**Potential of Reducing CO₂ Emission Using Parabolic Trough Collector for 13.75 MW Desalination Processes**

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**ABSTRACT**

Desalination is an important process in fulfilling the freshwater demands of both the industrial sector and human needs. Typically, thermal desalination processes rely on fossil fuels to minimize production costs. However, using fossil fuel in desalination contributes to releasing CO₂ emissions into the atmosphere. Therefore, it is essential to utilize renewable energy sources to mitigate the production of CO₂ emissions. To reduce CO₂ emissions research has been conducted to explore the potential use of parabolic trough solar collectors in harnessing available solar energy at the power plant site for thermal desalination processes which required 13.75 MW of thermal energy. The study utilized the system advisor model software to assess the collector's system performance. The research findings indicate that 416 units of parabolic trough solar collectors are required to fulfill the thermal power needs. The presence of these solar collectors has the potential to generate 26.06 GWh of thermal power, thereby reducing coal consumption by 5,740.4 metric tons per year and directly lowering CO₂ emissions by 13,892 metric tons per year.

**INTRODUCTION**

Desalination is the process of treating water with high salinity and mineral content to convert it into freshwater. The desalination process is common in various industrial sectors worldwide, including power generation, refining, oil & gas, electronics, food & beverage, mining, metal, pulp & paper, textile, and drinking-water supply [1]. It is estimated that there are approximately 18,000 desalination units scattered across the globe with a total freshwater production capacity reaching 38×10⁹ m³/year [1, 2]. It makes the desalination process a crucial component in providing freshwater for industrial and human needs. Based on its technology, the desalination process is divided into two groups: thermal desalination and non-thermal desalination (Figure 1) [3, 4]. Thermal desalination basically done through distillation processes which require a thermal energy source, and non-thermal desalination method is done by using any other forms of energy.

**Figure 1. Desalination Method** [4]

The use of desalination technology is dominated by reverse osmosis (RO) with a percentage of 69%, followed by multi-stage flash (MSF) at 18%, multi-effect distillation (MED) at 7%, and other technologies accounting for 6% (Figure 2) [1, 5].
Among the various thermal desalination technologies available, MSF (Multi-Stage Flash) is hailed as the most mature desalination technology and dominates 90% of the thermal desalination processes conducted worldwide [6]. In addition, the production cost of freshwater using MSF technology is the lowest compared to other thermal desalination processes, making it the preferred choice, especially in the Middle East region [7, 8].

Low production cost of traditional thermal desalination processes is generally attributed to the utilization of cheap energy sources derived from fossil fuels such as oil, gas, and coal [2, 5, 7, 8]. Therefore, thermal desalination technology is commonly preferred in coal-fired power plants that rely on fossil fuels as their primary source of fuel, such as the use of MSF technology in power plants that are the subject of this research. Because of that, the desalination process directly contributes to the addition of greenhouse gas emission (mainly CO₂) released by the power plant. It is essential to utilize other energy sources such as renewable energy to make thermal desalination processes cleaner.

The Ministry of Environment and Forestry of the Republic of Indonesia (KLHK RI) in 2020 states that the energy sector contributes approximately 67.84% of the total greenhouse gas emissions released into the atmosphere [9]. That means the energy sector contributed for the majority of greenhouse gas emission and take part for global warming and causing climate change. In 2022, the Ministry of Energy and Mineral Resources of the Republic of Indonesia (KESDM RI) has set a target to reduce 5.36 million metric tons of CO₂ emissions generated from power plants [10]. This target means an effort to slowing down the global warming and has been responded to by power plant administrator through the utilization of renewable energy sources, such as: the installation of solar panels on the roofs of administrative buildings [11], fuel substitution with biomass pellets [12], replacement and blending of different types of coal, efficiency improvements, and other innovations.

Indonesia is a country with abundant potential for renewable energy sources, and one of the abundant renewable energy sources available is solar energy with a potential reaching 4.8kWh/m² [13]. If harnessed and integrated with industrial processes, the significant potential of solar energy can assist in reducing greenhouse gas emissions and ensure the operational sustainability of power generation industries, aligning with the targets set by the Government of Indonesia.

