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ECONOMIZER DESIGN AND APPLICATION FOR ENERGY RECOVERY WITH REDUCING FLUE GAS TEMPERATURE

BESTE HOPLAMAZ
MASTER OF SCIENCE

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I hereby declare that all information in this thesis has been obtained and presented by academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

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ABSTRACT

ECONOMIZER DESIGN AND APPLICATION FOR ENERGY RECOVERY WITH REDUCING FLUE GAS TEMPERATURE

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Due to increasing energy costs and legal regulations regarding CO_2 reduction, economic solutions are required for application areas with high energy needs. One of the possibilities that can be used is energy recovery from waste heat. Only a certain part of the heat generally used in processes involving heating can be used for the realization of the process. The remaining part is discharged in different ways, mostly through flue gases. With the economizer, an efficiency increase between 3% and 15% is achieved in the efficiency of the boiler or plant by recovering some of the heat on the hot flue gases coming out of the boilers/furnaces and going to the chimney in heat, steam or power generation facilities. Depending on the increase in efficiency, fuel savings can be achieved. In this study, by using the exhaust gas waste heat of 4 steam generators with a capacity of 3 ton/h, 4 economizers were added to the system and the feed heating heated. In the new situation, the existing economizers will be dismantled, and the economizer will be instated in a higher capacity, making use of the exhaust gas. Thus, while making more use of exhaust gas, natural gas savings will be achieved.

Keywords: economizers, energy saving, waste heat recovery, exhaust gas, flue gas

ÖZET

BACA GAZI SICAKLIĞINI AZALTARAK ENERJİ GERİ KAZANIMI İÇİN EKONOMİZER TASARIMI VE UYGULAMASI

Beste HOPLAMAZ
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Artan enerji maliyetleri ve CO_2 azaltımına ilişkin yasal düzenlemeler nedeniyle, enerji ihtiyacının yüksek olduğu uygulama alanlarında ekonomik çözümlere ihtiyaç duyulmaktadır. Kullanılabilecek olanaklardan biri atık ısıdan enerji geri kazanımıdır. Genellikle ısıtma içeren işlemlerde kullanılan ısının sadece belirli bir kısmı işlemin gerçekleştirilmesi için kullanılabilir. Kalan kısım ise çoğunlukla baca gazları yoluyla farklı şekillerde tahliye edilir. Ekonomizer ile kazanlardan/fırınlardan çıkan ve bacaya giden sıcak baca gazlarındaki ısının bir kısmı ısı, buharda geri kazanılarak kazan veya tesisin verimliliğinde %3 ile %15 arasında verim artışı sağlanır. Verimlilik artışına bağlı olarak yakıt tasarrufu sağlanabilir. Bu çalışmada 3 t/h kapasiteli 4 adet buhar jeneratörünün baca gazı atık ısısı kullanılarak sisteme 4 adet ekonomizer eklenecek ve besleme suyu ısıtılacaktır. Yeni durumda mevcut ekonomizerler sökülecek ve ekonomizer baca gazından yararlanılarak daha yüksek kapasitede kurulacaktır. Böylece baca gazından daha fazla yararlanılırken doğal gaz tasarrufu sağlanacaktır.

Keywords: ekonomizerler, enerji tasarrufu, atık ısı geri kazanımı

Dedication

I would like to dedicate my thesis to my family.

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1. INTRODUCTION

Energy is a resource used in every field and it has an important place, especially in production costs. Today, the energy demand is increasing day by day. The reserves of fossil fuels, which meet a large part of the world's energy needs today, are rapidly depleting. On the one hand, alternative energy sources are sought instead of depleted fossil fuels, on the other hand, effective and efficient use of existing resources comes to the fore. Sustainable development is of great importance for organizations and achieving high growth rates. Companies that correctly assess social and environmental risks, create opportunities with innovative and sustainable business models, and rely on sustainability in their investment decisions will be able to gain an edge in "green competition", which will gain even more importance in the coming years. It is important to carry out these sustainability policies through sustainability in energy and energy efficiency studies that are appropriate for businesses.

Minimizing the amount of energy consumed without reducing the amount of product obtained from production and the quality rate, without adversely affecting economic developments and social welfare is called energy efficiency. In other words, energy efficiency; To prevent gas, steam, heat, air and electrical energy losses in the system, to recover and reuse the formations removed from the system as waste, or to reduce the energy need without reducing the amount of production, more efficient energy sources, more advanced industrial processes, efficiency such as energy recovery.

The main thing in energy efficiency is to reduce consumption by using energy effectively without any savings or restrictions. Another way to use energy more effectively is to use alternative energy sources. The efficient use of energy in industrial facilities with high production capacity and high energy consumption not only reduces costs, but also significantly reduces the resource consumption required for energy production.

The industrial sector occupies an important place all over the world, among the areas where energy is used most intensively. In this context, the use of energy in the industrial sector should be examined in order to prevent global warming and therefore reduce greenhouse gas emissions. About 38% of the final energy worldwide is used in industry. Therefore, the energy consumption of industrial processes should be reduced as much as possible. Today, reduction of energy consumption, especially in industry, has become one of the key factors due to the studies and legislations to reduce greenhouse gas emissions all over the world. It is also known that improvements in energy efficiency result in lower operating costs and increased profitability. However, even in enterprises with optimized thermal systems, waste heat at high temperatures is thrown out.

Almost 26% of the energy used in industry is thrown away as hot gases and liquids. This lost energy can be greatly reduced by waste heat recovery. The fact that the investment to be made in waste heat recovery systems can pay for itself in a minimum period of time provides advantages in the competitive environment. Industrial waste heat recovery systems are systems that can provide significant energy savings and significant reductions in greenhouse gas emissions. In this context, the use of waste heat recovery systems in industrial processes has been one of the important research areas to reduce fuel consumption, reduce harmful gas emissions and increase production efficiency. Considering all these advantages, the importance of industrial enterprises to install waste heat recovery systems suitable for them is clearly seen.

In this thesis, 4 different economizer systems will be designed and installed for 4 steam generators with a capacity of 3 t/h in a facility. Currently, there is an economizer behind the steam generators, but the capacities of these economizers are insufficient. The flue outlet temperatures of the existing economizers are very high. In the new situation, the existing economizers will be dismantled and economizers with higher capacity will be installed so that flue gas can be used. Thus, while making more use of flue gas, natural gas savings will be achieved.

2. LITERATURE REVIEW

The process of increasing the thermal performance by using fins in heat exchangers is a very common method. However, since the geometries encountered are often complex, it is very difficult and time-consuming to accurately predict the flow and heat transfer characteristics. However, when we look at the studies in the literature, it was seen that most studies were done on circular finned tubes. Energy is one of the most fundamental and pioneering stones of the civilization that mankind has today. For this reason, energy production and consumption is one of the issues that need careful consideration and strategy development (Varnca and Volunteer, 2002).

As in the world, the need for energy is increasing day by day in direct proportion to the rapid increase in the population and the developments in the industry in our country. Existing energy resources could not meet the increasing energy needs and as a result, the concept of energy efficiency emerged. Energy efficiency is defined as minimizing the amount of energy consumed without reducing the amount of product obtained from production and the quality ratio, in a way that does not adversely affect economic developments and social welfare (Tokgöz and Özgün, 2019).

Traditional fuels used for a long time; These are fuels such as coal, liquid fuels (fuel oil, gasoline, kerosene, etc.), gaseous fuels (lpg, natural gas, air gas, water gas). The usage patterns of these fuels differ among themselves. In addition to its negative effects on the environment, it has been forced to turn to alternative energy sources due to the gradual decrease of its reserves (Angın, 2007).

What needs to be done to control energy demand is to use energy efficiently. Thanks to energy efficiency, more products can be obtained with a certain amount of energy or less energy can be used for a certain product. It is stated that as a result of the efficient use of energy, especially in large facilities, the cost of energy can be reduced and the costs of the systems made to recover the lost energy will be minimized. In addition, harmful emissions to the environment are reduced during energy conversion in plants using fossil fuels (Çomaklı et al., 2006).

Today, around 26% of industrial energy consumption in many countries is lost in the form of waste gases and waste liquids. This loss can be significantly reduced by the application of waste heat recovery basic techniques. Rising energy prices have made investments in heat recovery equipment profitable and have shown that the amortization period is usually short, ranging from a few months to a few years. In order to evaluate this situation well, it is necessary to develop an appropriate and effective heat recovery system (Selbaş, 1992).

Most of the energy losses in a boiler are due to the heat released into the atmosphere by the exhaust flue gas. The released heat consists of sensible and latent heat. Due to biological and environmental safety, clean fuels such as natural gas have been widely used in boilers recently. Since these clean fuels contain a lot of hydrogen instead of carbon, the exhaust gas contains a lot of water vapor with latent heat. Therefore, latent heat recovery from flue gas is very important to increase boiler efficiency (Osakabe et al., 2001).

The fuel savings to be obtained by installing an economizer in a boiler have been examined. After the studies, it has been revealed that the fuel saving is between 6-16% (Gibbs, 1987).

In this study, they calculated the efficiency of condensing economizers used in boilers using coal as fuel and the possible use of flue gas outputs in terms of emission controls. In their study, they made experimental investigations of air and water cooled economizers integrated into such boilers by making heat transfer calculations (Butcher and Litzke, 1994).

In the case of using economizers in the annealing furnace in the rail and profile rolling mill, waste heat recovery work has been carried out. In his study, the energy usage possibilities, design criteria and amortization periods from the economizer were calculated by taking the results of the flue gas measurements and obtaining the mass and energy balances. He determined that the economizer was working with 84% efficiency and calculated that the annual gain as a result of using the economizer would be 513,916 € in total, and the depreciation period of the system would be 3.6 years (Çıtır, 2013).

In this study, a low-pressure economizer was designed as a waste heat recovery system for a coal-fired power plant and its thermodynamic analysis was carried out. He mentioned that by using the low pressure economizer, the heat in the exhaust flue gas can be recovered effectively and water consumption can be reduced at the same time (He, 2014).

In this study, the usability of the heat energy obtained as a result of the recovery of the waste gas from the annealing furnace chimney of an industrial facility in the iron and steel sector, by means of economizer, in central heating-cooling systems and hot water usage areas was investigated. Depending on the temperature of the gas discharged from the furnace chimney, thermal capacity calculations and optimum values were determined. As a result of the calculations, it has been calculated that an annual saving of approximately 6.300.000 TL is achieved as a result of obtaining the hot water needed by the facility with the waste heat energy recovered through the economizer (Kılınç, 2016).

In this study, the use of low pressure economizer for waste heat recovery in coal fired power plant was investigated thermodynamically. It has been observed that by installing a low pressure economizer in the flue before the flue gas desulfurizer, the heat contained in the exhaust flue gas can be recovered effectively and the water consumption resulting from the flue gas with reduced temperature in the flue gas desulfurizer can be reduced. In addition, after installing the low pressure economizer, the standard coal equivalent savings for this unit were calculated to be 3.85 g/(kW $ h). Again, Wang et al. (2012), a study was conducted on the recovery of flue gas waste heat before entering the desulfurizer in a 600 MW power plant. It has been determined that this waste heat can be recovered by installing a low pressure economizer capable of trapping the steam exiting the steam turbine to heat the condensed water. The analysis results show that it is possible to install the low pressure economizer in the flue gas system between the desulfurizer and the pressurization fan. Benefits achieved include saving 2–4 g/(kW·h) of standard coal equivalent, saving 25-35 tons/h of water, and corresponding reduction of CO_2 emissions (Wang et al., 2014).

In a study, a recuperator was designed to heat the boiler combustion air or to obtain hot water at 55°C by using high temperature flue gases in natural gas fueled systems. With the recuperator made as a result of the design, 20000 liters of water can be heated daily. In addition, it has been observed that the boiler efficiency has increased from 92% to 99.98%, and the recuperator used to heat the boiler feed water provides 5 Nm^3 /h fuel savings (Aras, 1991).

A spiral heat exchanger has been designed to take advantage of the sensible heat found in the flue gas coming out of the kitchen oven. According to the results of the research, it was determined that more than 60% of the waste heat in the kitchen oven can be recovered and the use of spiral heat exchanger is very economical (Alkhamis et al., 2014).

As a result of the use of economizer in heating the boiler feed water, it has been determined that 1% fuel savings can be achieved for every 10°C increase in feed water temperature (Farthig, 2011).

In their study, they compared the results with similar international applications by determining the efficiency of the high pressure steam boiler working with natural gas in the fruit juice preparation facility and the two economizers connected to the chimney line of this boiler. 90.11% instead of 89.5% efficiency given by the manufacturer company for the boiler, 4.18% instead of 5% for the first economizer, and 4.05% instead of 2.5% for the second economizer were calculated. As a result, it has been observed that the total efficiency calculated is 98.40% and this value is over 97%, which is the project value given by the manufacturer (Olgun et al., 2007).

In the study, an exemplary heat exchanger was designed to benefit from the high-temperature waste flue gas energy of the furnace in the factory. They stated that it would be possible to meet the hot water need in the facility or the space heating by using the waste flue gas temperature, thanks to the heat exchanger whose calculations were made (Dalkılıç et al., 2008).

