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EVALUATION OF THE STRUCTURE AND ENERGY GENERATION OF A INTEGRATED SOLAR COMBINED CYCLE POWER PLANT

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Abstract

Population growth, technological advancements, and growing living standards have all contributed to a rise in energy demand. Due to the fact that fossil fuels are not sustainable, renewable energy sources have emerged as a viable alternative. The need for development is growing all the time. In this study, a combined cycle power plant in which solar energy is integrated is discussed. For this purpose, in the designed model calculations; for solar energy data, the values of Emirgazi district of Konya province were used. The solar-field warms a thermal oil (Therminol VP-1) that is then circulated through a sequence of shell and tube heat exchangers that preheat feedwater, create steam, and superheat steam. The solar generator gets warmed feedwater from the HRSG and returns superheated steam, which is combined with HP steam when it exits the first superheater. As a result of model calculations; The net electricity efficiency (LHV) of the power plant was 56% and the heat recovery steam generator 89%.

Keywords: Energy Generation, Solar Energy, Combined Cycle Power Plant

ENTEGRE GÜNEŞ KOMBİNE ÇEVRİM SANTRALİNİN YAPISI VE ENERJİ ÜRETİMİNİN DEĞERLENDİRİLMESİ

Öz

Günümüzde nüfus artışı, teknolojik gelişmeler ve artan yaşam standartları, enerji talebindeki artışa katkıda bulunmaktadır. Fosil yakıtların sürdürülebilir bir kaynak olmaması nedeniyle yenilenebilir enerji kaynakları uygulanabilir bir alternatif olarak ortaya çıkmaktadır. Bu alanda teknolojinin geliştirilmesi ihtiyacı da her geçen gün artmaktadır. Bu çalışmada güneş enerjisinin entegre edildiği bir kombine çevrim santrali ele alınmıştır. Bu amaçla tasarlanan model hesaplamalarında; güneş enerjisi verileri için Konya ili Emirgazi ilçesinin değerleri kullanılmıştır. Model santralde, parabolik oluklu güneş alanı, besleme suyunu önceden ısıtan, buhar üreten bir dizi ve borulu ısı eşanjörlerinden pompalanan bir termal yağı (Therminol VP1) ısıtmaktadır. Model hesaplamaları sonucunda; santralin net elektrik verimi (LHV) % 56 ve ısı geri kazanımlı buhar jeneratörünün verimi de % 89 bulunmuştur.

Anahtar Kelimeler: Enerji Üretimi, Güneş Enerjisi, Kombine Çevrim Santrali

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Introduction

The rapidly increasing world population and the increasing energy need in parallel with industrialization cannot be met with the limited and limited traditional energy resources. On the other hand, most of the energy needs fossil fuels are one of the important causes of environmental pollution today [1,2]. Energy use based on fossil fuels; fuel in addition to important negativities such as foreign dependency, high import costs and environmental problems, due to the rapid depletion of world fossil fuel reserves, the importance of renewable energy sources increases [3].

Renewable energy sources, in addition to being sustainable due to their continuity, It is also of great importance as it can be found in every country. Solar energy, which has an important place among renewable energy sources, is located in the core of the sun. It is the radiation energy released by the fusion process in the form of hydrogen gas in the form of transformation into helium. Even a small part of the solar energy reaching the world is far above the world energy consumption. The technological progress of solar energy systems and the decrease in costs increase the importance of solar energy, which is a clean energy source [2,3]. Estimated "employment in renewable energy by technology" under IRENA's planned energy policies scenario Figure 1 It is also shown. As it is today, solar will have the largest share in renewable energy employment in 2050 with 19.9 million people, followed by bioenergy (13.7 million), wind (5.5 million) and hydropower (3.7 million) [4].

Figure 1. Employment scenario in renewable energy according to technology in the World [4].

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With USD 148.6 billion, solar power accounted for more than half of global renewable energy capacity investment in 2020. It was the only renewable energy technology to expand this year, increasing 12 percent from the previous year. Despite an increase in wind generating capacity installations during the year, investment has fallen. Biomass and waste-to-energy investment declined by 3% to USD 10 billion [4]. Other technologies' investment continued to fall in 2020, with small hydropower investment reaching USD 0.9 billion, geothermal investment reaching USD 0.7 billion, and biofuels investment reaching USD 0.6 billion - all down more than 70% since 2010. (Figure 2).

