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Tema 3 - Energetska efikasnost (domaćinstva, komunalni sektor, industrija, zgradarstvo, …

Poboljšanje energetske efikasnosti industrijske gasne peći korišćenjem sistema ponovne upotrebe toplote

Energy efficiency improvements of the industrial natural gas furnace using a heat recovery system

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Apstrakt **-** Preduzeća su snažno fokusirana na primenu različitih mera energetske efikasnosti za optimizaciju postojećih elektroenergetskih sistema, kao što su motori za proizvodnju električne energije, sistemi komprimovanog vazduha, osvetljenje, proizvodnja i distribucija tople vode i pare, grejanje i hlađenje, sistemi za oporavak i oporavak energije, itd. Potencijal za energetsku efikasnost uglavnom se može podeliti u dve grupe. Većina mera je određena na osnovu tehničkih rešenja, ali nekoliko mera se odnosi na ljudsku psihologiju i uključivanje promena u svakodnevne navike korisnika. Većina mera energetske efikasnosti je prihvatljiva sa finansijskog stanovišta i nudi relativno brz povrat investicije, ali neke stavke su finansijski intenzivnije i sa dužim periodom povratka investicije. Ovaj rad opisuje kombinovani projekat poboljšanja energetske efikasnosti zasnovan na primeni sistema rekuperacije energije izduvnih gasova industrijske peći, koja koriste prirodni gas kao primarno gorivo i automatskom regulacijom i kontrolom brzine ventilatora u zavisnosti od temperature proizvoda. Osnovna ideja ovog projekta je ponovo korišćenje energije izduvnih gasova razvojem novog sistema za rekuperaciju toplote koja je ranije slobodno išla u atmosferu. Energija dobijena rekuperacijom ponovo se koristi kod iste peći za grejanje svežeg vazduha poboljšavajući energetsku efikasnost peći. Pored toga, autori u radu opisuju regulaciju i kontrolu ventilatora za hlađenje pomoću VFD regulatora brzine na osnovu onlajn merenja temperature proizvoda. Implementirajući obe ideje mogli bi dobiti značajne uštede energije sa ROI periodom manjom od godinu dana.

Ključne reči **-** energetska efikasnost, industrijske gasne peći, rekuperacija toplote, vdf regulatori brzine motora

Abstract- Enterprises are strongly focused on the implementation of various energy efficiency measures for optimizing their existing power systems, such as power generation engines, compressed air systems, lighting, production and distribution of hot water and steam, heating and cooling, energy recovery and recuperation systems, etc.

The potential for energy efficiency can be divided mainly into two groups. Most of the measures are determined based on technical solutions, but several measures relate to human psychology and the inclusion of changes in the daily habits of users. Most energy efficiency measures are acceptable from a financial point of view and offer a relatively quick return on investment, but some are financially more intense and with a longer period of return of the investment.

This project describes a combined project for improvement of energy efficiency based on the implementation of an energy recovery system from exhaust gases on industrial furnaces, which use natural gas as primary energy fuel and automatic regulation and control of fan speed depending on the temperature of the product.

The basic idea of this project is to re-use the energy from exhaust gasses which was initially released freely into the atmosphere thought chimney by the development of a new heat recuperation system. Energy gained from the recuperation process was re-used in the same furnace as a pre-heat fresh air improving the energy efficiency of the same furnace. Additionally, the authors explained the regulation and control of the cooling fans with VFD speed controllers based on the online measurement of the product temperature. The implementation of both ideas could result in significant energy savings with an ROI period of less than 1 year.

Index Terms- Process Automation, Energy efficiency, Heat Recuperation, Gas-fired Furnace, Motor VFD Controllers.

I. INTRODUCTION

The term "Energy Management (EM)" was introduced in the 1980s. There are many definitions for it, but according to VDI 4602, EM represents proactive, organized and systematic coordination of procurement, energy conversion, transmission and use of energy, all to achieve demand. In doing so, the EM considers economic objectives as well as environmental objectives [1]. According to ISO50001: 2011 (E), Energy

Management is a set of interconnected or interactive elements to determine energy policy and energy goals, as well as the processes and procedures to achieve those goals [2].

