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A CASE STUDY: LIFE CYCLE COST ASSESSMENT OF A GEOTHERMAL BASED COMBINED MULTIGENERATIONAL SYSTEM FOR HYDROGEN AND POWER GENERATION

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ABSTRACT

A geothermal powered electricity and hydrogen power production system is considered for a case study. The system is analyzed by thermodynamic performance parameters such as energy and exergy analysis. An economic analysis of the system is performed to assess cost structure, potential revenues, payback periods and life cycle cost analysis. Effect of geothermal water temperature on the annual cooling cost and payback periods are investigated. A liquid geothermal source at a temperature of 200 °C with a mass flow rate of 100 kg/s is considered for west cites of Turkey. The energy and exergy efficiencies of the multigenerational power system are determined to be 17.4% and 80%. The full load working condition annual potential revenue of the power generation system is estimated to be 3,190,000 $/yr with simple and discounted payback periods of 3.27 and 4.16 years. The geothermal energy is provided an annual cost saving benefit of 5,429,000 $/yr on the entire lifetime of the system by the life cycle cost analysis. So, the unit product costs of electricity and hydrogen are calculated to be 0.029 $/kWh and 2.696 $/kg H_2, respectively.

Keywords:
Life Cycle Cost, Exergoeconomics, Fuel Cell, Hydrogen, Geothermal

1. INTRODUCTION

Energy plays important role and most important issues of the world economics and policies in nowadays. All the world governments are investigated to way of the sustainable energy economy. For sustainable energy economy, energy must be produced from renewable and environmental energy resources. Sustainability refers to continuity of things in the larger sense. But in engineering science that refers to using natural resources of Earth in a way that maintains their sustainability. That can be described for the energy sustainability refers to energy supply that can be sustained without hurting potential dangers future supply of energy. This means that is green energy or renewable energy today.

The sustainable energy economy always takes to be base concept through the applications. Most energy required for storages, transports and production is commonly selected using fossil fuels. But with a few scientific breakthroughs hydrogen the most abundant element in the universe, could be the energy carrier of a future sustainable end clean energy society. May be one step of this objective is hydrogen technology. Advanced energy technologies have developed a lower cost and easily useful to produce and liquefied hydrogen through the low energy processes. Scientists have been searching for good process to solution that can efficiently produce of hydrogen production and liquefaction methods. During this processes there will be no way products that are not environmentally clean. The current industrial methods of hydrogen production and storages result in the release harmful gas emissions into the environment. Renewable hydrogen production and liquefaction technologies can boost a clean energy of the future energy society. Not only energy in renewable energy sector but also to storage electrical energy produced by geothermal and other renewable resources [1].

Environmental pollutants problems are caused to be use of renewable energy resources that likely increase and more abundant. Among these renewable resource is geothermal that seems to be an efficient and sustainable resources [2]. Geothermal energy is provided cheap and useful way of generating electricity energy. High temperature energy intensity of geothermal resources is to be generated electricity with very low emissions. It can be seen on the open literature very different hydrogen storage methods. Each method in itself has a different methodologies and applications. In the most reliable, current, and environmentally appropriate of hydrogen storage methods is liquefaction. Hydrogen production in its not simplest form uses an electrical power passing through compressors to gas hydrogen into liquid form. For this process is necessary for the work as the provider of electricity used in a variety of sources. Geothermal, nuclear, wind and solar energy sources can be used such as integrating these systems for electricity production to the supply energy requirements of liquefaction cycle. Generated this electricity is may used as electrical work for hydrogen liquefaction process [3].

When considering the use of renewable energy for hydrogen production as an energy carrier and cautiously power supply, geothermal resources can be a viable option. Geothermal resources are proper renewable energy option for renewable and sustainable hydrogen energy chain. Especially our country of Turkey has abundant amounts of geothermal resources and one of the most popular in the world. All renewable energy plant has a problem of about the continually power supply. Because plants is not working full capacity that is caused by on - off grid time for electrify. So, at that time secondary energy producer or supply as an energy carrier of hydrogen liquefied by using geothermal energy that is to be become an important alternative [4].