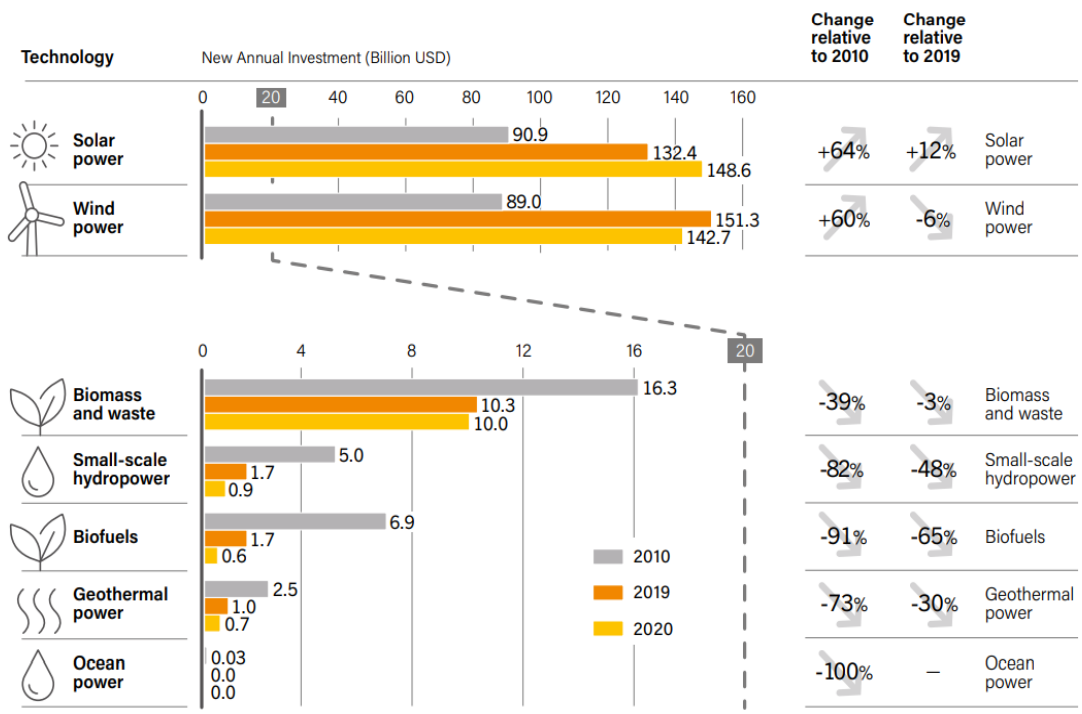

Figure 2. Change rates of investment amounts for Renewable Energy Resources [4].

Today, while solar energy technologies are becoming more and more widespread, it comes to the fore especially in studies related to the integration of solar energy into combined cycle power plants.

Kelly et al [5] used Gate Cycle modeling software to analyze the integrated combined cycle design. They saw an annual yield increase of 12% compared to a classic combined power plant. In addition to the heat recovery steam generator, producing high-pressure saturated steam further increased the

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efficiency. Rovira et al [6] calculated that direct steam generation (DGS) is the most efficient option for solar energy integration. Zhai R. et al. [7] found that the energy and exergy efficiency of a solar-assisted hybrid power plant is lower than that of a thermal power plant operating under the same conditions.

Feng L. et al. [8] found that when the boiler feed water entering the high pressure feedwater preheaters enters the solar area, the efficiency of converting the heat provided from the solar area to work is higher than the thermal solar power plants that produce electricity directly from the solar radiation, and they determined that this situation reduces the required solar area. Yang Y et al. [9] studied the methods of integrating the solar field into the coal-fired power plant and stated that if the required investment cost per unit area of the system was reduced, it would be more competitive against the energy produced by other renewable energy sources such as biomass and wind energy. Hou H. et al. [10] found that the specific fuel consumption of the solar-assisted hybrid power plant was lower than the reference thermal power plant, and they found that the specific fuel consumption decreased further with the increase in solar radiation value. Suresh et al. [11] have shown that using solar energy to heat the feedwater entering the high-pressure preheaters produces the best results in terms of fuel economy and reduction of carbon dioxide emissions. Philip et al. [12] fostered a computationally successful ISCC model that integrates a total recreation of the intensity recuperation steam generator by thinking about an extensive variety of true framework limitations. Baghernejad et al. [13] utilized exergoeconomic ideas and hereditary 14 calculations to advance the venture cost of hardware and the expense of exergy obliteration.

