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TECHNOLOGICAL INFORMATION

A case study-the effects of waste heat recovery applications on energy consumption, cost, and greenhouse gas emissions in the wheels production process

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ABSTRACT. The aim of this article is to present the effect of waste heat recovery applications in a wheel heat treatment process on energy consumption, cost, and greenhouse gas emissions. Within the scope of the study, two energy recovery applications were made. Instead of the heat needed in the aging furnace, the waste heat in the solution furnace was recovered and used, in the other application, the waste heat was used to pre-heat the burner supply air. Thus, the results of deactivating the burner system to be used for the heating process in the aging section, as well as the savings achieved by this method and the reduction in unit product cost, were evaluated. Thanks to the savings made to reach the zero-carbon footprint target, the carbon footprint has been reduced. By using the waste heat in the aging furnace, 762.659 MJ $hour^{-1}$ of energy was saved, and the return on investment was 482.8%. The amount of savings achieved by preheating the burner supply air was determined as 641.022 MJ $hour^{-1}$. The return-on-investment value was realized as 1116.1%. Thanks to the natural gas savings, 538 tons of CO_2 equivalent greenhouse gas emissions are prevented every year.

Keywords: Energy efficiency; waste heat recovery; aluminum wheels.

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Introduction

The efficient use of energy aims not to reduce the amount of energy used, but to reduce the energy consumed per product. From the point of view of industrial enterprises, efforts to increase energy efficiency save on fossil fuel costs, contribute to the efficient use of existing resources, and reduce environmental pollution (Terzi, 2011; Simsek et al., 2013; Rasmussen, 2017). The production sector of aluminum and aluminum products is one of the most energy-intensive sectors in the industrial field (Brough & Jouhara, 2020). The melting or heat-treating processes of materials require high temperatures. In addition, moderate temperatures are used to change crystal structures and chemically change the surface compounds of metals. These processes include aging, annealing, carburizing, hardening, and tempering (Milford et al., 2011; Tabereaux & Peterson, 2014; Kvande, 2015; European Commission. Joint Research Centre., 2018; Haraldsson & Johansson, 2018). Aluminum alloys are used as raw materials in the wheel industry. These alloys are subjected to solving, quenching, and aging processes, in which the mechanical properties and machinability properties of the products are improved in aluminum aging and solution heat treatment furnaces. Due to the high energy requirement, the aluminum production process is open to the development of new applications that will reduce energy use or allow the use of waste energy (Brückner et al., 2015; Miró et al., 2016; Rakib et al., 2017; Jouhara et al., 2018; Saghafifar et al., 2019; Thekdi et al., 2021).

In addition to energy consumption in the aluminum processing industry, greenhouse gas emissions are also one of the important issues to be examined (International Energy Agency [IEA]., 2021). According to 2012 data, the shares of the aluminum industry in total CO_2, airborne particles, NO_x, and SO_2 pollution were again determined as 3.53, 1.99, 3.47, and 5.34 %, respectively (Zhang et al., 2016). It is aimed to reduce greenhouse gas emissions by at least 75% per ton of aluminum produced by 2050 (Cullen & Allwood, 2013). Many applications have been carried out both to save energy and to minimize harmful environmental effects. In a study, the energy required for the aging furnace was provided by the existing old burners at a rate of 41.6% and by the waste heat recovery system at a rate of 58.4% (Bonilla-Campos et al., 2019). Waste heat recovery application was carried out in aluminum automotive part production facility, steel foundry, and ceramic tile production facilities in different countries, respectively 135, 600, and 797 tons year^{-1} CO_2 emission reduction, primary energy savings of around 597, 3020 and 4003 MWh year^{-1} have been achieved (Egilegor et al., 2020). Heat recovery studies are important and promising for the steel industry (Ma et al., 2016; Jouhara et al., 2018). The efficiency studies carried out in industrial furnaces, it has allowed the efficient re-use of waste heat, thus reducing energy consumption, reducing energy costs by 70%, and reducing CO_2 emissions by 60% (Scharf et al., 2018). With the low-temperature recovery technology developed for the automobile industry, the flue gas temperature was reduced from 160 to 110°C (Chang et al., 2018). In another study, a waste heat recovery system for the aging furnace was designed and it was observed that the natural gas consumption resulting from the heat treatment was reduced by about 3 to 14% (Bonilla-Campos et al., 2019).

