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CHAPTER I

Exergoeconomic Optimization of Heat Exchangers Using a Hybrid Genetic Algorithm

Suha Orçun MERT[1]
Ceyda KÖK[2]

1. Introduction

Energy plays a significant role in the progress of a society in terms of economic, technological, and environmental aspects. It is important that the efficiency of energy conversion is high, given the reduction of fossil fuels and the rise in energy prices. From energy production to transmission, the use of thermal systems is essential. One of the components commonly used in most thermal systems is systems that allow heat to flow between fluids at different temperatures. These systems are called the 'heat exchanger'. Heat exchangers are used to transfer energy between fluids at different temperatures. These systems allow heat to flow from one fluid to

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another without the fluids directly mixing, typically through a metal or other conductive material that separates them. Heat exchangers function in the food industry, waste heat recovery, power plants, air conditioning, chemical processes, automobiles and ships, aerospace vehicles and cooling of electronic equipment. The wide range of applications shows how important and necessary the design and efficiency of these devices are.

There are many types of heat exchangers used in different application areas. These devices are the flow pattern is classified in a very wide area according to its characteristics such as flow numbers, structures, surface densities and heat transfer mechanisms. In the literature, it is mostly classified according to flow patterns and construction types

When designing heat exchangers, firstly, the geometric configuration and operating data that meet the heat duty requirements and design criteria are selected. The pressure drop value is fixed within the allowable range. The design variable values are then defined to have a heat transfer coefficient to suit the heat exchange surface and according to the mechanical, thermodynamic and design features. Then, the designers' choices are verified by following an iterative procedure until they obtain the appropriate design that has design features between pressure drops and thermal performances (Hewitt and Barbosa,2008), (Rohsenow et al., 1973), (Chhabra,2017).

Even if this approach is proven, it is very time consuming and does not lead to effective cost designs as the cost criterion is not taken into account. Considering that heat exchangers are used in many application areas, maximum efficiency is an important goal with minimum cost design. Minimizing costs is critical in energy conservation and in protecting limited energy resources.

The design of the casing heat exchanger is quite complicated, even if single-objective optimization is successful in optimal designs, this method can only convergence instead of optimum design in complex problems. Cost and efficiency in heat exchangers

are two important parameters, but the optimization of each does not give the same optimal value. Multi-objective optimization explores a range of solutions and calculates the optimal value for each parameter. Therefore, in order to make the design of the heat exchanger better, a multi-objective optimization algorithm based on structural algorithm, which treats cost and efficiency as objective functions, is used.

According to the first law of thermodynamics, the main criterion in determining the type of energy for engineering is its capacity to do work. This criterion is the exergy of the energy source Exergy analysis is a technique used to evaluate a system based on the principles of mass and momentum conservation, along with the second law of thermodynamics. In short, exergy is theoretically a maximum useful work. Economic analysis using the second law parameter of thermodynamics is called thermo-economic. Exergoeconomic is an economic analysis of exergy and a special case of thermoeconomics. The exergoeconomic optimization procedure aims to minimize energy loss (maximum efficiency), minimize cost to maximize profit.

There are numerous studies about STHE's considering optimization, design, energy, exergy and Exergoeconomic analysis and so on (Mukherjee, 2004; Guo et al., 2009; Ordóñez and Bejan, 2000; Soria-Verdugo et al.,2009; Caputo et al.,2008; Assad,2010; Markowski et al.,2013; Mert et al.,2011). Studies about optimization (Haseli et al.,2008; Wen and Li, 2009; Cornelissen and Hirs, 1997) of STHE's generally focused on the evaluating the temperatures about the utility side of the system as well as the efficiency. Also, single optimization studies about cost or performance optimization is also carried out by the researchers (Guo et al., 2009; Soria-Verdugo et al.,2009; Caputo et al.,2008; Özçelik, 2007) for revealing the characteristic of defined heat exchangers beside new designs. In some of the attempts the multi-objective approach is also used (Han et al., 2015; Sanaye and Hajabdollahi, 2015; Hajabdollahi, et al.,2012; Fettaka,et al.,2013) considering cost of operation, heat transfer rate, pumping power, efficiency, and heat transfer

coefficient. The results of the general multi-objective optimizations lead to a Pareto set of solutions and must be evaluated depending on the decisions given in the trade off structure of the system.

Differing from these studies a multi-objective approach is implemented to the question of optimum design of STHE's considering both maximizing exergy efficiency and minimizing exergoeconomic cost of operation. The hybrid genetic algorithm-based program (HEX-OP) was developed to handle large systems.

2. S&T Heat Exchanger Design

In the design program, the heat exchanger was designed based on the process fluid's inlet temperature, outlet temperature, mass flow rates, and the utility fluid's inlet temperature. The design parameters to be estimated using the genetic algorithm include the pipe outer diameter, pitch ratio, number of tube passes, mass flow rate, pitch type, baffle spacing ratio, and tube placement angle. The following equations were used for design of specified heat exchanger (Kern,1950).

$$q = m_p c_{p_p}(\Delta T_p) \tag{1}$$

$$T_{u,2} = T_{u,1} + q/(m_u c_{p,u}) \tag{2}$$

$$\Delta T_{ln} = (\Delta T_1 - \Delta T_2)/\, log(\Delta T_1/\Delta T_2) \tag{3}$$

$$E = (\Delta T_{p,1} - \Delta T_{p,2})/\, (\Delta T_{p,1} - \Delta T_{u,1}) \tag{4}$$

$$\mathrm{R} = (\Delta T_{p,1} - \Delta T_{p,2})/\, (\Delta T_{u,2} - \Delta T_{u,1}) \tag{5}$$

$$P_{\mathrm{F}} = (\Delta T_{u,2} - \Delta T_{u,1})/\, (\Delta T_{p,1} - \Delta T_{u,1}) \tag{6}$$

F=1 (For NTP=1),

$$F = \frac{\sqrt{R^2+1}}{R-1} \frac{ln\,(\frac{1-P_F}{1-PR})}{ln\left[\frac{2-P_F(R+1-\sqrt{R^2+1}}{2-P_F(R+1+\sqrt{R^2+1}}\right]} \quad \text{(For NTP > 1)} \tag{7}$$

$$A = \frac{q}{(U*F*\Delta T_{LN})} \tag{8}$$

$$N_t = \frac{A}{\pi D_o l_t} \tag{9}$$

The following equations were used to determine the heat transfer coefficient of the tube side;

$$h_t = 1.86 \frac{k_t}{D_i} \left(\frac{Re_t Pr_t D_i}{l} \right)^{\frac{1}{3}} \text{(For laminar flow)} \tag{10}$$

$$h_t = 0.023 \frac{k_t}{D_i} {Re_t}^{0.8} {Pr_t}^{\frac{1}{3}} \text{(For turbulent flow)} \tag{11}$$

The heat transfer coefficient of the shell side was found by the Bell and Delaware method. Equations:

For triangular pitch;

$$D_e = \frac{1.026}{D_o} (PT^2 - 0.9069 {D^2}_O) \tag{12}$$

For square pitch;

$$D_e = \frac{4}{\pi D_o} (PT^2 - \pi \frac{{D_o}^2}{4}) \tag{13}$$

$$D_s = 0.637 \left(\left(\frac{CL}{CTP} \right)^{0.5} \left(PR^2 D_o \frac{A}{l_t} \right)^{0.5} \right) \tag{14}$$

$$A_s = \frac{((PT - D_o) BSD_s)}{PT} \tag{15}$$

$$a = \frac{a^3}{1 + 0.14 Re_s^{a^4}} \tag{16}$$

$$j = \left(\left(a_1 \left(1.33 / \left(\frac{PT}{D_o} \right) \right)^a \right) \right) R_s^{a_2} \tag{17}$$

$$h_s = F_{BD} j c_{p,s} \left(\frac{m_s}{A_s} \right) \left(\frac{k_s}{c_{p,s} \mu_s} \right)^{2/3} \tag{18}$$

Where; CL stands for the tube layout constant, CTP refers to the tube count calculation constant, and a_i represents the correlation coefficients for j. These parameters influence the layout angle, the number of tube passes, and ultimately

the Reynolds number. Finally, the following equations were applied to estimate the pressure drops, as well as the thermal and pressure-related components of exergy. (Dinçer and Rosen,2012):

$$\frac{1}{\sqrt{f}} = -4log\left(\frac{E}{D} + \frac{1.255}{Re\sqrt{f}}\right) \tag{19}$$

$$\Delta P_t = 4f\frac{1}{D_i}\rho\frac{v^2}{2} + 2.5n\,\rho\frac{v^2}{2} \tag{20}$$

$$f = e^{0.576-0.19ln(Re)} \tag{21}$$

$$\Delta P_s = f\frac{G_s^2 D_s(N_t+1)}{2D_e} \tag{22}$$

$$E_{\Delta T} = T_E(c_p m)_{min}\left\{ln\left[1 + E\left(\frac{T_{h,1}}{T_{c,1}} - 1\right)\right] + \frac{C_{p,h}}{C_{p,c}}ln\left[1 - \frac{C_{p,c}}{C_{p,h}}E\left(1 - \frac{T_{c,1}}{T_{h,1}}\right)\right]\right\} \tag{23}$$

$$E_{\Delta P} = m_h\frac{\Delta P_p}{\rho_p} + m_c\frac{\Delta P_u}{\rho_u} \tag{24}$$

The Hall method was used to estimate the cost of heat exchangers. The following equations were applied to estimate the individual and total costs.

$$CC_{Hex} = 10000 + 324A^{0.91} \tag{25}$$

Where; A represents the heat transfer area

$$ATC = TPc_e(E_{\Delta T} + E_{\Delta P}) + f_{cr}CC_{Hex} \tag{26}$$

$$f_{cr} = \frac{i_R(1+i_R)^{TL}}{(1+i_R)^{TL}-1} \tag{27}$$

The unit cost of the exergy is c_e, the period of the time of operation per year is TP, technical life is TL, interest rate is i_R and the capital recovery is f_{cr} symbolized. Also, the thermal and pressure component of the exergy destruction are symbolized as $E_{\Delta T}$ and $E_{\Delta P}$.

3. Materials and Methods

3.1. Exergoeconomic Optimization

Multi-objective optimization is a method that aims to simultaneously optimize several objectives within a given problem. Thermal systems are inherently multi-objective due to the complexity of the physical and chemical processes involved, making their structure quite intricate.

Exergoeconomic analysis investigates cost structure of a system including equipment costs, and operating costs. Exergy and economics are closely related as the exergy analysis searches for the efficient and effective use of energy in a system, so a cost-effective operation is achieved.

In this study a broad ExMOO study is accomplished to find out the design scheme of a STHE that operates at minimum exergoeconomic cost of operation and maximum efficiency.

Exergetic cost for heat exchange operation is aimed to be calculated by exergoeconomic analysis.

The overall exergetic cost balance is used as Equation 28 and 29:

$$\sum\left(\dot{E}x_{in,i} \cdot C_{in,i}\right) + \dot{Z}_{tot} = \sum\left(\dot{E}x_{out,i} \cdot C_{out,i}\right) + P_{net} \cdot C_W \quad (28)$$

$$Min\ C_{Ex} = \left(\left(Ex_{in,h} * C_{in,h} + Ex_{in,c} * C_{in,c}\right) - \left(Ex_{out,h} * C_{out,h} + Z\right)\right)/C_{out,c} \quad (29)$$

Where, respectively, $\dot{E}x_{in,h}$, $\dot{E}x_{out,h}$, $C_{in,c}$ and $C_{out,h}$ represent exergy of input and output flows and their costs, while $\dot{Z}_{tot}$ is the total annual cost in control volume. Then exergy cost is calculated depending on this situation Cost management is used to calculate $\dot{Z}_{eq}$ (levelized).

The exergy efficiency is calculated by considering the exergy output value recovered to the input. Equation 30 expresses exergy efficiency (Mert et al.,2012). The exergetic efficiencies of each

designed STHE is calculated according to the exergy balance (Dinçer and Rosen,2012)

$$\eta = \frac{Ex_{in}}{Ex_{out}} \tag{30}$$

Here; Ex_{in} is the total exergy entering the system and Ex_{out} is the exergy coming out of the system.

The nature of multi-objective optimization (MOO) problems requires careful consideration when forming objective functions. In this study, the weighted sum of objectives method (Özçelik and Mert, 2016) is applied to address the large-scale MINLP problem involved in designing Shell-and-Tube Heat Exchangers (STHEs). This method assigns a weight factor to the parameters of the objective function, with values ranging between 0 and 1. The choice of decision factors is critical as it influences the outcomes and aligns them with the desired goals. To facilitate this, the program allows the selection of weighting factors and includes a parametric study for different weighting scenarios, offering a user-friendly interface. The ExMOO problem related to STHE design is solved separately for each set of weighting factors, generating an extensive Pareto solution set for further analysis and discussion.

Equations 29 and 30 shows respectively the formulas for minimum exergoeconomic cost and maximum exergy efficiency. The mathematical combination of the model's minimum exergoeconomic cost and maximum exergy efficiency is shown in Equation 31 that is the generalized objective function.

$$Min\ Z = \left(w\left(Ex_{eff} - Ex_{ff,Max}\right)^2 + (1-w)\left(C_{ex} - C_{ex,min}\right)^2\right)^{1/2} \tag{31}$$

Where Z ; It represents the objective function to be minimized by combining two separate objective functions.

3.2. The Algorithm

An in-house program is developed specifically for the solution of this multi-objective optimization (Figure 1) problem. The problem lets to choose and enter (Figure 2) all the design parameters and the parameters of multi-objective weighing method. Besides the program is integrated with the Crane® chemical materials database that is developed previously (Özçelik and Mert,2016).

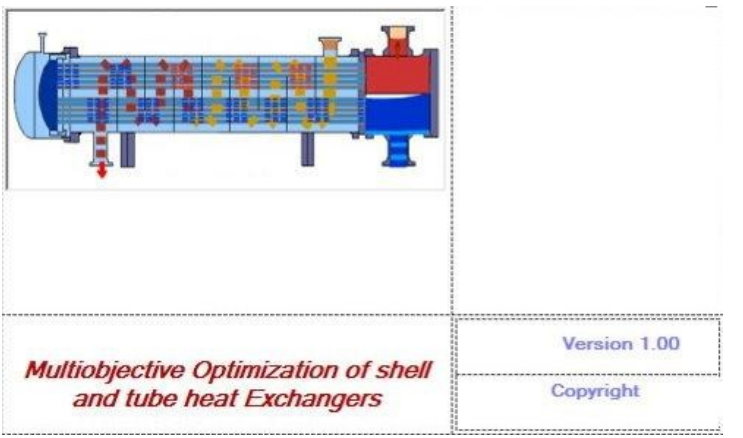

Figure 1: Splash Screen of the developed program ExMOO

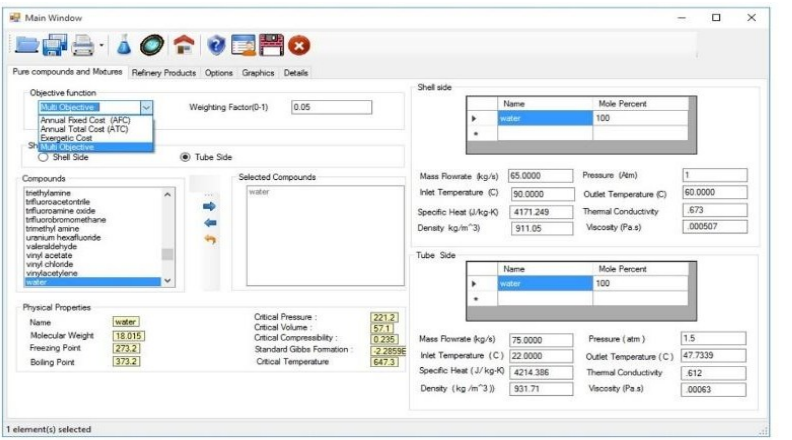

Figure 2: Data input screen of the ExMOO program

Following the entrance of variables and selecting components, the selection of some methods regarding estimating/calculating of heat transfer coefficient, density, vapor pressure and else is handled by options screen as given in Figure 3. Following the necessary data entrance and property selection hitting the calculate button executes the program and results are achieved.

The minimization of Equation 31, treated as the objective function and combined using the weighted sum of objectives method, is achieved through a "Nonlinear Simplex/Genetic" hybrid algorithm. This algorithm relies on the stochastic generation of solution vectors to find the optimal result.

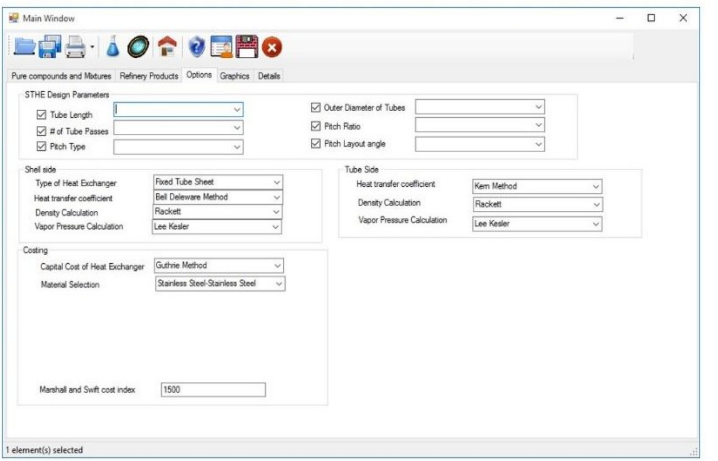

Figure 3: Options screen of the ExMOO program

When the algorithm of the calculation procedure considered it is seen that is started with the selection of the components and is connected to the sub program Crane®, then the Hex-Op starts ExMOO calculations until reaching the termination criteria. The algorithm of the HEX-OP is given in Figure 4.

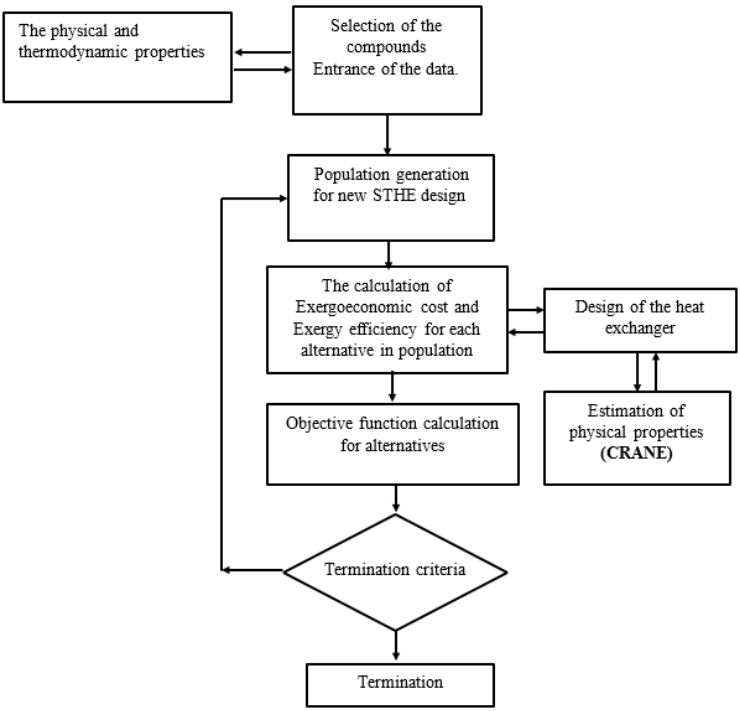

Figure 4: The HEX-OP algorithm

The evaluation of the objective function relies on the outcome of the fitness function (Eq. 30), which is influenced by the weighting factor generated by the genetic algorithm. The performance of the genetic algorithm developed for this purpose was previously tested in studies by Özçelik and Mert (2016) and Özçelik (2007). The program aims to simultaneously optimize the minimization of exergoeconomic cost and the maximization of exergy efficiency. But for high number of solutions, the genetic algorithm followed and the program tries to convergence depending on the fitness function. The algorithm is given in details in the previous studies (Özçelik and Mert,2016; Özçelik, 2007).

4. Results and Discussion

The effect of weighing factor on the multi-objective structure of the STHE is studied in a detailed design approach considering high exergy efficiency and low exergoeconomic cost.

As the main parameters of a STHE, the optimization procedure decides the design parameters of pass numbers, length of tubes, inner and outer diameters, number of tubes, pitch type, pith ratio and baffle spacing. The values of these design values with respect to the weighing factor (w) given for the exergoeconomic cost is tabulated in Table 1.

The cost structure of SHTE with varying weighing factor can be seen in Figure 5 considering AFC (Annual Fixed Cost), AOC (Annual Operating Cost), and ATC (Annual Total Cost). It is seen that as the weigh given to the exergetic efficiency is increased the ATC. The increase reaches up to 2000 $/year that comes to a 1% in percentage. This value is not high as the overall cost is considered but when the AFC and AOC considered separately it is seen that AOC is increasing in a higher tendency whereas AFC is decreases from 12000 $ to 4500 $ as weighing factor increases.

Moreover, overall heat transfer rate and heat transfer areas are given in Figure 6, supporting the results in Figure 5. As the importance of efficiency increases with the increasing weighing factor the overall heat transfer rate increases as a result of the optimization calculations. On the other hand, the area for heat transfer decreases as expected as the total heat load is unchanged. The heat transfer area decreases more then 4 times.

As a complement to these results, exergy efficiency and exergoeconomic cost values are given in Figure 7. The exergetic view of the results shows as weighing importance given to the Exergy efficiency increases the efficiency up to 72% while the costs decrease to 256$. these extreme results prove the dominant effect of multi-objective model. Besides in moderate weighs the exergy

efficiencies lie around 40-50% with exergoeconomic costs of 3000-4000$.

