International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 21 (2017) pp. 10802-10808

Exergoeconomics Model for Power and Chilled Water Cost Rates of Gas-Fueled District Cooling System

Mohd Amin Abd Majid
Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia.

Adzuieen Nordin, Didi Asmara Salim
Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia.

Abstract

Many researches have been published related to using exergoeconomic approach to assess the performance of the cogeneration plant and the cost rates of products generated by various thermal systems especially in the cogeneration plant. However, there are no detailed studies that had been carried out in the case of Malaysia, a tropical climate country, due to limited number of cogeneration plants, especially gas-fueled district cooling system. This study is on exergoeconomic analysis of gas-fueled district cooling system. The scope of this study focuses on district cooling plant with gas turbine, heat recovery steam generater and steam absorption chillers. The analysis was based on the first and second laws of thermodynamic principles and the cost rates balance equations. The analysis was based on a case study to determine the energy efficiency, exergy efficiency, exergy of fuel, exergy of product and exergy destruction for the gas turbine, heat recovery steam generator and steam absorption chillers of a gas-fueled DC system. In the analysis, the cost rates of power and chilled water were also calculated. From the analysis, it was noted that a difference of approximately 34% for power cost rates and 67% for chilled water rates, when compared with industrial rates. This shows exergoeconomic method provides a feasible approach for evaluating the performance and cost rates of power and chilled water of the gas-fueled district cooling system.

Keywords: Exergoeconomic; Gas Turbines; Heat Recovery Steam Generator; Steam Absorption Chiller.

INTRODUCTION

The concept of exergoeconomic involves an analysis of exergy which is the work capability and the economic aspect of an energy system. The second law of thermodynamic is applied in exergy in order to evaluate the maximum amount of work that can be generated by a system under the given environmental conditions. As exergy is closely related to the economic aspect of the system because users pay for the potential energy, so the evaluation of costs is taken into account, resulting in exergy used as a basis in the costing process.

The exergoeconomic approach has been used for analysis of efficient and cost-effective energy-conversion systems since 1950 [1]. Judging from the many published research on this subject, this approach has been widely used for assessing energy systems. It is also noted that exergoecomic analysis has become an integral part of the plant design for thermal, chemical and petro-chemical process plants. Exergoeconomic approach is also extensively used for power generation systems analysis. Yao et al. [2] applied an exergoeconomic analysis to investigate a combined cycle system for the steel production process which consisted of blast furnace gas, coke oven gas and sintering waste gas. They proposed the exegoeconomic model for analyzing three exergoeconomic indexes, including the cost difference, relative cost difference and the exergoeconomic factor. By evaluating the cost difference, the degree to which each subsystem contributes to the greater final cost of the products could be obtained. The relative cost difference was similar to cost difference but it was calculated proportionally to the input of the component. Besides, the exergoeconomic factor was used to determine the proportion to which the cost of the component influences the relative cost difference. The exergoeconomic model based on mathematical model was structured component by component. The model for each component represents the flow of fuel as an input and product as an output of the system. The analysis shows that by measuring the exergoeconomic index, the component that is required for improvement was known. By combining the cost of production, it was found that there was an internal relationship between exergy and capital streams. The findings indicate that, based on fuel-product model it is important to investigate the exergy stream for each component in order to reveal the estimated cost of the product produced.

Published studies show that the exergoeconomic approach is a useful tool to understand the behavior of an energy conversion system from the cost viewpoint. Mehmet et al. [3] conducted an exergoeconomic analysis on an actual cogeneration plant of an iron and steel factory. The model developed was based on mass, energy, exergy and cost balance for each component of the cogeneration plant. Using the mass and energy balance evaluations, the results of total net power and mass flow rate of steam generated were achieved. From the exergy balance evaluation, the efficiency of each component and that of exergy destruction were calculated. Their results show that the most efficient component is the turbine component of the gas turbine (GT) and the most inefficient component is that of the heat recovery steam generator (HRSG). By combining exergy and economic analyses, the cost of product of each component and the unit exergy cost can be determined. The findings prove that the exergoeconomic analysis is an effective method to identify the evaluation of inefficiency of a cogeneration plant.

In a thermal system, it is important to identify the location of energy wastage occurring in order to optimize the operation of the system. It is not sufficient enough to use of the first law of the thermodynamic method to identify the location of the energy lost [4, 5]. This is because the first law of thermodynamics only covers the energy utilized from the system. In order to obtain the useful potential of a certain amount of energy, the second law of thermodynamics is required [6]. This was done by Saidur [4] who applied the energy, exergy and economic analyses for analysis of industrial boilers. The mathematical model which was based on the mass, energy and exergy balance for each component was developed. The methods were also applied by [3] but the economic analysis was based on the cost saving and pay period formulations. Their findings showed that in the case of the HRSG, exergy efficiency was lower than energy efficiency. However, in terms of energy and exergy loss, exergy loss in the HRSG was greater when compared to energy loss. The findings also indicated that utilizing the waste heat of the HRSG was an effective and economical way to save energy.

