International Journal of Advanced Research and Development
ISSN: 2455-4030
Impact Factor: RJIF 5.24
www.advancedjournal.com
Volume 3; Issue 6; November 2018; Page No. 17-20

A new review in glass furnaces energy saving field by pairing between recuperative and regenerative systems

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Abstract
Cost reduction is the newest strategy in glass companies to decrease the cost of production while maintaining or increasing the glass quality. There are several perspective ways leading to this goal. The Optimization of the heating system, improving energy efficiency and reducing CO_2 emissions depending on waste heat recovery will be our scope in this research.

Keywords: cost reduction, CO_2 emissions and waste heat recovery

1. Introduction

Glass melting furnaces are energized by fuels and/or electricity. High energy costs, environmental roles, and the competition between glass manufacturers have resulted in the rise of smart solutions to reduce the fuel consumption of these furnaces. Glass industry is classified as one of the high scaled sectors in energy consumption. That is why it is very important to keep the energy consumption in that sphere in permissible limits and the efficiency of melting furnace is one of the most important issues.

A lot of research has been carried out to improve the thermal efficiency of glass furnaces. Some works [1-3] have employed simulation approaches to analyze the effect of different factors on heat consumption in glass furnaces. Other works [4-6] 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 preheating combustion air and raw material [7-11], to considering new geometries of combustion space and its elements [12,13]. There are also some works that focus on advanced control techniques to achieve the optimal performance of glass furnace [14].

2. Materials and methods

2.1 Utilization of waste heat recovery

This paper presents a new smart solution to reduce the fuel consumption depending on utilization of waste heat recovery which can be defined as a heat generated in a process by way of fuel combustion or chemical reaction, and then transfer to the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its value. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. Boilers, Kilns, Ovens and Furnaces can be considered as sources of a large quantity of hot flue gases. If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. Benefits from the utilization of Waste heat recovery can be classified to two categories, direct benefits and indirect benefits**.** The direct benefits of waste heat recovery are the benefits which have a direct effect on the process efficiency such as reduction in the utility consumption & costs, and process cost. As examples for indirect benefits for recovery of the heat, the reduction of the environmental pollution levels where a number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases and oil sludge etc, releasing to atmosphere when burnt. Reduction in equipment sizes is another example for indirect benefits for Waste heat recovery. Usually higher the temperature, higher the quality and more cost effective is the heat recovery.

Three solutions to reduce the fuel consumption in industrial glass melting furnaces were presented by Khoshmanesh [15]. The solutions include air preheating, raw material preheating, and improving the insulation of combustion chamber refractory. In the case of air preheating, the using of recuperators in furnaces with air combustion allows saving 30% in fuel consumption when the combustion air is preheated from 298 K to 600 K, this was presented by Turns [16]. Possamai [17] reported that the percentage of flue gases energy losses is 33% and the percentage of wall energy losses is 30% in frit production furnace, meaning that up to 63% of waste heat can be recovered. DOE [18] revealed that, in industrial furnaces, the efficiency improvements resulting from waste heat recovery can improve energy efficiency from 10% to as much as 50%. In the case of furnaces, the waste heat source is found mostly in the flue gases. The equipments to recover the waste heat often are heat exchangers and also the choice of heat recovery technology depends on the temperature source. The waste heat sources can be classified to three categories depending on the temperature range.

1. High Temperature: (> 650^{o}C).
2. Medium Temperature :(230-650^{o}C).
3. Low Temperature (< 230^{o}C).

2.2 Waste heat recovery techniques

Several techniques are employed for waste heat recovery according to furnace design, furnace capacity, the glass formulation, fuel prices, existing infrastructure and environmental performance. These techniques can be classified to.

A. Regenerative Furnaces
The term regenerative refers to the form of heat recovery system. Burners firing fossil fuels are usually positioned in or below combustion air/waste gas ports. The heat in the waste gases is used to preheat air prior to combustion. This is achieved by passing the waste gases through a chamber containing refractory material, which absorbs the heat. The furnace fires on only one of two sets of burners at any one time. After a determined period, the firing cycle of the furnace is reversed and the combustion air is passed through the chamber previously heated by the waste gases. A regenerative furnace has two regenerator chambers, while one chamber is being heated by waste gas from the combustion process, the other is preheating incoming combustion air.