Table 1: The results of the design parameters of STHE

WF	Pass	L	D_o	D_i	N_t	Pitch	Pitch Ratio	Baffle space
0	1--1	4	30	25	966	Triangular	1,3	0,36
0,05	1--6	3	38	33	591	Triangular	1,3	0,36
0,1	1--6	3	38	33	626	Triangular	1,3	0,42
0,15	1--1	5	16	12	667	Triangular	1,3	0,72
0,2	1--6	3	38	33	640	Triangular	1,3	0,45
0,25	1--6	3	38	33	619	Triangular	1,3	0,41
0,3	1--6	3	38	33	622	Triangular	1,3	0,42
0,35	1--1	5	16	12	674	Triangular	1,3	0,86
0,4	1--1	5	16	12	672	Triangular	1,3	0,72
0,45	1--1	5	16	12	677	Triangular	1,3	0,77
0,5	1--1	5	16	12	656	Triangular	1,3	0,81
0,55	1--1	5	16	12	668	Triangular	1,3	0,7
0,6	1--1	5	16	12	651	Triangular	1,3	0,8
0,65	1--1	5	16	12	682	Triangular	1,3	0,91
0,7	1--1	5	16	12	649	Triangular	1,3	0,79
0,75	1--1	5	16	12	658	Triangular	1,3	0,67
0,8	1--1	5	16	12	668	Triangular	1,3	0,78
0,85	1--1	5	16	12	649	Triangular	1,3	0,78
0,9	1--2	6	25	20	317	Triangular	1,25	0,57
0,95	1--2	6	25	20	321	Triangular	1,25	0,56
1	1--6	7	6	5	654	Triangular	1,3	0,29

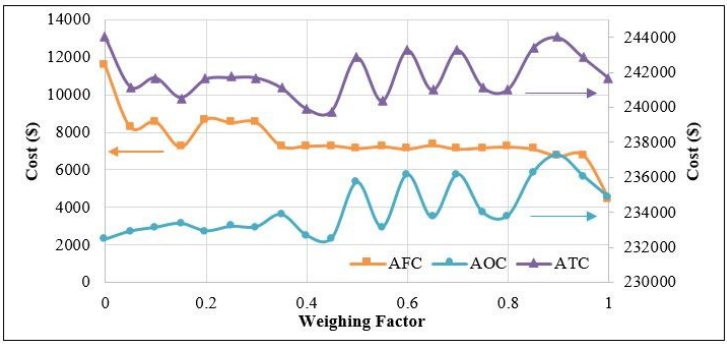

Figure 5: Cost structure of the STHE with varying weighing factor

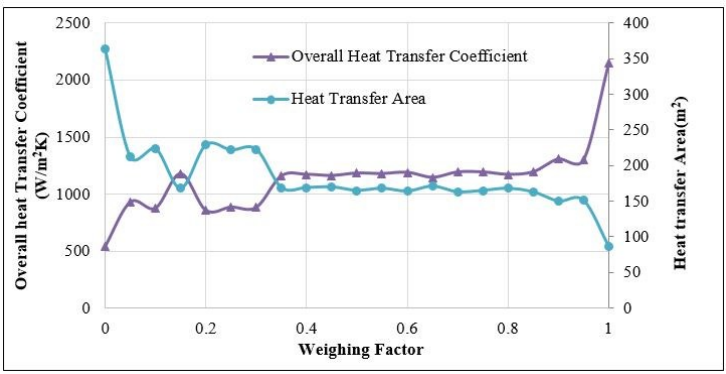

Figure 6: Heat Transfer performance of the STHE with varying weighing factor

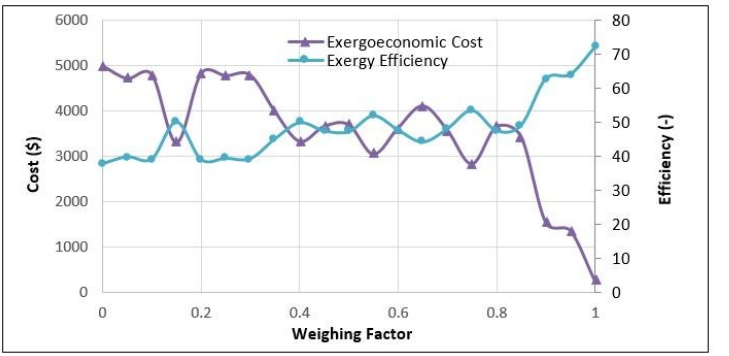

Figure 7: Cost structure of the STHE with varying weighing factor

5. Conclusion

A comprehensive multi-objective optimization study is completed in this study for a heat exchanger from design and operation point of view. The objective function is formed regarding maximizing exergy efficiency and minimizing exergoeconomic cost of operation. As result of the study, a wide PARETO set of solution has been calculated for each weighting factor. Every case in PARETO is an optimum one, and can be evaluated as "correct", regarding the fitness values. The best optimum selection is the duty of the decision-makers depending on their specific needs and circumstances.

It is found that the triangular pitch formation with 1.3 pitch ratio is the general solution for various weighing factors. 1-1 pass is the dominant pass structure where 1-2 and 1-6 is also shown in the results. In moderate weighing numbers Length is 5m and Diameter is 12/16 mm. Each of these values are the result of the ExMOO algorithm. Each of these results is the optimum within their cases in terms of maximum exergy efficiency and minimum exergoeconomic cost.

Moreover, when the exergetic structure and heat transfer performance is investigated, it is also seen that the tendencies of the

results are in expected ranges with fluctuating efficiencies around 40-60% and 2000-5000$ exergoeconomic costs. Corresponding cost structure follows the exergoeconomic costs and efficiencies in terms of AOC and AFC. So the study reveals the system dynamics for various cases of decision. It is seen that both of the objectives has a great dependence of the decision (weighing factor) and results in major differences in the STHE design.

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CHAPTER II

Bioenergy Potential as a Zero-Emission Fuel: The Case of Kırklareli[1]

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1. Introduction

Following the significant changes in the energy situation in the world and the devastating effects of climate change in many parts of the world recently, more effective approaches are needed to solve these problems. Due to both the increase in the prices of fossil fuels and the environmental degradation they cause, countries' demand for

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renewable energy sources is increasing. Renewable energy is regarded as essential for our future and a critical solution for saving the world. Energy sources are basically classified into three classes as fossil fuels, nuclear energy and renewable energy sources. Fossil fuels are the most widely used sources today and are divided into three classes as oil, natural gas and coal. Fossil fuels are formed as a result of the decomposition of organic substances in an oxygen-free environment for millions of years. Since their formation requires a very long time, they are classified as non-renewable energy sources. Studies and applications on clean and renewable energy sources have become important due to the depletion problem of fossil energy sources, the increase in fuel prices, climate change and other environmental problems. Nuclear energy, another energy source, cannot be widely used because it requires high technologies for production and its hazard class is high during the energy production phase. Renewable energy sources are becoming attractive in energy production because of their ability to be recycled and because they pollute the environment less. Renewable energy sources include solar, wind, hydropower, biomass, geothermal, wave, current, tidal and hydrogen energy. Countries are increasingly adopting new technologies to harness energy from sustainable, renewable sources as alternatives to finite, non-renewable energy sources. Research and studies in this area provide valuable insights for reducing pollution associated with energy production and consumption, shaping a cleaner and more sustainable future.

Biomass, a source of organic carbon, can be defined as the total mass of living organisms belonging to a species or a community consisting of various species at a certain time. Biomass energy is

generally used in the place where the source is located or close to the source. Production in the place where the energy source is located contributes to the development of the region by reducing the environmental impacts and costs that will occur with transportation, the return of waste to the economy and the employment of local people. The use of biomass in electricity generation contributes to the reduction of fossil fuel-based imports, the reduction of greenhouse gas emissions, the prevention of environmental pollution and also waste management.

Türkiye has a high potential in terms of biomass potential due to agriculture and animal husbandry. In this study, the biogas potential of Kırklareli province located in the Marmara Region that can be obtained from animal waste and plant residues was determined. The share of the agricultural sector in Kırklareli in the 2022 GDP (Gross Domestic Product) of the province is 11% with approximately 500 million USD (Republic of Türkiye Kırklareli Governorship, 2024a). Many studies are being carried out on the determination of biomass and biogas potential. In similar studies in the literature, biomass energy potentials were determined for different waste types with annually changing data. In this study, the electrical energy that can be produced depending on the methane (CH_4) potential that can be formed in Kırklareli, including all districts, was calculated by taking into account the animal presence and plant residues with the current data of 2023. It is expected that the obtained results will contribute to the utilization of the biomass energy potential in the province and waste management.

Biomass energy

Biomass is generally defined as the biodegradable part of wastes, including products, wastes and residues of biological origin from agriculture, forestry and related industries, fisheries and aquaculture, including plant and animal substances, as well as industrial and municipal wastes of biological origin (European Union [EU], 2009). Biomass refers to renewable organic matter from plants and animals and contains stored chemical energy from the sun produced by plants through photosynthesis. Biomass resources can be generally grouped under three main headings as organic wastes, energy plants, by-products and wastes.

According to the Regulation on Technical Assessment of Applications for Electricity Generation Based on Biomass Energy published in Türkiye on January 26, 2023, biomass is defined as municipal waste (including landfill gas), as well as vegetable oil waste, agricultural waste without food and feed value, forest products other than industrial wood, resources obtained from by-products resulting from the processing of waste tires, industrial waste sludge and treatment sludge, provided that they are not imported (Regulation on Technical Assessment of Applications for Electricity Generation Based on Biomass Energy, 2013). The main biomass sources are listed in Table 1.

Biomass energy, as a zero-emission fuel, constitutes a significant pillar of decarbonization in energy transition. It has the flexibility to be used in many different forms in many sectors, from solid bioenergy as biogas in domestic and industrial power and heat production to liquid biofuels used in automobiles, ships and aircraft (International Energy Agency [IEA] 2024). Biomass energy can be

converted into another form of energy by using it directly or indirectly. It is converted into heat, steam, and electricity by burning

Table 1. Biomass resources

Agricultural	Dry Lignocellulosic Plants Oilseed Plants	Herbaceous plants (miscanthus, reeds etc.) Canola, sunflower, soybean etc.
	Sugar and Starch Plants	Sugar beet, corn, wheat, sweet sorghum, potatoes etc.
	Fiber Plants	Flax, hemp, sorghum, miscanthus etc.
	Vegetable Wastes	Stem, straw, branch, root, bark, pruning etc. residues
	Protein Plants	Peas, beans etc.
	Animal Wastes	Excrements of cattle, sheep and poultry animals, slaughterhouse wastes and wastes generated during the processing of animal products
Forestry	Forests	Fast growing trees (willow, poplar, eucalyptus, etc.)
	Forestry Industry waste and waste products and by-products	Energy forestry products, energy crops, wood blocks, sawdust etc..
Industry	Industrial Waste	Paper, food, and wood etc. waste
Urban and Industrial Wastes	Dry Lignocellulosic Materials	Park and garden waste
	Organic Waste	Wood particles, biodegradable waste, sewage sludge, etc.
Waste tires	Byproducts resulting from processing	Pyrolytic oil, gas fuel, etc.

Reference: Regulation on Technical Assessment of Applications for Electricity Generation Based on Biomass Energy, (2013); Ministry of Energy and Natural Resources (MENR, 2024).

it directly and into another energy source by various processes in its indirect use. The products obtained with biomass conversion technologies are given in Table 2. Conversion technologies and process conditions are determined according to the nature of the raw material used as biomass and the desired end product. As a result of the processes, energy source products are obtained in solid, liquid and gaseous forms.

Table 2. Biomass conversion methods and types of fuels obtained

Method	**Product**
Physical Processes Drying, separation Grinding Shredding Compression	Pellets, briquettes
Biochemical and Microbial Processes Anerobic Digestion Aerobic and Anaerobic Fermentation Biomethanization Biophotolysis Composting	Biogas, bioethanol, biodiesel, methane, biohydrogen and oxygen
Thermochemical Processes Combustion Pyrolysis - Torrefaction - Slow pyrolysis - Fast pyrolysis Liquefaction Gasification Hydrothermal Processes Esterification	Heat, steam, Solid, liquid and gaseous biofuels Pellet, briquette, biocoal, biogas, syngas, biomethane, tar, organic compounds, water,biooil,ethanol, methanol, hydrogen, Fischer-Tropsch fuels, combustible gases, carbon monoxide, carbon dioxide and nitrogen, biodiesel
Physicochemical Transesterification Extraction	Liquid biofuels, biodiesel, bioethanol, Fischer-Tropsch fuels, etc.

Reference: MENR, (2024), Turkish Academy of Sciences (TÜBA,2022)

The European Union (EU) and 190 countries, which account for 95% of human-induced carbon emissions, took an important step in the fight against climate by ratifying the 2015 Paris Climate Agreement. Accordingly, The EU published the European Green Deal (EGD) declaration in 2019, which was within the scope of combating global warming. Türkiye ratified the 2015 Paris Climate Agreement in 2021. With the declaration, the EU initiated the transition process to a green economy in the fight against climate change in line with the goals of keeping the global temperature increase below 1.5°C and adapting to the effects of climate change in the Paris Climate Agreement. The green economy refers to the circular economy model with new policies covering all sectors that protect the environment as a solution to the climate crisis with resource efficiency and low carbon emissions (Küçük & Dural, 2022). It is expected that the EU will achieve its 2030 and 2050 targets through action plans aligned with the EGD and policies in line with the Paris Climate Agreement. In addition, the transition to a low-carbon economy with the circular economy action plan envisages radical changes in the lifestyles of countries, primarily in the economy, in all sectors, in agricultural policies and food security policies, as well as in growth strategies and sustainable development goals (EU, 2024). At the beginning of this radical change, the reduction of CO_2 emission factors in the energy sector, especially in electricity production, can be achieved by increasing the use of renewable energy sources. The use of biomass energy is important in achieving this increase.

For the last 20 years, investments and incentives for renewable energy sources have been increasing all over the world.

In Türkiye, incentives started with the YEK Law No. 5346 enacted in 2005 and through YEKDEM (Renewable Energy Sources Support Mechanism). This mechanism contributes to the reduction of fossil fuel and external dependency in energy by increasing the use of renewable energy sources in Türkiye. The purchase prices to be applied within the scope of YEKDEM have been determined as 8.10-9.9 US Dollar cents/kWh for electricity production with the biomethanisation method among biomass-based production facilities, higher than the production prices of hydroelectric, wind, solar and other biomass facilities (RES Certified Renewable Energy Sources, 2023)

Biogas and its importance

During the fermentation of biomass in an oxygen-free environment, the activity of various types of bacteria with different tasks at different stages produces flammable gas known as biogas- also referred to as swamp gas, sewage gas, or landfill gas- along with fermented waste (fertilizer) consisting of both liquid and solid phases (TÜBA,2022; Chynoweth, Owens & Legrand, 2001; Igoni & et al., 2008). Biogas is a colorless, flammable gas that is 20% lighter than air and burns with a bright blue flame. It primarily consists of CH_4 and carbon dioxide (CO_2), with small amounts of other gases. Raw biogas may also contain other gases such as O_2 and CO in different proportions. It is also a stable and non-toxic gas, with methane being its main component—similar to natural gas. The fuel value of biogas originates from its methane content, and its calorific value ranges between 17-25 MJ/m^3, depending on the methane concentration. The composition and specifications of biogas are presented in Table 3 and Table 4.

Table 3. Composition of biogas

Components	**Volume %**
Methane (CH_4)	50-75
Carbon dioxide (CO_2)	25-45
Hydrogen Sulphide (H_2S)	<1
Nitrogen (N_2)	<2
Hydrogen (H_2)	<1
Oxygen (O_2)	<2
Water Vapour	2 (20ºC) -7(40ºC)

Reference: Seadi & et al., (2008)

Improper disposal of organic waste leads to air pollution and contributes to the increase in greenhouse gas emissions. Furthermore, directly applying organic waste as fertilizer can cause it to mix with rainwater and infiltrate groundwater, resulting in contamination. For this reason, biogas production plays a crucial role in converting organic waste into energy in an environmentally responsible manner, minimizing pollution. Biogas facilities not only facilitate the proper disposal of organic waste but also convert the methane produced into energy, providing a sustainable solution to multiple environmental challenges.

Table 4. Specifications of biogas

Feature	Description
Areas of use	Heating with direct combustion and warming, energy production, electricity production with combined heat and power systems, biomethane production, lighting, motor fuel in transportation, fuel-cell fuel, additive to natural gas; as an industrial energy source for heat, steam, cooling and in chemical production
Ignition temperature	650 -700ºC
Explosion	Biogas does not burn alone, must be stored very carefully
Colour	Colorless
Calorific value of biogas	17-25 MJ/m^3
Smell	Rotten egg

Reference:Görmüş, (2018)

In the 1970s, due to the energy crisis caused by high oil prices, research and development studies on biogas gained momentum in line with the need for alternative energy sources and attempts were made to produce biogas with modern systems. Since the late 1990s, biogas facilities have been integrated into industrial and urban waste treatment systems and have begun to find more application areas in energy production (Bond &Templeton, 2011). The use of biogas facilities is steadily increasing as a means of making animal waste more useful through fermentation. The advantages of biogas production can be listed as follows; (Aktaş, 2008; Yokuş, 2011):

- It is a cost-effective, clean, environmentally friendly source of energy and fertilizer.

- It provides waste recovery.
- It offers flexibility in using a variety of raw materials for production, including animal waste, plant waste, municipal waste, and wastewater treatment plant waste.
- When the waste from fermentation facilities is stored, it results in reduced odour, methane, and NO_2 emissions. The nitrogen content is higher compared to untreated farm manure.
- It enhances productivity in fields by using the fermented slurry from biogas production as an organic fertilizer.
- Weed seeds found in animal manure lose their ability to germinate as a result of biogas production.
- The odor of animal manure is significantly reduced to the point where it is no longer noticeable.
- Biogas production largely eliminates disease agents in animal manure that threaten human health and groundwater.
- After biogas production, the waste is not discarded but transformed into a valuable organic fertilizer.
- The raw materials used for biogas production are easy to store.

- It produces fewer greenhouse gas emissions due to lower methane, CO_2, and nitrogen oxide formation compared to fossil fuels.
- It reduces dependence on imported fossil fuels.
- It contributes to sustainable energy production by promoting a circular economy and environmental protection.
- It can be used to generate electricity and meet heating needs.
- Biogas can be directly used for cooking and lighting, and with the combined heat and power (CHP) system, it can be utilized for heating, electricity, or fed directly into the gas grid, providing flexible and efficient fuel use in vehicles.
- It prevents irregular waste management and reduces groundwater pollution by keeping pollutants from mixing with groundwater.
- Compared to other biofuel production processes, biogas production consumes less water, which is a significant advantage considering the increasing global importance of water.
- The production of raw materials for biogas creates a new source of income for farmers.

The disadvantages of biogas production can be listed as follows (Öztürk, 2019);

- Biogas still contains some pollutants even after refining processes are carried out.
- The large-scale use of biogas and the waste collection process may not be economically feasible, and it is challenging to increase the efficiency of biogas systems.
- Biogas has an unstable structure, and methane can cause explosions if it comes into contact with oxygen, requiring careful monitoring of the process.
- Transportation vehicles are needed to bring raw materials to the biogas production facility and remove the by-products after production. These vehicles contribute to carbon dioxide emissions. However, this issue can be mitigated by using clean fuel vehicles, such as electric or biofuel-powered vehicles.
- Large areas are required for the storage of raw materials.
- Biogas facilities can produce unpleasant odors, so they should be located away from residential areas. The odor issue must be carefully considered.

2. Material and methodology

In this study, the biomethane potential that may occur in Kırklareli province and its districts was calculated based on the data from Turkish Statistical Institute (TurkStat) animal and plant production for 2023. In order to determine the amount of biomethane that can be produced from animal waste, the availability rates of wet

waste amounts formed according to cattle, sheep and poultry assets, methane yields depending on solid matter (SM) and volatile solid matter (VSM) rates were taken into account. In order to determine the amount of biomethane that can be produced from plant residues, agricultural production and agricultural residue amounts, availability rate and methane yields depending on VSM rates were taken into account. These data constitute the basic material of the research.

Kırklareli is located in the Marmara Region of Türkiye on the European continent (Figure 1) between 41°44′–42°00′ North Latitude and 26°53′–41°44′ East Longitude. It has a land area of 6,555 km^2. It is surrounded by Bulgaria with a border length of 159 km to the north, the Black Sea with a coastline of 58 km to the east, Edirne to the west, Istanbul to the southeast and Tekirdağ to the south. (Kırklareli Special Provincial Administration, 2024). The population of Kırklareli in 2023 was 377,156, approximately 50.6% of whom were male and 49.4% female. The population density of Kırklareli province is lower than the national average of 111 people/km^2 (Republic of Türkiye Kırklareli Governorship, 2024b)

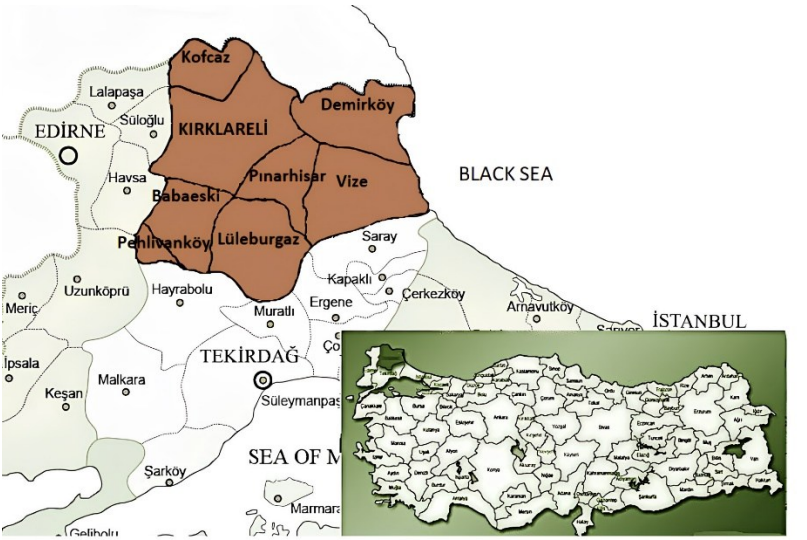

Figure 1. Kırklareli province map

The distribution of Kırklareli animal population as cattle, small ruminants and poultry by districts in 2023 is given in Table 5. Cattle includes bull, bullock, calf, and buffalo; small ruminants include sheep, goat whereas poultry includes chicken, turkey, goose and duck.

The distribution of agricultural cultivated areas for 2023, which is the basis for calculations, by products and districts is given in Table 6.

Table 5. Animal population of the districts in 2023

	Cattle	Small ruminats	Poultry	Total
Central	45,310	137,998	327,805	511,113
Lüleburgaz	52,369	50,953	201,919	305,241
Pınarhisar	7,279	55,995	64,821	128,095
Babaeski	25,202	38,763	54,244	118,209
Kofçaz	4,213	33,394	15,043	52,650
Vize	10,919	31,242	9,323	51,484
Demirköy	4,213	12,915	3,943	21,071
Pehlivanköy	2,519	6,518	6,915	15,952
Total	**152,024**	**367,778**	**684,013**	**1,203,815**

Reference: Turkish Statistical Institute (TurkStat, 2024)

In the calculation of animal methane potential, the availability rates (AR) of animal waste, SM and VSM rates and methane formation values per unit VSM were taken from Aktaş, Özer, Soyak, &Ertürk (2015) and Arslanhan (2023). The values used in the calculations are given in Table 7. Methane potential of manure, MPm (m^3 CH_4/year) is calculated with the Eq. 1, whereas electricity generation potential of methane for manure, $Em_{methane}$, kWh/year is calculated with Eq.2

$$MPm=P \times MG \times ARm \times SMm \times VSMm \times MYm \qquad \text{(Eq.1)}$$

P: animal population, head; MG: manure generation for each type of animal, ton/head-year; ARm: availability rate of manure, %; SMm: solid matter content of manure, %; VSMm volatile solid matter content of manure, %; MYm: methane yield of manure, m^3CH_4/tonVSM

$$Em_{methane}= MPm \times Enm \times \eta \qquad \text{(Eq.2)}$$

Enm: energy content of methane is assumed 10 kWh/m^3, η: electricity conversion factor, 40% (DBFZ 2011).

Table 6. Agricultural cultivated areas by district, daa

Districts	Wheat	Sunflower	Barley	Corn	Oat	Rye	Paddy	Total (daa)
Merkez	189,000	257,530	17,000	34,625	5,000	1350	0	504,505
Lüleburgaz	403,100	325,782	26,200	950	400	30	1433	757,895
Babaeski	275,985	175,916	13,289	5,200	250	250	7290	478,180
Pınarhisar	85,800	72,986	5,300	345	750	400	0	165,581
Demirköy	535	0	362	0	232	0	0	1,129
Vize	108,000	81,650	5,000	325	750	0	0	195,725
Pehlivanköy	40,800	31,650	1,200	250	400	0	6396	80,696
Kofçaz	37,750	31,786	3,020	0	7,370	59	0	79,985
Total	1,140,970	977,300	71,371	41,695	15,152	2,089	15,119	2,263,696

Reference: Turkish Statistical Institute (TurkStat, 2024)

Table 7. Values used in calculations according to animal species

	Cattle	Small ruminants	Poultry
MG	13,69 (DBFZ, 2011)	0,73 (Avcıoğlu & Türker, 2012)	0,1 (Baban et al., 2001)
ARm (%)*	41	41	99
SM (%)*	14	36	25
VSM (%)*	62	81	64
Mym*	316	324	436

**: Aktaş &et al., 2015*

Methane potential of agricultural residue, MPa (m^3 CH_4/year) is calculated with the Eq.3, whereas electricity generation potential of methane for agricultural residue, $Ea_{methane}$, kWh/year is calculated with Eq.4. The values used in the calculations are given in Table 8.

