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PREFACE

Ladies and gentlemen, dear colleagues,

Welcome to Vrnjačka Banja, to the International Scientific Conference Heavy Machinery. The first conference was held in 1993, so this is the thirtieth anniversary of the Heavy Machinery conference.

This year the Eleventh International Conference Heavy Machinery is held by the Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, from 21 to 24 June 2023.

The conference has gained a unique recognizable form of exchange of information, ideas and new scientific research. It is held in the year when the Faculty of Mechanical and Civil Engineering in Kraljevo celebrates 63 years of university teaching.

During several decades of its existence, the Faculty has acquired a specific and recognizable form in domestic and foreign scientific circles thanks to its scientific and research results.

The goal of the Conference is to make the research in the fields covered at the Faculty of Mechanical and Civil Engineering in Kraljevo available and applicable within both domestic and foreign frames. Also, our scientists will have the opportunity to learn about the results of research done by their colleagues from abroad in the fields of transport design in industry, energy control, production technologies, and civil engineering through the following thematic sessions:

- Earth-moving and transportation machinery,
- Railway engineering,
- Production technologies,
- Automatic control and fluid technique,
- Applied mechanics,
- Thermal technique and environment protection,
- Civil engineering.

The high scientific reputation of domestic and foreign participants as well as the number of papers provide guarantees that the Conference will be very successful. The papers reflect the state-of-the-art and deal with a wide spectrum of important topics of current interest in heavy machinery.

I would especially like to thank the Ministry of Science, Technological Development and Innovation of the Republic of Serbia for its support to the organization of the Conference and our efforts to promote science and technology in the areas of mechanical and civil engineering in Serbia. Also, I would like to express our gratitude to other sponsors of the Conference: Serbian Chamber of Engineers, TeamCAD d.o.o. Zemun-Belgrade, Banim reklame d.o.o. Kraljevo, Radijator Inženjering d.o.o. Kraljevo and Messer Tehnogas AD Belgrade.

My sincere thanks also go to all members of the scientific, organizing and technical committees, the reviewers, and all the participants including the invited speakers for their participation in the Conference and presentation of their papers.

Thank you and see you at the next conference in three years.

Kraljevo – Vrnjačka Banja, June 2023

Conference Chairman,
Prof. dr Mile Savković

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SESSION A: EARTH-MOVING AND TRANSPORTATION MACHINERY

SESSION B: RAILWAY ENGINEERING

SESSION C: PRODUCTION TECHNOLOGIES

SESSION D: AUTOMATIC CONTROL AND FLUID TECHNIQUE

SESSION E: APPLIED MECHANICS

SESSION F: THERMAL TECHNIQUE AND ENVIRONMENT PROTECTION

SESSION G: CIVIL ENGINEERING

The proposal of the recuperator design for the rotary kilns with a driving mechanism in the calcination zone

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The rotary kilns have been used in the industry in various applications, mostly in the cement industry and for calcination of dolomite ores. The rotary kilns characterize the high-temperature processes and therefore the heat losses are very high. In the order to increase the efficiency of the kiln and reduce fuel consumption, several different designs of recuperators are developed. One of the problems in the design of the recuperator is the position of the driving mechanism or tyre of the rotary kiln. This paper has presented a solution of the two separated recuperators in order to resolve the previous mentioned problems and increase the overall efficiency of the rotary kiln. The analytical model has been used for the determination of the geometry and heat losses of the recuperator while the CAD model has been used for the calculation of the heat losses and analysis of the airflow in the recuperator. The results obtained from both models have shown a good correlation and show that with the presented two-part recuperator design is possible to increase the efficiency of the rotary kiln when the driving mechanism or tyre is placed on the kiln shell in the calcination zone.

Keywords: recuperator, design, model, flow simulation, rotary kiln, energy efficiency, heat transfer, heat exchanger

1. INTRODUCTION

Rotary kilns are widely used in many industries, with the most technologically significant role in cement production [1] and the calcination of dolomite ore in magnesium production. Rotary kilns are devices that are applied in almost all processes in which it is necessary to raise the input raw material to a high temperature in a continuous process [2].