Within the scope of this study, a methodology was developed to increase the energy efficiency of the system by recovering the waste heat generated in the aluminum heat treatment furnace used during wheel manufacturing with two different methods. The first step of the methodology is to determine the homogeneous temperature distribution and existing losses by taking temperature measurements inside and outside the solution and aging furnace, and to eliminate the problems. In the second step, the energy balance is created according to the measurement values taken for both furnaces and an initial state analysis is performed. In the next stage, two improvement methods are recommended to improve the energy efficiency of the system. As the first method, waste heat was used to obtain the heat needed in the aging furnace, and as the second method, it was used to preheat the inlet air of the burners used in the solution furnace. Finally, for the situation before and after the application, efficiency studies were carried out by making measurements in a T6 type heat treatment furnace for 18” wheels, furnace consumption data were examined, investment payback periods were calculated, and the carbon footprint to be reduced with this application was calculated.

According to the results obtained, this paper wishes to contribute to the dissemination of energy savings through waste heat recovery practices in such industries and to help minimize harmful environmental impacts.

Material and Method

Heat treatment furnace

The products fed to T6-type heat treatment furnaces were preheated at 540°C. Afterward, the heated products were quenched by immersing them in the quenching pool at a temperature of approximately 80°C. In the next process, the same products were artificially aged in the aging furnace at a temperature of approximately 208°C. This process was done to improve the mechanical and machinability properties of the products. Heating processes were carried out using natural gas-fired burners in the heat treatment furnaces.

Waste heat recovery system

The schematic drawing of the waste heat recovery system is shown in (Figure 1). As seen in (Figure 1), it is the product flow direction shown with the blue dashed line. The products first enter the solution furnace, then they are taken to the quench pool for quenching, after waiting for approximately 2 minutes, they are taken to the aging furnace and separated from the process.

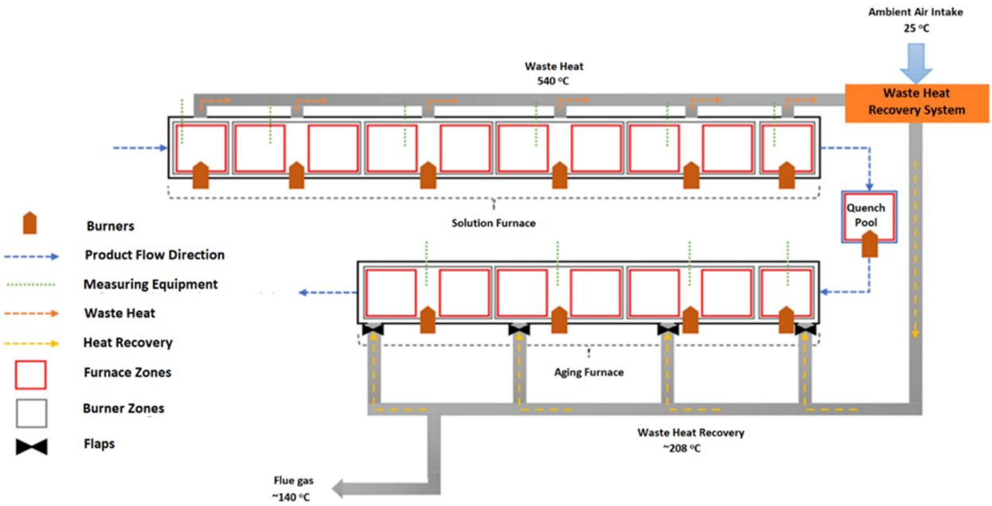


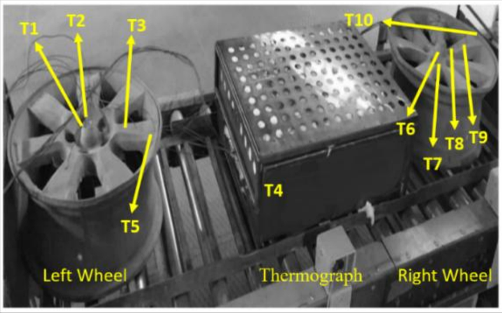
Figure 1. Use of waste heat from the solution furnace in the aging furnace.

The burners are operated automatically according to the temperature values measured by the K-type thermocouple equipment, shown with the green dashed line, and the temperature values set by the PLC control system. Waste heat (orange dashed line) collected by the waste heat recovery system at a temperature of 540ºC is mixed with the air at ambient temperature using PLC-controlled flaps. The air entering the aging furnace at a temperature of approximately 208°C is indicated by the yellow dashed line. The surplus waste heat is given to the atmosphere through the chimney.

