed to supply the balance. The assumed amount of infiltration air amount was varied to make the calculated O_2 concentration match the measured O_2 concentration as closely as possible. The amount of infiltration air that was finally used in the mass balance calculation represents 12% of the secondary air.

The four flows (natural gas, secondary air, batch volatilization gases and infiltration air) were then added together to give the total number of each elemental constituent flowing into the furnace per second. The result is presented in Table 5.

Combustion product flow

The following calculations give the composition and flow rates of the combustion products.

$$H_2 + 1/2\,O_2 \rightarrow H_2O$$

$$1\;kg\;H_2 + 8\;kg\;O_2 \rightarrow 9\;kg\;H_2O$$

$$0.066636\;kg/s\;H_2\;requires\;8 \times 0.066636 = 0.533088\,kg/s\,O_2$$

$$H_2O\;produced = 9 \times 0.066636 = 0.599724\;kg/s$$

$$C + O_2 \rightarrow CO_2$$

$$1\;kg\;C + 32/12\;kg\;O_2 \rightarrow 44/12\;kg\;CO_2$$

$$0.191137\;kg/s\;C\;requires\;32/12 \times 0.191137 = 0.509694\;kg/s\;O_2$$

$$CO_2 produced = 44/12 \times 0.191137 = 0.700836\,kg/s$$

$$Total\;O_2\;required = 0.533088 + 0.509694 = 1.042787\;kg/s$$

The products are entered in Table 6 and the analysis by volume obtained. The result of the mass balance is presented in Table 7.

3.2.2 Energy balance

The energy balance was performed in basically the same manner as the mass balance. Entering the furnace control volume are the following energy flows:

1. Secondary (combustion) air
2. Natural gas
3. Batch (if batch is preheated)
4. Infiltration air
5. Boost electricity

The following energy flows leave the furnace control volume:

1. Combustion gases from air/natural gas combustion via the exhaust port
2. Gases produced by batch volatilization via the exhaust port
3. Molten glass
4. Thermal (black body) radiation through openings (i.e peepholes)
5. Convection and radiation heat losses from the furnace walls
6. Uncounted losses. This comprise of heat storage loss, loss of furnace gases around charging door opening,

and thermal radiation through the exhaust port opening.

In carrying out the energy balance of the furnace, various temperature data were collected from the furnace instrument control room on 24th July 2005. The mass flow rates and temperatures of each stream that was used in preparing the energy balance are presented in Table 8.

(A) Fuel power Q_f

$$Q_f = m_f \times \Delta h \quad (Eastop\ and\ McConkey, 2003)$$

$$Q_f = 0.17663 \times 48504.32 \times 10^3 = 8567.32\ kW$$

(B) Secondary air duty Q_{as}

$$Q_{as} = m_{as}\, c_{pa}\, (T_{in} - 298)\ (Eastop\ and\ McConkey, 2003)$$

$$Q_{as} = 3.05776 \times 1.04296 \times 10^3 (1376 - 298) = 3437.87 kW$$

(C) Electrical power(Boost electrode), Q_{bc}

$$Boost\ electricity\ consumption = 997 kWh\ per\ day = 0.011539\ kWh\ per\ sec$$

$$1\ kWh = 3600\ kJ$$

$$Q_{bc} = 0.011539 \times 3600 = 41.54\ kW$$

(D) Exhaust gas heat loss, Q_{exh}

$$Q_{exh} = m_{prod}\, c_{pg}\, (T_{exh} - 298)$$

$$= 3.972802 \times 1.147 \times 10^3 \times 1242 = 5659.55\ kW$$

(E) Heat required to heat natural gas to reference temperature of 298 K, Q_g

$$Q_g = m_g\, c_p\, (298 - T_g) = 0.17663 \times 2150.45 \times (298 - 285.9) = 4.60\ kW$$

(F) Energy required to make glass, Q_{gl}

It is known that 6000 pounds (2722 kg) of batch produces 4743 pounds (2151 kg) of glass, 726 pounds (329 kg) of CO_2 and 509 pounds (231 kg) of H_2O. This process requires 2637 kJ per kg of glass at 2600^{0}F (1427^{0}C) (Brian and Olin, 2003).