In the ceramic industry with high energy consumption, an economizer has been designed to obtain hot water by utilizing waste heat from a vitrified ceramic furnace. In his study using 7 economizers, 2513000 m3 of natural gas was saved annually and the depreciation period of the system was determined as 8.3 months (Madan, 2014).

In the study, a new recuperator with high heat transfer capacity, resistant to corrosive effects, was designed to provide maximum efficiency by optimizing fuel and increasing heat transfer from 700-850°C furnace flue gas to furnace combustion air in the rail profile rolling mill annealing furnace. While in the old recuperator, the combustion air temperature is 375°C for the flue gas temperature of 820°C, the combustion air temperature of 575°C is provided for the flue gas temperature of 820°C in the corresponding new recuperator. While energy recovery and emission reduction were achieved in the new recuperator, high-quality products were obtained, as well as low-cost production (Selimli, 2012).

In a study investigating the effect of installing a high-pressure economizer in parallel, in addition to a lignite-fired power plant that has been in operation for 30 years and producing 620 MW of electricity, it has been shown that more than 30 MW of flue gas waste heat is recovered. It has been stated that the unit gross efficiency has increased by 0.53%, leading to 9.4 MW electrical energy production. It has been observed that the additional economizer connected in parallel also causes partial feedwater bypass of the high pressure heaters, enabling the plant electrical power to be increased up to 24.5 MW (Stevanovic et al., 2014).

In a study, the thermal economy and techno-economic performance of exhaust gas heat recovery processes, including low temperature economizer, partial air heating and bypass, were compared for 600 MW electricity generation using coal. It is stated that an important way to increase the power plant thermal efficiency is to recover the exhaust gas heat at the boiler cold end by the gradual integration of the steam turbine heat regenerative system. The results show that by using these three heat recovery processes, the unit net standard coal consumption rate can be reduced by 4.43, 5.84 and 6.48 g/(kW/h), respectively, and the initial cost is 3.84, 3.52 and 3, respectively. It showed that it was .39 million USD. It has also been observed that if the 600 MW unit operates 5500 hours per year at 7 rated loads, these three operations can increase the annual coal revenue by 1.49, 2.03 and 2.27 million USD, respectively, and dynamic payback periods of 3.12, 2.00 and 1 It is calculated to be 71 years (Ma et al., 2014).

In this thesis, an economic analysis was made with the performance of waste heat and water recovery from the flue gas by using condensing heat exchangers in the power plant. In addition, the effect on water condensation efficiency, total heat transfer and total annual cost was analyzed for five different arrangements. The influence of heat exchanger design parameters, such as heat exchanger pipe diameter and pipe transverse spacing, was analyzed (Goel, 2012).

A system has been developed to efficiently use the low-temperature waste heat in the flue gas of coal-fired power plants. The purpose of this system is to use the flue gas waste heat to preheat the air as well as to heat the feed water and low pressure steam extraction. According to the results of the study, the net power output increased by 19.51 MW, the exergy efficiency increased to 45.46% and the net annual income reached 4741 million USD (Huang et al., 2017).

In the thesis study, the recovery potential of the energy loss in the flue gas in the boiler using natural gas fuel was investigated and the condensation event of the water vapor in the flue gas for energy recovery was examined in terms of energy, exergy and economy. 5 different scenarios applicable for energy recovery of this system are considered. Selection and design of heat exchangers such as air preheater, economizer, condensing economizer used in these scenarios, as well as energy, exergy analysis and economic analysis have been made. As a result of the calculations, it has been determined that 3 condensing economizers can meet the hot water needs of 184 lodging flats. The approximate cost of this system is 205176.06 TL and the amortization period is 3 months. The total amount of fuel savings that the system will provide during its 20-year economic life has been calculated as 2443041.31 TL (Terhan, 2015).

It has presented several applications for industrial waste heat recovery systems. One of them is related to the use of condensing economizer in the chemical factory. In the condensing economizer, heat is recovered by cooling the boiler flue gases to a degree lower than the dew point. This heat gained is generally used to heat the feed water. The amount of natural gas saved by the use of condensing economizers is 273802 m3 and its monetary value is 104580 $. The implementation cost of this system is $347000 and the depreciation period of the investment is 3.32 years (Bhattacharjee, 2010).

In this study, an economizer system used in the production of hot water was designed to increase energy efficiency by utilizing the waste heat from the paint drying oven in the automotive factory and the benefits of this system were evaluated. According to the results obtained; It was determined that 4.04 m3 of fuel savings per hour from the drying oven and 6.27 m3 of fuel per hour from the cooking oven can be achieved. It has been calculated that the natural gas consumption of the facility will decrease by 10-12% and the payback period will be 2.76 years, with a total fuel saving of 10.31 m3 hours by using the two economizers to be applied together (Uysal, 2019).

Heating possibilities of Yatağan Thermal Power Plant with flue gas were investigated. The heat capacity of the power plant was calculated, and the costs of the flue gas heating system and solid fuel heating system to be installed according to this heat capacity were calculated. It has been evaluated that 1/55 of the gas coming out of one of the power plant chimneys is taken and transferred to a heat exchanger located at the chimney outlet and this gas is used for district heating. As a result of the comparisons, it has been observed that heating the power plant with flue gas is more advantageous (Demir, 2018).

Waste heat recovery methods are examined and types and properties of waste heat recovery devices are shown. Equipment used in waste heat recovery were compared with each other and their usability was evaluated. In his study, the heat wheel application added to an air handling unit was examined as a case. Thermal energy calculations were made for the heat wheel, the cost of the system and the payback period were calculated (Selbaş, 1992).

Using the existing data of the Basque country database and other databases of thermodynamic properties, waste heat energy and exergy properties for 10 industrial regions of the Basque country were determined. The properties of eight residual heat recovery technologies are examined to predict their potential applications in industry and the range of applications is defined for each case. These technologies are: heat exchangers, Rankine and Brayton cycles, heat pumps, absorption cooling, expanders, burners and cogeneration systems. A methodology has been developed to evaluate the application potential of these eight heat recovery technologies. For this, software has been developed that takes into account the limitations of each technology, and a pre-selection has been carried out to identify recovery technologies that are potentially suitable for any industry (Bonilla, 1997).

The methods of energy recovery from waste heat, the alternatives of using the methods in the industry and the waste heat recovery utilization processes of the facilities selected as a precedent have been researched, and suggestions have been put forward to increase the efficiency of the system. Different types of heat exchangers used in the recovery of waste heat energy were introduced and compared in all aspects. In addition, the areas of utilization in industry from the energy obtained by the recovery of waste heat were examined and the areas of efficiency and applicability were explained. As an exemplary enterprise, waste heat recovery systems have been implemented to minimize energy costs in Şişecam Otoproduktor Group power plants (Tarakçıoğlu, 2006).

In this study, R&D needs were evaluated for the improvement of waste heat recovery technologies in the USA. A bottom-up approach was used to assess the amount of waste heat, quality, recovery practices and technology barriers in the most energy-consuming units in US manufacturing. The results of this approach provide a basis for understanding the state of waste heat recovery and offering recommendations for advancing waste heat recovery technologies. Within the scope of the study, melting furnaces and boilers, coke ovens, blast furnaces, basic oxygen furnaces and steel arc furnaces in the electrical industry, glass melting furnaces, primary and secondary refining furnaces in the aluminum industry, cement furnaces and ethylene furnaces were investigated (BCS, 2011).

A systematic approach is presented to target waste heat recovery potentials and to design the best reuse options among facilities in industrial areas. In the approach, the existing waste heat quality was determined first and reused the feasibility features, taking into account the distances between individual plants. A target optimization problem is solved for the maximum possible waste heat recovery for the industrial zone. Next, a design optimization problem is solved to identify concrete waste heat recovery options keeping in mind the economic objectives (Linke, 2011).

In the study, he explained the importance of waste heat recovery by talking about the current situation of waste heat recovery potentials and possible technologies used in the industry. In his study, the concept of industrial waste heat is defined, waste heat sources originating from industries are determined and conclusions are drawn. Then, technologies that can be used in waste heat recovery are shown in terms of heat pumps, heat exchangers, heat pipes, boilers, cooling cycles, power cycles and heat storage according to the transfer mode of waste heat in the recovery process. Waste heat opportunities in developed and developing countries are discussed to identify possible benefits of heat recovery and also to conduct an overall research on the development of heat recovery technologies globally. Investigation of typical applications of industrial waste heat recovery in Asian countries and especially in China has been studied to demonstrate the practical performance of this engineering (Huang, 2016).

Advanced system controls and energy saving methods for industrial boilers are studied. He explained the methods that can be applied for energy saving in boilers in his research (Willems, 2006).

It has been studied to increase the efficiency of the steam boiler, to make the boiler surface blowdown and energy recovery from the blowdown, to return the condensate, to prevent steam leaks in the traps, to recover heat from waste heat and flash steam (Ünlü, 2008).

In the study, the effects of the heat discharged from the chimneys of cement factories and the use of the facility that produces electrical energy on energy efficiency in the industry were examined. In this study, the effects of waste heat recovery systems in cement factories on energy efficiency, thermodynamic examination and development of the system were aimed (Tütüncü, 2008).

In a study, they evaluated the performance of a condensing economizer installed in a dairy in New York state. The study results showed that enough energy was recovered to meet 86% of the normal heating demand and the fuel consumption was less than 4000 decatherms. It is also stated that the amortization period is approximately four years (DeFrees et al., 2008).

In a thesis study, low-grade waste heat recovery and energy transfer systems were designed on an industrial scale. This system design; It is about recovering the energy of exhaust gas at 485°F and distributing this energy throughout the facility for different tasks. These tasks include space heating, hot water production, maintaining minimum temperature in glue baths, powering the absorption chiller and preheating the boiler feedwater. The remainder of the energy is then stored in two thermal storage tanks, one for the sensible heat exchanger circuit and the other for the condensing economizer 8 circuit. It shows implementation costs of just over $323000 based on design, materials and labor. These values can be used to show a typical payback period of 2.7 years (Hill, 2011).

In this research, flue gas heat recovery performance for a natural gas fired boiler was investigated, and a recuperator was designed to utilize the heat in the flue gas. For this system; energy, heat transfer analyzes and economic analyzes were made. The total amount of fuel savings that the system will provide during its 15-year economic life has been determined as 1121410,23 TL (Tokgöz and Özgün, 2019).

Energy is one of the most fundamental and pioneering stones of the civilization that mankind has today. For this reason, energy production and consumption is one of the issues that need careful consideration and strategy development (Varınca and Gönüllü, 2002).

In their studies, they examined heating of combustion air, heat recovery from contaminated fluid, isolation of hot and cold surfaces, reduction of idle time, gave examples of energy saving studies carried out in different provinces of Turkey, in these examples the amount of savings, financial return of savings, investment amount and payback periods. they calculated (Kaya and Güngör, 2002).

In this study, a comprehensive literature review on industrial energy saving is presented. In his study, current literature, journal articles, conference papers, web materials, reports, books, industrial energy management handbooks, policies and energy saving strategies related to theses (MS and PhD) were examined. Based on the results of energy saving technologies, it has been determined that a large amount of electricity energy, emission and electricity bill savings can be achieved by using these technologies in industrial sectors (Saidur, 2014).

In this study, it was aimed to examine the energy demand within the UK industry and to evaluate the current improvement potential with efficiency measures. In the study, a database was created using sector-based emission data and a sub-sector decomposition that facilitates energy analysis was used. The database was used for the analysis of waste heat recovery options. It was found that dividing the industrial sector into a sub-sector as energy-intensive and non-intensive, with the grouping that drives energy efficiency, would allow generalizations to be made regarding the potential for future improvement. The non-intensive energy subsector appears to have relatively greater improvement potential through existing processes (Norman, 2013).

The potential of industrial waste heat for heating and cooling applications has been explored. For this reason, heat conversion technologies are presented and their technical and economic potential is discussed. Firstly, different industrial processes and operating temperatures are presented as possible sources of waste heat and low-temperature processes that can be supplied with waste heat. Next, a general economic analysis is made for three different waste heat use cases: a chiller unit, compression heat generation and a heat pump. The maximum acceptable investment cost for each case was estimated based on the operating hours of the system and compared with the current investment cost (Brückner, 2015).

Numerical analysis and experiments were conducted on the low temperature heat pipe with the effect of various heat sources and heat source dispersion in the evaporator section (Faghri and Buchko, 1991).