Mechthild et al. [14] inspected a coordinated sunlight based consolidated cycle framework in Egypt, expecting a CC power plant with practically identical complete yearly energy creation and incorporated an explanatory box gatherer field and a volumetric air getting tower. Quaschning [15] conducted an economic research for 61 locations worldwide, taking into account both PV and parabolic trough technology in solar thermal systems for electric generation. Woditsch [16] conducted a cost-benefit analysis of PV cells. The analysis is based on the assumption of doubling market volume every four years, with a 20% cost decrease for each doubling.

Combined cycle power plants with high efficiency and power in addition to offering flexible operating conditions, quick start-up, full load and variable load easily adaptable to situations, even

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variable load with high efficiency working properties they have. In this study, the structure and energy production of a solar energy integrated combined cycle power plant model were investigated. Solar data of Emirgazi district of Konya province was used as model input. "Thermoflow computer software" was used to design the plant model. The model allows different model designs related to electricity generation and conversion systems.

Renewable Energy and Solar in Turkey

Solar energy in Turkey is primarily due to its high potential, ease of use, renewable and environmentally friendly features. However, some difficulties must be exceeded. Some factors such as high installation costs, relatively low efficiency and capacity factor, technological and economic challenges. By solving these problems however, solar power generation will become much more attractive in the near future. Despite being in a lucky geographical location, Turkey has cannot use its solar energy potential sufficiently today. Turkey's ranking and place among all the countries in the world in terms of the use of renewable energy sources are shown in Figure 3 [4].

	1	2	3	4	5
POWER					
Renewable power capacity (including hydropower)	China	United States	Brazil	India	Germany
Renewable power capacity (not including hydropower)	China	United States	Germany	India	Japan
Renewable power capacity *per capita* (not including hydropower)[1]	Iceland	Denmark	Sweden	Germany	Australia
Bio-power capacity	China	Brazil	United States	Germany	India
Geothermal power capacity	United States	Indonesia	Philippines	Turkey	New Zealand
Hydropower capacity[2]	China	Brazil	Canada	United States	Russian Federation
Solar PV capacity	China	United States	Japan	Germany	India
Concentrating solar thermal power (CSP) capacity	Spain	United States	China	Morocco	South Africa
Wind power capacity	China	United States	Germany	India	Spain
HEAT					
Modern bio-heat demand in buildings	United States	Germany	France	Italy	Sweden
Modern bio-heat demand in industry	Brazil	India	United States	Finland	Sweden
Solar water heating collector capacity[2]	China	Turkey	India	Brazil	United States
Geothermal heat output[3]	China	Turkey	Iceland	Japan	New Zealand

Figure 3. Turkey's ranking and place in terms of the use of renewable energy sources

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Our country, which is in the process of EU membership, is also expected to regulate its legislation and investment environment in order to produce energy from renewable energy sources in accordance with the said directive. In this direction, renewable energy and energy under the title of Energy, which is one of the chapter titles of the EU acquis, energy efficiency issues are important Turkey's solar energy potential due to its geographical location advantageous compared to most countries. Figure 4. shows the solar energy potential of Turkey distribution by regions. Highest While South East Anatolia shows its energy potential, it is the most Black Sea shows low potential.