In Beta glass plant, glass is produced at a temperature of 1400^{0}C to 1540^{0}C. Thus, the above energy requirement for glass production has been assumed.

$$Q_{gl} = 2637 \times m_{gl} = 2637 \times 1.896 = 4999.75\ kW$$

(G) Cooling water losses, Q_w

$$\text{For batch charger}, Q_{bc} = m_w\ c_{pw}\ \Delta t = 1.5 \times 4.182 \times (305 - 298) = 43.91\ kW$$

$$\text{Similarly, for throat}, Q_{th} = 1.5 \times 4.182 \times (301 - 298) = 18.82\ kW$$

$$\text{For boost electrode}, Q_{be} = 1.5 \times 4.182 \times (318 - 298) = 125.46\ kW$$

$$Q_w = 43.91 + 18.82 + 125.46 = 188.19\ kW$$

(H) Wall losses, Q_{wa}

An infra-red thermometer was used to measure the outer surface temperature of the various sections of the furnace in order to calculate the heat losses through these sections. The temperature measurements were taken at about three to five points in each location and the average was computed. The average outer surface temperature measurements for the various locations of the furnace taken on 24th July 2005, are shown in Table 9.

The quantity of heat, Q released from the wall of a heating furnace can be calculated using the following formular given by Trinks(1961):

$$Q = a \times (t_1 - t_2)^{5/4} + 488\text{E}\left[\frac{(t_1+273)^4}{100} - \frac{(t_2+273)^4}{100}\right] \quad (1)$$

Where:

Q = Quantity of heat released (kcal/ m^2h)

a = Factor regarding direction of the surface of natural convection

For crown, a = 2.8

For side wall, a = 2.8

For bottom (hearth), a =1.5

t_1 = Temperature of external wall surface of furnace (^{0}C)

t_2 = Temperature of air around the furnace (^{0}C)

E = Emissivity of external wall surface of furnace.

A summary of the calculations of heat loss for the different sections of the furnace is highlighted in Table 9.

Thus, $Q_p = 477.72\ kW\ (see\ Table\ 9)$

(I) Radiation heat loss through openings(peep holes), Q_p

The furnace melting tank has 6 peepholes on the breast wall which is about 465 mm thick. Each peep hole is about 110 mm high and 100 mm wide.

The heat loss from an opening Q_p (kcal/hr) can be calculated using the following formular (Trinks,1961):

$$Q_p = 4.88\ (T/100)^4\ \times a \times A \qquad (2)$$

Where:

T = Absolute temperature

a = Factor for total radiation

A = Area of opening (m^2)

Taking average temperature of furnace T = 1540^{0}C (1813 K)

$$\frac{D(Height)}{X(width)} = \frac{110}{465} = 0.24$$

The shape of the peep hole is square, therefore from the Graph in Appendix A2, the factor of radiation, a is estimated as 0,25

$$Area\ of\ opening = 0.1 \times 0.11 = 0.011\ m^2$$

$$Q_p = 6[4.88(1813/100)^4 \times 0.25 \times 0.011] = 8699.5\ kcal/hr = 10.12\ kW$$

The furnace energy balance result for 24th July, 2005 is presented in Table 10.

Efficiency of furnace

In beta glass, heat is introduced into the glass furnace in two ways; direct natural gas firing over the glass melting tank, and electric booster heat arcing between electrodes immersed in the glass melt. To recover some of the heat lost through the inefficiency of the direct firing process, the glass furnace uses checker brick regenerators to capture some of the waste heat. This heat is returned to the furnace by using it to preheat the secondary air for combustion.

From the energy balance result (Table 11),

$$Secondary\ air\ duty, = 3437.32\ kW$$

$$Required\ heat\ imput = 12046.73 + 3437.87 = 8608.86\ kW$$

$$Useful\ heat\ output = 4999.75\ kW$$

$$Furnace\ efficiency\ = \frac{Useful\ heat\ output}{Heat\ input}$$ (Trinks,1961)

$$= \frac{4999.75}{8608.86} \times 100 = 58.08\ \%$$

Furnace stack heat loss

The heat loss to the atmosphere through the furnace stack is given by:

$$Q_{stack} = m_{prod}\ c_{pg}\ \Delta t = 3.972802 \times 1.147 \times (711.5 - 298) = 1884.24\ kW$$

Fig 2 shows the Sankey diagram of the regenerative furnace.

4.0

RESULTS AND DISCUSSION

Producing glass is an energy intensive process. Efficient use of energy is necessary to ensure that glass manufacturers, Beta glass in particular, remain competitive.

The glass furnace is the largest energy consumer unit in the glass plant. Periodic evaluation of a furnace's efficiency can potentially pay big dividends through reduced energy usage. With significantly higher prices for natural gas, the primary fuel of choice in the glass industry, reducing energy use will become increasingly important. The procedure developed through this work can be extremely beneficial by providing a structured approach for assessment of the furnace efficiency and the identification of potential system improvements.