The operation principle of rotary kilns is very simple, and it is based on heating the material to the point where chemical reactions generate degradation and change in its structure. The kiln is slanted at an appropriate angle in relation to the horizontal axis, and the rotary movement is achieved through the drive mechanism. The raw material is inserted at the upper end of the kiln and under the influence of gravitational force and rotational motion it slides towards the lower end of the kiln, where the burners for burning fuel are located. Figure 1 shows the basic parts of a rotary kiln, which consists of a kiln mantle, drive mechanism, supporting wheel, kiln head cover, kiln head seal, kiln end seal, kiln end exhaust chamber, centrifugal fan and burner.

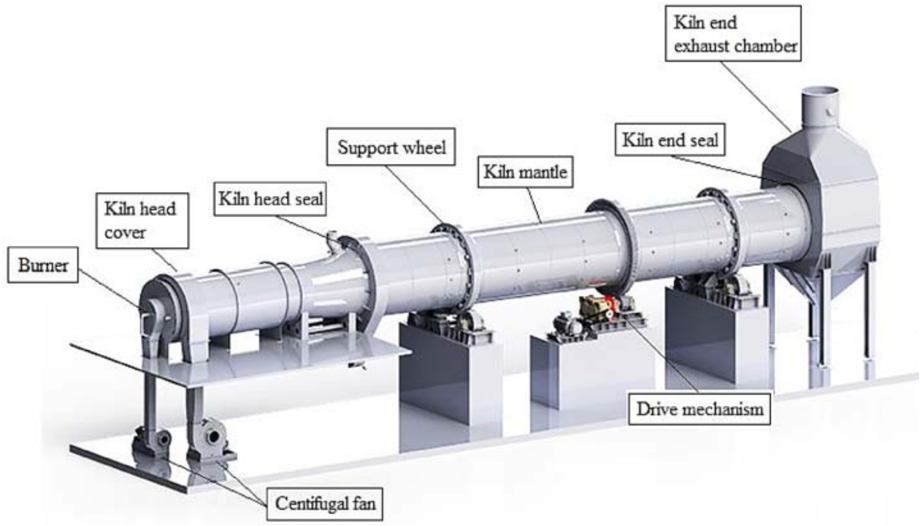

Figure 1. The basic parts of a rotary kiln

The importance of these devices is evidenced by the fact that the world production of cement and clinker increased by more than 240% in the first 20 years of the 21st century [3,4]. In the case of rotary kilns in which high-temperature processes take place, an increase in energy efficiency can be achieved by using waste heat. Nearly 40% of the total input energy is wasted, 19.15% is waste heat contained in combustion products, 5.61% is waste heat due to cooling of clinker, and 15.11% is waste heat from the mantel of the rotary kiln [5].

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Taking into account the operation principles, the amount of energy required to carry out the calcination process as well as the estimated energy losses, it is clear that one of the primary tasks is to find ways to increase the energy efficiency of these kilns. The proposed measure is also in line with the aspirations for the adoption of national strategies with the aim of increasing the energy efficiency of the industrial sector. Finding a solution to increase the energy efficiency of the rotary kiln, would affect the reduction of energy consumption, which would have a positive effect on environmental protection and the reduction of greenhouse gas.

Several types of kilns are used in industrial applications, such as vertical kilns and horizontal rotary kilns. In horizontal rotary kilns, the position of the drive mechanism depends primarily on the temperature regimes of the technological process in the kilns. This paper analysed the possibility of using the waste heat from a mantle of the rotary kiln with the drive mechanism placed on its central part, as shown in Figure 2.

