Süleyman Demirel Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
Cilt 24, Sayı 2, 387-393, 2020

Süleyman Demirel University
Journal of Natural and Applied Sciences
Volume 24, Issue 2, 387-393, 2020

DOI: 10.19113/sdufenbed.678843

Energy and Exergy Analysis of an Industrial Annealing Furnace

Mehmet ALTINKAYNAK*[1], Doğan ÇELİK[2], Ali Kemal YAKUT[3]

[1,3]Isparta University of Applied Sciences, Faculty of Technology, Department of Mechanical Engineering, 32300, Isparta, Turkey
[2]BMC Otomotiv Sanayi A.Ş., 35060, İzmir, Türkiye

(Alınış / Received: 31.01.2020, Kabul / Accepted: 06.08.2020, Online Yayınlanma / Published Online: 20.08.2020)

Keywords
Energy,
Exergy,
Annealing furnace,
CH_4,
Steel

Abstract: The industry sector is one of the sectors with the highest energy input in Turkey. When these sectors are analyzed, it is seen that iron and steel sector is in the first place. In this iron and steel sector, where there is high energy need, it is necessary to ensure the maximum efficient use of energy. Exergy is a term that expresses the availability of energy to the forefront in this industry. In this study, energy and exergy analysis of annealing furnace which has high energy input is done. Analysis showed that the ideal flue gas pressure was 40 kPa. Furthermore, the highest Exergy destruction occurred in annealing furnace with 63%. It was found that there is an energy need of 565 kj/kg per annealed billet. It has been proposed that the flue gas at about 200 °Cejected from the flue can be produced with an ideal rankine cycle of about 3 MW. In addition, it is stated that this waste gas thrown from the chimney can be used to meet the heating and hot water (domestic water) needs of the factory.

Endüstriyel Bir Tav Fırının Enerji ve Ekserji Analizi

Anahtar Kelimeler
Enerji,
Ekserji,
Tav fırını,
CH_4,
Çelik

Özet: Türkiye'de en yüksek enerji girdisine sahip sektörlerin başında endüstri sektörü gelmektedir. Bu sektörler içerisine bakıldığında, demir çelik sektörünün ilk sıralarda olduğu görülmektedir. Yüksek enerji ihtiyacının olduğu bu demir çelik sektöründe enerjinin maksimum düzeyde verimli kullanılmasını sağlamak gerekmektedir. Enerjinin kullanılabilirliğini ifade eden ekserji terimi bu sektörde ön plana çıkmaktadır. Bu çalışmada yüksek enerji girdisine sahip olan, yanma havası fanı, havanın ön ısıtılmasını sağlayan reküpertör, kütüğün tavlandığı tav fırını, yakma havasının ortamdan uzaklaştırıldığı baca gazı fanı ve sistemdeki kütük taşıyıcı ve rölelerin ısıl deformasyonunun önlenmesini sağlayan gövde soğutma sistemi bileşenlerinden oluşan bir tav fırınının enerji ve ekserji analizi yapılmıştır. Yapılan analizlerde ideal baca gazı basıncının 40 kPa olduğu görülmüştür. Ayrıca en yüksek ekserji yıkımının % 63 ile tav fırınında gerçekleştiği görülmüştür. Tavlanan kütük başına 565 kj/kg'lık bir enerji ihtiyacının olduğu görülmüştür. Baca dan atılan yaklaşık 200°C'deki baca gazının ideal bir rankine çevrimi uygulamasıyla yaklaşık 3 MW'lık bir güç üretiminin sağlanabileceği önerilmiştir. Ayrıca bacadan atılan bu atık gazın fabrikanın ısınma ve sıcak su (kullanım suyu) ihtiyacını karşılamasında kullanılabileceği ifade edilmiştir.

1. Introduction

The steel industry is among the most energy consuming sectors in the world. The use of energy-intensive steel sector, its share in Turkey's total energy consumption, 7.5%, and the share of industrial consumption is around 23%. In the steel sector, the share of energy in input costs ranks second after raw materials. Turkey regional steel producers are given in Figure 1. The share of energy in input costs has a high ratio of around 15-25%. The share of energy in production costs is enough to show the importance of energy for the steel sector. Therefore, our steel sector has drawn a road map for the development of energy efficiency enhancing projects. The steel sector has been continuously developing its technology and continues to work towards renovation. Considering the studies carried

*İlgili yazar: mehmetaltinkaynak@isparta.edu.tr

out in the last 10 years in the steel sector; energy consumption per ton of raw steel was saved by around 18-20% [1].