In a nutshell, EM is a systematically organized technical tool that enables the identification and application of measures to reduce energy consumption and energy costs and enables the reduction of the environmental impact of energy use. Within a company, the typical process of EM starts with:

- analysis of the existing energy situation,
- analysis of the energy supply and production process,
- improvements in the energy utilization.

Implementation of EM is based on the P-D-C-A principle (**Plan-Do-Check-Act**) [3]:

- ***Plan*** **–** Establish energy analysis, check major energy indicators, goals, tasks, and take appropriate Action measures to improve energy performance adhere to the company policies,
- ***Do*** – Implementation of EM action plans,
- ***Check*** – Monitor and measure processes demonstrating energy performance and comparing them with objectives and policies, reporting results, and finally,
- ***Act*** – Taking actions to continuously improve energy performance.

During analyzing energy consumption in a company, it was found the potential to reduce energy consumption. The company uses 4 large furnaces, each with an installed capacity of about *4[MW]*, to heat the company's products to a temperature of approximately *500[°C]*. The furnaces use natural gas as a primary energy source for the burners and electricity to drive the conveyor belt and the fans used to circulate hot air inside the furnace. The exhaust gas temperatures of these furnaces are above *300[°C]* with the hot airflow capacity of about *4000 – 5000[*m^3*/h]*, thus a significant amount of energy is wasted out in the air through the chimney. The purpose of the project was to examine whether this currently wasted heat from the exhaust gas flow can be reused elsewhere as process heat. At the exit end of the furnace, two fans are installed in the so-called cooling zone each with an installed power of *22[kW]*. Their purpose is to cool the product by circulating air down to a temperature of about *37[°C]*. The furnace is divided into zones and there is a supply of fresh air in each zone and a certain amount of hot air is carried and combined into one channel and discharged into the atmosphere as waste gases through the chimney.

The idea of this project was to harness the energy of these exhaust gases, recuperate the heat of the gasses through a heat exchanger and return the heat as preheated fresh air at the furnace entrance. At the secondary intake side of the heat exchanger, the cooling zone exhaust should be used as fresh air which does not fall below *20[°C]* throughout the year. Additionally, a non-contact infrared temperature sensor could be installed to measure the temperature of the product. Depending on the product's temperature, one could adjust the fan speed in the cooling zone, and adjust the amount of cooling air. If the product's temperature is less than *37[°C]*, the fan speed should gradually decrease and vice versa, when the product is warm, the fan speed will increase. Adjusting the fan speed depending on the temperature could result in additional energy savings.

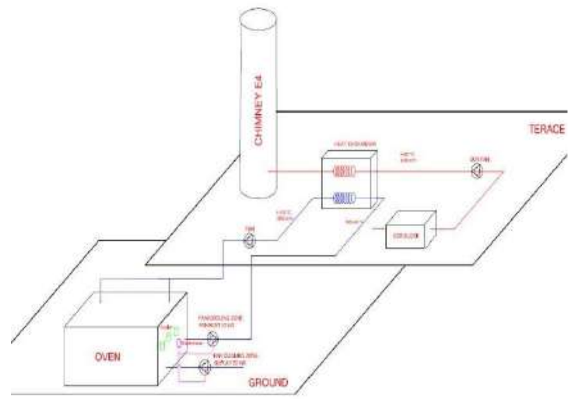

Figure 1 Graphic illustration of equipment layout

II. IDENTIFY, RESEARCH AND COLLECT IDEA

A recuperation system is a device designed to reuse the heat generated using a heat exchanger and the cross-flow of fluids in ventilation and air-conditioning systems or the exhaust of industrial equipment. Generally, they use the heat from the exhaust gases to preheat the returning air in the process. Thus, the recuperation system as schematically shown in Figure 2, uses the usually wasted energy and increases the energy efficiency of whole systems [4].

Figure 2 Wey of working on the recuperation process

In many processes, a combustion process is used to obtain a certain energy-heat and the recuperation system serves to reuse some of this heat and return it to the system to improve its efficiency. The general rule for recuperates is to have a pressure drop between *150* and *250 [Pa]* to avoid additional fan overload and increased power consumption.