A geothermal power based hydrogen fuel cell system is analyzed using exergoeconomic method and life cycle cost analysis and its yearly performance is investigated. Thermodynamic model for predicting the power outputs of the GPP and FC system are presented. The results showed include the GPP output and the shares attributable to the electrolysis and the FC in supplying the electrical demand. Moreover, to study the performance of the multigenerational system in supplying the energy demand, results are presented for timely range in kg/s. An exergoeconomic analysis and life cycle cost are performed to determine the electricity unit cost over the system lifetime. The geothermal assisted electrolysis system is able to produce a sufficient amount of hydrogen during lifetime, so periodic hydrogen storage is required to feed the FC. Multigenerational hydrogen energy systems appear to be one of the most effective solutions, can play an important issue in better environmental sustainability. The primary objective of this study is to discuss the role of hydrogen and fuel cell systems from the sustainability point of view, highlight the importance of life cycle cost and thermodynamic analysis in achieving this, and present some key approaches for environmental impact and sustainability aspects of hydrogen and fuel cell systems and applications. In addition, two case studies on the life cycle assessment of fuel cell vehicles and hydrogen production systems from energy, environment and sustainability points of views are also presented.

2. SYSTEM DESCRIPTION

The present thermoeconomic model includes a geothermal energy based hydrogen and electricity production and storage system. The geothermal energy is considered to be an energy source of electrolysis of water or according to the need to feed directly power supply for the grid network. General system equipment consists of geothermal power system, generator, power control systems, electrolyzer, hydrogen and oxygen storage systems and fuel cell. The general layout of the overall system is illustrated in Fig. 1.

The multi generation renewable energy system provided electricity, which can be stored in the in the battery group or delivered to the electrolyzer. At the same time, water is taken from water tank and sent to the electrolyzer to produce hydrogen and oxygen. The produced hydrogen and oxygen can be stored in various storage systems. Hydrogen is fed to the fuel cell unit from the hydrogen storage system, while oxygen is fed from oxygen storage system or using atmospheric air. Hence, fuel cell produces electricity. The produced electricity can be storage in the battery group or utilized by the load. Here, water is going out from the fuel cell, is sent to the water tank to reuse. The geothermal energy can be operated single or combined from for electricity demand, and peak time of the system depending on the network requirements. Generated electricity from the geothermal water is given to the network as needed. In the network is less need for increasing amounts being sent to the electrolysis unit, and hydrogen is produced and stored. When needed to excess electricity to the grid, the stored hydrogen is converted into electricity in the fuel cell and the network is given. The power generation system is assisted by a fuel cell unit that is attractive for power generation because their direct output is electrical energy. In this study, it is considered a geothermal energy powered hydrogen and electricity production system (Fig. 1). The system is analyzed primarily by the first law of thermodynamics and economic analysis. The hydrogen system receives energy from geothermal power plant. The life cycle cost analysis of multi generation power system is evaluated in comparison with electricity assisted by a fuel cell unit. The thermodynamic properties of geothermal water and hydrogen are calculated from the thermodynamic tables and Engineering Equation Solver (EES) software.

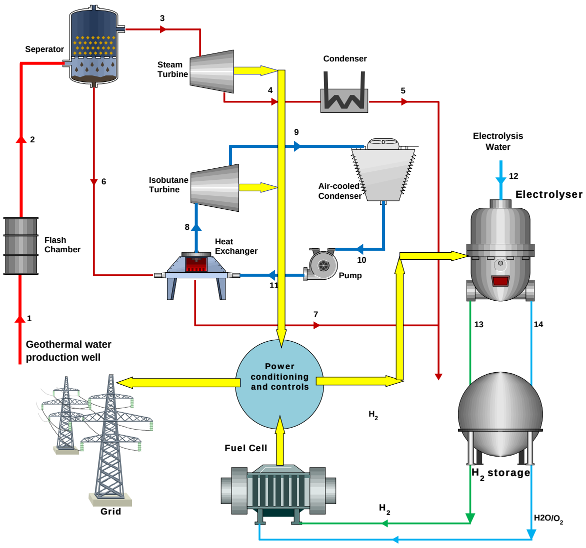

Fig. 1. Hydrogen and electricity power generation system assisted by geothermal energy.