2. THE USE OF WASTE HEAT FROM THE ROTARY KILN MANTLE

The heat loss from the rotary kiln mantle represents a significant loss that depends on the purpose of the kiln, whose value is in the range of 3-25% of the total input energy [5-8]. Depending on the area of application, heat loss from the mantle of the rotary kiln is, about 8-15% in the cement industry [9], in the magnesium production process 24.8% [10], in the calcination process of dolomite ore 17.7% [2] even up to 26.35 [11] of the total input energy. If the heat losses were used for preheating processes of the raw material or combustion air before entering the rotary kiln, the energy efficiency of the rotary kiln would be significantly increased.

The simplest solution would be to insulate the mantle, but at high-temperature regimes, this solution may compromise the structural stability of the rotary kiln. A solution with inspection openings for monitoring the temperature and condition of the surface of the rotary kiln mantle is shown in the references [5,7]. One of the solutions for utilizing heat losses from the kiln mantle is shown in references [12, 13]. The solution in the form of a recuperator for preheating water is shown in reference [9, 14, 15, 16].

Unlike the previously presented solutions for utilizing heat loss from the rotary kiln mantle, the authors in the reference [2] propose a recuperator that uses the total heat loss from the mantle to preheat the combustion air. The step-shaped heat recuperator is placed above the calcination zone. Due to the very small distance between the rotary kiln surface and the recuperator, the proposed solution is ineffective for rotary kilns with high eccentricities. The significance of this problem was investigated in reference [17], where it was concluded that the positioning of the recuperator in relation to the supporting wheel and the drive mechanism of the rotary kiln plays a significant role in order to utilize the total heat losses. In the reference [18], the authors proposed modified solutions for the recuperator presented in the reference [2]. The solution of the recuperator in the case when the supporting wheel is located in the zone where the heat losses are the highest was not examined in detail by the author [18], but a schematic presentation of the possible solution was given, including the solution for using preheated air.

The aim of this paper is to analyse the possible design of the recuperator for the use of the total heat loss in the case when the drive mechanism and/or the supporting wheel is located in the zone where the heat loss from the rotary kiln mantle is the highest. The proposed design uses the total heat loss from the kiln mantle for air preheating. The energy of the preheated air may be used in the combustion process and/or for preheating the input dolomite ore, which would have a positive effect on reducing fuel consumption.

3. PROPOSED DESIGN

The schematic presentation of the construction in the case, when the driving mechanism is located in the zone of the highest temperatures, is shown in Figure 2. In this case, the increase in energy efficiency would be achieved by the construction consisting of two recuperators, as shown in Fig. 2. The diameter of the rotary kiln is 2.8 m, and the length of the 80 m, but both recuperators would be placed only on the part of the kiln mantle with the highest temperatures, above the calcination zone, in total length of 15.45 m.

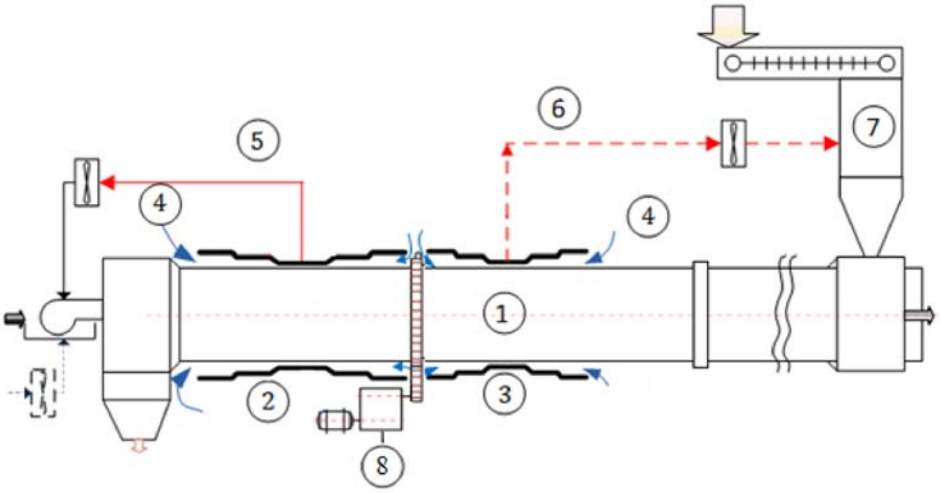

Figure 2. Schematic presentation of the proposed design; 1-rotary kiln, 2-recuperator 1, 3-recuperator 2, 4-airflow, 5-combustion air, 6-air used for preheating input material, 7-feeder