Measurement method and devices used in measurements

Values such as speed, temperature, and flow rate were measured in the aging furnace, and the measured data were recorded with the meters used. Energy analysis was carried out using the measured values and the data obtained from the meters. The natural gas data used as fuel in the furnace was taken from the natural gas meter. Flue gas measurements were made using a Testo brand 330LL-2 model analyzer. Flue gas flow measurements were made using the Environmental Supply brand C-5000 model device.

Furnace temperature measurements to determine whether the temperature distribution in the furnace is homogeneous were made using K-type thermocouples placed on Phoenix brand PTM1-220HT type thermograph. The thermograph device used in the measurements was sent into the furnace by connecting a total of 10 K type thermocouples on 2 wheels and setting it to record automatically every 5 seconds, and the measurement was ensured. The Thermograph experiment set is passed through the solution and aging zones of the heat treatment furnace sequentially. The thermograph device collects data for a total of 360 minutes, approximately 180 minutes in each oven. In (Figure 2), the channel numbers and naming of the thermocouple equipment connected to the products are shown. Solution and aging furnaces consist of 3 floors. For this reason, the thermograph device is sent into the furnace separately from each floor.



Kanal	Adı
1	Left Hub Hole
2	Left Bolt Hole
3	Left Middle of the Disc
4	Air Temperature Probe
5	Left Rim Flange
6	Right Hub Hole
7	Right Bolt Hole
8	Right Middle of The Disc
9	Right End of The Disc
10	Right Rim Flange

Figure 2. Temperature measuring points on the wheel.

Energy saving potentials

Energy saving potential in the heating process of the aging furnace with waste heat recovery method

In the aging furnace, the desired temperature value is reached by using a total of 4 burners, 3 of which are 90 kW and 1 each with 230 kW. With the waste heat recovery system, it is planned to use the waste heat at 540°C used in the solution furnace in the aging zone due to the process needs. Since the waste heat temperature value to be transferred is above the desired temperature value, fresh air supply was added to the waste heat recovery system at an average temperature of 25°C. Fresh air mixture is realized with the help of PLC-controlled flaps. The flaps operate according to the temperature values measured by the thermocouples in the furnace. When the recovered waste heat energy exceeds the requirement of the aging section, the system automatically closes all the flaps and discharges the waste heat from the chimney.

In the transmission lines used for the transfer of waste heat, the internal air duct was manufactured from 1.4307 / DIN X2CrNi18-9 – AISI 304L material with a diameter of 300mm. To prevent heat losses, 180mm thick ceramic fiber insulation was made around the pipe, and it was covered with a 1mm galvanized coating for insulation purposes. In the energy saving potential calculations, it is foreseen that the annual operating time of the furnace will be 24 hours and 300 days a year.

Energy saving potential in the burner inlet air pre-heat process using waste heat

It is planned to increase the burner combustion efficiency by preheating the inlet air of the burner. Of the burners with an installed power of 2360 kW on the heat treatment furnace, those with a capacity of 500 kW are used in the aging furnace, those with a capacity of 1710 kW are used in the solution furnace and a burner with a capacity of 150 kW is used in the quenching pool. The installed power of the burner, which is included in the pre-heating savings calculation of the burner air fan, consists of only 6 burners with a capacity of 1710 kW serving the solution furnace. Since the burners used in the aging furnace were decommissioned by the waste heat recovery system and burner used in the quenching pool had a low capacity, it was not considered in this saving method. The new efficiency value of the burners after preheating was calculated using Equation 1 The IE (coefficient of increase efficiency) value used here is taken as 2800 (Kanoglu & Cengel, 2019).

$$\eta_{burner,H} = \eta_{burner,L} + \frac{\Delta T}{IE} \quad (1)$$

Calculations assume that the facility will operate 24 hours a day and 300 days a year. In the calculation of fuel savings due to the increase in efficiency, the natural gas heating value is taken as 37.98 MJ Nm^{-3} in the conversion of the MJ unit to the kWh value, which is the electricity bill unit price. The conversion of the natural gas unit from Nm^3 to kWh is based on the value of 10.55 kWh Nm^{-3}. In addition, the fuel-saving value due to the increase in efficiency was calculated by using Equation 2. In calculating the financial value of the savings, the unit price of natural gas is 0.0261345 \$ kWh^{-1} was used for the November 2021 in Izmir/Türkiye.

$$Fuel\ Saving_{IE} = \frac{Useful\ Work\ x\ Operating\ Time}{Fuel\ Calorific\ Value}\left(\frac{1}{\eta_{burner,L}} - \frac{1}{\eta_{burner,H}}\right) \quad (2)$$

The Equation 3 was used in the calculation of fuel savings due to heat gain

$$Fuel\ Saving_{HG} = \frac{Amount\ of\ Heat\ Gained\ x\ Operating\ Time}{Fuel\ Calorific\ Value} \quad (3)$$

