

**THE MANAGEMENT AND ENERGY AUDIT OF SUNGLASS INDUSTRY
LIMITED KADUNA, NIGERIA
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ABSTRACT

This research was aimed at analyzing energy utilization in sunglass industry furnace. Data was collected from various units that constitute the furnace operation. Useful results were obtained from the analysis of the data collected. The results revealed that total energy produced was 52.642MW, energy consumed was 22.4MW. This indicated a loss of 30.242MW and furnace efficiency of 42.56%. The number of factors: flue gas losses, moisture present in fuel and evaporation of water due to presence of hydrogen. solutions were suggested which included further pre-heating of combustion air, pre-heating of raw material and reduction of overall heat transfer coefficient

INTRODUCTION

All heat treatment processes consist of three steps: generation, holding time (during which the temperature is kept constant) and cooling. The temperature kept during the holding time is usually very high, sometimes up to 1500°C, and the holding time can be up to several hours.

This taken into account, it is obvious that a large amount of energy is needed for the processes and this reflects in a large energy cost.

Driven by today's increasing energy prices and implemented energy policies, energy efficiency measures have become a top priority for large energy consuming companies. The idea of this project is to study energy utilization especially with regard to an industrial furnace in sunglass limited Kaduna state Nigeria. Based on the study, recommendations will be made on how to improve the energy utilization as well as improving the efficiency of the furnace. The main form of energy [fuel] used is Low Pour Fuel Oil [L.P.F.O] and automotive gasoline oil [A.G.O] i.e. diesel oil .Sunglass limited furnace oil consumption from **2004 to 2013** was **42,508,800** kl. The furnace consumed 100% of the oil [L.P.F.O.] used in the industry.

BACKGROUND OF THE STUDY

Glass melting furnaces are energized by fossil oil or electricity. High energy cost, tight environmental regulations and severe competition amongst glass manufacturers have resulted to the emergence of several solutions to reduce the fuel consumption of these furnaces. In spite of the current advancement in energy reduction, there is still a long way to achieve the ultimate goals of glass production: enhancing thermal efficiency, minimizing environmental impact, and maintaining glass quality. The problem is more severe for existing furnaces operating in poor thermal conditions around the world. A lot of research has been carried out to improve of glass melting furnaces. Some works have employed simulation approaches to analyze the effect of different factors on heat consumptions in glass furnaces. Other works utilize the following innovative methods to improve the thermal performance of glass furnaces. The methods range from applying new burners and heat recovery systems for pre heating the

combustion air and raw material, to considering new geometrics of combustion space and its elements.

METHODOLOGY

The data used in the research is from the detailed information of energy utilization in the furnace operation. Data for fuel/energy consumption was collected for a period of ten years.

The process of manufacturing quality glass comprise of six basic steps.

- i) material selection
- ii) Batch operation i.e weighing and mixing raw materials
- iii) Melting and refining Raw
- iv) Conditioning
- v) Forming
- vi) Post- processing I. e annealing, tempering or coating.

The raw materials for glass production are as follows; silica sand, limestone, dolomite, feldspar, sodium sulphate, selenium, charcoal, iron chromate, carborn90 and cullet.

The glass composition determines the physical and chemical properties of the glass container. For melting and refining purposes, sunglass uses a continuously operated tank furnace commonly use for the melting of glass. The furnace [tank] consists of a batch charging area [dog house], attached to a refractory basin, covered by a refractory super structure [crown].

The common heating methods are combustion heating[oxy-fuel, air fuel burners].To keep the glass level constant, the mixture of batch and cullet is continuously charged into the glass melting furnace to compensate for the glass withdrawn.

The process of refining and melting takes place in the melting chamber. During this process the batch of molten glass is freed of bubbles, homogenized, and heat condition before the glass is introduced into the fore hearth.

INDUSTRIAL GLASS FURNACE

Furnace is by definition a device for heating materials and therefore a user of energy. Heating furnaces can be divided into batch-type (Job at stationary position) and continuous type (large volume of work output at regular intervals). The types of batch furnace include box, bogie, cover, etc. For mass production, continuous furnaces are used in general. The types of continuous furnaces include pusher-type furnace, walking hearth-type furnace, rotary hearth and walking beam-type furnace.