B. Recuperative Furnaces
In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic walls. Duct or tubes carry the air for combustion to be preheated, the other side contains the waste heat stream. The simplest configuration for a recuperator is the metallic radiation recuperator, which consists of two concentric lengths of metal tubing. The inner tube carries the hot exhaust gases while the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air which now carries additional energy into the combustion chamber.

C. Electric Melting
An electric furnace consists of a refractory lined box supported by a steel frame, with electrodes inserted either from the side, the top or more usually the bottom of the furnace. The energy for melting is provided by resistive heating as the current passes through the molten glass. It is, however, necessary to use fossil fuels when the furnace is started up at the beginning of each campaign.

D. Oxy-fuel Melting
This technique involves the replacement of the combustion air with oxygen of high purity. The elimination of the majority of the nitrogen from the combustion atmosphere reduces the volume of the waste gases, which are composed almost entirely of carbon dioxide and water vapor, by about two thirds. Therefore, energy savings are possible because it is not necessary to heat the atmospheric nitrogen to the temperature of the flames.

E. Fuel and electric melting combination
Electric boosting is a method of adding extra heat to a glass furnace by passing an electric current through electrodes in the bottom of the tank. It can be installed while a furnace is running, and it is often used to support the pull rate of a furnace as it nears the end of its operating life or to increase the capacity of an existing furnace. This method can also be used to improve the environmental performance of the furnace by substituting electrical heating for combustion for a given glass pull rate.

2.3 New review for waste heat recovery in glass furnaces
Our review for waste heat recovery is depending on combination between two systems of waste heat recovery in the same furnace in the same time, *recuperative and regenerative systems*. In Egypt and as a Case study, there is an end port regenerative glass furnace to produce soda lime glass for lighting purposes. The combustion process occur using natural gas with a sufficient amount of fresh air to burn the gas. As it mentioned above about regenerative furnace, the waste gases is used to preheat air prior to combustion. This is achieved by passing the waste gases through a chamber containing refractory material, which absorbs the heat. In our case about 2500m^3/hour leave the melter with a temperature upto 1300°C as a waste gasses then pass through a chamber containing refractory material, which absorbs the heat. After fifteen minutes the cycle will reverse and the fresh air will pass through the chamber previously heated by the waste gases with a temperature upto 1100°C (Fig. 1).
But there is a forgotten source of waste heat recovery should be utilized, the chimney of Forehearth. This part of the furnace should be used as a source of cost reduction and energy saving. About 500 m^3/hour with a temperature up to 1000°C leave the region of Forehearth to the environment without any benefit. This chimney can be converted to recuperator (Fig. 3) and can be used in preheating the fresh air. Figure (2) explains the furnace diagram after combination between the two waste heat recovery systems.

3. Results and Discussion
According to the temperature of the flue gases, the kind and the material of recuperator is determined. In our case, the exhaust gases are leaving the chimney of the Forehearth at 1000°C at the rate of 500 m^3/hour. The total heat recoverable at 180°C final exhaust can be calculated according to following equation:

$$Q = V \text{ x } \rho \text{ x } Cp \text{ x } \Delta T$$

Where
Q is the heat content in KCal
V is the flow rate of the substance in m^3/hour
ρ is density of the flue gas in Kg/m^3
C*p* is the specific heat of the substance in KCal/Kg ºC
ΔT is the temperature difference in ºC
C*p* (Specific heat of flue gas) = 0.24 KCal/Kg/ºC
Heat available (Q) = 500 x 1.19 x 0.24 x (1000-180) = 117096 KCal/hour