3. THERMODYNAMIC ANALYSIS OF SYSTEM

Thermodynamic analysis of the systems refers to the first law of thermodynamics for a control volume. System components are considered steady-state, steady-flow process. Energy and exergy balance equations are applied accordingly to the Fig. 1.

$$\sum \dot{m}_i = \sum \dot{m}_e \tag{1}$$

$$\dot{Q} - \dot{W} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i \tag{2}$$

$$\sum \frac{\dot{Q}}{T_s} + \sum \dot{m}_i s_i + \dot{S}_{gen} = \sum \dot{m}_e s_e \tag{3}$$

$$\dot{E}x_{heat} - \dot{W} = \sum \dot{m}_e ex_e - \sum \dot{m}_i ex_i + \dot{E}x_{dest} \tag{4}$$

where $\dot{Q}$ and $\dot{W}$ are the net heat and work inputs, $\dot{m}$ is the mass flow rate of the fluid stream, *h* is the enthalpy, *ex* is the specific flow exergy, $\dot{E}x_{heat}$ is the rate of exergy transfer by heat, $\dot{E}x_{dest}$ is the rate of exergy destruction, and the subscripts *i* and *e* stand for inlet and exit states. Also; *s* is entropy, T_0 is the dead state temperature, and the subscript 0 stands for the restricted dead state.

The specific flow exergy and the rate of total exergy are given by [5]

$$ex = (h - h_0) - T_0 (s - s_0) \tag{5}$$

$$\dot{E}x = \dot{m}(ex) \tag{6}$$

3.1. Thermodynamic Analysis of Geothermal Power Plant

The energy efficiency of the plant may be defined as the ratio of the power output to the energy input to the plant [6]

$$\eta = \frac{\dot{W}_{\mathrm{net,out}}}{\dot{E}_{\mathrm{in}}} \tag{7}$$

Referring to Fig. 1, the thermal efficiency of combined flash-binary geothermal power plant can be determined from [6]

$$\eta = \frac{\dot{m}_3 (h_3 - h_4) + \dot{m}_8 (h_8 - h_9) - \dot{W}_{\mathrm{pump}} - \dot{W}_{\mathrm{fan}}}{\dot{m}_{\mathrm{geo}} \left(h_{\mathrm{geo}} - h_0 \right)}$$

(8)

where $\dot{W}_{\mathrm{fan}}$ is the power consumed by the fans in the air-cooled condenser. Note that power is produced from both the steam and binary turbines in the plant.

Using the exergy of geothermal water as the exergy input to the plant and overall system (in the reservoir or at the well head). The exergy efficiency of the combined flash-binary geothermal plant can be expressed as [6]

$$\varepsilon = \frac{\dot{W}_{\text{net,out}}}{\dot{m}_{\text{geo}}\left(h_{\text{geo}} - h_0 - T_0\left(s_{\text{geo}} - s_0\right)\right)} \qquad (9)$$

3.2. Thermodynamic Analysis of Electrolysis Unit

The thermodynamic analysis of electrolysis operation is presented in this section. This analysis is performed to calculate the voltage and flow rate in the electrolysis unit. For the electrolysis unit, the validity range of the temperature range is usually between 25 and 80ºC [7]. In the following analysis, all gases involved are assumed to be ideal gases and any side reaction or mixing is neglected. Focusing on electrolysis; a control volume surrounding an isothermal electrolysis process is considered, as shown in Fig. 1.

The total energy demand for the electrolysis operation can be calculated as [7]

$$\Delta H = \Delta G + T\Delta S \qquad (10)$$

where ΔG is the electrical energy demand (change in Gibb's free energy) and $T_{\text{electrolysis}}\Delta S$ is the thermal energy demand (kJ/kmol). The values of G, S, and H for H_2, O_2, and H_2O can be obtained from the JANAF table. Two essential voltages, taking into account the energy needed for hydrogen production, can be defined as follows [7]

The total energy demand is the theoretical energy required for H_2O electrolysis without any losses. In actual systems, losses are inevitable and the performance of the system can be evaluated in terms of energy and exergy efficiencies. The energy and exergy efficiencies of the overall system can be defined as the total energy value of the hydrogen produced (heating value of hydrogen times its production rate) divided by the energy (or exergy) input to the system, which is energy (or exergy) value of geothermal water at the plant inlet with respect to the environmental state.

$$\eta_{\text{overall}} = \frac{\text{LHV}_{H_2} \times \dot{m}_{H_2,\text{out}}}{\dot{m}_{\text{geo}}\left(h_{\text{geo}} - h_0\right)} \qquad (11)$$

$$\varepsilon_{\text{overall}} = \frac{\dot{Ex}_{H_2}}{\dot{m}_{\text{geo}}\left(h_{\text{geo}} - h_0 - T_0\left(s_{\text{geo}} - s_0\right)\right)} \qquad (12)$$

Here, LHV is the lower heating value of H_2, $\dot{m}_{H_2,\text{out}}$ is the mass flow rate of H_2 at the outlet, $\dot{W}_{\text{net,geo}}$ is the rate of electric energy input by geothermal power plant for the electrolysis operation, respectively, and $\dot{Ex}_{H_2}$ is the exergy rate of H_2 produced in the electrolysis unit.