The primary energy required for reheating / heat treatment (say annealing) furnaces are in the form of Furnace oil, LSHS, LDO or electricity

The various losses that occur in the fuel fired furnace are listed below.

- I. Heat lost through exhaust gases either as sensible heat or as incomplete combustion
- II. Heat loss through furnace walls and hearth
- III. Heat loss to the surroundings by radiation and convection from the outer surface of the walls
- IV. Heat loss through gases leaking through cracks, openings and doors.

Energy Consumption

Energy costs are significant in the glass industry and account for 15% of the industry costs. (GMIC, Glass Manufacturing Industry Council,2002). In the glass industry, energy is consumed in the form of fuel and electricity. A critical look at the energy (fuel) consumption for the past ten years in sunglass limited clearly indicates that there is increase in consumption rate each year, all things being equal.

RESEARCH METHODOLOGY

DATA COLLECTION

DATA ON FURNACE

The data used in this research work was collected from the industry furnace Original Equipment Manufacturer (OEM) and the following were the data obtained

Flue gas temperature – 1120°C

Stack temperature – 420°C

Consumption of fuel / hour – 492 kJ/hr

Temperature of raw material – 300K

The temperature of the ambient air- 40°C

The temperature of preheated air – 1373°C

Specific gravity of fuel – 0.92

Calorific value of fuel- 418680kJ/kg

Capacity of furnace tons / day -100 tons/day

Fuel flow rate – 1880m²/h

Gross heat of combustion of fuel oil- 24010417kcal/kg

DATA ON LOW POUR FUEL OIL (LPFO) CONSUMPTION

TABLE 3.1: LOW POUR FUEL OIL (LPFO) CONSUMPTION FROM 2004-2013

YEAR	MONTH	AVERAGE CONSUMPTION IN KI/yr	FUEL CONSUMPTION IN KL/YEAR
2004	JAN – DEC	420	3,628,800
2005	JAN – DEC	440	3,801,600
2006	JAN – DEC	430	3,715,200
2007	JAN – DEC	460	3,974,400
2008	JAN – DEC	450	3,888,000
2009	JAN – DEC	460	3,974,400
2010	JAN – DEC	540	4,665,600
2011	JAN – DEC	570	4,924,800
2012	JAN – DEC	580	5,011,200
2013	JAN – DEC	570	4,924,800
TOTAL		,9204	42,508,800

DATA ON DIESEL OIL CONSUMPTION

TABLE 3.2: DIESEL OIL CONSUMPTION FROM 2004-2013

Year	Month	CONSUMPTION IN KILOLITRES			
		Day	Week	Month	Year
2004	JAN-DEC	5	35	150	1800
2005	-	6	42	180	2160
2006	-	5	35	150	1800
2007	-	5	35	150	1800
2008	-	7	49	210	2520
2009	-	5	35	150	1800
2010	-	4	28	120	1440
2011	-	5	35	150	1800
2012	-	5	35	150	1800
2013	-	6	42	180	2160

HEAT BALANCE OF A FURNACE

Heat balance helps us to numerically understand the present heat loss and efficiency and improve the furnace operation using these data. Thus, preparation of heat balance is a pre-requirement for assessing energy conservation potential.

PERFORMANCE TERMS AND DEFINITIONS

$$1. \text{ Furnace Efficiency, } \eta = \frac{\text{HEAT OUTPUT}}{\text{HEAT INPUT}} \times 100$$

$$= \frac{\text{heat in stock(material)(kCals)}}{\text{heat in fuel/electricity(kCals)}} \times 100$$

$$2. \text{ Specific Energy Consumption} = \frac{\text{Quantity of energy or fuel consumed}}{\text{Quantity of material processed}}$$

DIRECT METHOD TESTING

The efficiency of the furnace can be computed by measuring the amount of fuel consumed per unit weight of material produced from the furnace

$$\text{Thermal efficiency of the furnace} = \frac{\text{Heat in the stock}}{\text{Heat in the fuel consumed}}$$