By installing a recuperator, this heat can be recovered to pre-heat the combustion air in Forehearth region. The value of ΔT depends on the recuperator type, its material and design. Hot air temperatures can be achieved to 600-800ºC in metal recuperator and up to 900 ºC in conventional ceramic recuperator, but in high efficiency ceramic recuperator it can be up to 1250 ºC. This is the direct benefits for waste heat recovery, but the important indirect benefit is the reducing of the emission of harmful gases such as COx, NOx and SOx. As an example carbon dioxide levels have risen to 380 ppm in the last century. This dramatic increase is the result of huge human activity. In our case natural gas is the furnace fuel which formed from methane CH_4 (95%), ethane (3%) and small amounts of heavier hydrocarbons. It burns according to:

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O \quad \text{………… (1)}$$

And $$n = \frac{PV}{RT} \quad \text{…………. (2)}$$

Accordingly, 1 m^3 of natural gas (100% methane) produces 42.3 mol of CO_2, or 1.86 kg. Since 1 mol of ethane produces 2mol of CO_2, 1 m^3 of ethane C_2H_6 produces twice as much CO_2, or 3.72 kg. For natural gas that is, say, 95% CH_4 and 5% C_2H_6, the weighted average is 1.95 kg CO_2/ (m^3 natural gas), or approximately 0.002 T/m^3. Table (1) illustrates the chemical composition of natural gas and its British thermal units.

According to the average of composition of these samples the calorific value of 1 cubic meter of this natural gas approximately equal 9300 Kcal/m^3. So the results of this combination between the recuperative and regenerative systems are reduction in natural gas consumption reach to 109500 m^3/year from natural gas as a direct benefits and reduction in CO_2 emission about 212 tons/ year as an indirect benefit.

Table 1: Natural Gas Composition Mole %

Sampling Point	Nitrogen	Methane	Carbon Dioxide	Ethane	Propane	Iso Butane	N-Butane	Neo Pentane	Iso Pentane	N-Pentane	Hexanes	Heptanes	Octanes	Molecular Weight	Gross Heating Value Btu/ft3	Relative Density
Banha Power Station	0.107	95.730	0.686	2.526	0.577	0.129	0.098	0.000	0.042	0.027	0.050	0.021	0.007	16.958	1040.219	0.586
El Nobaria	0.130	95.294	0.380	2.789	0.741	0.226	0.190	0.006	0.090	0.058	0.065	0.020	0.011	17.099	1055.063	0.590
Shabshir	0.105	96.121	0.767	2.347	0.463	0.087	0.061	0.000	0.021	0.013	0.010	0.005	0.000	16.822	1030.938	0.581

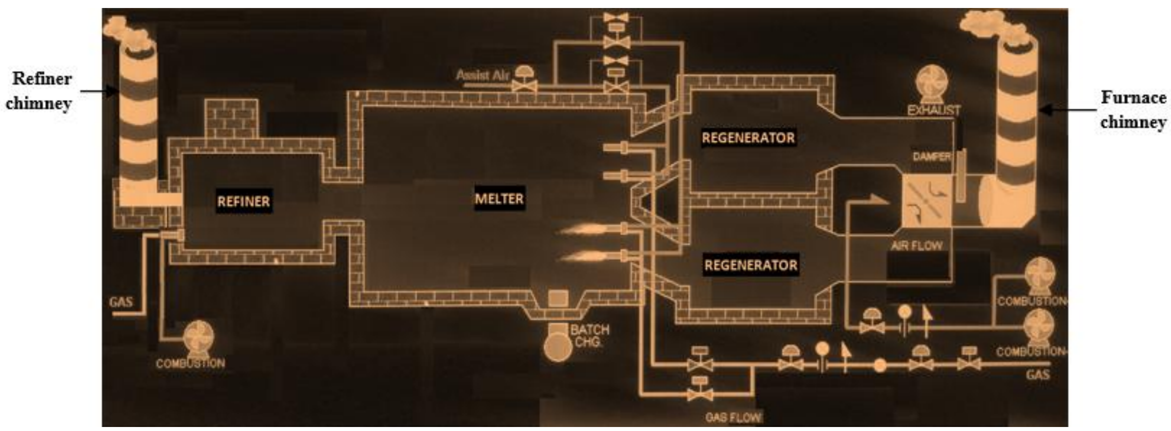

Fig 1: End fired regenerative furnace (Before Combination)

