

ENERGY EFFICIENCY OPTIMIZATION IN POLYISOPRENE FOOTWEAR PRODUCTION

Alka Mihelić-Bogdanić¹; Ivana ŠPELIĆ²

¹ University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; alka.mihelic.bogdanic@ttf.unizg.hr

² University of Zagreb Faculty of Textile Technology, Zagreb, Croatia; ivana.spelic@ttf.unizg.hr

* Corresponding author: ivana.spelic@ttf.unizg.hr

Abstract: The evaluation of energy efficiency improvements in polyisoprene footwear production is shown. The paper discusses the possibility of decreasing the natural gas consumption using flue gases heat recovery for feed water preheating applying an air preheater. By installing air preheater, combustion air natural gas consumption is reduced by 7 %. Simultaneously, the boiler outlet flue gases temperature is decreased from 204°C to 66,93°C providing sound basis for both economical savings, energy efficiency improvements as well as ecological benefits to the environment.

Keywords: polyisoprene; footwear production; energy efficiency improvements; flue gases heat recovery, air preheater

1. Introduction

One of the most well-known natural polymers is polyisoprene. Polyisoprene is polymer found in nature as natural polymer derived from rubber trees (stereoregular polymer composed of isoprene units attached in a cis con-figuration). However, it also exists as man-made fibre. Isoprene could be used as adhesive bond in footwear industry or as a coating in textile processing industry. Man-made polyisoprene has better mechanical and thermal properties when compared to natural rubber due to good inherent tack, good hot tensile strength and hot tear resistance, a high modulus, a high degree of resilience and excellent compression values [1,2].

Isoprene or 2-methyl-1,3-butadiene chemical formula is $\text{CH}_2=\text{C}(\text{CH}_3)\text{CH}=\text{CH}_2$. It is a colorless liquid with a boiling point of 34.1°C (307.25 K), soluble in alcohol. Isoprene is the second important conjugated diene for synthetic rubber production [1]. The main source for isoprene production is found by dehydrogenating the C5 olefin obtained by the extraction of a C5 fraction from catalytic cracking units or by using reactive chemicals such as isobutylene, formaldehyde, and propylene. The main use of isoprene is the production of polyisoprene. It is also a comonomer with isobutylene for butyl rubber production [1]. Synthetic cis-1,4-polyisoprene is manufactured to a high degree of stereoregularity and became an important polymer for the rubber industry, especially for tyres. Synthetic polyisoprene is similar to natural rubber but demonstrates excellent tensile strength, slower cure rates, lower hot tear, and lower aged properties than its natural counterpart. Man-made polyisoprene exceeds the natural types in consistency of product, cure rate, processing, and purity. It is superior in mixing, extrusion, molding, and calendaring processes [2]. Polyisoprene is a synthetic polymer (elastomer) that can be vulcanized by the addition of sulfur. Cis-Polyisoprene has properties similar to that of natural rubber, however it is characterized by high tensile strength and insensitivity to temperature changes and has low abrasion resistance. Trans-Polyisoprene, on the other hand has different properties from the cis form and cannot be vulcanized [2].

The significant differences between natural rubber and cis-polyisoprene and among different sources of the synthetic polymers relate to [2]:

1. Stereoisomeric purity
2. Molecular weight and distribution
3. Presence of functional groups in the hydrocarbon chain
4. Non-rubber constituents

The synthetic polyisoprenes may be compounded and processed using formulations and techniques similar to those used for natural rubber, but they have far better rheological behaviour. The most important production factors are time and substantial reductions in mixing cycles. The synthetic polyisoprene can be implemented for special coating applications is synthetic NR or synthetic polyisoprene. The Polyisoprene elastomer is produced in the solution medium using a stereospecific catalyst with controlled molecular weights, and with a higher percentage of rubber hydrocarbons. It is characterised by good inherent tack, good hot tensile strength, a high modulus and good hot tear resistance in addition to a high degree of resilience and excellent compression set values. The lower viscosity of polyisoprene may

reduce the breakdown time during mixing, and also shorten the warm-up time for calendaring, thus saving in power and operational costs. It has low viscosity, less nerve and less swell.