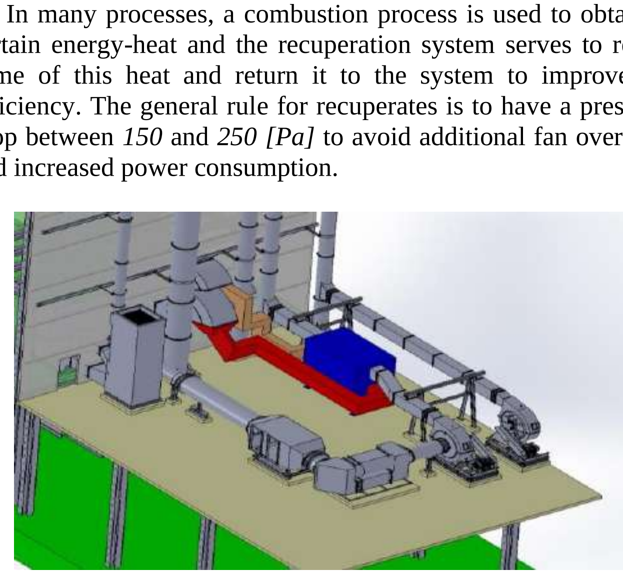

Figure 3 Layout of the heat exchanger on the terrace

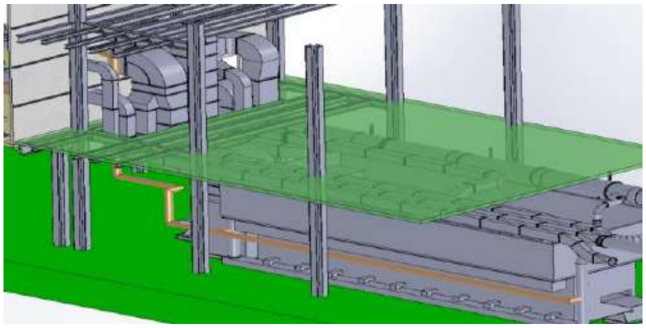

Figure 4 Installation of preheating air on the entrance of the oven

In Figures 3 and 4 the concept of installing a recuperation system on the exhaust production line is shown. The recuperation system could be installed on the terrace, after the process fan and in front of the chimney. It is envisaged to additionally install two fans in the recuperation system which could serve to transfer fresh air and meet the required flow and pressure. Filters could be placed on the input sides of the primary and secondary sides. The heat exchanger material is intended to be SS 316 due to the corrosive environment and could be designed in such a manner to prevent the mixing of the two media.

The heat exchanger is designed to be cassette-mounted for inspection and regular cleaning purposes to ensure the smooth operation of the system and reduced energy efficiency caused by dirt. The entire heat exchanger could be thermally insulated externally. To define the amount of the energy being discharged, thus wasted through the chimneys, as well as the amount of fresh air needed for the cooling process, the first necessary task was to make measurements of the airflow volume and the air temperatures.

III. MEASUREMENT AND ANALYSIS

The measurements of the data were done at separate measuring points; inserts in the fresh airline and the furnace exhaust line, using portable flow and temperature measuring instrument KURZ 4222, shown in Figure 5.

Figure 5 Instrument for airflow measurements Kurz 4222

Five consecutive measurements at different positions of the channels were made and the average value of the obtained results was taken in the analysis.