4.1 EFFICIENCY OF GLASS PRODUCTION

The furnace specific energy consumption was estimated as 5.78 GJ/ton glass. This is in agreement with what is obtainable in some present day furnaces, hence the furnace energy performance result is relatively good. However, some plants still use as low as 3.69 GJ to melt and refine a ton of glass. Thus there is still vast potential to further reduce the specific energy consumption of the furnace.

4.2 MATERIAL- HEAT BALANCEE OF FURNACE

The result for discussion regarding the furnace should have been made to cover a longer period (say one month). That is, the sample calculations should have been carried out for daily measurements taken for different days in the entire one month period and the average taken. This was however not possible for the following reasons:

1. No bank of data was available as at the time of the research.
2. The various measurements needed to be taken require a lot of personnel, time and effort and as a result could only be taken once a while.

Therefore, the result for discussion has been based on the measurement taken on 24th July 2005.

However, it was observed from data collected (Table 11) that the operating parameters of the furnace did not change much during the month of July and as such the material- energy balance of 24th July can be taken as average situation of the furnace.

The energy balance failed to close by approximately 5.87 % .This means that all losses have not been accounted for. These losses could be attributed to the radiation heat loss to the atmosphere through other openings like the exhaust ports and charging door opening, enthalpy loss due to gases produced by batch volatilization via exhaust port and heat loss to air infiltration into the furnace. However, the result obtained from the analysis showed that energy is conserved in accordance with the first law of thermodynamics.

From the energy balance result (Table 10), and the Sankey diagram (Fig 1) it can be clearly seen that the greatest amount of energy lost from the furnace unit, occurred through the combustion products leaving the furnace. The heat loss through the combustion gases leaving the furnace is 5659.55 kW. Out of this, about 3437.87 kW of heat is absorbed by the regenerator for preheating of combustion air. The remaining 2221.68 kW of heat representing about 26% of the heat input into the furnace, is lost through the stack and herein lies a major opportunity to further increase the furnace efficiency.

The sensible heat in the stack can be generally recovered by the following methods:

- Charge (batch) preheating
- Preheating of primary air for spraying in burners
- Utilizing waste heat to generate steam or hot water by a waste heat boiler
- Preheating of incoming secondary air through a gas- to-gas heat exchanger (recuperator)

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

A study of the Beta glass furnace was carried out to evaluate the efficiency of energy use and to identify potential system improvements. The specific energy consumption of the furnace was estimated as 5.78 GJ per ton of glass and the furnace thermal efficiency was estimated as 58.08 %.These results are relatively satisfactory but there is still room for improvement.

The first law of thermodynamics analysis of the furnace reveals that the greatest energy loss occur through the furnace exhaust gases and this represents the greatest opportunity to further increase the furnace efficiency.

The energy assessment procedure developed under this work is specific to the glass industry. However, the principles-particularly the use of heat and material balance- are general and can be easily adapted to other energy intensive industries.

5.2 RECOMMENDATIONS

- Further work should be carried out to estimate quantitatively the amountt of electricity that could be generated through the furnace stack waste heat.
- Further work should be carried out to determine the average amount of excess air used in the furnace because the amount of heat lost in the flue gases depends upon the amount of excess air. The optimization of combustion air is one of the most attractive and economical measure for energy conservation.
- Subsequent data for the material-heat balance should be taken to cover a longer period of time, say one (1) month to give a better average of the state of the furnace.