The first recuperator (position 2 in Figure 2) is used for preheating air used for fuel combustion and it is placed on the left side of the driving mechanism with a total length of 9.27 m. The preheated air from the second recuperator (position 3 in Figure 2) is used to preheat the input material and it is placed on the right side of the driving mechanism with a total length of 6.18 m.

The proposed design has not been applied in practice, but this paper analyses the possibility of implementation by applying a mathematical model as well as a thermodynamic flow analysis of the proposed design in the SOLID WORKS software package.

4. HEAT LOSS FROM THE MANTLE OF THE ROTARY KILN

The heat loss of the rotary kiln mantle was calculated based on the balance equation (1). This heat loss was calculated and verified [2] whereby the kiln mantle was divided into 24 segments with the aim of obtaining approximately equal temperatures on its surface. The total heat loss is:

$$\dot{Q}=\sum_{i=1}^{24}\dot{Q}_{conv\,s,i}+\sum_{i=1}^{24}\dot{Q}_{rad\,s,i}=\sum_{i=1}^{24}\alpha_{s,i}A_{s,i}(t_{s,i}-t_o)+\sum_{i=1}^{24}\sigma\varepsilon A_{s,i}\left(T_{s,i}^4-T_o^4\right) \quad (1)$$

where are

$\dot{Q}_{convs,i}$ - convective heat loss from the i-th segment calculated for the case of natural convection around a horizontal cylinder [19] taken from [20],

$\dot{Q}_{rads,i}$ - radiation heat loss from the i-th segment calculated for the case of a pipe in a big room [21].

The obtained results were presented in the reference [18] and they represent the input data for defining geometry for both recuperators in this paper.

5. MODELLING METHODS

An analytical cell model for define the unknown geometry and operating parameters of both recuperators was applied. In addition to the analytical model, the rotary kiln with appropriate recuperators was modelled in the SOLID WORKS software package and the analysis of the recuperator operation was performed using the FLOW module for the same input parameters as for the analytical model.

5.1. Cell modelling

The first recuperator is designed to preheat air to the highest temperature which is needed for fuel combustion. The remaining heat loss from the rotary kiln mantle would be used for preheating of additional amount of air to the highest possible temperature which will be used for preheat the input material (dolomite). The recuperators are divided into segments of corresponding lengths, similar as the kiln itself.

The air flowing through the formed annular duct between the kiln mantle and the recuperator in i-th segment, and it is heated by convective heat loss ($\dot{Q}_{convs,i}$) from the mantle of rotary kiln and ($\dot{Q}_{convr,i}$) from the recuperator, so for i-th segment it is:

$$\dot{Q}_{conv\,s,i}+\dot{Q}_{conv\,r,i}=\frac{\dot{m}_a}{2}\cdot c_{p,a}\cdot\left(t_{a\,out,i}-t_{a\,in,i}\right) \quad (2)$$

where $t_{a\ in,i}$ and $t_{a\ out,i}$ are the inlet and outlet air temperature at the i-th segment. For the end (first) segments, the inlet temperature of the air is equal to the ambient air temperature $t_{a\,in,1}=t_{a\,in,8}=t_0$). Halves of defined mass airflows ($\dot{m}_a/2$) are introduced from one and from other side of both recuperators (see Figure 2) whereby the air flow is directed towards extraction point. The other important balance equations needed for the i-th segment are:

$$\dot{Q}_{s,i}=\dot{Q}_{conv\,s,i}+\dot{Q}_{rad\,sr,i} \quad (3)$$

$$\dot{Q}_{rad\,sr,i}=\dot{Q}_{conv\,r,i}+\dot{Q}_{r,i} \quad (4)$$

In the equation (3), $\dot{Q}_{s,i}$ represents the heat loss from the rotary kiln mantle on the i-th segment which is transferred to the air by convection $\dot{Q}_{convs,i}$ and $\dot{Q}_{radsr,i}$ represents the amount of heat which is transferred by radiation from the kiln mantle to the surface of the recuperator.