The rubber-coated fabric products with high water resistance, bright colours and pure-white mixes can be produced using synthetic polyisoprene-based compounds because of the absence of impurities, which usually affect the colour of the coatings. The rubbers most commonly used for latex adhesives or shoes manufacturing are natural rubber (polyisoprene) or synthetic rubber (cis-polyisoprene). Other end-use for polyisoprene include adhesives, lubricants, and useful elastomers such as surgical gloves and golf balls. Important uses of cis-polyisoprene include the production of tires, specialized mechanical products, conveyor belts, footwear, and insulation [2]. Exceptional characteristics of high purity and high gum tensile strength polyisoprene can be used in the coating of textiles, the product of which are used for medical, pharmaceutical, food-processing, and sports-goods applications [3].

The flue gases heat recovery allows significant efficiency improvements and simultaneous decrease of the waste heat rejected to the surrounding. This heat contained in flue gases could be recovered. To reduce expensive fuel consumption, heat of flue gases produced by fuel combustion is preferable for air preheating. To reduce furnace stack emissions, it is important to install the air pre-heaters and advanced process controls can increase the overall furnace efficiency. The primary air is heated using an air pre-heater prior to entering the furnace of a boiler. The air preheaters (AP) are the shell and tube type heat exchangers used for preheating the air which is fed to the boiler or furnaces/kilns for combustion of fuels. The air preheater's primary objective is to extract the waste heat from the flue gases leaving the boiler. Normally in simple process configuration, the fuel is fed to the boiler at normal room temperature and for combustion to take place; the temperature of the fuel is increased from its room temperature to ignition temperature. In order to increase the efficiency of the combustion process as well as a boiler, hot air is fed from the air preheater to the furnace for the combustion of fuel. In general, the air preheaters are designed to maximize the efficiency by increasing the heating surface area without increasing the space requirement and are designed for both flue gases and air to extract maximum heat from the flue gases. The air preheaters are used to extract waste heat from the flue gases leaving the boiler exhaust thereby increasing the boiler efficiency by 2-3 %.

2. Technological process relevant data

This study presents the energy consumption in continuous manufacturing process of polyisoprene production and such process requires large amounts of thermal, electrical energy as well as water. To evaluate such system a realistic study is carried out from the industrial process data. The flow diagram of the process is shown in Fig.1. where following operations are presented: polymerization, surge vessel, solvent stripper, dewatering, drier, baler and packaging. Basic process needs electrical energy in amount of $e_e=0.893 \text{ kWh}_e/\text{kg}_p$ is supplied from the grid and used by polymerization vessel ($e_e=0.261 \text{ kWh}_e/\text{kg}_p$), dewatering machine ($e_e=0.328 \text{ kWh}_e/\text{kg}_p$), baler ($e_e=0.152 \text{ kWh}_e/\text{kg}_p$) and packaging machines ($e_e=0.152 \text{ kWh}_e/\text{kg}_p$). The dry saturated steam in amount of $d_s=1.320 \text{ kg}_s/\text{kg}_p$ is produced in a boiler with efficiency $\eta_b=70\%$ and supplied to the solvent stripper with temperature of $t_s=121^\circ\text{C}$ (394 K). The process uses also cold water for polymerization in amount of $d_w=3 \text{ kg}_w/\text{kg}_p$.