The quantity of heat to be imparted (Q) to the stock can be found from the formula

$$Q = m \times C_p(t_2 - t_1)$$

Where

Q = Quantity of heat in Kilojoule

m = Weight of the material in kilogram

C_p = Mean specific heat, kJ/Kg°C

t₂ = Final temperature desired, °C

t₁ = Initial temperature of the charge before it enters the furnace, °C

Measurement Parameters

The following measurements are to be made for doing the energy balance in oil fired reheating furnaces (e.g. Heating Furnace)

- i) Weight of stock / Number of billets heated
- ii) Temperature of furnace walls, roof etc
- iii) Flue gas temperature
- iv) Flue gas analysis
- v) Fuel Oil consumption

Instruments like infrared thermometer, fuel consumption monitor, surface thermocouple and other measuring devices are required to measure the above parameters. Reference manual should be referred for data like specific heat, humidity etc.

ENERGY BALANCE EQUATIONS OF FURNACE

The enthalpies of fresh air, fuel and raw material, while its outlets are glass melt heat losses through combustion space and glass tank refractory and stack flue. The energy balance equations of the control volume as well as regenerator and raw material pre-heater,

$$Q_{fuel} + Q_{fresh\ air} = Q_{melting} + Q_{glass\ tank\ loss} + Q_{combustion\ space\ loss} + Q_{Stack\ loss} \dots\dots\dots 1$$

The control volume of a glass melting plant is shown in Fig. 1. The control volume's inlets are

$$Q_{flue} + Q_{fresh\ air} = Q_{preheated} + Q_{regenerator\ exit} \dots\dots\dots 2$$

$$Q_{regenerator\ exit} = Q_{stack\ loss} + Q_{preheated\ raw} \dots\dots\dots 3$$

Therefore the energy balance equation of furnace can be represented in the form of Eq. (5).

$$Q_{fuel} + Q_{preheater} - Q_{flue} = Q_{melting} + Q_{glass\ tank\ loss} + Q_{combustion\ space\ loss} - Q_{preheated\ raw\ material} \dots\dots\dots 4$$

$$Q_{fuel} + Q_{preheater} - Q_{flue} \times u_{combustion} = Q_{melting} + Q_{glass\ tank\ loss} - Q_{preheated\ raw\ material} \dots\dots\dots 5$$