Manatura and Tangtrakul [3], compared annealing furnaces with recuperators and combination annealing furnaces. They concluded that energy can be saved 43.4% in combination annealing furnaces. Ertem et al. [4], conducted energy balance and energy saving methods of slap annealing furnace No. 3 in Erdemir factory. The energy efficiency of the slap annealing furnace was found to be 64.26%. Si et al. [5], performed the energy efficiency potential of the annealing furnace of the iron and steel plant. The energy efficiency of the annealing furnace at the plant was calculated to be 60%. 29.5% of flue gas losses were discussed in the calculations. Hasanuzzaman et al. [6], carried out the energy and exergy yields, losses, energy saving and cost advantages of the industrial annealing furnace. The exergy efficiency of the combustion in the annealing furnace was calculated as 47.1%. The energy efficiency of the annealing chamber was calculated as 17.7% and the exergy efficiency was calculated as 12.9%. The total energy yield of the annealing furnace was 16.7% and the exergy yield was 7.3%. It is envisaged that 8.1% of the energy can be saved if a heat recovery system is installed to utilize the heat in the waste gas. Kılınç [7], found that the efficiency of the annealing furnace of the rolling mill I was 61.83% and that of the rolling mill II annealing furnace was 60.86% in the calculations made in the industrial annealing furnace of Kardemir A.Ş. As a result of the improvements, it is calculated that the energy efficiency of the rolling mill I annealing furnace can be increased to 76.80% and the energy efficiency of rolling mill II annealing furnace can be increased up to 77.20%. Tütünoğlu et al. [8], the energy efficiency of the glass tempering furnace was found to be 16.23%. They calculated that the energy efficiency could be 27.38% if the losses in the furnace were recovered. Tontu et al. [9], energy and exergy analysis of variable loads of steam power plant producing 660 MW power at full load were performed. In the calculations, it was observed that the most energy loss was in the condenser and the most exergy loss was in the boiler.

Eyidogan et al. [10], examined the energy efficiency of a rolling mill annealing furnace using LNG as fuel. The yield of industrial annealing furnace was found to be 52.76%. Possible saving points were determined and suggestions were made. Feng et al. [11], heat dissipation rates on the walls of the industrial annealing furnace were examined. They found that if the thickness of the insulation materials is used instead of the insulation materials of constant thickness, the heat loss that occurs is reduced by 8.85%. Caglayan and Caliskan [12] conducted energy, exergy and sustainability analyzes to simulate the gas turbine based cogeneration power plant model in the ceramic sector. They have tested their working temperature between 10-30°C at different ambient temperatures (5°C interval). They observed that the cogeneration system had an energy efficiency of 17.51% and that the maximum exergy efficiency 29.98% at an ambient temperature of 30°C. Turgutlu and Yurddas [13] applied thermodynamic analysis to a heat treatment furnace. The energy efficiency of the heat treatment furnace was 25.52%, the exergy efficiency was 19.99% and the exergy destruction

Figure 1. Steel map of Turkey [2].

was 43.83%. Vatandas [14], thermodynamic analysis was applied to the enamel cooking oven. As a result of the calculation, the energy efficiency of the furnace was 13% and the exergy efficiency was 9%. As a result of the improvement, it is predicted that energy efficiency can be increased to 28% and exergy efficiency to 20.3%.

2. Material and Method

Thermodynamic analysis of the annealing furnace in the rolling mill where rod iron was produced in an iron and steel plant was performed. The annealing furnace in the rolling mill has a capacity of 180 tons/hour. The width of the oven is 12.80 meters and the length is 24 meters. The billet entering the furnace must have a maximum reference of 180 mm. The industrial annealing furnace has a capacity of 95 billets. Standard annealing furnace is shown in Figure 2.

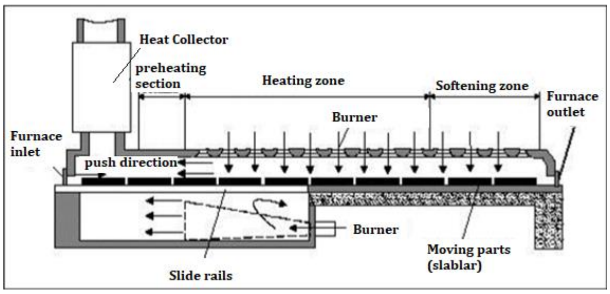


Figure 2. Annealing furnace [15].

