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Fuel Consumption Reduction Strategies for Heating Steel Charge Prior to Plastic Processing

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ABSTRACT

This paper investigates strategies for reducing fuel consumption during the heating of steel charge before plastic processing. The study examines the impact of flue gas recuperation for combustion air preheating and the utilization of enthalpy from hot charge supplied by COS. We conducted calculations to analyze the effect of combustion air temperature and charge temperature at the furnace inlet on fuel consumption. Furthermore, an estimation of potential cost savings in heating is presented. The results of the calculations show that the use of recuperation and enthalpy of the hot charge allows for significant economic and ecological savings. These savings can range from more than 30% to more than 60% in economic terms.

1. INTRODUCTION

Steel products are essential for constructing infrastructure and play a strategic role in the national economy. The iron and steel industry are one of the most energy-intensive, accounting for around 5% of total global energy consumption. Scientific and industrial research worldwide aims to improve the energy efficiency of the steel industry, including reducing the energy consumption costs of reheating furnaces in rolling mills [1]. Furnaces, which heat the charge before forming, are the most energy-intensive equipment in rolling mill sections [2-4].

In recent months, natural gas prices have fluctuated on the Polish and European markets. Therefore, Russia's invasion of Ukraine could threaten uninterrupted gas supplies from abroad [5], although no such threat was anticipated [6]. The outbreak of the war in Ukraine caused a sharp increase in the price of energy carriers. In Polish steelworks, this met with an immediate reaction in the form of seeking savings in gas consumption. In addition, military operations in Ukraine resulted in a reduction in gas supplies. Security of gas supply to end-users can be ensured by introducing natural gas off-take restrictions. Reducing fuel consumption is almost the most crucial aspect of steel mill production in such a situation.

This is a priority action also due to the price competitiveness of products in the steel market.

Apart from the employed technology, the operation of heating furnaces plays a decisive role in the process of heating a steel charge. Proper operation of the furnace can ensure minimization of heat consumption, scale loss as well as ensure high quality of the final products and semi-finished products [7-9]. Increasing the efficiency of heating furnaces is possible by modeling the phenomena occurring in them [10-13], including the oxidation of the charge [14-18].

One possible measure to reduce fuel (gas) consumption is using exhaust gas waste heat for combustion air heating (recovery). This can be achieved through two methods: the use of waste heat from the exhaust gases to heat the combustion air (recuperation), and the use of enthalpy of the hot charge. The analysis of the fuel consumption reduction strategy, which is achieved by the use of recuperation and heating of the hot charge, is presented in the paper. The results of the analyzes show great opportunities to reduce gas consumption, which was the aim of the article. This may be used, for example, to convince decision makers of steelworks to implement technologies that allow the use of hot charge heating in heating furnaces.

2. RECOVERY OF EXHAUST WASTE HEAT

The exhaust gases leaving a furnace have a high temperature of more than 800°C. They are a significant source of heat, the recovery of which can significantly reduce chimney losses, thus reducing fuel consumption and heating costs [7, 19].

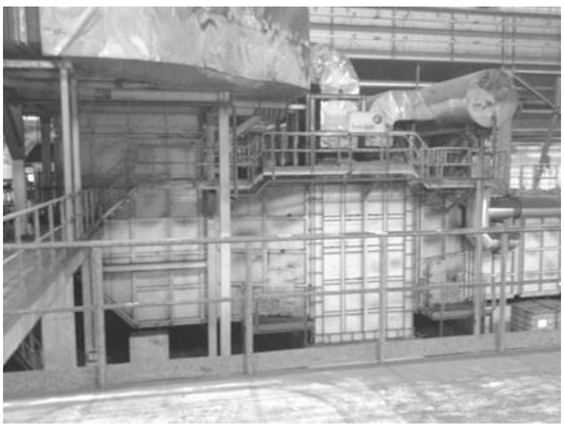

Figure 1. View of an industrial recuperator in a steelworks

The heat contained in exhaust gases is mainly used to heat up the combustion air in recuperators [19, 20] (Figure 1).