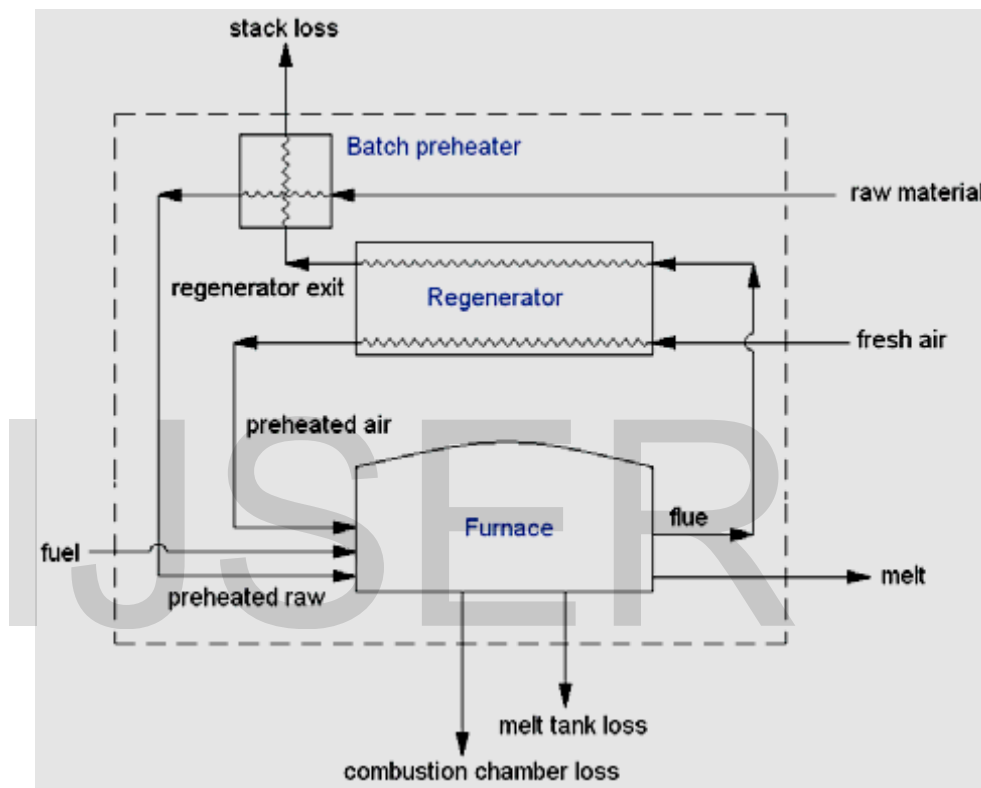


Figure 3.1:. The control volume of a glass melting plant.

Table3.3: PARAMETERS OBTAINED FROM SUNGLASS INDUSTRY INVOLVED IN ENERGY BALANCE EQUATION OF FURNACE

Group.	Parameter	Value
Combustion	Fuel flow rate	1880 m ³ /h
	excess air ratio	20%
	N ₂ /O ₂	⁷⁹ / ₂₁ =3.76

	Temp. preheated air	1373k
	Temp. of flue gas	1120k
<i>fuel flow rate</i> measured	Mass of raw materials	$100^{ton}/day$
	Temp preheated raw material	300k
	Cullet %	60 %
Wall losses	μ tank	$5^w/m^2k$
	Glass tank loss	1.62 mw
	μ chamber	$10^w/m^2k$
	Combustion space	4.64 mw

Table 3.4 CONSUMPTION IN EACH UNIT

Component	Consumption in MW
Glass melting	4.4
Regenerator	7.4
Glass tank loss	4.6
Stack flue loss	1.6
Combustion	4.4
Total	22.4

RESULTS AND DISCUSSIONS

ANALYSIS OF DATA COLLECTED

An oil-fired reheating furnace in sunglass limited has an operating temperature of around 1500°C . Average fuel consumption is 492 liters/hour. The flue gas exit temperature after air pre-heater is 1120°C . Air is preheated from ambient temperature of 40°C to 190°C through an air pre-heater. The furnace has 460 mm thick wall on the billet extraction outlet side, which is 1 m in height and 1 m wide. The other data are as given below.

Flue gas temperature after air pre heater = 1120°C

Ambient temperature = 40°C

Preheated air temperature = 190°C

Specific gravity of oil = 0.92

Average fuel oil consumption = 492 Litres / hr

= $492 \times 0.92 = 452.64 \text{ kg/hr}$

Calorific value of oil = $10000 \text{ kCal/kg} = 418680 \text{ kJ/kg}$

Average O_2 percentage in flue gas = 12%

Weight of stock = 4166.67 kg/hr

Specific heat of Billet = $0.12 \text{ kCal/kg/}^{\circ}\text{C} = 0.502 \text{ kJ/kg/}^{\circ}\text{C}$

Surface temperature of roof and side walls = 366°C

Surface temperature other than heating and soaking zone = 85°C

Sensible Heat Loss in Flue Gas:

$$\text{Excess air} = \frac{O_{2\%}}{21 - O_{2\%}} \times 100 \text{ (Where } O_2 \text{ is the \% of oxygen in flue gas)}$$

$$= 12\%$$

$$\frac{12}{21 - 12} \times 100$$

$$= 133\% \text{ excess air}$$

Theoretical air required to burn 1 kg of oil = 14 kg (Typical value for all fuel oil)

$$\text{Total air supplied} = \text{Theoretical air} \times (1 + \text{excess air}/100)$$

$$\begin{aligned} \text{Total air supplied} &= 14 \times 2.33 \text{ kg / kg of oil} \\ &= 32.62 \text{ kg / kg of oil} \end{aligned}$$

$$\begin{aligned} \text{Sensible heat loss} &= m \times C_p \times \Delta T \\ m &= \text{Weight of flue gas} \\ &= \text{Actual mass of air supplied / kg of fuel} + \text{mass of fuel (1kg)} \\ &= 32.62 + 1.0 \\ &= 33.62 \text{ kg / kg of oil.} \end{aligned}$$

