UTILISATION OF THE WASTE HEAT OF THE FLUE GAS FROM THE MELTING AND FIXING FURNACE

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Abstract

The constant increase of demand for aluminium products that are the integral part of our lives resulted in increased production of aluminium. Essential part of the aluminium industry and one of the options for sustainable development is its recycling, which has economic, technological and ecological reasons. Melting of the aluminium waste is carried out in the melting furnace. During the process, heat needs to be brought to the working area of furnace.

The aim of this paper is to analyze the options of using the waste heat from melting furnace, as a secondary source of heat, with regard to the reduction of the energy consumption in this technology process. Another aim is to evaluate the solution of the exploitation of the waste heat from this process in the recuperative heat exchanger.

Key words

aluminium scrap remelting, thermal content of flue gas, heat exchanger

Introduction

Aluminium belongs to a group of metals with medium melting temperature, generally set around 660 °C. To reach the necessary temperature of the melted alloy, we need to transform the metallic materials from the solid state into liquid and reach its overheating temperature, which is the highest temperature of melt reached in the process of melting metals and alloys. Considered maximum temperature of alloys in this case is 800 °C (1, 3, 4).

Increased demand for the aluminium products in different industrial areas has a consequence of permanently increasing demands of the market (7). It is necessary to mention that production of aluminium from its ore (bauxite) requires a high level of energy resources, so any energy saving procedure is highly welcomed. It concerns the entire process of aluminium production as well as the exploitation of the thermal capacity of the produced melted aluminium.

Aluminium and its recycling

One of the options of the aluminium production is recycling, which is in use from its first commercial implementation. Today, one third of the produced aluminium comes from recycling. Atomic structure of aluminium does not change throughout the process of melting, so it can be recycled over and over without losing its qualities. Aluminium products are collected at the end of their lifetime; however, the collected waste has to have certain level of quality before it can be melted. To reach this level of quality, we need to remove all the accompanying materials and separate the waste according to the content. Before we reuse the aluminium and its alloys, we need to look at its physical, mechanical and chemical attributes. The use of aluminium scrap eliminates the waste. Today, there is an aluminium recycling plant in each European country.

The main advantage of this process is the energy saving. During the melting process, the physical, mechanical, chemical attributes of the melted material are changed. Material changes its enthalpy; its inner structure is also changed. These material changes require the supply of considerable amount of energy. Source of this energy for the charge melting comes from the gas combustion.

Production of the secondary aluminium depends on the structure of aluminium waste. For this process, applied can be one of many melting aggregates. One of the recycling options is melting the waste in melt-fixing aggregates. In this analysis, we consider the melting of aluminium waste in a melt-fixing aggregate of SAS type with melting capacity of 35 – 40 t, burner capacity of 350 m^3h^{-1} and sizes: width 6.1 m, height 3.5 m, length 6.4 m. The fuel used is natural gas. To estimate heat consumption of the given aggregate, we need to set the furnace heat balance which allows estimating its performance and options for the energy savings (1).

Table 1 provides the basic overview of the input parameters characterizing calculated melting parameters.

OVERVIEW OF PARAMETERS CHARACTERIZING THE MELTING Table 1

Overall melting period	399	min
Charge heating period	145	min
Total gas consumption	1 059	m^3
Gas consumption during the charge heating period	605	m^3
Weight of residual melt	3 872	kg
Weight of massive type of charge	9 760	kg
Weight of thin wall type charge	3 450	kg
Weight of newly charged melt	18 390	kg
Volume of generated flue gas	11 717	m^3
Average temperature of flue gas	766	°C
Volume of combustion air per melt	10 655	m^3

