Abstract—Carbon dioxide from exhaust heat emission is one of the major contributors to the environmental pollutant in power generation plants. This problem could be addressed if the emitted exhaust heat is recovered. In cogeneration plant, the exhaust heat from the gas turbine is used to generate steam using Heat Recovery Steam Generator. The steam from Heat Recovery Steam Generator is then used for chilled water generation in Steam Absorption Chillers by absorption process. This study analyzed the total estimated amount of CO\textsubscript{2} released to the environment due to chilled water production by using gas turbine exhaust heat. University Teknologi Petronas, Malaysia cogeneration system is used as a case study. The energy balance principle was adopted for the analysis. Results indicate that approximately 44% of CO\textsubscript{2} is avoided from being released to the environment by this process.

Index Terms—Absorption process, carbon dioxide emission, cogeneration and exhaust heat.

I. INTRODUCTION

It is a common practice to use chilled water as a cooling medium for district cooling systems. Chilled water is generated by absorption process in cogeneration systems. Cogeneration systems can be defined as the simultaneous production of electrical or thermal energy from a single energy source, by capturing exhaust heat from the gas turbines which would otherwise be rejected to the environment [1]. Cogeneration system has been installed to enhance the efficiency of generated power compared to the conventional plant. The enhancement is achieved through the utilization of exhaust heat from the gas turbine to generate additional energy.

The cogeneration system consists of Gas Turbine (GT), Heat Recovery Steam Generator (HRSG) and Steam Absorption Chiller (SAC). GT generates electricity for the power supply. During the generation of power by GT, exhaust gas is released to the environment. The exhaust heat is captured and diverted to HRSG for steam production. The steam in turn is channeled to SAC for the generation of chilled water. In the process of steam and chilled water generation heat is generated which is represented as heat loss in Fig. 1. However, the amount of heat loss recovered from the GT for chilled water generation by absorption process assists in enhancing efficiency of the cogeneration system as well as reduced the emission of exhaust heat to the environment thus reducing CO\textsubscript{2} emission.

Carbon dioxide (CO\textsubscript{2}) emission is one of the major sources contributed to the environmental pollutant. CO\textsubscript{2} emission released to the environment by combustion of fossil fuels in transportation, manufacturing industries and the power generation system. In many power generation systems, the source of CO\textsubscript{2} emission is the combustion process of the fuel. CO\textsubscript{2} released to the environment by the combustion process gives rise to several environmental concerns which can threaten the sustainability of our ecosystem. Thus, a study on the CO\textsubscript{2} emissions could assist in mitigation of this problem.

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Fig. 1. Schematic diagram for cogeneration system.

II. METHODOLOGY

In order to assess the CO\textsubscript{2} emissions, an energy balance model was developed based on the principle of First Law Thermodynamics. Using the energy balance model, the heat loss for GT, HRSG and SAC were evaluated. Based on the heat loss, the CO\textsubscript{2} emission is then estimated from GT and HRSG.

A. Energy Balance Model

Fig. 2 shows a typical model for the GT. The GT consists of a compressor, combustor and turbine section. Ambient air is first compressed in the compressor. Fuel is added and combusted in the combustor. Most GT applications rely on natural gas or fuel oil for fuel. The combustion products exit the combustor and expand in the turbine section. The expansion drives an electric generator to generate electricity. The exhaust heat from the turbine is normally used to produce process steam or hot water. The steam in turn could
either be used to power steam turbine or to produce chilled water for absorption process.

![Typical GT system](image)

**Fig. 2. Typical GT system.**

Fig. 3 shows the energy balance model for the GT. For the analysis of the GT, the following assumptions were used:

- The gas turbine engine was at steady state.
- The process at the gas turbine was an adiabatic process.
- Heating due to lubrication was eliminated.
- Only 66.6% of the exhaust heat from the GT was taken into account of the steam conversion. The remaining is 33.4% of the exhaust heat was released to the environment [9].

![Energy balance model for GT](image)

**Fig. 3. Energy balance model for GT.**

The heat loss is the exhaust heat released to the environment. The amount of exhaust heat used steam conversion was the energy input for HRSG. The energy balance model for HRSG and SAC are shown in Fig. 4 and Fig. 5 respectively.

![Energy balance model for HRSG](image)

**Fig. 4. Energy balance model for HRSG.**

![Energy balance model for SAC](image)

**Fig. 5. Energy balance model for SAC.**

**B. Heat Loss**

The energy balance equation was used to evaluate the energy input, energy output and the difference between them by using Eq. (1) [10].

\[
m_{i} \left( h_{i} + \frac{V_{i}^2}{2} + Z_{i} \right) + Q = m_{o} \left( h_{o} + \frac{V_{o}^2}{2} + Z_{o} \right) + W
\]

where \( m_{i} \) is mass flow rate (kg/s), \( h \) is enthalpy (kJ/kg), \( V \) is velocity (m/s), \( Z \) is elevation (m), \( Q \) is the rate of heat and \( W \) is power generated by the system. Mass and energy balance for any control volume with negligible potential and kinetic energy is expressed by Eq. (2);

\[
m_{i}(h_{i}) + Q = m_{o}(h_{o}) + W
\]