It consists of industrial annealing furnace, combustion air fan system, recuperator system, chimney fan system, open and closed circuit cooling system. The flow chart of the annealing furnace is given Figure 3.

Steel inputs (billets) are heated up to 1050 °Cand 1300°Cin the hot rolling process performed in iron and Steel Rolling Mills. As a result of annealing, the billet is rolled and shaped. In order for the material to be rolled as desired, the regional thermal distribution in the annealed product must be equal and regular. In order to distribute heat evenly on the material, annealing furnaces are divided into temperature zones. The thermal energy requirement in the annealing furnace thermal zones is provided by the so-called burner. Input of burners from petroleum products (natural gas, fuel oil, etc.) are provided. Thermal energy generated in annealing furnace allows the products to reach the desired annealing temperature through heat transfer. The products in the oven are operational base (moving beam, etc.) Systems) Act with the help of. The capacity of the industrial furnace is determined by the tonnage of the steel it can anneal in one hour. An illustrative visual of the annealing furnace is given Figure 4.

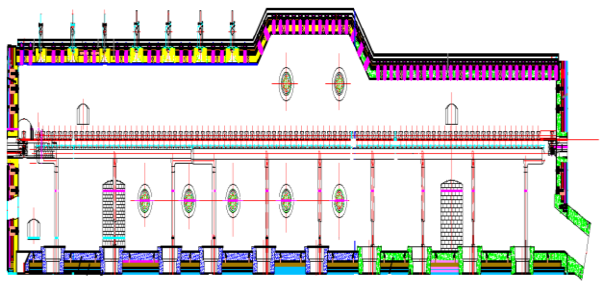


Figure 4. Cross section of oven with girder.

Using the temperature of the waste gas generated as a result of combustion in the annealing furnaces, energy design is provided in the furnaces.

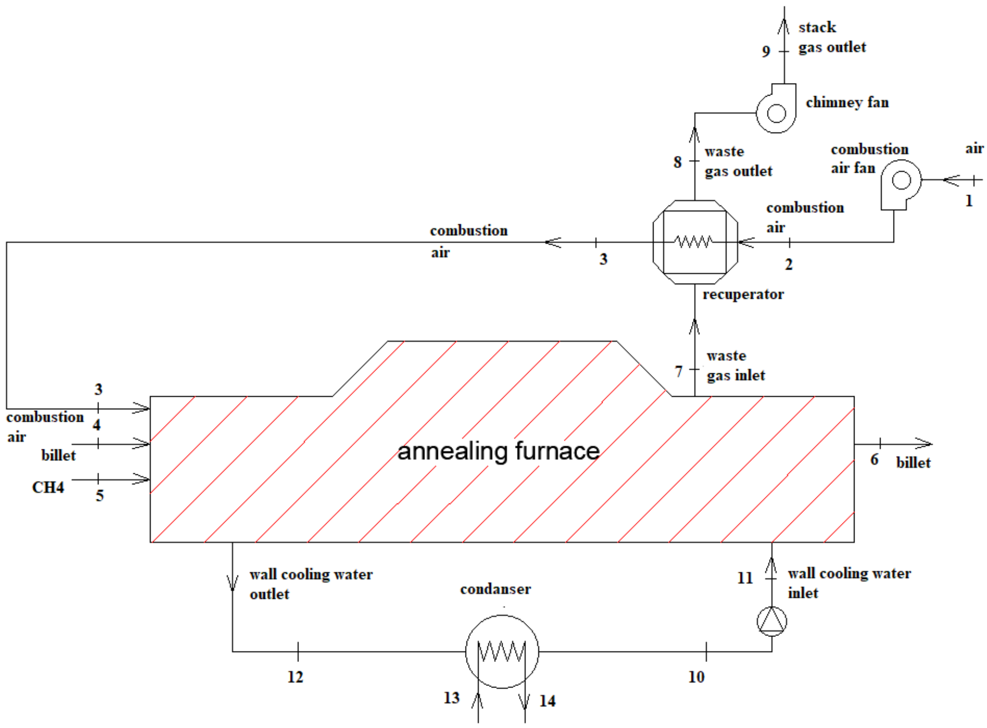


Figure 3. Flow diagram of industrial annealing furnace.