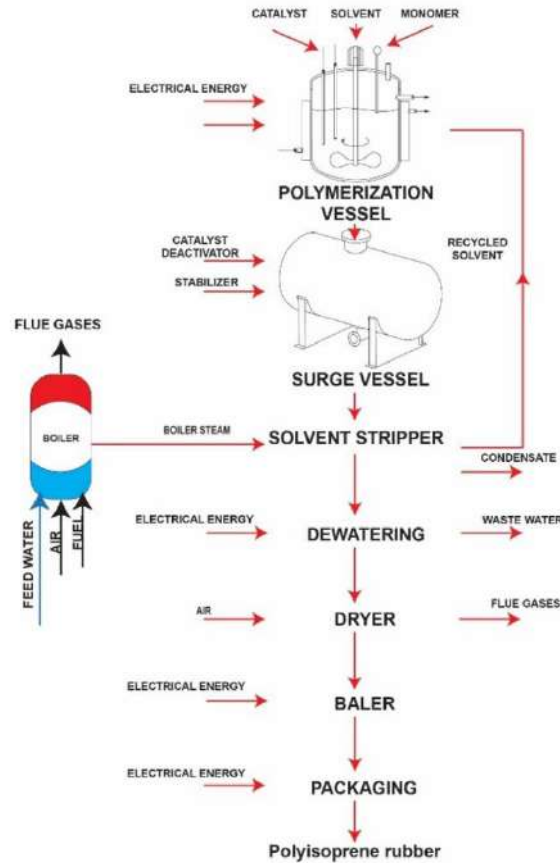


Figure 1: Block flow diagram of polyisoprene rubber production

Feed water enters the boiler with temperature $t_{FW_b}=24^{\circ}\text{C}$ (297 K) and the whole condensate with temperature $t_c=104.4^{\circ}\text{C}$ (377.4 K) is withdrawn to the surrounding. The air required for combustion passes into firebox with temperature $t_a=24^{\circ}\text{C}$ (297 K), while the temperature of exhaust stacks is $t_{FG_{AP_0}}=204^{\circ}\text{C}$ (477 K), Figure 1 [4].

The natural gas with composition 0,85% CO_2 , 0,56% N_2 , 98,05% CH_4 , 0,36% C_2H_6 , 0,12% C_3H_8 , 0,05% C_4H_{10} and 0,01% C_5H_{12} is burned with the excess air coefficient $\alpha=1,25$. Based on this composition, the lower heating value of the fuel is calculated by the following formula [5] as:

$$H_L = 358 \cdot \text{CH}_4 + 640 \cdot \text{C}_2\text{H}_6 + 915 \cdot \text{C}_3\text{H}_8 + 1190 \cdot \text{C}_4\text{H}_{10} + 1465 \cdot \text{C}_5\text{H}_{12} \quad (1)$$

$$H_L = 358 \cdot 98,05 + 640 \cdot 0,36 + 915 \cdot 0,12 + 1190 \cdot 0,05 + 1465 \cdot 0,01 = 35516,25 \text{ kJ/m}^3$$

The heat transferred to the boiler per unit of product is:

$$q_{S_b} = d_s \cdot (h_s - h_b) \quad (2)$$

$$q_s = 1,320 \cdot (2708 - 100,4) = 3442,03 \text{ kJ/kg}_p$$

where h_s ($t_s=121^{\circ}\text{C}$ (394 K)) and h_b ($t_{FW_b}=24^{\circ}\text{C}$ (297 K)) are the steam and water enthalpies taken from thermodynamically tables [6].

From this data the unit volume of fuel requirement using heat balance is:

$$v_{F_p} = q_s / (H_L \cdot \eta_B) \quad (3)$$

$$v_{F_p} = q_s / (H_L \cdot \eta_B) = 3442,03 / (35516,25 \cdot 0,7) = 0,1384 \text{ m}^3_F / \text{kg}_p$$

The specific steam consumption is:

$$d_{sp} = d_s / v_{F_p} = 1,320 / 0,1384 = 9,537 \text{ kg}_s / \text{kg}_F \quad (4)$$

The heat of the condensate is calculated as:

$$q_c = d_c \cdot h_{104,4^{\circ}\text{C}} = 1,320 \cdot 505 = 666,6 \text{ kJ/kg}_p \quad (5)$$

where $h_{104,4^{\circ}\text{C}} = h_c$ is enthalpy value taken from thermodynamically tables [6].

The present study of energy consumption in polyisoprene production process, working in two shifts at rate $D_p=12000 t_p/\text{yearly}$, is carried out. The process consists of the processes in polymerization vessel, surge vessel, solvent stripper, dewatering, drier, baler and packaging. This technology is supplied with large amounts of thermal and electrical energy, as well as water. The plant works 16 hours in day, 25 days in month ($\tau=16 \text{ h/day}=25 \text{ days/month}=400 \text{ h/month}=4000 \text{ h/year}$), i.e. so the plant use factor becomes $\beta=45.66\%$.

