

Energy efficiency solutions for driers used in the glass manufacturing and processing industry

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Abstract. Energy conservation is relevant to increasing efficiency in energy projects, by saving energy, by its' rational use or by switching to other forms of energy. The goal is to secure energy supply on short and long term, while increasing efficiency. These are enforced by evaluating the companies' energy status, by monitoring and adjusting energy consumption and organising a coherent energy management. The manufacturing process is described, starting from the state and properties of the raw material and ending with the glass drying technological processes involved. Raw materials are selected considering technological and economic criteria. Manufacturing is treated as a two-stage process, consisting of the logistic, preparation aspect of unloading, transporting, storing materials and the manufacturing process itself, by which the glass is sifted, shredded, deferried and dried. The interest of analyzing the latter is justified by the fact that it has a big impact on the final energy consumption values, hence, in order to improve the general performance, the driers' energy losses are to be reduced. Technological, energy and management solutions are stated to meet this problem. In the present paper, the emphasis is on the energy perspective of enhancing the overall efficiency. The case study stresses the effects of heat recovery over the efficiency of a glass drier. Audits are conducted, both before and after its' implementation, to punctually observe the balance between the entering and exiting heat in the drying process. The reduction in fuel consumption and the increase in thermal performance and fuel usage performances reveal the importance of using all available exiting heat from processes. Technical faults, either in exploitation or in management, lead to additional expenses. Improving them is in congruence with the energy conservation concept and is in accordance with the Energy Efficiency Improvement Program for industrial facilities.

Keywords: energy efficiency, heat recovery, glass industry, drier, energy audit.

Introduction

Harnessing with maximum efficiency the different categories of resources: material, financial and human, represents a priority both for productive and nonproductive activities.

Amongst the previously mentioned resources, the energy resources, which play an important part, are exhaustible, this being the reason for seeking a maximum performance in exploitation. The energy audit and management have the same goal, that of maximizing energy efficiency. It implies the correlation and combining the two types of energy services, and the systematic application of techniques and procedures developed and perfected over time. Improving energy efficiency in a given structure, in the interior of which a profitable activity is undertaken, is a demand which derives from the general necessity that the said activity brings maximum profit to those who invest financial resources for its' set-up.

Increasing energy efficiency in glass industry is a very important issue due to the fact that this industry is a large energy consumer. But, at the same time, the increase in energy efficiency should not come with some drawbacks for product quality (VUORISTO, 2007). Thus, it is important that any energy efficiency measure implemented within a certain analyzed circuit should also comply with quality standards of produced glass (MÄNTYLÄ, 2007).

Another important issue with regard to glass industry is that due to the fact that it consumes a large amount of energy for the technological process, and usually it is fossil fuel, it leads to large pollutant emissions (KOBAYASHI, 2005). Thus, by implementing energy efficiency measures can also have a positive environmental impact.

Thus, it can be said that implementing energy efficiency measures in glass industry can have several positive aspects/impacts: increasing energy efficiency, increasing the quality of glass products, increasing economic efficiency and decreasing pollutant emissions (Dumitrescu et al., 2005).

Correlating the Energy Efficiency Program to the Energy Management Program and to the Energy Audit in Industrial Processes

The basic concepts of energy conservation can be formulated through different forms (Romanian Law, 2014):

1. energy savings, which represents the overall measures or results of the activities undertaken by the energy producers and consumers, to avoid waste (for example: limiting the machineries' idle time, avoiding the overheating of living spaces, etc.);
2. rational energy utilization, which signifies the usage of energy by consumers in the most appropriate ways to meet objectives, by taking into account social, political, financial, ecological and other restrictions (for example: heating through systems of combined heat and electrical energy production);
3. substituting some forms of energy and energy processes with other, better adapted, solutions are done through measures which refer to deliberately made changes, as a part of an energy policy, apart from economical, technologic, or ecologic motives.