The heat generated in the industrial annealing furnace must be given linearly to the log. For this reason, the oven is divided into 8 heat zones. Homogeneous distribution of billet heat energy is provided with the help of thermal zones in the furnace. The thermal energy needed in the heat zones is provided by 79 burners operating with natural gas. There are 14,250 kW, 9,140 kW, 32.90 kW and 24.45 kW burners placed in different zones in the annealing furnace. Temperature adjustment is made for the furnace by means of burners with different thermal power in the thermal zones. In the temperature adjustment made in the furnace, pre-annealing is performed in the 1st and 2nd zones, medium annealing in the 3rd, 4th, 7th, and 8th zones and corrective annealing of the heated billet in the 5th and 6th zones. That is, the part in which the heat in the furnace is distributed homogeneously.

The technical characteristics of the recuperator and in the annealing furnace system are presented Table 1.

Table 1. Recuperator specifications

Waste Gas Inlet Temperature	750°C(max 850 °C)
Waste Gas Volume	80000 Nm³/h
Air Volume	85000 Nm³/h
Combustion Air Inlet Temperature	20°C
Combustion Air Outlet Temperature	40°C

The specifications of the chimney fan system are shown Table 2.

Table 2. Features of the chimney

Capacity	70000 (Nm³/h)(20°C)
Static pressure	500 mm.wc
Operating temperature	(20°C)
Installed power	250kW

The chemical components of the billet heated in the annealing furnace are shown Table 3. In the production of steel profiles by rolling method, properties such as strength, ductility and toughness depend on chemical composition and microstructure [18].

Table 3. Chemical components of SAE 1008

SAE 1008	Molecular Weight (kg/kmol)	Mass Percent (%)	Mass Flow (kg/s)
Carbon (C)	12.01	0.1	5.04
Silicon (Si)	28.08	0.3	15.65
Mangan (Mn)	54.90	0.51	26.79
Phosphorus (P)	31.00	0.04	2.12
Sulfur (S)	32.00	0.05	2.39
Lead (Pb)	207.20	0.02	1.06

The chemical components and technical characteristics of natural gas entering the annealing furnace are given in the following Table 4, Table 5 respectively.

Table 4. Chemical components of natural gas

Natural Gas		Molecular Weight (kg/kmol)	Mass Percentage (%)	Mass Flow Rate (kg/s)
Compound	Formula			
Methane	CH_4	16.043	0.93	0.59055
Ethane	C_2H_6	30.070	0.03	0.01905
Propane	C_3H_8	44.097	0.013	0.008255
Nitrogen	N_2	28.013	0.0270	0.017145

Table 5. Technical characteristics of natural gas

Property	Definition	Value
SG	Specific gravity	0.60274
P	Specific mass	0.738357 kg/m³
LHV	Lower thermal value	45000 kJ/kg
C	Heat capacity	2 kJ/kgK
Φ	Chemical exergy coefficient	1.04

2.1. Thermodynamics Analysis

The systems connected to annealing furnace were analyzed according to thermodynamic laws. In the analysis, the equipment mass, energy and exergy balance equations were used in the annealing furnace. Thermodynamic equilibrium equations of annealing furnace (mass, energy, exergy, balance) are given Table 6.

3. Results

The analysis and investigations of the industrial annealing furnace were made with the of EES (Engineering Equation Solver) software [19]. As a result of the analyzes, energy and exergy balance was applied to all the equipments of the system. Exergy destructions were investigated for all equipment. The results are given Figure 5-10. The yield diagram for the destruction of Exergy occurring in the stack gas fan is given Figure 5.

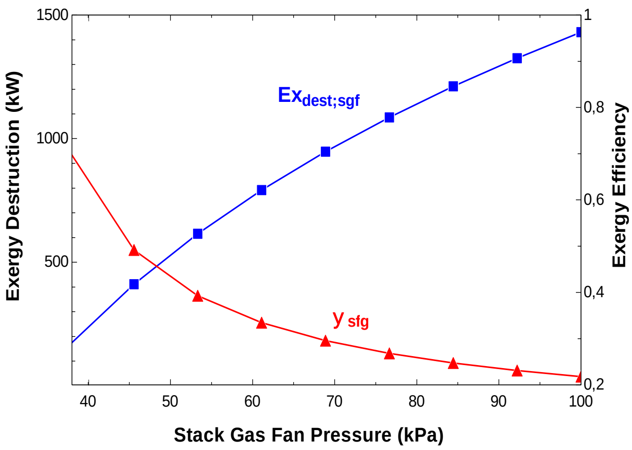
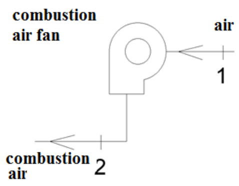


Figure 5. Stack gas fan pressure exergy destruction.