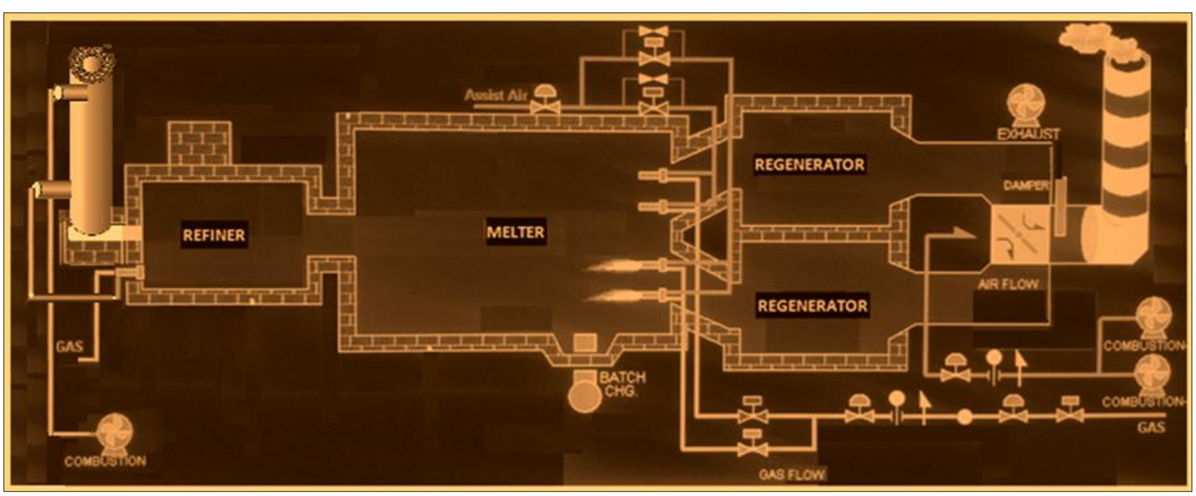

Fig 2: End fired regenerative furnace (After Combination)

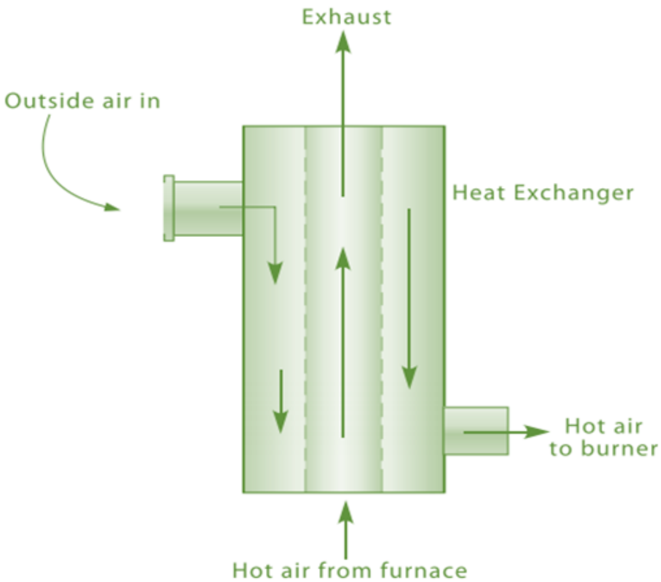

Fig 3: Recuperator system

4. Conclusion

According to continuous increasing in energy price, strong competition between companies and the harmful of waste heat in environment, the research in field of waste heat recovery is continuous to achieve maximum utilization from waste heat recovery. Here we present a new review in this field depending on combination between two systems in the same furnace. This can be occurred by converting the chimney of Forehearth region to recuperator. This makes a pairing between regenerative system (for exhaust gases out from melter region) and recuperator system (for exhaust gasses out from Forehearth). With smart selection for recuperator material and design and in presence of good heating system control, 30% of the energy consumption of Forehearth region and equal percent from CO_2 emission will be reduced.

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