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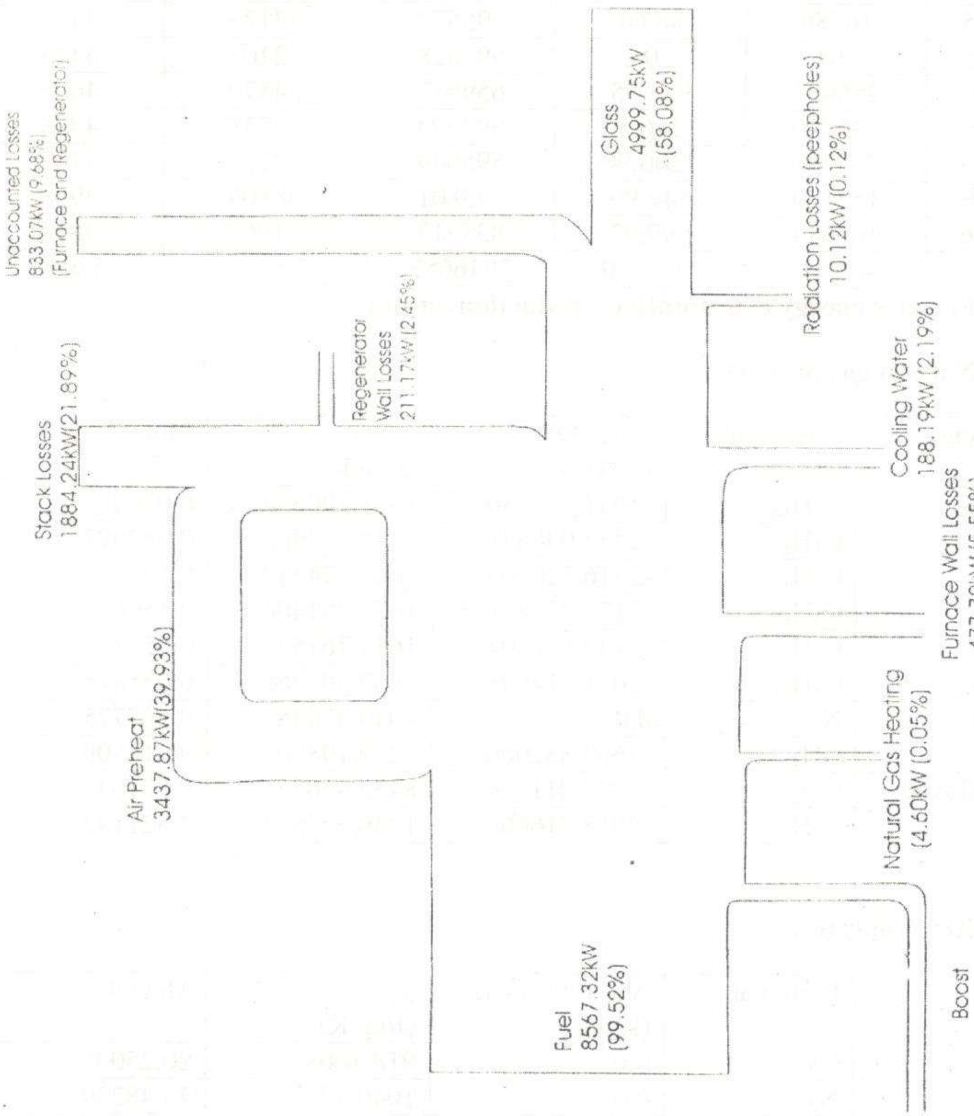


Fig. 1 . Sankey Diagram of Regenerative Furnace

Month	Boost electricity		Gas		Melted ton
	KWh	GJ	m^3	GJ	
Jun.-05	27012	97.24	603534	22470	38271
Jul.-05	26967	97.08	665681	24783	4946
Aug.-05	30521	109.88	682056	25393	4941
Sept.-05	30426	109.53	661022	24610	4609
Oct.-05	33186	119.47	683973	25464	4935
Nov.-05	16288	58.64	595574	22173	3482
Dec.-05	0	0	593628	22101	3415
Jan.-05	256653	923.95	659957	24570	4605
Feb.-06	346250	1246.50	597309	22238	4398
Mar.-06	335250	1206.90	595609	22175	4102
Apr.-06	152220	547.99	773801	28809	3968
May.-06	166644	599.92	834513	31069	4812
Total	1421417	5117.10	7946657	295855	52040

Table 1 Furnace energy consumption/production output

Table 2 Natural gas properties

Species	Formular	Δh_{fo} (298.15 K) (kJ/kg)	c_p (J/kg.K)	Mole %
n- Hexane	C_6H_{14}	-1941.787950	1661.890587	0.070083
Propane	C_3H_8	-2357.036398	1670.437963	0.682992
i-Butane	C_4H_{10}	-2316.320403	1667.174312	0.143467
n-Butane	C_4H_{10}	-2172.225821	1677.981406	0.150675
i-Pentane	C_5H_{12}	-2142.852304	1647.767522	0.053833
n-pentane	C_5H_{12}	-2031.414698	1667.501265	0.035875
Nitrogen	N_2	0.0	1040.57045	0.305775
Methane	CH_4	-4669.832066	2229.198762	95.14509
Carbon dioxide	CO_2	-8949.011836	843.9950557	0.891042
Ethane	C_2H_6	-2818.716666	1746.378804	2.521192

