Thermodynamic analysis of Solar Geothermal Power Cycle

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ABSTRACT- Solar geothermal power cycle was developed with a Flash chamber is used for power production, in which the geothermal mass under goes flashing process for production of steam. In Thermodynamic Analysis of Solar Geothermal power cycle a Heat exchanger is used and analysed instead of Flash chamber in which lot of geothermal mass is extracted for power production, such that there will be reduction in geothermal energy consumption and the efficiency can also be increased with the same available data of the one with flash chamber. For a 50 MW turbine, with an inlet temperature of 533 ^{0}C, condenser exit temperature as 50 ^{0}C, cooling water circulation at 2 ^{0}C, Geothermal mass extraction temperature at 200 ^{0}C from earth crust and ambient temperature during day time is taken as 38.1 ^{0}C, the solar radiation data can be taken as per the location from NASA data sheets, the efficiency of the plant has been analysed and found it to be improved by 4.7% and the consumption of geothermal fluids is reduced from 44.1kg/s to 13kg/s when heat exchanger is used. Energy and Exergy analysis of each component of Solar Geo Thermal power plant is analyzed to find the losses and to identify the points where rework is required and a computer code using Java language has been generated.

Keywords – Energy, Enthalpy, Entropy, Exergy, Geothermal Energy, Heat Exchanger, Mass, Power Cycle, Solar Energy, Thermodynamic analysis, Radiation.

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1. Introduction

In recent years the conventional energy sources are depreciating day by day demanding for alternate energy sources, and are looking towards renewable energy sources like Solar, Geothermal, Tidal, and Wind...etc. Coming to Thermal power generation, it consumes lot of conventional sources for its operation now a day. So, there is a need for developing thermal power plants that can operate on renewable sources of energy.

Most of the power plants that operate on renewable sources of energy will have certain drawbacks. In order to reduce their disadvantages and to attain more advantages, combined cycles that operate with different renewable sources is used. In such cycles, solar energy is coupled with geothermal, solar coupled with biomass, solar coupled with wind energy …etc. are used to get uninterrupted power supply as solar energy is not a continuous source of energy. This increases the overall efficiency of the cycle as well as reduces the drawbacks when they operated individually.

Solar and geothermal power cycle which is currently running is one of the solutions to conventional thermal power plants. The world's first solar-geothermal power plant [1] was dedicated in Fallon, Nevada. It operates on Rankine cycle [2] provide 50 megawatts (MW) of combined capacity to power more than 50,000 local homes.

To provide the solar energy, Enel Green Power North America (EGP) [3, 9] installed more than 89,000 polycrystalline photovoltaic panels on a 240-acre parcel of land adjacent to the Stillwater geothermal plant, which opened in 2009. In Solar Geothermal power plant the geothermal power plant is coupled with concentrated solar power plant.

Solar-Geothermal Hybrid Cycle Analysis for Low Enthalpy Solar and Geothermal Resources [4-8] has been analysed by many researchers.

In Solar-geothermal power plant with heat exchanger, the geo fluids collected in a chamber from the earth crust are made to pass through a heat exchanger and is sent back to the rejection well to maintain back pressure. The water that passes through this heat exchanger gets heated and then flows through another heat exchanger which is attached to the solar field [10-16]. Then the resultant steam is made to pass through the turbine where expansion takes place and then it is passed through a condenser to decrease its pressure and the process continues. Depending upon the solar energy availability the number of tubes through which HTF flows will be changed and during night time the mass of geothermal energy that flows through heat exchanger is increased to maintain continues power production.

Exergy and Energy analysis is aimed to determine which component of the system should be revised first to raise the efficiency and decrease the loss of Exergy and Energy [17-18]. For this purpose, First and second law analysis of thermodynamics is applied to each component due to consider the effects of environmental conditions and take the quality of energy into consideration as well as the quantity of it. The Exergy and Energy balance equations are produced and Exergy loss and Energy loss is calculated for each component.

1. Solar Geo Thermal power plant layout

The following is the schematic diagram for Thermodynamic analysis solar geothermal power cycle

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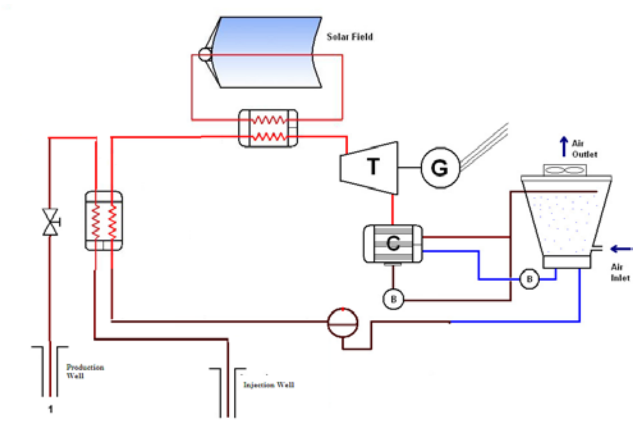
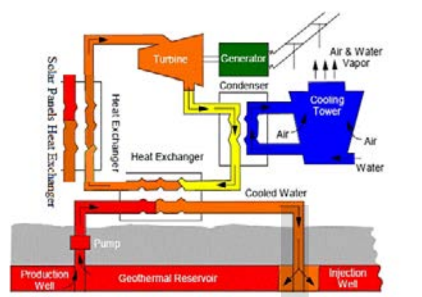