The central objective of the energy conservation policy is obtaining the same practical usefulness while having reduced energy consumption levels. In this context, the energy efficiency improvement and ensuring energy supply safety in short and long term is made by:

- the efficient use of energy throughout the entire energy cycle of the company;

- incorporating the energy efficiency in the existing equipment and machinery, as well as imposing selection criteria for acquiring new equipment;
- respecting the regulations in force regarding the energy consumption and the emissions on a national or local level;
- implementing an energy management program coherent to meeting the set-out objectives.

At an industrial company level, the development of the energy efficiency component is implemented through general actions, such as (ANRE regulation, 2015):

Evaluating the companies' energy state, which is made by:

- developing an energy audit program, quantifying energysavings, emission reduction and financial savings.
- developing an optimal operating program for inefficient equipment, including optimal loading, to obtain maximum yield in the existing conditions.
- avoiding equipment over-sizing

Monitoring energy consumption, which is made by:

- identifying the measuring equipment in continuous functioning;
- acquiring portable measuring equipment for various parameters;
- developing a periodic report and evaluation of measured data program.

Energy consumption adjustment, which is made by:

- ensuring the correct operation of the existing equipment
- developing a "no cost/low-cost" program to enhance equipment adjustment
- evaluating the opportunity and installing EMCs (Energy Management Controls – adjustment system for energy management / adjusting systems with integrated software)

Organizing a coherent energy management, which is made by:

1. delegating a stable workgroup for energy management
2. establishing a collaboration with the superior management level including an implication in the process of acquisition of energy efficient equipment.
3. "No-Cost/Low-cost" measure packs can be implemented, determining the reduction in energy consumption, implicitly the bill:
4. modifying tariffs, changing the energy provider, bulk acquisitions, combined acquisitions of energy and other utilities, etc.
5. automatic shutdown when idling, flattening the consumption curve, minimizing the functioning at load peaks
6. eliminating unjustified consumption (excess illumination, excess pressure for steam or compressed air, excess temperature for hot water, etc.)

The characteristic aspects of the manufacturing and the processing industry of household glass

Household glass products have a large variety (glass, bowls, cups, vases, ashtrays, etc.), having a composition of many different types, with a wide range of uses. Chemical stability conditions are imposed for some products and technological demands. The latter impose that the glass mass easily melts and hardly devitrifies, to adapt to the functioning conditions

of automated machinery and to suit a mechanic or chemical processing. For these reasons, household glass has a wide range of oxidic compositions.

Raw materials

The oxidic components of glass are given by several raw materials, in which they are found, in the form of chemical components. The raw materials used in manufacturing glass can be (Dumitrescu et al., 2005):

PICBE | 202

- materials extracted from natural deposits: sand (SiO_2), calcium carbonate (CaCO_3), dolomite ($\text{CaCO}_3 \text{ MgCO}_3$), feldspar ($\text{Ba, Ca, Na, K, NH}_4, (\text{Al, B, Si})_4\text{O}_8$), etc;
- synthesis chemical products: sodium carbonate decahydrate ($\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$), borax ($\text{Na}_4\text{B}_2\text{O}_7 \cdot 7\text{H}_2\text{O}$), boric acid (H_3BO_3), lead oxide or minium (Pb_3O_4), etc;
- secondary products like: glass chippings resulted from the manufacturing process or from third parties, furnace slag, etc.

Regardless of the nature of raw materials, in order for them to be selected for the purpose of household glass manufacturing, they must meet several technological and economical criteria.

Technological criteria

Each raw material must contain at least one of the oxids demanded by the chemical composition of the glass. A higher amount of the before mentioned oxid is preferred in the composition, as well as the capacity of producing other oxids of interest. The presence of chemical impurities must be at its' lowest, in order to eliminate additional purification processes. Raw material granulation must be within certain limits. Raw material composition must be as constant in time, as possible.

Economical criteria

The raw materials must be cheap and available in the quantities demanded by the household glass products manufacturer. Also, the distances between raw materials and suppliers and the beneficiary (manufacturer) must be small in order to have small transport fees. Choosing a smaller number of raw materials is imposed, in order that the processing expenses during the manufacturing process to be minimal. Based on these principles, the raw materials that will be used are chosen to be used for manufacturing the desired household glass products [2]. Generally, 4 to 7 main raw materials are used. A series of secondary raw materials are added in small quantities to clear the melted glass, coloration or discoloration, oxidation or reduction, obscuring, etc.