$$C_p = \text{Specific heat of flue gas}$$

$$= 0.24 \text{ kCal/kg}^\circ\text{C} = 1.004 \text{ kJ/kg}^\circ\text{C}$$

$$\Delta T = \text{Temperature difference}$$

$$\begin{aligned} \text{Heat loss} &= m \times C_p \times \Delta T \\ &= 33.62 \times 0.24 \times (1120 - 40) \\ &= 8714.304 \text{ kCal / kg of oil} \end{aligned}$$

$$\begin{aligned} \% \text{ Heat loss in flue gas} &= 8714.304 \times 100/10000 \\ &= 87.14\% \end{aligned}$$

2 Loss Due to Evaporation of Moisture Present in Fuel

$$\% \text{ Loss} = m \frac{\{584 + 0.45 (T_{fg} - T_{amb})\} 100}{GCV \text{ of Fuel}}$$

Where,

M - % Moisture of in 1 kg of fuel oil (0.15 kg/kg of fuel oil)

T_{fg} - Flue Gas Temperature

T_{amb} - Ambient temperature

GCV - Gross Calorific Value of Fuel

$$\begin{aligned} \% \text{ Loss} &= \frac{0.15 \{584 + 0.45 (750 - 40)\}}{1000} \times 100 \\ &= 1.36\% \end{aligned}$$

Loss Due to Evaporation of Water Formed due to Hydrogen in Fuel

$$\begin{aligned} \% \text{ Loss} &= \frac{9 \times H_2 \{584 + 0.45 (T_{fg} - T_{amb})\}}{GCV \text{ of Fuel}} \times 100 \end{aligned}$$

Where, H_2 – % of H_2 in 1 kg of fuel oil (0.1123 kg/kg of fuel oil)

$$\begin{aligned} &= 9 \times 0.1123 \frac{(584 + 0.45 (750 - 40))}{1000} \times 100 \\ &= 9.13\% \end{aligned}$$

Source: Bureau of Energy Efficiency. www.pcra.org

Source:- (Bureau of Energy Efficiency. www.pcra.org)

Figure 4.1 Graph for Determining Black Body Radiation at a Particular Temperature

The reheating furnace in example has 460mm thick wall (X) on the billet extraction outlet side, which is 1m height (D) and 1m wide. With furnace temperature of 1340°C , the quantity (Q) of radiation heat loss from the opening is calculated as follows:

The shape of the opening is square and $D/X = 1/0.46 = 2.17$

The factor of radiation = 0.71

Black body radiation corresponding to $1340^{\circ}\text{C} = 36.00 \text{ kCal/cm}^2/\text{hr}$ (Refer Figure 4.1 On black body radiation)

Area of opening = $100 \text{ cm} \times 100 \text{ cm}$

$$= 10000 \text{ cm}^2$$

Emissivity = 0.8

Total heat loss = Black body radiation x area of opening x factor of radiation x emissivity

$$= 36 \times 10000 \times 0.71 \times 0.8$$

$$= 204480 \text{ kCal/hr}$$

$$\text{Equivalent Oil loss} = 204480/10,000$$

$$= 20.45 \text{ kg/hr}$$

$$\% \text{ of heat loss} = 20.45 / 368 \times 100$$

$$= 5.56\%$$

LOW POUR FUEL OIL (L.P.F.O) CONSUMPTION FROM 2004 -2013

TABLE 4.1

YEAR	MONTH	AV.CONP T.IN ltr/hr	FUEL CONPT. IN kl/yr	COST OF oil/ltr	TOTAL COST
2004	JAN- DEC.	420	3,628,800	67	243,129,600
2005	-	440	3,801,600	71	263,779,200
2006	-	430	3,715,200	76	282,355,200
2007	-	460	3,974,400	79	313,977,600
2008	-	450	3,888,000	82	318,816,000
2009	-	460	3,974,400	84	333,849,600
2010	-	540	4,665,600	91	424,569,600
2011	-	570	4,924,800	96	472,780,800
2012	-	580	5,011,200	102	511,142,400
2013	-	570	4,924,800	105	517,104,000
TOTAL		4,920	42,508,800		3,681,504,000