Schematic diagram of Solar – Geothermal power plant



The first law of thermodynamics is simply a statement of the conservation of energy principle, and it asserts that total energy is a thermodynamic property. Energy transfer to or from a system by heat, work and mass flow was discussed. In this work, the general energy balance relation, which is expressed as Ein - Eout = Esystem, is developed in a step-by-step manner using an intuitive approach. The geo mass from earth crust is made to pass through heat exchanger and then allowed to reject back in to the crust to maintain back pressure. Then the heated fluid is further passed through solar heat exchanger where it gets further heated and converts into steam and is allowed to pass through turbine where it expands and enters the condenser. A cooling tower is provided to cool the rejected water, which further circulated through heat exchanger through which geo fluid is circulated and forms a closed cycle. The energy balance is first used to solve problems that involve heat and work interactions, but not mass flow (i.e., closed systems) for general pure substances, ideal gases, and incompressible substances. Then the energy balance is applied to steady flow systems, and common steady-flow devices such as nozzles, compressors, turbines, throttling valves, mixers, and heat exchangers are analyzed. Solar heat exchanger and geothermal heat exchanger are sized as per the requirement. Therminol VP_1 which operates in the range of 12 to 400 ^{0}C is taken as the heat transfer fluid in case of solar heat exchanger.

The components that are used in this power plant are Turbine, Condenser, Geothermal Heat exchanger and Solar Heat exchanger. Energy analysis of each component is done and the results are tabulated.

3. Methodology

Calculations

Geothermal Heat exchanger

$$M_h = 44.33 - (0.336 \times p) - (0.1357 \times p \times p)$$

Heat supplied by solar energy

Solar Energy mostly depends on the solar radiation in a particular day, taking value of solar radiation at 6.00am in the morning,

$$I_{incident} = I_b \times \cos\theta$$

$$E_{in} = I_{incident} \times A = 814.5 \text{ w}$$

$$E_{out} = 0.41 \times (T_{in}-T_{day}) + 1.21 \times 10^{-8} \times (T_{in}-T_{day})^4$$

After getting the values of energy input and energy out for a solar field, next the minimum amount heat transfer fluid has to be determined by using the relation:

$$M_{htf} = (E_{in} - E_{out}) / ((T_{in}-T_{out}) \times (CpVp_1))$$

$$\eta_{Cycle} = W_{net}/q_{net.}$$

3.1 Energy Losses

Turbine:

$$M_1 \times h_1 = M_2 \times h_2 + E\text{ (turbine losses)} + W_t$$

Condenser:

The relations that are useful in determining energy losses in Condenser are:

$$M_c \times h_c + M_s \times h_2 = M_c \times h_h + M_s \times h_3$$

Geo Thermal Heat Exchanger:

$$Q_h = Q_c + E\text{ (heat exchanger)}$$

Solar Heat Exchanger:

$$Q_h = Q_c + E\text{ (heat exchanger)}$$

3.2 Exergy Analysis

Turbine:

$$M_1 \times a_1 + Q \times (1 - \frac{T0}{T}) = M_2 \times a_2 + W_t + I$$

Condenser:

$$M_2 \times a_2 + M_4 \times a_4 = M_3 \times a_3 + M_5 \times a_5 + I$$

Geo Thermal Heat Exchanger:

$$(1-[\frac{T0}{Tinlet}])Q + (M_h \times a_1 + M_c \times a_3) - (Mh \times a_2 + M_c \times a_4) - I = 0$$

Solar Heat Exchanger:

$$(1-[\frac{T0}{Tinlet}])Q + (M_h \times a_1 + M_c \times a_3) - (M_h \times a_2 + M_c \times a_4) - I = 0$$

4. Results and Discussions

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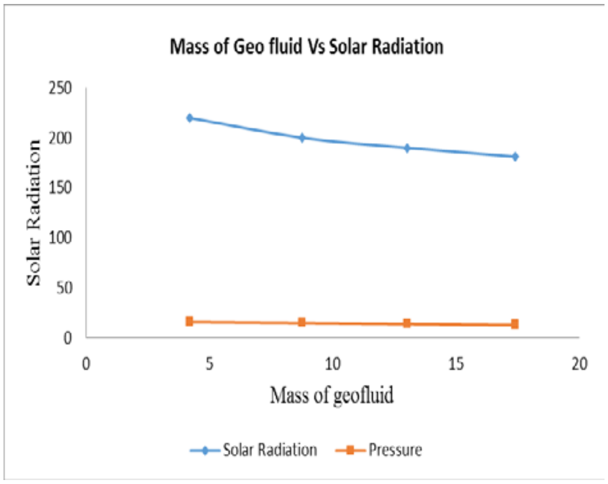
The different parameters like solar radiation, month of the year, cycle efficiency are plotted to obtain their optimum conditions.