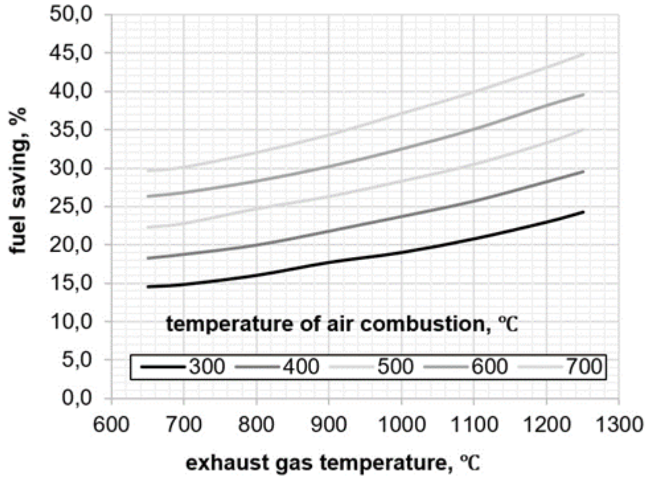

Figure 2. Possibilities of reducing fuel consumption through recuperation [19, 21]

When natural gas is used in a furnace, a heated air temperature of 600°C saves 32.5% of fuel when the exhaust gas temperature is 1000°C. If the exhaust gas temperature is 800°C and the heated air temperature is 500°C, the fuel saving is 24% (Figure 2) [7, 19, 21]. Theoretical calculations for two-stage steel briquette heating confirm that using combustion air at 600°C reduces specific heat consumption and heating costs by about 28% [22]. The use of recovery also reduces pollutant emissions, i.e., an ecological effect [23].

Recuperators operate continuously. The hot flue gases and the heated gas medium flow simultaneously through separate channels, and the heat exchange takes place through the walls separating their streams. Recuperators can be made of metal or ceramic. Metal recuperators, most often used for heating furnaces, are made of heat-resistant steel. Their operating temperatures can range from 450 to 900°C [24]. This causes restrictions in the flow of flue gases with a temperature above 900°C. The use of ceramic recuperators requires much more space in the production hall and is much more expensive.

In the case of recuperation, there are therefore temperature limitations. On the one hand, a certain flue gas temperature specified for a given recuperator cannot be exceeded, as this could damage the recuperator. If the temperature exceeds the permissible value, then the flue gases are cooled before entering the recuperator. On the other hand, there may also be a limitation of the air heating temperature caused by the materials used in the burners.

In addition, recuperators, like any device, must be periodically inspected and repaired. It is also important to clean recuperators to ensure the best quality of heat exchange surfaces.

3. HOT CHARGE HEATING

Significant savings can be made in heating steel charge by using the enthalpy of the charge entering the furnace (Figure 3). Charges with a higher temperature, up to about 700°C, can be transferred directly from the COS line to the furnace. This makes it possible to achieve technological heating conditions in about 50% less time [19].

Figure 3. Hot charge entering the furnace

Continuous casting of steel (COS) technology guarantees low costs and high quality of steel production. This process consists in supplying liquid steel to a water-cooled crystallizer with a suitable cross-section. The material from the steel ladle is poured into the tundish, which is a tank that ensures constant ferrostatic pressure of the steel. In the crystallizer, the steel solidifies, and after leaving it is cooled with water, then it goes to the roller table, where it is cut to the appropriate length using gas-air burners. This process produces semi-finished products whose cross-section corresponds to traditional ingots pre-processed into flat, rectangular and square cross-sections. The use of this method of steel casting allows for the elimination of such operations from steel production as: casting steel into ingot moulds, heating ingots in pit furnaces and preliminary rolling in a crusher type rolling mill. As a result of this solution, the energy consumption of steel production and its production costs are reduced, and the proper selection of COS parameters allows the production of semi-finished products without surface and internal defects. The most important advantages of continuous casting of steel include the elimination of long-term and costly heating of ingots [25].

When calculating the economic impact of using heat from hot charge, the primary consideration is the fuel savings in the furnaces, which are directly reflected in the unit value of heat consumption. The use of hot charge enthalpy in the heating process can reduce specific heat consumption by about 25% [21]. Studies at Mobareke Steel Company show that hot charging can reduce energy consumption by 40% [26].

The possibilities associated with hot charge heating are also described in the study [27].

Heating the hot charge requires adapting the heating furnace and its fittings to much higher temperatures than in the case of the cold charge. First of all, a new charge heating technology dependent on the charge temperature at the entrance to the furnace should be implemented. The heating curves must correspond to the initial charge temperature measurement signal before entering the kiln. In addition, a number of protection devices, instruments and furnace fittings against high temperatures should be introduced. The high-temperature radiant charge could damage electrical wiring, plumbing, and other kiln instrumentation. It is therefore necessary to adequately insulate all kiln auxiliary equipment exposed to high temperatures.

4. CHARACTERISTICS OF ANALYZED HEATING UNITS

In the paper, in order to improve the economic efficiency of steel charge preheating technology, a walking beam furnace (furnace No. 1) and a pusher furnace (furnace No. 2) were subjected to analysis of the possibility of using exhaust waste heat. These are the two types of furnaces most commonly used in rolling mill departments in steelworks. These furnaces are used to heat steel charge. In this case, the source of heat is the combustion of natural gas. Characteristic data for the analyzed units are presented in Table 1.