The possible savings obtained because of the calculations were compared with the application study savings calculated using the data obtained as a result of the experimental studies. During this comparison, the payback period (PP) and return on investment (ROI) values were calculated and the effect of the improvements was examined. ROI is a simple ratio that divides net profit by the cost of investment. Because it is expressed as a percentage, it can compare the effectiveness or profitability of different investment options. Return on investment is calculated using Equations 4-5. The useful life of the realized investment cost in calculating the ROI value is taken as 10 years (Alcorta et al., 2014; Bakhshi & Sandborn, 2018; Diesendorf & Wiedmann, 2020).

$$ROI = \left(\frac{Net\ Profit}{Cost\ of\ Investment}\right) x100 \quad (4)$$

$$ROI = \left(\frac{Present\ Value - Cost\ of\ Investment}{Cost\ of\ Investment}\right) x100 \quad (5)$$

The payback period is the period during which the project generates sufficient revenue to cover its initial investments, that is, the number of periods required for the cash revenues generated by an investment to equal the original investment (Wang et al., 2015). It is calculated with Equation 6.

$$Payback\ Period = \left(\frac{Cost\ of\ investment}{Annual\ after-tax\ cash\ inflow}\right) \quad (6)$$

Calculation of carbon emission

Greenhouse gas emissions are one of the most important agenda items of developed and developing countries in the world. The calculation of CO_2 gas, which directly affects global warming, has led to the emergence of the concept of carbon footprint. The values showing the decreasing amount of greenhouse gas emissions caused by unused natural gas fuel after energy-saving implementation projects were calculated using the values found in the Greenhouse Gas Emission Factors, Constant Combustion Emission Factors table published by the US Environmental Protection Agency (US Environmental Protection Agency, 2021) on April 1, 2021.

Results

Temperature data were collected from different points inside and outside the heat treatment furnace. The temperature values of the inner and outer surfaces of the aging furnace and solution furnace and insulated areas were measured with a thermal camera. While the outer surface temperatures are observed as low as 43°C in the insulated areas, it has been determined that the temperatures in the flange-connected areas range between 86°C and 184°C, and heat losses are experienced. Since low-temperature values in the range of 24°C

- 35.6°C are measured in the thermal camera measurements made on the outer surface of the aging furnace, heat losses that may occur on the outer surfaces of the furnace were excluded from the recovery calculation. In the thermal camera measurements made at the exit area of the aging furnace during the experiments, it is seen that the internal temperature of the furnace is around 167°C and the furnace regime has reached the desired values. In the thermal camera measurements made in the solution furnace exit region, it is seen that the furnace internal temperature values are between 571 °C and 596 °C, therefore, there is no loss in the solution furnace regime after heat recovery.

To monitor the internal temperature distributions of solution and aging furnaces, apart from thermal camera measurements, a thermograph was sent into the furnace. In the first preliminary trial, the thermograph was sent to the heat treatment furnaces from the ground floor. Thermocouple sensors 1, 2, 3, 4, and 5 were sent to the solution furnace from the left side, and thermocouple sensors 6, 7, 8, 9, and 10 were sent to the solution furnace from the right side to measure temperature. The Thermograph measurement trial was started by setting the solution furnace temperature to 540°C and the aging furnace temperature to 155°C via the PLC control system. As can be seen in (Figure 3a), fluctuations in the temperature regime are observed inside the furnace during the first trial periods. It has been determined that the cold air entering the furnace causes a sudden temperature change, which is reflected in the measurements. Cold air entry was prevented by shortening the opening and closing times of the back doors of solution and aging furnaces. Similarly, Bonilla-Campos et al., drew attention to the thermal losses caused by doors and carried out improvement studies on this issue (Bonilla-Campos et al., 2019).