3. Exhaust product analysis

The products of fuel combustion are mostly gaseous. For complete gas combustion, 25% excess air is supplied (excess air coefficient $\alpha=1.25$). The minimum oxygen volume $V_{O_2}^m$ and stehiometric air volume V_a required for combustion [7].

The minimum oxygen volume $V_{O_2}^m$ ($\text{m}^3_{O_2}/\text{m}^3_{\text{fuel}}$) is calculated as:

$$V_{O_2}^m = 0.01 \cdot \left[2 \cdot \text{CH}_4 + \sum \left(x + \frac{y}{4} \right) C_x H_y \right] \quad (6)$$

$$V_{O_2}^m = 0.01 \cdot \left[2 \cdot 98.05 + \left(2 + \frac{6}{4} \right) \cdot 0.36 + \left(3 + \frac{8}{4} \right) \cdot 0.12 + \left(4 + \frac{10}{4} \right) \cdot 0.05 + \left(5 + \frac{12}{4} \right) \cdot 0.01 \right] = 1.9837 \text{ m}^3_{O_2}/\text{m}^3_F$$

The minimum air volume V_a ($\text{m}^3_a/\text{m}^3_{\text{fuel}}$) is calculated as:

$$V_a = \frac{V_{O_2}^m}{0.21} = \frac{1.9837}{0.21} = 9.446 \text{ m}^3_a/\text{m}^3_F \quad (7)$$

The actual volume of air calculated with the excess air coefficient $\alpha=1.25$ is:

$$V_{a\alpha} = V_a \cdot \alpha = 9.446 \cdot 1.25 = 11.807 \text{ m}^3_a/\text{m}^3_F \quad (8)$$

Volume of each gas component is calculated using following expressions:

The volume of carbon dioxide:

$$V_{CO_2} = 0.01 \cdot \left[\text{CO}_2 + \sum x C_x H_y \right] \quad (9)$$

$$V_{CO_2} = 0.01 \cdot [0.85 + 98.05 + 2 \cdot 0.36 + 4 \cdot 0.05 + 5 \cdot 0.01] = 1.0023 \text{ m}^3_{CO_2}/\text{m}^3_F$$

The volume of water vapour:

$$V_{H_2O} = 0.01 \cdot (0.05y \cdot C_x H_y) + [(V_a \cdot \alpha \cdot d) / \rho] \quad (10)$$

$$V_{H_2O} = 0.01 \cdot [2 \cdot 98.05 + 3 \cdot 0.36 + 4 \cdot 0.12 + 5 \cdot 0.05 + 6 \cdot 0.01] + \frac{9.446 \cdot 1.25 \cdot 0.13}{0.805} = 2.152 \text{ m}^3_{H_2O}/\text{m}^3_F$$

where $d=0.13 \text{ kg/m}^3$ is air moisture and $\rho=0.805 \text{ kg/m}^3$ is steam density.

The volume of nitrogen:

$$V_{N_2} = \alpha \cdot [(0.79 \cdot V_a) + (N/100)] \quad (11)$$

$$V_{N_2} = 1.25 \cdot \left(0.79 \cdot 9.446 + \frac{0.56}{100} \right) = 9.334 \text{ m}^3_{N_2}/\text{m}^3_F$$

The volume of oxygen:

$$V_{O_2} = 0.21 \cdot (\alpha - 1) \cdot V_a \quad (12)$$

$$V_{O_2} = 0.21 \cdot (1.25 - 1) \cdot 9.446 = 0.4959 \text{ m}^3_{O_2}/\text{m}^3_F$$

The total volume of flue gases is summed by adding together the volume of carbon dioxide, water vapour, nitrogen unconsumed during the combustion process and excess oxygen:

$$V_{FG} = V_{O_2} + V_{H_2O} + V_{N_2} + V_{CO_2} \quad (13)$$

$$V_{FGF} = 1.0023 + 2.152 + 9.334 + 0.4959 = 12.984 \text{ m}^3_{FG}/\text{m}^3_F$$