The list of parameters of the furnaces allows for a possible analysis of their impact on possible savings in fuel consumption in the context of the calculations carried out.

Table 1. List of parameters of analyzed furnaces

Characteristic parameter	Furnace No. 1	Furnace No. 2
Nature of continuous	work	work
The furnace is designated	for heating the charge before rolling	for heating the charge before rolling
Fuel type	natural gas PN-C-04753-E (formerly GZ-50)	natural gas PN-C-04753-E (formerly GZ-50)
Initial charge temperature, °C	20; 300; 400; 500; 600; 700	20; 300; 400; 500; 600; 700
Final charge temperature, °C	1180	1250
Final temperature difference in cross-section, K	50	50
Type of heated charge	medium carbon steel	medium carbon steel
Dimensions of heated charge	160 x 160 x 14000	250 x 250 x 3400
Number of pieces of charge in furnace	70	176
Unit weight of heated charge, kg	3000	1670
Total weight of heated charge in furnace, t	210	294
Average time of charge heating, min	71	176
Average furnace efficiency, t/h	175	100
Outer surface area of furnace, m^2	1004	740
The temperature of exhaust exiting the furnace, °C	830	950
Average outside furnace temperature, °C	126	150
Average ambient furnace temperature, °C	28	30

5. METHODOLOGY OF CALCULATIONS

The following composition of natural gas supplied to the heating furnaces was used for the calculations: CH_4 - 95.5%; C_2H_6 - 1.4%; C_3H_8 - 0.2%; N_2 - 2.9%. It was assumed that the combustion process is carried out with the value of excess air ratio $\lambda = 1.05$. Combustion calculations were carried out using an authorial computer program.

The computer calculation program "Program for calculations of gas combustion with excess air" allows to determine the basic values characteristic for the combustion of gaseous fuels with the value of the ratio of excess air $\lambda \geq 1.0$. The program was created for calculations related to didactic activity at the Faculty of Production Engineering and Materials Technology of the Częstochowa University of Technology, but it can also be used for simple calculations in research work.

The scheme of the calculation methodology is presented in Figure 4 and described in detail in study [8].

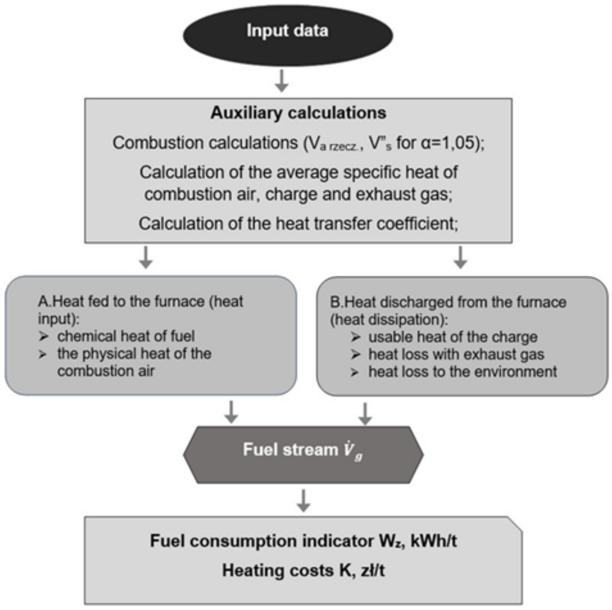

Figure 4. Scheme of the calculation method

6. CALCULATION RESULTS AND THEIR ANALYSIS

Based on the dependencies concerning the combustion process and those related to heat losses to the environment, the values presented in Table 2 were determined.

Summary of results of specific heat of steel charge and useful heat of steel charge presented in Table 3.

The specific combustion air and exhaust gas temperature was calculated for varying combustion air temperatures. The results are presented in Table 4.

In accordance with the adopted scheme, the gas stream, the chemical heat of the gas, the physical heat of the combustion air and the heat losses with the exhaust gases were determined for the variable values of the combustion air temperature and for different charge temperatures at the entrance to the furnace. The results are summarized in Tables 5-10.