Table 8. Coefficients used in calculations according to crop species

Crops	URA*	ARa**	VSM*	Mya*
Wheat	0.325	15	79	295
Sunflower	0.153***	60	81***	338***
Barley	0.2	15	76	352
Corn	1.48	60	62	251
Oat	0.434	15	76	291
Rye	0.45	15	81	274
Paddy	0.6	70	76	261

*References: *DBFZ, (2011), **Başçetinçelik & et al.,(2006), ***: Tuncez&Soylu,(2022),*

MPa: CA x URA x ARa x VSMa x MYa (Eq.3)

CA: cultivated area, daa; URA: Unit Residue Amout, ton/daa

ARa: availability rate of agricultural residue, %; VSMa volatile solid matter content of agricultural residue, %; MYa: methane yield of agricultural residue, m^3CH_4/ton VSM

$$Ea_{methane} = MPa \times Enm \times \eta \quad \text{(Eq.4)}$$

3. Results

The total methane potential from animal waste for a total of 1,203,815 animals corresponds to approximately 38.5 million m^3 CH_4/year, whereas the methane potential from agricultural residue is calculated as approximately 45.24 million m^3 CH_4/year from 2,263,696 decares of cultivated land (Table 9, Table 10).

Table 9. Animal manure CH_4 potential, $10^3 m^3$/year

	Cattle	Small ruminants	Poultry	Total
Central	6,976	3,902	2,264	13,142
Lüleburgaz	8,062	1,441	1,395	10,898
Babaeski	3,880	1,096	375	5,351
Pınarhisar	1,121	1,583	448	3,152
Demirköy	649	365	27	1,041
Vize	1,681	883	64	2,629
Pehlivanköy	388	184	48	620
Kofçaz	649	944	104	1,697
Total	23,405	10,400	4,724	38,529

The distribution of Kırklareli 2023 animal wealth was determined as approximately 13%, 30.5%, and 57% for cattle, sheep, and poultry, respectively, while the methane production potential was determined as approximately 61%, 27%, and 12%, respectively. The reason for this reverse ranking is that the animal waste methane potential is 153.96 m^3CH_4/animal-year, 28.28 m^3CH_4/animal-year

and 6.91 m^3CH_4/animal-year for cattle, sheep and poultry, respectively (Table 11).

In terms of cultivated land size, wheat and sunflower rank first and second with 1,140,970 decares and 977,300 decares, respectively. However, regarding methane potential per unit of cultivated area, corn with 137.96 m^3 CH_4/daa and paddy with 83.29 m^3 CH_4/daa are the top two crops. On the other hand, according to CH_4 generation per unit of residue sunflower with 163.5 m^3CH_4/ton residue and paddy 138.8 m^3CH_4/ton residue are in the top two (Table 12).

Table 10. Methane potential of agricultural residue, $10^3 m^3$ CH_4/year

District	Wheat	Sunflower	Barley	Corn	Oat	Rye	Paddy	Total
Central	2,150	6,441	137	4,777	72	20	0	13,596
Lüleburgaz	4,585	8,147	211	131	5.76	0.446	11	13,199
Babaeski	3,139	4,399	107	717	3.6	3.7	607	8,977
Pınarhisar	976	1,825	43	48	11	5.9	0	2,908
Demirköy	0	0	3	0	0	0	0	2.9
Vize	1,228	2,042	40	45	11	0	0	3,366
Pehlivanköy	464	792	10	35	5.8	0	533	1,838
Kofçaz	429	795	24	0	106	1.5	0	1,356
Total	12,971	24,441	574	6	215	31.7	1,259	45,244

Table 11. Unit CH_4 generation values for animal manure

	m^3 CH_4/head-year
Cattle	153.96
Small ruminants	28.28
Poultry	6.91
Total	32

Table 12. Unit CH_4 generation values for agricultural crops

	m^3 CH_4/daa	**$m^3$$CH_4$/ton residue**
Wheat	11.37	35
Sunflower	25.01	163.5
Barley	8.04	40.2
Corn	137.96	93.2
Oat	14.18	33.2
Rye	15.17	33.1
Paddy	83.29	138.8
Total	19.99	75

The total methane potential was calculated approximately 84 million m^3 CH_4/year, corresponding to an electricity production potential of 335 GWh/year, which corresponds to approximately 12% of Kırklareli's annual electrical energy demand. In 2021, electricity consumption in Kırklareli was approximately 2,716 GWh (Republic of Türkiye Kırklareli Governorship, 2024c).

Based on this potential, electricity production plants with a total installed capacity of 44.7 MW can be established across various districts. The districts with the highest methane potential from animal and agricultural waste have been identified as Merkez**,** Lüleburgaz**,** and Babaeski where livestock farming and agriculture are most intensive. (Table 13). By taking into account the installed power potential and transportation distance criteria, it is feasible to set up facilities of different capacities in all districts of Kırklareli province.

4. Conclusion

Given Türkiye's significant biomass energy potential, evaluating biogas energy potential and increasing its share in electricity production is crucial for ensuring energy supply security, reducing external energy dependency, and mitigating climate change. Moreover, biomass serves as a key energy resource in Kırklareli, a region characterized by intensive agricultural and livestock activities. Harnessing the energy potential of agricultural residues and animal manure is particularly important, especially in the districts of Merkez, Lüleburgaz, and Babaeski, which feature extensive cultivated agricultural land and significant livestock production.

Table 13. Kırklareli electricity potential, GWh/year

Districts	**Agricultural**	**Manure based**	**Total**	**Installed Capacity, MW**
Central	54.4	52.5	107	14.3
Lüleburga	52.8	43.5	96.4	12.9
Babaeski	36	21.4	57.3	7.6
Pınarhisar	11.6	12.6	24.2	3.2
Demirköy	$11.6x10^{-3}$	$4.1x10^{-3}$	4.2	0.6
Vize	13.5	10.5	24	3.2
Pehlivankö	7.4	2.5	9.8	1.3
Kofçaz	5.4	6.8	12.2	1.6
Total	181	154	335	44.7

The methane potentials, calculated based on annually changing livestock populations and agricultural production data,

vary. However, with an integrated plan that includes agricultural, livestock, and energy production throughout Türkiye, the opportunities to utilize the existing biomass potential can be increased. Thus, biomass can move beyond its potential and become a consistently used energy source. By targeting consistent production values, a continuous, stable, and sustainable energy source can be ensured instead of variable annual figures.

Considering the advantages of biogas systems, they can stand out and become more widespread. Accordingly, designing facilities based on regional potential and climate conditions with a focus on low investment costs will encourage the development of biogas technology in Türkiye.

According to the Türkiye National Energy Plan**,** primary energy consumption is projected to increase by approximately 39.5% between 2020 and 2035. While the share of renewable energy in primary energy sources was 16.7% in 2020, it is expected to rise to 23.7% by 2035 (MENR, 2022). It can be stated that the growth of biogas plants could contribute to achieving Türkiye's national targets for preventing climate change.

Increasing the use of renewable energy sources will contribute to the protection of the environment, the solution of waste management problems, the reduction of greenhouse gases, and finally the transition to a circular economy.

Disadvantages related to the waste collection process can be overcome by the widespread use of mechanized farms, and the establishment of regional facilities close to the source of waste.

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CHAPTER III

Helisel Borulu Termal Güneş Enerjili Sıcak Su Hazırlama Sistemin Tasarımı, İmalatı ve Deneysel İncelenmesi

Burak KERSE[1]
Halil İbrahim VARİYENLİ[2]

GİRİŞ

Güneş enerjisi, doğrudan güneş ışınlarını kullanarak ısı veya elektrik üretimi sağlamak için çeşitli teknolojiler kullanır. Bu teknolojiler arasında, özellikle güneş enerjisi ile ısıtma sistemleri, evsel ve endüstriyel alanlarda yaygın olarak tercih edilmektedir. Güneş ısı kollektörleri, bu sistemlerin temel bileşenlerinden biridir ve güneş ışınımını ısıya dönüştürerek, suyun ısıtılması, hava ısıtılması veya diğer ısıtma işlemleri için kullanılabilir. Türkiye, yıllık ortalama 2.737 saatlik güneşlenme süresi ve 1.527 kWh/m²

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yıllık ortalama güneş enerjisi potansiyeli ile güneş enerjisi uygulamaları açısından büyük bir avantaja sahiptir [1]. Türkiye gibi güneş ışınımının yüksek olduğu ülkelerde, güneş enerjisi kullanımının artırılması, enerji bağımsızlığını güçlendirebilir ve çevreye duyarlı enerji çözümleri sunabilir. Bu bağlamda, güneş enerjisine yönelim ve ısı kollektörlerinin kullanımı, ülkemizin enerji politikaları ve sürdürülebilir kalkınma hedefleri açısından büyük bir öneme sahiptir. Türkiye'deki mevcut güneş enerjisi teknolojilerinin yaygınlaştırılması ve bu alanda verimliliği artıracak yenilikçi sistemlerin geliştirilmesi de enerji bağımlılığını azaltmak ve karbon ayak izini düşürmek adına kritik öneme sahiptir. Bu doğrultuda, güneş enerjisi tabanlı termal sistemlerin daha verimli, ekonomik ve sürdürülebilir hale getirilmesine yönelik katkılar sağlamak çalışmamızın amacıdır.

YÖNTEM

Bu çalışmada, yüksek ısıl verim sağlamak amacıyla helisel diğer adıyla sarmal sargılı güneş enerjili kollektör tasarlanmış ve soğurucu yüzey silindirik olarak şekillendirilmiştir. Silindirik tasarım, güneş ışınlarının farklı açılarda gelmesini sağlayarak kolektörün verimli ısıl soğurmasını ve verimi artırmasını hedefler. Ayrıca, bu tasarım geleneksel kolektörlere kıyasla daha küçük bir hacimde daha yüksek verimlilik sunmaktadır. Kolektör camı, dış yüzeyde maksimum emilim sağlamak için düz, iç yüzeyde ise güneş ışınımının atmosfere geçmesini engellemek için pürüzlü cam kullanılmıştır. Sistemde suya ek, çalışma sıvısı olarak nanoakışkan da kullanıldığı için bir pompa sistemi de yer almıştır. Sarmal sargılı kolektörün performansı, farklı debilerde yapılan testlerle karşılaştırılmış ve su ile yapılan denemelere ek olarak MgO-TiO2/su

ve MgO-CuO-TiO2/su nanoakışkan karışımları ile de deneyler tekrarlanmıştır. Elde edilen sonuçlar karşılaştırılarak değerlendirilmiştir. Şekil 1'de çalışma kapsamında hazırlanan düzeneğin tasarımı gösterilmektedir.

Çalışmamızda, sarmal sargılı bir güneş kollektörü üretilmiş ve deneysel analizleri yapılmıştır. Geliştirilen güneş kollektöründe sarmal sargılı boru kullanılmış olup, boru tipi olarak bakır tercih edilmiştir. Sistemde kullanılan bakır borunun çapı 8 mm'dir. Ayrıca, geliştirilen sarmal kollektörün çapı 85 mm'dir. Bobin hatvesinin çapı ise 15 mm, toplam bobin dönüş sayısı ise 49 adet olarak belirlenmiştir.

Şekil 1. Deney şablonunun görseli

Sarmal yapı kullanılması, düz plaka şeklinde tasarlanan geleneksel güneş enerjisi kollektörlerine kıyasla daha küçük bir hacimde soğurucu yüzeyin artırılmasına olanak verir. Sistemde kullanılan sarmal kollektör, % 95 emiciliğe sahip endüstriyel tip mat siyah boya sürülerek hazırlanmıştır. Kollektörün kasası üretilirken 4

mm kalınlığında, %92 geçirgenliğe sahip cam dikdörtgenler prizması tercih edilmiştir. Helisel diğer adıyla sarmal sargılı kollektörün alt kısmına da güneş ışınlarının ulaşması amacıyla prizmanın alt iç yüzeyine bir reflektör plaka yerleştirilmiştir. Açık şekilde tasarlandığı takdirde kollektörün arka tarafında ısı kayıpları oluşacağı için bu kayıpları önlemek adına kollektör alt kısmı ısıl olarak yalıtılmıştır.

Tasarlanan ve üretilen sarmal sargılı güneş enerjili su kollektörü testleri, Eylül ayında Ankara, Türkiye'de yapılmıştır. Bu çalışmada, farklı debi ve çalışma sıvılarının etkileri incelenmiştir. Geliştirilen sarmal sargılı güneş enerjili su kollektörü testleri, farklı debi ve çalışma sıvılarının ısıl ve ekserji performansları üzerindeki etkisini belirlemek amacıyla 2 farklı debide ve 3 farklı sıvıda gerçekleştirilmiştir. Bu testler sırasıyla güneş enerjili su kollektörüne 0,5 l/dk-0,9 l/dk, MgO-TiO2/su çalışma sıvılı kollektörüne 0,5 l/dk-0,9 l/dk, MgO-CuO-TiO2/su çalışma sıvılı kollektörüne 0,5 l/dk-0,9 l/dk debileri için yapılmıştır. Hibrit ve trihibrit nanoakışkanların kullanıldığı deneylerde, baz akışkanla nanoakışkanlar %2 oranında sentezlenmiştir. Bu deneyler toplamda 6 gün sürmüştür. Helisel sargılı güneş kollektörü deneyleri azimut açısı 0 olacak şekilde güneye yönlendirilmiştir. Ek olarak eğim açısı ise açısal yerleşiminde deney yapılan yerin yıllık eğim açısına karşılık gelen 40° seçilmiştir. Sistemin kararlı hale gelmesi için deneylere başlamadan, kapalı kollektörde 15 dakika su dolaşımı yapılmıştır. 6 gün süren deneylere, öğleden önce 10:00'da başlanmış ve öğleden sonra 16:00'da deneyler sonlandırılmıştır. Testlerde sıcaklık için ölçüm alınan noktalar kollektör girişi, kollektör çıkışı ve ortamdır. Sıcaklık değerleri 30 dakikada bir kaydedilmiştir.

TERMODİNAMİK HESAPLAMALAR

Tasarımı yapılan ve üretilmiş olan helisel sargılı güneş enerji sistemimiz için sayısal analiz yapılmak istenildiği takdirde enerji ve ekserji analizleri kullanılabilir. Reynolds ve Nusselt sayıları denklemlerle hesaplanabilir [2]:

$$Re = \frac{\rho_w v_i D_h}{\mu_w} \tag{1}$$

$$Nu = \frac{h D_h}{k_w} \tag{2}$$

Kollektörden elde edilen faydalı enerji şu şekilde hesaplanabilir:

$$\dot{Q} = \dot{m}.C_p.(T_{w,o} - T_{w,i}) \tag{3}$$

Güneş kollektörünün termal verimliliği, performansın tahlil edilmesinde kritik bir parametre olup şu şekilde hesaplanabilir:

$$\eta_t = \frac{\dot{Q}}{IA} \tag{4}$$

Ekserji, termodinamiğin birinci ve ikinci yasalarının birleşimi olarak tanımlanır. Bu analiz, ısıl sistemlerin tasarım aşamalarında sıklıkla kullanılır. Ekserjinin genel formülü şu şekilde edilebilir [3]:

$$\sum \dot{E}x_{i,net} - \sum \dot{E}x_{o,net} = \sum \dot{E}x_{loss} \tag{5}$$

Aşağıdaki denklem aracılığıyla ekserji verimliliği hesaplanabilir [4]:

$$\eta_e = \frac{\sum \dot{E}x_{o,net}}{\sum \dot{E}x_{i,net}} = 1 - \frac{\sum \dot{E}x_{loss}}{\sum \dot{E}x_{i,net}} \tag{6}$$

Güneş enerjili su kollektörünün net giriş ekserjisi şu denklem aracılığıyla hesaplanabilir [5]:

$$\sum \dot{E}x_{i,net} = IA\left[1 - \frac{4}{3}\left(\frac{Ta}{Ts}\right) + \frac{1}{3}\left(\frac{Ta}{Ts}\right)^4\right] \tag{7}$$

Bunun yanı sıra, güneş enerjili su ısıtma sisteminin net çıkış ekserjisi aşağıdaki şekilde elde edilebilir [6, 7]:

$$\sum \dot{E}x_{o,net} = \dot{Q}\left(1 - \frac{T_a}{T_{w,o}}\right) \tag{8}$$

Sürdürülebilirlik indeksi, ekserjiye dayalı bir faktör olup, aşağıdaki denklemle hesaplanabilir [8]:

$$SI = \frac{1}{1-\eta_e} \tag{9}$$

Deneysel belirsizlik, deneysel sonuçların analizinde önemli bir parametre olup, aşağıdaki şekilde hesaplanabilir:

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right]^{1/2} \tag{10}$$

BULGULAR VE SONUÇ

Çalışmamızda, helisel borulu bir güneş kollektörü dizayn edilerek deneysel incelemesi yapılmıştır. Deneylerde çalışma akışkanı su kullanarak iki farklı debide ölçümler alınmıştır. Sonrasında ısıl performansını mukayese edebilmek adına aynı debilerde MgO-Tio2/su ve MgO-CuO-TiO2/su çalışma akışkanlarıyla deneyler tekrarlandı. Böylece su, hibrit nanoakışkan/su ve tri hibrit nanoakışkan/su çalışma sıvılarıyla deneyler yapıldı. Çalışma kapsamında yapılan deneyler 0,5 l/dk su için 1.deney, 0,9 l/dk su için 2.deney, 0,5 l/dk MgO-TiO2/su için 3. deney, 0,9 l/dk MgO-TiO2/su için 4. deney, 0,5 l/dk MgO-CuO-TiO2/su için 5. deney ve 0,9 l/dk MgO-CuO-TiO2/su için 6. deney olarak adlandırılacaktır. Çalışmadan elde edilen sonuçlar şu şekildedir:

- Kazanılan yararlı termal enerji ortalama değerleri sırasıyla 1. deneyde 83,36 W, 2. deneyde 112,51 W ve 3. deneyde 98,60 W olarak ölçülmüştür. Ayrıca, 4. deneyde 135,20 W, 5. deneyde 109,55 W ve 6. deneyde 148,25 W olarak ölçülmüştür.
- Ortalama ısıl verim değerleri sırasıyla 1. deneyde %31,9, 2. deneyde %43,76 ve 3. deneyde %37,24 olarak kaydedilmiştir. Ayrıca 4. deney, 5. deney ve 6. deneylerde sırasıyla %51,95, %41,86 ve %56,77 olarak bulunmuştur.
- Sürdürülebilirlik İndeksi değerleri 1. deneyde 1,00574, 2. deneyde 1,00916 ve 3. deneyde 1,00713 olarak kaydedilmiştir. Ayrıca 4. deney, 5. deney ve 6. deneylerde sırasıyla 1,01125, 1,00829 ve 1,01419 olarak bulunmuştur.

Yapılan literatür araştırmalarında helisel boru kullanılması durumundaki ısı transfer katsayısı, düz boruya oranla yüksek olduğu görülmüştü [9]. Bunun nedeni kollektör yapısının sarmal olması ve güneş ışınlarını her yönden dik şekilde alabilmesidir. Bunun yanında tasarlanan deney düzeneğine eklenen reflektör de kollektörü daha fazla ışınla buluşturdu. Aynı şekilde kollektörün prizma şeklinde cam ile çevrilmesi sera etkisi yarattı ve kollektörün siyah boya ile boyanması ise kollektör soğurganlığını arttırdı. Deneyler incelendiğinde çalışma sıvısında nanoakışkan kullanımı, çalışma sıvısı suya göre ısıl verimi artırdı ve sürdürülebilirlik endeksi de yüksek çıktı. Aynı şekilde tri hibrit nanoakışkanın kullanımı da hibrit nanoakışkana göre ısıl verim ve sürdürülebilirlik endeksi olarak daha

avantajlı olduğu görüldü. Farklı debilerde yapılan deneylerde ise yüksek debide daha yüksek ısıl verim ve sürdürülebilirlik endeksi elde edilmiştir.

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CHAPTER IV

Energy Optimization in Steam Bypass Systems Using Advanced Globe and Control Valve Designs

Soner ENEKÇİ[1]

1. Introduction

The continuous rise in energy consumption on a global scale has fueled the development of solutions to mitigate the negative impacts of industrial and residential energy use. The industrial sector is one of the largest consumers of energy; increasing efficiency and reducing the losses in manufacturing processes can subsequently decrease this consumption of energy in industrial operations. The substitution and optimization of steam-based systems have the potential to improve the overall efficiency of a plant. Steam optimization involves the elimination of non-useful steam via steam bypass systems in power plants. Various bypass scenarios calculate the steam consumption through the previous development of mass and heat balance in a process consisting of steam turbines, regenerative and saturated steam loops, or once-through boilers used

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for steam generation (Samnioti & Gaganis, 2023; Manesh et al., 2020; Alkemade et al., 2023)

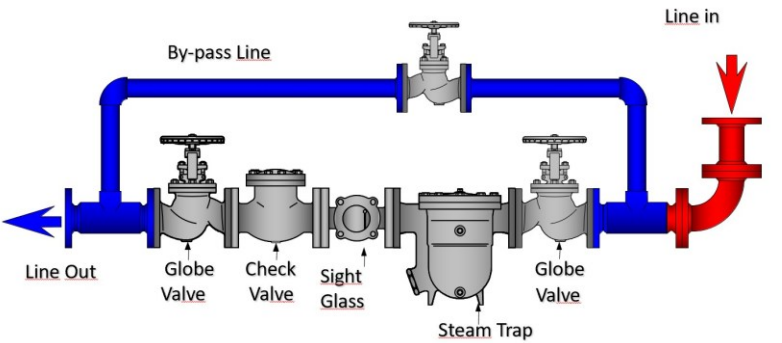

Figure 1: Steam line General drawing

Low mass flow rates of steam lead to significant entropy imbalances arising in adjacent equipment and process pipelines. Thus, a secure and common solution is applied to preheat the steam working fluid or preheat process streams. Energy considerations are essential for improving the efficiency of energy systems, with a significant link between environmental protection and economics in several configurations. Advanced valve solutions improve the operability of the current systems, leading to the achievement of a high degree of flexibility and substantial energy savings. This is an increasingly attractive plant modernization choice because it does not require significant investments in legislative research or new equipment. In the case study, the contribution of the globe and control valve optimization was presented (Padovani et al., 2024; Serrano et al., 2020).

1.1. Background and Significance

Steam bypass systems have been used in the paper industry since 1955 to route wet steam around the dryer section when there is a web break on the paper machine. In recent years, with the drive to reduce energy usage and increase system efficiencies, the bypass

system is used to power a turbine-generator or to provide steam to a district energy system. Bypass systems can and should be utilized to maximize the efficient operation of the facility where installed. In the pulp and paper industry, recently proposed projects use advanced automation and integrated heat exchangers in the bypass line to optimize energy use while operating in turbine bypass mode. Engineering technologies have advanced which could allow for the optimization of bypass systems using currently available globe and control valves, including estimated energy reduction per paper machine (Dickinson, 2022; Silalahi et al.2024).

