MATEC Web of Conferences 38, 01009 (2016)
DOI: 10.1051/matecconf/20163801009

Study on Relative COP Changes with Increasing Heat Input Temperatures of Double Effect Steam Absorption Chillers

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Abstract. Absorption chillers at cogeneration plants generate chilled water using steam supplied by heat recovery steam generators. The chillers are mainly of double effect type. The COP of double effect varies from 0.7 to 1.2 depending on operation and maintenance practices of the chillers. Heat input to the chillers during operations could have impact on the COP of the chillers. This study is on relative COP changes with increasing the heat input temperatures for a steam absorption chiller at a gas fueled cogeneration plant. Reversible COP analysis and zero order model were used for evaluating COP of the chiller for 118 days operation period. Results indicate increasing COP trends for both the reversible COP and zero model COP. Although the zero model COP are within the range of double effect absorption chiller, it is not so for the actual COP. The actual COP is below the range of normal double effect COP. It is recommended that economic replacement analysis to be undertaken to assess the feasibility either to repair or replace the existing absorption chiller.

1 Introduction

Double effect LiBr-H_2O steam absorption chillers (SAC) at cogeneration plants are driven by steam from heat recovery steam generators (HRSG). The HRSG in turn are driven by exahaust gas from gas turbines. The choice of double effect SAC is due to its high COP in comparison to single effect SAC. The double-effect absorption chillers have COP of approximately 1.0.[1]. COP range of 1.0 to 1.2 are reported by [2]. Whereas, Yin et al. [3] experimental measurement of double effect LiBr-H2O steam-driven absorption chiller under various load conditions reported COP range of 0.7 to 1.0. However, Gomri [4] reported lower COP figure of between 0.73 to 0.79. Studies reported that COP is influenced by a number of factors. Among them are driving temperatures and heat exchanger effectiveness. Studies related to this these factors have been done by Kaynaki and Klic [5]. To calculate COP a number of methods have been proposed. Methods adopted by Nag [6] and Herold et al. [2] are cited in this paper. Nag has clustered the COP into two components One component is a refrigerator working between the temperatures of the region to be cooled and the atmosphere. The other component is the ideal thermal efficiency of an engine working between the driving temperature and the temperature of the region. The COP is the product of these two components. Harold et al. discussion on COP cover a number of models which could be used to evaluate COP. Among the models proposed are reversible COP, zero model COP, half effect cycle, triple effect cycle and resorption cycle. Reversible cycle and zero order model are used in this study. Details on the equations of these models are included in the methdology section. The reversible cycle and the zero model fit the requirement of study objective to analyse the relative COP changes with increasing the heat input temperatures.

2 Methodology

Three approaches were used to evaluate COP for this study. The first two approaches are adopted from [2]. The choice of these two models is based on their usefulness to evaluate the influence of COP to increasing heat input temperatures. The third COP equation is based on the method used by the understudied plant to calculate COP. Additional to COP evaluation, effectiveness of the heat exchanger was also evaluated. Equations used to evaluate effectiveness are included in (iv).

(i) Reversible COP for Double-Effect Steam Absorption Chiller

Eq. (1) was used for calculating the reversible COP of SAC [1].

$$\mathrm{COP}_{rev} = \frac{T_{chw(return)}}{T_s}\left(\frac{T_s - T_{cw(return)}}{T_{cw(return)} - T_{chw(return)}}\right) \quad (1)$$

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Where T_{chw}, , temperature of chilled water return, T_s , temperature of steam and T_{cw} , temperature of cooling water return.

(ii) Zero-order Model COP for Double-Effect Steam Absorption Chiller

The COP of zero-order model was calculated using [2];

$$\mathrm{COP}_{zo} = \frac{Q_e}{Q_h} = \frac{T_{e(i)}}{T_{h(i)}}\left(\frac{T_{h(i)} - T_{c(i)}}{T_{c(i)} - T_{e(i)}}\right) \quad (2)$$

where;

$$T_{h(i)} - T_{c(i)} = 2\left(T_{c(i)} - T_{e(i)}\right) \quad (3)$$

Eq. (3) is simplified as;

$$T_{e(i)} = T_{c(i)} - \left(\frac{T_{h(i)} - T_{c(i)}}{2}\right) \quad (4)$$

where $T_{h(i)}$, the exhaust heat temperature to HRSG and $T_{c(i)}$, the temperature of steam.

(iii) COP equation used by UTP GDC plant.

COP used by UTP GDC plant is calculated as;

$$COP_{SAC\ act} = \frac{Tons\ of\ refrigeration\ hour\ (RTh)}{\dot{m}_{steam} \times (h_{steam} - h_{SAC\ drain})(RT/kg)} \quad (5)$$

where $\dot{m}_{steam}$, mass flow rate of steam, h_{steam} , enthalpy of steam and $h_{SAC\ drain}$, enthalpy of SAC drain.

(iv) Effectiveness of heat exchanger.

The effectiveness of heat exchanger was calculated using equation (8), [2];

$$\varepsilon_{HEX} = \frac{Q_{act}}{Q_{max}} \quad (6)$$

$$\varepsilon_{HEX} = \frac{\left(m \times C_p\right)_{cold}\left(T_{c(1)} - T_{c(2)}\right)}{\left(m \times C_p\right)_{cold}\left(T_{h(1)} - T_{c(2)}\right)} \quad (7)$$

$$\varepsilon_{HEX} = \frac{\left(T_{c(1)} - T_{c(2)}\right)}{\left(T_{h(1)} - T_{c(2)}\right)} \quad (8)$$

2.1 Case Study

The steam absorption Li/Br chiller at Universiti Teknologi Petronas (UTP) District Cooling plant was taken as a case study. The District Cooling plant is a gas fueled cogeneration plant producing electricity and chilled water. The SAC is operated during the day. During peak periods, the absorption system is operated with full load capacity. For this study, only one unit of SAC with 1250 RT capacity was analysed.