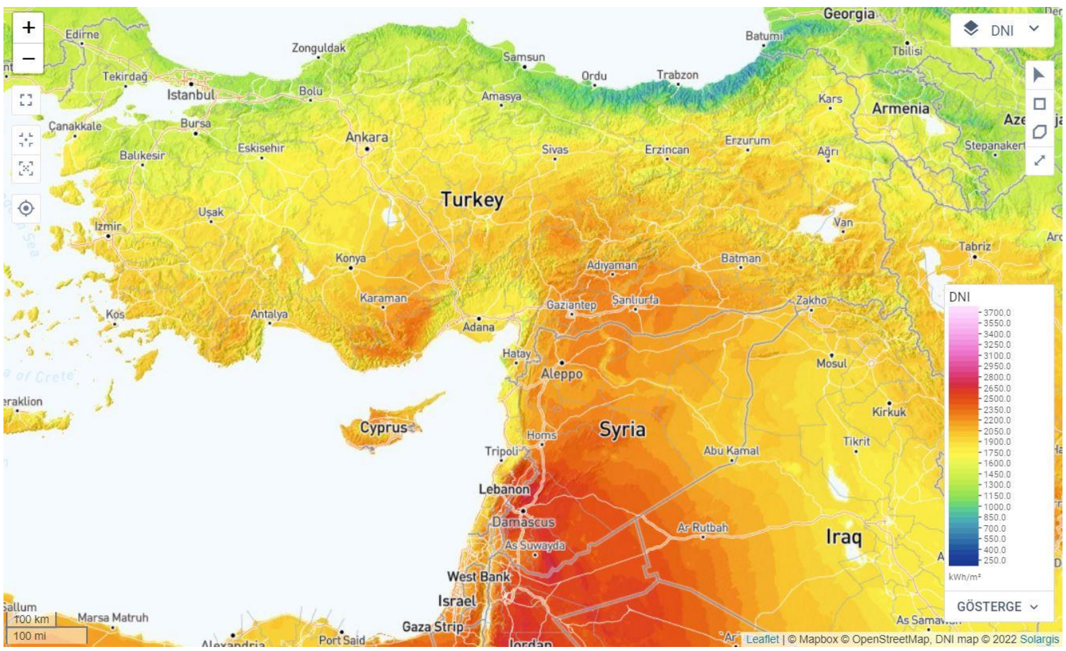

Figure 4. Turkey's solar energy potential distribution map by regions

Materials and Methods

Combined cycle power plants are the power plants consisting of the combination of the Rankine cycle and the Brayton cycle. Gas turbines and steam turbines are used together in this type of power plant. Basically; It is based on the principle of generating additional energy by using the high-temperature exhaust gases from the gas turbine in the steam cycle. In the hybridization of this type of power plants, the steam produced with the heat provided from solar energy can be injected into different parts of the waste heat boiler or directly into the steam turbine of the combined cycle

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power plant. Thus, additional power is obtained without burning any additional fuel. Solar thermal power plants generally, use a large field or array of collectors to heat a turbine and generator.In combined cycle power plants, the electricity conversion efficiency is much higher than in conventional power plants; having pre-combustion pollutant prevention technology, emitting lower emissions; use less water and produce less solid waste; It has many advantages such as having input and product flexibility. In this study, an analysis was made on a combined cycle power plant model. In the combined cycle power plant considered, solar energy is also integrated. A software program was used for the calculations and analysis of the designed combined cycle power plant model. The "Thermoflow" software program used is a design program that models different energy conversion systems and power plants. In Figure 5, the combined cycle power plant model structure designed with this program is shown.