Table 2. Calculation results concerning the combustion process and heat losses to the environment

Actual Combustion Air Demand, m^3 p/ m^3 g	Volume of Humid Exhaust Gas Generated in the Combustion Process, m^3 sp/ m^3 g	Calorific Value of Fuel, J/m^3	Coefficient of Heat Transfer through the Walls and Ceiling, W/($m^2 \cdot$ K)	Heat Losses to the Environment, W
		Furnace No. 1		
9.845	10.854	34851000	12.418	1221831,86
		Furnace No. 2		
9.845	10.854	34851000	13.450	1194360,00

Table 3. Summary of results of specific heat of steel charge and useful heat of steel charge

Initial Temperature of Charge Entering Furnace, °C	Specific Heat of Steel Charge, J/(kg· K)	Useful Heat of Steel Charge, W
	Furnace No. 1	
20	549	30964654,86
300	600	25664345,33
400	605	22942507,33
500	618	20416397,43
600	637	17960378,42
700	659	15376147,08
	Furnace No. 2	
20	554	18948050,46
300	605	15975864,07
400	611	14415364,24
500	623	12981170,07
600	642	11600289,83
700	664	10151154,96

Table 4. Summary of results of specific heat of combustion air and gas exhaust

Combustion Air Temperature, °C	Specific Heat of Combustion Air, J/(m ^{3}· K)	Specific Heat of Gas Exhaust, J/(m ^{3}· K)
20	1290	1359
300	1322	1417
400	1334	1442
500	1346	1469
600	1358	1498
700	1369	1529

Table 5. Summary of results of gas stream, chemical gas heat, physical heat of combustion air and heat loss of the exhaust gases for charge temperature at the furnace inlet 20°C

Combustion Air Temperature, °C	Gas Stream, m^3 /s	Chemical Gas Heat, W	Physical Heat of Combustion air, W	Heat Loss of the Exhaust Gases, W
		Furnace No. 1		
20	1.892	65940820,95	480589,78	23164688,90
300	1.648	57434038,01	6434614,56	21037390,43
400	1.575	54907358,56	8276502,47	20466730,80
500	1.509	52589498,59	9998033,11	19969789,70
600	1.448	50455608,90	11613441,81	19537722,21
700	1.392	48496670,67	13128463,15	19167791,47
		Furnace No. 2		
20	1.322	46058529,21	335683,70	18519433,63
300	1.139	39693343,52	4447038,29	16641241,05
400	1.086	37840005,98	5703842,09	16144129,60
500	1.037	36153754,29	6873357,65	15713516,15
600	0.993	34612970,41	7966918,38	15340830,20
700	0.953	33208631,13	8989860,21	15022998,99

Table 6. Summary of results of gas stream, chemical gas heat, physical heat of combustion air and heat loss of the exhaust gases for charge temperature at the furnace inlet 300°C

Combustion Air Temperature, °C	Gas Stream, m^3 /s	Chemical Gas Heat, W	Physical Heat of Combustion air, W	Heat Loss of the Exhaust Gases, W
		Furnace No. 1		
20	1.581	55082016,62	401448,66	19350043,88
300	1.377	47976088,11	5374994,44	17573058,28
400	1.316	45865489,59	6913569,47	17096372,02
500	1.260	43929323,19	8351607,06	16681264,69
600	1.209	42146831,78	9700998,35	16320347,91
700	1.162	40510481,69	10966533,55	16011335,51
		Furnace No. 2		
20	1.127	39262195,97	286150,67	15786731,47
300	0.971	33836248,33	3790839,44	14185682,40
400	0.926	32256386,73	4862190,99	13761924,03
500	0.884	30818956,02	5859134,45	13394851,32
600	0.847	29505528,09	6791330,86	13077158,39
700	0.812	28308411,18	7663328,80	12806225,92

Table 7. Summary of results of gas stream, chemical gas heat, physical heat of combustion air and heat loss of the exhaust gases for charge temperature at the furnace inlet 400°C

Combustion Air Temperature, °C	Gas Stream, m^3/s	Chemical Gas Heat, W	Physical Heat of Combustion air, W	Heat Loss of the Exhaust Gases, W
		Furnace No. 1		
20	1.420	49505756,18	360807,77	17391130,78
300	1.237	43119200,54	4830853,71	15794039,36
400	1.183	41222269,69	6213670,18	15365610,72
500	1.133	39482112,25	7506127,20	14992527,02
600	1.087	37880072,40	8718912,06	14668147,87
700	1.045	36409379,18	9856330,06	14390418,52
		Furnace No. 2		
20	1.024	35693887,9	260144,13	14351969,08
300	0.883	30761072,4	3446312,52	12896429,87
400	0.841	29324795,1	4420295,29	12511184,38
500	0.804	28018003,9	5326632,47	12177472,73
600	0.770	26823945,6	6174107,08	11888653,03
700	0.738	25735627,6	6966854,30	11642344,00