Figure 2: Steam line leakages

Typical dryer sections on a paper machine account for 55–65% of a paper mill's total added energy input. In the U.S., the paper industry uses about 14.9 million BDT in energy while the production of paper uses 1.125 TBtu. During periods of wet paper breaks, an energy-efficient and properly designed steam bypass should be the first choice to remove dryer section energy from the process as there could be a large number of extended breaks in a month. Steam bypass flow rates for the paper industry can be as high as 80% of the maximum thermally equivalent maximum sore rates at a 97% level. A case study illustrates the impact of poorly designed steam and condensate systems. Regulatory pressures and increasing energy prices are topics of growing concern for many operations across various energy-intensive industries. The paper addresses possible energy waste and the potential economic and environmental impact

of poorly designed steam bypass systems (Chojnacka et al.2021; Rahnama Mobarakeh et al., 2021)

1.2. Research Objectives.

There is often too much slack for process control loops during production line turnarounds and when inconsistent feed occurs. The steam bypass system represents an important cost factor in power plants of oil and gas refineries where the feed rate and product demand fluctuate significantly throughout the year. The development of economics for such a steam bypass system requires the minimization of the costs approached in two situations: the capital installed costs, including such items as the turbo-expander and the valves, and the energy used from the HP steam. The study examines advanced control valves for steam bypass applications aiming to maximize the variation between the valve's minimum and maximum flow rates. Research objectives are defined as follows: to investigate alternative advanced globe and downstream control valve designs, optimized for steam bypass systems, and to predict the developed energy savings and performance of these designs. Inter-laboratory valve calibrations can be performed on valves manufactured to the latest designs to further evaluate their performance. This research concentrates on control valves that actually function correctly in their own right. Sliding stem and rotary control valves operating in liquid and gas service are included, while air-operated valves and rotary valves used in solids service are excluded. The objective is to provide a comprehensive data set to assist users in selecting the best valve for their application when optimal control is to be applied. Both control and on-off valves are included for isolation applications. The main scope is to evaluate valve performance across a range of valve types, pressure classes, sizes, and materials, and for different flow media. It will enable a critical review of European and international standards (Khaleel et al.2022; Fahmi et al., 2022; Shaghaghi et al.2024).

2. Steam Bypass Systems: Overview

Steam bypass systems are used to handle the venting of high-pressure steam by guiding the steam around the steam turbine until the steam pressure matches the available power demand. The main functionalities of a steam bypass system are: 1. A method to guide steam around the majority of the steam turbine at low-load operation using pipes. 2. Control mechanisms to re-enter the steam turbine from a stable pressure as the power demand increases. The selection of the steam bypass design configuration has implications for the efficiency of the entire plant. Energy flows are affected by production policies and steam turbine design flow area ratios. Steam near the design point flows directly from the main steam pipe to the steam turbine inlet valve. Configurations with low numbers of steam bypass valves have the potential to reduce turbine operating efficiency and produce poor part-load efficiency values and fixed power generation characteristics. The operation of a steam turbine bypass system is ultimately governed by the thermal and mechanical properties of steam and the physical components of the bypass system. Steam properties heavily influence how heat and energy flow within the system, and what happens when the parameters of the steam turbine and boiler change. Key components of the bypass system include pipes, pipe dimensions, and control valves. Valves used in steam bypass systems have conventionally been globe and gate types, with the globe valve opening based on the response of the positioner. Control valves are used in most power plants to direct steam into the steam turbine under a range of operating loads and modes. Once the bypass system components are defined, their combined behavior is key to understanding the operation of the entire system. An investigation of the intrinsic properties of a bypass system is of interest for just this reason. Energy optimization is discussed in detail in the next section and is based on a deep understanding of valves, control systems, and dynamic pressures, as well as interactions between installed systems and provided steam. (Silva et al.2020; Martelli et al., 2021; Magrini et al.2020)

2.1. Basic Components and Functionality

A moderate degree of system knowledge is assumed in this document. Steam bypass systems are designed with the capability to bypass a certain amount of process steam around a steam turbine while maintaining as constant a steam pressure and temperature as possible entering the turbine. Piping and piping elements such as valves, control valves, and bypass pipes connect the steam chest, if the steam turbine is of the side-entrance variety, or the line leading to one or more turbine nozzles, to the remainder of the process flow system external to the steam turbine. Steam chest valves of various designs are employed to control the flow of live steam into the steam turbine (Neto et al.2021; Wei et al., 2022).

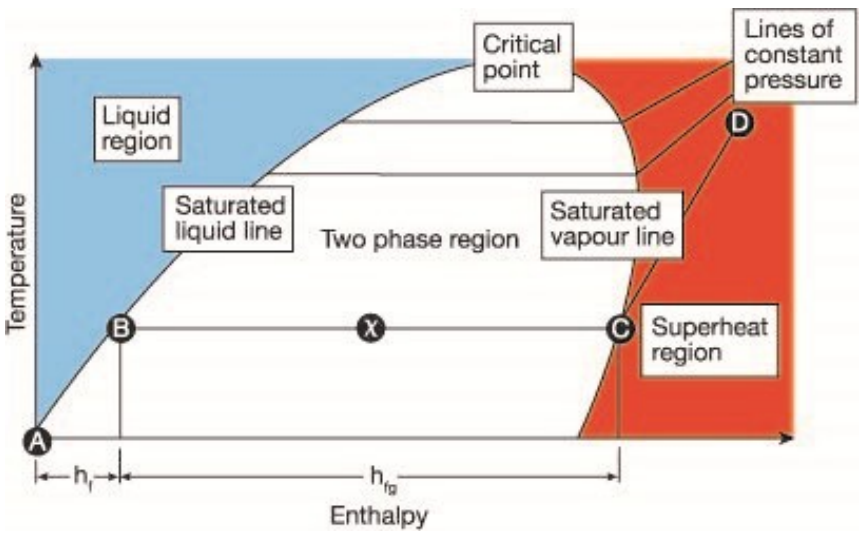

Figure 3: Best Steam Quality values

Piping on both sides of the steam turbine has one or more drains as part of the piping or add-ons to the piping structure. Drains can be free draining when steam condensate accumulates over time and then is blown down or pumped out of the drain, or condensate drains can have a steam trap assembly attached. Steam traps will blow down according to a design plan, so steam always fills the

space around the steam trap to the trap's setpoint condition. Steam traps are slightly more energy-efficient at maintaining proper drainage rates compared to free draining pulse loads. A condenser attached to the steam exhaust side of the steam turbine lowers the temperature of exhausted steam. Piping on one side of the steam turbine is a steam outlet from the steam turbine and is led out of the turbine hall to avoid the buildup of atmospheric moisture from the condensing steam flow. Two or three low-pressure exhaust safety valves are attached to the condensing exhaust steam pipeline system to relieve excess steam overpressure in the exhaust steam system or at the electric generator housing if a direct condenser temperature bypass valve is used (Singh et al.2022; Filkoski et al.2020; Golwalkar & Kumar 2022).

3. Valve Types and Functionality

The main aim for any steam bypass system is to change the flow path and reduce the steam volume flowing through the main steam turbines while keeping the casing at a particular pressure. The main issue, therefore, is how to allow this particular controlled pressure on the inlet of the bypass. This system uses different types of valves for control operations, and valves are categorized in various ways based on the operational principles, based on the control mechanisms, or even based on general design features. Operating conditions and applications help to determine the appropriate selection of valves for industrial purposes. The valve selection process is influenced by the type of service for which the valve is used, size and pressure drop, fluid erosiveness and corrosion rate, and the generated noise. (Zheng et al., 2020; Min et al., 2022; Mojaver & Khalilarya, 2024)

Figure 4: Steam turbine

A control valve is a throttling type of valve that is used to regulate the flow or pressure of a fluid in a controlled system. The valve opens and closes according to controller signals. When the valve is fully closed, there is no flow through the system, and vice versa when the valve is fully opened. The control valve plays a central role in control operations, and different components are required. The operating part of the valve aids in controlling pressure and flow through the system, with the actuator regulating the valve position and opening according to the control signals, while the feedback gives positional status. This makes the control valve mechanism, function, and role very important in regulating system flow and pressure. Consequently, it remains imperative to incorporate in this research the response of this component on steam and system management to contribute additional information for performance evaluation. Having described the role of the globe, angle, and poppet valves in the steam bypass operation, it is critical to look at the strength of pressure and flow regulation and the operating mechanism and design features for the respective valves. (Agh et al.2020; Zhang et al., 2022; Xu et al.2020)

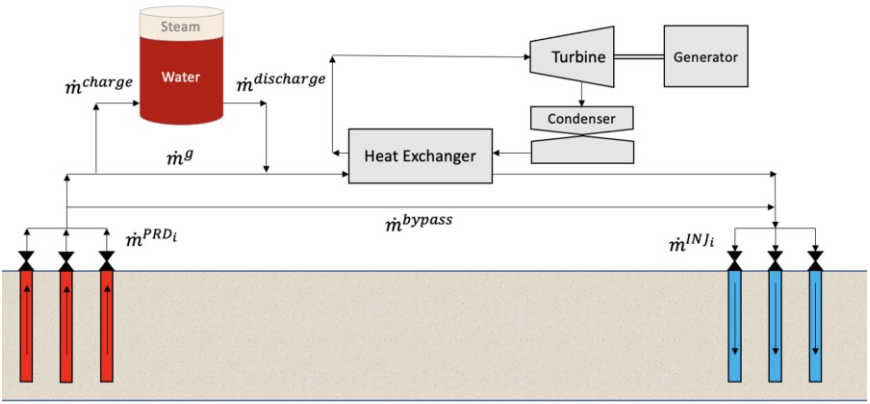

Figure 5: Steam turbine by pass Lines

Control valves are throttling valves for pressure and flow regulation typically used on a direct flow path. Operational Mechanism and Design Features: - Sliding stem globe-angle valve where the flow characteristics are determined by valve plugs and seats to produce equal percent, linear, and quick opening. - The sliding stem valve's actuator position can be pneumatically or electronically operated with a double or single-acting diaphragm. - Rotary globe control valves such as the ball, plug, and butterfly can operate in the throttling and shutoff modes. Control Range, Functions, and Limitations: - Smaller control range of 20:1. - Installed in a single loop diagram for controlling pressure and flow. - Higher range ability and flow coefficients of seated sliding stem globe angles. - The installation of sliding stem globe angle valves results in higher energy losses (Chen et al.2021; Lin et al., 2021).

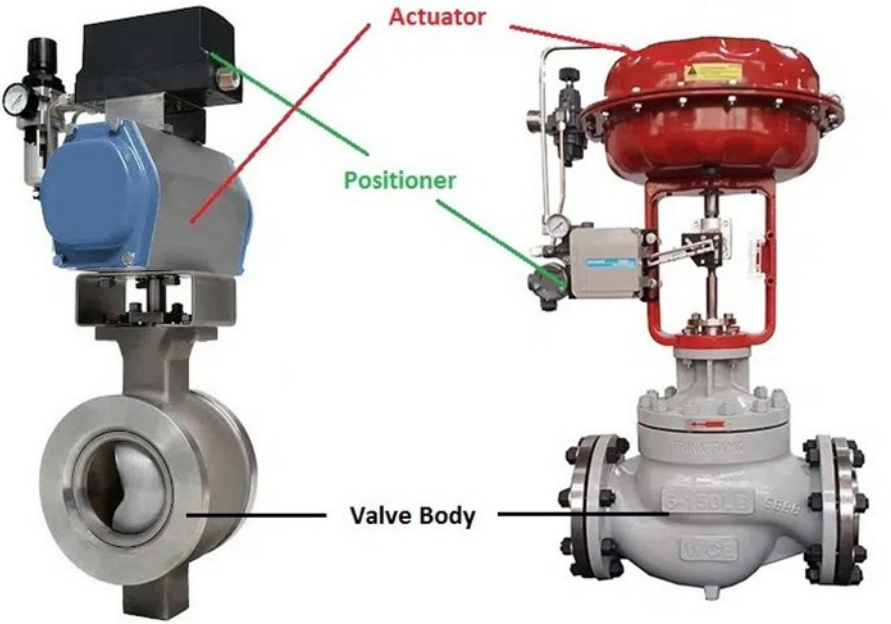

Figure 6: Pic.control valve

3.1. Globe Valves

When discussing valve technology, globe valves are the more widely used valve type. The well-known additional features of a globe valve are that they act as intercepting valves since the seat closes off the fluid around an obtusely beveled or contoured disc. As a result, changing the differential pressure across the valve can significantly change the fluid flow rate, which allows globe valves to be used for many applications requiring good control over a wide range of duties. The compact design of the internal parts suits the globe valve for precise throttling. Because of the standing plug and its motion, the flow rate and capacity may change in special cases due to any erosion over time. The valve bonnet design and the seal, placed under the disc, are the two aspects of the valve that seal the globe valve and mechanisms from the media. The distance between the seat and the disc makes the globe valve unsuitable for operations.

Motions, wear, and leaking hazards are inevitable because all these components can be sealed only by compression. In comparison to gate valves, globe valves require much less stroke to close because of the globe valve's force system in favor of the close direction (Nguyen et al., 2020).

Figure 7: Manuel globe valves

Globe valves can either have a linear or vertical-stem motion screw down to throttle perfectly. Furthermore, one of the major drawbacks is the pressure drop that occurs across the valve because of the required multiple right-angled directional changes when the fluid flows through the globe valve. Reaction time may also be affected, especially for the bigger valve sizes, due to the flow turning. The downcomer also plays an excessive energy loss role as it is typically undersized to prevent accumulation of vapor after shut-off. The globe valve's stem may sometimes also induce operational difficulty due to high loads on the stem. The globe valve can still be modified to operate under high-pressure drops. Low TAN and compatible sealing materials can operate in applications. The same features also apply to controlling severe service inlined valves, whereas the stem may be exposed to very low temperatures. Innovations in globe valve technology have seen energy improvements and lower pressure drop with the improvements in the

design of the moving components of the valve. As a result, a detailed understanding of the globe valve's operating principles will directly influence the system performance in configuration. (Lv et al., 2021; Wang et al., 2021; Qian et al.2020).

3.2. Control Valves

The control valve is the most vital and readily recognized part of the bypass system. It plays a pivotal role in correctly setting the steam flow and pressure, either by diverting or returning the steam to the feed water heater. There are four main types of control valve designs, namely, globe, butterfly, ball, and plug. Despite their fundamental operation being identical, essential differences exist between their flow capacities, accuracy, response times, and effective operating range that would affect the flow rate adjustments either upstream or downstream of the valve (Soave & Barolo, 2021; Idris et al., 2020).

The advantage of control valves is their quick response times combined with very good control accuracy. One of the biggest challenges is to keep the valve operating accurately within its calibrated pressure range, which might be operationally induced by dirty process fluids, initially wrong installations, vibrations, or just general wear and tear from the moving parts. In a somewhat new development, ultrasonic cleaning can offer in situ cleaning and regeneration of the valves' internals, in advance of failure or undue control valve wear. There is also conclusive research that is in its infancy where multi-objective optimization and machine learning offer the possibility to extract every bit of energy that bypass control flow can conduct back to the main steam, thus optimizing the full process. Recent developments in valves, including their mechanical workings, have utilized piezoelectric actuators to have better control of the moving or sliding valve members, enhanced by 3D printed housing to channel the flow more effectively for the optimization (Gregorovičová & Pospíšil, 2024; Chen et al.2024).

Three valve concepts are in use in various steam applications: 1. On-off valves can physically stop the flow but would

need the services of a bypass control valve to determine fluid flow and pressure. They are mainly deployed to stop fluid flow. 2. Plug valves are quarter-turn and continuous service, such as a plug cock which is capable of longer life in steam conditions. 3. The so-called quick closing or fast acting solenoid or pneumatic type valves, which close or open the passage rapidly. To effectively bypass the energy into the heater using a control valve, the right selection and design are necessary to attain an optimal operational plant design. This viewpoint considers the current state of the art, literature on advanced steam control valves to optimize energy mindset, i.e., minimizing wastage and full utilization of energy by employing a different angle, which would be used to apply appropriate valve designs to optimize energy. The type, design, and size of the bypass control globe valve are chosen for this application. The control valve is selected since the water flow needs to be adjusted remotely. These valves are designed to be highly energy-efficient and durable in line with the duty they are expected to perform (Sotoodeh, 2020; Qian et al.2020; Bhowmik et al., 2023).

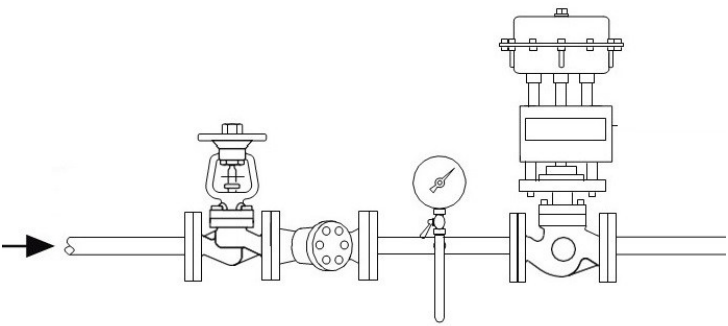

Figure 8: General steam line view

In summary, the first section was to give an overview of the bypass system and its function, focusing on the application where it diverts or bypasses the steam into or to the feed water heater if it has one. The central part of the bypass system is a section that gives an overview and the importance of all the main parts. The control valve and the negative effects of an incorrectly sized bypass system are

highlighted. The different shapes of bypass systems are introduced in the next section, highlighting steam bypass and why plant operators often want to use a very big steam bypass control valve. A large steam control or bypass valve can have many difficulties in sizing it correctly using traditional methods. It was discussed as a standalone item that the poor selection of control valves can lead to energy loss and a cascade of events associated with it. Lastly, the part gives guide points on how to size a steam bypass control valve. (Li et al.2023; Bhowmik et al., 2023)

4. Energy Optimization Techniques

Energy optimization techniques can be applied to various parts of a steam bypass system. In terms of energy consumption reductions, the best and most efficient technical approach is to reduce the steam bypass loads on the turbine using advanced steam turbine designs and improve the control strategies to reduce or eliminate the energy waste in the combustion turbine, as well as reducing loads on the air compressor in combined cycle power islands. There are many advanced technologies or techniques that can be integrated into power or process plants to reduce energy consumption. Some of the advanced technologies that can be utilized in power and process plants to reduce energy consumption are as follows (Martelli et al., 2021; Wang et al.2022; Khaleel et al.2022).

Figure 9: Energy effiency Plan for steam lines

System Design Optimization: Reducing thermodynamic losses through the application of the first and second laws of thermodynamics in plant design (such as recuperators, regenerators, or optimization of turbine or compressor designs). System Analysis Optimization: Using various tools and techniques to collect plant field data to optimize processes, electrical energy consumption. Design Modifications in Existing Systems: Studies performed for the design modifications in the existing systems to improve plant performance. Data-Driven Technologies Using Machine Learning and AI to Track Performance of Off-the-Shelf Technology. In this study, the efficiency improvement techniques that could be segmented into three distinct types were presented. These include system design and operation optimization, system analysis by using data, and innovative globe valve and control valve design modifications. Retrofit case study examples of the actual impact on the system showed significant energy reduction. Thus, this paper focuses on the blading and valves as the key methods to reduce the total system energy consumption in mill operation (Gennari et al.2024; Smiarowski, 2024).

4.1. Advanced Valve Designs on Steam Lines

Valves are a key control element in energy-optimized steam bypass systems. Design requirements for any advanced valve design are optimal flow control with the lowest possible energy loss based on fluid system behavior, application requirements, and supporting control system operation. Technology can make valves "smarter" through a deeper level of automation, including self-tuning, cooperative control, and the use of system principles such as control envelope and control hierarchy. Today's digital valve systems can provide data on valve and fluid system health that can enable effective management for maximum process availability. Control valves continue to evolve, and the future needs are taking shape in the evolution of reliability and safety products that address life cycle maintenance costs and system reliability goals. Typical advanced designs are more reliable and suffer fewer repairs than standard valves do. Innovations in materials remain one of the process industries' research needs to move forward. (Fronterotta, 2024; Porowski & Jakubiak, 2022).

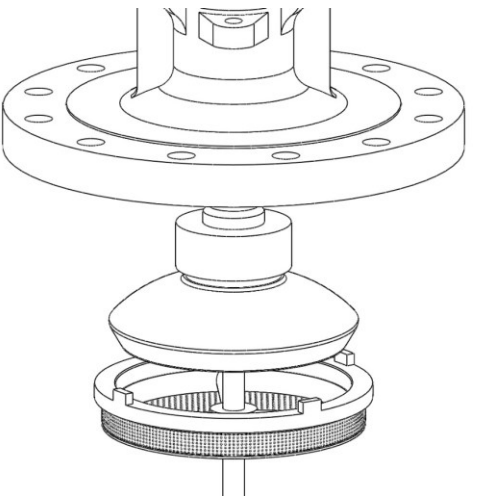

Figure 10: Advanced designs for inner parts of globe valves

One of two advanced valve design case studies for a steam bypass system is of a larger steam control valve that fulfills an extreme requirement for very low flow conditions. This valve has valvetric seat applications for much lower packing friction and a potential extension beyond positioner zero shift for actuators. Without advanced valve design, tight shutoff and economical control of this system may well have been mutually exclusive. New and innovative smart control valves are designed with the latest engineering principles that are a direct result of more than 45 years of control valve testing and development. Smarter diagnostic technology solutions offer local and remote users an advantage by allowing them to surveil the condition of the valve, its actuator, and the performance of the digital positioner (Lee et al., 2021; Padovani et al.2020; Gao et al., 2023).

4.2. Efficiency Metrics and Measurements

Efficiency metrics and measurements are important means of monitoring steam bypass system performance and identifying cost-saving potential for the purposes of optimization. Traditionally, efficiency measurements are made for similar processes or equipment designs and provide a broad baseline for energy usage comparisons. Measurements made over time or for equipment of varying design can often point to systems that merit further performance scrutiny for potential improvements, with a long-term goal of reducing steam use or decreasing energy costs. The most common of these test applications involve flow rate, pressure drop, energy consumption, and pressure and temperature monitoring. By monitoring these conditions consistently over time, a facility can pinpoint which areas most need optimization based on these core KPIs. The key to establishing rigorous KPIs is through collective and accurate data and consistent monitoring of said data, along with regular analysis and optimization with the help of various tools (Yu et al., 2020; Soltanali et al., 2021).

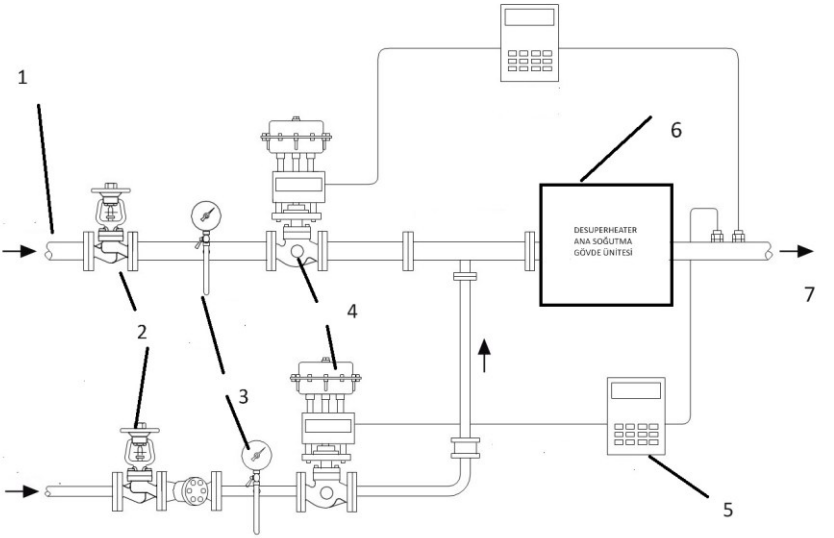

Figure 11: Advanced Steam effiency Control systems

A variety of issues have arisen regarding measurement practices and evaluations. Engineers must carefully consider, and in some cases, question the measurements they take because past practice has shown some engineers have difficulty accurately measuring steam flow, density, orifice conditions, and pressure. Since these parameters are crucial to evaluating energy, energy waste, and nozzle correctness, these values must be carefully vetted. Additionally, engineers assessing systems must be aware of some common pitfalls. There are a number of different behaviors of systems and equipment that will confound simple mathematical or engineering analyses of system performance. When assessing equipment and setting up KPIs for optimization, it is important to keep in mind a number of system and equipment attributes that will affect the outcomes of the assessments. Finally, the relationships between measurements and system behavior over time should be measured and assessed. Although many steam-using systems are tested or monitored only once, when they are first installed, historically encountered opportunities to reduce energy or decrease steam use are often found during performance evaluations designed

to show the system's actual behavior over its working life (Zhang & Wang, 2022; Steven & Solutions, 2022).