1) **For the case of GT:**

The exhaust heat released by the turbine was calculated as [11].

\[
\text{Energy loss (GT)} = m_{g3}C_{pex}T_{ex}
\]

where \( m_{g3} \) is mass flow rate (kg/s), \( T_{ex} \) is exhaust heat temperature (K) and \( C_{pex} \) is specific heat of gas for the exhaust temperature (kJ/kg.K)

2) **For the case of HRSG:**

The HRSG generated steam by utilizing the energy in the exhaust heat from the gas turbine. Three assumptions were used to analyze the model namely [12]:

a) The temperature of steam coming out from HRSG was kept constant at 177°C.

b) The flow rate of steam from HRSG was 5.5T/h.

c) The total steam generated by HRSG was taken as energy input to SAC.

The heat loss for HRSG was calculated as:

\[
\text{Energy loss (Heat loss)} = \text{Energy}_{in} (\text{from exhaust heat}) - \text{Energy}_{out} (\text{from steam})
\]

The calculation of energy in HRSG was expressed by :

\[
\text{Energy}_{in} (\text{HRSG}) = m_{ex}C_{pex}T_{ex}
\]

where \( m_{ex} \) is mass flow rate of exhaust heat (kg/s), \( C_{pex} \) is specific heat of gas for the exhaust temperature (kJ/kg.K) and \( T_{ex} \) is exhaust heat temperature (K). For the amount of energy out was calculated as:

\[
\text{Energy}_{out} (\text{HRSG}) = m_{st}C_{pst}T_{st}
\]

where \( m_{st} \) is mass flow rate of steam (kg/s), \( C_{pst} \) is specific heat of steam temperature (kJ/kg.K) and \( T_{st} \) is steam temperature (K).

3) **For the case of SAC:**

In SAC, the steam from HRSG was converted to chilled water by absorption process. The heat loss due to this process was calculated as:

\[
\text{Energy loss (Heat loss)} = \text{Energy}_{in} (\text{from steam}) - \text{Energy}_{out} (\text{from chilled water})
\]
The amount of energy in SAC is the amount of energy out of the HRSG. Whereas the amount of energy out from SAC was calculated as:

$$\text{Energy}_{out\_SAC} = m_{chw}C_{p\_chw}\Delta T_{chw}$$

where $m_{chw}$ is mass flow rate of chilled water (kg/s), $C_{p\_chw}$ is specific heat of chilled water temperature (kJ/kg.K) and $\Delta T_{chw}$ is the difference of chilled water temperature (K) out and in of SAC.

C. CO₂ Emissions Evaluation

The equivalent of CO₂ being released to the environment was calculated based on kWh heat loss for each of the GT and HRSG respectively. The equivalent of CO₂ was based on 474 g/kWh as reported by R. Kannan et al. [13].

Since the heat loss by SAC is through cooling system, it is assumed the heat loss from SAC does not contribute to CO₂ emission.

The total of the amount of CO₂ for chilled water production by GT exhaust heat was estimated. Eq. (9) was used for analysis:

$$\sum CO_2_{(cogen)} = CO_2_{(GT)} + CO_2_{(HRSG)}$$

III. CASE STUDY

The absorption system of Universiti Teknologi Petronas (UTP) District Cooling plant as shown in Fig. 6 is taken as a case study. The plant started operation in April 2003. The plant operates on a 24 hour basis. During peak periods, the absorption system is operated with full load capacity. The exhaust heat from GT is used to generate steam by HRSG. A study on the conversion process has been done and the findings from the study indicate, only a maximum of 66.6% of the exhaust heat could be used to generate steam and the remaining was released to the environment [9]. The steam was used to generate chilled water by SAC. This study is to focus on the evaluation of CO₂ emission during the process of chilled water production by using exhaust heat from the GT.

CO₂ emissions can be reduced from power generation by implementing the best practice of technology. Fig. 8 shows, by utilization of exhaust heat from the GT to generate chilled water by absorption process will reduce the amount of exhaust heat released to the environment.

Fig. 8 shows the amount of heat loss from GT, HRSG and SAC by accounting 66.6% of the exhaust heat used for steam generation in the HRSG. The results indicate the average amount of the estimated heat loss from the GT during this period is equivalent to 3,262 kWh daily. From the analysis, it is estimated that the total average heat loss from GT, HRSG and SAC due to absorption process during this period is 10,700 kWh. It is shown by applying the absorption technology for a chilled water generation will reduce the amount of heat loss and it is also reduced the amount of CO₂ being released to the environment.

The estimation of CO₂ is used conversion factor from [13]. Fig. 9 shows the results for the estimated amount of CO₂ emitted to the environment by the GT and HRSG respectively during chilled water production using exhaust heat from GT.
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