In this study, the way of using flue gases for the recovery of waste heat via the heat pipe was investigated experimentally. In the experiments, 7 heat pipes with a diameter of 12 mm and a system (heat pipes) prepared by using ethanol (commercial spirit) for these heat pipes were used. The ends of the heat pipes are placed in the chimney designed as a prototype. Other parts are placed in a warehouse. By putting water, fuel-oil and diesel into the tank, it was investigated to what extent the heat discharged from the chimney could heat the water and other fuels in the tank. The results obtained were interpreted with graphics and the amount of heat gain was examined (Ersöz, 2002).

he experimentally investigated the recovery of the heat thrown by flue gases with the help of a heat pipe, a heat transfer device with high heat conductivity, and in the results of the examination, he examined and interpreted the temperature values obtained in the fluid to be heated depending on the degree of flue gas temperature (Ersöz, 2009).

the thermal performance of an installed system for the heat that can be recovered from the waste flue gases with gravity assisted heat pipes is investigated experimentally. The system installed for recovery consists of 16 pipes and R-134a and R-410a refrigerants are used as the working fluid. The installed system works with the principle of transmitting the heat energy received from the waste flue gases of the evaporator zone placed in the chimney to the condenser area placed in a warehouse where the cooling water is circulated. Experiments for the system were carried out at 5 different flue gas temperatures, 4 different flue gas speeds and 4 different cooling water flow rates. In the data obtained as a result of the experiments, it was determined that the heat pipe conductivity of the R-134a fluid (57.7%) was higher than the conductivity of the R-410a fluid (44.1%) under the same conditions. For heat pipe heat recovery, R-134a refrigerant was found to be more effective than R-410a refrigerant (Ürün, 2010).

In this work, he developed a passive heat transfer and work heat exchange system for simultaneous heat recovery and power generation, using a heat pipe thermoelectric generator. A detailed design process, a theoretical model, experimental analysis and cost-benefit analysis are made for a real system. It has been mentioned that the system has the potential to simultaneously recover waste heat and generate electrical energy in a completely passive system without any auxiliary power (Remeli, 2015).

In this study, the design, manufacture and testing of an innovative heat recovery system based on a straight heat pipe heat exchanger (FHP) for use in the steel industry is described. The thermal performance of the heat exchanger used was investigated both in the laboratory and in an industrial facility, and the operating temperatures of the recovered energy and heat exchanger were reported. A theoretical modeling tool was created to predict the performance of the device in the lab. Consistency was observed between the experimental and theoretical results. From the results it was concluded that FHP is an innovative high efficiency technology for waste heat recovery from such industrial applications (Jouhara, 2017).

he mentioned the importance of condensing heat exchangers for cooling boiler flue gas. He included calculations on modeling and optimization of heat exchangers in his work (Hazell, 2011).

In this study, since the waste heat from the flue gas in an industrial facility has a great energy potential, this heat energy was recovered and used in the double-effect absorption cooling system. With the double-effect absorption cooling system, the cooling process was carried out by utilizing the waste heat (Görgülü, 2013).

2.1. Waste Heat Recovery Systems

Industrial waste heat, is produced from industrial processes. Waste heat is the part that is required for the recovery of the heat released after any production process and is at a temperature above the atmospheric temperature. Waste heat sources; It mostly includes heat loss by conduction, convection and radiation from industrial products, equipment and processes, as well as heat from combustion processes. Heat loss can be classified as high temperature, medium temperature and low temperature degrees. High temperature range for waste heat recovery Temperatures above 400°C; The medium temperature range includes temperatures below 100-400°C and the low temperature range below 100°C. Waste heat recovery systems; It is determined for each waste heat loss range to ensure optimum efficiency from waste heat recovery.

Ejection of unburned but combustible fuel types in industry, sensible energy storage, especially sensible and latent heat loading is from flue gases. Recovery of waste energy is achieved by using the waste gas of the combustion equipment installation, so that the heat recovery equipment for subsequent use regains sensible and latent heat. While installing these systems, economic conditions should be taken into account, and the concepts of return time of waste heat and lifetime cost should be considered while applying.

Waste heat recovery methods involve capturing and transferring waste heat from a gas or liquid containing process to the system as an extra energy source. Recovery of waste heat can be accomplished with various waste heat recovery technologies to provide energy resources and reduce total energy consumption. Systems used to utilize waste heat can be divided into two groups as direct and indirect utilization systems. In direct utilization systems, waste heat can be utilized without the aid of any heat exchanger. In indirect utilization systems, waste heat is utilized by means of a heat exchanger where direct injury is not possible. There are many different heat recovery technologies used to recover waste heat and they mainly consist of energy recovery heat exchangers in the form of a waste heat recovery unit.

Recovery of energy by using the waste gas thrown out in heat recovery systems is limited to the following limits;

1. The waste gas discharged must be as clean as possible. Because contamination in the heat exchanger affects the heat transfer negatively.
2. The dew point temperature must not fall below. Because condensation causes corrosion.
3. Thermal stress should not be caused. Otherwise, the material will get tired.
These limits described above reduce the life and efficiency of the heat recovery system.

The amount of heat recovery from the exhaust gas depends on the permissible low temperature limit. Because these gases should be able to be cooled as desired. Polluted gases contain sulfur oxide and nitrogen oxide. If these are cooled below 100 ºC, they condense to form sulfuric and nitric acids. This dangerous situation should be avoided. Otherwise the acid solutions will destroy the heat recovery equipment.

Systems used for waste heat recovery:

1. Economizer
2. Regenerator
3. Recuperator
4. Heat Pipes (Heat Exchangers)
5. Heat Pumps
6. Regenerative and Recuperative Burners

Waste heat recovery systems; It is determined for each waste heat loss range to ensure optimum efficiency from waste heat recovery. Waste heat recovery methods involve capturing and transferring waste heat from a gas or liquid containing process to the system as an extra energy source. Recovery of waste heat can be accomplished with various waste heat recovery technologies to provide energy resources and reduce total energy consumption. There are many different heat recovery technologies used to recover waste heat and they mainly consist of energy recovery heat exchangers in the form of a waste heat recovery unit. These units mainly include waste heat recovery systems such as furnace regenerators, rotary regenerators, air preheaters such as recuperators, regenerative and recuperative burners, heat tube heat exchangers, plate heat exchangers, economizers, waste heat boilers and direct electrical conversion devices (Jouhara et al. ., 2018).

2.1.1. Recuperators

Recuperators are systems used to recover waste heat from flue gases in a furnace or boiler. Heat is exchanged between flue gas and air by conduction through the metallic walls of the recuperator. The ducts are used to carry air to the preheat before it goes into combustion. The waste heat recovery recuperator from the flue gas is shown in Figure 2.1 (Hasanuzzaman et al., 2012).

Figure 2.1. Recuperator.

2.1.2. Regenerators

Regenerators is shown in Figure 2.2 are systems that transfer the heat from the hot gas channel to the cold gas channel by storing the waste heat in a material with a high heat capacity. The system consists of a room used as a connection between the cold air duct and the hot air duct, which receives, stores and transmits the heat energy from the hot side to the cold side. For example, regenerative furnaces consist of two brick chambers in which the heat exchange of hot and cold air takes place. As the hot combustion gases pass through the brick chamber, the heat from the hot flue gas is absorbed, stored, and transmitted to the cold air stream as it passes through the chamber. The flow of preheated gas is then injected into the flow to the combustion chamber, thereby reducing the amount of energy required to heat the system. The direction of the inlet flow is changed frequently to achieve a constant heat transfer rate. Regenerators; It is suitable for high temperature applications such as glass furnaces and coke ovens and especially for applications using exhaust gas. However, the high initial investment costs are the disadvantage of this system (Jouhara et al., 2018).

Figure 2.2. Regenerator.

2.1.3. Waste Heat Boilers

Waste heat boilers, or as they are sometimes called, heat recovery steam generators are used to recover energy from waste gas streams in sulfuric acid or hydrogen plants, refineries, solid, liquid and gas fuel burner systems, power plants, cogeneration systems using gas turbines or reciprocating engines. Basically, waste heat boilers or heat recovery steam generators can be examined in two broad categories. These;

In plants where energy recovery is secondary, such as hydrogen plants or sulfuric acid plants, waste heat boilers can be used to cool the gas, which is the fluid in the process, to the desired temperature range.

Considering the corrosive effects that may occur at high and low temperatures, waste heat boilers can be used to maximize energy gain economically. As an example, gas turbine-based combined cycle systems or cogeneration systems, combustion plants, in other words, any system where flue gas heat recovery can be made in general can be given.

There is no standard design methodology or procedure for the engineering of waste heat boilers. Because a wide variety of gas temperatures, gas compositions, pressures and steam parameters are encountered.

While a smoke tube boiler is preferred in scenarios with high gas pressure, a water tube boiler may be appropriate in scenarios where gas flow is high and there are multiple levels of steam pressure.

Waste heat boiler is shown in Figure 2.3 consist of pipe bundles placed parallel to each other and it can be mentioned that there are waste heat boilers of different capacities. Steam produced in waste heat boilers; It can be used for heating purposes, generating electricity in turbines, compressing vapors or pumping liquids. However, the steam coming out of the waste heat boilers may not have the desired dryness level. For this reason, it may be necessary to use a ventilation system and a high performance separator in order to provide maximum steam quality to the process in which the steam produced in the waste heat boiler will be used. In cases where the waste heat is not sufficient to produce the required amount of steam, auxiliary burners are used to achieve a higher steam performance.

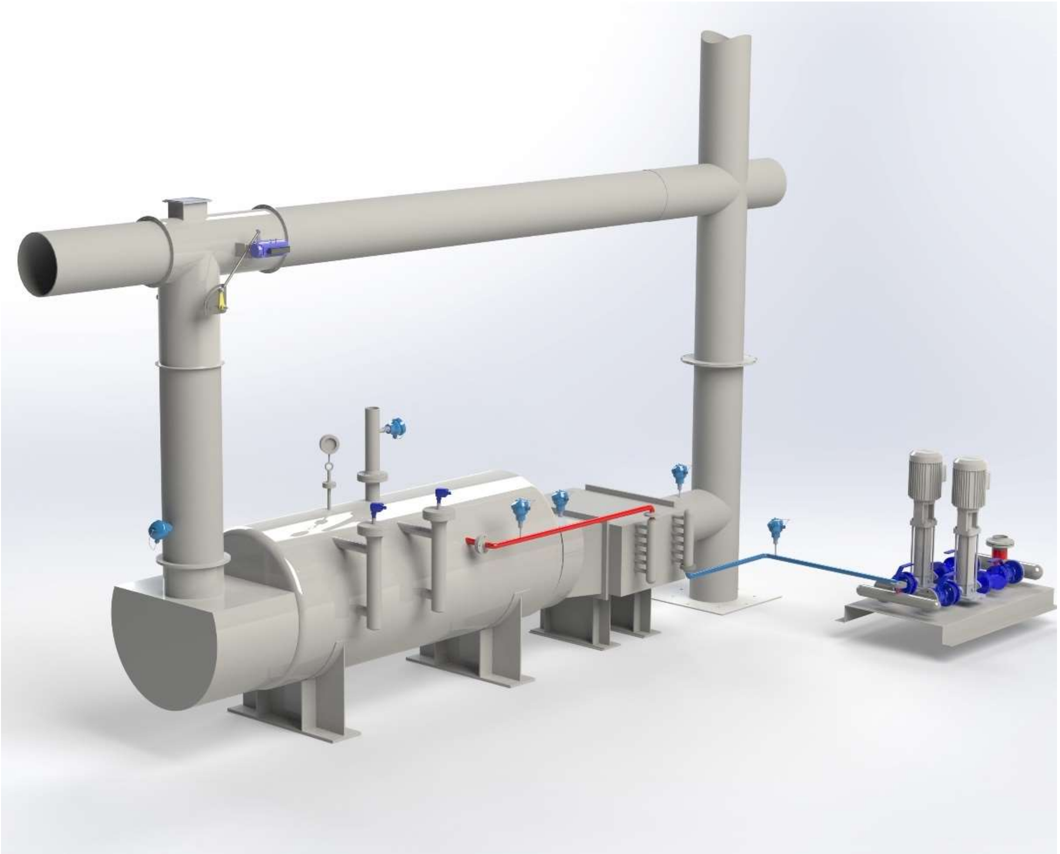

Figure 2.3. Waste heat boiler.

2.1.4. Economizers

Economizers; It is an application used for preheating fluids and in systems that save energy by reducing energy consumption. With the use of economizers in waste heat or gas generating systems, the energy of waste liquid or gas with high calorific value can be recovered. Economizers are generally used in water and hot oil boilers, steam boilers because of their high calorific value, and in the textile industry where waste water and combustion product gases occur. Economizer applications are highly preferred because they amortize the initial investment costs in a very short time.

Economizers use some of the heat on the exhaust gases thrown from the boiler or transmitted to the chimney to provide recovery by transferring it to the water circulating in itself. Recovering heat can be used for heating, hot water use and boiler feedback in facilities. The size of the heat to be recovered with the economizer is directly proportional to the outlet temperature of the exhaust gas. As the temperature difference between the incoming and exhausted gases in the economizer increases, the recovered heat and the efficiency value of this heat become larger at the same rate.

The heat gained in economizers can be given to the boiler feed water as well as used for purposes such as heating and hot water use in the facility. The system consists of pipes covered with metallic fins to maximize heat absorption surface area and heat transfer rate. The system is located in the duct carrying the exhaust gases and absorbs the waste heat by allowing the hot gases to pass through the sections where the finned pipes are located. The liquid is passed through the pipes and absorbs the heat through the finned tubes. The heated fluid is then fed back into the system, maximizing thermal efficiency. In a study by Spirax Sarco, it was shown that the use of economizer for the boiler system can increase efficiency by 1% for every 5°C reduction in flue gas temperature. It has been determined that the depreciation period of the system will be less than 2 years and the fuel consumption can be reduced by 5-10%. By preheating the feed water in the steam generator or boiler, economizers recover waste heat and increase the efficiency of the system, so less energy is required to reach boiling temperature. In a study conducted by Maxxtec, it is stated that fuel consumption can be reduced by 7% if the flue gas temperature is reduced by 140°C, regardless of the design of the system.