Table 3 Air Properties

Species	Formular	Δh_{fo} (298.15 K) (kJ/kg)	c_p (J/kg.K)	Mole %
Oxygen	O_2	0.0	918.1668	20.25005
Nitrogen	N_2	0.0	1040.57	75.48239
Argon	Ar	0.0	520.7775	0.902881
Carbon dioxide	CO_2	-8949.011836	843.995056	0.030354
Water vapour	H_2O	-13434.6	1865.399	3.331807

Parameter	
Date	24th July, 2005
Gas consumption	20046 Nm^3 per day (0.17663 kg/s)
Secondary air consumption	207005 Nm^3 per day (3.05776 kg/s)
Infiltration air consumption	41400 Nm^3 per day (0.366931 kg/s)
Boost electricity consumption	997 kWh
Glass pull rate	163.8 tons
Furnace average pressure	0.8896 bar
Oxygen percentage by volume, measured by O_2 analyzer	2.71 %

Table 4 Operating data list for furnace mass balance

Table 5 Estimation of total mass flow entering into furnace

Constituent	V (kmol/s)	M (kg/kmol)	ṁ (kg/s)
Carbon (C)	0.015928	12	0.191137
Hydrogen (H)	0.066636	1	0.066636
Oxygen (O)	0.071195	16	1.139115
Nitrogen (N)	0.180912	14	2.532762
Argon (Ar)	0.001082	39.9	0.0431523
Total	0.335752		3.972802

Table 6 Wet and dry volumetric analysis of the products of combustion

Product	ṁ (kg/s)	$\dot{m}_i/m$ (%)	M_i (kg/kmol)	$n_i = \dot{m}_i/M_i$ (kmol)	Wet n_i/n(%)	Dry n_i/n(%)
CO_2	0.700836	17.64	44	0.015281	10.67	12.91
H_2O	0.599724	15.10	18	0.0333183	23.27	-
N_2	2.532762	63.75	28	0.090456	63.19	82.36
O_2	0.096328	2.42	32	0.003010	2.10	2.74
Ar	0.043152	1.09	39.9	0.001088	0.76	0.99
Total	3.972802	100.00		0.143153 (wet)	100.00	100.00
				0.109835 (wet)		

Table 7 Mass balance result for July, 2005

Predicted Exhaust Gas Composition (Molar,Dry)		
Species	Predicted mole fraction (dry basis)	Measured mole fraction (dry basis)
Carbon dioxide	0.1391	Not measured
Oxygen	0.0274	0.0271
Nitrogen	0.08236	Not measured
Argon	0.0099	Not measured

Table 8 Data list for furnace energy balance calculation

Date of measurements	24th July 2005
Temperature of combustion products leaving furnace	1267^{0}C
Temperature of secondary air entering into furnace	1103^{0}C
Temperature of glass leaving furnace	1093^{0}C
Temperature of natural gas entering furnace	12.95^{0}C
Temperature of cooling water leaving boost electrode, batch charger and furnace throat	45^{0}C, 32^{0}C, 28^{0}C
Temperature of surrounding air	25^{0}C
Temperature of stack	438.5^{0}C
Mass flow rate of natural gas fuel, m_f	0.176663 kg/s
Mass flow rate of combustion products, m_{prod}	3.972802 kg/s
Mass flow rate of secondary air, m_{as}	3.05776 kg/s
Mass flow rate of glass, m_{gl}	1.896 kg/s
Mass flow rate of CO_2 gas, m_{CO2}	0.21992 kg/s
Mass flow rate of H_2O, m_{H2O}	0.15167 kg/s
Specific heat of air , c_{pa}	1.04296 kJ/kgK
Specific heat of combustion products, c_{pg}	1.147 kJ/kgK
Specific heat of natural gas, c_{pf}	2.15045 kJ/kgK
Specific heat of glass	0.8400 kJ/kgK
Specific heat of water, c_{pw}	4.182 kJ/kgK
Enthalpy of combustion of natural gas fuel, Δh	48504.32 kJ/kg fuel

Table 9 Estimation of furnace wall losses

Location	Area (m^2)	Outer temp (^{0}C)	Heat flux (kW/m^2)	Heat loss (kW)
Crown	53.64	1977	3.88496	208.39
Back wall	1.42	152	2.21356	3.14
Front wall	12.52	54	0.33320	4.17
Breast wall	18.9	92	0.93805	17.73
Breast wall	18.9	87	0.84949	16.05
Basin side wall	12.6	92	0.93805	11.82
Basin side wall	12.6	116	1.40041	17.65
Basin end wall (back)	8.34	72	0.59991	5.00
Basin end wall (front)	4.77	132	1.74360	8.31
Basin bottom	53.64	173	2.33845	147.97
Port wall	13.20	144	2.01998	26.67
Throat wall	3.20	81	0.74675	2.39
Total				477.72