3.3. Thermodynamic Analysis of Fuel Cell Unit

Fuel cells are one of the most viable and promising hydrogen technologies. In a fuel cell hydrogen combines with oxygen without combustion in an electrochemical reaction (reverse electrolysis) and produces direct current (DC) electricity. Proton exchange membrane fuel cells (PEM) are the most widely used type of fuel cells in the industrial power generation application. The operating temperature is typically between 60 and 80 ºC. A typical fuel cell consists of the electrolyte, in contact with anode reaction and cathode reaction, on both sides. The overall electrochemical reaction of PEM fuel cell is generally represented by the following chemical reaction [8]

$H_2 \rightarrow 2H^+ + 2e^-$ anode reaction
$1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$ cathode reaction
$1/2O_2 + H_2 \rightarrow H_2O + \dot{W}_{electricty}$ overall reaction

The reversible potential of the above the electrochemical reaction is 1.229 V at standard conditions (25 ºC 100 kPa) and it corresponds to the Gibbs free energy according to the fallowing equations. Consider a reversible reaction occurring at constant temperature equal to that of its environment. The work output of the fuel cell is [8]

$$W = -\left(\sum n_e g_e - \sum n_i g_i\right) = -\Delta G \qquad (13)$$

where ΔG is the change in Gibbs function for the overall chemical reaction. We also realize that the work is given in terms of the charged electrons flowing through an electrical potential *E* as[8]

$$W = nFE \quad (14)$$

Where *n* is the number of kilo moles of electrons flowing through the external circuit, *F* is the Faraday's constant (96,485 kJ/kmol V) and *E* is the reversible potential at 25 ºC and atmospheric pressure (V). The actual voltage of an operational fuel cell is always lower than the reversible potential due to the variable irreversible losses, such as activation polarization, concentration polarization, and ohmic resistance. The fuel cell efficiency is a function of cell voltage. The theoretical fuel cell efficiency is[8]

$$\eta_{FC} = \frac{\Delta G}{\Delta H} \quad (15)$$

where ΔH is hydrogen enthalpy. The theoretical fuel cell efficiency, defined as a ratio between produced electricity and higher heating value of hydrogen consumed is therefore 83%. So, unit electricity production in kW of fuel cell can be calculated as:

$$\dot{W}_{electrcity} = \frac{\eta_{FC} \times W \times \dot{m}_{H_2}}{MW_{H_2}} \quad (16)$$

Where *MW* is the molecular weight of 1 kmol of hydrogen (2.016 kg/kmol), $\dot{m}_{H_2}$ is the hydrogen flow rate comes from electrolysis unit (kg/s), *W* is the maximum possible work output of the fuel cell unit (kJ/kmol), and η_{FC} is the fuel cell efficiency

3. ECONOMIC ANALYSIS OF SYSTEM

The economic analysis takes into account the cost of the each component, operating and maintenance costs and the cost of fuel consumption. Component costs have to be expressed as functions of system defined thermodynamic variables. In an economic analysis, the levelized capital investment costs, fuel supplied costs, and operating and maintenance spend costs (OMC) for the first economic life of the analyzed plant is typically calculated. Here, total revenue requirement (TRR) method is applied. Table 1 summarizes the main assumptions and parameters used in the economic analysis. The economic life for the model components and for the overall model is assumed to be 20 years except for the liquefaction cycle [9].

Table 1. Economic parameters and assumptions used in the system's Life Cycle Cost Analysis calculations [9].

Parameter	Value
Interest rate (%)	10
Escalation rate (%)	5
Plant life time (yr)	20
Working capacity rate plant (%)	95
Labour cost ($/yr)	482,130
Operating and maintenance cost ($/yr)	200,000
Salvage value (%, percent of Initial Capital Cost)	20
Annuity factor %	5
Hydrogen market cost	3-10 US$/kg H_2
Electricity market cost	0.05-0.07 $/kWh
Average operating capacity (%)	95

The purchased equipment costs of the components are calculated using by Aspen Plus software of the economic analysis data base [9]. The capital recovery factor (CRF) depends on the interest rate as well as estimated equipment life time. CRF is determined using [9]

$$\mathrm{CRF} = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (17)$$

where *i* is the interest rate and *N* is the year period the plant.