Table 8. Summary of results of gas stream, chemical gas heat, physical heat of combustion air and heat loss of the exhaust gases for charge temperature at the furnace inlet 500°C

Combustion Air Temperature, °C	Gas Stream, m^3/s	Chemical Gas Heat, W	Physical Heat of Combustion air, W	Heat Loss of the Exhaust Gases, W
		Furnace No. 1		
20	1.272	44330486,13	323089,37	15573083,64
300	1.108	38611573,05	4325842,29	14142950,17
400	1.059	36912945,00	5564100,85	13759308,92
500	1.014	35354701,44	6721446,01	13425226,93
600	0.973	33920136,85	7807447,86	13134757,97
700	0.936	32603188,06	8825961,60	12886062,10
		Furnace No. 2		
20	0.930	32414395,84	236242,55	13033335,25
300	0.802	27934798,85	3129671,35	11711528,44
400	0.764	26630484,15	4014166,29	11361678,63
500	0.730	25443758,68	4837230,79	11058627,82
600	0.699	24359408,42	5606840,91	10796344,37
700	0.671	23371083,12	6326751,91	10572665,79

Table 9. Summary of results of gas stream, chemical gas heat, physical heat of combustion air and heat loss of the exhaust gases for charge temperature at the furnace inlet 600°C

Combustion Air Temperature, °C	Gas Stream, m^3/s	Chemical Gas Heat, W	Physical Heat of Combustion air, W	Heat Loss of the Exhaust Gases, W
		Furnace No. 1		
20	1.128	39298812,09	286417,54	13805481,08
300	0.982	34229016,79	3834843,20	12537673,04
400	0.939	32723189,29	4932554,83	12197576,50
500	0.899	31341812,14	5958537,05	11901414,05
600	0.863	30070075,93	6921273,67	11643914,39
700	0.829	28902605,70	7824182,33	11423446,42
		Furnace No. 2		
20	0.839	29256813,84	213229,46	11763719,58
300	0.723	25213587,62	2824800,83	10570673,87
400	0.690	24036330,07	3623134,50	10254903,97
500	0.659	22965207,03	4366021,86	9981374,24
600	0.631	21986486,52	5060661,99	9744640,59
700	0.605	21094436,91	5710444,32	9542751,20

From Table 3, it can be seen for both furnaces that the useful heat of the charge decreases as the initial temperature of the charge at the furnace inlet (t'_w) increases. By analyzing Tables 5-10, it can be observed that as the combustion air temperature (t_p) increases, the physical heat of the combustion air increases, and the heat loss carried by the flue gas decreases. As the combustion air temperature (t_p) increases steadily, the chemical heat of the fuel at the furnace entrance (t'_w) decreases. This is due to a reduction in gas consumption.

Summary calculations were also performed for both furnaces on the effects of furnace inlet charge temperature and combustion air temperature on the fuel consumption rate (Figures 5 and 6). A conversion factor of E=10.972 was used for the calculations based on the standard heat of combustion of natural gas [28].

The heating cost per 1t of steel was calculated assuming a gas price of PLN 0.1094 per kWh [8]. The results are presented in Figures 7 and 8.

Table 10. Summary of results of gas stream, chemical gas heat, physical heat of combustion air and heat loss of the exhaust gases for charge temperature at the furnace inlet 700°C

Combustion Air Temperature, °C	Gas Stream, m^3 /s	Chemical Gas Heat, W	Physical Heat of Combustion air, W	Heat Loss of the Exhaust Gases, W
		Furnace No. 1		
20	0/976	34004467,99	247831,31	11945603,81
300	0/850	29617676,56	3318212,33	10848595,14
400	0.812	28314714,46	4268040,03	10554316,47
500	0.778	27119436,72	5155801,70	10298053,08
600	0.747	26019029,08	5988838,24	10075243,83
700	0.718	25008840,68	6770106,87	9884477,35
		Furnace No. 2		
20	0.744	25943157,8	189078,88	10431348,90
300	0.642	22357871,4	2504861,05	9373428,75
400	0.612	21313951,2	3212774,65	9093423,26
500	0.584	20364144,6	3871521,84	8850873,78
600	0.559	19496275	4487486,33	8640952,82
700	0.537	18705259,8	5063673,67	8461929,62