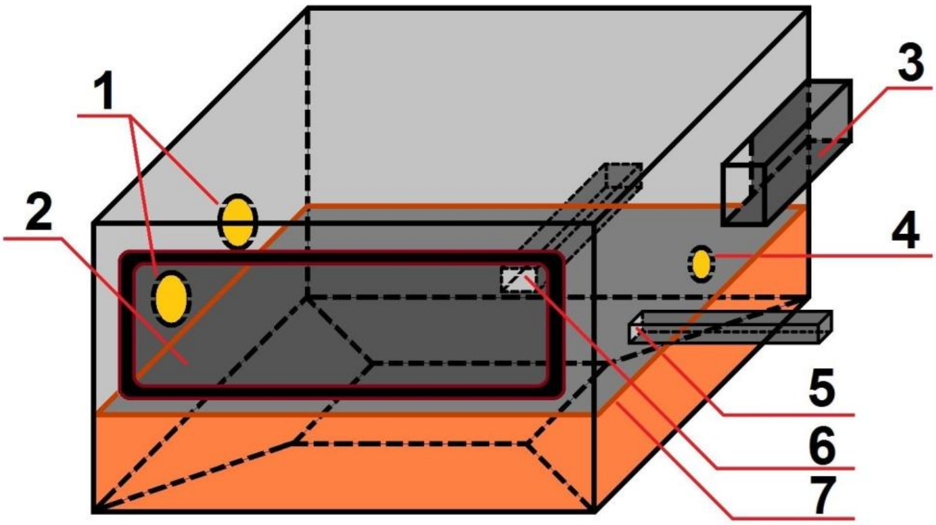

Fig. 1 *Scheme of the melting – and fixing furnace, [1]*

1. Main burners	*– supply the necessary amount of heat during the process*
2. Feed door	*– used for charging the scrap and the necessary additives*
3. Combustion gas duct	*– used for combustion gas evacuation from the furnace*
4. Auxiliary burner	*– used to ignite the main burner and maintenance of temperature*
5. Inlet hole	*– is fed through it into the furnace area of the new melt*
6. Outlet hole	*–used to drain molten metal after the processes termination*
7. Surface of the molten metal	

Melt-fixing aggregate is in a shape of a rectangular prism with the pyramidal bottom. In front of the oven, there is the charging door *(2)*, which is used for charging the aluminium waste at the beginning of the process; it is also used for adding the alloying agents, and for other technological operations such as mixing and taking samples from the surface of the melt. At the left side of oven, there are two primary burners *(1)* that are used for heating of the melting process. The heat is produced by burning the natural gas and exothermic reactions. Auxiliary burner *(4)* is placed on the right side of the furnace. It serves to ignite the main burners and maintain the temperature in the furnace area when the furnace is out of operation. On this side, there is also the combustion gas duct *(3)* which serves to evacuate the combustion gases from the furnace area after their heat exchange with feed. The inlet hole *(5)* through which the new melt is poured to the furnace is on the right side, too. Through the outlet hole *(6)* on the backside wall of the furnace, the molten metal is discharged from the tilted furnace after the melting process termination. The surface height of the molten metal is independent from the mass of the molten scrap and the melt obtained from electrolysis. Furnace walls are made up of several layers of heat-insulating material, thus preventing heat loss.

Considering that melting of aluminium is energetically a highly demanding process, the goal of this article is to analyze the possibilities of using the waste heat from the remelting process. One of the options is using the heat in the regeneration heat exchanger - preheating the combustion air. This reduces the fuel consumption for this thermal process, which has an economical significance. The reduction of heat loss is caused by the temperature of the flue gases in to the air, which has an ecological impact and leads to the mitigation of the emissions released into the atmosphere as less fuel is consumed.

Possibilities of waste heat exploitation

The base for the estimation of the usable heat for the recuperation is the law of energy conservation, which averages equality between heat input and output in the given aggregate. One of the possibilities of decreasing the heat consumption is the elimination of the heat loss by the discharged flue gas. This can be done by the heat recuperation using the heat exchanger. When considering the availability and efficiency, it is possible to gain maximum amount of heat in exchanger for the outgoing flue gas with temperature of 180 °C (1, 4). If we cooled the exiting flue gases below the temperature of the dew point, water in the form of vapour would condense. This effect should cause the corrosion of the metallic parts of the flue gas duct.