The term $\dot{Z}_k$ is the total cost rate ($/h) associated with capital investment and the maintenance costs for the *k*th equipment item

$$\dot{Z}_k = \dot{Z}_k^{\mathrm{CI}} + \dot{Z}_k^{\mathrm{OM}} \quad (18)$$

Each of the above cost rate parameter can be defined as

$$\dot{Z}_k^{\mathrm{CI}} = \frac{\mathrm{CRF}}{\tau} C_k (1 + r_n)^2 \quad (19)$$

$$\dot{Z}_k^{\mathrm{OM}} = \left(\mathrm{CRF} \frac{C_{\mathrm{L,OM}}}{\tau} \right) \frac{C_k}{\sum_k C_k} \quad (20)$$

where C_k is the purchased equipment cost of *k*-th component in US dollar, τ is the annual plant operation hours at full load, $C_{\mathrm{L,OM}}$ is the system operating and maintenance cost, and r_n is the nominal escalation rate. The levelized operating and maintenance cost of $C_{\mathrm{L,OM}}$ are calculated and the values are distributed to each component. This calculations and objective values are proportionally to the purchased equipment cost in the system economy. The values are transformed to the capacity factor of the entire plant operation by total cost rate of each component ($\dot{Z}_k$).

The levelized costs values of the each system equipments and the economic data are used in thermoeconomic analysis as a system inputs. Total purchase equipment costs of the overall system are calculated to be using the Aspen Plus program in the computer environment [10].

In this study, the modeled of economical and thermoeconomic analysis of the system, Aspen Plus and EES program with the necessary data are calculated by coding to our programs. As known, it is very difficult to reach current economic data. Trying to find them with some approaches is also difficult and often the results are not very accurate. Because all of these, using Aspen Plus program in our economic analysis gives us a great advantage and convenience. With this program, it is possible to perform both energy analysis and to obtain the initial investment costs of all the past and present economic data of the thermal systems and the systems informants. These calculations and data are given in Table 2 for the system economic analysis [11,12].

Table 2. Estimation of total capital investment costs of the system [11,12].

I. Fixed capital investment (FCI)	**8063 kW**
A. Direct cost (DC)	
1. Onsite cost (ONSC) – Purchased equipment cost (PEC) • Heat exchanger • Binary turbine • Air-cooled Condenser • Steam turbine • Water cooled condenser • Separator • Pump • Flash valve • Electrolyzer • Fuel Cell • Other system equipments • Purchased equipment cost (PEC)	450,000 750,000 300,000 750,000 300,000 20,500 100,000 20,000 3,000,000 2,000,000 250,000 7,870,000
Total Onsite cost	7,870,000
2. Offsite cost (OFSC)	
• Civil, structural and architectural work (20% of ONSC) • Service facilities (hot source and cold sink connection) (20% of ONSC) • Contingencies (10% of ONSC)	1,574,000 1,574,000 787,000
Total Direct cost (DC)	**11,805,000**
B. Indirect cost (IDC)	
• Engineering and supervision (15% of DC) • Construction cost including contractor's profit (15% DC) • Contingencies (20% of DC)	1,180,500 1,180,500 1,777,500
Fixed capital investment, total (FCI)	**15,988,500**
II. Other outlays	
A. Start up cost (6% of FCI) B. Working capital (5% of FCI) C. Cost of licensing, research and development	959,310 799,425 20,000
Total capital investment (TCI)	**17,767,735 $**

4. LIFE CYCLE COST ANALYSIS OF SYSTEM

One can use the economic equations to convert expenses occurring at different times to a desired time so that the total cost of the project can be expressed by a single value. It also allows the comparison of competing projects and options. This comparison can be done by calculating the total cost of a project, known as life cycle cost analysis.

The life cycle cost of a system can also be calculated using the levelized annual cost (or levelized annual value) method. The net cost (or benefit) of the project is expressed by equal annual amounts over the lifetime of the project. Each benefit/expense of the project occurring at different times is expressed by a uniform series amount U. The net value of U is calculated by adding benefits and subtracting expenses on an annual basis.