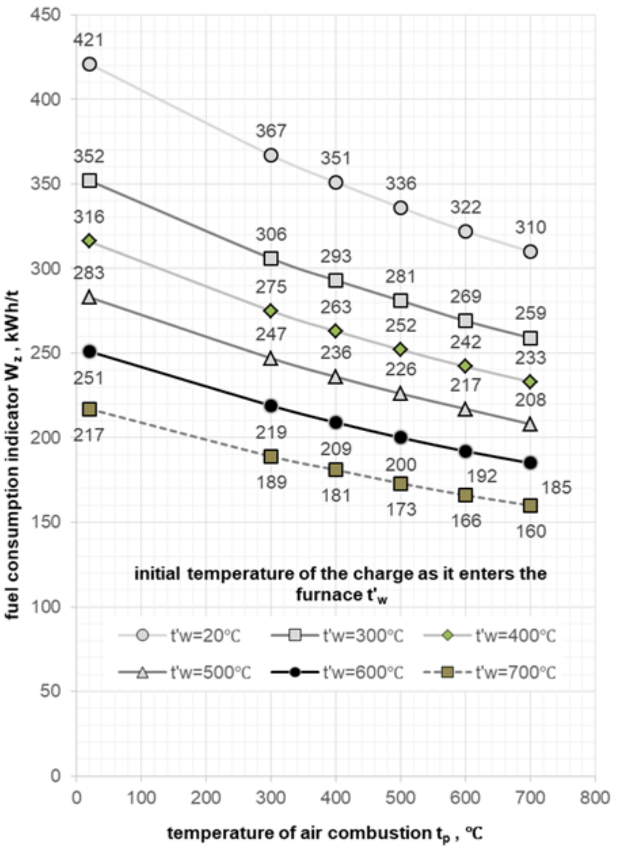

Figure 5. Effect of furnace inlet charge temperature and combustion air temperature on the fuel consumption meter - furnace No. 1

Analyzing Figure 5 and Figure 6, it can be observed that as combustion air temperature (t_p) increases, the fuel consumption index (W_z) decreases. It also decreases with an increase in the initial temperature of the charge at the furnace inlet (t'_w).

If reference temperatures of t_p =20°C and t'_w =20°C, are assumed, then:

- heating the air to t_p =400°C results in a reduction of the fuel consumption rate W_z by 70 kWh/t for furnace no. 1 and by 93 kWh/t for furnace no. 2,
- heating of the charge at t'_w =400°C results in a reduction of the fuel consumption rate W_z by 105 kWh/t for furnace no. 1 and by 117 kWh/t for furnace no. 2,
- heating the air to t_p =400°C and heating the charge by t'_w=400°C results in lowering the fuel consumption rate W_z by 158 kWh/t for furnace no. 1 and by 189 kWh/t for furnace no. 2,
- heating the air to t_p =700°C and heating the charge at t'_w=700°C results in lowering the fuel consumption rate W_z by 261 kWh/t for furnace no. 1 and by 309 kWh/t for furnace no. 2.

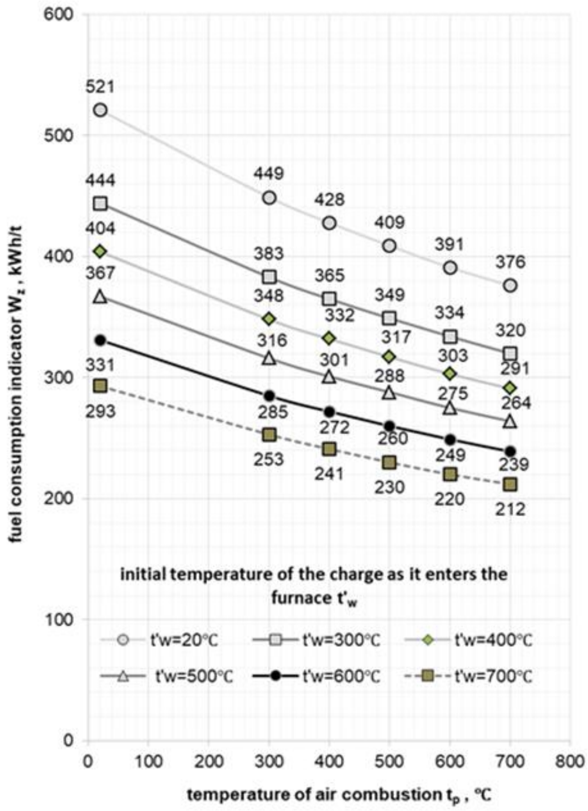

Figure 6. Influence of furnace inlet charge temperature and combustion air temperature on the fuel consumption indicator - furnace No. 2

On the other hand, assuming reference temperatures of t_p=400°C and t'_w =400°C, then heating the air to t_p =700°C and heating the load by t'_w =700°C results in a reduction of the fuel consumption rate W_z by 103 kWh/t for furnace 1 and by 120 kWh/t for furnace 2.