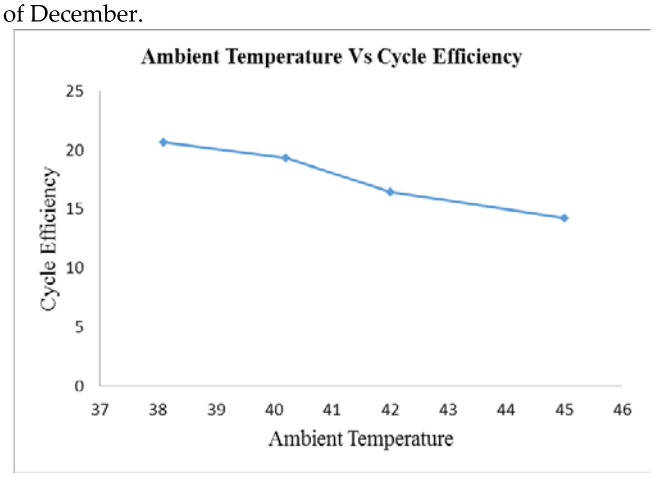


Mass of Geo fluid vs solar radiation at different pressures

In geothermal mass extraction, when pressure increases, there will be decrease in mass extraction. This phenomena is provided for varying geothermal extraction depending upon the solar radiation in day time. Hence from the above graph it can be said that with increase in pressure, geothermal extraction is reduced as well as solar radiation is increased.

Solar Radiation Vs Month at Early Hours of first day of every month

The Solar radiation depends on many factors out of which climate at a particular location and time are major factors. The above graph shows the variation of solar radiation of Nevada in each and every month starting from January to the end of December.

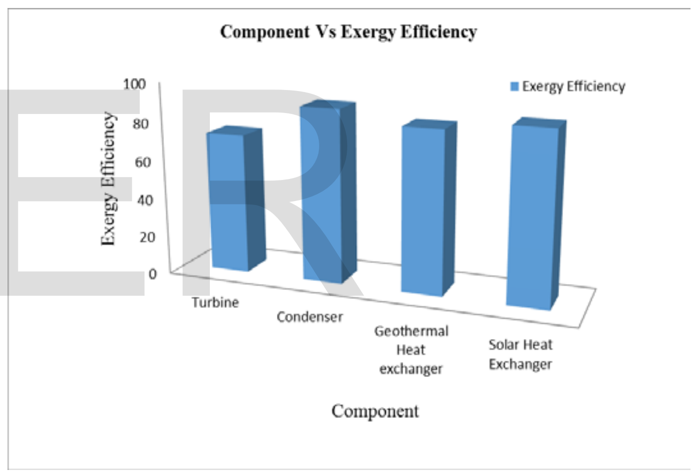


Ambient Temperature Vs Efficiency

As the power plant is coupled with the solar field, the temperature of the particular day (ambient temperature) plays important role in finding the efficiency of the cycle. From the above graph it can be concluded that if ambient temperature increases beyond a limit, the efficiency instead of increasing, it starts decreasing. This is the solar energy out will increase; whereas the capacity of plant cannot be increased. Hence after the limit instead of increase in efficiency, there will be a decrease in the efficiency of the cycle.

Component Vs Energy Efficiency

Energy losses in each component of the power plants helps in finding where there is more loss and by changing the parameters, it can be reduced such that the efficiency of the cycle improves. From the above graph, it can be concluded that there is high energy loss in turbine. Hence by incorporating a reheater or a regenerator, the efficiency of cycle can be increased.



Components Vs Exergy

Exergy analysis is done to find the irreversibilities in the components of the power plant. The above graph is drawn from the results obtained by the Exergy analysis of each component like Turbine, Condenser, Geothermal heat exchange and solar heat exchanger. From the graph it can be concluded that, there is high irreversibility in condenser and hence by increasing the temperature of water circulating in the condenser, the irreversibility can be reduced.

5. Conclusion

Solar Geothermal power plant with a heat exchanger had been analysed and it is found that the efficiency of the cycle is improved by 4.7% (which is 15.69% when a flash chamber is used and it is 20.99% when heat exchanger is used) and the consumption of geothermal fluids can also be reduced. When a flash chamber is used it is 44.1kg/s and 13kg/s when heat exchanger is used.

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