The base for the estimation of the heat available for air preheating is the stoichiometry of combustion. Input data for the calculation include the composition of natural gas and measured temperatures of flue gas. The temperature data were measured in the time interval of 1 minute and for entire 480 minutes of the melting period.

Excess of the combustion air in time periods of 1 minute, depending on measured changing O_2 values may be calculated as follows (1, 3):

$$m_\tau = 1 + \frac{V_{DFG,MIN}}{L_{MIN,AIR}} \cdot \frac{O_2}{21 - O_2} \; (-) \qquad [1]$$

- $V_{DFG,MIN}$ – minimum amount of the dry flue gas ($m^3.m^{-3}$),
- $L_{MIN,AIR}$ – minimum amount of air needed for the complete combustion ($m^3.m^{-3}$).

As mentioned above, with regard to the availability and efficiency, it is possible to gain the maximum amount of heat in exchanger for the flue gas with the temperature of 180 °C. It is the maximum possible amount of heat, which can be used in heat exchanger for air preheating and it is given by the equation:

$$\Delta Q_{FG,MAX.HEAT,\tau} = V_{NG,\tau} \cdot V_{FG,\tau} \cdot \left(t_{FG,\tau} \cdot Cp_{t_{FG,\tau}} - t_{FG,180} \cdot Cp_{t_{FG,180}} \right) (J) \qquad [2]$$

- $V_{NG,\tau}$ - natural gas consumption within the given time interval (m^3),
- $V_{FG,\tau}$ - amount of flue gas within the given time interval ($m^3.m^{-3}$),
- $t_{FG,\tau}$ - flue gas temperature within the given time interval (°C),
- $Cp_{t_{FG,\tau}}$ - specific thermal capacity of flue gas within the given time interval ($J.m^{-3}.K^{-1}$),
- $t_{FG,180}$ - flue gas temperature (180°C) (°C),
- $Cp_{t_{FG,180}}$ - specific thermal capacity of flue gas at the temperature of 180°C ($J.m^{-3}.K^{-1}$).

Exploiting the iteration procedure, it is possible to estimate the temperature of the preheated air and the temperature to which air can be heated in the given time interval:

$$t_{PH.AIR,\tau} = \eta \cdot \frac{\Delta Q_{FG,MAX:HEAT,\tau}}{V_{NG,\tau} \cdot L_{ACT.AIR,\tau} \cdot Cp_{t_{AIR,\tau}}} + \frac{Cp_{t_{AIR,20}}}{Cp_{t_{AIR,\tau}}} \cdot t_{AIR,20} \ (J) \qquad [3]$$

- η - efficiency of heat exchanger (0,95) (-),
- $L_{ACT.AIR,\tau}$ - actual amount of air needed to burn completely natural within the time interval ($m^3.m^{-3}$),
- $t_{AIR,20}$ - temperature of air (20 °C) determined for the preheating (°C),
- $Cp_{t_{AIR,\tau}}$ - specific thermal capacity of air within the given time interval ($J.m^{-3}.K^{-1}$),
- $Cp_{t_{AIR,20}}$ - specific thermal capacity of air at 20 °C ($J.m^{-3}.K^{-1}$).

Chemical heat of fuel is also released during the complete combustion of natural gas, which represents a product of the thermal capacity of natural gas and sum of its individual volumes in the given time intervals of 1 minute during the whole melting process. The heat brought by the preheated air at the income side of the balance equation is the regenerated heat.

The amount of heat from recuperation obtained by the air preheating to the average value of temperature is given as:

$$Q_{REC,AVE} = \sum_{i=1}^{n} V_{NG,\tau} \cdot L_{ACT.AIR,\tau} \cdot \left(t_{AIR,AVE} \cdot Cp_{t_{AIR,AVE}} - t_{AIR,20} \cdot Cp_{t_{AIR,20}} \right) (J) \qquad [4]$$

- $Cp_{t_{AIR,AVE}}$ - specific thermal capacity of air at the average temperature ($J.m^{-3}.K^{-1}$),
- $t_{AIR,AVE}$ - average air temperature (°C).