The exergoeconomic model is important to determine the locations, causes and true magnitude of inefficiencies of the thermal system [5, 7, 8]. Several authors had expanded their research to environmental analysis [9, 10]. Ahmadi et al. [11] studied the impact of exergy and exergoeconomic evaluations for combined cycle power plants. They applied exergy analysis to evaluate the exergy of each flow of the plant, changes in the exergy and to determine exergy destruction and exergy efficiency for each component. The plant consists of the GT, HRSG and steam absorption chiller (SAC). In terms of exergoeconomic evaluation, the cost of exergy destruction, which is the inefficiency cost of each component, was obtained by using the matrix solution. They noted that the GT inlet temperature affected the overall cycle of exergy destruction. If the GT was analyzed as one component, the results show that the GT was the component with the highest exergy destruction as studied by [3] and [4].

Although, this approach has been widely implemented in western countries [3-9], in countries with a tropical climate, particularly Malaysia, very little focus has been given to the exergoeconomic approach for power generation [12]. Therefore, it is proposed that the exergoeconomic approach should be applied in the energy sector in Malaysia in view of the present energy consumption scenario.

With regards to energy usage, the power and chilled water produced by the gas-fueled district cooling (DC) system play an important role in potentially reducing the overall cost incurred by the region when meeting its growing electricity demand. The current approach in determining the cost rates of power and chilled water by industries in Malaysia is based on an economic analysis which takes into account capital expenditure (CAPEX) and operational expenditure (OPEX). There is no evidence of incorporating technical aspect which is thermodynamic evaluation for analysis [13]. As a result, the evaluated cost rates of power and chilled water produced by the gas-fueled DC system do not represent actual costs. In order to evaluate the actual cost rates exergoeconomic analysis is required. This study proposed an exergoeconomic cost rates to evaluate the cost rates.

PLANT DESCRIPTION

The Gas District Cooling (GDC) at Universiti Teknologi Petronas (UTP) which is located at Tronoh, Perak in Malaysia was used as a case study. This plant started operating in November 2005. The overall plant configuration is shown in Figure. 1 and the plant equipment specifications are listed in Table 2. The plant produces power and chilled water. The main component that produces power is GT which requires compressed air and fuel for the combustion process. GT generates power and emit exhaust gas. In a typical GT, the exhaust gas is released to the environment but for the under studied gas-fueled DC system, the exhaust gas is used to drive HRSG to generate steam. This steam in turn produces chilled water by absorption process using the SAC.

Table 1: Specification of UTP GDC plant equipment(14).

Types of component	No. of unit	Specification
GT	2	Power output: 4.2 MW each
HRSG	2	Steam flow: 12 tons/hour each Steam pressure: 14 bar (saturated)
SAC (double effect)	2	1250RT each
Electric Chiller (EC)	4	325 RT each
Thermal Energy Storage (TES)	1	10 000 RT

METHODOLOGY

The developed exergoeconomic model was used to evaluate the power and cost rates of a gas-fueled DC system. A number of steps were carried out. First, the components installed in the gas-fueled DC system were identified. The second step involved the formulation of exergetic analysis equations used to evaluate the exergy associated with fuel and product, exergetic efficiencies and exergy destruction for the components.

The third step was formulating the capital cost equations which were based on the costs of capital investment, operation and maintenance. The final step involved the integration of the exergy and the cost rates equations by developing the exergoeconomic model to calculate the cost rates of power and chilled water produced by the plant.

A. Identification the component installed

The first step in the construction of the exergoeconomic model was to identify the components installed in the gas-fueled DC system. The gas-fueled DC system produces power and chilled water. The process consists of three components that make up the gas-fueled DC system namely, GT, HRSG and SAC. The system was divided into fourteen streams as show in figure 1:

.

