THE EVALUATION OF THE PERFORMANCE OF A GLASS MELTING FURNACE IN TERMS OF ENERGY CONSUMPTION

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Abstract

The price of energy in Thailand is higher than in other countries in ASEAN. This is a threat for glass industries in Thailand because they consume substantial amounts of energy in a high temperature melting process, i.e. 1500-1600°C. Fifty percent of total costs is spent on energy and 80% of total energy is used in a glass melting furnace. Energy reduction in a glass melting furnace should be taken into account. However, before employing the proposed energy conservation scheme, it is essential to identify the existing furnace performance in terms of energy consumption in order to know where the problems are that should be solved and to be able to assess the effectiveness of the scheme. In this study, the glass furnace performance is evaluated by balancing the energy (heat) used in the furnace. The heat balances of 2 furnaces, which are operated under different conditions, are calculated. The output of this project will be used as a guideline for the industry to optimize the energy in the furnace.

Keywords: Glass furnace, heat balance, energy, efficiency

Introduction

The glass industry is one of the important industries in Thailand. It can generate an income for the country of as much as 500-600 million US dollars a year. Among the ASEAN countries, it can be said that Thailand is the most competitive in this business because it has the advantage on technology, human resources, raw material availability, infrastructure, and so on. However, the costs of labor and energy in Thailand are threats for businesses, especially the cost of energy due to the higher price than in other countries in ASEAN. Fifty percent of the total costs is spent on energy and 80% of total energy is used in a glass melting furnace. To remain competitive, the industry must introduce an energy conservation scheme in order to reduce the cost of energy. Energy reduction in a glass melting furnace should be taken into account. However, before employing the scheme, it is

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essential to identify the existing furnace performance in terms of energy consumption, in order to know where the problems are that should be solved and to be able to assess the effectiveness of the scheme.

Figure 1 illustrates the flow of heat in a glass furnace. The heat input to the furnace (H_{in}) is supplied from combustors. Oil and natural gas are frequently used as fuel. Electric booster systems can be installed to supply additional energy to increase the melting capacity (Warnatz, 2010). The heat used for batch-to-melt conversion is called exploited heat (H_{ex}) (Conradt, 2008). During the firing, the offgas heat (H_{off}) in the furnace flows into a heat exchanger, where the heat contained in the offgas is recovered. The recovered heat (H_{re}) circulates to the furnace to increase the furnace efficiency. Losses of heat take place in 2 ways. The first is the remaining heat in the offgas which is lost to the atmosphere through the stack (H_{stack}). The second is the heat lost through the furnace's walls, crown, and opening holes (H_w). Only a small portion of the heat is used for melting the glass, normally about 30%. The major amount of the heat is carried with the heat losses.

The amount of heat losses is important in evaluating the performance of the furnace in terms of energy consumption. Generally, the heat losses are evaluated by measuring the temperature at the furnace's walls, but this gives a very rough result due to the complicated shape of the furnace. As a result, an indirect method using heat balance calculations is introduced. The heat balance of the furnace is normally represented by the Sankey diagram as shown in Figure 2. It points out where the heat has gone in the melting process.

To determine the heat balance of glass melting furnaces, firstly, the amount of H_{ex} needs to be known. Conradt (2008) has proposed thermodynamic calculations to determine the accuracy of H_{ex}. More details of the H_{ex} determination can be found in Conradt (2004), Conradt (2008) and Tapasaand Jitwatcharakomol (2012). Secondly, the value of Hin has to be calculated by the amount of fuel and electricity (if used) that are fed into the melting process. Thirdly, the heat contents of Hoff, H_{re}, and H_{stack} have to be calculated. Lastly, H_w in the furnace can be evaluated by heat balancing.

The objective of this project is to calculate the heat balances of 2 glass melting furnaces, which are operated under difference conditions, in order to compare their energy consumption characteristics. The output of this project will be used as a guideline for glass technologists to employ thermodynamic calculations for analyzing their processes.

Methods

The heat balance equations are shown in Equations (1)–(3).