Table 1 Average value of temperature and airflow in the furnace

	Airflow *[Nm³/h]*	Temperature *[°C]*
Exhaust - Oven output	5000	300
Furnace Fresh Air - Furnace Entry	5000	35

Table 2 Technical details of the heat exchanger

Energy efficiency: 49.1%	Class: H4			
Technical details	Case 1		Case 2	
Sens. effectiveness wet [%]	50.8		50.8	
Sens. effectiveness dry [%]	50.8		50.8	
Temp. efficiency wet [%]	50.8		50.8	
Temp. efficiency dry [%]	50.8		50.8	
Recuperation power [kW]	258.7		217.7	
	Supply	Exhaust	Supply	Exhaust
Pressure drop [Pa]	68	68	68	68
Face velocity [m/s]	1.85	1.85	1.85	1.85
Condensate [l/h]	0.0	0.0	0.0	0.0
In				
Volume flow [m3/h]	5000	5000	5000	5000
Density [kg/m3]	1.16	1.16	1.16	1.16
Mass flow [kg/s]	1.610	1.610	1.610	1.610
Temperature [°C]	-15.0	300.0	35.0	300.0
Relative humidity [%]	85	0	40	0
Absolute humidity [g/kg]	0.9	0.0	14.6	0.0
Enthalpy [kJ/kg]	-12.9	301.2	72.6	301.2
Out				
Volume flow [m3/h]	5000	5000	5000	5000
Density [kg/m3]	1.16	1.16	1.16	1.16
Mass flow [kg/s]	1.610	1.610	1.610	1.610
Temperature [°C]	144.9	140.1	169.5	165.5
Relative humidity [%]	0	0	0	0
Absolute humidity [g/kg]	0.0	0.0	0.0	0.0
Enthalpy [kJ/kg]	145.5	142.9	170.2	203.6

Construction	
Plate material:	Stainless Steel 316Ti
Casing material:	Stainless steel AISI 316L
Mode:	Single
Layout:	Vertically
Width splitted:	No
Extra sealant:	Yes
Sealing	
Silicone sealing (max. 300°C)	
Bypass	
Without bypass	
Environment	
Level above sea level:	
300 m (980.25 hPa)	
Calculation base	
Input: Standard volume	
Density defined at 20°C and effective level used	
Common information	
Max. differential pressure = 10000 Pa	

The efficiency of the recuperation system could be greater, however, due to the limited space on the terrace and the size of the equipment, only *50[%]* efficiency of the heat exchanger was taken. The amount of energy that could be obtained was calculated by the following formula:

$$Q = m \cdot Cp \cdot \Delta t; \quad m = \rho \cdot V; \quad P = \frac{Q}{t};$$

where, Q is the energy, m is the mass, $Cp = 1.006$ *[kJ/kgK]*, is the specific heat capacity, $\rho = 1.16$ *[kg/m³]* is the specific density, $\Delta t = 134.5$ *[°C]*, $V = 5000$ *[Nm³/h]* is the volume of the airflow within the furnace, and P is the total power.

Due to the uninterrupted working process, the total number of working hours and the total amount of heat could be calculated as:

- ***The total number of working hours:***

  365·24 = 8760[hours/year],
- ***The total amount of heat:***

  Q = P·t = 217·8760 = 1,900[MWh].

Initial calculations showed that this recuperation process has a large potential for energy savings that amount to *217[kW/h]*, or in total, approximately *1900[MWh/year]*. Part of the waste gas energy through a heat exchanger is returned to the same furnace as preheated air at the inlet of the furnace on the fresh airside. Figures 3 and 4, show the locations where the heat exchanger could be installed, the recirculated hot air inlet in the furnace and the cooling zone exhaust duct which will serve to provide stable year-round temperatures.