Table 4.2 DIESEL OIL CONSUMPTION FROM 2004-2013

YEAR	MONTH	AV CONPT /DAY(kl)	CONSU MT/WEE K(kl)	CONSUMI ON/MONTH (kl)	CONSUMT /YEAR(kl)	PRICE/ LTR(N)	TOTAL COST/YEAR-N
2004	JAN- DEC	5	35	150	1800	110	198000000
2005	-	6	42	180	2160	115	248400000
2006	-	5	35	150	1800	125	225000000
2007	-	5	35	150	1800	130	234400000
2008	-	7	49	210	2520	135	340200000
2009	-	5	35	150	1800	135	243000000
2010	-	4	28	120	1440	140	201600000
2011	-	5	35	150	1800	145	261000000
2012	-	5	35	150	1800	150	270000000
2013	-	6	42	180	2160	150	324000000
							2344000000

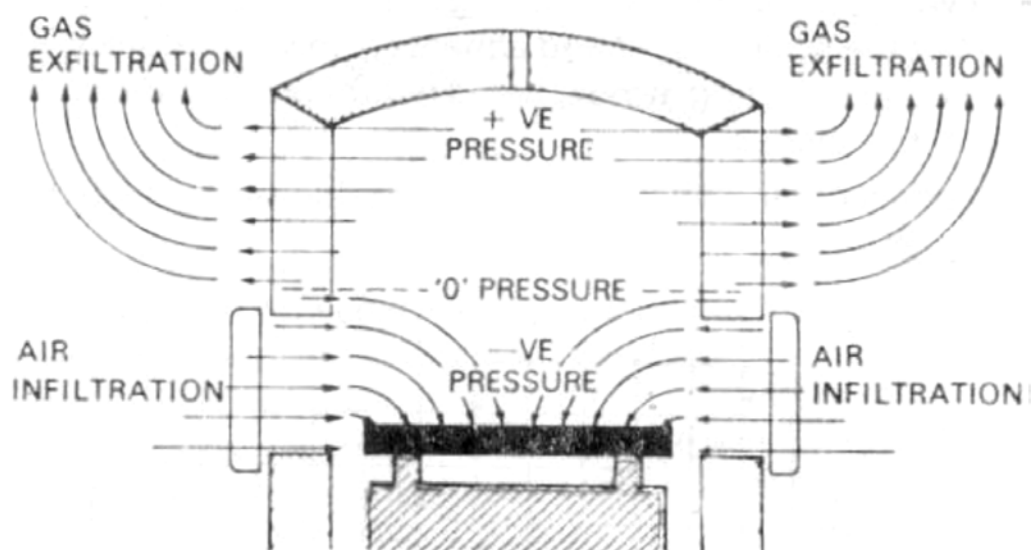


Fig 4.2 Pressure Balance

Table : 4.3 SUMMARY OF RESULTS

Loss Component	Heat Loss	%
Sensible heat loss in Flue gas	34685.048kJ/kg	87.14
Loss due to evaporation of moisture	0.013kJ/kg	1.36
Loss due to evaporation of water	0.0913kJ/kg	9.13
Loss due to openings	0.0056k/kg	0.56