One potential area for improvement is the steam quality of any steam bypass system's input stream. The combined temperature and pressure of the inlet steam bypass should be used to find out its overall pressure. Pump curves and minimum flow requirements should then be checked to verify pressure not less than 10 to 25 aged steam inlet pounds, which can result in steam qualities of as little as 75% to 80%. Although a steam's specific volume has not been published, any medium-pressure steam used in lowest flow rates is theoretically in its 80.3% quality range. For systems or equipment demanding at least 200 pounds of superior steam, careful testing and consideration of available source steam properties is needed to determine potential transmission losses or sufficiency. All of these exceptionally desirable measures have the potential to monitor system performance and profitability for energy and operational optimization. Although some of them are straightforward, such as measuring pressures, temperatures, and other engineering system properties, they all allow system and equipment design-related changes to be evaluated on the often trivial additions or reductions in energy costs (Lindsley & Grist; Gaikwad et al., 2024).

5. Case Studies

The first two case studies provide examples of the current performance of steam bypass applications that are in operation. The other three case studies are improvements from the original valves installed at each location, but they provide ideas about problems that occur in the field and how improvements in valve design, sizing, material, and actuator types have proven beneficial in either energy savings or reduction in overall performance or plant maintenance. The case studies provide a good overview of the type, age, and service of control valves that are used in steam bypass applications and why they may not operate at their most economical point on a more frequent basis. It is interesting to evaluate the age of the plant. All plants have had equipment changes over the years to increase

production, which also increased operating pressures and, in some cases, higher steam flow rates (Wang et al., 2021; Denkena et al.2020).

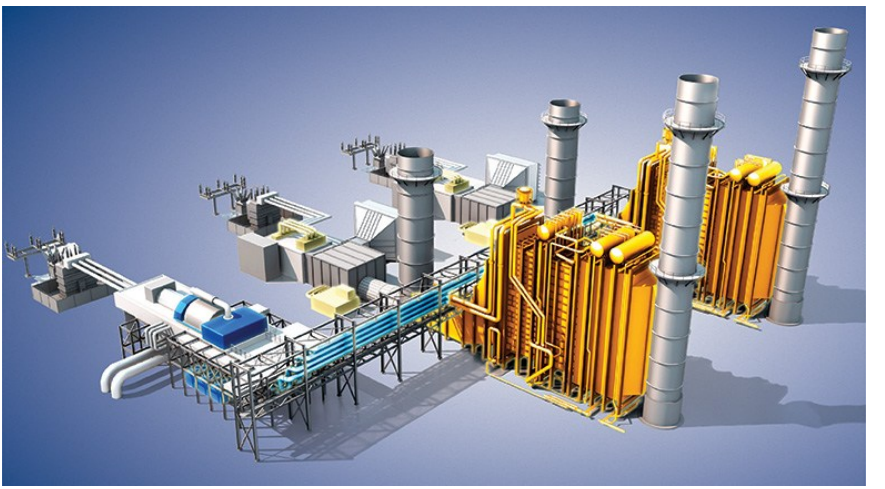

Figure 12: General view of line construction

The last two case studies are application examples where a cost-benefit evaluation shows valve performance based on a control valve applied to a process where it was designed to fit all required steam dump requirements. It is interesting that the new valve design did the job, but because of the pressure drop reduction due to the new valve design, the plant replaced two less expensive turbine-driven blowers to return to the original pressure drop, which allowed them to go back to the original horsepower required by the blowers after they were replaced. Overall, there is a wealth of new technology to recover power and save on operating costs in power and processing industries. The case studies provide practical applications for end users in the real world. If not for technological improvements, we all would continue to experience high steam flow, which is highest at 5:00 in the morning (Hossain et al., 2024; Li et al., 2024).

Case Study 1 Industrial Process, Eastern United States. Petrochemical plant designed to produce 225 MMSCFD. Steam bypasses reduce energy. Methanol, acetic acid, ethyl acetate, and

butyl acetates are produced. Processing has been constant, with an eight-hour shift for ten years. The enthalpy drop in the DPC was $1,220,000 in 2005. The enthalpy drop in the DPC is expected to cost $1,405,000 in 2006 due to increased raw material costs. The current process is designed to operate at 250°F. The temperature was increased from 220°F to 230°F in the DPC until 5:00 a.m. At 5:00 a.m., the temperature is increased to 250°F, (250-230) 20°F, which is the same area as the (250 - 220) 30°F. The ΔT is increased as consumption demand attempts to keep the temperature for processing constant. If the temperature demand results in a 40,000 H.P. consumption over design, the ΔT is raised to 40°F. Potential yearly enthalpy savings would increase from $1,405,000 to $1,610,000 without having to upgrade turbine-driven blowers, resulting in an increase of $320,000 yearly.

Lessons: Information on correctly sizing and designing a steam conditioning valve is key to troubleshooting the control valve. The valve used was a rotary type with a severely reduced, 90° expanded outlet, which had an adverse effect on increasing pressure drop to eliminate vibration, cavitation, and noise on the outlet relief valve when the pressure increased. When the new pressure-reducing valve was installed, which used a low-pressure drop design, they were able to replace two new casings of the DG compressors very quickly. It is always beneficial to document the energy consumption and potential savings at all points in a processing facility to aid in presenting data leading to a capital project if one is beneficial. In this case, it was proven to assist in the presentation to add extra cooling capacity to the project. Though a direct savings value was omitted from this paper, the final savings can be summed up as 'an indirect charge of $10,000 savings on one short weekend shutdown' after doing the design work more than five years ago.

5.1. Industrial Applications

Steam bypass systems are utilized across various industries for several applications, such as steam turbine bypass, which is specifically used in power plants. Process steam bypass and integral

valve design applications are most commonly found and used in several industries. These applications are exclusively designed according to the process requirements and system capabilities. In food processing, the steam bypass is used to regulate minimal energy consumption for maintaining the food processing temperature. Manufacturing industries, such as petrochemicals, pulp, and paper, utilize economizer and air preheating steam bypass systems to reduce the combustion temperature, which leads to efficient fuel utilization. Moreover, industries like chemicals, pipe coating, oil and gas, palm oil plants, and steel plants are installing steam bypass systems to maintain process steam demand with manual or pneumatic operation on existing globe valves. (Amiri et al., 2021; Eggers et al.2022).

The installation of the advanced control valve on the system based on real-time applications has never been considered in particular industrial applications. In the heavy-duty turbines with higher steam flow, multiple main steam control valves are installed in a series to bypass the flow from the economizer. Currently, none of the industries have considered installing composite or multistage bypass systems because of a lack of understanding in sizing and operation with turbomachinery and steam turbine manufacturers. These small-scale systems were retrofitted to the existing main control valves in series to the main steam inlet of the turbines. The existing bypass systems are custom-designed based on the industry requirements. Information gathered from this energy optimization method and results were not shared with stakeholders, as the compressor performance and steam valve designs are found to be confidential. The energy-saving mechanisms were installed as part of a research project using advanced valves. A collaborative project shall commence to install the low-cost dynamically updated steam valve control mechanism. This will meet the current needs and targets for oil production (Dabravolskaite et al.2024; Torabi et al., 2022).

6. Challenges and Future Directions

Systems for optimization pose significant challenges. Modern plants are integrated with the existing infrastructure and procedures. While new technologies should facilitate improvement, they are often chosen because they fit into the existing structure with relatively little hassle. Furthermore, people are resistant to change. Large companies resist changes that can bring improvement because changing to a new method requires revalidation of product quality and changes to operating licenses. Because manufacturing processes are interconnected, changes in one often require changes in others. Due to these constraints, the most likely opportunities for improvements in industrial control systems will come by improving the critical flow and bypass sections. Still, full energy savings may not be possible due to design constraints. The bypass systems are designed to meet the pressure drop requirements for the turbine. Any decrease in pressure drop will impact the turbine operation. There is current research going on in completely redesigning the critical flow bypass systems to make them energy efficient in addition to serving their purpose (Javaid et al., 2021; Zhang et al., 2021).

Steam control valve technology to date has been designed primarily for sphere design control. Today's advanced actuator control capability allows the development of a new control valve design approach specifically for more efficient steam bypass applications. A substantial improvement in the valve internal flow efficiency is attained by significantly altering the valve's overall pressure differential drops between the inlet to bypass and the outlet exhaust. Therefore, only advanced control valve designs posted with percentage flow characteristics for significantly reduced pressure loss can be directly applied to control of steam bypass applications for larger power generation plants. The valve and actuator design and control to energy savings will be researched and further elaborated. Finally, to develop an energy efficient control valve requires industry collaboration in customizing valve actuation, valve digital control, and combined development and field trials to develop

full industry system optimization solutions. (Slama et al.2021; Abd et al.2021).

6.1. Technological Innovations

Technological innovations are a primary part of dynamic changes in energy sector efficiency. In particular, advanced valve and control designs for devices used in steam bypass systems can increase their operational flexibility and thus energy efficiency. Besides, it has been characterized by the significant growth of new developments in areas that increase the degree of automation and dynamic knowledge of the controlled process, such as information technologies. The connection of complex control and safety systems is a significant challenge, which is a promising means of increasing the safety integrity of systems. The latest improvements in industrial systems are also related to developing a new class of advanced materials. These systems are the result of the influence of engineering properties, combined with advanced low-emission materials and manufacturing processes, on the new shape of the solutions. The future will also be due to the use of massive amounts of data that can be generated through the integration of a new generation of the Internet of Things with advanced data analytics and big data to optimize plant operations and plant control. (Eze et al.2024; Bian et al.2022; Ding et al., 2024).

Following this, the most significant recent technological innovations are described. The state of the steam bypass system is also presented from the point of energy optimization because of the lack of details. However, many summaries and guidelines have recommended integrating steam bypass systems in plants to reduce energy costs. This sub-section points out the opportunity trends and ongoing research topics. Such a forward-looking angle of the work could assist professional readers in evaluating new technological opportunities and setting the focus of future research directions in steam bypass system optimization (Chae & Lee, 2022; Khaleel et al.2022; Li et al., 2024).

7. Conclusion and Recommendations

In this study, energy optimization is examined in steam bypass applications in various configurations and in accordance with different control strategies. The most advanced modern, high-capacity designs, including desuperheating globe and control valves, were employed during the study. The research encompassed both analytical, non-linear, and CFD studies. This research provides a comprehensive and novel understanding of not only the steam bypass application but also the individual flow characteristics of these valves, with the result that there are recommended valve inlet or outlet piping configurations for each. (Martelli et al., 2021; Khaleel et al.2022; Alfani et al.2021).

Applying oversizing via simplified selling channels to achieve a design 15% turndown, these valves were shown to achieve or exceed the process efficiency associated with code level 1 valves, including control valves during non-linear simulations. Based on this, a set of practical recommendations relating to the use of the analysis and design of valves discussed to help manufacturers, buyers, and construction companies optimize their steam bypass processes at multiple locations is provided. The paper concludes with closing remarks about the necessity of further research in addressing the expected future challenges and the related potential measures, together with any challenges attached to this. It is worth noting the importance of collaboration in areas of mutual interest in identifying the effective deployment of proposed solutions across all the relevant stakeholders. In the meantime, the best practices explained should be adopted by the industries immediately. In presenting this paper for further discussion and ease of reading, comments and discussions are all welcomed. (Sotoodeh, 2021; Brentan et al.2021).

Applying advanced design of valves is essential to improve energy usage in multiple sectors, especially in petrochemical plants, where the approach might need to be applied in the near future to ensure sustainability efforts. A global effort will always be required

to secure solutions in the case of future challenges with energy (Sotoodeh, 2021; Zhang et al.2023).

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BÖLÜM V

Vakum Cam Tüplü Isı Borulu Termal Güneş Enerjisi Sistemlerinde ‘’Çinko Demir Oksit’’ Nano Akışkanının Performansa Etkisinin Deneysel Olarak İncelenmesi

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1. GİRİŞ

Enerji ihtiyacının karşılanması günümüzde en önemli problemlerdendir. Bu kapsamda; son dönemde enerji üretimi kapsamında yenilenebilir türdeki enerji kaynaklarının kullanımı çoğalmaktadır. Dünya ülkeleri fosil enerji kaynaklarından yenilenebilir enerji kaynaklarına yönelmeye başlasalar bile daha verimli sistemlerin kullanımı için çalışmalar yapılmaktadır. Güneş enerjisi, birçok yenilenebilir enerji kaynaklarının arasında enerji ihtiyacını karşılayabilecek en önemlilerindendir. Bu kapsamda

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güneş enerjisi yaygın olarak sıcak su üretimi için kullanılmakta, sıcak su üretimi güneş kolektörleri sayesinde gerçekleşmekte ve eş zamanlı şekilde ısı enerjisine çevirmek amacıyla termal güneş enerjisi sistemleri kullanılmaktadır. Düzlemsel tipteki güneş kolektörleri yerine son yıllarda sıklıkla vakum tüplü güneş kolektörleri yer almaktadır. Bu kapsamda ısı borulu vakum tüp güneş kolektörleri geliştirilmiştir. Bu kolektörlerde temelde bir ısı transfer akışkanı ile solar hücreye ait sıcaklığın düşürülmesi ve gerçekleştirilen ısı transferi ile akışkanını yükseltilmesi amaçlanmakta ve enerji uygulamalarının literatüründe nanoakışkanların ısı transferi üzerine çokça çalışma bulunmaktadır.

Bu yüksek lisans tez çalışmasında güneş enerjisinin önemli uygulama noktalarından olan ısı borulu vakum tüplü güneş kolektörleri ve nanoakışkanlar üzerine çalışılmıştır. Vakum cam tüplü ısı borulu termal güneş enerjisi sistemlerinde kullanılan çalışma akışkanlarına alternatif olarak çinko demir oksit nanoakışkanı kullanılarak sistem performansına etkileri araştırılmıştır. Çalışmanın ikinci bölümünde literatür araştırılmasına yer verilmiştir. Çalışmanın üçüncü bölümünde güneş enerjisi, ısı boruları, vakum tüplü güneş kolektörleri ve çalışma ekipmanlarıyla ilgili bilgiler verilmiş, dördüncü bölümünde materyal, metot kısımları anlatılmış, deney setinin çalışması ve analizin nasıl yapıldığına dair bilgiler verilmiştir. Çalışmanın beşinci bölümünde elde edilen deney sonucu sunulmuş ve değerlendirilmiş, altıncı bölümünde sonuç ve öneriler kısmına yer verilmiş ve kullanılan akışkanın sistem verimi üzerindeki etkisi detaylı olarak anlatılmıştır. Yedinci ve son bölümde ise yararlanılan kaynaklar açıklanmıştır.

2. LİTERATÜR ARAŞTIRMASI

Literatür incelendiğinde, çeşitli güneş enerjisi sistemlerinde tek veya iki veya daha fazla türden oluşmuş kombinasyonlu nano akışkan kullanımının incelendiği birçok çalışmanın bulunduğu

görülmektedir. Nano akışkanların güneş enerjisi sistemlerinde daha yüksek performans göstereceği konusunda genel fikre varıldığı gözükmekte ve bu durum başka nano akışkan çeşitlerinin performanslarını tespit edebilmek için yeni araştırmaların gerekli olduğunu göstermektedir. Bu kapsamda vakum cam tüplü ısı borulu termal güneş enerjisi sistemlerinde kullanılan tüm çalışma akışkanlarına alternatif olarak çinko demir oksit nano akışkanı kullanılarak sistem performansına etkileri araştırılmak istenmiştir.

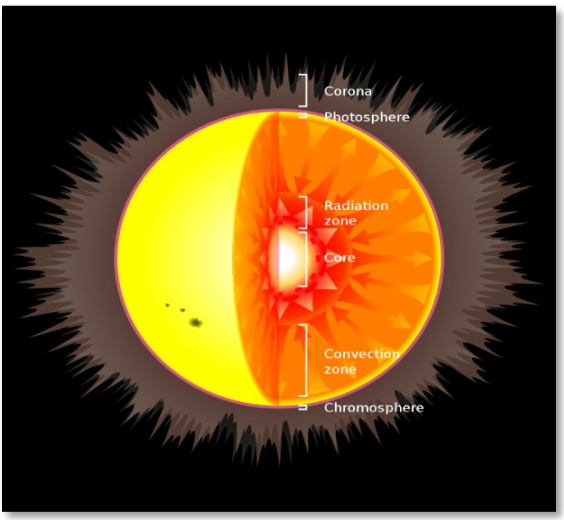
3.GÜNEŞ ENERJİSİ, ISI BORUSU, VAKUM TÜPLÜ GÜNEŞ KOLEKTÖRLERİ VE ÇALIŞMA AKIŞKANLARI

3.1. Güneş Enerjisi

3.1.1. Güneşle ilgili kavramlar

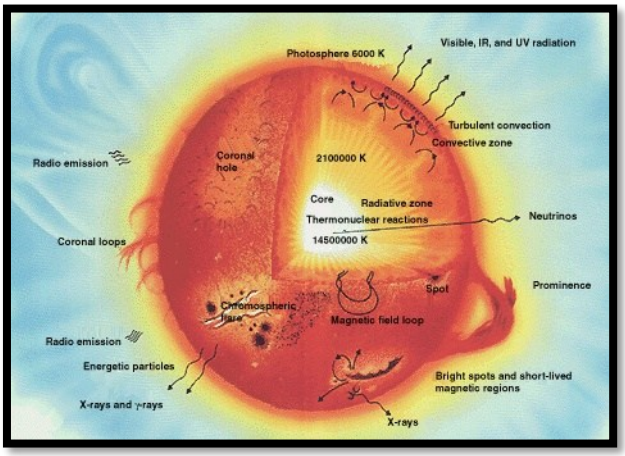
Güneş Sistemi'nin merkezinde yer alan yıldız olan Güneş kendi etrafında dönme hareketini yaparken aynı zamanda Samanyolu Galaksisi etrafında dolanır. Orta büyüklükte bir yıldız olan Güneş, buna rağmen tek başına Güneş Sistemi kütlesinin neredeyse tamamını oluşturur. Güneş'in Samanyolu galaksisi etrafında yörüngesi vardır, bu yörüngede 828.000 km/s hızda hareket eder, yörüngede hareket ederken kendi sistemindeki gezegen, meteor, vs. tüm parçalar güneş ile birlikte Samanyolu etrafında dönmektedir. Güneş kendi ekseni etrafında saatte 7.000 km hızla döner ve bir tam turunu yaklaşık ortalama 27 günde tamamlar. Güneşin yüzeyi yaklaşık 5500 °C ve çekirdek sıcaklığıysa yaklaşık 15,6 milyon °C'dir. Güneş'te üretilen enerjinin yalnızca yaklaşık yalnızca 2 milyarda 1'i yeryüzüne ulaşır, geriye kalan enerjisi uzayda kaybolur. Güneş'in yaklaşık üç günde yaymış olduğu enerji miktarı Dünya'daki tüm enerji kaynaklarının miktarına eşdeğerdir. Güneş yüzeyi kütlesinin yaklaşık dörtte üçünü ve hacminin yaklaşık onda dokuzundan fazlasını oluşturan hidrojen, kütlesinin yaklaşık %24-25'ini ve hacminin yaklaşık %7'sini oluşturan helyum ile çok ufak miktarlarda diğer elementlerden oluşur. Hidrojen çekirdeklerinin füzyon tepkimesiyle beraber helyuma dönüşmesinden enerjisini elde

eder, bu tepkimeyle dakikada yaklaşık 36 trilyon ton hidrojen atomu helyuma dönüşür.



Şekil 3.1. *Güneşin iç yapısı (Vikipedi 2010, Güneş '' https://tr.wikipedia.org/wiki/G%C3%BCne%C5%9F_enerjisi'')*

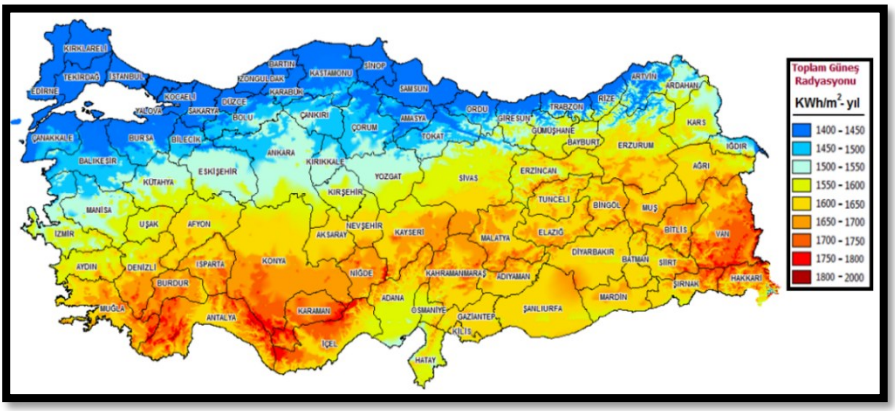
Güneş enerjisi, güneşin çekirdeğindeki füzyon tepkimesi ile açığa çıkan ışıma enerjisidir. Güneş, yaklaşık $3{,}9 \times 10^{23}$ KW güç kapasitesinde en önemli yenilenebilir enerji kaynağıdır. Güneşte üretilen bu enerjinin çok çok düşük bir miktarı dünyaya ulaşmakta, atmosferin dış kısmındaki her bir metrekare alana ortalama yaklaşık 1.400 W güç düşmektedir. *(T.C. Enerji ve Tabii Kaynaklar Bakanlığı web sitesi/Bilgi Merkezi/Enerji/Güneş, https://enerji.gov.tr/bilgi-merkezi-enerji-gunes.,2024).*



Şekil 3.2. *Güneşin bölümleri (Vikipedi 2010, Güneş ‘’ https://tr.wikipedia.org/wiki/G%C3%BCne%C5%9F_enerjisi’’)*

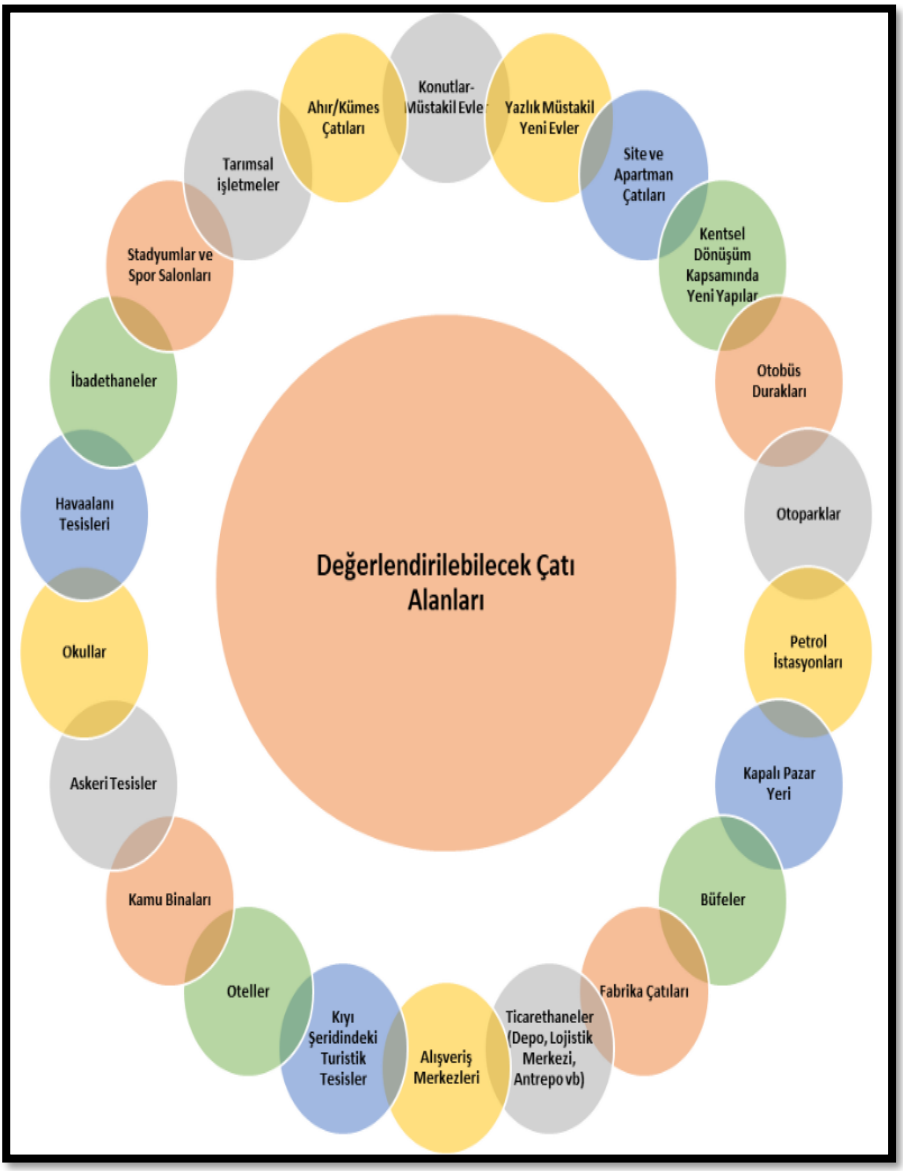
3.1.2. Ülkemizin güneş enerjisi potansiyeli