Solar energy can be harnessed using solar collectors to generate thermal energy for industrial heat processes, such as thermal desalination in a power plant. The utilization of solar collectors has the potential to reduce the amount of fossil fuel burned and subsequently decrease CO₂ emissions and help slowing down the global warming. One solar collector technology that can be integrated with the desalination process in the power plant is the Parabolic Trough Collector (PTC) [14] (Figure 3). The development of this collector type in the past 18 years has focused on harnessing the thermal energy generated for industrial process heat (IPH) and electricity generation purposes [15]. PTC possesses characteristics of high efficiency and a wide operating temperature range. On average, the efficiency of this solar collector type is above 70%, and it can operate within a wide temperature range of 50°C to 400°C [16].

The utilization of the generated thermal energy can be done through direct or indirect means, with the following details: In the direct method, the thermal energy generated by solar collectors is used to generate steam with specific quality for direct use in industrial processes, and in the indirect method, the thermal energy generated by solar collectors is transferred to a specialized working fluid. This working fluid is then directed to a heat exchanger to convert water into steam that will be used in industrial processes [17].
Figure 3. Parabolic Trough Collector

METHOD
The Configuration of Solar Collector Utilization for Thermal Desalination

In order to be utilized in the desalination process, solar collectors will be assembled into a solar field. The array of solar collectors will be used to generate steam, which is then utilized in the desalination process using the MSF technology present in the power plant within the research area. Figure 4 shows the configuration of solar collector utilization for desalination processes. However, this study does not consider the use of thermal energy storage systems to assess the performance of solar collectors in supplying thermal energy under varying sunlight conditions.

Figure 4. Configuration of Solar Collector Utilization for MSF Desalination

Figure 5 shows the system modelling using system advisor model (SAM). The MSF desalination considered as a heat sink with constant demand of thermal energy. The research is conducted by utilizing the technical specifications of the desalination plant in the power plant to determine the solar collector system. The study utilizes data from the Typical Meteorological Year (TMY) for the period of 2016-2020 provided by the National Solar Radiation Database (NSRDB), within the research area [18]. Then the simulation is performed using SAM to generate a performance overview of the system [19, 20]. The performance overview, primarily the thermal energy generated by the solar field then used to find the mass of coal to generate an equal amount of thermal energy.

Figure 5. System Modelling in SAM

Collector’s Profile

Mathematically, a parabola can be represented using a coordinate system with the following equation.

\[ x^2 = 4fy \]  

(1)

The values of x and y represent the coordinates on the x-axis and y-axis of the coordinate system, while f represents the focal point of the parabola.

Collector’s Aperture Area (A_a)

The aperture is the area of the solar capture surface (a reflector) when viewed from the top of the collector. The aperture area can be calculated using equation 2.

\[ A_a = l \times w \]  

(2)

With:

- \( l \) = Reflector Length (m)
- \( w \) = Reflector Width (m)

Collector’s Optical Efficiency (\( \eta_o \))

Optical efficiency is the value of the ratio between the energy accurately reflected towards the absorber and the energy received by the reflector with an area (\( A_a \)). The optical efficiency can be calculated using equation 3 [21].

\[ \eta_o = \rho_m \tau_c a_n \gamma \cos(\theta) \]  

(3)
The mass of coal $\text{coal}_A$ can be calculated using the equation:

$$\text{coal}_A = \eta \times K = \frac{Q_{\text{load}}}{Q_{\text{load}}/1000}$$

With:
- $\eta$ = Boiler's Efficiency
- $Q_{\text{load}}$ = Thermal Energy Required by Load (W)

The value of $Q_{\text{load}}$ is provided by the technical specification of the MSF desalination available with a 13.75 MW thermal energy requirement.

### Coal Mass

The equal mass of coal burned by the boiler can be estimated using equation 8 with a known value of average boiler efficiency and coal GCV. The mass of coal that can be reduced with the presence of solar collectors can be used to determine the CO₂ emissions.

$$m_{\text{coal}} = \frac{Q_{\text{steam}}}{\eta_b \times GCV}$$

With:
- $\eta_b$ = Boiler's Efficiency
- $Q_{\text{steam}}$ = Steam Thermal Energy (kJ/s)
- $m_{\text{coal}}$ = Coal Mass Flow (kg/s)
- $GCV$ = Gross Caloric Value (kJ/kg)

The value of $Q_{\text{steam}}$ in the equation 8 can be substituted by $Q_{SF}$ in equation 6.