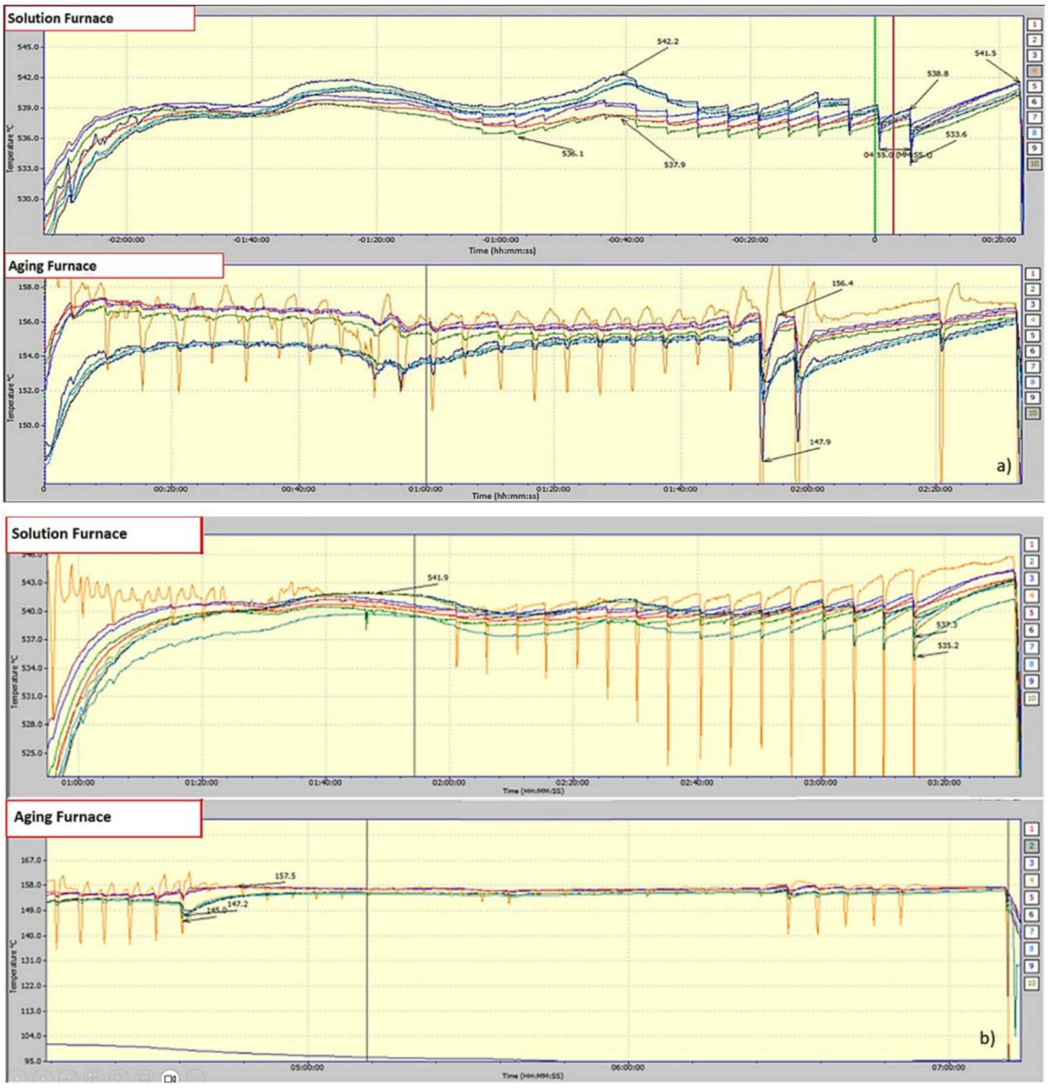


Figure 3. a) Furnace temperature values obtained by thermography measurement, b) Furnace temperature values obtained by thermography measurement in the second trial.

In addition, when the measurement results were examined, it was observed that the waste heat sent to the solution furnace was not homogeneously distributed, and different temperature values occurred on the right and left sides of the furnace. To eliminate this problem, a homogeneous distribution of temperature distribution was achieved by revising the fins of the fans that circulate the hot air sent inside the furnace. The measurement results of the second experiment were shown in (Figure 3b).

The temperature values measured by thermograph in the experimental study carried out because of the improvements are given in detail in (Figure 4). As can be seen, the thermograph data reached a temperature of 540°C from room temperature within 30 minutes and 15 seconds. It is observed that the temperature values measured by thermograph remained within ±5°C variation tolerance for 3 hours, 2 minutes, and 45 seconds in the solution furnace. Since the thermograph device cannot be immersed in water, the quenching process was not carried out with the device. For this reason, in the QZ, the thermograph was left to cool under ambient temperature conditions. With the aging furnace process starting with AZ, the thermograph was taken to the aging zone, and it was observed that the temperature values measured by the thermograph during the last 3 hours, 10 minutes, and 5 seconds remain within the ±3°C variation tolerance. Using the values measured in the experiments, the energy balance for the solution furnace and the aging furnace was created and the results were shown in (Table 1) and (Table 2).