The component percentage in flue gases composition:

$$V_{CO_2} = \frac{1.0023}{12.984} = 7.72\% \quad (14)$$

$$V_{H_2O} = \frac{2.152}{12.984} = 16.57\% \quad (15)$$

$$V_{N_2} = \frac{9.334}{12.984} = 71.89\% \quad (16)$$

$$V_{O_2} = \frac{0.4959}{12.984} = 3.82\% \quad (17)$$

The specific heat of exhaust gases with temperature $t_{FG_{bb}} = 204^\circ\text{C}$ (477 K) and the percentage by volume of products as well as the specific heat of each gas, should be obtained [8]:

$$c_{p_{FG}} = c_{p_{CO_2}} \cdot \%V_{CO_2} + c_{p_{H_2O}} \cdot \%V_{H_2O} + c_{p_{N_2}} \cdot \%V_{N_2} + c_{p_{O_2}} \cdot \%V_{O_2} \quad (18)$$

$$c_{p_{FG}} = 1.827 \cdot 0.0772 + 1.5227 \cdot 0.1657 + 1.310 \cdot 0.7189 + 1.3415 \cdot 0.0382 = 1.3864 \text{ kJ/m}^3_{FG} \text{ grad}$$

The energy derived on complete combustion per unit volume of natural gas or per unit of polyisoprene product depends on the total flue gases volume (V_{FG_F}), specific heat ($c_{p_{FG}}$) and flue gases temperature (t_{FG}):

$$q_{FG} = V_{FG_F} \cdot c_{p_{FG}} \cdot t_{FG} \quad (19)$$

$$q_{FG} = 12.984 \cdot 1.3864 \cdot 204 = 3672.2 \text{ kJ}_{FG}/\text{m}^3_F$$

$$q_{FG_p} = q_{FG} \cdot V_{F_p} \quad (20)$$

$$q_{FG_p} = 3672.2 \cdot 0.1384 = 508.23 \text{ kJ}_{FG}/\text{kg}_p$$

The volume of exhaust flue gases per unit of product rejected to the surrounding in basic process is:

$$V_{FG_p} = V_{FG_F} \cdot V_{F_p} \quad (21)$$

$$V_{FG_p} = 12.984 \cdot 0.1384 = 1.7969 \text{ m}^3_{FG}/\text{kg}_p$$

The volume of exhaust flue gases per hour rejected to the surrounding in basic process is:

$$V_{FG_h} = V_{FG_F} \cdot V_{F_h} \quad (22)$$

$$V_{FG_h} = 12.984 \cdot 415.2 = 5390.95 \text{ m}^3_{FG}/\text{h}$$

4. Air preheating using heat of exhaust flue gases in air preheater

To improve process plant efficiency, the exhaust flue gases could be used to preheat air, which is required for fuel combustion. The flue gases with the temperature $t_{FG_{APi}} = 204^\circ\text{C}$ (477.15 K) in amount of $V_{FG_F} = 12.984 \text{ m}^3_{FG}/\text{m}^3_F$ enter the heat exchanger, i. e. an air preheater with efficiency $\eta_{AP} = 90\%$, Figure 2. The ambient air enters the air preheater with the temperature $t_{a_{APi}} = 24^\circ\text{C}$ (297.15 K). The excess air coefficient is $\alpha = 1.25$ and the actual volume of air becomes $V_{a\alpha} = 11.807 \text{ m}^3_a/\text{m}^3_F$. The specific heat of flue gases is $c_{p_{FG}} = 1.3864 \text{ kJ/m}^3_{FG} \text{ grad}$ and for air $c_{p_a} = 1.29 \text{ kJ/m}^3_a \text{ grad}$.

The air preheater (AP) acts as a heat exchanger preheating the combustion air before entering the boiler [9]. The high flue gases outlet temperature exhaust gases from the boiler to the surroundings. However, flue gases temperature can be lowered using air preheater system simultaneously resulting in smaller fuel consumption, thus solving a problem of clean energy generation.