Table 10 Furnace energy balance result for 24th July, 2005

ENERGY IN			ENERGY OUT		
	Kw	%		kW	%
Fuel	8567.32	71.12	Furnace exhaust gases	56559.55	46.98
Secondary air	3437.87	28.54	Energy used to make glass	4999.75	41.50
Boost electricity	41.54	0.34	Natural gas energy sink	4.60	0.04
			Wall losses	477.72	3.97
			Batch charger cooling water	43.91	0.36
			Throat cooling water	18.82	0.16
			Electrode cooling water	125.46	1.04
			Radiation loss through peep holes	10.12	0.08
			Energy unaccounted for	706.80	5.87
Total	12046.73	100.00		12046.73	100.00

Table 11 Furnace operating data for July 2005

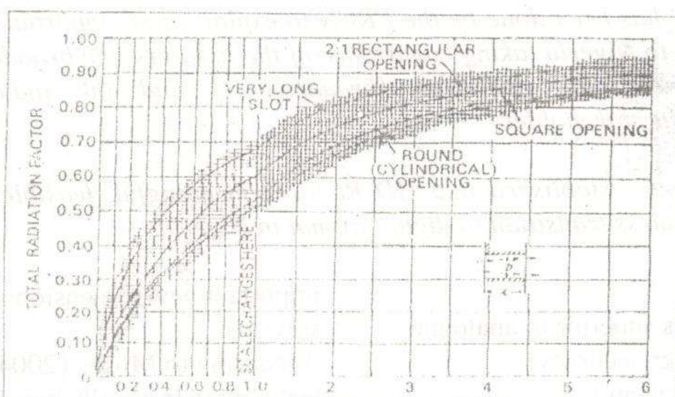
Days	Pull(ton)	Gas(Nm^3)	Boost (kWh)	Crown Temp(^0C)	Bottom Temp(^0C)	Energy Consumption GJ/ton
01	161.8	19322	815	1540	1213	4.46
02	163.0	19679	811	1540	1212	4.51
03	165.2	19721	840	1540	1212	4.47
04	165.2	19630	798	1540	1209	4.44
05	165.1	20251	894	1541	1210	4.59
06	165.6	20127	863	1540	1201	4.54
07	157.8	19706	967	1540	1204	4.67
08	161.8	19955	834	1540	1208	4.61
09	161.8	19675	874	1540	1201	4.55
10	162.0	19670	930	1540	1205	4.54
11	162.0	19269	936	1540	1208	4.45
12	162.4	19588	776	1540	1205	4.55
13	164.7	20038	785	1545	1203	4.55
14	167.1	19998	983	1545	1212	4.48
15	155.4	19450	867	1542	1214	4.68
16	149.3	19250	610	1540	1225	4.82
17	163.7	19624	976	1540	1198	4.48
18	156.1	19770	926	1540	1201	4.74
19	159.8	19587	791	1540	1199	4.54
20	161.9	19789	892	1540	1197	4.57
21	162.3	20232	848	1540	1190	4.66
22	162.0	20100	985	1540	1198	4.64
23	162.0	19975	893	1541	1187	4.61
24	163.8	20046	997	1540	1187	4.58
25	130.0	19031	923	1540	1212	4.48
26	132.2	17420	621	1535	1133	4.92
27	143.8	18128	645	1538	1116	4.71
28	165.3	20156	1000	1540	1208	4.56
29	165.7	19802	979	1541	1208	4.58
30	161.7	19802	979	1541	1208	4.58
31	163.4	19889	908	1541	1237	4.55

APPENDIX A.1

ENERGY CONVERSION FACTORS

UNIT	MULTIPLY BY	TO OBTAIN
Kilowatt-hour	3.6×10^{6}	Joules
	860	Kcal
British thermal unit	1055	Joules
	0.252	Kcal
Therm(100,000 Btu)	29.3	kilowatt hour
	1.055×10^{8}	Joules
	25200	Kcal
Calorie	4.184	Joules
Kilocalorie	4184	Joules
Electron-volt	1.6202×10^{-19}	Joules
Horse power	746	Watts

APPENDIX A.2



Graph for estimation of factor of total Radiation