Many different economizer designs are available for different applications, although they have the same functionality. These designs are; operating pressure, fuel type, temperatures, gas pollution status, operating conditions, layout, etc. They can be designed and manufactured as welded or seamless pipes, stainless pipes, straight pipes, u hairpin pipes, spiral pipes, spiral pipes or finned pipes, taking into account the factors. Condensing and non-condensing types are generally used to increase the efficiency of boiler systems, while other types are widely used in thermal power plants and large enterprises to recover waste heat from flue gas.

Economizer is shown in Figure 2.4 or finned tube heat exchangers, which are mainly used to heat liquids, are an effective means of recovering waste heat from flue gas. In traditional applications, economizers are used to heat the boiler feed water. The heat gained in economizers can be given to the boiler feed water as well as used for purposes such as heating and hot water use in the facility. The system consists of pipes covered with metallic fins to maximize heat absorption surface area and heat transfer rate. The system is located in the duct carrying the exhaust gases and absorbs the waste heat by allowing the hot gases to pass through the sections where the finned pipes are located. The liquid is passed through the pipes and absorbs the heat through the finned tubes. The heated fluid is then fed back into the system, maximizing thermal efficiency. In a study by Spirax Sarco, it was shown that the use of economizer for the boiler system can increase efficiency by 1% for every 5°C reduction in flue gas temperature. It has been determined that the depreciation period of the system will be less than 2 years and the fuel consumption can be reduced by 5-10%. By preheating the feed water in the steam generator or boiler, economizers recover waste heat and increase the efficiency of the system, so less energy is required to reach boiling temperature. In a study conducted by Maxxtec, it is stated that if the flue gas temperature is reduced by 140°C, regardless of the design of the system, fuel consumption can be reduced by 7% (Defrees et al., 2008; Çıtır, 2013; Jouhara et al., 2018).

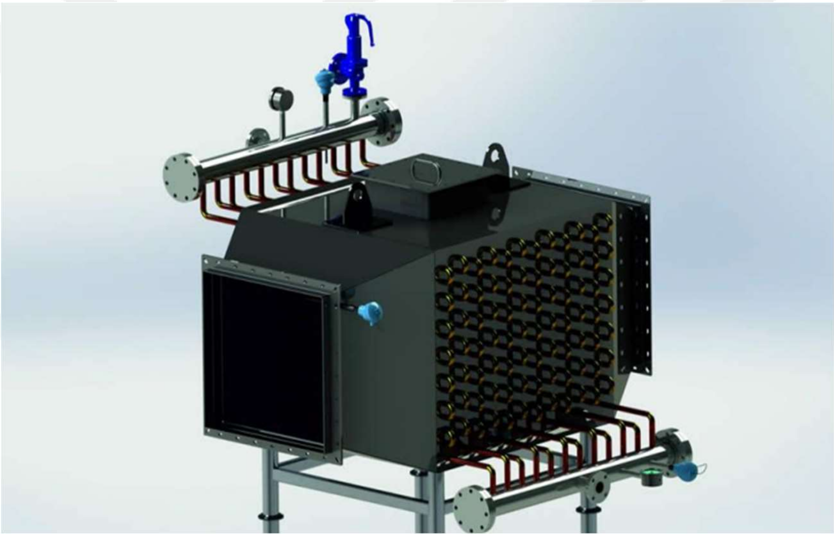

Figure 2.4. Economizer.

2.1.4.1. Usage Areas of Economizers

They are used for the following purposes in steam, boiling water and hot oil boilers.

• In preheating the feed water of the boiler,

• In heating the feed water of the boiler, in the supply of the heat requirement of the degasser,

• For heating hot water (for general purpose),

• For heating any space,

• Preheating of the return lines of the installation.

2.1.4.2. Classification of Economizers

2.1.4.2.1. Straight or Hairpin Tube Economizers

Coal, fuel oil, etc. They are shown in Figure 2.5, used for heat recovery from relatively polluted flue gases obtained from fuels. Straight pipe types are used at low pressures and U pipe types are used at high pressures.

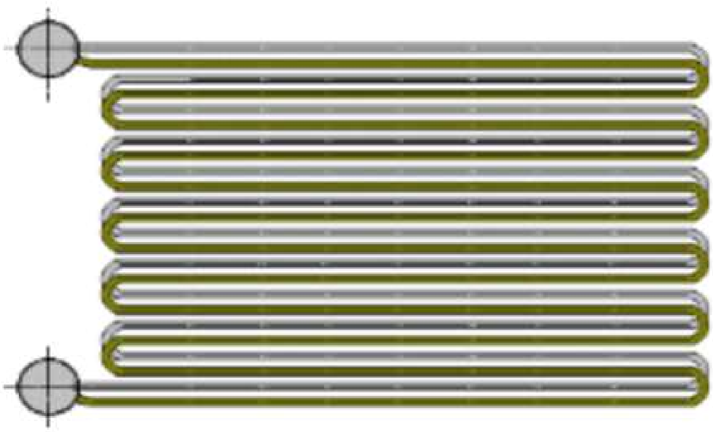

Figure 2.5. Economizer with flat or hairpin tube.

2.1.4.2.2. Finned Tube Economizers

They are hown in Figure 2.6, used for relatively clean exhaust gases obtained from fuels such as natural gas, LPG, and heat recovery from heat sources such as hot air. Straight pipe types are used at low pressures, and hairpin (U) pipe types are used at high pressures. Capacity/volume ratios are high, as very large surfaces can be accommodated in very small volumes. Cost/Capacity ratios are low.

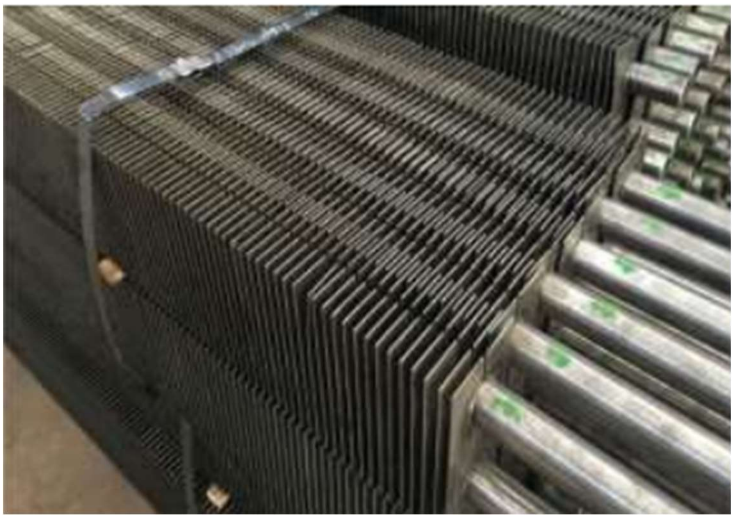

Figure 2.6. Finned tube.

2.1.4.2.3. Spiral and Spiral Tube Economizers

These economizers are shown in Figure 2.7, economizers used in all kinds of waste gases, as they are in a structure that is not affected by the pollution conditions of the flue gases. They are generally placed between the duct or chimney or inside the chimney (Çıtır, 2013).

Figure 2.7. Coil and spiral tube economizer.

2.1.4.2.4. Smoke Pipe Economizers

They can be used in all kinds of waste gases, as they are in a structure that is not affected by the pollution conditions of the exhaust gases. They are shown in Figure 2.8 of the heat exchanger type. Since the heat transfer coefficients are low, their surfaces and the area and volume they cover are very high compared to other types. They are used in very special situations. Economizers; operating pressure, fuel type, temperatures, gas pollution status, operating conditions, layout, etc. They can be designed and manufactured as welded or seamless black pipe, stainless pipe, straight pipe, U elbow return pipe, spiral pipe, spiral pipe or finned pipe, taking into account the factors.

They are economizers that can be used in all kinds of waste gases, as they are in a structure that is not affected by the pollution conditions of the flue gases, as in the economizers with spiral and spiral pipes. They are of the heat exchanger type and are used in very special situations. Since the heat transfer coefficients are low, their surfaces, areas and volumes are very large compared to other types (Çıtır, 2013).

Figure 2.8. Economizer with smoke tube.

2.1.4.3. Working Principle of Economizers

Economizers are systems that increase fuel savings and boiler efficiency by using the waste heat of flue gases to heat the system return fluid in steam boilers, hot oil boilers, hot and hot water boilers shown in the figure 2.9.

As the operating temperature of the boiler and, accordingly, the boiler flue gas outlet temperature rises, the amount of energy released to the environment by means of flue gases also increases. Recovering some of this waste heat discharged from the chimney will increase the efficiency of the boiler or system and provide fuel savings. Economizers are used in heat, steam or power generation facilities in order to recover some of the heat found on the flue gases coming out of the boilers and given to the chimney, by transferring it to the circulating water. This recovered heat can be given to the boiler feed water, as well as for heating, bathing, washing, etc. in the facility. It can also be given to the water to be used for other purposes. Air heaters are used when it comes to transferring the heat to be recovered to air or a gas. The boiler flue gas outlet temperature is at a certain size depending on the operating regime of the boiler, the inherent efficiency of the boiler, the boiler-burner compatibility and the type of fuel. The gas outlet temperature of the economizer is determined by the type of fuel used and the operating conditions of the fluid to which the heat will be transferred.

The amount of heat that can be recovered in an economizer depends on the boiler flue gas outlet temperature as well as the flue gas exit temperature from the economizer. The greater the difference in flue gas temperatures entering and exiting the economizer, the greater the recovered heat, and thus the greater the increase in efficiency. However, it should be taken into account that the temperature of the waste gases cannot be lowered below a certain degree in order to prevent the condensation of acid gases that may cause corrosion. In an economizer, it is possible to benefit economically from flue gas temperatures of 140°C in natural gas and similar gas-fired boilers, and 220°C and higher in diesel, fuel-oil and coal-fired boilers. The minimum level of flue gas temperature that can be reached in a flue gas heat recovery system depends on the type of fuel used. Economizer gas outlet temperature can be reduced to 180ºC in fuel oil boilers, 150ºC in diesel fuel boilers, and up to 110ºC in natural gas and LPG fueled boilers.

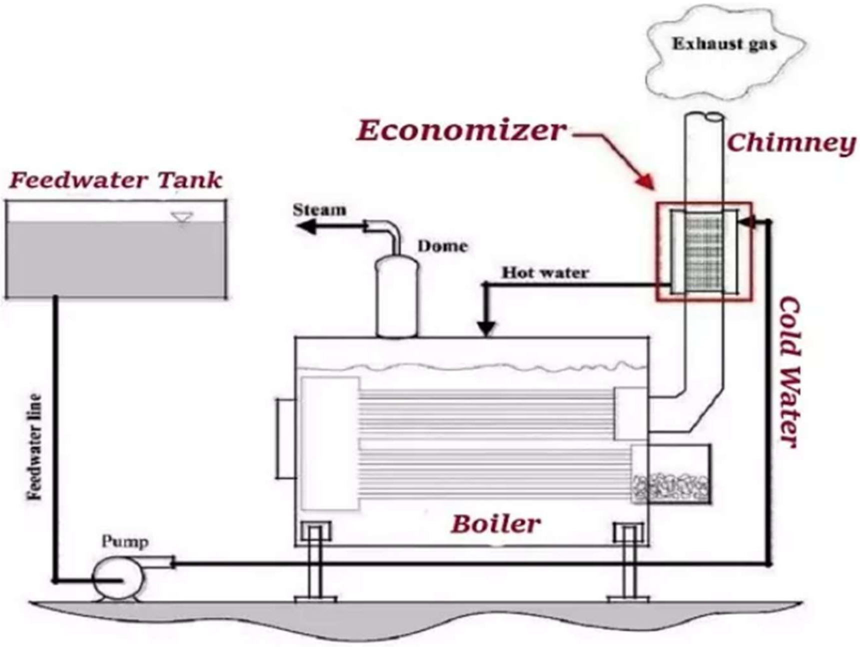

Figure 2.9. Economizer in a steam boiler system.

The benefits of using economizers in heat, steam or power generation facilities are as follows; Depending on the boiler flue gas outlet temperature and fuel type, an increase in efficiency between 3% and 7% is achieved in the efficiency of the boiler or plant. Depending on the increase in efficiency, less fuel is consumed for the same capacity or more heat is produced for the same amount of fuel consumption. If the heat gained is given to the boiler feed water, it is ensured that the boiler operates without difficulty even at maximum loads, better adapts to different loads, and the boiler efficiency remains relatively high and constant at different loads. Boiler capacity and efficiency can be increased to optimum levels by adding an economizer to boilers that operate above their optimal capacity or that have low efficiency due to their nature. Economizer application areas are quite diverse. The important thing is that the heat recovered from the system is used throughout the operating period of the system.