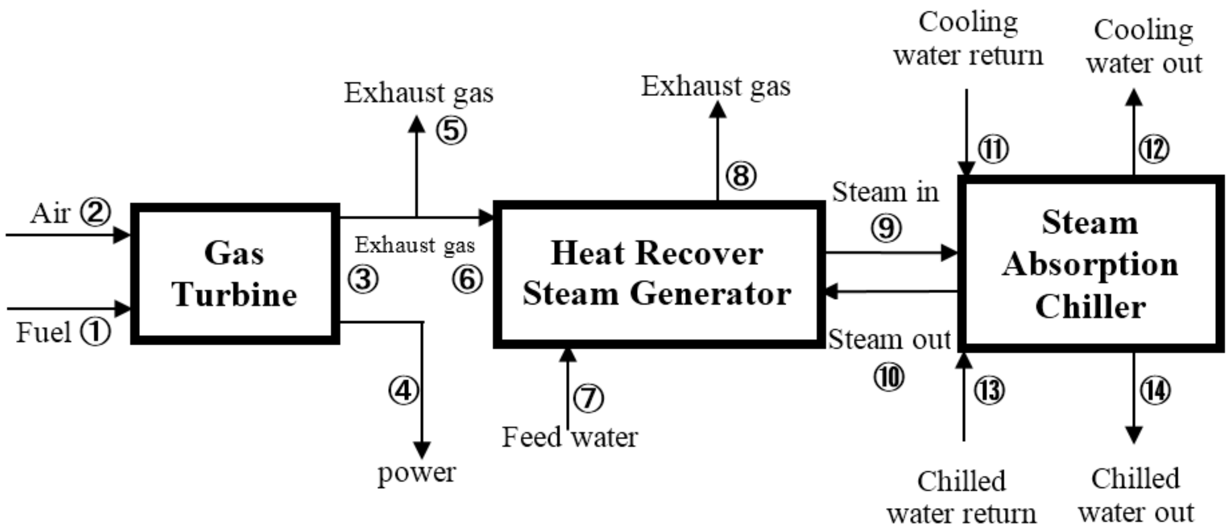

Figure 1: Configuration plant of UTP gas-fueled System

Table 2: Average of the flow stream properties and results of exergoeconomic analyses.

Stream no.	Identification	$\dot{m}$ (kg/s)	T (K)	$\dot{E}$(MW)	$\dot{c}$ (RM/GJ)	$\dot{C}$ (RM/h)
1	Fuel	0.22	298.15	11.42	14.41	592.42
2	Air	19.00	298.15	0.00	0.00	0
3	Exhaust gases	19.27	661.93	2.73	0.00	0
4	Power	-	-	3.86	47.50	660.06
5	Exhaust gases	6.47	661.8	0.91	0.00	0
6	Exhaust gases	12.80	661.93	1.82	0.00	0
7	Water	23.35	298.15	0.09	0.00	0
8	Exhaust gases	12.80	445.68	0.42	0.00	0
9	Steam	1.18	453.00	1.01	43.81	159.29
10	Steam	1.18	90	0.401	0.00	0
11	Water	21.47	298.15	0.08	0.00	0
12	Water	21.47	304.47	0.08	0.00	0
13	Chilled Water	210.59	284.3	0.63	8.30	18.82
14	Chilled Water	210.59	287.6	0.64	0.00	0.00

The GT consists of three subcomponents, namely, the air compressor, combustor chamber and turbine. Ambient air is first compressed in the compressor, then fuel is added and combusted in the combustor chamber to produce power. At the same time, the GT releases exhaust gas.

A portion of the exhaust gas from the GT is diverted to the HRSG for heating the feed water to produce steam. The steam from the HRSG is used for the absorption process in the SAC. The absorption process cooled the returned chilled water from approximately 12°C or 13°C to 6°C or 7°C. The cooled chilled water is then piped out to the clients. During the absorption process, the cooling water is circulated into and out of the SAC. The SAC is of LiBr-H2O type.

B. Formulation of mass and energy balance equations

Equation (1) was used for the energy analysis:

$$\dot{Q} - \dot{W} + \sum_i \dot{m}_i\left(h_i + \frac{1}{2}V_i^2 + gz_i\right) - \sum_o \dot{m}_o\left(h_o + \frac{1}{2}{V_o}^2 + gz_o\right) = 0 \quad (1)$$

where $\dot{m}_i$ and $\dot{m}_o$ are the mass flow rate (kg/s) of inlet and outlet respectively, h is enthalpy (kg/kJ), V is velocity (m/s), z is elevation (m), $\dot{Q}$ is the rate of heat and $\dot{W}$ is power generated by the system. The mass and energy balance for any control volume with negligible potential and kinetic energy is

$$\dot{m}_i(h_i) + \dot{Q} = \dot{m}_o(h_o) + \dot{W} \quad (2)$$

expressed by Equation (2);

The first law of efficiency of a system is defined as the ratio of energy output to the energy input of the system [15] as in Equation (3);

$$\eta_{th} = \frac{Desired\ output\ energy}{Input\ energy\ supplied} \quad (3)$$

C. Formulation of exergy analysis equations

Similar approach is applied to carry out exergy evaluation [6, 16,17]. Equation (4) was used to evaluate the exergy;

$$\dot{E}_Q + \sum_i \dot{m}_i ex_i = \sum_o \dot{m}_e ex_e + \dot{E}_W + \dot{E}_D \quad (4)$$

where i and o denotes inlet and outlet of control volume and $\dot{E}_D$ is the exergy destruction. $\dot{E}_Q$ and $\dot{E}_W$ is the exergy transfer by heat and exergy transfer by work respectively.