Ülkemiz, coğrafi konumu nedeniyle önemli bir güneş enerjisi potansiyeline sahiptir. Türkiye Güneş Enerjisi Potansiyeli Atlasına (GEPA) göre yıllık ortalama güneşlenme süresi 2741 saat olup ortalama yıllık toplam ışınım değeri yaklaşık 1.527 kWh/m² olarak hesaplanmıştır. GEPA’da bulunan aylık ortalama global radyasyon dağılımı ve genel potansiyel görünümü aşağıdaki şekilde bulunmaktadır. *(T.C. Enerji ve Tabii Kaynaklar Bakanlığı web sitesi/Bilgi Merkezi/Enerji/Güneş, https://enerji.gov.tr/bilgi-merkezi-enerji-gunes., 2024).*



Şekil 3.3. *Türkiye güneş enerjisi potansiyeli haritası (T.C. Enerji ve Tabii Kaynaklar Bakanlığı web sitesi/Bilgi Merkezi/Enerji/Güneş, https://enerji.gov.tr/bilgi-merkezi-enerji-gunes., 2024).*

Türkiye İstatistik Kurumu verilerine göre ülkemizde yaklaşık 12 milyon adet yerleşik bina mevcut olup bunların neredeyse %90'ı konut nitelikli binalardır. Ülkemizdeki bina stoku miktarı her yıl 100.000 adet üzerinde artmakta, bu binaların dış yüzeylerine ciddi oranlarda güneş enerjisi yatırımlarının yapılabileceği düşünülmektedir. Ülkemizde bu kapsamda değerlendirilebilecek yüzey alanları bir sonraki şekilde görüldüğü gibi birçok farklı alanda sınıflandırılmıştır. *(Vikipedi 2010, Güneş '' https://tr.wikipedia.org/wiki/G%C3%BCne%C5%9F_enerjisi'')*

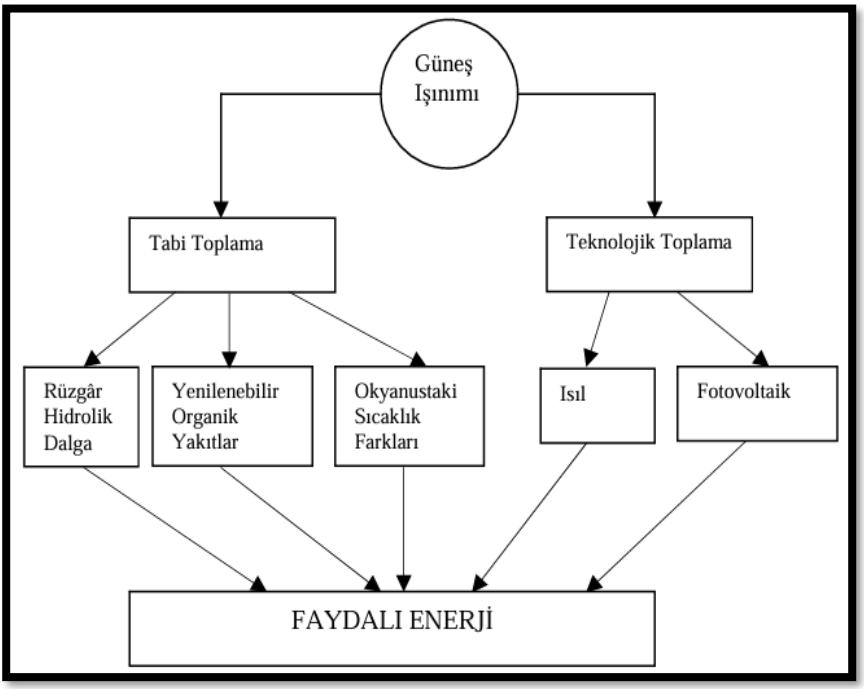


Şekil 3.4. *Güneş enerjisinden çatı alanlarında faydalanma şekilleri (Vikipedi 2010, Güneş ‘’ https://tr.wikipedia.org/wiki/G%C3%BCne%C5%9F_enerjisi’’)*

Gerek sanayi gerekse kişisel maksatlı kullanımlarda gerek duyulan enerji talebini direkt olarak güneş enerjisinden elde etmek mümkün olmadığından güneş enerjisinin farklı biçimlere çevirerek kullanımı daha uygundur. Bu kapsamda güneşten faydalanmak için birçok farklı teknoloji üretilmiştir. Bu teknolojiler materyal, metot veya teknolojik seviye bağlamında birçok farklılık göstermekte olup kimisi enerjiyi ışık ya da ısı enerjisi şeklinde doğrudan alıp kullanırken, kimisi ışık ya da ısı enerjisinden elektrik enerjisi elde etmek biçiminde kullanmaktadır.

3.1.3. Güneş enerjisinden yararlanılan sistemler

Yenilenebilir enerji kaynaklarının neredeyse tümü güneşin maddeler üstündeki etkilerinin sonuçlarından oluşmaktadır. Güneş ışınımının teknolojik toplama yöntemi ile faydalı enerji kaynağına çevrilmesinde ısıl (termal) ya da foto-voltaik esastan faydalanılır. Isıl (termal) esasa dayalı olan sistemlerin günümüzde foto-voltaik'e oranla daha çok yararlanma alanı mevcuttur. Şekil 3.5'de güneş ışınımından yararlanma yöntemleri gösterilmiştir. *(Ezen H. H., ''Vakum Tüplü Güneş Kolektörlerinin Teorik Ve Deneysel İncelenmesi'', Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü, Isparta, (2010).).*



Şekil 3.5. *Güneş enerjisinden yararlanma şekilleri (Ezen H. H., ''Vakum Tüplü Güneş Kolektörlerinin Teorik Ve Deneysel İncelenmesi'', Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü, Isparta, (2010).)*

3.1.4. Güneş enerjisi uygulamaları

- Düzlemsel güneş kolektörleri
- Yek-odaklı güneş enerjisi santralleri
- Vakum tüplü güneş enerjisi sistemleri
- Güneş ocakları
- Trombe duvarı
- Geçişli hava paneli

- Güneş havuzları
- Güneş bacaları
- Su arıtma sistemleri

3.1.5. Isıl güneş enerjisi teknolojisi

Isıl (termal) güneş enerjisine yönelik teknolojiler; sistemlerde kazanılan sıcaklık miktarına göre düşük sıcaklık uygulamaları ile yoğunlaştırıcılı ısıl sistemler olarak iki bölüme ayrılır.

3.1.5.1. Düşük sıcaklık uygulamaları

Güneş enerjisinden düşük sıcaklık elde edilmesine dair bazı uygulamalara örnek olarak farklı tipteki kolektörler, güneş enerjisi için yapılmış güneş bacaları, güneş enerjisi havuzları, güneş mimarisi, tatlı su üretme sistemleri, ısıtarak kurutma sistemleri, sera sistemleri ve yemek pişirme gibi uygulamalar verilebilir. Bu uygulamalar içerisinde düzlemsel tipteki güneş kolektörleri en basit ve sıklıkla kullanılan faydalanma yöntemidir. Bu kolektörler, üzerine ulaşan güneş ışığının enerjisinin bir başka akışkana transferi prensibiyle çalışmakta ve en çok evlerde su ısıtma amacıyla kullanılmaktadır.

3.1.5.2. Yoğunlaştırıcılı ısıl sistemler

Bu sistemler ekseriyetle elektrik üretimi amacıyla tasarlanmakta, yoğunlaştırıcı olarak; heliostatlar, parabolik aynalarla birlikte çanaklar kullanılmakta ve elektrik üretimi; bir kolektör sistemi kullanımıyla güneşten ulaşan radyasyonunun toplanıp bir alıcı üzerine yoğunlaştırılması, alıcı yardımıyla elde edilen radyasyonun ısıl enerjiye çevrilmesi, ısıl enerjinin de bir güç çevirim sistemine iletimi biçimindeki bazı belli başlı yöntemlerle

gerçekleştirilmektedir. *(Vikipedi 2010, Güneş ‘’ https://tr.wikipedia.org/wiki/G%C3%BCne%C5%9F_enerjisi’’)*

3.1.6. Güneş enerjili sıcak su hazırlama sistemleri

Bunlar içerisinde çoğunlukla kullanılan sistem suyu ısıtma üzerine tasarlanmış olan sistemlerdir. Güneşten alınan enerjiyle ısınan suyun kullanıma hazır olması ve kurulum maliyetinin düşüklüğü ile ülkemizin güneşlenme süresinin uzun olması yaygınlaşmasında etkili olmuş ve sistemi daha da cazip hale getirmiştir. Bu sistemler farklı özelliklerine göre aşağıdaki biçimde gruplandırılmıştır;

Sirkülasyon Biçimine Göre	Devre Şekline Göre	Kolektör Tipine Göre
Tabi Dolaşımlı Tip	Açık Sistem	Düzlemsel Kolektör
Zorlanmış Dolaşımlı Tip	Kapalı Sistem	Vakum Tüplü Kolektör

Gruplandırmaları ayrıntılı olarak açıklarsak;

I. Sirkülasyon Biçimine Göre;

a) Tabi Dolaşımlı Tipteki Sistemler: Bu sistemlerdeki akışkan herhangi bir zorlama olmaksızın dolaşır, çalışma prensibi kolektörde ısınan suyun yoğunluğunun değişimi üzerine tasarlanmıştır.

b) Zorlanmış Dolaşımlı Tipteki Sistemler: Bu türdeki sistemler, akışkanın pompa vasıtasıyla zorlanmış şekilde dolaştığı sistemler olup sirkülasyon için pompa kullanılması sebebiyle depo uygun herhangi bir yerde bulunabilir.

II. Devre Şekline Göre;

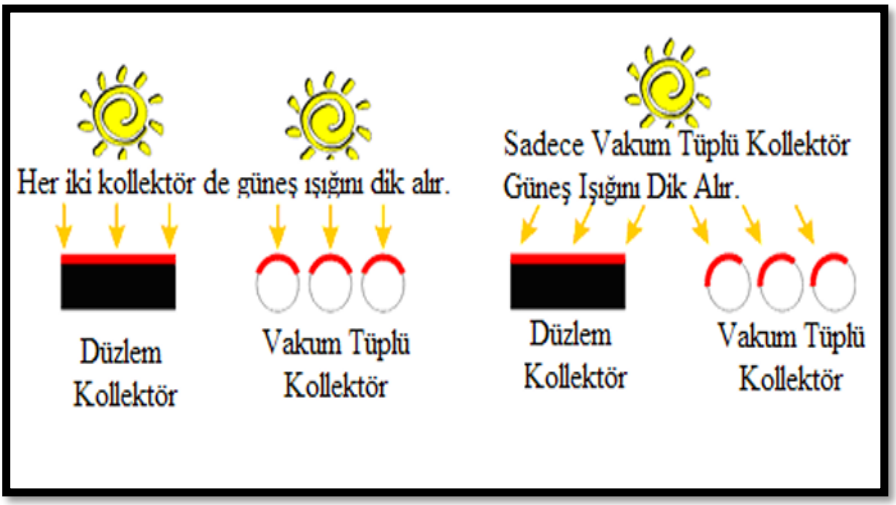
a) Açık Sistemler: Bu sistemde kolektördeki ile kullanım suyu aynıdır. Kapalı sistemlere kıyasla maliyeti daha az ve verimleri daha fazladır.

b) Kapalı Sistemler: Açık sistemlerin aksine iki adet birbirinden bağımsız devre mevcuttur. Kolektör devresindeki akışkan güneşten aldığı enerjiyi kullanım suyuna iletmektedir.

III. Kolektör Tipine Göre;

a) Düzlemsel Güneş Kolektörü: Güneşten gelen enerjiyi toplayıp bir çalışma maddesine ileten ısı sistemleridir. Ev, sanayi ve tesisler için sıcak su üretiminde, ısıtma ve soğutma sistemlerinde, havuzların ısıtılmasında bu tip sistemler kullanılır. Düzlemsel güneş kolektörleri genelde ısı taşıyan borular, enerji toplayıcı panel, saydam örtü, yalıtım malzemesi ve gövdeden oluşur. Kolektör verimliliğinde çevresel faktörler dışında; kolektörün modeli ile yüzey alanı, kullanılan camın özellikleri, yutucu yüzeyin ısıl değerleri, yalıtım malzemesinin cinsi, kalınlığı ve ısıl iletkenliği etki etmektedir.

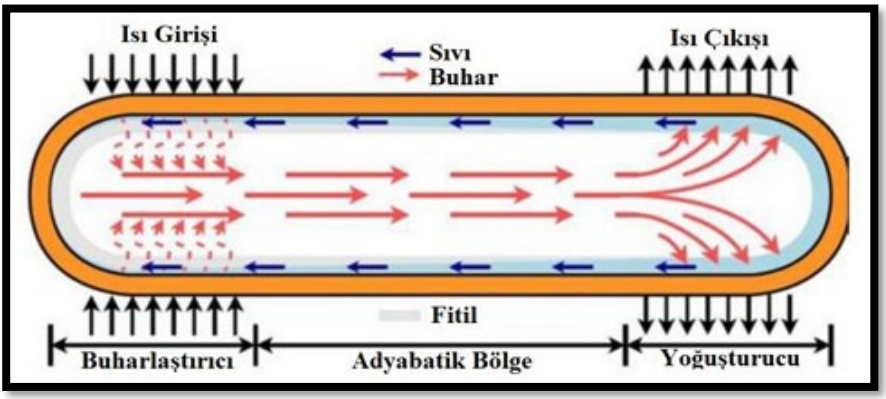
b) Vakumlu Tüplü Kolektörler: Bu kolektörlerde kullanım koşullarına göre metal veya cam yansıtıcılarla cam borular kullanılabilir. Düzlemsel biçimdeki güneş kolektörlerinden en belirgin farkları; kolektörün cam tüplerden oluşması ve kullanılan camın vakumlanması sebebiyle oluşan basınç farklarına dayanıklı olmasıdır. Güneş ışınlarının geliş açısına göre de düzlemsel güneş kolektörlerine göre daha avantajlıdır, bu durumu açıklayan görsel Şekil 3.6.'da yer almaktadır.



Şekil 3.6. *Isı borusu güneşlenme yapısı (''Yenilikçi Soğutma Teknolojileri: Isı Boruları'', B. Markal, K. Aksoy, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.set-science.com/manage/uploads/ISAS2018_005/SETSCI_ISAS2018_005_00246.pdf, (2018).*

3.2. Isı Borusu

Yuvarlak ya da daha dörtgensel kesitte, bünyesinde belirli miktarda akışkan ve sızdırmazlık materyali mevcut olan kapatılarak sınırlandırılmış hacmi tanımlar, ayrıca, buharlaştırıcı bölge, adyabatik bölge ve yoğuşturucu bölgenin tamamını içerir. Geleneksel ısı borusunun şematik resmi Şekil 3.7.'de sunulmuştur. Çoğunlukla bakır gibi ısı iletimi kolay malzemeden üretilir ve genelde içerisinde hacmin üçte birlik kısmında buharlaşması basit bir akışkan bulunur, arta kalan hacmindeki havası vakumlanmış şekilde kapalı bir borudan oluşan ısı transferi cihazıdır.

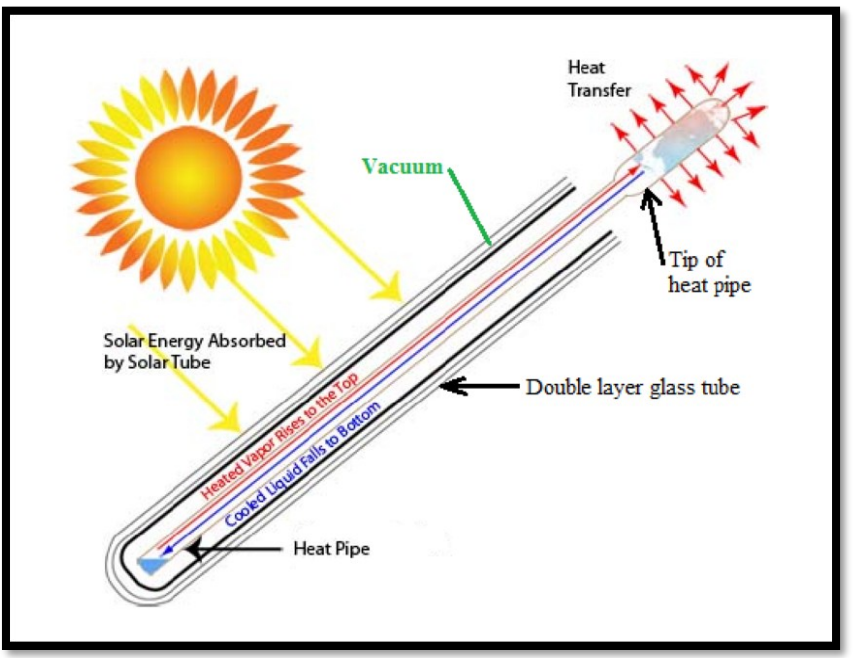


Şekil 3.7. Isı borusu yapısı *Güneş enerjisinden yararlanma şekilleri (Ezen H. H., ''Vakum Tüplü Güneş Kolektörlerinin Teorik Ve Deneysel İncelenmesi'', Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü, Isparta, (2010).)*

Isı borusu; buharlaştırıcı (evaporatör), adyabatik bölge ve yoğuşturucu (kondenser) bölge olarak üç bölümden oluşmaktadır. Isı borusunun buharlaştırıcı bölgesi ısıya maruz kalınca içerisindeki akışkan buharlaşmaya başlar, akışkanın buharlaşmasıyla birlikte borunun boş tarafı buharla dolar. Ardından yoğuşturucu kısmının sıcaklığı düşük bir yüzeyle teması halindeyse bu bölgede ısının dışarıya atımı gerçekleşir, yoğuşturucu kısımdan ısısını atan akışkan yoğuşarak buharlaştırıcı kısma damlamaya başlar. Isı borusunun buharlaştırıcı kısmı ısı almaya devam ettikçe yoğuşan çalışma sıvısı tekrar buharlaşarak yükselir ve yoğuşturucu bölgeden ısısını atmayı sürdürür. Yoğuşturucu tarafına oranla daha yüksek sıcaklığa sahip buharlaştırıcı bölgesinde sıvıdan buhar fazına; nispeten sıcaklığı daha düşük olan yoğuşturucu bölgesinde ise buhardan sıvı fazına doğru faz değişimi olur. Sonuç olarak her iki uç bölgede de faz değişimi mevcut olur ve sistem bu döngüyü sürdürür.

3.3. Vakum Tüplü Güneş Kolektörleri

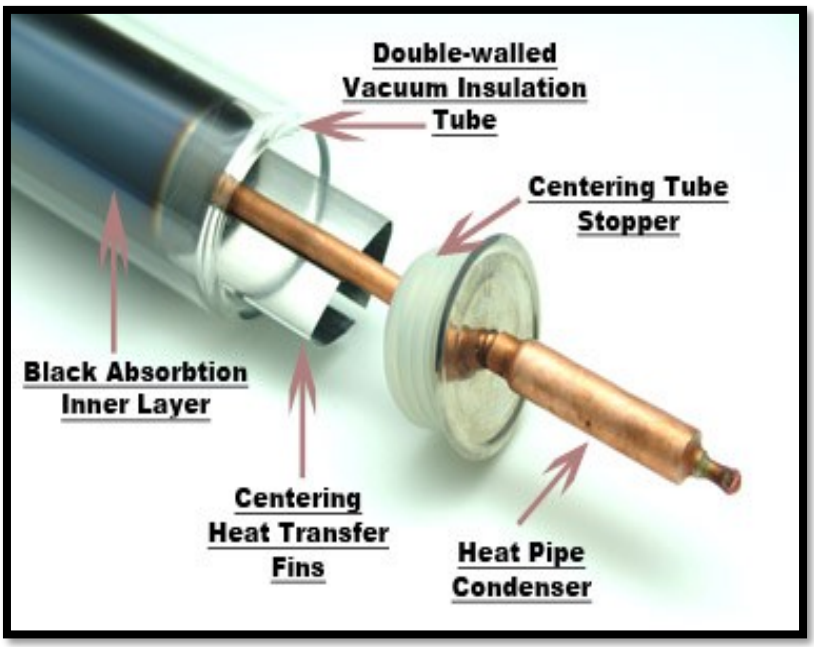
Güneş ışığını termal enerjiye dönüştüren ve bu enerjiyi azami düzeyde koruyan, iç içe iki silindir biçiminde tüpten oluşan kolektördür. Vakum tüpte bulunan ısıyı kaybetmeme konusundaki mantık; hava yoluyla oluşan ısı transferini (konveksiyon) ortadan kaldırmak olup çift cam pencere ve termosların ısı yalıtım mantığıyla aynıdır. Vakum tüp silindirik şekli dolayısıyla gün boyu güneş ışınlarını dik olarak alır. Bu sayede güneş ışınlarının büyük bir kısmını emerek ısıya çevirebilir. *(Ezen H. H., ''Vakum Tüplü Güneş Kolektörlerinin Teorik Ve Deneysel İncelenmesi'', Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü, Isparta, (2010).)*



Şekil 3.8. *Vakum tüp ısı borusu Güneş enerjisinden yararlanma şekilleri (Ezen H. H., ''Vakum Tüplü Güneş Kolektörlerinin Teorik*

Ve Deneysel İncelenmesi'', Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü, Isparta, (2010).)

Şekil 3.8. ile basitçe çalışma mantığı açıklanan vakum tüp ısı borusunun temel parçaları Şekil 3.9.'da gösterilmiştir.