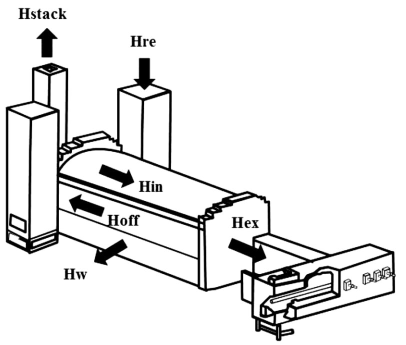

Figure 1. The flow of heat in a glass furnace

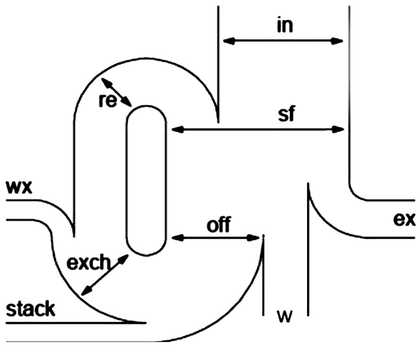

Figure 2. The Sankey diagram of a glass-melting furnace

$$H_{sf} \ = H_{in} + H_{re} \ = H_{off} + H_{ex} + H_{w}, \qquad (1)$$

where H_{sf} is the total heat stored in a glass furnace.

$$H_{off} \ = H_{stack} + H_{re} + H_{wx} \qquad (2)$$

$$H_{exch} = H_{off} - H_{stack} = H_{re} + H_{wx}, \qquad (3)$$

where H_{exch} is the heat in the heat exchanger.

The glass melting furnaces studied in this project are from different factories. Table 1 shows the details of the furnaces. One produces glass blocks (Furnace A) and the other one produces glass tubes (Furnace B). Both are regenerative end-port furnaces. The capacity of furnace B (200 tons) is greater than furnace A (120 tons). The pull of furnace A is around 90.8–96.6 tons/day while furnace B is 83.4–85.6 tons/day, as shown in Figure 3. Both furnaces use natural gas as the fuel but furnace A employs electric boosters at the bottom of the tank to increase the melting ability. Furnace A consumes natural gas (NG) at a rate of 16286–17621 m^3/day and 4752-6240 KW/day of electricity. Furnace B consumes NG at a rate of 15862–16482 m^3/day. The air/gas ratios of furnaces A and B are 10 and 15, respectively. The data of Furnace A was collected between 1st January–30th June 2012 (6 months) and furnace B between 1st December

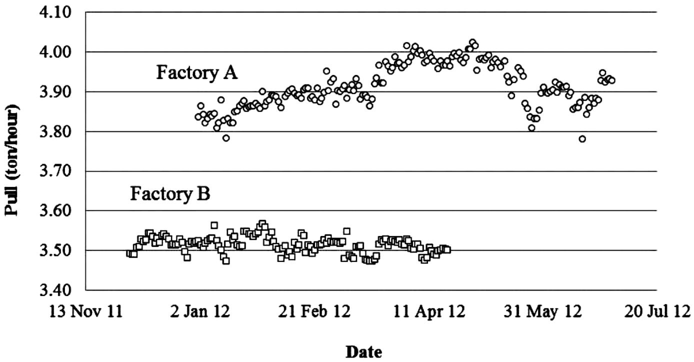

Figure 3. Pull of furnaces A and B during the data collection period

Table 1. General data of furnaces A and B

Data	Furnace A	Furnace B
Furnace Type	Regenerative end-port furnace	Regenerative end-port furnace
Basin Area	52 m^2	60 m^2
Capacity	120 tons	200 tons
Total Pull	90.8 – 96.6 (tons/day)	
3.78 – 4.03 (tons/h)	83.4 – 85.6 (tons/day)	
3.48 – 3.57 (tons/h)		
Input energy	NG and Electricity	NG
Air / Fuel ratio	10	15
Date of data collection	1 Jan-30 June 12 (6 months)	1 Dec 11-19 April 12 (5 months)

2011–19th April 2012 (5 months). In this study, it was assumed that furnaces A and B used NG with the same heating value and that the efficiency of the regenerators of both furnaces is 60%. The glass batch in furnace A uses 20% glass cullet while furnace B uses 26-38%. The more glass cullet that is used in the batch the less H_{ex} is consumed.