2.2. Importance of Energy

Energy is the ability to do work. It is a value that cannot be measured directly and can be found by the work required to change the state of a physical system or by different calculations depending on the type of energy. Energy is a conservative quantity and can also change form. The most common example of this is the potential energy of water, which is converted into electrical energy in hydroelectric power plants. This conversion process cannot be one-to-one in practice, losses occur. Although it is an energy-conserving quantity, the energy that cannot be converted into another form and therefore spreads around as heat is considered a loss.

The power that runs our machines, drives our cars, enables production, enlightens us, runs our computers; Sometimes it appears as electrical energy, sometimes as chemical energy, sometimes as potential, and sometimes as magnetic energy. The energy and power offered to humanity by the conversion of potential, kinetic and magnetic energies found in nature and / or artificially produced into other types of energy, has become one of the indispensable elements of social life today. The energy issue, which is important according to its source; It has become a critical issue due to developing technology, population growth and ever-increasing demand. In the works published in the 1990s, it is seen that the world conditions between the years 2020-2050 are generally tried to be predicted. In these years we can follow from the literature that the population of the countries to be released, the energy need to be seen accordingly, and the measures that can be taken against the environmental pollution that will arise from the production of this energy have been the subject of discussions since the nineties. The first thing that draws attention in this regard is population growth, and according to the United Nations scenarios, it is estimated that the world population, which was 5.3 billion in 1990, will reach 8.1 billion in 2020, 10 billion in 2050, and 12 billion in 2100. The population of Turkey, which was more than 65 million as of 2003, is increasing by 1.7% per year and is expected to be 83.4 million in 2022. According to these data, it can be said that the increase in the need to be encountered with the increase in population will cause an increase in production and therefore in the need for energy. It is observed that the population increase is expected to occur mostly in developing countries and it is also predicted that there will be excessive energy consumption in these countries. “Developing countries will soon become the world's largest energy market. Although the energy consumption of these countries is half of the rich countries today, this consumption doubles every fifteen years. One of the remarkable points in this regard is that while the need for energy increases due to population growth in developing countries; This is because rich countries will not see significant changes in their population numbers and therefore in their per capita energy needs”.

Energy, which is an indispensable part of human life, is managed by some national and international policies in terms of both production and consumption. Because, it is observed that the ever-increasing energy production and consumption due to the ever-increasing production has become a political factor in terms of resources and a dangerous factor in terms of environmental conditions. “In the world, there is a transition process to an information society with radical changes in production systems and the technology base on which it is based. Advanced automation technology, which is a result of developments in information (information) technology, has given the opportunity to replace not only simple workforce but also brain power to a certain extent. In this context, knowledge-intensive industries and advanced production methods based on qualified manpower have been the determinants of rapid development. Changes in the information age are so rapid that it is no longer possible to make predictions beforehand.

Change for a business today is shaped by the competitive environment it is in and the strategies it has to develop in order to survive in this environment. These new conditions that have been emerging recently, along with the fact that energy resources are not evenly distributed over the world geography, as well as the fact that energy production and consumption do not occur equally on the world geography; It can be shown as both a cause and a consequence for the classification of countries as developed, developing and underdeveloped. It is a phenomenon that requires strategic planning, especially since electrical energy cannot be stored and needs to be consumed as soon as it is produced. Due to the environmental pollution and global warming, it is seen as a vital necessity to invest in renewable energy sources in increasing amounts of energy for future generations.

2.3. Energy Management

Energy management; It includes training, survey, measurement, monitoring, planning and implementation activities carried out to ensure the efficient use of energy resources and energy. Energy management system; It is a disciplined work structured and organized in line with the more efficient use of energy without sacrificing product quality, safety or all environmental conditions and without reducing production. The primary purpose in energy management is to save energy in use with the changes that can be made in the current process, unit or system and the measures that can be taken. Up to 10% of energy savings can be achieved in businesses with simple precautions in studies carried out without being tied to a specific program.

With the implementation of a comprehensive energy management program, energy saving efforts can be sustained and the savings rate can reach 25%. Many aspects, from product and design equipment to the transportation of production, from minimizing waste to disposal, are considered among the energy management possibilities. The second purpose in energy management is; is to establish a relationship between energy consuming equipment and cost management, taking into account the principles of energy economy.

The effectiveness of the energy management program depends on the determination and support of the top management. The senior management levels are the main responsible for the energy problem in the enterprise, as they are not guiding, but encouraging, supervisory, timely and correct decision-making bodies on energy and energy saving.

The benefits of energy management to the business are;

• Low energy costs
• Reduction of carbon emissions
• Better working conditions
• Better control
• Compliance with the law
• Contribution to ISO 14001 accreditation
• Contribution to corporate and social responsibility.

For the implementation of energy management in enterprises; Ensuring energy savings, efficient use of energy with energy economy practices (energy economy studies consist of analysis, modeling, application and evaluation stages), appointing an energy officer in the organization and determining his powers, establishing an energy committee to assist the energy responsible can be carried out. In this way, within the scope of plans and programs to be made, activities such as providing thermal insulation, correcting the power factor in electricity (compensation), effective use of lighting, benefiting from waste energy and alternative energy sources, R&D studies, personnel training and ensuring the functionality of the control mechanism can be used more efficiently than energy. will be possible to take advantage of.

2.4. Energy Conservation Methods for Steam Systems

In industrial systems where steam is used for process purposes and in large-scale heating systems using steam, the rate of energy that can be converted from fuel energy to useful energy is severely limited. Especially in facilities where energy efficiency is not taken care of, this value, which we can define as system efficiency, can drop to the order of 60%. Here, inefficiency or loss elements; It can be collected in two groups as in the process of the boiler itself and in the steam installation. Said yield refers to the sum of these. Among the losses that occur at many points and depending on many parameters, the energy thrown from the chimney with hot flue gases and the energy lost by condensate are the leading ones. Flue temperatures of 350°C can be measured in conventional liquid fueled steam boilers still used in industry. Chimney temperatures in modern two-stage condensing steam boilers burning natural gas under the same conditions. It is possible to reduce it to 50°C and to benefit from its energy by condensing the water vapor in the flue gases. Thus, boiler efficiency can be increased by 23%.

3. MATERIALS AND METHODS

3.1. Materials

Within the scope of this thesis, the Testo 300 LL flue gas analyzer device indicated in the figure 3.1 and 3.2 was used for flue gas analysis, and the Testo L Type Pitot Tube integrated Testo 340 device was used for measurement of gas velocity in the flue.

Figure 3.1. Testo 300 LL flue gas analyzer.

Figure 3.2. Testo L Type Pitot Tube integrated Testo 340 device.

Within the scope of this thesis, 4 different economizer systems were installed for 4 steam generators with a capacity of 3 t/h in the facility. Currently, there is an economizer behind the steam generators, but the capacities of these economizers are insufficient. Chimney outlet temperatures at the outlets of existing economizers are very high. In the new situation, the existing economizers were dismantled and economizers with higher capacity were installed to benefit from the flue gas. Thus, while making more use of flue gas, natural gas savings will be achieved.

Currently, 4 steam generators with a capacity of 3 t/h each are used. Photographs of the existing facility are given in Figure 3.3 and Figure 3.4.

Figure 3.3. Steam Generators.

Figure 3.4. Old economizers (all identical).

3.2. Heat Transfer Analysis

The heat transferred by the water to the heater pipe surface,

$$Q_{\text{water}} = \dot{m}_{\text{water}} * c_{\text{water}} * \Delta T_{\text{water}} \tag{3.1}$$

found using the formula.

Through this heater pipe surface, the air passing outside the finned pipe will be transferred by convection and radiation heat transfer methods. The irradiance value is considered to be so small that it is negligible.

The amount of heat transferred from the water side to the air side;

$$Qh = \dot{m}_h * c_h * \Delta T_h \tag{3.2}$$

found using the formula.

Equation (3.3) shows the amount of heat that can pass from water to air. Since the energy entering the heater pipe will be equal to the output energy,

$$\dot{m}_{water} * c_{water} * \Delta T_{water} = \dot{m}_h * c_h * \Delta T_h + Q_{enviroment} \tag{3.3}$$

is in the form.

$Q_{enviroment}$ is negligibly small due to insulation.

Convection heat transfer calculation,

$$Q = k * f * \Delta T_m \tag{3.4}$$

The following formula is used when calculating the total heat transfer coefficient.

$$k = \frac{1}{\frac{1}{h_i} + \frac{1}{h_d}} \tag{3.5}$$

The following formula is used when calculating the convection heat transfer coefficient of the outside fluid. When calculating the thermal conductivity coefficient, the internal fluid is not included in the formulas, since the outside fluid will affect the system significantly.

$$h_d = \frac{Nu_d \, k_d}{d_d} \tag{3.6}$$

The following formula was used to calculate the Nusselt number of the outside fluid.

$$Nu_d = 0,35 \left(\frac{St}{Sl}\right)^{0,2} Red^{0,6} \left({}^{Pr}/_{Pr_s}\right)^{0,25} \tag{3.7}$$

The Reynolds number of exhaust gas, which is the outer fluid, is calculated by the formula 3.6.

$$\mathrm{Re}_d = \frac{\mathrm{V}_{d,max}\ \mathrm{d}_d}{\mu_d / \rho_d} \tag{3.8}$$

Heat transfer to or from a tube bundle in cross flow; It is applicable in many industrial applications such as steam generation in a boiler or cooling of air in the coil of an air conditioner. A tube bundle is schematically shown in Figure 3.5. One of the fluids with different temperatures flows through the pipes and the other over the pipe bundles. The maximum velocity of the exhaust moving in the opposite direction is found with the help of the following formula. For S_T and S_L values, commercially available elbow measures are accepted.

$$\mathrm{V}_{\max} = \frac{\mathrm{S_T}}{\mathrm{S_T} - \mathrm{R}_d}\ \mathrm{V} \tag{3.9}$$

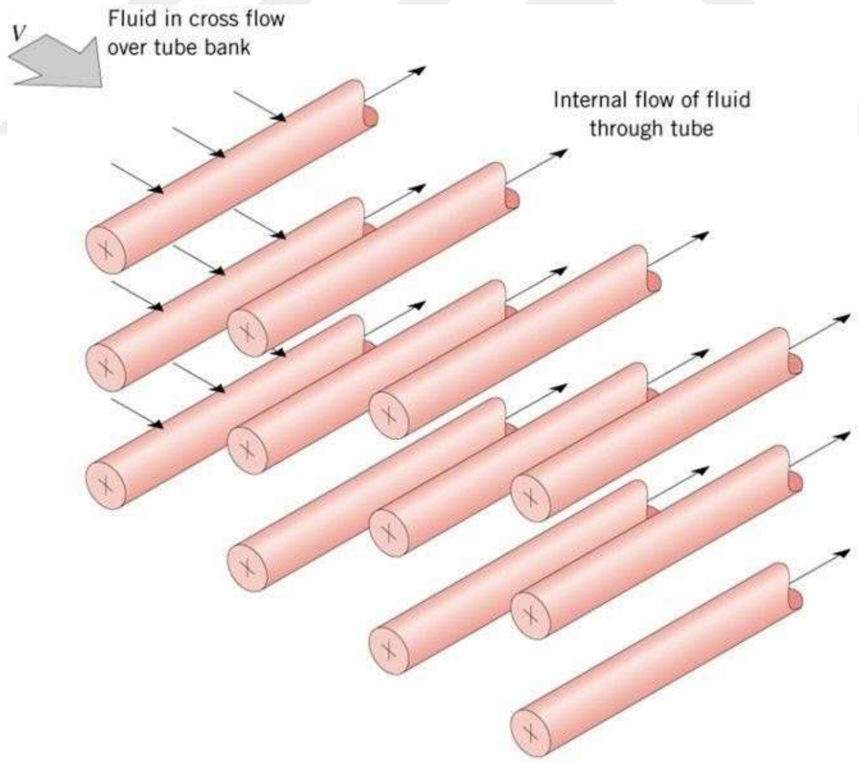

Figure 3.5. Schematic view of cross flow on a pipe bundle.

The pipes forming the pipe bundle are either shifted in the direction of V flow velocity or placed in a regular order (Figure 3.6.). The arrangement is determined by the pipe diameter D, the spacing between the pipe axes in the direction perpendicular to the flow, ST, and the spacing SL in the direction parallel to the flow.

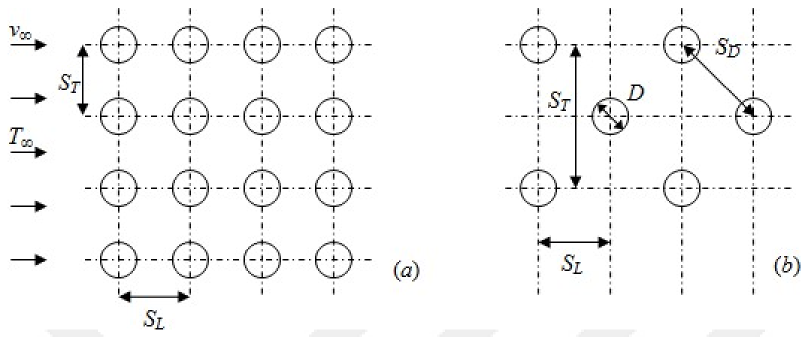

Figure 3.6. Pipe arrays in a pipe bundle: (a) in regular order, (b) in shifted order.