As shown in the diagram Figure 6, increasing the stack gas fan pressure increases the Exergy destruction of the recuperator and thus reduces the Exergy efficiency of the recuperator. It is important for the efficiency of the system to work at as low pressures as possible to reduce efficiency loss and exergy destruction.

Table 6. First and second law analysis of the system components [16,17]

Schematic Figure | **Mass, Energy, Exergy Balance**

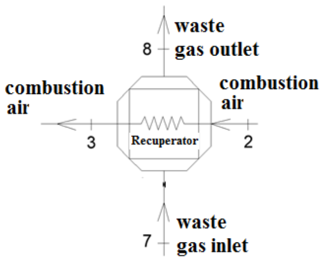


$$\dot{m}_1 = \dot{m}_2 \quad (1)$$

$$\dot{m}_1 h_1 + W_{yhf} = \dot{m}_2 h_2 \quad (2)$$

$$\dot{m}_1 s_1 + \dot{S}_{gen,yhf} = \dot{m}_2 s_2 \quad (3)$$

$$\dot{m}_1 ex_1 + W_{yhf} = \dot{m}_2 ex_2 + \dot{E}_{dest,yhf} \quad (4)$$

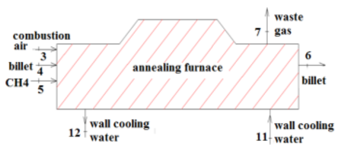


$$\dot{m}_2 + \dot{m}_7 = \dot{m}_3 + \dot{m}_8 \quad (5)$$

$$\dot{m}_2 h_2 + \dot{m}_7 h_7 = \dot{m}_3 h_3 + \dot{m}_8 h_8 \quad (6)$$

$$\dot{m}_2 s_2 + \dot{m}_7 s_7 + \dot{S}_{gen,rec} = \dot{m}_3 s_3 + \dot{m}_8 s_8 \quad (7)$$

$$\dot{m}_2 ex_2 + \dot{m}_7 ex_7 = \dot{m}_3 ex_3 + \dot{m}_8 ex_8 + \dot{E}_{dest,rec} \quad (8)$$

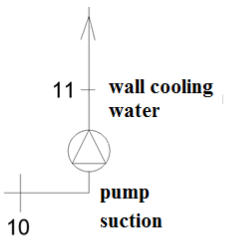


$$\dot{m}_3 + \dot{m}_4 + \dot{m}_5 + \dot{m}_{11} = \dot{m}_6 + \dot{m}_7 + \dot{m}_{12} \quad (9)$$

$$\dot{m}_3 h_3 + \dot{m}_4 h_4 + \dot{m}_5 h_5 + \dot{m}_{11} h_{11} = \dot{m}_6 h_6 + \dot{m}_7 h_7 + \dot{m}_{12} h_{12} \quad (10)$$

$$\dot{m}_3 s_3 + \dot{m}_4 s_4 + \dot{m}_5 s_5 + \dot{m}_{11} s_{11} + \dot{S}_{gen,furn} = \dot{m}_6 s_6 + \dot{m}_7 s_7 + \dot{m}_{12} s_{12} \quad (11)$$

$$\dot{m}_3 ex_3 + \dot{m}_4 ex_4 + \dot{m}_5 ex_5 + \dot{m}_{11} ex_{11} = \dot{m}_6 ex_6 + \dot{m}_7 ex_7 + \dot{m}_{12} ex_{12} + \dot{E}x_{dest,furn} \quad (12)$$

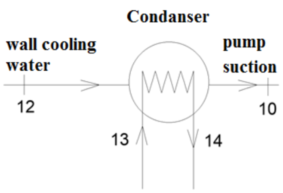


$$\dot{m}_{10} = \dot{m}_{11} \quad (13)$$

$$\dot{m}_{10} h_{10} + W_{pump} = \dot{m}_{11} h_{11} \quad (14)$$

$$\dot{m}_1 s_1 + \dot{S}_{gen,pump} = \dot{m}_{11} s_{11} \quad (15)$$

$$\dot{m}_{10} ex_{10} + W_{pump} = \dot{m}_{11} ex_{11} + \dot{E}_{dest,pump} \quad (16)$$