The stages of the manufacturing process, stage characteristics, afferent equipment and machinery

Unloading – Transporting – Storing Raw Materials

Generally, for large facilities, raw materials are delivered loaded in bulk, in wagons, in railroad containers or truck containers, the quantity factor imposing the usage of fast unloading systems and transport to the storing area.

In medium and small facilities, which generally have horizontal storage rooms, the raw materials are supplied in sacks. These are deposited on wooden pellets with standard dimensions and placed in storerooms in the horizontal storage with lift trucks and forklifts.

Preparing the raw material composite

The preparation of the raw material composite imposes dosing, weighting and homogenizing the manufacturing recipe components, the raw materials composite quality obtained, depending on the accuracy with which this operation is realized.

Ideally, the household or technical glass manufacturing factories, receive raw materials from the supplier, which correspond to the technological processing demands. Nevertheless, in some cases a raw material preparation is imposed, prior to the preparation of the mixture. These operations are:

- Drying, applied especially to the sand which arrives to the factory, transported in railroad wagons. This is the reason for which it has a variable humidity and must be dried until it reaches the imposed value of about 5%. To this end driers of different types are used. For example: tunnel dryer, cylindrical rotors heated with flue gasses;
- Sifting is executed with various sieves and is meant to filter towards manufacturing only the particles with dimensions, comprised between certain values;
- Shredding (grinding) shards, which are to be used in fabricating household or technical glass, to acceptable dimensions using wedge presses;
- Deferrization is used to remove the magnetic impurities, especially the iron particles. The operation takes place in defferizers equipped with a magnet which extracts the magnetic impurities found especially in sand.

In order to manufacture the raw material mixture, the quantities (percentage proportions) to be used must be known. Knowing the oxidic composition of glass and the raw materials used, the raw material mixture calculus is made.

The oxidic composition is made after the raw material calculus and considers the type of raw materials used and their percentage in the raw material mixture, with the purpose of obtaining a household glass with certain imposed properties.

Solutions for enhancing energy performances of the drying equipment

The main solutions for enhancing the energy performances of the drying equipment derive from defining the energy audit on a contour and from the notion of energy efficiency. Generally, the glass industry represents one of the biggest energy consumers, imposing the implementation of efficiency measures for the technological processes and towards augmenting the energy performance. Reducing the losses represents the main way of increasing the energy performance, hence the energy efficiency. This can be done through technological, energy and managerial activities.

The technological activities are:

- optimising the massic load from the furnaces' workload capacity;
- respecting the work diagram (following the pressure and temperature graphs output);

- controlling the combustion in order to meet optimal excess air coefficients and reduce the incomplete combustion.

The energy activities are:

- reducing the convection and radiation heat losses to the surrounding environment, through the correct construction and maintenance of the ovens' brickwork and thermal insulation;
- recovering the physical heat of 1st class flue gas, in order to preheat the combustion air;
- recovering the physical heat of the 2nd class flue gas, in order to prepare a heat carrier usable in associated processes of the same company or sellable to third parties;
- recovering the flue gas heat to preheat raw materials and materials necessary to the process;
- recovering residual heat in recovery boilers;
- recovering residual heat with or without postcombustion processes in order to simultaneously produce combined electric and thermal energy;
- recovering low potential heat (water and cooling agents) through thermal pump solutions, etc.

The managerial activities are:

- a good organisation of the production processes, with measures of optimally loading the furnace;
- reducing the idle time between the furnaces' workloads;
- monitoring the work parameters;
- the energy monitoring of technological processes;

An example of applying the solutions of enhancing the energy efficiency of the drying equipment of the household glass manufacturing process

In the following case study, the effects of heat recovery over the efficiency of a rotating sand drier, with an independent combustion chamber running on natural gas, from the glass industry, based on the energy audit analysis before and after implementing the recuperation. The heat recovery consists in preheating the combustion air until the temperature of about 300°C, based on the flue gas cooling when exiting the drier.