Flow around pipes in the first row of a pipe bundle is similar to flow for a single cylinder in cross flow. Therefore, the heat transfer coefficient for the first row pipe is the value found for the cross flow on a single cylinder. For the back row pipes, the flow conditions depend on the pipe bundle alignment. (Figure 3.7). Regular rows of pipes after the first row are in the posterior region of the previous pipes, and for intermediate values of SL, the convection coefficients of the next rows increase due to mixing or turbulence.

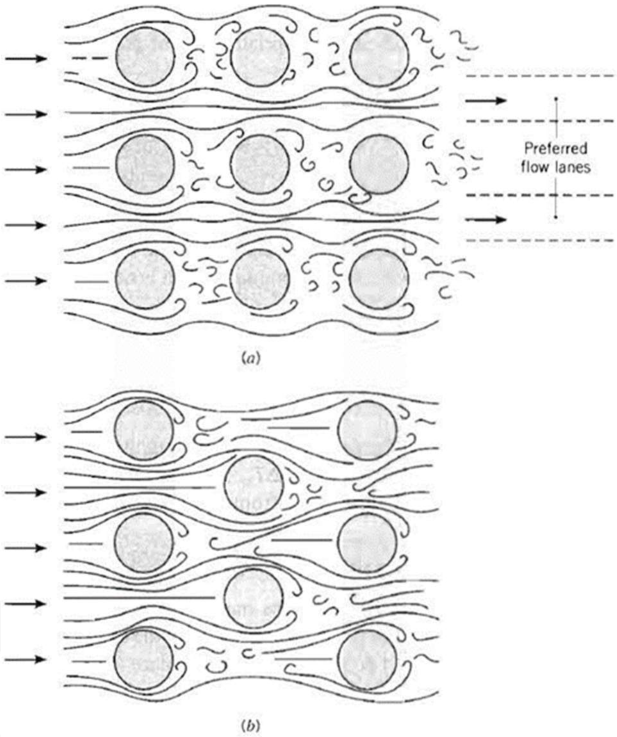

Figure 3.7. Flow conditions for (a) straight-row and (b) offset-row tube bundles.

With the economizer placed in the steam generator chimney, the flue gas temperature was reduced from 270 °C to 140 °C. The heat gained by the sensible energy of the waste flue gas was used to heat the steam generator feed water from 70°C to 114°C. The pipe and body material of the economizer used here is 316 quality stainless steel in order to protect it from corrosion that may result from possible condensation. Pipe details are given in the figure.

Table 3.1. The economizer detail.

Parameters	**Unit**	**Value**
Tube Length, L	mm	1000
Tube Outer diameter, d	mm	33,7
Fin height, H	mm	16
Fin Thickness, t	mm	1,2
Fin Pitch	mm	5
Transverse tube pitch, ST	mm	80
Longitudinal tube pitch, SL	mm	65,8
Surface Area for a Fin (m2)	m^2	0,004996
Surface Area for Pipe	m^2/m	0,106
Surface Area for Finned Tube	m^2/m	1,105

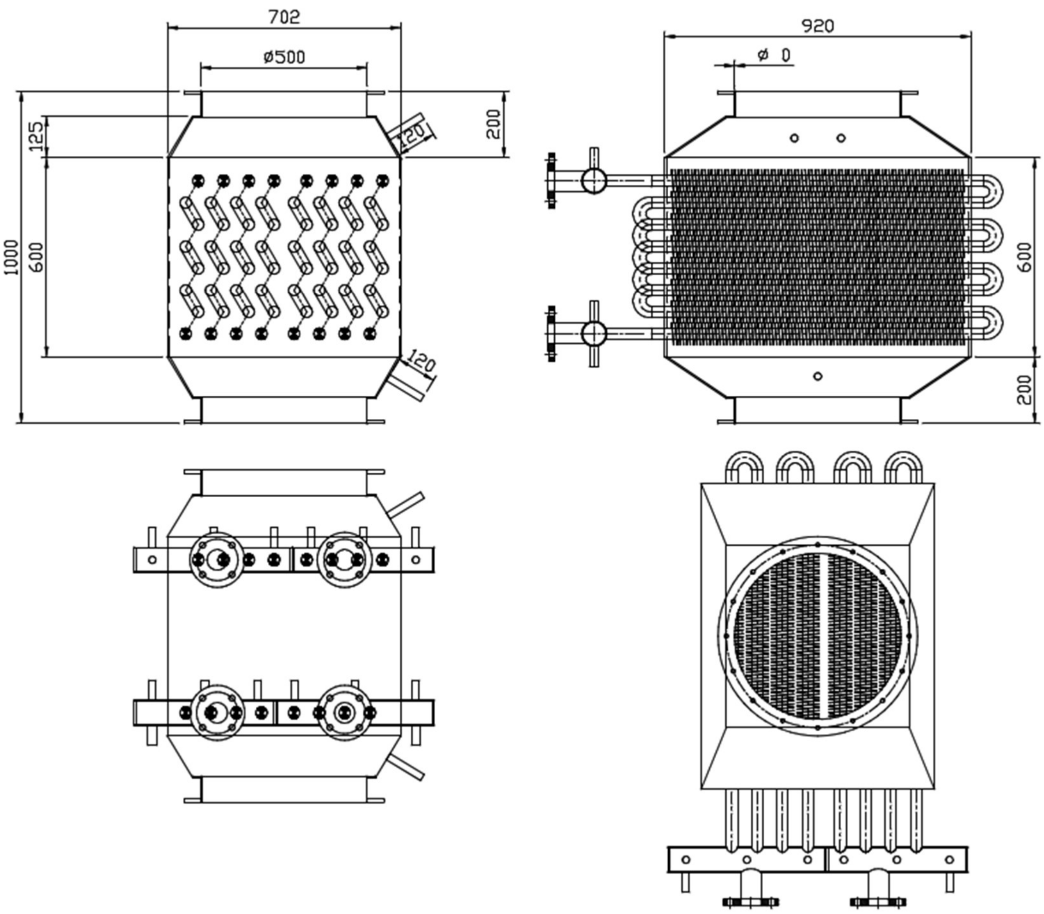

Figure 3.8. Economizer detail.

In this study, an economizer has been designed to recover this waste energy and use it in the system by making use of the sensible energy carried by the high-temperature flue gases emitted into the atmosphere from the generators at the mentioned facility.

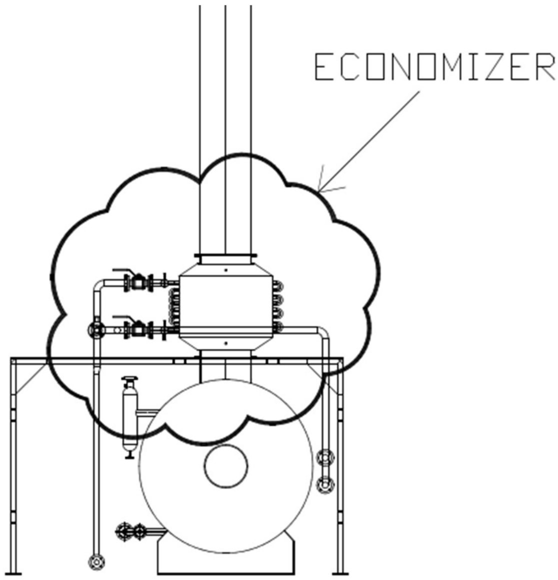

Figure 3.9. Economizer design.

With the application, the system efficiency will be increased by removing the existing economizers and installing a more efficient single economizer. In order to calculate the savings to be achieved after the application, flue gas analysis was made before and after the existing economizer, and the flow rate was reached by measuring the flue gas velocities.

Table 3.2. The exhaust gas measurements (pre new economizer).

EXHAUST	STEAM GENERATOR 1	STEAM GENERATOR 2	STEAM GENERATOR 3	STEAM GENERATOR 4
EXHAUST GAS TEMPERATURE	271,80	239,30	271,40	235,40
CO2 (%)	10,56	10,27	9,36	10,08
O2 (%)	2,15	2,21	4,62	3,33
CO (ppm)	2680	210	20	190
SO2 (ppm)	2	0	0	0

In order to calculate the energy to be taken on the exhaust gas side, the exhaust gas flow rate must also be measured. For all chimneys, velocity was measured with a pitot tube, and since the chimney diameter is known, the flow rate was calculated by multiplying the velocity with the diameter.

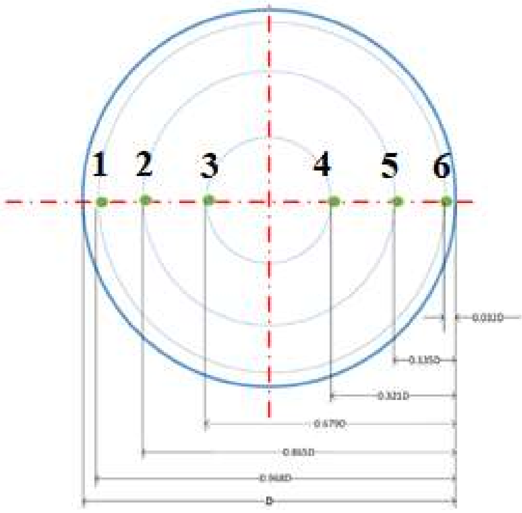

Figure 3.10. Velocity Measurement in a Circular Section.

In order for the speed measurement to give the most realistic result, measurements should be taken from the above points and the average value should be accepted as the speed.

Table 3.3. Chimney velocity measurement values.

FLUE VELOCITY MEASUREMENT (m/sn)				
MEASUREMENT POINTS	FLUE 1	FLUE 2	FLUE 3	FLUE 4
1	2,57	2,54	3,40	3,31
2	2,98	3,86	4,23	3,36
3	2,66	4,96	4,26	4,00
4	3,22	4,13	3,47	3,75
5	2,45	3,13	4,00	3,02
6	2,30	2,76	3,23	3,00
AVERAGE	2,696	3,562	3,765	3,406

The speed measurement made in the chimneys is presented for your information in the table above. The chimney diameters of the generators are the same and 0.5 meters. The area of each chimney is 0.196 m^2. In the calculations section, the chimney velocities are converted from (m/s) to (m/h) by multiplying by 3600.

The water inlet temperature is 70 °C, and the water outlet temperature will vary depending on the water requirement of the steam generators (as the flow rate will change).

The measurements made are summarized in the table below. Flow rates calculated according to the velocity measurements are also given in the table.

Table 3.4. Flow values calculated according to velocity measurements.

Steam Generator		1	2	3	4
Exhaust Gas Temperature (Pre-Existing Economizer)	°C	282,1	275,7	275,3	252,3
Exhaust Gas Temperature (After Existing Economizer)	°C	271,8	271,4	239,3	235,4
Average Exhaust Gas Speed	m/s	2,696	3,562	3,765	3,406
Chimney Section Area	m^2	0,196	0,196	0,196	0,196
Exhaust Gas Flow	m^3/h	1.902,30	2.513,35	2.656,58	2.403,27
Exhaust Density at Overall Temperature	kg/m^3	0,6753	0,6767	0,6953	0,7126
Exhaust Gas Flow	kg/h	1.284,6	1.702,8	1.847,1	1.712,5

After the project is finished, the energy gain can be calculated in two ways in the four economizers. By measuring the current flue gas flow rate, energy gain can be calculated from the economizer flue inlet and outlet temperature. As an alternative, water flow and water inlet and outlet temperature can be measured and calculated with an ultrasonic flowmeter in the secondary circuit of the system.

4. RESULTS AND DISCUSSIONS

Savings to be achieved by renewing the existing inefficient economizer system; After the application, the difference between the heat taken from the economizer and the heat taken from the existing economizer was calculated. In order to make this calculation, the heat taken from the existing economizer and the heat to be taken from the new economizer after the application were calculated separately. After the application of the new economizers, the measurements taken from the field and the flow rates were found and the thermal capacities were calculated.

Table 4.1. The measurements after the application of the new economizers.

Steam Generator		1	2	3	4
Exhaust Gas Temperature (Pre-Existing Economizer)	°C	282,1	275,7	275,3	252,3
Exhaust Gas Temperature (After Existing Economizer)	°C	140	140	140	140
Average Exhaust Gas Speed	m/s	2,696	3,562	3,765	3,406
Chimney Section Area	m^2	0,196	0,196	0,196	0,196
Exhaust Gas Flow	m^3/h	1.902,30	2.513,35	2.656,58	2.403,27
Exhaust Density at Overall Temperature	kg/m^3	0,7805	0,7819	0,7823	0,7993
Exhaust Gas Flow	kg/h	1.484,7	1.965,1	2.078,2	1.920,9

4.1. Calculation Of Heat Recovered with Existing Economizer

Calculations of the heat recovery with the existing economizers are carried out below.