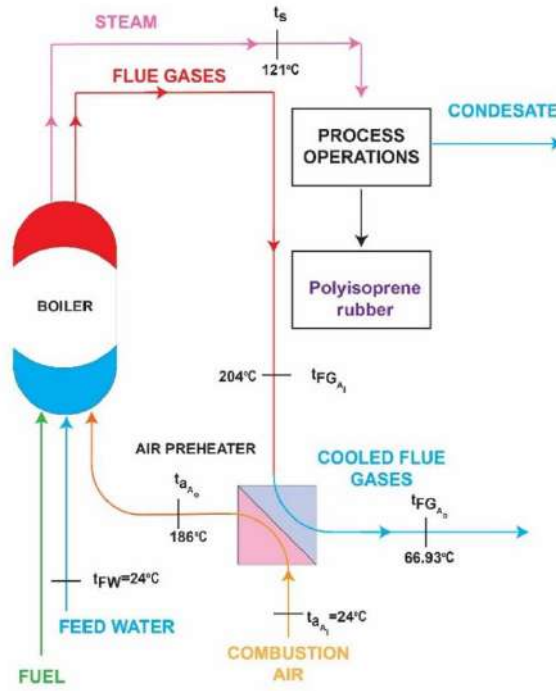


Figure 2: Process of Polyisoprene rubber production with air preheater

The air preheater heat balance equation [8] is:

$$V_{a\alpha} \cdot c_{pa} \cdot (t_{aAPo} - t_{aAPi}) = V_{a\alpha} \cdot c_{pa} \cdot (t_{FGAPi} - t_{aAPi}) \cdot \eta_{AP} = V_{FGF} \cdot c_{pFG} \cdot (t_{FGAPi} - t_{FGAPo}) \quad (23)$$

The air preheater air outlet temperature (t_{aAPo}) can be calculated using the air preheater heat balance equation, while $t_{FGAPo} = t_{FGAPi} = 204^\circ\text{C}$ (477.15 K):

$$t_{aAPo} = \frac{V_{a\alpha} \cdot c_{pa} \cdot (t_{FGAPi} - t_{aAPi}) \cdot \eta_{AP}}{V_{a\alpha} \cdot c_{pa}} + t_{aAPi} = \frac{11.807 \cdot 1,29 \cdot (204 - 24) \cdot 0,9}{11.807 \cdot 1,29} + 24 = 186^\circ\text{C} \quad (459.15 \text{ K}) \quad (24)$$

The ambient air with temperature at $t_{aAPi} = 24^\circ\text{C}$ (297.15 K) in volume $V_{a\alpha} = 11.807 \text{ m}^3_a / \text{m}^3_F$ passes through air preheater where they are heated by flue gases to temperature of $t_{aAPo} = 186^\circ\text{C}$ (459.15 K).

The flue gases outlet temperature (t_{FGAPo}) can also be calculated using the air preheater heat balance equation:

$$t_{FGAPo} = t_{FGAPi} - \frac{V_{a\alpha} \cdot c_{pa} \cdot (t_{FGAPi} - t_{aAPi}) \cdot \eta_{AP}}{V_{FGF} \cdot c_{pFG}} = 204 - \frac{11.807 \cdot 1,29 \cdot (204 - 24) \cdot 0,9}{12.984 \cdot 1,3864} = 66.93^\circ\text{C} \quad (340.08 \text{ K}) \quad (25)$$

The flue gases heat recovery in process with air preheating:

$$q_{FGAP} = V_{FGF} \cdot c_{pFG} \cdot V_{FP} \cdot (t_{FGAPi} - t_{FGAPo}) = 12.984 \cdot 1.3864 \cdot 0.1384 \cdot (204 - 66.93) = 343.951 \text{ kJ}_{FG} / \text{kg}_P \quad (26)$$

The natural gas savings in process with air preheater:

$$v_{FAPS} = q_{FGAP} / H_L = 343.95 / 35516.25 = 0,00968 \text{ m}^3_F / \text{kg}_P \quad (27)$$