Equation (4) represents the balance equation for the recuperator surface where $\dot{Q}_{convr,i}$ represents the convective heat loss that is transferred to the air from the recuperator surface and $\dot{Q}_{r,i}$ represents the heat loss to the environment. For a known insulation thickness, the heat loss $\dot{Q}_{r,i}$ can be calculated. A detailed explanation of the equations is shown in the reference [18, 2].

The thermodynamic characteristics of the air used in the analytical model were calculated in accordance with the references [22-24].

5.2. CAD model

The CAD model which is developed in the SOLID WORKS software package is used for analysis of the recuperator work. The CAD model is formed by the results obtained from the analytical model as shown in Figure 3. The thermodynamic and flow analysis is conducted in the FLOW module of the SOLID WORKS software package. Boundary conditions for flow simulation are:

- air of the temperature of 8°C enters at the annular duct between the rotary kiln mantle and recuperators at ambient pressure from both sides (see Figure 2),
- the air mass flows for both recuperators are the same as in the analytical model,

- the temperatures on the segments of the CAD model are the measured values of the temperatures on the rotary kiln mantle used in the analytical model.

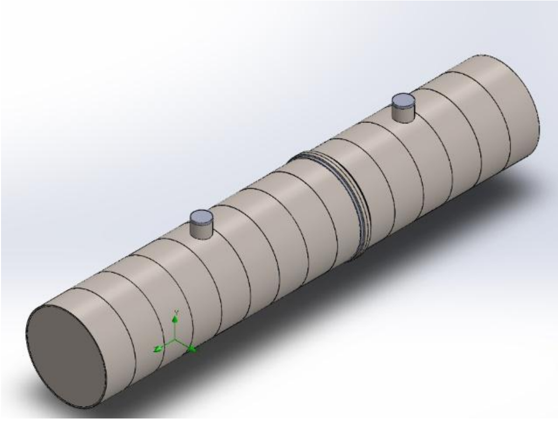

Figure 3. The CAD model formed in SOLIDWORK

6. RESULTS

Both air streams preheated in the recuperators were extracted at the position placed so that both halves utilize equal heat losses of the kiln mantle for each air streams. In the first recuperator and the second recuperator, two air streams are mixed isothermally above the kiln section with the highest surface temperature. It is advantageous from a thermodynamic standpoint since the temperature difference between the air and the kiln surface can be compared to the temperature difference along a counter-current heat exchanger.

Figure 4 shows the maximal temperatures of preheated air at both recuperators and the position where preheated air should be extracted for a defined inlet parameter. The temperatures of the kiln and recuperator surfaces are also shown in Figure 4.