By analyzing Figure 7 and Figure 8, it can be concluded that combustion air temperature increases (t_p) the heating costs (K) decrease. They also decrease as the initial charge temperature at the furnace inlet (t'_w) increases.

Assuming reference temperatures of t_p =20°C and t'_w =20°C, then:

- heating the air to t_p =400°C results in the reduction of K heating costs by PLN 7.71/t for furnace no. 1 and by PLN 10.17/t for furnace no. 2,
- heating of the charge with t'_w =400°C results in lowering of the heating costs K by 11.48 PLN/t for the furnace no. 1 and by PLN 12.82/t for furnace no. 2,
- heating the air to t_p =400°C and heating the charge with t'_w =400°C results in lowering the cost of heating K by PLN 17.27/t for the furnace no. 1 and by PLN 20.70/t for the furnace no. 2,
- heating the air to t_p =700°C and heating the charge to t'_w =700°C results in lowering the cost of heating K by PLN 28.60/t for furnace no. 1 and by PLN 33.84/t for furnace no. 2.

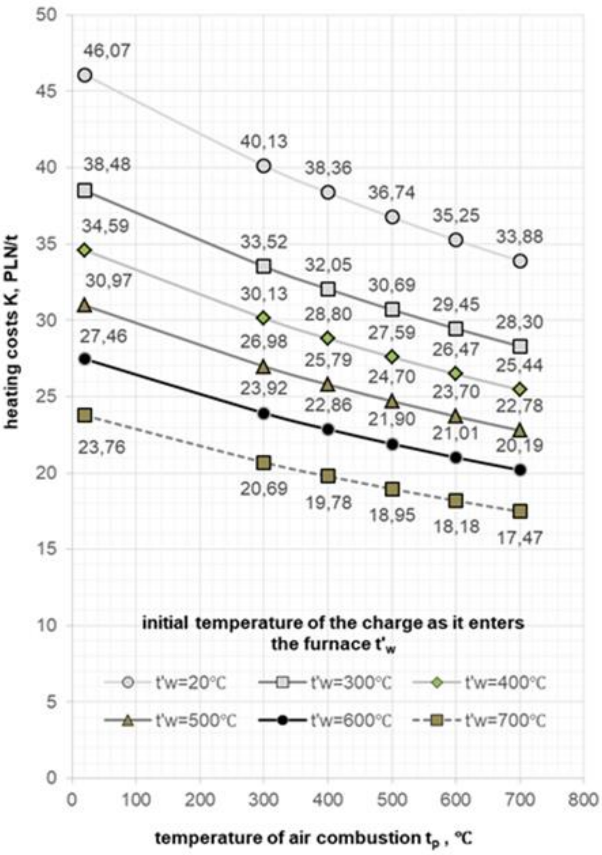

Figure 7. Effect of furnace inlet charge temperature and combustion air temperature on heating costs - furnace No. 1

Assuming, in turn, the reference temperatures at t_p =400°C and t'_w =400°C, then heating the air to t_p =700°C and heating the charge by t'_w =700°C results in a reduction of the heating cost K by PLN 11.33/t for furnace no. 1 and by PLN 13.14/t for furnace no. 2.

The study also determined the savings resulting from the use of heated combustion air and/or the use of hot charge. It was assumed that furnace No. 1 heats 600,000 tons of feedstock per year, while furnace No. 2 heats 400,000 tons of feedstock per year.

For a reference temperature of t_p =20°C and t'_w =20°C, then:

- heating the air to t_p =400°C results in annual savings in the order of PLN 4.63 million for furnace no. 1 and PLN 4.07 million for furnace no. 2,
- heating of the charge at t'_w =400°C results in annual savings of PLN 6.89 million for furnace no. 1 and PLN 5.13 million for furnace no. 2,
- heating the air to t_p =400°C and heating the charge at t'_w=400°C results in annual savings of PLN 10.36 million for furnace no. 1 and PLN 8.28 million for furnace no. 2,
- heating the air to t_p =700°C and heating the charge at t'_w=700°C results in annual savings of PLN 17.16 million for furnace no. 1 and PLN 13.54 million for furnace no. 2.

Assuming, in turn, reference temperatures of t_p =400°C and t'_w=400°C, then heating the air to t_p =700°C and heating the charge by t'_w =700°C results in annual savings of PLN 6.80 million for furnace no. 1 and PLN 5.26 million for furnace no. 2.