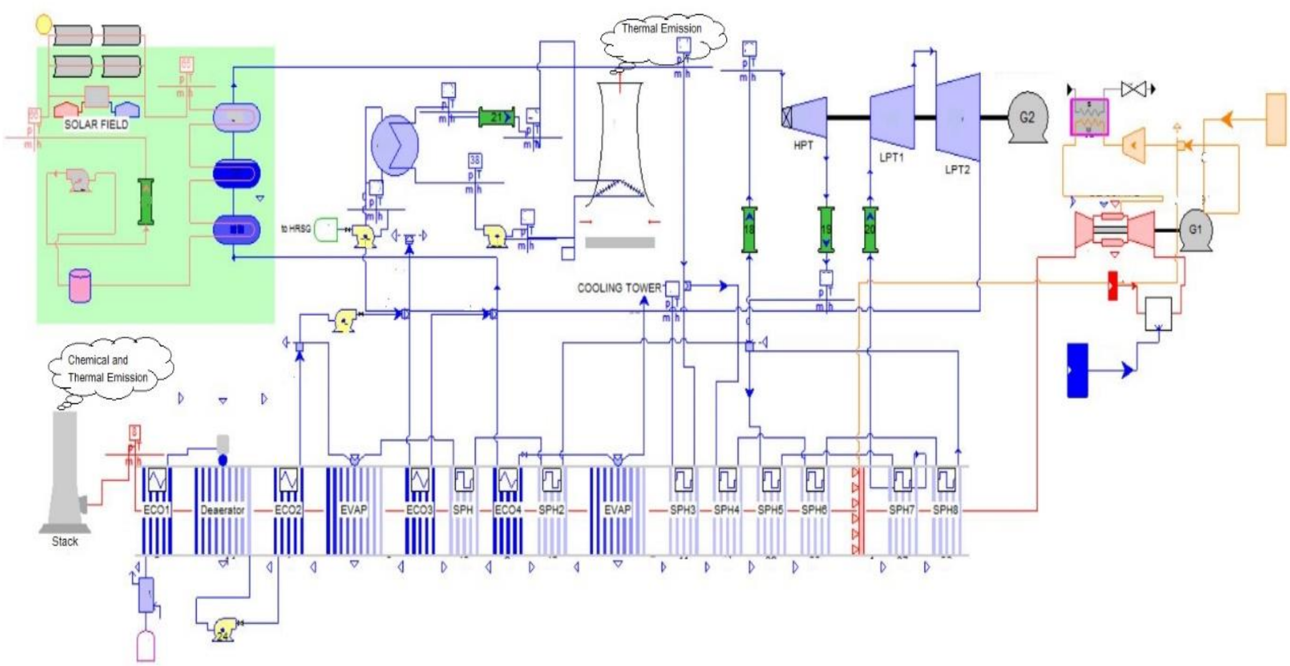

Figure 5. Solar integrated combined cycle plant structure and workflow

These power plants are a modern cycle power plant with gas and steam turbines and additional heat energy from solar energy to the thermal cycle. The difference of the working principle of the system from the combined cycle power plant is that the energy required to produce steam is supplied from the solar field as well as the waste exhaust gases in the gas turbine. The main elements of a solar

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integrated combined cycle power plant are; reflective surface, absorber pipe, heat transfer fluid, carrier structures, gas turbine, steam turbine, generator, boiler, waste heat boiler, expansion tank, degasser, pump, condenser, preheater, reheater, superheater, and feed water heaters. In the solar energy integrated combined cycle power plant model, Emirgazi district of Konya province was chosen as the location (Figure 6).

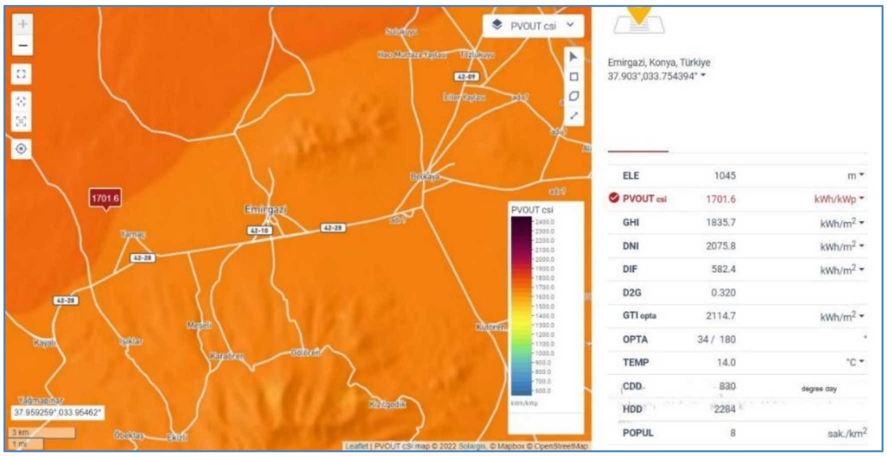

Figure 6. Solar radiation data of Emirgazi district of Konya province

Results and Discussion

While the average decarbonization rate of all countries was 2.5% in 2020, this rate was 5.7 % and 0.8% in the G7 and E7 countries, respectively. It is seen that the average annual decarbonization rates of the G20 countries, which make up 76.3 % of the total carbon emissions, have changed between 0.6% and 5.5% since 2016. The above-average rates of change in 2020 were largely due to the reduction in carbon emissions as a result of the economic restrictions imposed by the COVID-19 pandemic. Limited reserves of fossil resources and fluctuations in prices, energy problems such as greenhouse gas emissions caused by renewable energy sources have caused a transformation in favor of renewable energy sources. Which of the technologies applied to generate electricity using solar energy source will be preferred depends on many variables.