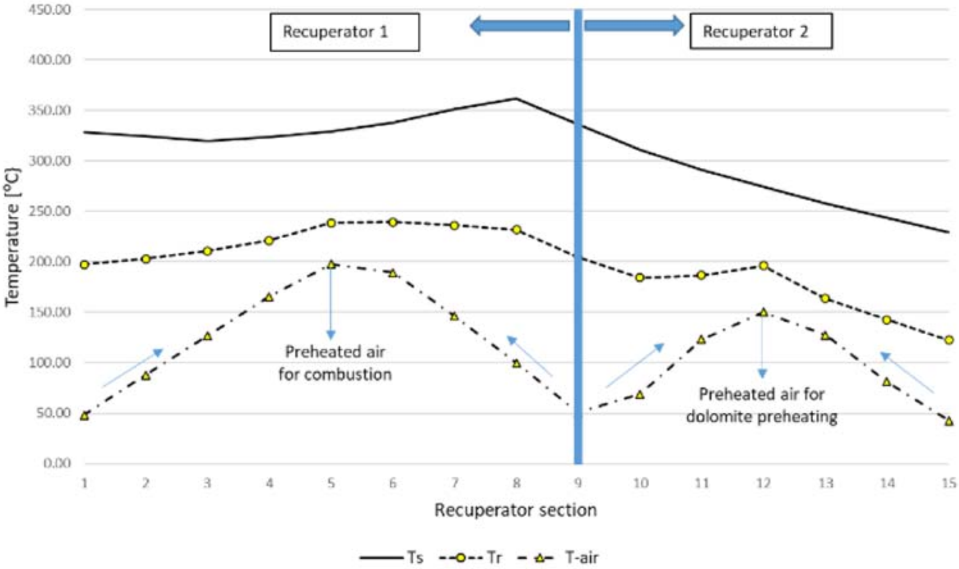

Figure 4. The preheating air and recuperators surface temperatures

The stepped shape of the recuperator and the diameters for each segment obtained by the analytical model are shown in Figure 5. For both recuperators, the dashed line in Figure 5 represents the minimum permissible segment diameter.

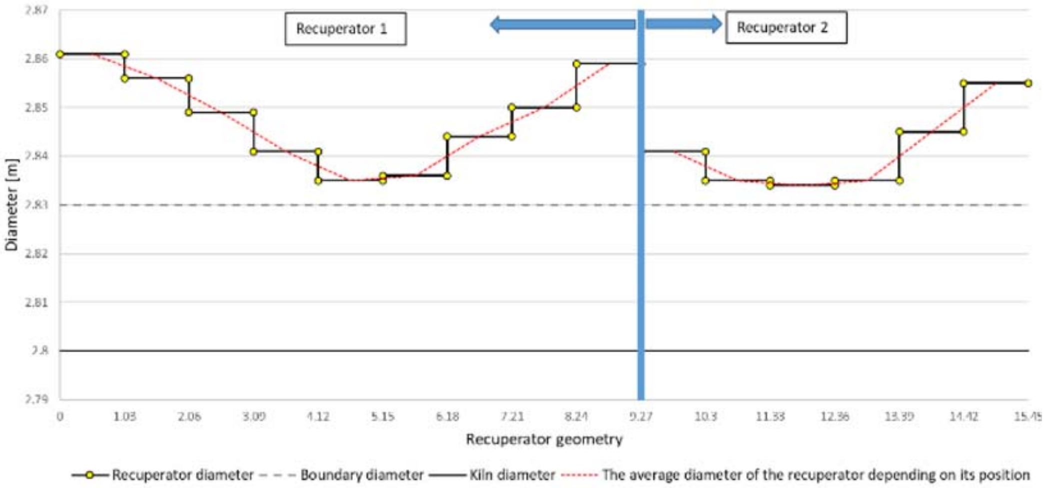

Figure 5. The diameters of recuperators along its length for each segment

In the case of the first recuperator, for a mass air flow of 3.3788 kg/s and an inlet temperature of 8°C, the maximum outlet temperature of the preheated air obtained by the analytical model is 198.68°C. This amount of preheated air is used for fuel combustion. In the second recuperator, for a mass air flow of 1.9973 kg/s and an inlet temperature of 8°C, the maximum outlet temperature of the preheated air obtained by the analytical model is 146.8°C and this air is used for preheating the input material.

The result obtained by the CAD model for the same input parameters as in analytical model are shown on the Figure 6.