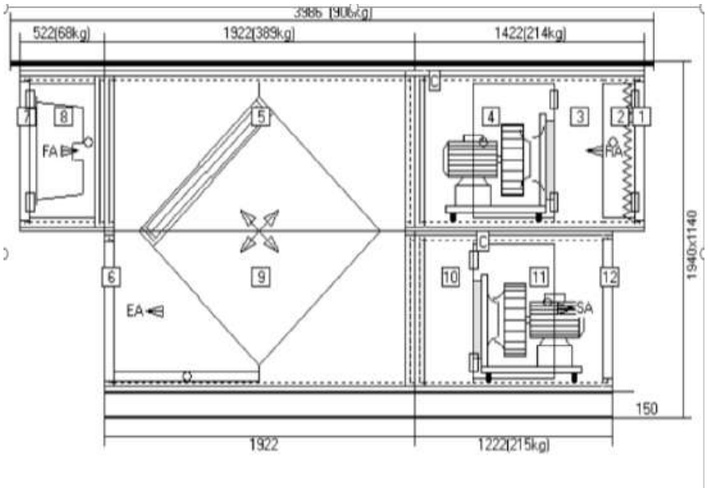

Figure 6 Heat exchanger cross-section

Figure 6 shows a cross-section of the proposed recuperation system. It has filters on sides, the fresh airside and the returns airside. Inside is an air-to-air crossover heat exchanger. Two fans should be fitted on the inlet and outlet side which could be powered by high-speed regulators and will provide a continuously identical flow of air in order not to cause a pressure imbalance inside the furnace. This could be achieved by installing an airflow meter in the ducts that could provide information data for the regulation of the fan speed.

Table 2 shows the recuperation system calculations data. The recuperation system power in summer operating conditions is *217[kW]*, with an output useful air temperature of *165.5 [°C]* and a flow rate of *5000 [m^3/h]*. With these characteristics, the energy efficiency ratio would be *49.1[%]*. The energy efficiency of the heat exchanger is conditioned by its size and the installation conditions.

Every automated control system has two parts – *execution of the process and control of the process*. The control system is required to receive information, the logic algorithm to process the data, and to issue executable commands to the devices. This process needs to be repeated cyclically. Automated control systems are composed of several inherently different subsystems (e.g. electrical, mechanical, and hydraulic) that are interconnected properly to accomplish a given function of the system. There are three basic types of control system:

- an open-loop control system,
- a closed-loop control system, (system with the feedback),
- control system based on the principle of compensation.

Principle of feedback – closed-loop control is formed as a function of the deviation i.e. error between the output parameters and the specified goal. This control system is widely used and will be used in this project as well. Additionally, these control systems can be continuous and discrete. In continuous systems, variables are monitored over time and discrete variables are monitored only at certain intervals, depending on the needs and process. We will look at a stochastic system in which we cannot predict the output characteristics. Practically, by changing the input and output parameters, we will define a probability distribution. In this project, we use sequential control. The logic algorithm is based on a certain condition, in this case, the temperature of the product. The statement (*If – then*), is used with: *if* (**condition**) – *then* (**action**) [5].

The temperature of the final product is variable in size depending on the size of the section, its heat, the outside temperature as well as the velocity of airflow to cool the section and it depends on the fan speed. As mentioned above, the product is preheated to about *500[°C]*, and then cooled in the so-called cooling zone utilizing two *22[kW]* fans. One fan is used to inject fresh air and the other to remove hot air from the cooling zone, heated by subtracting the temperature from the parts. Fan motors are powered by VFDs (*Variable Frequency Drives*) for online control and regulation of the speed of the motor, i.e. the fan. They usually work in dual mode, winter and summer, and most of the time they work faster than the optimum speed.

An infrared non-contact temperature sensor Micro epsilon CTF SF15 is selected for temperature measurement (Figure 7). This model is chosen because it has a very short measurement time of *150[ms]*.

Figure 7 Infrared temperature sensors

The shortest measurement time is required due to the specific installation space. The temperature infrared sensor is positioned in a narrow slot between two moving lanes along which the product moves. The elapsed time in the measuring space is longer than the sensitivity and speed of the temperature gauge and is enough to obtain useful and accurate values. The product must be measured at the bottom since that part is the warmest and is used as the reference value for its temperature.

The temperature sensor has an analog output of *4-20[mA]* and is connected to the AI (analog input) of the PLC. An appropriate algorithm regulates the speed of both motors with a nominal power of *22[kW]* each, powered by VFDs. The temperature reading was in the range between *0 – 100[°C]*. Any other readings were considered invalid. In that case, the motor speed regulation was kept fixed, as predefined. Obtaining data from the temperature section is discretionary at a precise time. For this purpose, a detection sensor was installed and at the same time, the temperature gauge measures the product. This avoids misreading the ambient temperature without the product being present. The system analyzes twelve successive products and takes the mean temperature value of the two warmest products. The preset temperature was *35[°C]* with an acceptable temperature discrepancy range between *32[°C]* and *37[°C]*. If the average temperature was lower than 32*[°C]*, the fan speed would decrease by *2[Hz]* (maximum up to *20 [Hz]*). If the temperature was above 37*[°C]*, the fan speed would increase by *10[Hz*]. The maximum speed was limited to the original set for that section. If the temperature of the product was within the range between 32*[°C]* and 37*[°C]*, the fan speed would not change. If the temperature rises above 45*[°C]*, the SCADA alarm occurs and the process and furnace stopped.