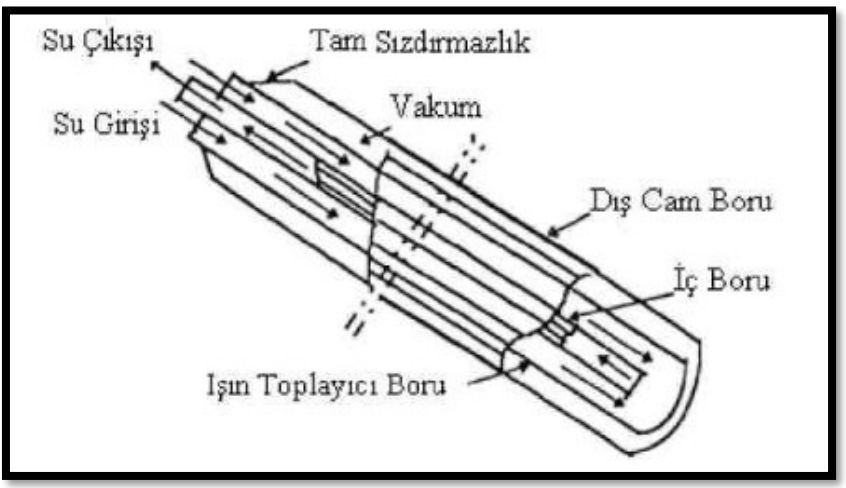


Şekil 3.9. *Vakum tüp ısı borusu parçaları Güneş enerjisinden yararlanma şekilleri (Ezen H. H., ''Vakum Tüplü Güneş Kolektörlerinin Teorik Ve Deneysel İncelenmesi'', Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü, Isparta, (2010).)*

Vakum tüplü güneş kolektörlerinin genel olarak kabul görmüş birkaç tipi mevcuttur. Bunların en önemlileri; Owens Illionois, General Electric tipi ve Philips tipidir.

3.3.1. Owens ıllionois tipi vakum tüplü güneş kolektörleri

Taşınım işleminin kayıplarını azaltmak için vakum borulu biçimdeki toplayıcının dış kısmında yer alan saydam olan cam boru ile iç kısmındaki selektif yüzeye sahip boru aralığında vakum yaratılmıştır. Buna istinaden bu tip toplayıcıların ısıl verimi düz toplayıcılardan fazladır. Şekil 3.10‘da görüldüğü gibi bu tip, eş eksendeki iç içe geçmiş üç adet borudan oluşur, Dış ve orta boruların arasında vakum mevcuttur ve sıvı orta boruya girer, ısınır ve iç borudan çıkar. Vakum borulu toplayıcının içerisinde genelde su, bazense hava dolaştırılır.

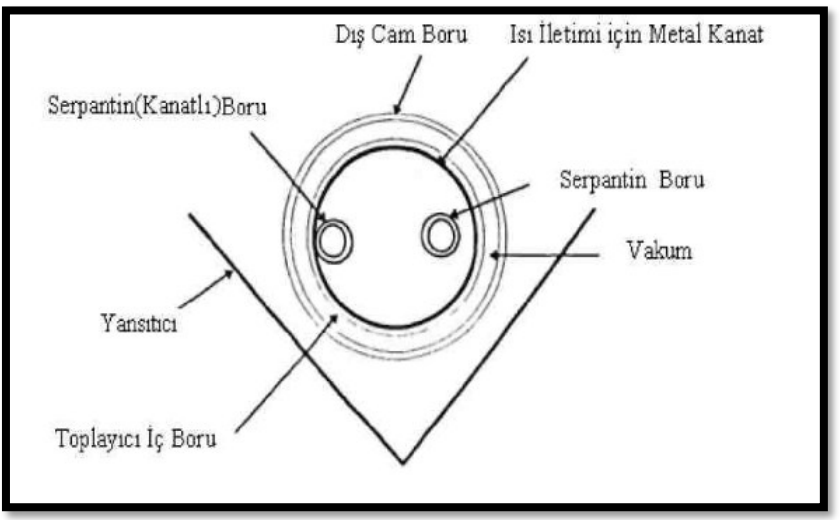


Şekil 3.10. *Owens-ıllionois tipi vakumlu güneş kolektörü (Sözbir N., ‘’Isı İletim Katsayısının Belirlenmesi Deneyi’’, Sakarya Üni., (2014).*

3.3.2. General electric tipi vakum tüplü güneş kolektörleri

Şekil 3.11.’deki gibi; General electric tipi kolektörlerde tüpün iç yüzeyinde yer alan toplayıcı boru ile etkileşimde olan ve yüksek miktarda ısı transferine haiz metalden üretilmiş bir kanatçık

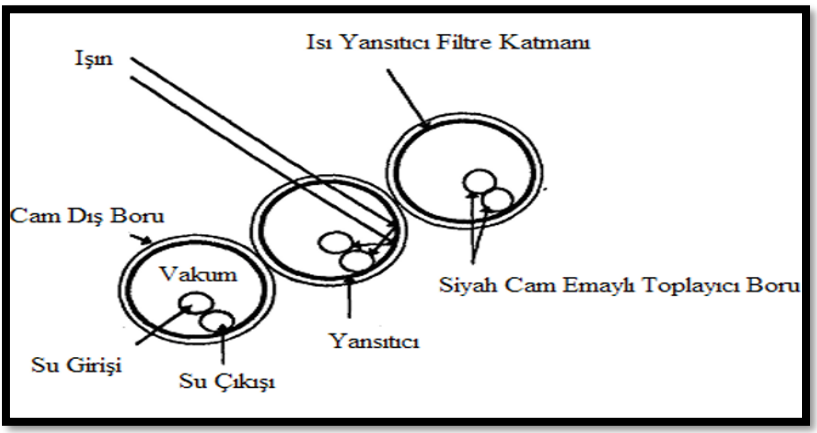
kullanılmakta, vakum tüpünün maruz kaldığı güneş ışınlarının etkisiyle bu kanatçık ısınmakta, ısısını serpantinlere aktarmaktadır. Böylece borunun içinden geçen akışkan ısınır, dışta yer alan boru ile iç boru arasında yer alan vakum ile taşınım kaybı önlenmektedir.



Şekil 3.11. *General electric tipi vakumlu güneş kolektörü (Sözbir N., ''Isı İletim Katsayısının Belirlenmesi Deneyi'', Sakarya Üni., (2014).*

3.3.3. Philips tipi vakum tüplü güneş kolektörleri

Şekil 3.12.'deki gibi; bu tip toplayıcıda dış borunun saydam olan üst kısmı ışınları geçirir, alt kısım ise bu kısma uygulanan katmanla, yansıtıcı haline getirilmiştir. Borunun içinde vakum mevcut olup cam olan dış borunun içerisinde serpantin tipinde toplayıcı borular bulunmakta ve bu toplayıcı boruların üzeri siyah katmanla kaplanmış biçimdedir. Güneşten gelen ışınlar dış cam boru içerisinden geçer ve direkt olarak serpantin borular üzerine ulaştığı gibi aynı anda da alt kısımda yer alan yansıtıcıdan yansıyarak toplayıcı boruları ile içinden geçen sıvıyı ısıtır. . *(Sözbir N., ''Isı İletim Katsayısının Belirlenmesi Deneyi'', Sakarya Üni., (2014).*



Şekil 3.12. *Philips tipi vakumlu güneş kolektörü Güneş enerjisinden yararlanma şekilleri (Ezen H. H., ''Vakum Tüplü Güneş Kolektörlerinin Teorik Ve Deneysel İncelenmesi'', Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü, Isparta, (2010).)*

3.4 Çalışma Ekipmanları

Bir ısı borulu güneş enerjisi sistemi tasarımında dikkat edilmesi gereken en önemli hususların başında uygun akışkan seçimi gelmektedir. Isı borusundaki akışkan, buharlaştırıcı kısımdan aldığı ısıyı yoğuşturucu kısmına çok yüksek hızda iletebilmeli ve bunu gerçekleştirebilmesi için, belirli bazı özelliklere sahip olması gerekmektedir. Bu kapsamda ısı borularında en çok kullanılan akışkanlardan bazıları; özellikleri, kullanılan sistemin sıcaklık işletme aralığı ile malzeme seçimine yönelik bilgilerle beraber Şekil 3.13.'de verilmiştir. *(''Yenilikçi Soğutma Teknolojileri: Isı Boruları'', B. Markal, K. Aksoy, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.set-science.com/manage/uploads/ISAS2018_005/SETSCI_ISAS2018_005_00246.pdf, (2018).*

İşletme Aralığı (ºC)	Akışkan Cinsi	Kaynama Noktası (ºC)	Uygun Malzeme
-200 ile -80	Nitrojen	-196	Paslanmaz Çelik
-70 ile -60	Amonyak	-33	Paslanmaz Çelik
-60 ile 40	Freon 134A	-26.5	Paslanmaz Çelik
-40 ile 120	Freon 21	8.92	Paslanmaz Çelik
-10 ile 180	Freon 113	47.6	Paslanmaz Çelik
40 ile 220	Freon 114	92.8	Paslanmaz Çelik
-20 ile 120	Pentan	28	Paslanmaz Çelik
0 ile 120	Aseton	56.2	Bakır, Pasl. Çelik
10 ile 130	Metanol	65	Bakır, Pasl. Çelik
0 ile 130	Etanol	78.6	Bakır, Pasl. Çelik
10 ile 200	Su	100	Bakır, Nikel
190 ile 500	Civa	356	Paslanmaz Çelik
400 ile 800	Potasyum	760	Nikel, Pasl. Çelik
500 ile 900	Sodyum	883	Nikel, Pasl. Çelik

Şekil 3.13. *Isı borusunda kullanılan iş akışkanları ve uyumlu olduğu malzemeler (''Yenilikçi Soğutma Teknolojileri: Isı Boruları'', B. Markal, K. Aksoy, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.set-science.com/manage/uploads/ISAS2018_005/SETSCI_ISAS2018_005_00246.pdf, (2018).*

Isı transferi cihazlarındaki gelişimlere rağmen geleneksel ısı transferi akışkanlarının düşük seviyelerdeki ısıl iletkenliği sistem performansları üzerinde ciddi sınırlamalara yol açmaktadır. Literatür taramasında da görüldüğü üzere kullanılan geleneksel akışkanlara ek olarak yapılan deneylerde ısı transfer akışkanı olarak Au, Ag, Cu, CuO, TiO_2, Fe_2O_3, CaO, MgO, MnO, K_2O, Fe_2O, SiO_2, WO_3 ve Na_2O gibi birçok nano akışkan kullanılmıştır.

3.4.1 Nanoakışkanlar

Termal iletkenlikleri fazla olan nano boyuttaki partiküllerin ısı transferi için kullanılan geleneksel akışkanın içine katılmasıyla oluşturulan ısı transferi akışkanına "nanoakışkan" denmektedir.

Nanoakışkan; baz ya da temel akışkan ile birlikte katı nano partikülden oluşturulan bir süspansiyon olarak ta ifade edilebilir. Katı haldeki bir metalin ısıl iletkenliği; sistemdeki temel akışkanın ısıl iletkenliğinden fazla olduğundan geleneksel akışkan içerisine katılan nano boyuttaki katı metaller; ısıl iletkenliği, taşınım özelliklerini, ısı transferi performansını farklılaştırır ve sistemin veriminde artış sağlayabilir.

Sıvı maddelerin içerisine katı parçacıklar ekleyerek ısı transfer özelliğini artırma çabaları denenmiş bir yöntemdir, fakat büyük boyutlu katı parçacıkların; ısıl özellikler üzerinde, ancak yüksek hacimsel katkılarda, çok düşük oranda bir iyileşme sağladığı gözükürken; parçacıkların çökelme yapması, sistem ekipmanlarının aşınması, mikro boyuttaki kanallarda tıkanma yapması ve basınç kaybı gibi olumsuzluklar nedeniyle istenen seviyede fayda görülemedi.

Dünya genelinde nanoakışkan üzerine araştırma yapan gruplardan elde edilmiş olan çalışmaların sonuçları, nanoakışkanların bilinen diğer ısı akışkanlarının haiz olduğundan çok daha farklı ısıl (termal) özelliklere haiz olduğunu göstermekte, yapılan bir çalışmada ise çok düşük miktarda (hacim olarak %1'den daha az) nano parçacık eklenmesinin, bilinen akışkanların ısıl iletkenliğini yaklaşık iki kata kadar yükselttiğini göstermiştir. *(Şahin T., ''Düzlemsel Ve Bükülmüş Kolektörlerinin Deneysel İncelenmesi'', Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü, Isparta, (2010).)*

3.4.2 Kolektör malzemeleri

Oda sıcaklığında bulunan bakırın ısıl iletkenliği suya oranla yaklaşık 650 kat, etilen glikole oranla ise yaklaşık 2500 kat daha fazladır. Metal türdeki akışkanların ısıl iletkenliklerinin ametallerden çok

daha yüksek olması nedeniyle geleneksel akışkanlara göre katı parçacık içeren akışkanların ısıl iletkenliklerinin yüksek olması beklenir. Bu kapsamda en fazla kullanılan kolektör malzemeleri ile ilgili bilgiler aşağıda verilmiştir.

Malzemeler	Isıl İletkenlik 25 ºC (W/mK)
Grafit	100-400 (düzlem üzerinde)
Karbon siyahı	6-174
Karbon nanotüp	2000-6000
Elmas	2000
PAN esaslı karbon elyaf	8-70 (eksen boyunca)
Zift esaslı karbon elyaf	530-1100 (eksen boyunca)
Bakır	483
Gümüş	450
Altın	345
Alüminyum	204
Nikel	158
Bor nitrür	250-300
Alüminyum nitrür	200
Berilyum oksit	260
Alüminyum oksit	20-29

Şekil 3.14. *Bazı malzemelerin ısıl iletkenlik değerleri (2015, ''Polimer Malzemelerin Isıl İletkenlik Özelikleri'', https://www.plastik-ambalaj.com/tr/plastik-ambalaj-makale/3014-polimer-malzemelerin-is-l-iletkenlik-oezelikleri)*

4. MATERYAL VE METOT

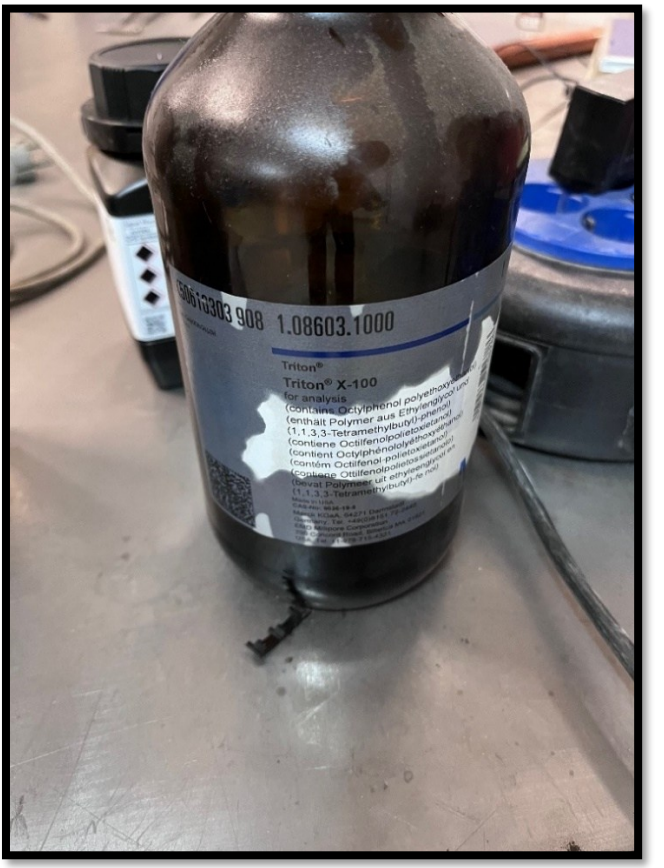
4.1. Materyal

Yapılan araştırmada materyal olarak hazırlanan nano karışım kullanılmıştır. 490 ml saf suya, hassas terazi kullanılarak yaklaşık 10 mg ''Çinko Demir Oksit (Zinc Iron Oxide)'' ve yine yaklaşık olarak 2 ml Triton X-100 eklenerek nano akışkan karışım hazırlanmış,

ultrasonik banyoda birkaç kez 60 dakika süreyle bekletilmiştir. Yapılan bu işlemlere ait görseller Şekil 4.1 ile Şekil 4.6 arasında gösterilmiştir.

Resim 4.1. *Akışkanın hazırlanması-490 ml saf su*

Resim 4.2 *Akışkanın hazırlanması-10 ml nano akışkan eklenmesi*



Resim 4.3. *Triton X-100*

Resim 4.4. *Akışkanın hazırlanması-2 ml Triton X-100 eklenmesi*

Resim 4.5. *Nanoakışkan karışımın ultrasonik banyoya alınması*

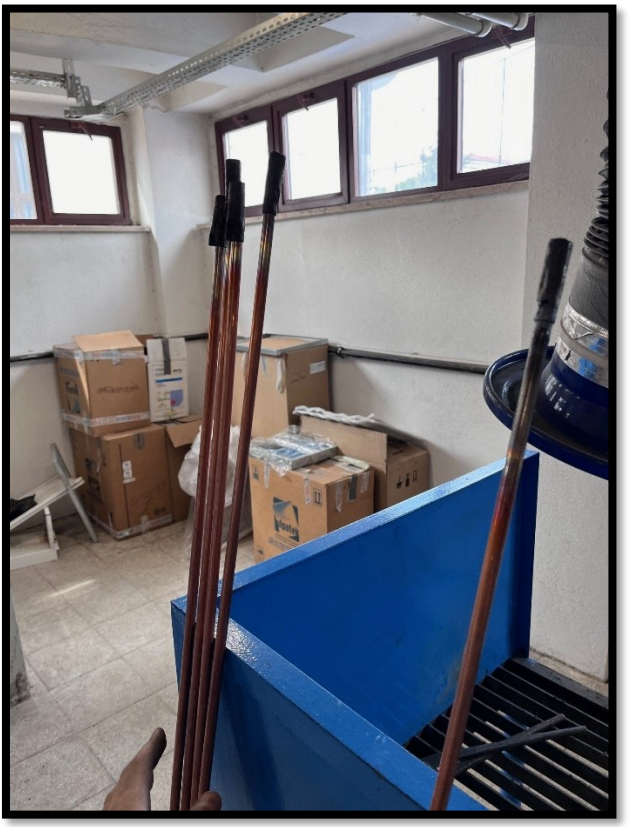
***Resim 4.6**. Ultrasonik banyo işlemi*

4.2. Metot

Yapılan araştırmada deneysel metot kullanılmıştır. Üniversitemizin, Resim 4.7'de yer alan düzeneği deneye uygun olarak yeniden hazırlanmıştır. 168 cm uzunluğunda; 8 mm iç, 10 mm dış çapa sahip bakır borular hacimlerinin 1/3'ü kadar akışkanla doldurulmuş, ısıtılarak havası alınmış ve uçları kaynakla körlenmiştir. Bu kapsamdaki işlemler; Resim 4.8, 4.9, 4.10 ve 4.11'de gösterilmiştir.

Ardından bakır borular vakum cam tüplerin içerisine yerleştirilmiş, tüpler manifoldlara bağlanarak sistem açık havaya çıkarılmıştır.

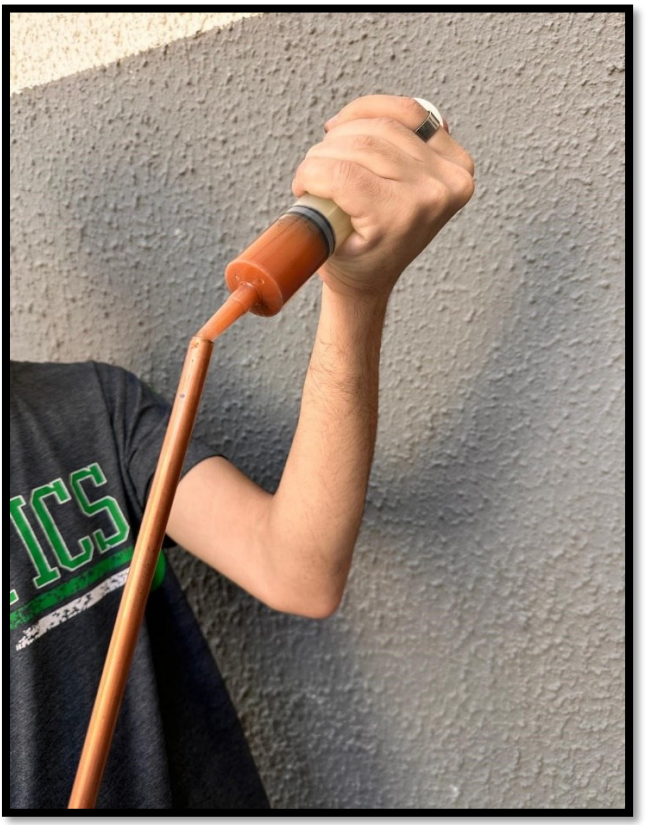
Resim 4.7. *Deney seti*



Resim 4.8. *Bakır boruların hazırlanması*

Resim 4.9. *Bakır boruların körlenmesi*

Resim 4.10. *Nano akışkanın ultrasonik banyodan bir saat sonraki görüntüsü*



Resim 4.11. *Nanoakışkanın bakır borulara şarj edilmesi*

Düzenekte 6 cam tüpe normal akışkan olarak su, 6 cam tüpe ise hazırlanan karışım belirtilen hacimde konularak 1-2-3 Ağustos 2024 tarihlerinde sabah saat 10.00 ile akşam saat 16.00 arası 15'er dakikalık dilimler halinde güneş ışığı altında ölçümler yapılmıştır. Su debisi; 1 Ağustos 2024 Perşembe günü 1 litre/dakika, 2 Ağustos 2024 Cuma günü 1,5 litre/dakika, 3 Ağustos 2024 Cumartesi günü 2 litre/dakika olarak ayarlanmıştır. Resim 4.12'de görüldüğü üzere; normal su ile dolu olan tarafın giriş çıkış değerleri ile nano akışkan dolu olan tarafın giriş çıkış değerleri termokupl'lar aracılığıyla elektronik olarak okunmuştur. Ayrıca Resim 4.13 ve 4.14'te

görüldüğü üzere radyasyon ve rüzgâr verileri de kayıt altına alınmıştır.

Resim 4.12. *Deney setinde sıcaklık verisi ölçümü*

Resim 4.13. *Deney setinde radyasyon verisi ölçümü*

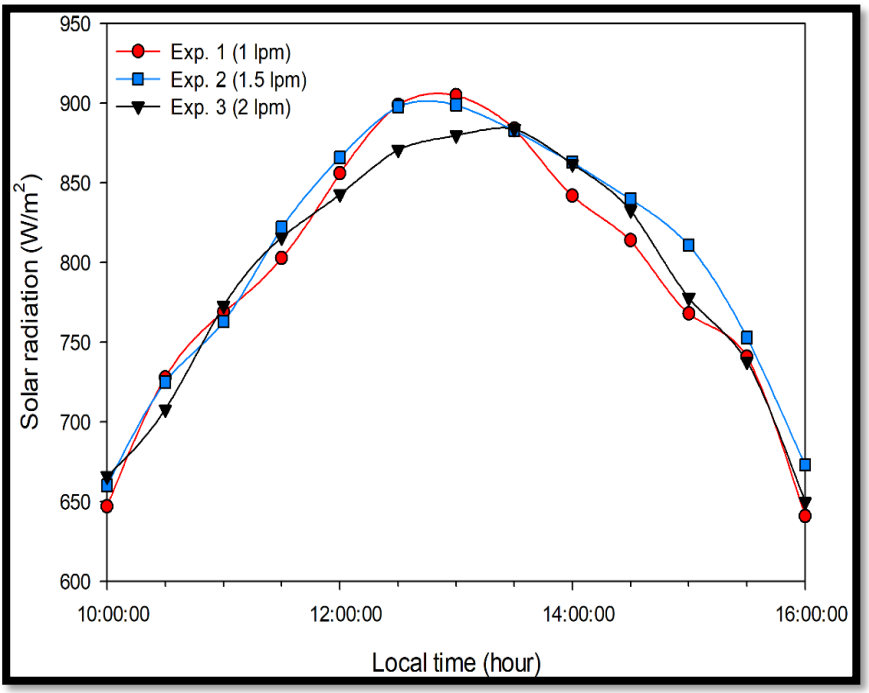
Resim 4.14. *Deney setinde rüzgâr verisi ölçümü*

5. DENEY VE SONUÇLARI

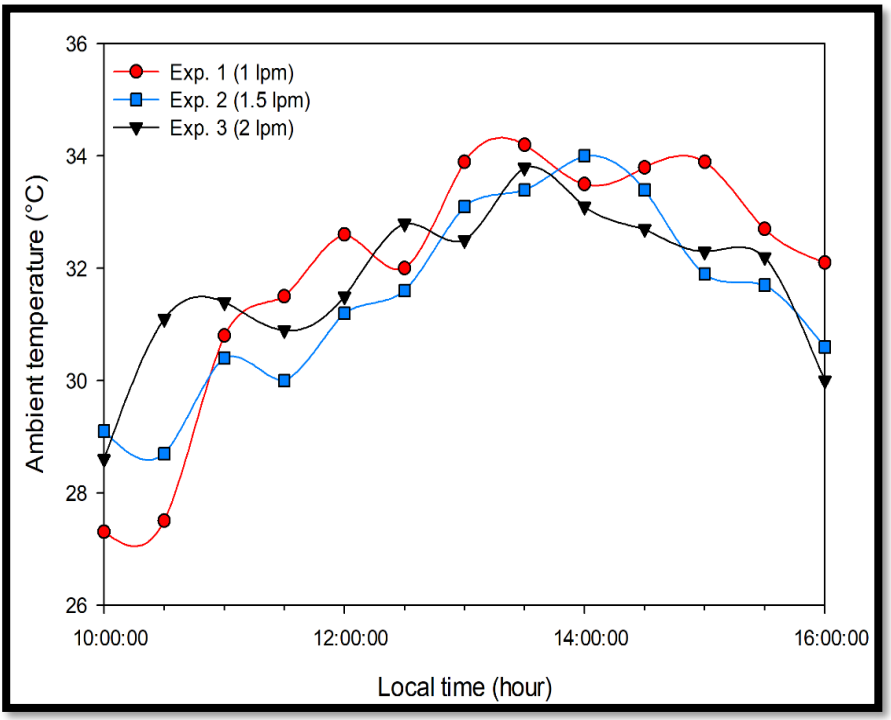
Yapılan deney setine ait fotoğraf ve deneylerin sonuçları şu şekildedir.