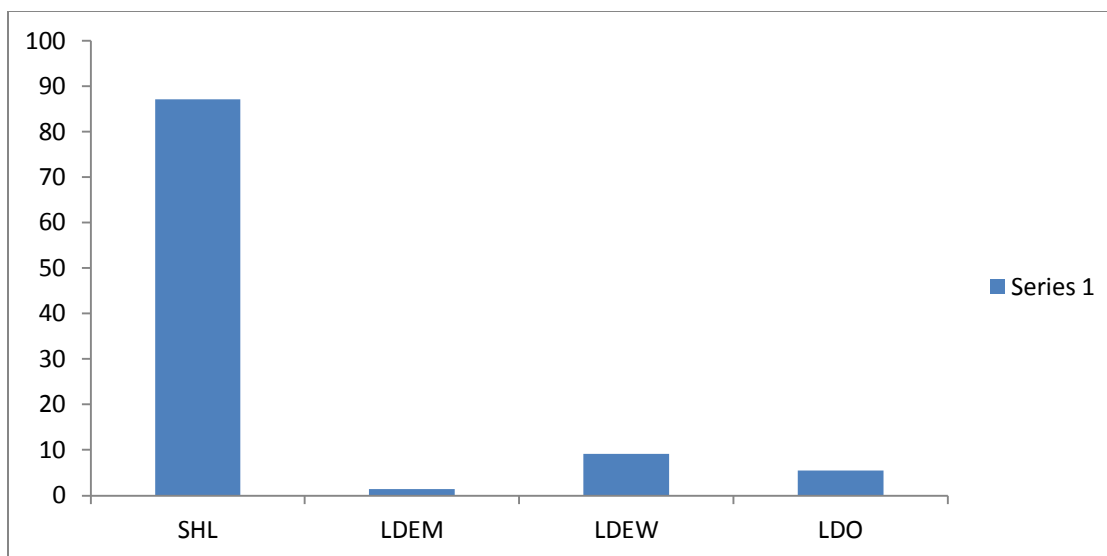


Fig:

4.3 Graphical Representations of Results

LOSS IN MONETARY TERMS

Total energy loss = 30.242 MW

Total cost of oil = 3,681,504,000

Percentage loss = 57.44

Price loss = $0.5744 \times 3,681,504,000$

= 2,114,655,989

Table 3.4 Percentage of Consumption

Component	Consumption in MW	% energy consumption
Glass melting	4.4	$\frac{4.4}{22.4} \times 100 = 20\%$
Regenerator	7.4	$\frac{7.4}{22.4} \times 100 = 32\%$
Glass tank loss	4.6	$\frac{4.6}{22.4} \times 100 = 21\%$
Stack flue loss	1.6	$\frac{1.6}{22.4} \times 100 = 7\%$