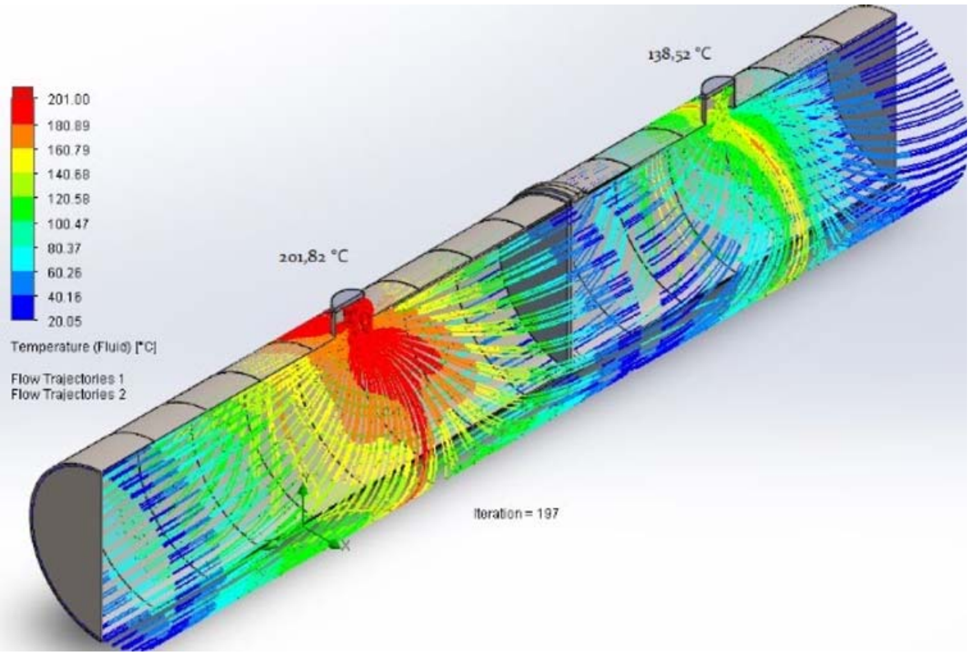

Figure 6. The result obtained by FLOW analysis

Based on the FLOW analysis, for the first recuperator and input parameters such as air temperature of 8°C and mass flow rate of 3.7888 kg/s, the maximum outlet temperature is 201.82°C, which is 1.58% higher than the value obtained by the analytical model. For the second recuperator, for a mass flow of 1.9973 kg/s and an inlet air temperature of 8°C, the maximum outlet temperature of preheated air is 138.52°C, which is 5.98% less than the value obtained by the analytical model.

Based on the material and heat balance equation shown in reference [11] the potential reduction of fuel consumption and improvement of kiln efficiency can be calculated. In this case for obtained results reduction of fuel consumption is about 2000 l/day which represent a saving of 9,9%.

7. CONCLUSION

In this paper, the possibility of using the total heat losses from the mantle of a rotary kiln in the case where the driving mechanism of the rotary kiln is placed in the central part was analysed. In order to increase the energy efficiency of the rotary kiln, a design solution consisting of two recuperators was proposed. A mathematical cell model was created to determine the total available energy as well as to determine the geometry of the recuperators and the maximal temperature of preheated air. In addition, the working analysis for the recuperators was done using CFD in the SolidWorks software package. The results obtained using the presented models shows a good correlation and show that in the proposed way it is possible to use the energy from the rotary kiln mantle by using two recuperators and achieve significant energy savings. The reduction of about 2000 l/day in fuel consumption illustrates the importance of recuperators for utilizing waste heat from rotary kiln mantles.

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REFERENCES

[1] Vijayan, S.N., Sendhilkumar, S., Industrial Applications of Rotary Kiln in Various Sectors - A Review, Int. J. Eng. Innov. Res. 3 (2014) 342–345

[2] Karamarković, V., et al., Recuperator for waste heat recovery from rotary kilns, Applied Thermal Engineering, Volume 54, Issue 2, 30 May 2013, Pages 470-480

[3] Golewski, G. L., Energy Savings Associated with the Use of Fly Ash and Nanoadditives in the Cement Composition, Energies, 13 (2020), 9, 2184