The investment decision as a result of the comparison of factors such as the geographical and topographic characteristics of the area where the solar power plant is planned to be established, the installed power of the plant, energy efficiency and the cost per unit kWh generation is taken. The

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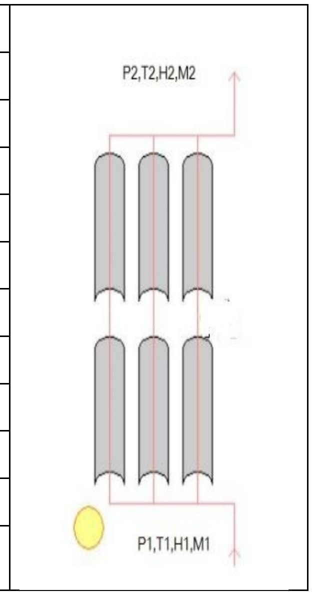
main difference between these technologies is; while solar energy is directly converted to electrical energy in PV systems, in CSP systems, firstly heat energy and then electrical energy are produced from solar energy. As a result of the analysis of the solar integrated combined cycle power plant model; energy production amounts and basic parameter values are shown in Table 1.

Table 1. Solar Integrated Combined Cycle Power Plant model energy production and parameter values

Parameter	**Value**
Solar Field(Energy Input)	56984 kW
Integral Deaerator(Mass flow out)	0,082 t/h
Net electric efficiency (LHV)	56 %
Water discharge	98 t/h
Gas Turbine	567 kW
Wet Cooling Tower (fan)	1288 kW
Design Point Generator Efficiency	97 %
HRSG efficiency	89 %
HRSG gas inlet temperature	635 ^{0}C
Tube velocity at collector exit	5,1 m/s
Total number of existing cells in Wet cooling tower	8



Therminol VP-1 heat transfer fluid is a synthetic ultra-high temperature heat transfer fluid developed to fulfill the demanding requirements of vapor phase or liquid phase systems. The pressure and enthalpy values at the process points of the "Therminol VP-1" fluid used in the solar integrated combined cycle power plant are given in Figure 7.

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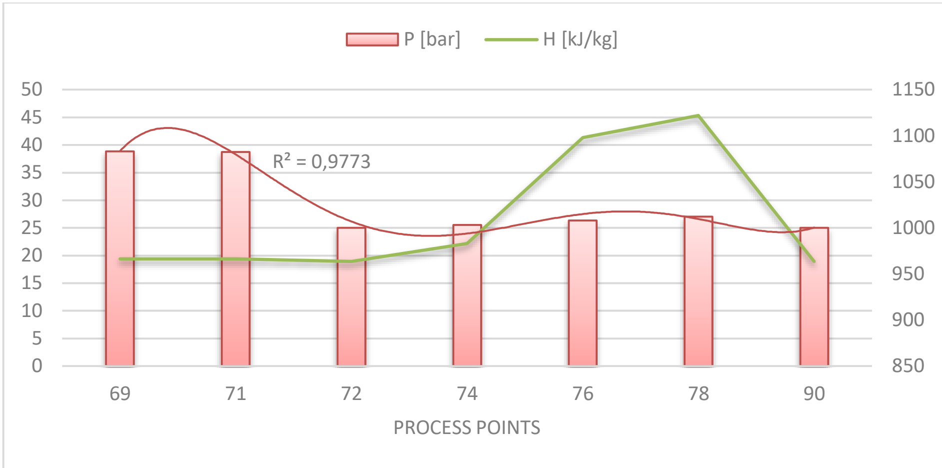

Figure 7. Pressure and enthalpy values at the process points of "Therminol VP-1" fluid.

Utilizing gas turbine waste heat production of steam in a waste heat boiler and from this steam generating electricity via a steam turbine is the most common known type of combined cycle. Heat transfer in steam boiler, condenser heat and mass transfer, and pressurization by consuming power in pumps. In Figure 8, the changes in the process gas velocities and obtained heat transfer coefficients for the HRSG (Heat recovery steam generator) in the combined cycle power plant are shown.