Combustion	4.4	$\frac{4.4}{22.4} \times 100 = 20\%$
Total	22.4	100%

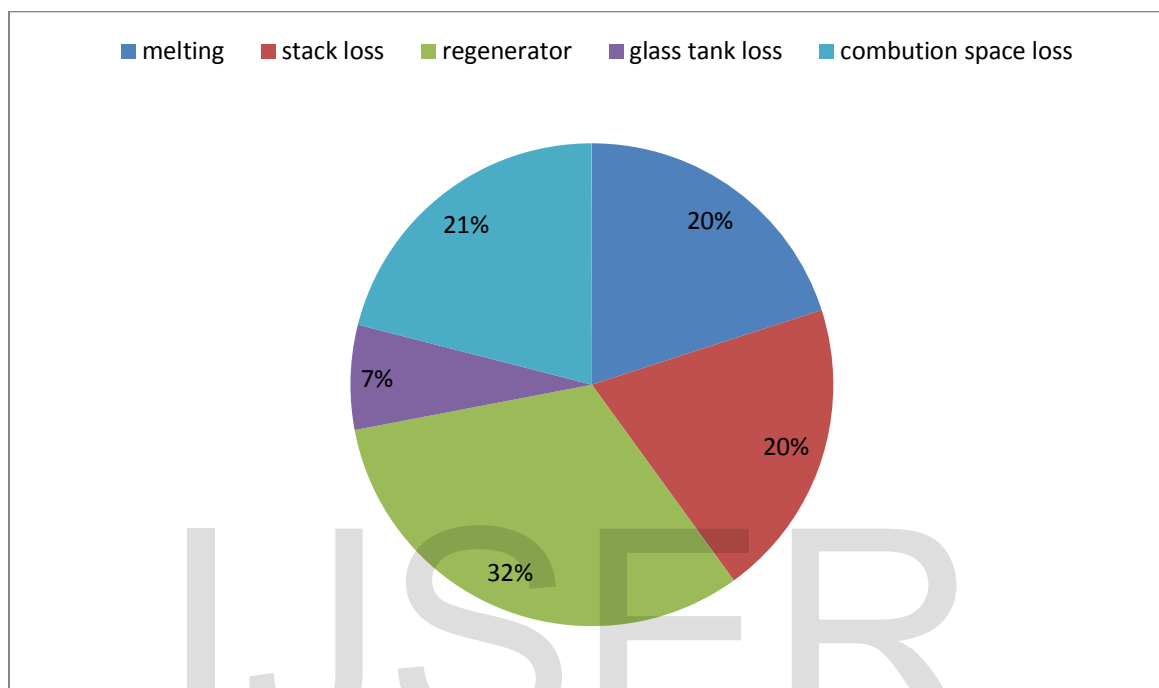


Fig. 4.3 Pie chart

Applying the above terms, the heat consumption associated with different components of the furnace was computed and displayed (see Fig. 3.2). It can be seen that 4.4 MW (20%) of total energy is consumed for glass melting and another 7.4 MW (32%) is recovered in regenerator. The rest of energy is lost through the combustion space refractory, the glass tank refractory and the stack flue as 4.6 MW (21%), 1.6 MW (7%) and 4.4 MW (20%) respectively.

The values obtained from the results above are calculated as shown below:

1. Energy lost through the combustion refractory

$$\text{Using } Q = \frac{KA(T_1 - T_o)}{t}$$

Q = heat loss at combustion space

K = Coefficient of thermal conductivity = $10 \text{ w/m}^2 \text{ k}$

T_i = Temperature of preheated air = 1373 k

T_o = Temperature of flue gas = 1220 k

T = Thickness 313

A = area 751 m^2

$$Q = \frac{10 \times 751 \times (1373 - 1220)}{313}$$

$Q = 6070.38 \text{ Joules}$

Converting to watt

$= 6070.38 \times 764$

$= 4637770.32 \text{ W}$

$Q_{\text{combustion space}} = 4.64 \text{ MW}$

The other results for energy lost through regenerator, glass tank loss, stack loss, and melting are obtained via same procedure above.

ENERGY BALANCE EQUATION

$$Q_{\text{fuel}} + Q_{\text{preheater}} - Q_{\text{flue}} \times u_{\text{combustion}} = Q_{\text{melting}} + Q_{\text{glass tank loss}} -$$

$$Q_{\text{preheated raw material}} \dots \dots \dots 5$$

Mass of fuel = 452.64 kg/hr

Calorific value (CV) = 418680 kJ/kg

$$Q_{\text{fuel}} = \text{mass of fuel} \times \text{cv}$$

$= 452.64 \times 418680$

$= 189511315 \text{ kJ/hr}$

$$=52.642\text{MW}$$

Total energy produced by the combustion LPFO =52.642MW

Total energy consumed in various units = 22.4MW

$$\text{Energy loss} = 52.642 - 22.4$$

$$= 30.242\text{MW}$$

FURNACE EFFICIENCY BY DIRECT METHOD

$$\text{Efficiency} = \frac{\text{heat output}}{\text{heat input}} \times 100$$

$$= \frac{22.4}{52.642} \times 100$$

$$= 42.56\%$$

SPECIFIC ENERGY CONSUMPTION

$$\text{SEC} = \frac{\text{quantity of energy or fuel consumed}}{\text{quantity of materials processed}}$$

$$= \frac{22.4}{452.64} \quad (452.64 \text{ is from data analysis})$$

$$= 0.049\text{kJ/hr}$$

DISCUSSION

The energy balance calculations above clearly indicates a large difference between energy supplied and energy utilized. The excessive energy loss depicts drastic reduction in furnace efficiency as shown above and consequently increased expenditure on fuel.

CONCLUSIONS

Simulation of glass melting furnaces can be used as a good tool to analyse the effect of different factors on the fuel consumption as regards to energy utilization in Sunglass limited. In this work, the temperature of preheated air, the temperature of raw material, and the overall heat transfer coefficient

of combustion space are varied over a wide range to analyse the sensitivity of fuel consumption. The results indicate a large energy loss, which could be a combination of several factors including: insufficient preheating of combustion air, non-preheating of raw materials and excessive heat transfer coefficient.

RECOMMENDATIONS

A combination of different methods could be applied to achieve further fuel reduction. Sunglass Limited should therefore as a matter of fact, consider the following:

- i. Further preheating of combustion air
- ii. Preheating of raw materials, which at present is not done?
- iii. Decreasing the overall heat transfer coefficient. This is very necessary.

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