To compute H_{ex}, the standard enthalpy and chemical compositions of each raw material in glass batches must be known. Table 2 shows the standard enthalpy of the raw materials and their quantity per 1 ton of glass in kilograms. Table 3 indicates the chemical compositions of the glasses from these 2 furnaces. Due to the variation of the pulls of furnaces A and B being rather narrow, i.e. ~ 3.5-4 tons/h, the furnaces' performance can be compared at any pull. The pull of 4 and 3.5 tons/h for furnaces A and B, respectively,

Table 2. The standard enthalpy of the raw materials in glass batches and the amount of raw materials per 1 ton of glass

Raw materials	H^o (kWh/kg)	Amount of raw materials per 1 ton of glass (kg)	
		Furnace A	Furnace B
Silica sand (SiO_2)	4.2112	685	628
Sodium Feldspar ($NaAlSi_3O_8$)	4.1649	51	110
Potassium feldspar ($KAlSi_3O_8$)	3.9635	12	-
Dolomite ($CaMg(CO_3)_2$)	3.4873	193	161
Sodium Carbonate (Na_2CO_3)	2.9608	231	250
Borax.5 H_2O ($Na_2O \bullet 2B_2O_3 \bullet 5H_2O$)	4.5676	-	14
Potassium Carbonate (K_2CO_3)	2.3117	-	13
Total		1172	1176
% cullet		20%	26-38%

Table 3. The chemical composition (%wt) of glasses

Components	Chemical composition %wt	
	Furnace A	Furnace B
SiO_2	72.45	67.94
TiO_2	0.03	0.06
Al_2O_3	1.38	2.10
B_2O_3	-	0.54
Fe_2O_3	0.11	0.09
P_2O_5	0.01	0.01
MgO	3.38	3.67
CaO	7.27	6.53
Na_2O	15.06	17.54
K_2O	0.30	1.28

are chosen to calculate the heat balance for comparison.The efficiency of a glass furnace (ηex) is equal to H_{ex}/H_{in}.

Results and Discussion

The performances of furnaces A and B in terms of power (P = H × pull) are shown in Figure 4. It is found that, at the chosen pull, the efficiency of both melting furnaces is 35%, which is quite common. H_{ex} of furnace A is 540-560 KW/ton while furnace B is 514-155 KW/ton. H_{ex} of furnace A is slightly higher due to the greater amount of silica sand, which is the major contributor of H_{ex}, even though furnace B uses more glass cullet than furnace A.

Considering the heat losses in the furnaces, furnace A has Pw of 40.6% and furnace B has 27.7%. This is because the wall area of furnace A is larger than that of furnace B. The major difference between these 2 furnaces is the heat content in the exhaust gas leaving the furnace to the heat exchanger (H_{off}). Furnace A wastes this energy at 60.5%, while furnace B's waste is 92.5%. Furnace B loses a lot of energy from the combustion space which results in a higher quantity of H_{re} and H_{stack}. This is because Furnace B uses too high an air/gas ratio, i.e. 15. Thus, a lot of energy is carried with the exhaust gas out of the furnace. To solve this problem, the factory must reduce the air/gas ratio or attempt to recycle this waste heat, for example by preheating a batch before melting.

Conclusions

Before introducing the energy conservation plan for glass melting furnaces, the industry must know the existing furnace performance in terms of energy consumption in order to know which problems should be solved and to be able to assess the effectiveness of the plan. Furnace engineers have to know the amount of energy used for melting their batch, the input energy, and the temperature of the exhaust gas in the system in order to calculate the heat content in the gas. This is also important when the production rate is altered. Calculating the amount of energy used will provide knowledge of the energy consumption as a function of the pull which is a characteristic of an individual furnace.

Acknowledgements

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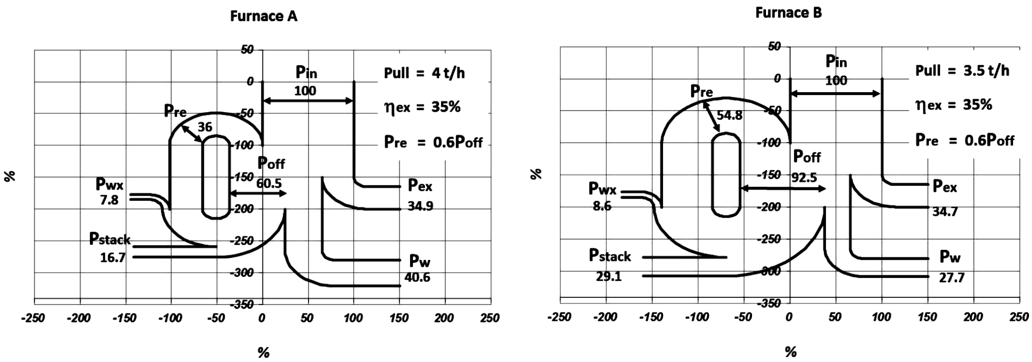

(a) (b)

Figure 4. The Sankey diagrams of furnaces A and B at 4 and 3.5 tons/h, respectively

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