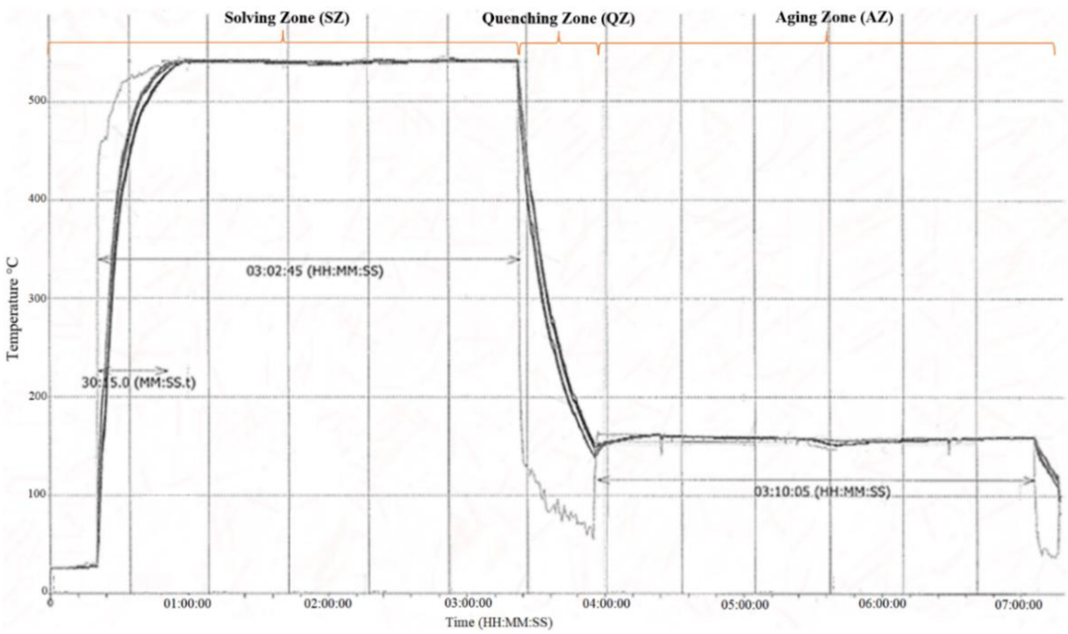


Figure 4. The temperature values measured by thermograph in the experimental study carried out because of the improvements.

Table 1. Energy balance results for the solution furnace.

Energy balance for aging furnace					
Inputs	Flow Rate	Temperature	Heating Value / Cp	Q (kW)	%
Waste Heat Recovery	5600 $Nm^3 h^{-1}$	208°C	0.001347 MJ Nm^{-3} K	435.829	72.02
Product	8400 kg h^{-1}	80°C	0.000907 MJ kg^{-1} K	169.306	27.98
Total				605.135	100
Outputs	Flow Rate	Temperature	Heating Value / Cp	Q (kW)	%
Product	8400 kg h^{-1}	155°C	0.000907 MJ kg^{-1} K	328.031	54.21
Flue Loss	4760 $m^3 h^{-1}$	140°C	0.0013305 MJ Nm^{-3} K	246.290	40.70
Other Losses				30.814	5.09
Total				605.135	100

Table 2. Energy balance results for the aging furnace.

Energy balance for solution furnace					
Inputs	Flow Rate	Temperature	Heating Value / Cp	Q (kW)	%
Natural Gas (Comb. Heat)	160 $Nm^3 h^{-1}$		37.98 MJ Nm^{-3}	1688	94.23
Natural Gas (Sensible heat)	160 $Nm^3 h^{-1}$		0.0013 MJ Nm^{-3}	0.057	0.0
Combustion Air	2600 $m^3 h^{-1}$	25°C	0.0013 MJ Nm^{-3} K	23.472	1.31

Recovery Inlet Air	3000 $m^3 h^{-1}$	25°C	0.0013 MJ Nm^{-3} K	27.083	1.51
Product	8400 kg h^{-1}	25°C	0.000907 MJ kg^{-1} K	52.908	2.95
Total				1791,52	100
Outputs	Flow Rate	Temperature	Heating Value / Cp	Q (kW)	%
Product	8400 kg h^{-1}	540°C	0.000907 MJ kg^{-1} K	1142.82	62.24
Waste Heat Recovery	5760 $m^3 h^{-1}$	208°C	0.001347 MJ Nm^{-3} K	448.281	24.42
Flue gas	0 $m^3 h^{-1}$	140°C	0.0013305 MJ Nm^{-3} K	0	0.00
Other Losses				200.419	11.18
Total				1791.52	100

The Sankey diagram of the final state was created in (Figure 5), by using the energy balances with the data obtained from the measurement results. As can be seen in the Sankey diagram, 62.24% of the energy entering the solution furnace is transferred to the products, while 11.18% goes to insulation and other losses, 24.42% of the input energy is transferred to the aging furnace as waste heat recovery. It is seen that 54.21% of the waste heat energy entering the aging furnace is transferred to the products, 5.09% goes to other losses, and the remaining 40.70% of the energy is thrown into the atmosphere as chimney loss.