3 Results and Discussion

Figure 1 shows the plot of reversible COP, zero order model COP and actual COP during 118 days period. The plot of reversible COP shows increasing trend. The COP of zero-order model also shows increasing trend, however on smaller scale. The high values of reversible COP in comparison to lower values of zero order COP is in agreement as reported by [2]. The plot of actual COP shows lower values than the zero order COP. The values of actual COP are not consistent.

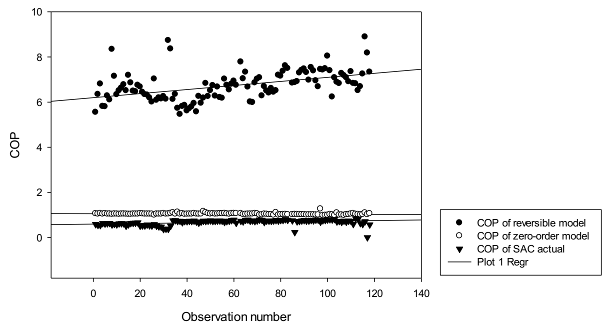

Figure 1. Plot of three COPs for 118 days.

Figure 2 shows the plot COP vs heat input temperatures for SAC at the plant. The plot shows major variation of reversible COP and COP calculated by zero-order model. The variation happens because of heat transfer irreversibility at the three temperature levels. The thermal resistance effects the internal temperature to be different than the external ones. This variance is typical of an actual absorption cycle as reported in [2]. Nevertheless the zero order plot gives the ideal COP which is useful.

Effectiveness of the heat exchanger was also evaluated. Figure 3 shows the plot of COP vs effectiveness. The average value of effectiveness varies from 0.40 to 0.57 with an average of 0.44. This is lower than as reported by [2] which gives an effectiveness value of 0.5. In order to find the reason for this deviation, further study is required.

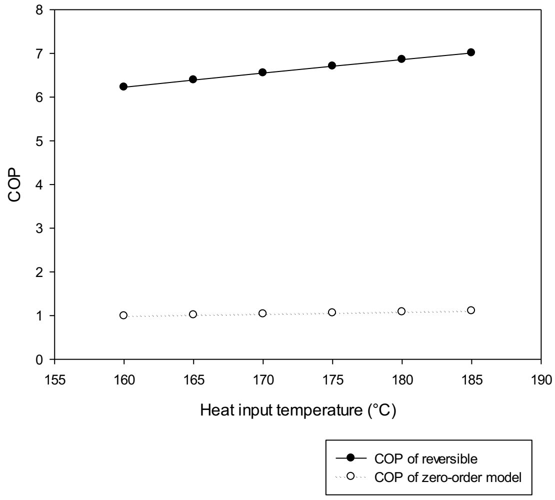

Figure 2. Variation of COP with heat input to SAC.

Table 1 gives the values of reversible COP and zero order model COP with respect to changes in temperatures. As shown in Table 1 the zero order model gives COP values ranging from 0.99 to 1.10. This is within the range for double effect absorption chillers. However the actual calculated values of COP are from 0.51 to 0.84 with an average of 0.67 for 118 days period. The COP values are below the expected COP for double effect chiller. In fact the COP values are within single effect absorption chiller COP. Hence the chiller need to be evaluated either to be repaired or replaced. One option is to undertake economic replacement analysis. The analysis will involve evaluating of marginal cost of repair the existing chiller and the equivalent annual cost of the prospective chiller. The choice of either to repair the old chiller or to replace with new chiller will depend on which is minimum. If the marginal repair cost of existing chiller is lower than the equivalent annual cost of new chiller than retain the existing chiller for another year, otherwise replace with new chiller. This analysis need to be done on annual basis until the existing chiller is replaced with the new chiller.

Table 1. Summarize of reversible and zero-order model COP.

Heat input (°C)	COP_{rev}	COP_{zo}
160	6.23	0.99
165	6.39	1.01
170	6.55	1.04
175	6.70	1.06
180	6.86	1.08
185	7.01	1.10

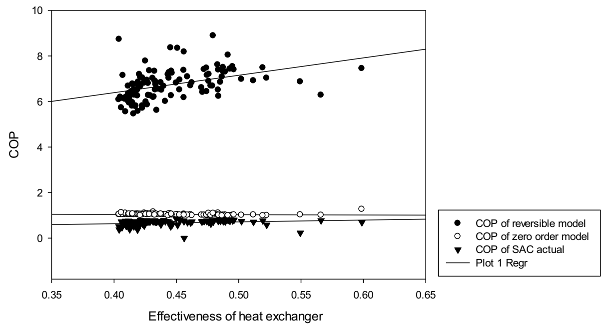

Figure 3. COP vs effectiveness of the heat exchanger

4 Conclusion

The study demonstrated that the heat input temperatures influence both the reversible COP and zero order COP of the understudied 1250 RT. The calculated COP using zero order model are in the acceptable range for double effect LiBr absorption chiller. However, the actual COP of the chiller which is in the range of 0.51 to 0.84 are of lower range for double effect absorption chiller. Due to this reason, it is recommended that economic replacement analysis to be undertaken to evaluate economic feasibility either to repair or replace the existing chiller.

Acknowledgement

Authors would like to thank Universiti Teknologi PETRONAS and MOHE for supporting this research study.

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