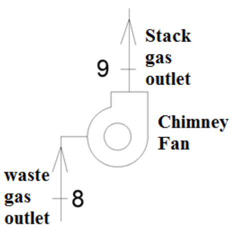


$$\dot{m}_{12} + \dot{m}_{13} = \dot{m}_{10} + \dot{m}_{14} \quad (17)$$

$$\dot{m}_{12} h_{12} + \dot{m}_{13} h_{13} = \dot{m}_{10} h_{10} + \dot{m}_{14} h_{14} \quad (18)$$

$$\dot{m}_{12} s_{12} + \dot{m}_{13} s_{13} + \dot{S}_{gen,cool,tow} = \dot{m}_{10} s_{10} + \dot{m}_{14} s_{14} \quad (19)$$

$$\dot{m}_{12} ex_{12} + \dot{m}_{13} ex_{13} = \dot{m}_{10} ex_{10} + \dot{m}_{14} ex_{14} + \dot{E}x_{dest,cool,tow} \quad (20)$$



$$\dot{m}_8 = \dot{m}_9 \quad (21)$$

$$\dot{m}_8 h_8 + W_{chimney,fan} = \dot{m}_9 h_9 \quad (22)$$

$$\dot{m}_8 s_8 + \dot{S}_{gen,chimney,fan} = \dot{m}_9 s_9 \quad (23)$$

$$\dot{m}_8 ex_8 + W_{chimney,fan} = \dot{m}_9 ex_9 + \dot{E}_{dest,chimney,fan} \quad (24)$$

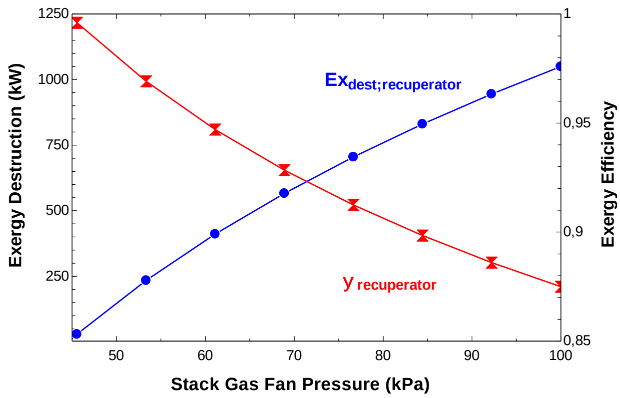


Figure 6. Recuperator exergy destruction and exergy efficiency diagram.

Figure 7 shows the effect of the change of pressure of the stack gas fan, the exergy destruction of the annealing furnace, and the exergy destruction of the recuperator, which allows the combustion air to be preheated, enabling the system to operate under ideal combustion conditions.

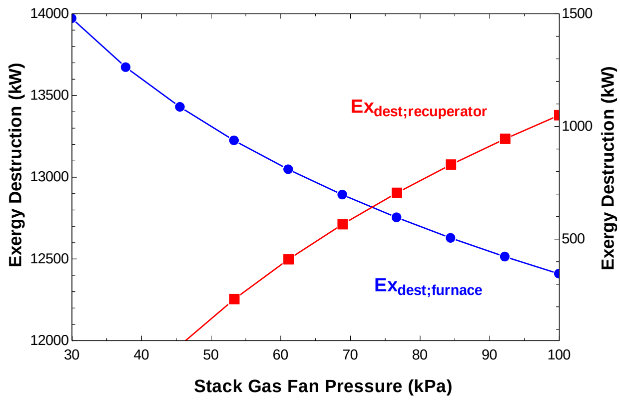


Figure 7. Annealing furnace exergy destruction diagram.

The diagram is showing exergy destruction and exergy efficiency of the annealing furnace where natural gas and incineration air are fed is presented Figure 8.

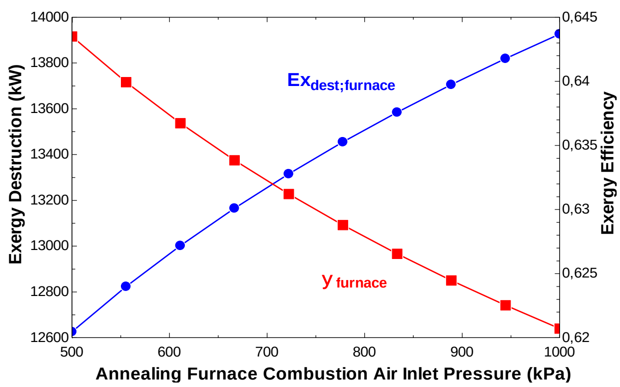


Figure 8. Annealing furnace combustion air Exergy efficiency diagram.