From the point of the current financial and material availability of acquiring the heat exchanger, it is more advantageous to preheat air to 350 °C or 300 °C, depending on the input investment expenses, what is considered in the following equation:

$$Q_{REC,350} = \sum_{i=1}^{n} V_{NG,\tau} \cdot L_{ACT.AIR,\tau} \cdot \left(t_{AIR,350} \cdot Cp_{t_{AIR,350}} - t_{AIR,20} \cdot Cp_{t_{AIR,20}} \right) (J) \qquad [5]$$

- $Cp_{t_{AIR,350}}$ - specific thermal capacity of air at the temperature of 350 °C ($J.m^{-3}.K^{-1}$),
- $t_{AIR,350}$ - selected temperature of the pre-heated air (°C).

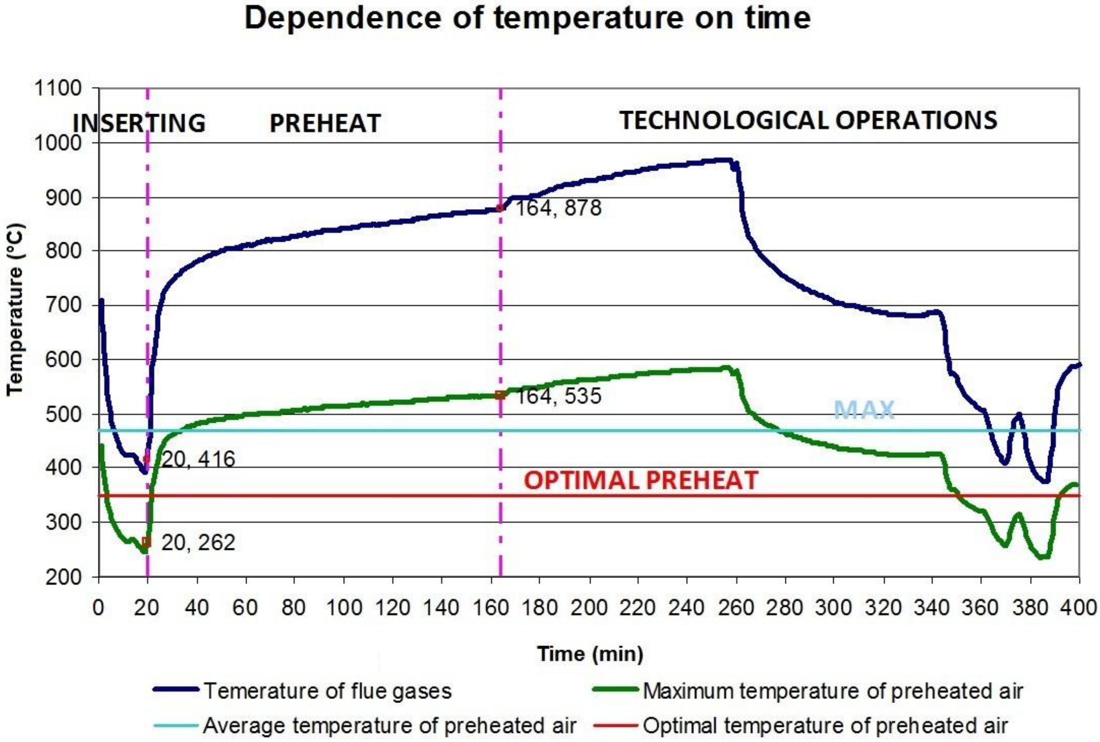

Fig. 2 *Time dependence of temperature of flue gas and preheated air*

Based on the calculated data, it is possible to construct the diagram, which shows dependence of temperature on time in three periods of the thermal process (Fig. 2):

1. charging,
2. heating,
3. technological operations.