The incomes and expenditures occur over the time in each time period. Salary deposits, mortgage payments, and car lease payments are some examples. They can be on a yearly or monthly basis. The periodic income or expenditure in this case is called uniform series amount, and denoted by *U*. It may be expressed as a function of the present value as

$$U = P\left[\frac{i}{1-(1+i)^{-N}}\right] \tag{21}$$

where *P* represent the present value of money and *F* the single future value of money. *i* represent the interest rate. Economic parameters and assumptions are given in Table 3 for life cycle cost analysis of system. Table 1 summarizes the assumptions and parameters used in fundamental economic analysis (Aspen Plus, 2015). The economic life of the components and the whole system is assumed to be 20 years for the geothermal water unit with 95% of capacity factor cover nearly 20 years. The future value of the purchased equipment cost of the system units is predicted using the nominal escalation rate (e.g. 5.0%), and discounted to the present value using the average interest rate of return (e.g. 10%).

The levelized annual cost is determined by adding benefits and subtracting expenses from it

$$\text{Levelized annual cost} = (\text{Benefits}) - (\text{Expenses}) \tag{22}$$

The installation of the fuel cell and geothermal assisted power generation system will provide an annual monetary benefit of 2,612,000 $/yr (Levelized annual cost, LAC) on the entire lifetime of the project.

In geothermal assisted power system, the cost of producing electricity is of prime interest. This may be expressed in terms of the levelized annual cost as [13]

$$\text{UPC} = \frac{\text{Levelized annual cost}}{\text{Annual production}} \tag{23}$$

Unit product cost (UPC) is different from specific cost. Specific cost refers to energy cost of a unit product while unit product cost refers to total cost (including initial cost, energy cost, operating and maintenance cost, and salvage value) expressed on levelized annual cost basis per unit product.

A geothermal power plant produces energy in kWh unit, and the unit electricity cost (UEC) is expressed in $/kWh. In the calculation of the unit electricty cost, the levelized annual cost should include all costs including energy cost. So in this study, unit cooling cost by geothermal water is calculated from [13]

$$\text{Unit electricity cost (UEC)} = \frac{\text{LAC}}{\dot{E}_{\text{elec,yaerly}}} \tag{24}$$

When the geothermal power plant is directly fed full load working for network grid system, from this equation, the unit electricity product cost is calculated to be 0.029 $/kWh (3,190,000/108,600,000 = 0.029 $/kWh) for the network system. This value also represents the potential revenue if geothermal power is sold at the price of conventional electric-powered network system.

5. RESULTS AND DISCUSSIONS

5.1. Thermodynamic Analysis Results of System

The geothermal power plant operates on a liquid dominated resource at 200°C with a mass flow rate of 100 kg/s. Under realistic operating conditions, 8063 kW power can be produced in the flash-binary geothermal power plant. The produced power is used for the electrolysis process. The electrolysis water can be preheated to 25ºC by the geothermal water leaving the power plant and hydrogen can be produced at a rate of 0.0514 kg/s. The actual specific work input for the electrolysis of hydrogen is calculated to be 156,860 kJ/kg H_2 or 43.57 kWh/kg H_2 at an electrolysis water temperature of 25 ºC. The energy and exergy inputs from the geothermal water are calculated to be 74,734 kW and 16,227 kW. The net power output from the overall system when it is worked full load is calculated to be 13,085 kW (8063 kW for geothermal plant and 4985 kW for fuel cell). When the grid is not worked in the off time, all generated power from the geothermal plant is used for hydrogen production in the electrolysis unit. Hydrogen gas is stored in the tank and power control unit to use for later. The fuel cell is fed with hydrogen gas from the electrolysis unit. Electricity power production is calculated to be 4985 kW from the fuel cell with full load working conditions.

The energy and exergy efficiencies of the flash-binary geothermal power plant are 10.7% (8063/74,734 = 0.107) and 65.9 % (8063/12,227 = 0.659), respectively. The corresponding efficiencies for the electrolysis system are 76.6% and 74.5%, respectively. The multi generation system net power output is calculated to be 13,048 kW (8063 kW for geothermal plant and 4985 kW for fuel cell) for system full time load. But, semi load study condition, all power is converted to the hydrogen gas in electrolysis unit to feed the fuel cell unit. In that time, net power output of the system is calculated to be 4985 kW. The energy and exergy efficiencies of the multi generation power system, when it is worked with full load, are calculated to be 17.4% ((8063+4985)/74,734 = 0.174) and 80% ((8063+4985)/16,227 = 0.80), respectively. This is to be expected, since additional power generation is added to the fuel cell unit during the system is worked with full load to the supply power for network grid system. In this study, two conditions have been conducted, first one of that is i) full load power production, total work output is calculated to be 13,048 kW and second one of that is ii) semi load working condition, total work output is depending on the fuel cell power generation. Net work output is calculated to be 4985 kW. When it is worked of the system in this condition, overall energy and exergy efficiencies are to be 6.67% and 30.7%.