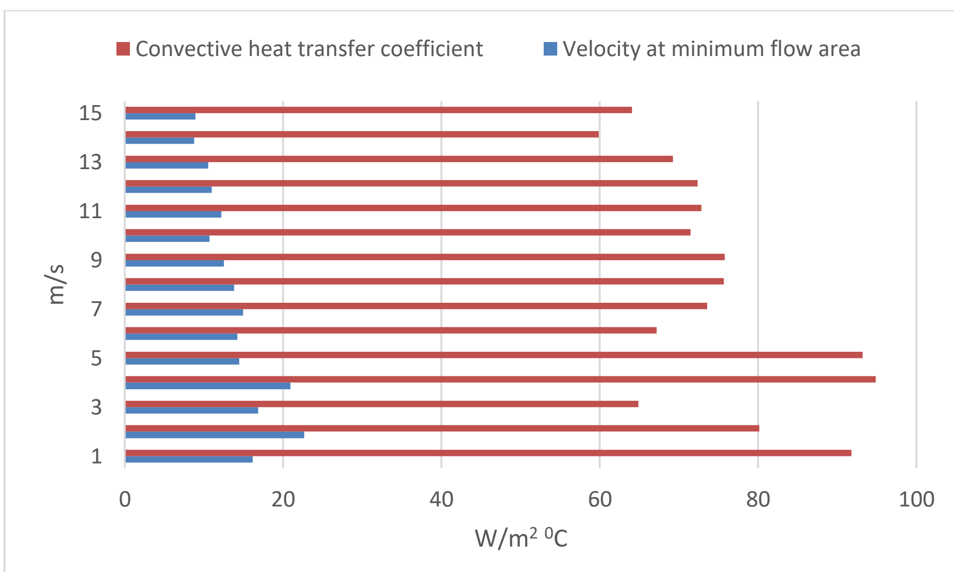

Figure 8. Changes in process gas velocities and obtained heat transfer coefficients

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REFERENCES

[1] Turkish Academy of Sciences, TUBA-Solar Energy Technologies Report, Ankara, 2018.

[2] World Energy Council, Turkey 2021 Renewable Energy and Employment Annual Evaluation Report, 2021.

[3] Ministry of Energy and Natural Resources, 2019-2023 Strategic Plan, Ankara, 2019.

[4] The International Renewable Energy Agency (IRENA), The Energy Progress Report, 2022

[5] B. Kelly, U. Herrmann, M.J. Hale, Optimization studies for integrated solar combined cycle systems, in: Proceedings of Solar Forum 2001 Solar Energy: The Power to Choose, April 21e25, 2001. Washington, DC.

[6] A. Rovira, M.J. Montes, F. Varela, M. Gil, Comparison of heat transfer fluid and direct steam generation technologies for integrated solar combined cycles, Appl. Therm. Eng. 52 (2013).

[7] Zhai, R., Zhu, Y., Yang, Y., Tan, K. ve Hu, E., (2013). Exergetic and Parametric Study of a Solar Aided Coal-Fired Power Plant, Entropy, 15 (3): 1014-1034.

[8] Feng, L., Chen, H., Zhou, Y., Zhang, S., Yang, T. ve An, L., (2016). The Development of a Thermo-Economic Evaluation Method for Solar Aided Power Generation, Energy Conversion and Management, 116: 112-119.

[9] Yang, Y., Cuı, Y., Hou, H., Guo, X., Yang, Z. ve Wang, N., (2008). Research on Solar Aided Coal-Fired Power Generation System and Performance Analysis, Science in China Series E-Technological Sciences, 51 (8): 1211-1221.

[10] Hou, H., Mao, J., Yang, Y. ve Luo, N., (2012). Solar-Coal Hybrid Thermal Power Generation-an Efficient Way to Use Solar Energy in China, International Journal of Energy Engineering, 2 (4): 137-142.

[11] Suresh, M.V.J.J., Reddy, K.S. ve Kolar, A.K., (2010). 4-E (Energy, Exergy, Environment, and Economic) Analysis of Solar Thermal Aided Coal-Fired Power Plants, Energy for Sustainable Development, 14 (4): 267-279.

[12] Philip G. Brodrick, Adam R. Brandt, Louis J. Durlofsky, Operational Optimization of an integrated solar combined cycle under practical time-dependent constraints, Energy 15 (2017) 1569-1584.

[13] A. Baghernejad, M. Yaghoubi, Exergoeconomic analysis and optimization of an Integrated Solar Combined Cycle System (ISCC) using genetic algorithm, Energy Conversion and Management 52 (2011) 2193-2203.

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[14] Mechthild Horn, Heiner Führing, Jürgen Rheinländer, Economic analysis of integrated solar combined cycle power plants. A sample case: The economic feasibility of an ISCCS power plant in Egypt, Energy 29 (2004) 935-945.

[15] V. Quaschning, Technical and economical system comparison of photovoltaic and concentrating solar thermal power systems depending on annual global irradiation, Solar Energy, vol. 77, pp. 171-178, 2004.

[16] P. Woditsch, Kostenreduktionspotenziale bei der Herstellung von PV-Modulen, Proceedings of FVS Themen, pp. 72–86, 2000.