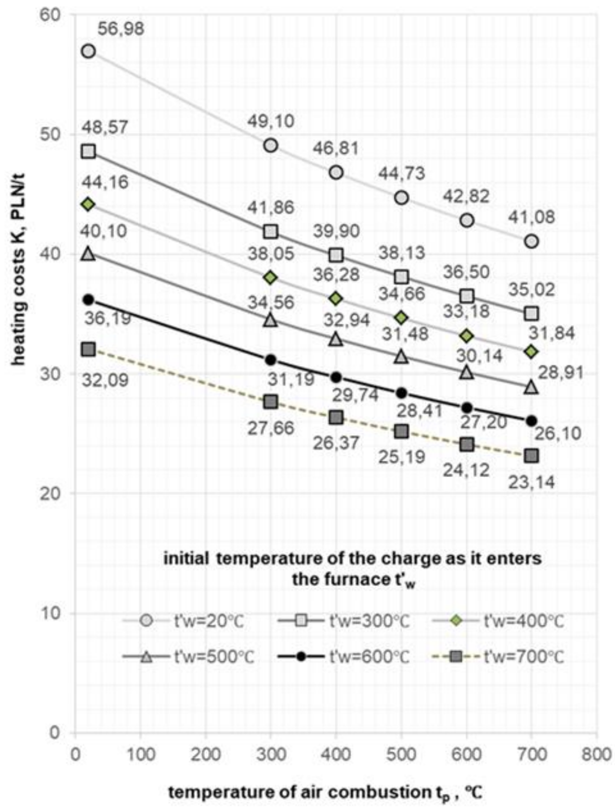

Figure 8. Effect of furnace inlet charge temperature and combustion air temperature on heating costs - furnace No. 2

7. CONCLUSIONS

Steelworks use large amounts of energy from gaseous fuel to heat the charge before rolling. Given the current geopolitical and economic situation on the gas market, all solutions to reduce gas consumption should be sought at this time.

Analyzing the results of the calculations, it can be concluded that using recuperation and hot charging enthalpy will significantly reduce fuel consumption and thus bring economic and environmental savings. The selected options (reference temperatures t_p =20°C and t'_w =20°C), it is possible to reduce the fuel consumption index (W_z) and heating costs (K):

- heating the air to t_p =400°C and heating the charge at t'_w=400°C by 37% for furnace 1 and by 36% for furnace 2,
- heating the air to t_p =700°C and heating the charge at t'_w=700°C by 62% for furnace 1 and 59% for furnace 2.

As gas prices are expected to continue to rise (up to 400-1000%), different fuel-saving options should be analyzed. Other considerations could include replacing air with oxygen in the combustion process or removing the reheating furnaces, and feeding the mill charge directly from the COS.

The considerations carried out in the work show that the use of recuperation and hot charge brings the expected effect in the form of reducing fuel consumption. The results of individual balance calculations show that with the increase in the temperature of the heated air, the chemical heat supplied to the furnace decreases, because it is replaced by the physical heat of the air. In the case of an increase in the temperature of the charge at the entrance to the furnace, the chemical heat also decreases, because the temperature gradient by which the charge must be heated decreases.

A similar reduction is achieved in the case of gas consumption (Vg, m^3).

The presented solutions can be successfully used in steelworks. In many steelworks, they are already used, but not on such a large scale, because the temperature limitations regarding recuperation prevent the full use of exhaust gas waste heat. In the case of using a hot charge, such solutions also work, but due to the small capacity of the steel plant, and thus also the COS, the enthalpy of the hot charge cannot be used to the full extent. A certain limitation here is also the transport of hot charge and temperature losses of the charge during transport. Further research work should be aimed at solving the problems limiting the presented trends in fuel consumption reduction.

It should also be remembered that the natural gas in question consists mainly of hydrocarbons, the combustion of which causes the release of CO_2 into the atmosphere. Every 1 m^3 of natural gas generates over 1 m^3 of CO_2, which means that by reducing gas consumption by an average of 50%, greenhouse gas emissions from the charge heating process are also reduced by 50%.

However, feeding the batch directly from COS is possible only with a long-term and unchanging assortment over time. Such solutions function in mini mills operating in the USA, where one assortment is rolled for at least several days. In Polish conditions, steel mills cannot afford such solutions, at least at present, hence the need to modify and improve the heating technology.

The introduction of oxycombustion, i.e., combustion with oxygen-enriched air, still requires much research. However, these are very difficult tasks to accomplish, if only due to the fact that every percentage of additional oxygen in the air raises the combustion temperature. Its uncontrolled growth may cause overheating of the charge or damage to the burners.

There are a number of problems in the steel industry that limit the possibilities of reducing fuel consumption, however, research should be successively conducted that will show specific economic and ecological benefits and will convince the steelworks authorities to new solutions.

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