5.2. Life Cycle Cost Analysis Results of System

The costs of a multi generational hydrogen and electricity power production system consist of investment costs and operational costs. The investment costs are mainly the cost of equipment (heat exchangers, pumps, valves…etc.) and piping system, mounting cost, and cost of the control system (sensors, PLC's, and other parts of control system). Operational costs are related to the operation of the system. The purchased equipment costs (PEC) and total cost of investment (TCI) are estimated based on the Aspen Plus economic analysis library (Aspen Plus, 2015) and updated to the values for January 1, 2016. When all economic parameters are contributed, the purchase and equipment costs and the capital investment cost of the system are calculated to be 7,870,000 and 17,767,735 $ (Table 2). Yearly system operation and maintenance cost is to be 200,000 $/yr. The installation of the geothermal assisted multigenerational power system will provide an annual monetary benefit of 3,190,000 $/yr (Levelized annual cost, LAC) on the entire lifetime of the project for the full capacity working condition of the system. The annual saving cost is calculated to be 5,429,000 $/yr depending on the market value of the electricity. According to the market cost of electricity, the electricity selling price is taken to be 0.05 $/kWh. The unit product cost of electricity (UPC) of the system is calculated to be 0.029 $/kWh. The annual electricity production rate is calculated to be 180,600,000 kWh/yr, when the system is worked with full load working condition. The unit exergetic cost of electricity produced in the geothermal power plant is 0.012 $/kWh and that of produced hydrogen unit product cost is calculate to be 2.696 $/kg H2 from the electrolysis unit. When the system is worked with off time load condition, so electricity is directly send to electrolysis and then produced hydrogen is used for fuel cell unit for power generation. In this condition, the net power output of the system is to be 4985 kW from the fuel cell power generation side. In the second condition, the levelized annual cost value of the system is calculated to be 1,495,000 $/yr on the entire life time of the system. The annual electricity production rate is calculated to be 41,490,000 kWh/yr, when the system is worked with off time load working condition. In this conditions, the unit product cost of electricity (UPC) of the system is calculated to be 0.036 $/kWh. Simple payback period and discount payback period are calculated to be 3.27 and 4.16 years. As given below figures, parametric studies are performed at varying geothermal source temperatures while operating conditions that performed the unit production cost of hydrogen and electricity are obtained in different working conditions. The effect of geothermal temperature at the geothermal assisted power generator system outlet on the hydrogen unit production cost is given in Fig. 2.

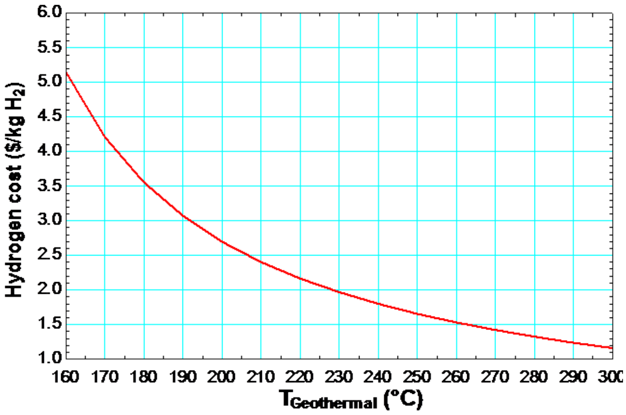

Figure 2. Variation of unit production cost of hydrogen as a function of geothermal water temperature at electrolysis unit.

It is investigated the effect of geothermal water temperature on the unit production cost of electricity, as shown in Fig 4. The unit electricity cost of system decreases with increasing geothermal water temperature. At higher geothermal temperatures, more power capacity is supplied and more revenue is generated.

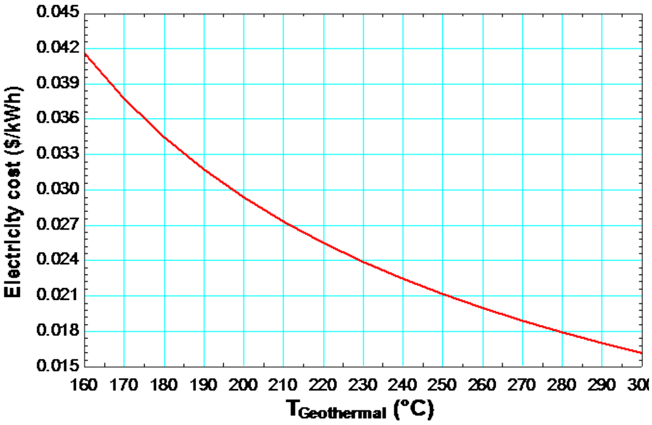

Figure 3. Variation of unit production cost of electricity as a function of geothermal water temperature.