4.1.1. Steam Generator 1

According to the measured values, the Cp value and density of the exhaust gas are calculated. According to these values, the volumetric heating temperature of the exhaust gas was calculated.

$$d = 1 / (4x10^{-09} T^2 + 0.0028*T + 0.7701) \quad (4.1)$$

d=0,6753 kg/m^3

$$d = m / V \quad (4.2)$$

0,6753 kg/m^3= m / 1.902,30 m^3/h

m = 1.284,6 kg/h

$$Q = m * C_p * \Delta T \quad (4.3)$$

m = 1.284,6 kg/h

C_p = 0,2674 kcal/ kg °K

ΔT = 10,3 (282,1-271,8) °K

Q = 1.284,6 kg/h * 0,2674 kcal/kg °K * 10,30 °K

Q = 3.538,07 kcal/h

4.1.2 Steam Generator 2

According to the measured values, the Cp value and density of the exhaust gas are calculated. According to these values, the volumetric heating temperature of the exhaust gas was calculated.

$$d = 1 / (4x10^{-09} T^2 + 0.0028*T + 0.7701) \quad (4.1)$$

d=0,6753 kg/m^3

$$d = m / V \quad (4.2)$$

$0,6767\ kg/m^3 = m / 2.513,35\ m^3/h$

$m = 1.702,8\ kg/h$

$$Q = m * C_p * \Delta T \tag{4.3}$$

$m = 1.702,8\ kg/h$

$C_p = 0,2650\ kcal/\ kg\ {}^oK$

$\Delta T = 4,3\ (275,7\text{-}271,4)\ °K$

$Q = 1.702,8\ kg/h * 0,2650\ kcal/kg\ {}^oK * 4,30\ °K$

$Q = 1.940,34\ kcal/h$

4.1.3. Steam Generator 3

According to the measured values, the Cp value and density of the exhaust gas are calculated. According to these values, the volumetric heating temperature of the exhaust gas was calculated.

$$d = 1 / (\ 4x10\text{^-}09\ T^2 + 0.0028*T + 0.7701\ ) \tag{4.1}$$

$d=0,6753\ kg/m^3$

$$d = m / V \tag{4.2}$$

$0,6953\ kg/m^3 = m / 2.656,58\ m^3/h$

$m = 1.847,1\ kg/h$

$$Q = m * C_p * \Delta T \tag{4.3}$$

$m = 1.847,1\ kg/h$

$C_p = 0,2664\ kcal/\ kg\ {}^oK$

$\Delta T = 36\ (275,3\text{-}239,3)\ °K$

$Q = 1.847,1 \text{ kg/h} * 0,2664 \text{ kcal/kg } {}^oK * 36 \text{ °K}$

$Q = 17.714,42 \text{ kcal/h}$

4.1.4. Steam Generator 4

According to the measured values, the Cp value and density of the exhaust gas are calculated. According to these values, the volumetric heating temperature of the exhaust gas was calculated.

$$d = 1 / (4x10\text{^-}09\ T^2 + 0.0028*T + 0.7701) \quad (4.1)$$

$d=0,6753 \text{ kg/m}^3$

$$d = m / V \quad (4.2)$$

$0,7126 \text{ kg/m}^3 = m / 2.403,27 \text{ m}^3\text{/h}$

$m = 1.712,5 \text{ kg/h}$

$$Q = m * C_p * \Delta T \quad (4.3)$$

$m = 1.712,5 \text{ kg/h}$

$C_p = 0,2640 \text{ kcal/ kg } {}^oK$

$\Delta T = 16,9\ (252,3\text{-}235,4) \text{ °K}$

$Q = 1.712,5 \text{ kg/h} * 0,2640 \text{ kcal/kg } {}^oK * 16,9 \text{ °K}$

$Q = 7.640,49 \text{ kcal/h}$

4.2. Calculation of Recovered Heat with the New Economizer

With the economizer to be used after the application, the exhaust gas temperature will be reduced to 140°C and the feed water will be preheated with the recovered heat.

4.2.1. Steam Generator 1

According to the measured values, the Cp value and density of the exhaust gas are calculated. According to these values, the volumetric heating temperature of the exhaust gas was calculated.

$$d = 1 / (4x10\text{^-}09\ T^2 + 0.0028*T + 0.7701) \qquad (4.1)$$

$d=0,6753\ kg/m^3$

$$d = m / V \qquad (4.2)$$

$0,7805\ kg/m^3 = m / 1.902,3\ m^3/h$

$m = 1.484,7\ kg/h$

$$Q = m * C_p * \Delta T \qquad (4.3)$$

$m = 1.484,7\ kg/h$

$C_p = 0,2632\ kcal/ kg\ {}^oK$

$\Delta T = 142,1\ (282,1\text{-}140,0)\ °K$

$Q = 1.484,7\ kg/h * 0,2632\ kcal/kg\ {}^oK * 142,1\ °K$

$Q = 55.528,84\ kcal/h$

4.2.2. Steam Generator 2

According to the measured values, the Cp value and density of the exhaust gas are calculated. According to these values, the volumetric heating temperature of the exhaust gas was calculated.

$$d = 1 / (4x10\text{^-}09\ T^2 + 0.0028*T + 0.7701) \qquad (4.1)$$

$d=0,6753\ kg/m^3$

$$d = m / V \tag{4.2}$$

$0{,}7819\ kg/m^3 = m / 2.213{,}35\ m^3/h$

$m = 1.965{,}1\ kg/h$

$$Q = m * C_p * \Delta T \tag{4.3}$$

$m = 1.965{,}1\ kg/h$

$C_p = 0{,}2610\ kcal/ kg\ ^oK$

$\Delta T = 135{,}7\ (275{,}7-140{,}0)\ °K$

$Q = 1.965{,}1\ kg/h * 0{,}2610\ kcal/kg\ ^oK * 135{,}7\ °K$

$Q = 69.599{,}32\ kcal/h$

4.2.3. Steam Generator 3

According to the measured values, the Cp value and density of the exhaust gas are calculated. According to these values, the volumetric heating temperature of the exhaust gas was calculated.

$$d = 1 / (4x10\text{^-}09\ T^2 + 0.0028*T + 0.7701) \tag{4.1}$$

$d=0{,}6753\ kg/m^3$

$$d = m / V \tag{4.2}$$

$0{,}7823\ kg/m^3 = m / 2.656{,}58\ m^3/h$

$m = 2.078{,}2\ kg/h$

$$Q = m * C_p * \Delta T \tag{4.3}$$

$m = 2.078{,}2\ kg/h$

$C_p = 0{,}2634\ kcal/ kg\ ^oK$

$\Delta T = 135,3\ (275,3-140,0)\ °K$

$Q = 2.078,2\ kg/h * 0,2634\ kcal/kg\ °K * 135,3\ °K$

$Q = 74.062,93\ kcal/h$

4.2.4. Steam Generator 4

According to the measured values, the Cp value and density of the exhaust gas are calculated. According to these values, the volumetric heating temperature of the exhaust gas was calculated.

$$d = 1 / (4x10^{-09}\ T^2 + 0.0028*T + 0.7701) \quad (4.1)$$

$d=0,6753\ kg/m^3$

$$d = m / V \quad (4.2)$$

$0,7993\ kg/m^3 = m / 2.403,27\ m^3/h$

$m = 1.920,9\ kg/h$

$$Q = m * C_p * \Delta T \quad (4.3)$$

$m = 1.920,9\ kg/h$

$C_p = 0,2611\ kcal/ kg\ °K$

$\Delta T = 112,3\ (252,3-140,0)\ °K$

$Q = 1.920,9\ kg/h * 0,2611\ kcal/kg\ °K * 112,3\ °K$

$Q = 56.323,72\ kcal/h$

4.3. Efficiency Calculation of Existing Steam Generator

The steam generator produces 3,000 kg/h of steam per hour at a steam pressure of 8 bar. Natural gas consumption is 217.4 m³/h. Boiler feed water inlet temperature is taken as 90°C as reference.

The efficiency of the steam generator is calculated below.

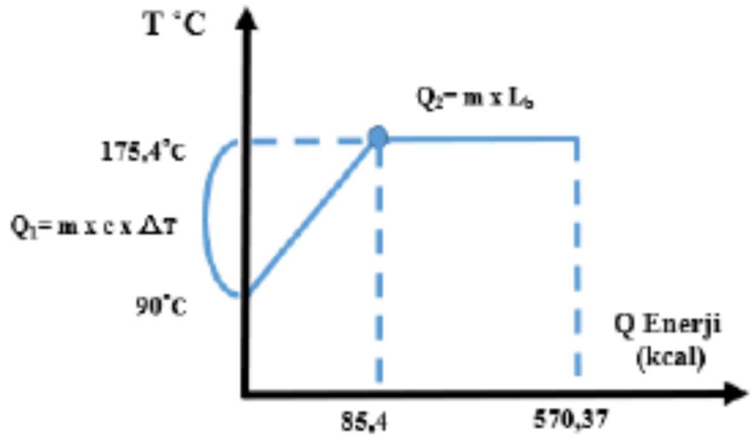

Figure 4.1. Enthalpy change of existing steam generator.

According to the data above, the amount of energy required to convert 1 kg of feed water entering the boiler into steam at 8 bar pressure and 175.4 °C saturation temperature is 570.37 kcal/kg. The lower heating value of natural gas used as fuel in the system is 8.250 kcal/m³.

Boiler Direct Efficiency = Steam Amount * (Steam Enthalpy − Feedwater Enthalpy) / Fuel Amount * Fuel Calorific Value

Steam Energy = (3,000 kg/h) * (570,37kcal/kg) = (1,711.110 kcal/h)

Fuel Energy = (217.4 Nm3/h) * (8.250 kcal/Nm3) =1.793.550 kcal/h)

System Efficiency = 1.711.110 / 1.793.550 = 0.954 ≅0,96

The unit energy gains of the system before and after the application were calculated separately. The savings calculated according to these values are given below.

Values used in the calculations;

Generator efficiency (%) (n, Taken from the technical document) : 96%

Natural gas lower thermal value : 8250 kcal / Sm3

Annual working time : 3600 h /year

Natural gas unit price : 1,4 TL / kWh

TCMB 23.08.2022 dated currency sales rate (euro) : 17,92 TL / EURO

Table 4.2. Calculated values.

	Steam Generator Number		1	2	3	4	Formula	Total
a	Heat Gained with the Existing Economizer	kCal/h	3.538,07	1.940,34	17.714,42	7.640,49	-	30.833,32
b	Heat Gained with the Existing Economizer	kWh	4,11	2,26	20,60	8,88	a/860	35,85
c	Heat to be Recovered with the New Economizer	kCal/h	55.528,84	69.559,32	74.062,93	56.323,72	-	255.474,81
d	Heat to be Recovered with the New Economizer	kWh	64,57	80,88	86,12	65,49	c/860	297,06
e	Unit Savings to be Provided After Implementation	kCal/h	51.990,77	67.618,98	56.348,51	48.683,23	c-a	224.641,49
f	Unit Savings to be Provided After Implementation	kWh	60,45	78,63	65,52	56,61	e/860	261,21
g	Steam Generator Efficiency	%	0,96	0,96	0,96	0,96	-	0,96
h	Net Savings After Implementation (including boiler efficiency)	kW	62,97	81,90	68,25	58,97	f/g	272,09
i	Annual Working Hours	hour	3.600	3.600	3.600	3.600	-	3.600
j	Annual Energy Gain	kWh/yıl	226.703,94	294.850,20	245.705,71	212.281,53	h*i	979.541,38
k	Natural Gas Unit Price	TL/kWh	0,1574	0,1574	0,1574	0,1574	-	0,1574
l	Annual Monetary Earnings	TL/yıl	317.385,52	412.790,28	343.987,99	297.194,14	j*k	1.371.357,93
m	Investment Cost (Euro)	€	14.375,00	14.375,00	14.375,00	14.375,00	-	57.500
n	Investment Cost (TL)	TL	258.318,75	258.318,75	258.318,75	258.318,75	m*17,97	1.033.275,00
o	Payback Period	Yearly	0,81	0,63	0,75	0,87	n/l	0,75

Figure 4.2. Photo of the installation of new economizer.

5. CONCLUSIONS

In this thesis, 4 economizer systems have been designed and installed coupled with 4 steam generators with a capacity of 3 t/h in a facility. Considering the current flue outlet temperatures of the existing economizers in the facility are very high, it is decided that these economizers are insufficient. In the planned scenario, the existing economizers will be dismantled and economizers with higher capacity will be installed to acquire better efficiency of the overall system. Considering the parameter total heat transfer coefficient, economizer design was carried out and payback period calculations were made for the determined construction.

With the economizer placed in the steam generator stack, the flue gas temperature was reduced from 270 °C to 140 °C. The heat gained by the sensible energy of the waste flue gas was used to heat the steam generator feed water from 70°C to 114°C. The heat to be recovered with the new economizers is 255.474,81 kcal/h, whereas the recovered heat with the existing economizers in the facility was 30.833,32 kcal/h.

Considering the rising costs and importance of energy, green deal sanctions aimed at limiting carbon emissions, and the climate crisis, energy efficiency is critical. It has been concluded that the designed economizers are environment and producer friendly considering the payback period of approximately 0,8 years.