Resim 5.1. *Deney seti*

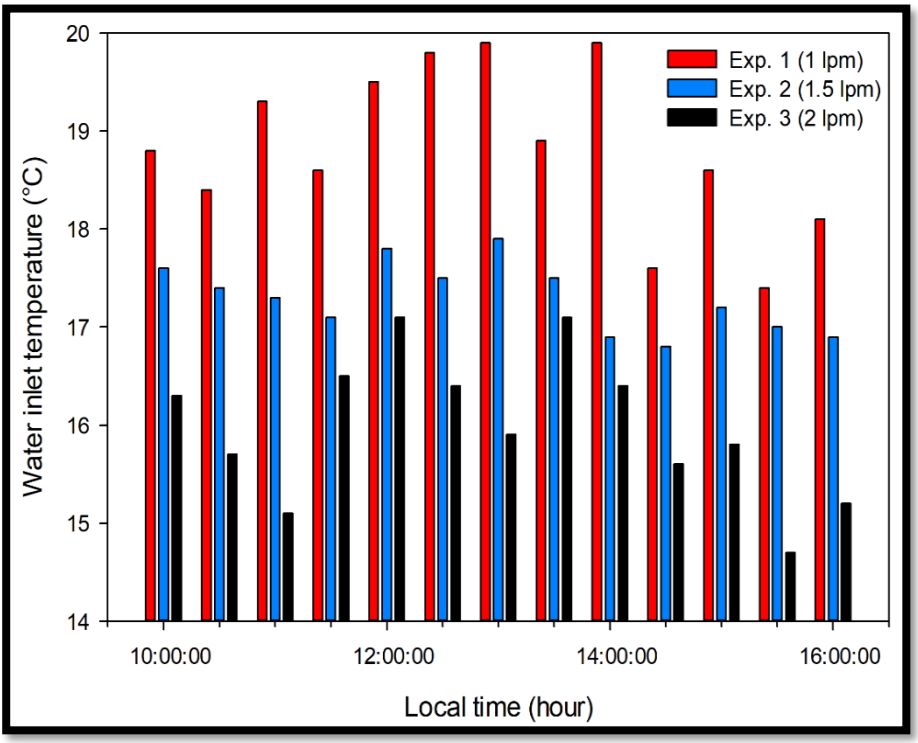
Yapılan deney sonucunda elde edilen tüm veriler ‘’Fluent’’ programında işlenerek grafikler elde edilmiş ve aşağıda paylaşılmıştır.



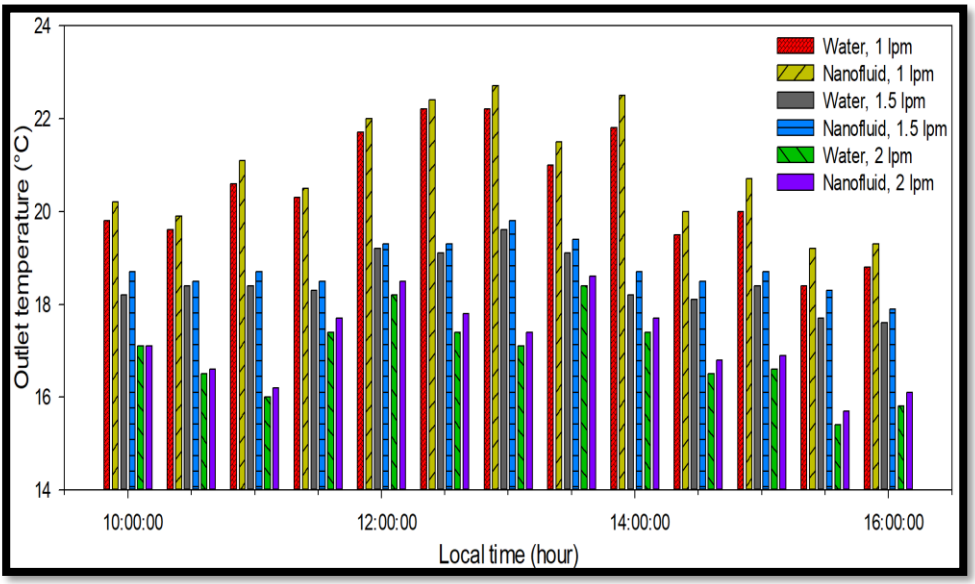
Şekil 5.1. *Güneş ışığı radyasyon değerlerinin zamana göre değişimi*



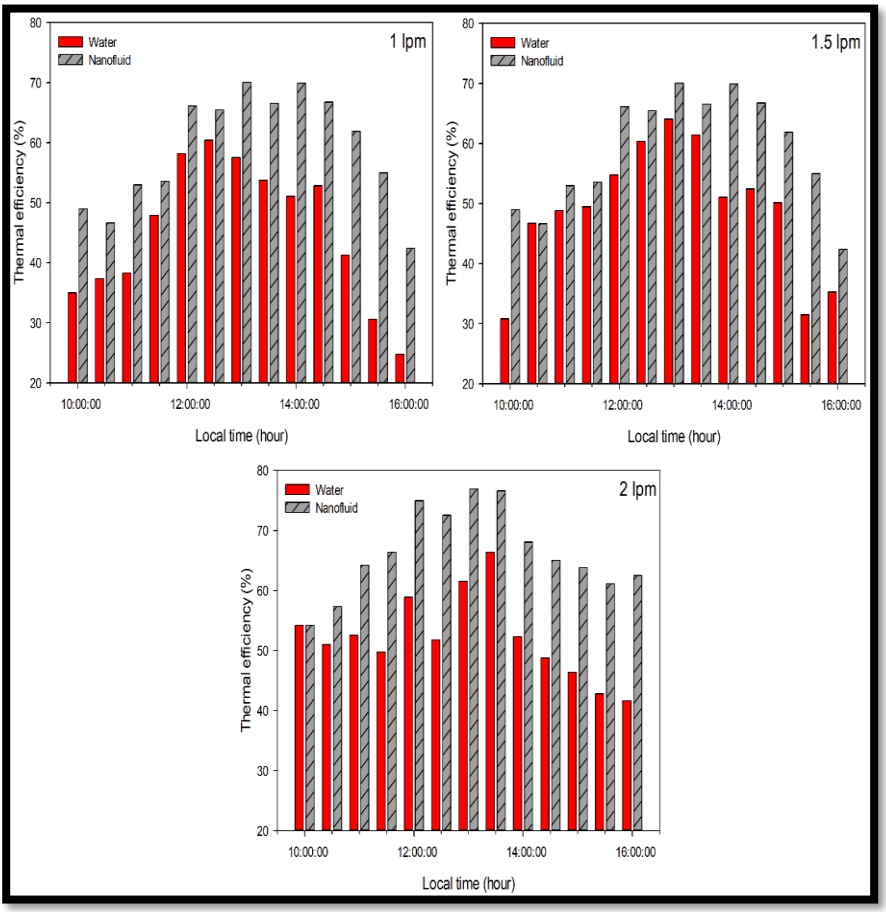
Şekil 5.2. *Ortam sıcaklığının zamana göre değişimi*



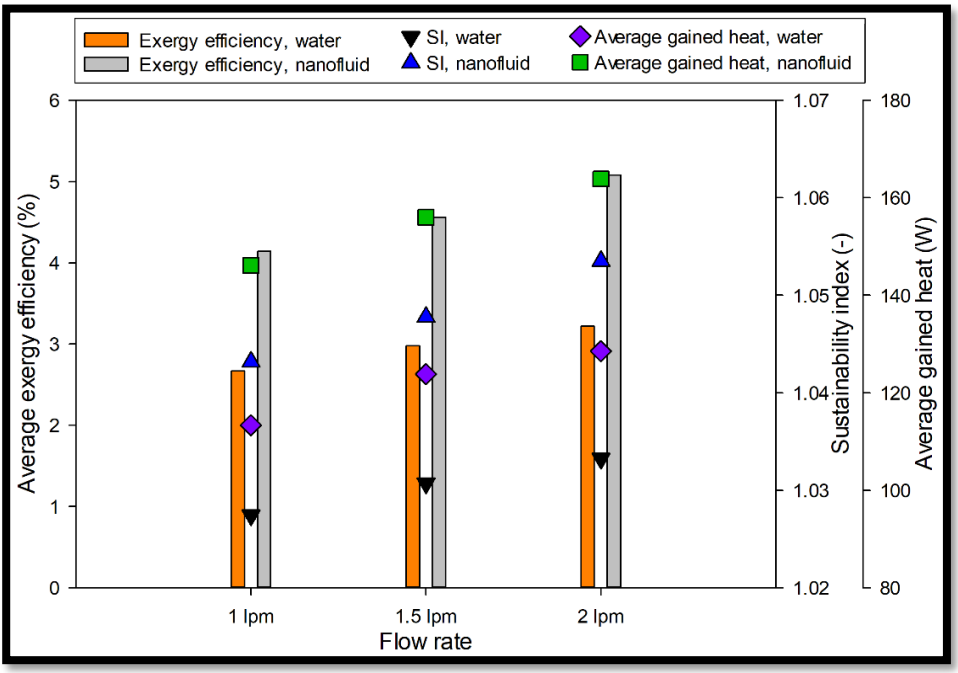
Şekil 5.3. *Su giriş sıcaklığının zamana göre değişimi*



Şekil 5.4. *Su çıkış sıcaklığının zamana göre değişimi*



Şekil 5.5. *Termal verim değerlerinin zamana göre değişimi*



Şekil 5.6. *Ekserji verimi, sürdürülebirlik endeksi, ortalama kazanılan ısı değerlerinin zamana göre değişimi*

6. SONUÇ VE ÖNERİLER

Tez çalışmasının sonucunda oluşan genel kanı ve öneriler aşağıda belirtilmiştir.

Isı borularının içerisine su ve çinko demir oksit ($ZnFe_2O_4$) nanoakışkanı ile su karışımı kullanan, iki özdeş vakum cam tüplü güneş kolektörünün performansı, 1 lt/dk., 1,5 lt/dk. ve 2 lt/dk. olmak üzere üç farklı debi altında değerlendirilmiştir. Deneyler üç gün boyunca aynı anda yürütülmüş olup güneş ışığı radyasyonu, ortam sıcaklığı, giriş ve çıkış suyu sıcaklıkları, termal ve ekserji

verimlilikleri ile sürdürülebilirlik endeksleri gibi temel parametreler ölçülmüş ve analiz edilmiştir.

Şekil 5.1.'de gösterilen güneş radyasyonu değerleri, üç deney boyunca tutarlı günlük değişimler göstermiştir. Ortalama güneş radyasyonu, sırasıyla 1 lt/dk., 1,5 lt/dk. ve 2 lt/dk. debileri için 792,08 W/m², 804,31 W/m² ve 792,46 W/m² olarak ölçülmüştür. Güneş radyasyonu değerlerinin aralığı 641 W/m² ile 905 W/m² arasında değişmiş olup bu değer deneyin ilk gününde maksimumu, deneyin son günü ise minimumu kaydetmiştir. Şekil 5.2.'de gösterildiği gibi ortam sıcaklığı eğilimleri de benzer şekilde sabit kalmış olup üç akış hızı için ortalama değerler sırasıyla 31,98°C, 31,47°C ve 31,76°C olmuştur. Sıcaklık 27,3°C ile 34,2°C arasında değişmiş olup bu da termal enerji toplanması için uygun koşulları göstermektedir.

Giriş ve çıkış suyu sıcaklıkları kolektör performansının önemli göstergeleridir. Ortalama giriş suyu sıcaklığı 1 lt/dk. için 18,83°C, 1,5 lt/dk. için 17,3°C, 2 lt/dk. için 15,98°C olup akış hızı ayarlamalarının başlangıç akışkan koşulları üzerindeki etkisini yansıtmaktadır. Şekil 5.4.'te sunulan çıkış suyu sıcaklıklarının, su bazlı kolektöre kıyasla nanoakışkan kolektör için sürekli olarak daha yüksek olduğu tespit edilmiştir. 1 lt/dk.'de, ortalama çıkış sıcaklığı su için 20,45°C ve nanoakışkan için 20,92°C olup 0,47°C'lik bir artışı temsil etmektedir. Benzer şekilde, 1,5 lt/dk.'de, nanoakışkan kolektör, su için 18,48°C'ye kıyasla 18,79°C'lik bir ortalama çıkış sıcaklığına ulaştı ve bu da 0,31°C'lik bir artışı temsil etmektedir. 2 lt/dk.'de nanoakışkan toplayıcının çıkış sıcaklığı ortalama 17,16°C olup su bazlı sistemden 0,25°C daha yüksektir. Daha yüksek akış hızlarındaki daha küçük sıcaklık farkları, ısı değişim periyodunu sınırlayan azaltılmış kalış sürelerine atfedilebilir.

Kolektörlerin ısı transferi ve güneş radyasyonu değerlerine göre hesaplanan termal verimlilikleri Şekil 5.5.'te gösterilmiştir. 1 lt/dk.'de, su bazlı kolektör %45,29'luk ortalama bir termal verimliliğe ulaşırken, nanoakışkan kolektör %58,93'e ulaşarak yaklaşık %30,1'lik bir iyileştirme sağlamıştır. 1,5 lt/dk.'de, verimlilikler su için %48,98'e ve nanoakışkan için %62,28'e yükselerek %27,1'lik bir iyileştirmeyi yansıtmıştır. 2 lt/dk. akış hızı için, verimlilikler su için %52,16 ve nanoakışkan için %66,44 olmuş ve %27,4'lük bir iyileştirmeyle sonuçlanmıştır. Bu sonuçlar, daha yüksek akış hızlarının her iki sistem için de termal verimliliği artırırken, nanoakışkanın göreceli avantajının tüm test edilen koşullarda tutarlı kaldığını göstermektedir.

Kolektörler tarafından kazanılan termal enerji miktarı da değerlendirilmiştir. 1 lt/dk.'de, su bazlı kolektör ortalama 113,35 W kazanırken, nanoakışkan bazlı kolektör 146,13 W'a ulaşmış olup bu %28,9'luk bir artışı temsil etmektedir. 1,5 lt/dk.'de, kazanılan termal enerji su için 123,85 W'a ve nanoakışkan için 156,02 W'a yükselmiş olup bu %26,0'lık bir iyileştirme gerçekleştiğini göstermiştir. 2 lt/dk.'de, su bazlı sistem 128,55 W kazanırken, nanoakışkan bazlı sistem 163,90 W'a ulaşmış olup bu da %27,5'lik bir iyileştirmeyle sonuçlanmıştır. Şekil 5.6.'da gösterilen bu sonuçlar, nanoakışkanın üstün ısı transfer özelliklerini, özellikle güneş kolektörlerinde enerji emilimini ve depolamasını iyileştirme yeteneklerini doğrulamaktadır.

Ekserji verimliliği ve sürdürülebilirlik endeksi değerleri, nanoakışkanın kullanımının termodinamik avantajlarını daha da vurgulamaktadır. 1 lt/dk.'de, su ve nanoakışkan için ekserji verimliliği sırasıyla %2,67 ve %4,14 iken sürdürülebilirlik endeksleri 1,03 ve 1,04'tür. 1,5 lt/dk.'de, bu değerler ekserji verimliliği için %2,98 ve %4,56'ya ve sürdürülebilirlik endeksi için 1,03 ve 1,05'e yükselmiştir. 2 lt/dk.'de, ekserji verimlilikleri su için

%3,22 ve nanoakışkan için %5,08 iken sürdürülebilirlik endeksleri 1,03 ve 1,05'tir. Bu bulgular, Şekil 5.6.'da gösterildiği gibi nanoakışkanın ekserji verimliliğini ve sistem sürdürülebilirliğini artırmada tutarlı üstünlüğünü göstermektedir.

Akış hızını artırmanın ve nanoakışkan kullanmanın kombine etkisi önemlidir. Daha yüksek akış hızları, deneyler boyunca termal verimlilik ve ısı transferi değerlerindeki kademeli artışla kanıtlandığı gibi, genellikle konvektif ısı transferini geliştirerek termal performansı iyileştirir. Ancak, nanoakışkan kullanımı, nanoakışkanın daha yüksek termal iletkenlik ve ısı kapasitesi gibi gelişmiş termofiziksel özelliklerini kullanarak bu iyileştirmeleri artırır.
Akış hızı ayarlamaları ve nanoakışkan kullanımı arasındaki sinerji, gelişmiş çalışma akışkanları ve operasyonel stratejilerin bir kombinasyonu yoluyla güneş kolektörü performansını optimize etme potansiyelini vurgular.

Deneylerde kullanılan nanoakışkanın çökelmesinin çok yavaş olduğu görülmüştür. Düzenekte ve bakır borularda herhangi bir olumsuzluk yaşanmamış, nanoakışkanın deney süresince deney setine herhangi bir zararı tespit edilmemiştir. Daha yüksek kapasitedeki düzeneklerde ya da farklı debi ve/veya farklı sıcaklıklarda da söz konusu nanoakışkanın katkı sunacağı değerlendirilmiştir.

Deneysel sonuçlar, vakumlu güneş kolektörlerinde ısı transfer akışkanı olarak $ZnFe_2O_4$/su nanoakışkanının geleneksel suya göre avantajlarını açıkça göstermektedir. Nanoakışkan, tüm test edilen akış hızlarında çıkış sıcaklığı, termal verimlilik, ısı transferi, ekserji verimliliği ve sürdürülebilirlik endeksi açısından sudan sürekli olarak daha iyi performans göstermiştir. Bu bulgular, nanoakışkanın güneş termal sistemlerinin verimliliğini ve sürdürülebilirliğini

önemli ölçüde artırma potansiyelini vurgulayarak, yenilenebilir enerji uygulamalarında daha geniş bir şekilde benimsenmelerinin önünü açmaktadır. Nanoakışkanın uzun vadeli kararlılığı ve ekonomik uygulanabilirliği üzerine daha fazla araştırma yapılması, büyük ölçekli güneş enerjisi sistemlerinde pratik uygulamalarını kolaylaştırmak için önerilmektedir.

KAYNAKÇA

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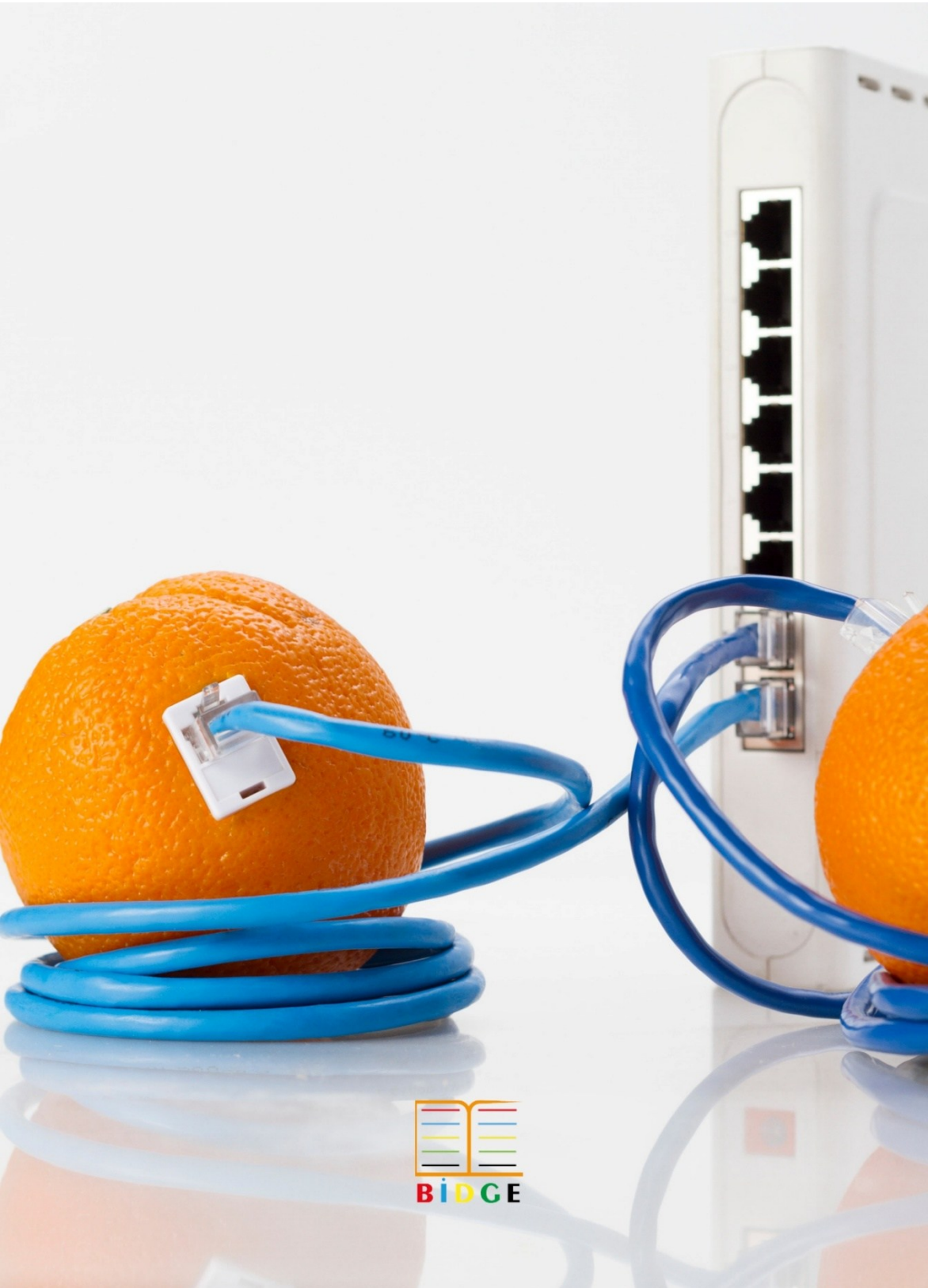
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