Fig. 4 shows the effect of geothermal water temperature on the simple payback period (N_{spp}) and discount payback period (N_{dpp}). As the geothermal temperature increases the payback periods decrease. This can be explained due to the fact that higher energy efficiency and power loads are achieved at higher geothermal temperatures and the multigenartional system can pay for itself in shorter time periods.

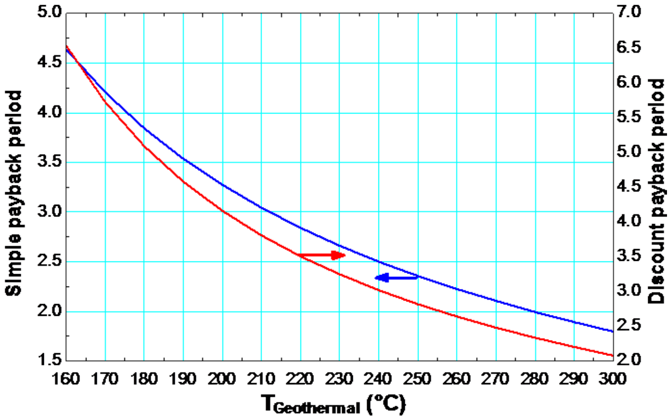

Figure 4. Variation of simple and discounted payback periods as a function of geothermal water temperature.

3. CONCLUSIONS

This study helps give a good insight to researchers and designers working in areas of hybrid renewable energies and hydrogen/electricity production systems for better operation and assessment. In a future work, a thermo-economic assessment of this system is aimed. A geothermal energy driven hydrogen/electricity power generation system is considered. Thermodynamic and economic investigation of geothermal powered system for power generation has allowed several main considerations to be drawn.

- In this paper, it has been analyzed the full time power load of the thermodynamic and economic analysis of geothermal sources and determined the performance of the hydrogen and electricity production system to be satisfactory. It has been shown that this geothermal source can be utilized better for a case study of Turkey.
- The peak power rate is determined to be 13,048 kW. The energy and exergy efficiencies of the system are determined to be 17.% and 80%. Parametric studies results show that hydrogen and electricity power production costs are decreases with geothermal water temperature increasing. The annual power cost (or

annual potential revenue) is calculated to be 5,429,000 \$/yr. The geothermal energy is provided an annual monetary benefit of 3,190,000 \$/yr on the entire lifetime of the system by the life cycle cost analysis. According to this approach, the unit product hydrogen and electricity cost are calculated to be 2.696 \$/kg H_2 and 0.029 \$/kWh, respectively.

- Simple payback period and discount payback period are calculated to be 3.27 and 4.16 years. Also, Parametric studies results show that simple payback period (N_{spp}) and discount payback period (N_{dpp}) decreases with geothermal water temperature increasing. The use of geothermal energy for hydrogen/electricity production provides good return on investment. It also help environment by eliminating the emission of pollutants associated with the combustion of fossil fuels and the generation of electricity.
- Geothermal energy and fuel cell systems are the best suited for multigenerational power applications. For comparable installation costs and cooling offer much high return on investment than geothermal power generation

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NOMENCLATURE

c	unit energy cost (\$/kJ)
$\dot{C}$	energy cost rate (\$/h)
CRF	capital recovery factor
h	enthalpy (kJ/kg)
i	interest rate (%)
LAC	levelized annual cost (\$/yr)
$\dot{m}$	mass flow rate (kg/s)
N	period (year)
OMC	operating and maintenance costs (\$/yr)
PEC	purchased equipment cost (\$)
P	present value of the payment (\$)
$\dot{Q}$	heat (kW)
r_n	nominal escalation rate (%)
T	temperature (ºC)
TCI	total cost of investment (\$)
T_0	environment temperature (ºC)
$\dot{W}$	power (kW)
U	uniform series amount of money (\$)
UPC	unit product cost (\$/Wh)
UEC	unit electricity cost (\$/kWh)
$\dot{Z}$	equipment cost rate (\$/h)

Subscripts

0	dead states
act	actual
elect	electricity
cond	condenser
dpp	discount payback period
geo	geothermal
rev	reversible
spp	simple payback period

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