The setting of the fan speed is defined by the recipe and depends on the working product. When changing the product, the logic starts from the beginning of processes and the fans rotate at a higher speed. This is done to avoid the possibility of overheating the products with the previously set data for the previous process and/or product. Before practically implementing this logic, a test was performed with manual adjustment of the fan speed and constant monitoring of the temperatures of products.

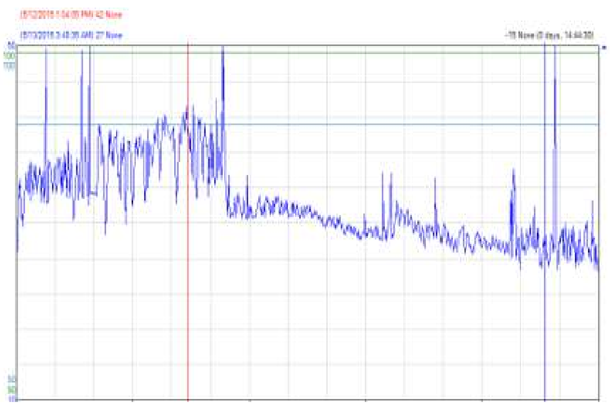

Figure 8 Graphical explanation of recorded temperature of the product

Figure 8 shows the trend of recorded temperature change of the measured products during one day in May. As shown, the temperature changes from *27[°C]* to *42[°C],* while the fan speed was at maximum. This indicates that the automatic temperature regulation is achievable with reducing the fan speed at night and/or throughout the day as the production process requires cooling of parts with ambient air temperature below *30[°C].*

During the test, it was observed that the temperature of the products could be slightly increased by shifting the speed gradually or halving, based on the measured temperature of the products coming out of the furnace (see Figure 9).

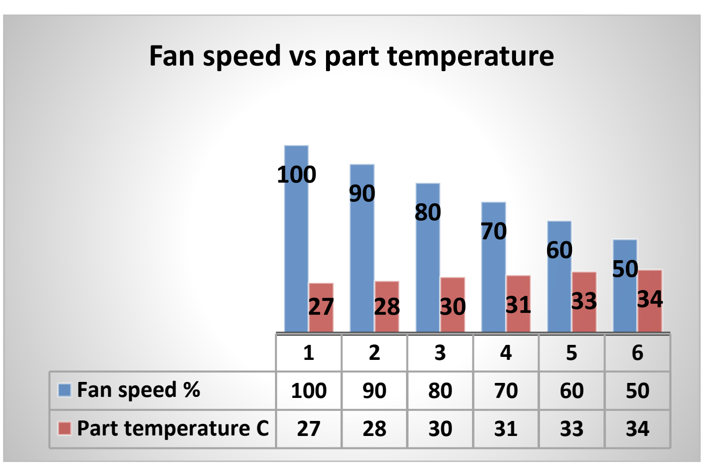

Figure 9 Ratio between product temperature and fan speed

Controlling the fan speed was done in accordance with the following basic equitation:

1. Airflow is proportional to the speed:

$$\frac{V_2}{V_1} = \frac{U_2}{U_1}$$

2. The air pressure is proportional to the velocity squared:

$$p_2 = p_1 \cdot \left(\frac{U_2}{U_1}\right)^2$$

3. The ventilation power is proportional to the velocity cubed:

$$P_2 = P_1 \cdot \left(\frac{U_2}{U_1}\right)^3$$

The electric power is calculated from the mechanical power of the motor:

$$P_{el} = P_{meh}/\eta$$

where, P_{el} is the electrical power of the motor, P_{meh} is the mechanical power of the engine, while η is the efficiency coefficient of the motor.