The thermal-energy audit was analyzed in order to improve the processes, from the energy, but also the technologic point of view. The thermal-energetic audit takes into account:

- the entering and exiting energy flows
- the energy efficiency indicators, which are predetermined as representative, are calculated for the current situation;
- the European Unions' energy efficiency indicator levels in the field;
- projects and patents related to similar or identical equipment to the ones analyzed;
- the properties of the materials which condition the improvement of the energy efficiency of the equipment integrated in the glass manufacturing process

- the technical characteristics of the measurement, control, adjustment and automation equipment (which allow better tracking and management of the processes).

The energy audit analysis, detailed in Table 1 must locate the energy losses, determine their types and causes and also establish the measures which must be applied towards optimizing the determined energy indicators.

Also the analysis must emphasize all secondary energy resources, their types, characteristics and energy potentials.

Following the analysis, the real energy indicators are determined, their level being compared to that of previous audits, to those obtained in similar situation both on both a national and an abroad level and also to those resulted from project, homologation and reception audits.

Based on the conclusions resulted from the real audit analysis a plan of measures will be elaborated. It will be comprised of all the possible technical measures of eliminating or reducing losses through: improving energy and technological processes, improving exploitation, organizing the activity, capitalizing all reusable energy resources.

In Table 1 are shown the structure, the percentage and the main energy indicators for the energy audit of the drying-preparation furnace used for manufacturing the glass, with the preheating of the combustion air.

Table 1. *The independent combustion chamber and cold air preheating ($t_{a,r} = 20\text{ }^{\circ}\text{C}$) driers' thermal audit*

Entering	Symbol	Quantity		Exiting	Symbol	Quantity	
		kJ	%			kJ	%
Gas fuel heat	Q_{cc}	310480	88.32	Dried material heat	$Q_{nis,ies}$	122400	34.82
Cold air enthalpy	Q_{ar}	850	0.24	Exiting gas chemical heat	$Q_{ch,ev}$	112000	31.86
Added chemical exothermal products' reactions	Q_{ex}	15700	4.47	Exiting gas enthalpy	$Q_{f,ev}$	67500	19.2
Entering sand heat	$Q_{nis,int}$	24500	6.97	Heat losses to the surrounding environment	$Q_{p,ma}$	49600	14.12
TOTAL entering heat	ΣQ_{intr}	351530	100	TOTAL exiting heat	ΣQ_{ies}	351500	100

Source: Authors' own research.

Based on the energy audit results, the following energetic indicators were determined:

- the combustion chamber thermal performance
- the fuel usage performance

$$\eta_t = \frac{Q_{nis,ies}}{\Sigma Q_{intr}} \cdot 100 = \frac{122400}{351530} \cdot 100 = 34.82\% ;$$

$$\eta_{ut,comb} = \frac{Q_{nis,ies} + Q_{p,ma}}{Q_{cc}} \cdot 100 = \frac{122400 + 49600}{310480} \cdot 100 = 55.4\%$$

Table 2. *The independent combustion chamber and combustion air preheating ($t_{a,r} = 20\text{ }^{\circ}\text{C}$) driers' thermal*

Entering	Symbol	Quantity		Exiting	Symbol	Quantity	
		kJ	%			kJ	%
Gas fuel heat	Q_{cc}	244500	76.57	Dried material heat	$Q_{nis,ies}$	126.6	39.67
Preheated air enthalpy	$Q_{aer\ pr}$	34600	10.83	Exiting gas chemical heat	$Q_{ch,ev}$	90500	28.36
Added chemical exothermal products reactions	Q_{ex}	15700	4.93	Exiting gas enthalpy	$Q_{f,ev}$	53500	16.77
Entering sand heat	$Q_{nis,int}$	24500	7.67	Heat losses to the surrounding environment	$Q_{p,ma}$	48500	15.2
TOTAL entering heat	ΣQ_{intr}	319300	100	TOTAL exiting heat	ΣQ_{ies}	319100	100

Source: Authors' own research.