Figure 9 shows that energy efficiency increases as exergy destruction in the pump increases. Furthermore, it was observed that the pump's operating efficiency decreased while the exergy value of the pump increased.

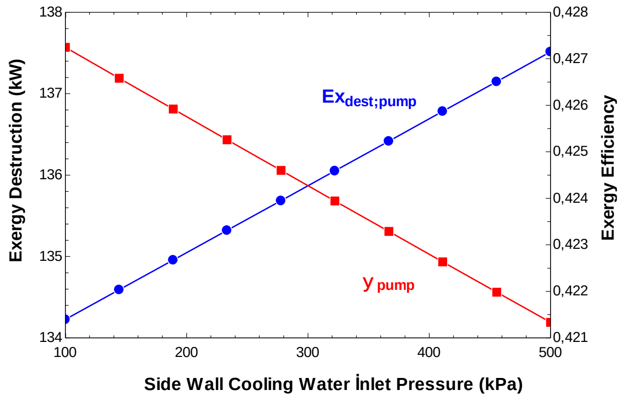


Figure 9. Annealing furnace side wall cooling pump exergy destruction and exergy efficiency diagram.

Figure 10 shows that as the air inlet pressure increases in the condenser, the exergy destruction value in the pump increases but the operating efficiency of the condenser decreases.

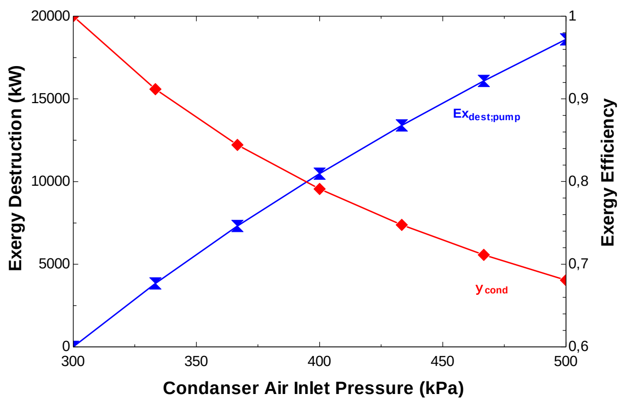


Figure 10. Effect of condenser air inlet pressure on exergy destruction.

4. Discussion and Conclusion

Mostly, the thermal efficiency of annealing furnaces is between 35-45% [20]. As a result of the efficiency analysis, the oven efficiency was found to be 36.8%.

Each strip annealing temperature is different depending on the strip quality. The temperature value of the oven varies according to the line speed and strip dimensions. Since increasing the line speed will increase the production level, it will be provided in savings in the ideal annealing process [21].

In this study, energy and exergy analyzes were performed by EES (Engineering Equation Solver) software by using real factory data of an annealing furnace with a capacity of 95 billet annealing per hour.

Exergy destruction and exergy efficiency of the flue gas fan of the furnace were investigated. At the suction pressure of 40 kPa, minimum exergy destruction and maximum exergy efficiency were obtained. The equipment with the highest exergy destruction is the annealing furnace with a length of 12 meters and a length of 18 meters. This annealing furnace enters 3100 m^3 of natural gas fuel per hour. When coal is used as an alternative fuel, bag filters or electro-filters are required in the system.

In addition, since the flue gas outlet temperature is 200°C, it is stated that steam can be produced with a heat exchanger that can be placed here and it can be used both in power generation (about 3 MW) and factory needs.

References

[1] TOBB, 2016. Türkiye Demir ve Demirdışı Metaller Meclisi Raporu. https://www.tobb.org.tr/Documents/yayinlar/2017/T%C3%9CRK%C4%B0YE%20DEM%C4%B0R%20VE%20DEM%C4%B0R%20DI%C5%9EI%20METALLER%20MECL%C4%B0S%C4%B0%20SEKT%C3%96R%20RAPORU%202016_e-kitap/files/assets/common/downloads/publication.pdf (Access Date: 10.02.2020).