In parallel with the increasing population and industrial developments in the world and in our country, the need for energy is also increasing. Existing energy resources cannot meet the energy needs and accordingly energy recovery gains importance. Although energy recovery from the exhaust gas is important, scientific studies on this subject are very limited. For this purpose, in this thesis, energy recovery from exhaust gas in a natural gas-powered steam generator was investigated.

REFERENCES

Demir, Ö. (2008). Yatağan Termik Santrali Baca Gazı ile Bölgesel Isıtma Olanakları. Yüksek Lisans Tezi, Muğla Üniversitesi, Fen Bilimleri Enstitüsü, Muğla.

Uysal, H. L. (2019). Endüstriyel Boyahane Tesislerinde Baca Gazı Atık Isısının Geri Kazanım Analizi ve Bir Uygulama. Yüksek Lisans Tezi, Balıkesir Üniversitesi, Fen Bilimleri Enstitüsü, Balıkesir.

Terhan, M. (2015). Doğalgaz Yakıtlı Bir Kazanda Baca Gazından Enerji Geri Kazanımı ve Yoğuşma Olayının Enerji, Ekserji ve Ekonomik Yönden İncelenmesi. Doktora Tezi, Atatürk Üniversitesi Fen Bilimleri Enstitüsü, Erzurum.

Huang, S., Li, C., Tan, T., Fu, P., Xu, G., and Yang, Y. (2017). An Improved System for Utilizing Low-Temperature Waste Heat of Flue Gas from Coal-Fired Power Plants. Entropy, 19-423.

Goel, N. (2012). Design and Performance Analyses of Condensing Heat Exchangers for Recovering Water and Waste Heat from Flue Gas. Master of Science, Lehigh University, Department of Mechanical Engineering, Ann Arbor.

Ma, Y., Yang, L, Junfu, L. J., Pei, Y. (2016). Techno-Economic Comparison of Boiler Cold-End Exhaust Gas Heat Recovery Processes for Efficient Brown-Coal-Fired Power Generation. Energy, 116, 812-823.

Stevanovic, V. D., Wala, T., Muszynski, S., Milic, M., Jovanovic, M. (2014). Efficiency and Power Upgrade by an Additional High Pressure Economizer İnstallation at an Aged 620 Mwe Lignite-Fired Power Plant. Energy, 66, 907-918.

Madan, E. (2014). Seramik Fırınlarında Atık Baca Gazından Enerji Geri Kazanımı ve Bir Uygulama. Yüksek Lisans Tezi, Bilecik Şeyh Edebali Üniversitesi, Fen Bilimleri Enstitüsü, Bilecik.

Dalkılıç, A.S., Alpay, N. ve Demir, H. (2008). Bir Fırına Ait Bacadan Isı Değiştirici Yardımıyla Atık Isı Geri Kazanımı. Tesisat Mühendisliği Dergisi, 108, 5-11.

Olgun, B., Batur, B., Batur, H., Tüter, H. ve Heperkan, H. (2007). Bir Gıda İşletmesinde Fonksiyon Kalite Kontrol Uygulaması. Vıı. Ulusal Tesisat Mühendisliği Kongresi, 25-28 Ekim 2007, İzmir, Türkiye.

Farthing, D.C. (2011). Improving Boiler Room Efficiencies. Oklahoma, http: //www. federalcorp. com/ tech/econpapr.htm (13.05.2020)

Aras, H. (1991). Doğal Gaz Yakan Sistemlerde Baca Gazından Isı Geri Kazanımı. Yüksek Lisans Tezi, Anadolu Üniversitesi, Fen Bilimleri Enstitüsü, Eskişehir.

Osakabe, M., Ishida, K., Yagi, K., Itoh, T. and Ohmasa, K. (2001). Condensation Heat Transfer on Tubes in Actual Flue Gas. Heat Transfer-Asian Research, 30 (2), 139- 151.

Wang, C., He, B., Sun, S., Wu, Y., Yan, N., Yan, L., Pei, X. (2012). Application of a Low Pressure Economizer for Waste Heat Recovery from The Exhaust Flue Gas in a 600 Mw Power Plant. Energy, 48, 196-202.

Wang, C., He, B., Yan, L., Pei, X., Chen, S. (2014). Thermodynamic Analysis of a Low-Pressure Economizer Based Waste Heat Recovery System for a Coal-Fired Power Plant. Energy, 65, 80-90.

Kılınç, H., 2016. Endüstriyel Tav Fırını Bacalarından Atık Isının Geri Kazanımı, İskenderun Teknik Üniversitesi Mühendislik ve F.B.E, Yüksek Lisans Tezi, Hatay, 1-56.

Gibbs, B.M., 1987. Boiler Fuel Savings by Heat Recovery and Reduced Stanby Losses, Heat Rec. Systems and CHP Journal, 7, 151-157.

Çıtır, H., 2013. Endüstriyel Tav Fırınında Ekonomizer Tasarımı, Karabük Üniversitesi Enerji Sistemleri Mühendisliği, Yüksek Lisans Tezi, Karabük, 1-50.

He, B., 2014. Thermodynamic Analysis of a Low-Pressure Economizer Based Waste Heat Recovery System for a Coal-Fired Power Plant, Energy Journal, 65, 80-90.

Bonilla, J., Technological Recovery Potential of Waste Heat in the Industry of the Basque Country, Elsevier Applied Thermal Engineering Journal, 17(3), 283-288, 1997.

Tarakçıoğlu, A., Sanayide Atık Isıdan Yararlanma Yöntemleri, Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, İstanbul, 114, 2006.

BCS, Waste Heat Recovery: Technology and Opportunuties in U.S. Industry, USA, 2008

Linke, P., Optimal Waste Heat Recovery and Reuse in Industrial Zones, Elsevier Energy Journal, 36, 4019-4031, 2011.

Huang, F., Heat Recovery Potentials and Technologies in Industrial Zones, Journal of the Energy Institute, 90, 951-961, 2016.

Willems D., Advanced System Controls and Energy Savings for Industrial Boilers, Transactions of the Citrus Engineering Conference, USA, 11-22, 2006.

Ünlü, C., Buharlı Sistemlerde Enerji Geri Kazanımı, Tesisat Mühendisliği Dergisi, 108, 53-63, 2008.

Tütüncü, G., Çimento Sektöründe Atık Isı Geri Kazanım (WHR) Sisteminin Termodinamik İncelemesi, Ege Üniversitesi Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, İzmir, 98, 2012.

Defrees, J., Stuckey, R. and Associates, L. (2008). Demonstration of a Condensing Economizer. Energy Engineering, 105 (5), 19-43.

Çomaklı, K., Yüksel, B., Şahin, B. ve Karagöz, Ş. (2006). Kazan Bacalarında Meydana Gelen Enerji ve Ekserji Kayıpları. Tesisat Mühendisliği Dergisi, 92, 12- 16.

Hill, J. M. (2011). Study of Low-Grade Waste Heat Recovery and Energy Transportation Systems in Industrial Applıcations. Master Thesis, The University of Alabama, Department of Mechanical Engineering, Tuscaloosa

Tokgöz, N., Özgün, Ö. (2019). Atık Isı Geri Kazanım Sistemlerine Yönelik Literatür Araştırması ve Sanayiden Örnek Vaka İncelemesi. Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 34 (2), 57-72.

Kaya, D. ve Dündar, C., Sanayide Enerji Tasarrufu Potansiyeli-II, Mühendis ve Makine Dergisi, 515, 2002.

Saidur, R., A Review on Electrical Motors Energy Use and Energy Savings. Renewable and Sustainable Energy Reviews, Journal of Power and Energy Engineering, 14, 877-898, 2014.

Norman, J.B., Industrial Energy Use and Improvement Potential University of Bath Department of Mechanical Engineering, Master's Thesis, England, 250, 2013.

Sarah, B., Industrial Waste Heat Recovery Technologies:An Economic Analysis of Heat Transformation Technologies, Elsevier Applied Energy Journal, 15, 1157–1167, 2015.

Faghri A. and Buchko M., Experimental and Numerical Analysis of Low_Temperature Heat Pipes With Multiple Heat Sources, J. Heat Transfer Journal, 113, 728-734, 1991.

Ersöz, M.A., Baca Gazlarındaki Atık Isının Isı Borusu ile Geri Kazanımının Araştırılması, Gazi Üniversitesi Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, Ankara, 133, 2002.

Ürün, E., Atık Baca Gazlarından Isı Geri Kazanımının Deneysel Olarak İncelenmesi, Karabük Üniversitesi Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, Karabük, 57, 2010.

Remeli, M., Simultaneous Industrial Waste Heat Recovery and Power Generation Using Heat Pipe Assisted Thermoelectric Generator, School of Aerospace Mechanical and Manufacturing Engineering College of Science Engineering and Health RMIT University, Master's Thesis, Australia, 158, 2015.

Jouhara, H., Experimental Investigation on a Flat Heat Pipe Heat Exchanger for Waste Heat Recovery in Steel Industry, 1st International Conference on Sustainable Energy and Resource Use in Food Chains, Berkshire-UK, 19-20 April 2017.

Hazell, D.D., Modeling and Optimization of Condensing Heat Exchangers for Cooling Boiler Flue Gas, Lehigh University, Department of Mechanical Engineering, Master's Thesis, Ann Arbor, 82, 2011

Görgülü, B., Atık Isı Kaynaklı Çift Etkili Absorpsiyonlu Soğutma Sisteminin Termodinamik Analizi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, Isparta, 87, 2013.

Varınca, K.B., Gönüllü, M.T. (2002). "Kojenerasyon Sistemlerinin Çevresel Etkilerinin Değerlendirilmesi.

Kaya, D. ve Dündar, C., Sanayide Enerji Tasarrufu Potansiyeli-II, Mühendis ve Makine Dergisi, 515, 2002.

Alkhamis, T.M., Alhusein, M.A. ve Kablan, M.M. (1998). Utilization of Waste Heat from The Kitchen Furnace of an Enclosed Campus. Energy Conversion and Management, 10, 1113-1119.

Angın, B. (2007). Cam Sanayinde Geleneksel Yakıtlar Yerine Doğal Gaz Kullanımının Enerji Ekonomisi Açısından İncelenmesi. Yüksek Lisans Tezi, Mersin Üniversitesi, Fen Bilimleri Enstitüsü, Mersin.

Aras, H. (1991). Doğal Gaz Yakan Sistemlerde Baca Gazından Isı Geri Kazanımı. Yüksek Lisans Tezi, Anadolu Üniversitesi, Fen Bilimleri Enstitüsü, Eskişehir.

Butcher, T.A. and Litzke, W. (1994). Condensing Economizers for Small Coal- Fired Boilers and Furnaces, New York.

Çadırcı, S. (2004). Doğalgaz Yanma Mekanizmasının İncelenmesi. Yüksek Lisans Tezi, İTÜ, Fen Bilimleri Enstitüsü, İstanbul.

Çengel, Y.A. and Boles, M.A. (2006). Thermodynamics an Engineering Approach. Mcgraw-Hill, USA, 963.

Çengel, Y.A. (2011). Isı ve Kütle Transferi. Güven Bilimsel Yayınları, 875, İzmir.

Çomaklı, K., Yüksel, B., Şahin, B. ve Karagöz, Ş. (2006). Kazan Bacalarında Meydana Gelen Enerji ve Ekserji Kayıpları. Tesisat Mühendisliği Dergisi, 92, 12- 16.

Defrees, J., Stuckey, R. and Associates, L. (2008). Demonstration of a Condensing Economizer. Energy Engineering, 105 (5), 19-43.

Genceli, O.F., 1997. İki fazlı akış. Tesisat Mühendisliği Derneği Teknik Yayınlar, 2, 4.1-4.20.

Hasanuzzaman, M., Rahim, N. A., Hosenuzzaman, M., Saidur, R., Mahbubul, I. M., Rashid, M.M. (2012). Energy Savings in The Combustion Based Process Heating in İndustrial Sector. Renewable and Sustainable Energy Reviews, 16, 4527-4536.

Jouhara, H., Khordehgah, N., Almahmoud,S., Delpech, B., Chauhan, A., Tassou, S. A. (2018). Tassouwaste Heat Recovery Technologies and Applications. Thermal Science and Engineering Progress, 6, 268–289.

Okka, O. (2006). Mühendislik Ekonomisi. Nobel Yayın Dağıtım, 563 s.

Özdemir, M. ve Parmaksızoğlu, İ.C. (2003). Mekanik Tesisatta Ekonomik Analiz. VI. Ulusal Tesisat Mühendisliği Kongresi, 8-11 Ekim 2003, İzmir, Türkiye.

Selbaş, R. (1992). Atık Isı Enerjisinden Yararlanma Yöntemleri ve Uygulamaları. Yüksek Lisans Tezi, Akdeniz Üniversitesi, Fen Bilimleri Enstitüsü, Antalya.

Selimli, S. (2012). Endüstriyel Tav Fırını İçin Reküperatör Tasarımı. Yüksek Lisans Tezi, Karabük Üniversitesi, Fen Bilimleri Enstitüsü, Karabük.