### RESULT AND DISCUSSION

Meteorological Conditions of the Research Area

Table 1 presents a summary of meteorological information from the research area. Based on Table 1, it is found that the research area has a solar energy potential reaching 5.41 kWh/m²/day that is 12.7% higher than the average (4.8 kWh/m²) for the regions in Indonesia.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>-5.87°</td>
<td>°</td>
</tr>
<tr>
<td>Longitude</td>
<td>106.02°</td>
<td>°</td>
</tr>
<tr>
<td>Time Zone</td>
<td>GMT+7</td>
<td></td>
</tr>
<tr>
<td>Elevation</td>
<td>1</td>
<td>MASL</td>
</tr>
<tr>
<td>GHI</td>
<td>5.41</td>
<td>kWh/m²/day</td>
</tr>
<tr>
<td>DNI (beam)</td>
<td>3.36</td>
<td>kWh/m²/day</td>
</tr>
<tr>
<td>DHI</td>
<td>3.00</td>
<td>kWh/m²/day</td>
</tr>
<tr>
<td>Average</td>
<td>28</td>
<td>°C</td>
</tr>
<tr>
<td>Average Wind Speed</td>
<td>2.4</td>
<td>m/s</td>
</tr>
</tbody>
</table>
Figure 6 illustrates the monthly average variation of DNI received by the research area. The monthly variation in DNI will influence the determination of DNI values for system design to achieve high performance and availability throughout the year [15].

Figure 6. Monthly DNI Profile of Research Area

The Number of Collector’s Module

The determination of DNI is based on the TMY data from the research area. By taking the average daily DNI value received by the research area of 600 W/m², the number of solar collector modules required to meet the thermal energy of 13.75 MW is 416 units of PTC modules. The calculation results are summarized in Table 2.

Table 2. Number of Solar Collector

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNI_{Design}</td>
<td>600</td>
<td>W/m²</td>
</tr>
<tr>
<td>Number of PTC Module</td>
<td>416</td>
<td>Module</td>
</tr>
<tr>
<td>$A_a$</td>
<td>35.580</td>
<td>m²</td>
</tr>
<tr>
<td>$\eta_o$</td>
<td>68</td>
<td>%</td>
</tr>
<tr>
<td>$Q_{solar field}$</td>
<td>13.57</td>
<td>MW</td>
</tr>
<tr>
<td>Solar Multiple</td>
<td>1.06</td>
<td>times</td>
</tr>
</tbody>
</table>

Thermal Energy Supplied

Based on the simulation results (Figure 7), it is found that during a day of operation, the solar collector system can supply 71.4 MWh thermal energy. In a year the energy supplied by it reach 26.06 GWh with a capacity factor of 20.6%. The relatively low-capacity factor is expected in the utilization of renewable energy sources, compounded by the absence of thermal energy storage considerations. The absence of thermal energy storage means the solar field can only supply thermal energy when sun is available during the day and stop generating thermal energy during the night or when the sun is not available.

Figure 7. Thermal Energy Supplied in Year One

Potential Reduction in Coal Consumption

During a day of operation, the solar collector system can generate average 71.4 MWh thermal energy that equal with burning 15.3 metric tons of coal. Therefore, over the course of 1 year, the total reduction in coal consumption amounts to 5,740.4 metric tons (Figure 8).

Figure 8. The Reduction of Coal Consumption per Year

Potential Reduction in CO₂ Emission

The combustion process of every 1 kg of coal typically generates approximately 2.42 kg of CO₂ gas. Utilizing the daily thermal energy generated by the solar collector system, as obtained in the previous subsection, the potential reduction in CO₂ emissions amounts to 38.06 tons per day, or equivalently, 13,892 metric tons of CO₂ per year (Figure 9).

The existence of a solar collector system can provide benefits for the environment and help slow global warming by reducing the amount of CO₂ released into the atmosphere. When the impact of reducing other greenhouse gas emissions such as SOₓ and NOₓ, particulates such as fly ash, and
solids such as bottom ash and heavy metals from reducing the mass of coal burned is taken into account, this could be reducing the burden of processing flue gas, particulate waste, and other by-products that must be carried out by the power plant and also has the potential to improve air quality for local residents. This potential needs to be investigated in more in-depth research.

CONCLUSION

Research on the Potential Reduction of CO₂ Emissions using Parabolic Trough Solar Collectors for Industrial Process Heat has concluded that the solar collector system can generate a total of 26.06 GWh of thermal energy in a year. This has the potential to reduce coal consumption by 5,740.4 metric tons and CO₂ emissions by 13,892 metric tons. The study highlights the significant contribution of solar thermal energy in reducing both coal consumption and greenhouse gas emissions in thermal desalination processes.

REFERENCES