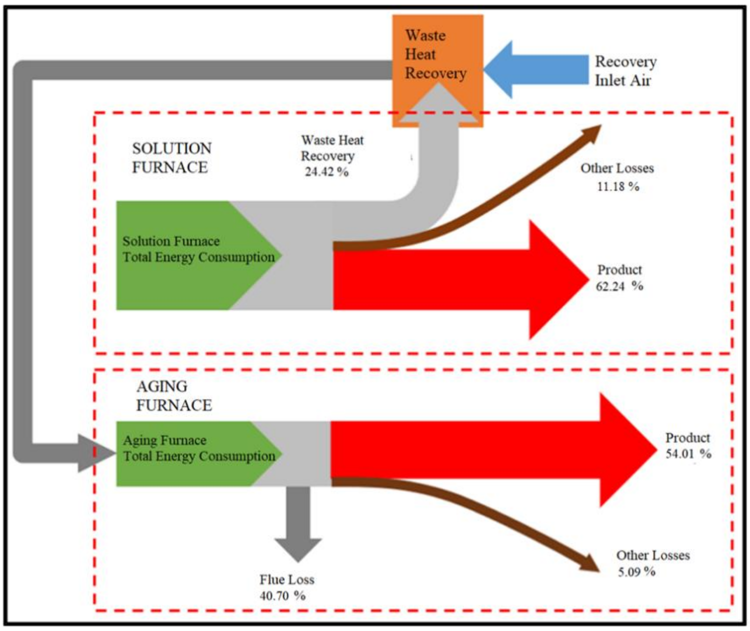


Figure 5. The Sankey Diagram of the final state.

The amount of savings and payback period realized in the heating of the aging furnace with the heat recovery application, which was commissioned after the design processes were completed within the scope of the energy-saving study, are shown in (Table 3). The realized energy savings are calculated by using the production data from the facility and the data obtained from the existing meters installed on the heat treatment furnace. The annual operating time was calculated by learning that the facility operates 24 hours a day and 286 days a year, with data obtained from the enterprise.

Table 3. The amount of savings and the payback period obtained by using the waste heat recovery system.

Use of waste heat in the aging furnace		
Expected savings	Waste Heat Flow Rate ($m^3 h^{-1}$)	3000
	Recovery Inlet Temperature (°C)	540
	Recovery Outlet Temperature (°C)	208
	Cp (MJ Nm^{-3} K)	0.001347
	Amount of Heat Gained (MJ h^{-1})	1341.612
	Furnace Annual Working Time (h $Year^{-1}$)	7200
	Annual Energy Savings (MJ $Year^{-1}$)	9659606.4
	Financial Value of Savings (\$ $Year^{-1}$)	77830.620
Realized amount of savings	Energy-saving (MJ h^{-1})	762.659
	Furnace Annual Working Time (h $Year^{-1}$)	6864
	Annual Energy Savings (MJ $Year^{-1}$)	5234891.38

Payback period	Financial Value of Savings ($ $Year^{-1}$)	42171.472
	Investment Cost ($)	67364.341
	Operating Cost ($)	2913.178
	Total cost ($)	70277.519
	Payback Period (Year)	1.67 Year
	ROI	482.8%

The burner combustion air temperature value has a direct effect on the combustion efficiency. When the combustion air temperature value increases, the burner efficiency increases, and the fuel consumption decreases. Reducing fuel consumption also means a decrease in emission values. In (Table 4), information including the amount of savings realized after the burner air preheating and the payback periods of the system are shared. The realized energy savings are calculated by using the production data from the facility and the data obtained from the existing meters installed on the heat treatment furnace. The annual operating time was calculated by learning that the facility operates 24 hours a day and 286 days a year, with data obtained from the enterprise.

As a result of the measurements made after the implementation of the energy-saving project, it was observed that 5234891.38 MJ/year energy savings were achieved with waste heat recovery. In addition, 4399965.39 MJ/year energy savings were achieved with the application of preheating the burner supply air. In return for the total energy savings, natural gas savings equivalent to 9634856 MJ/year energy consumption were achieved.

Table 4. The amount of savings and the payback period obtained by using the burner air pre-heat.