By applying the obtained formulas, the choice of power and power output when applying a fan speed is expressed in *[%]* of the maximum capability. Total energy savings in nine months (not applicable in summer) if fans worked with the reduced speed down to *60[%]* amounts *146[MWh].*

Figure 10 also shows a graph derived from fan speed control calculations showing the dependence of the amount of energy required for nine months of operation and the fan speed. By reducing the fan speed down to *50[%],* its power consumption was only 1/8 of the energy consumed at top speed.

IV. ECONOMICA BENEFITS OF THE PROJECT

We presented the technical solution and technical benefits that the proposed project could achieve in the process of improvements in the energy efficiency of the production process. However, to be applicable, we also had to investigate its economic benefits in terms of investment cost, energy savings, and investment rate of return. This data is provided in Tables 3 and 4.

As shown in Table 3, the installation of *217[kW]* heat exchanger for the continuous production process of *8760* hours/year contributes to a significant annual energy savings of *1,900[MWh]* or financial benefit of approximately *81,709 Euro/year*. For the estimated total investment cost of approximately *60,000 Euro*, the return of the investment is very favorable, and even including modest banking interest rates, it is less than one year.

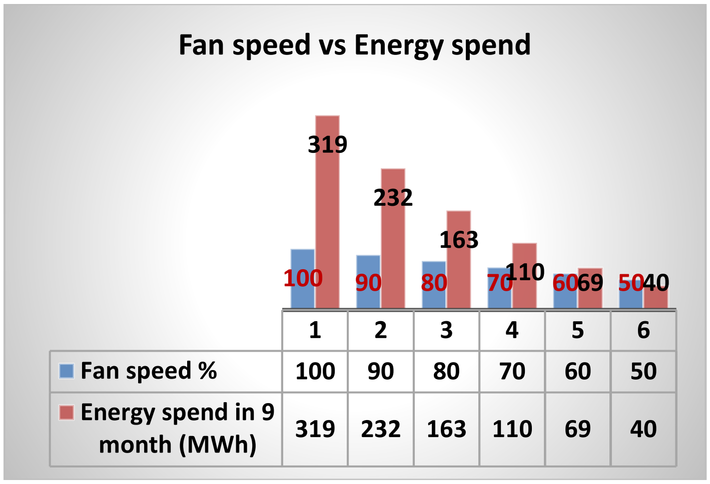

Figure 10 Ratio between energy and fan speed

Table 3 Analysis of energy-saving and return of investments

Heat Exchanger power *[kW]*	*217*
Yearly energy savings *[MWh]*	*1,900*
Yearly savings *[Euro]*	*81,709*
The investment *[Euro]*	*60,000*
Return on investment ROI *[years]*	*0,7*

Fan speed regulation additionally contributes to the improvement of the energy efficiency of the whole production process. Using VFDs fans with regulated speed leads to annual energy savings of approximately *146[MWh]*, or in cash annually savings of *14,200 Euro*. The total investment for this equipment is estimated at *2,400 Euro*, thus the return on investment including interest rates and all costs could be *0.2 years*.

Table 4 Analysis of energy-saving and return of investments

Yearly energy savings *[MWh]*	146
Yearly savings *[Euro]*	14200
The investment *[Euro]*	2400
Return on investment ROI *[years]*	0.2

V. CONCLUSIONS

The high energy savings and rapid return on investment indicate the realization of this project. The full realization of the proposed project would additionally lead to reducing CO2 emissions. The potential of saving energy and money is twofold; first, due to additional installation of heat exchanger and heat recuperation the energy of the waste gas returned back to the same furnace as preheated air at the inlet of the furnace, and second, by regulating the amount of cooling air for cooling the products using fan speed regulator based on utilization of VFDs. The economic analysis shows that the rate of return of the investment is less than one year which is very favorable for this and any other similar production process. After full implementation of the proposed project on the first furnace and proving the expected results and benefits, the same procedure is scheduled to be repeated at the second furnace.

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