It shows the dependence of the flue gas temperature and the maximum temperature of preheated air during three periods of one melt. Blue line represents the actual temperature of the flue gases measured at the furnace outlet or in the flue gas duct. Based on the calculations mentioned above, determined were the temperatures of the preheated combustion air during the observed melt represented by green line. The average temperature of preheated air is 414 °C, the optimum preheating temperature is 350 °C.

Using available operating methods and obtained results, the calculated data as heat content of fuel, regenerated heat during the preheating to the average temperature of around 350 °C and 300 °C, the following values were obtained:

CALCULATED RESULTS OF THE CHEMICAL AND RECOVERED HEAT Table 2

Q_{CH} (MJ)	$Q_{REC,AVER}$ (MJ)	$Q_{REC,350}$ (MJ)	$Q_{REC,300}$ (MJ)
38 058.10	9 803.75	7 904.85	6 521.55

It is obvious that the inseparable part of such production process as the aluminium melting and at the same time the main component of the operational costs, is the component including the expenses related to the natural gas consumption. Based on the measured and counted values, we can specify, that for the given thermal process lasting for 8 hours, and for one melting – consolidation aggregated, we need 1045 m^3 of natural gas. This calculation was used for three aggregates for the period of one year in use. Operational costs are given in Table 2.

SUPPLY OF NATURAL GAS AS DEPENDED ON THE FURNACE UNITS AND TIME OF OPERATION

Table 3

V_{NG}/1 AGGREGATE/MELTAGE	1 045.22	m^3
V_{NG}/3 AGGREGATES/DAY	9 406.98	m^3
V_{NG}/3 AGGREGATES/YEAR	3 433 547.70	m^3
	36 223 928.24	kWh

With current price of natural gas around 0.0508 €/kWh and based on the above calculations, we can set the operational costs and savings, using the flue gas regeneration depending on the temperature of preheated air (300 °C – 350 °C). The changes in the percentage of saved energy are given in Table 3.

RESULTS OF OPERATING COSTS AND SAVINGS Table 4

	(€)	(%)
Annual costs	1 840 175.55	100
Savings costs/ preheat to 350°C	382 213.66	20.8
Savings costs/ preheat to 300°C	315 328.44	17.1

Expenses of the company operating three melting aggregates with the natural gas consumption of 36 223 928 kWh, at the actual price of fuel, represent about 2 million EUR per year. Using the flue gas regeneration, this price can be reduced by 21% with air preheating at 350 °C and 17% with air preheating at 300 °C. However, from the economical point of view, we need to prove the return on investment, which depends on the price of the selected heat exchanger.

Conclusion

The aim o this paper was to review and analyze the possibilities of using the waste heat from process of melting the aluminium scrap in melt-fixing furnace. The analysis was carried out based on the measured data from the real industrial process. From the gained results and considering the actual process, the following solution was proposed: using the waste heat for preheating the combustion air in the implemented heat exchanger.

Based on the stoichiometry of the natural gas combustion and condensation point of the exhaust gas, the optimum temperature to which the flue gas may be cooled is 180°C. This temperature provides protection against the unwanted condensation of water vapours in heat exchanger, parts of duct system and stack.

The heat exchanger, as a technological part of production, and aluminium waste heat recycling may increase the process heat efficiency. Input costs for introducing it into production depend on the heat exchanger type and selected material. Temperature of preheated air can be set according to the financial limits. The temperature closely depends on the selected material of chosen heat exchanger. The price of material rises in proportion to the value to which the air is preheated.

Recuperation is based on heat transfer from the exiting flue gas to the air without mixing. After the summarization of findings of the energy and material balance, entering air, used as oxidant, is preheated to 300 °C, respectively to 350 °C. This process allows reusing of the waste heat, increases energy savings and reduces operating costs.

In connection to the worldwide raise of demand for the aluminium products, it is necessary to upgrade the production process and increase its efficiency. This goal may be achieved by using the highest level of recycling as a part of energy saving items in the operation costs.

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