	Burner Air Pre-heat Application	
Expected Savings	Burner Air Supply Flow Rate ($m^3 h^{-1}$)	2600
	Air Supply Temperature After Recovery (°C)	208
	Current Air Supply Temperature (°C)	25
	Cp (MJ Nm^{-3} K)	0.001347
	Amount of Heat Gained (MJ h^{-1})	641.022
	Current Burner Efficiency (%)	85
	New Burner Efficiency (%)	92
	Furnace Annual Working Time (h $Year^{-1}$)	7200
	Fuel Savings Due to the Increase in Efficiency (MJ $Year^{-1}$)	4131547.2
	Fuel Saving due to Heat Recovery (MJ $Year^{-1}$)	5121568.8
	Total Fuel Saving (MJ $Year^{-1}$)	9253116
	Financial Value of Savings ($)	67173.876
Realized Amount of Savings	Energy-saving (MJ h^{-1})	641.022
	Furnace Annual Working Time (h $Year^{-1}$)	6864
	Annual Energy Savings (MJ $Year^{-1}$)	4399965.39
	Financial Value of Savings ($)	35445.426
Payback Period	Investment Cost ($)	29147.286
	Operating Cost ($)	2913.178
	Total cost ($)	32060.464
	Payback Period (Year)	0.90
	ROI	1116.1%

After two applications for energy saving, a large amount of natural gas fuel was not consumed. Due to this unconsumed natural gas, the amount of greenhouse gas emissions released into the atmosphere has decreased. Values showing the decreasing amount of greenhouse gas emissions are given in (Table 5). As can be seen in (Table 5), an annual reduction of approximately 538 tons of CO_2 equivalent greenhouse gas emissions has been achieved thanks to energy-saving implementation projects. The reduction in greenhouse gas emissions achieved as a result of each waste heat recovery application has been expressed in similar studies (Egilegor et al., 2020).

Table 5. Decreasing amount of greenhouse gas emissions.

		Greenhouse Gas Emissions (ton CO_2e)			
Fuel	Fuel Amount	CO_2 (ton)	CH_4 (ton)	N_2O (ton)	CO_2e (ton)
Natural Gas	9634856 MJ $year^{-1}$	537.695	0.010	0.001	538.247

Discussion

As a result of flue gas temperature and flow rate measurements, it was concluded that the energy requirement of the aging furnace can be provided by using the waste heat energy of the solution furnace. In addition, an increase in burner combustion efficiency was observed by pre-heating the air of the burners that meet the solution furnace heating need by using waste heat. The energy efficiency assessment carried out in this study offered a solution that will significantly reduce energy consumption. These efforts to significantly improve energy management will reduce natural gas consumption and environmental impact, as well as reduce unit product costs due to the reduction in energy bills. The results obtained in energy efficiency-enhancing applications within the scope of recovery and reuse of waste heat in the heat treatment furnace are summarized below.

1. By using the waste heat from the solution furnace as an energy source in the aging furnace, 762.659 MJ hour^{-1} of energy savings were achieved. The return on the operation of the energy savings is calculated as 42171.472 \$ year^{-1}. The investment cost of the aforementioned project is 70277.519 \$, including the operating costs. Under these conditions, the investment payback period is 1.67 years. If the useful life of the investment is considered as 10 years, the ROI value is realized as 482.8%.
2. Energy savings of 641.022 MJ hour^{-1} have been achieved with the preheating of the burner supply air within the scope of energy recovery practices. The return on the operation of the energy savings is calculated as 35445.426 \$ year^{-1}. The investment cost of the aforementioned project is 32060.464 \$, including the operating costs. Under these conditions, the investment payback period is 0.90 years. The ROI value is realized as 1116.1%.
3. With energy savings achieved, natural gas equivalent to 9634856 MJ year^{-1} of energy that should normally be consumed in heat treatment furnaces has not been used. Due to unconsumed natural gas, 538 tons of CO_2 equivalent greenhouse gas emissions are prevented every year.

Despite the improvements made, it is seen that 40.70% of the total energy escapes from the chimney. This energy can be used for space heating or obtaining hot water. In addition, 18.43% of the energy is consumed as other losses. To reduce the rate of other losses, the problems in thermal insulation should be reviewed, and studies should be carried out to reduce the amount of cold air that enters the furnace.

Conclusion

This study carried out on the wheel production line has important results in terms of waste heat recovery applications and environmental results.

Thanks to these results, we demonstrate in detail the waste heat recovery applications, the points to be considered during these applications, the energy efficiency, and the environmental consequences.

This study not only addresses potential waste heat recovery applications in the wheel production line and their consequences but also raises awareness of the effects of energy efficiency applications on the energy-cost-environment triangle in energy-intensive processes.

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