[4] U.S.G. Survey, National Minerals Information Center, (n.d.) https://www.usgs.gov/centers/nmic/mineral-commodity-summaries

[5] Tahsin Engin, Vedat Ari, Energy auditing and recovery for dry type cement rotary kiln systems –A case study, Energy Conversion and Management 46 (2005), pp. 551–562

[6] A. Atmaca, R. Yumrutaş, Analysis of the parameters affecting energy consumption of a rotary kiln in cement industry,Appl. Therm. Eng., 66 (1) (2014), pp. 435-444

[7] G. Kabir, A.I. Abubakar, U.A. El-Nafaty, Energy audit and conservation opportunities for pyroprocessing unit of a typical dry process cement plant, Energy, 35 (3) (2010), pp. 1237-1243

[8] Q. Yin, W.-J. Du, L. Cheng, Optimization design of heat recovery systems on rotary kilns using genetic algorithms, Appl. Energy, 202 (2017), pp. 153-168

[9] Caputo, A.C., et al., Performance modeling of radiant heat recovery exchangers for rotary kilns, Appl. Therm. Eng. 31 (2011) 2578–2589

[10] B. K. Chakrabati, Investigations on heat loss through the kiln shell in magnesite dead burning process: a case study, Appl. Therm. Eng. 22 (2002) 1339-1345

[11] Nenad P. Stojić (2022), RECUPERATORS FOR THE USE OF WASTE HEAT FROM ROTATING CYLINDRICAL SURFACES, Doctoral dissertation, Faculty of Mechanical and Civil Engineering in Kraljvo, University of Kragujevac, April 2022

[12] Luo, Q., et al., A Thermoelectric Waste-Heat-Recovery System for Portland Cement Rotary Kilns, J. Electron. Mater. 44 (2015) 1750–1762

[13] Mirhosseini, M., et al., Power optimization and economic evaluation of thermoelectric waste heat recovery system around a rotary cement kiln, J. Clean. Prod. 232 (2019) 1321–1334

[14] W.-J. Du, Q. Yin, L. Cheng, Experiments on novel heat recovery systems on rotary kilns, Appl. Therm. Eng., 139 (2018), pp. 535-541

[15] Q. Yin, et al., Design requirements and performance optimization of waste heat recovery systems for rotary kilns, Int. J. Heat Mass Transf., 93 (2016), pp. 1-8

[16] Yin, Q., et al., Optimization design and economic analyses of heat recovery exchangers on rotary kilns, Appl. Energy. 180 (2016) 743–756

[17] Zheng, K., et al., Rotary kiln cylinder deformation measurement and feature extraction based on EMD method, Eng. Lett. 23 (2015) 283–291

[18] Stojić, Nenad P. et al., Improving design and operating parameters of the recuperator for waste heat recovery from rotary kilns, Thermal Science 2021 OnLine-First Issue 00, Pages: 239-239

[19] Churchill W, C.H., Correlating equations for laminar and turbulent free convection from a horizontal cylinder, Int. J. Heat Mass Transf. 18 (1975) 1049–1053

[20] Werner Kast, H.K., Heat Transfer by Free Convection: External Flows, in: VDI Heat Atlas, 2nd ed., Springer, Heidelberg, 2010: pp. 667–672

[21] Kabelac D, Vortmeyer S, Radiation of Surfaces, in: VDI Heat Atlas, Heidelberg, 2010: pp. 947–959

[22] Kleiber M, Joh R, Calculation Methods for Thermopysical Properties, in: VDI Heat Atlas, 2nd ed., Springer, Heidelberg, Germany, 2010: pp. 121–152

[23] Kleiber M, Joh R, Properties of Selected Importanat Pure Substances, in: VDI Heat Atlas, 2nd ed., Heidelberg, Germany, 2010: pp. 153–299

[24] Kleiber M, Joh R, Properties of Pure Fluid Substances, in: VDI Heat Atlas, 2nd ed., Heidelberg, Germany, 2010: pp. 301–417