The natural gas consumption is:

$$v_{FAP} = v_{FP} - v_{FAPS} = 0.1384 - 0,00968 = 0.12872 \sim 0.13 \text{ m}^3_F / \text{kg}_P \quad (28)$$

Comparison made with a basic process without flue gases heat recovery for air preheating shows natural gas savings in amount of:

$$S_{FAP} = (v_{FP} - v_{FAP}) / v_{FP} = (0.1384 - 0.12872) / 0.1384 = 0.0699 = 6.99 \sim 7\% \quad (29)$$

The volume of exhaust flue gases per unit of product rejected to the surrounding in process with air preheater is:

$$V_{FGAB} = V_{FGF} \cdot d_{FAP} = 12.984 \cdot 0.128772 = 1.671 \text{ m}^3_{FG} / \text{kg}_P \quad (30)$$

Air preheating using the flue gases heat recovery results in natural gas savings of 7%, the flue gases exhaust temperature is decreased from 204°C (477.15 K) to 66.93°C (340.08 K), while the volume of the flue gases is lowered from $V_{FGP} = 1.7969 \text{ m}^3_{FG}/\text{kg}_P$ to $V_{FGAP} = 1.671 \text{ m}^3_{FG}/\text{kg}_P$ or by 7,01%.

5. Conclusion

In order to improve energy efficiency through minimization of natural gas consumption and pollutants emission in polyisoprene footwear production process, process with air preheating using exhaust flue gases was analysed. Using an air preheater for combustion air preheating results in the exhaust temperature lowering to 66.93°C (340.08 K), while the volume of the flue gases is lowered to $V_{FGAb} = 1.671 \text{ m}^3_{FG}/\text{kg}_P$. The energy and environmental analysis show the efficiency increasing by using flue gases for combustion air preheating. Comparison made with a basic process without flue gases heat recovery for air preheating shows natural gas savings in amount of 7%. Further improvements in polyisoprene footwear production process could be made by using exhaust flue gases waste heat and reusing boiler condensate for feed water preheating, as well as combining all methods to gain maximum natural gas savings.

Acknowledgements

This paper is funded by project HRZZ IP-06-2016 5278: Comfort and antimicrobial properties of textiles and footwear (ComforMicrobTexFoot).

References

- [1] Speight, J. G. Handbook of Petrochemical Processes, CRC Press, Taylor&Francis Group, ISBN 978-1-4987-2970-3, Boca Raton, Florida, USA (2019)
- [2] Wehlan, A. & Lee, K. S. *Developments in Rubber Technology—2*, Springer, ISBN 978-9-40098-110-2, Dordrecht, Netherlands (1981)
- [3] Akovali, G. *Advances in Polymer Coated Textiles*, Smithers Rapra Technology Ltd., United Kingdom, ISBN 978-1-84735-497-6, (2012)
- [4] Brown, L. H.; Hamel, B. B. & Hedman, B. A.: *Energy analysis of 108 industrial processes*, Fairmont Press, ISBN 0-915586-93-2, Philadelphia, USA, (1996)
- [5] Budin, R.; Mihelić-Bogdanić A. & Vujasinović, E.: Cogeneration and Heat Recovery in the Industrial Process, *Chemistry in Industry*, Vol. 56 (2007) No. 11, pp. 551-555
- [6] Budin, R. & Mihelić-Bogdanić A.: *Basics of technical thermodynamics*. Third edition. Školska knjiga, ISBN 9789530316881, Zagreb, Croatia, 2012
- [7] *Energy Management Handbook*, Eight edition. Eds. Turner, W.C., Fairmont Press, ISBN 9781466578289, Philadelphia, USA, (2012)
- [8] Bošnjaković, F.: *The science of heat*. Volume 1, 2 i 3. Grafis, Zagreb, Croatia, 2012, ISBN 9789532790177
- [9] *Flue Gas Heat Recovery*. Power Systems, Babcock Borsig Steinmüller GmbH; Brochure, 2012; available at: http://www.bbs.bilfinger.com/fileadmin/power_steinmuller/Mediathek/Broschuere_Rauchgasw_rmenutzung_BB_S_web_E.pdf