[2] TCUD, 2019. Türkiye Çelik Üreticileri Derneği http://celik.org.tr/harita/#! (Access Date 01.08.2019)

[3] Manatura, K., Tangtrakul, M. 2010. A study of specific energy consumption in reheating furnace using regenerative burners combined with recuperator. Silpakorn U Science & Tech J, 4(2), 7-13.

[4] Ertem, G., Çelik, B., Yeşilyurt, S. 2008. Endüstriyel tav fırınlarında ısı denkliği hesaplamaları ve enerji verimliliğinin belirlenmesi. IV. Ege Enerji Sempozyumu, İzmir, 1-8.

[5] Si, M., Thompson, S., Calder, K. 2011. Energy efficiency assessment by process heating assessment and survey tool (PHAST) and feasibility analysis of waste heat recovery in the reheat furnace at a steel company. Renewable and Sustainable Energy Reviews, 15(1), 2904-2908.

[6] Hasanuzzaman, M., Saidur, R., Rahim, N. A. 2011. Energy, exergy and economic analysis of an annealing furnace. International Journal of the Physical Sciences, 6(6), 1257-1266.

[7] Kılınç, E. 2012. Endüstriyel fırınlarda enerji analizi ve verim arttırıcı yöntemler", Karabük University Institute of Science and Technology, Master's Thesis, 90p.

[8] Tütünoğlu, Y., Güven, A., Öztürk, İ. T. 2012. Cam temperleme fırınında enerji analizi. TMMOB MMO Mühendis ve Makina Dergisi, 53(629), 55-62.

[9] Tontu, M., Bilgili, M., Sahin, B. 2018. Performance analysis of an industrial steam power plant with varying loads. International Journal of Exergy, (27)2, 231-250.

[10] Eyidogan, M., Kaya, D., Dursun, Ş., Taylan, O. 2014. Endüstriyel tav fırınlarında enerji tasarrufu ve emisyon azaltım fırsatları. Gazi Üniversitesi Mühendislik Mimarlık Dergisi, 29(4), 735-743.

[11] Feng, H., Chen, L., Xie, Z., Sun, F. 2014. Constructal entransy dissipation rate minimization for variable cross-section insulation layer of the steel rolling reheating furnace Wall. International Communications in Heat and Mass Transfer, 52, 26-32.

[12] Caglayan, H., Caliskan, H. 2018. Energy, exergy and sustainability assessments of a cogeneration system for ceramic industry. Elseiver, 136, 504-515.

[13] Turgutlu, G. A., Yurddaş, A. 2015. Bir ısıl işlem fırınının termodinamik analizi. Celal Bayar Üniversitesi Fen Bilimleri. Dergisi, 12(1), 75-92.

[14] Vatandaş, S. 2016. Sanayi fırınlarında enerji ve ekserji verimliliği; örnek çalışma emaye pişirme fırını verimlilik projesi enerji ve ekserji analizlerinin gerçekleştirilmesi. Uludağ University Institute of Science and Technology, Master's Thesis, 94p.

[15] Remus, R., Monsonet, A. A., M. Roudier, S. Sancho D. L. 2013. Integrated Pollution Prevention and Control (IPPC) Best Available Techniques Reference Document on the Production of Iron and Steel. European Union, Spain, 597s.

[16] Dincer, I., Zamfirescu, C. 2012. Sustainable energy systems and applications, Springer New York, NY, 816s.

[17] Dincer, I., Rosen, M. A. 2013. Exergy: Energy, Environment and Sustainable Development. Elseiver, USA, 547s.

[18] Akkaş, M., Çulha, O. 2018. Sıcak haddelenmiş düşük karbonlu gemi inşa çeliklerinin farklı ortamlarda soğutulmasının mekanik özelliklerin değişimine tesirinin incelenmesi. El-Cezerî Journal of Science and Engineering, 5(3), 862-874.

[19] Klein, S. A., Engineering Equation Solver, version 9.022-3D, F-Chart Software, 2011.

[20] U.S Departmant of Energy, 2014. Waste Heat Reduction and Recovery for Improving Furnace Efficiency, Productivity and Emissions Performance. https://www.energy.gov/sites/prod/files/2014/05/f15/35876.pdf (Access Date: 14.02.2020).

[21] Sezer, Ö.F., Coşkun, E. 2016. Energy saving in continuous annealing line using heating optimization. Alphanumeric Journal, 4(1), 73-83.