In the case of the drier with the regenerative recuperation of residual heat from flue gas, for the preheating of combustion air the following performances, both thermal and fuel usage, have resulted:

$$\eta_t^{rec} = \frac{Q_{nis,ies}}{\Sigma Q_{intr}} \cdot 100 = \frac{126600}{319300} \cdot 100 = 39.64\% ;$$

$$\eta_{ut,comb}^{rec} = \frac{Q_{nis,ies} + Q_{p,ma}}{Q_{cc}} \cdot 100 = \frac{126600 + 48500}{244500} \cdot 100 = 71.62\%$$

The following effects have been observed, after implementing the recuperation:

- a significant reduction of gas fuel consumption, of circa:

$$\Delta B_{cc} = \frac{310480 - 244500}{8250 \cdot 4.18} = 1.92\text{ } m_N^3 / h \text{ } gas \text{ } fuel$$

- an increase in the driers' thermal performance, of about:

$$\Delta \eta_t = 39.64 - 34.82 = 4.82\%$$

- an increase in the fuel usage efficiency, of about:

$$\Delta \eta_{ut,comb} = 71.62 - 55.4 = 16.22\%$$

Conclusion

The effects of implementing the energy efficiency solutions for the drying equipment

Once entered into force, the 27/2012 Directive regarding energy efficiency, respectively the 121/2014 Law which transposes this Directive in Romania, the monitoring process of progresses made by Romania towards reaching the national energy consumption goal is based on:

- the necessity of eliminating deficiencies in elaborating the energy efficiency enhancing program, established by anterior reports;

- the necessity of supplying benchmark data, which allows the comparison of own energy performances to the branch levels of performance or to the domains' best available technologies (BAT);
- constantly supplying information regarding the possible measures of energy efficiency improvement of different types of machinery and equipment (boilers, furnaces, drive systems, etc.), which can offer additional options to those who draw up the energy efficiency improvement programs;

Generally, implementing projects on energy efficiency is done taking into account certain technical conditions, which characterise the equipment, when applying the proposed solutions. These technical conditions, can subsequently reflect economical aspects, which are quantified in the financial flows of these projects. During their lifetime, when exploiting the implemented projects, these factors can modify independently (some technical properties depreciate over time) or dependently (defectuous organizing and leadership) by those who execute the beforementioned projects. Besides the aspects of technical nature, there can also be economic and financial factors, which characterise the economic environment at a certain moment in time.

Technical and economic factors, which can modify financial flows (income and expense flows) during the project exploitation duration, can be synthesised in the following aspects:

- the modification through time of the equipments' and energy machineries' technical characteristics;
- the modification of the initial parameters and of the energy flows' characteristics (fuel, air, heat carrier, thermal energy, electric energy);
- the partial load operation of machinery and of equipment (the modification over time of the loading of technological aggregates, boilers, furnaces and turbines);
- the modification of the simultaneity degree of energy components' consumption (in the case of complex energy efficiency projects)

Reducing the highlighted losses and applying the beforementioned measures lead to an enhancement of the energy performance of the finite product, respectively to a decrease in specific consumptions of primary energy.

In the case of glass industry, the average specific energy consumption is situated to values of about 6250 kWh_t/ton. An important role in perfecting the heat recovery methods is attributed to choosing the optimal type and characteristics of the heat exchangers, through optimising the heat drops, hydraulic losses, all of them having direct effects over the primary energy consumption.

The two-phased heat recovery from the flue gas (preheating the combustion air and the simultaneous production of hot water or steam) augments the fuels' utilisation performance in sand driers and glass furnaces from 8-12% to about 16%, through regenerative recovery and to a about 20% through recovery in the form of steam or hot water.

A very efficient heat recovery solutions for glass furnaces consist in implementing a steam recoverer on the combustion gas circuit, after the regenerative preheating of the combustion air, a solution which can pair two or more machinery from the same section.

The analyzed case study shows that by implementing an energy efficiency measure, such as internal recuperation of residual heat from flue gases, can lead to different

advantages. Thus, by implementing this measure there has been reduced fuel consumption leading to fuel savings. At the same time thermal performance of dryers has increased with about 5 %. These facts also led to increase of economic efficiency and to decreasing pollutant emissions due to fuel savings.

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PICBE | 208

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