The amount of exergy transfer by heat was evaluated using Equation (5) [18];

$$\dot{E}_Q = \left(1 - \frac{T_0}{T_i}\right)\dot{Q}_i \quad (5)$$

where T_0 and T_i are the ambient temperature and inlet temperature respectively. $\dot{Q}_i$ is the inlet heat transfer rate.

Exergy transfer by work is the useful work potential. It is also a form of mechanical energy which can be converted to work entirely. As such exergy transfer by work is expressed by Equation (6) [19] ;

$$\dot{E}_W = \dot{W} \quad (6)$$

where $\dot{W}$ is the work output.

Exergy for a flowing stream which is the specific exergy was determined by adding the exergy of nonflow exergy and flow exergy. The specific exergy at a steady flow system was evaluated using Equation (7) [20];

$$ex = (h - h_0) - T_0(s - s_0) \quad (7)$$

where ex denotes the specific exergy, h is enthalpy and s is entropy, while ($_0$) refers to ambient condition.

D. Formulation of capital cost rates equations

The system was assumed to operate at a steady state. The cost balance was formulated as Equation (8) [25]:

$$\dot{C}_{P(total)} = \dot{C}_{F(total)} + \dot{Z}_k \quad (8)$$

where $\dot{C}$ denotes the cost rate per hour associated with exergy stream while $\dot{Z}$ represents all remaining costs. $\dot{C}_{P(total)}$ is the total cost rate of the products generated and $\dot{C}_{F(total)}$ is the total cost rate of fuel. The equation expresses $\dot{Z}_k$ as the sum of the cost rates associated with capital investment and operation and maintenance costs.

$$\dot{Z}_k = \dot{Z}_{CI(k)} + \dot{Z}_{OM(k)} \quad (9)$$

The rates of cost associated with capital investment and cost associated with operation and maintenance were calculated by dividing the annual contribution of capital investment and the annual operating and maintenance costs by time units of the system operation as expressed in Equations (10) and (11) respectively.

$$\dot{Z}_{CI(k)} = \frac{CI_{(k)}.(A/P, i\%, n) - S_{(k)}.(A/F, i\%, n)}{Operation\ hours \times Number\ of\ days\ per\ year} \quad (10)$$

$$\dot{Z}_{OM(k)} = \frac{C(OM)_{(k)}}{Operation\ hours \times Number\ of\ days\ per\ year} \quad (11)$$

where $CI_{(k)}$, $S_{(k)}$ and $C(OM)_{(k)}$ are the present worth of the following: the investment cost; future worth as it is salvage value and the operation and maintenance costs of the kth component.

Then, these costs are converted to annualized costs by using the capital recovery factor $(A/P, i\%, n)$ and sinking fund factor $(A/F, i\%, n)$ [21, 22]. The capital investment cost is based on the relationship between the annual amounts of a uniform series of cash flows that could be traded for the present equivalent, whereas the salvage value cost is the capital recovery factor that shows the relationship found between the annual amounts that would have the same values as the future value.

E. Integration of the Exergy Equations and the Capital Cost Rates Equations

By combining the cost balance with the exergy rate balance, the exergoeconomic balance equation for kth component is defined as per Equation (12) [2, 3, 11, 19, 23]:

$$\sum\left(c_e\dot{E}_e\right)_k + c_{w,k}\dot{W}_k = c_{q,k}\dot{E}_{q,k} + \sum\left(c_i\dot{E}_i\right)_k + \dot{Z}_k \qquad (12)$$

Here, c_e, c_w, c_q and c_i denote average costs per unit Ringgit Malaysia per gigajouls (RM/GJ), while $\dot{E}_e$ and $\dot{E}_i$ are the exergy transfer for exiting and entering stream, $\dot{W}$ is power and $\dot{E}_q$ is the exergy heat transfer (MW).

From Equation (14), exergy destruction cost is assumed as a hidden cost [7]. For a thermal system associated with fuel as the input and product as the output, the exergy destruction rate is obtained using Equation (13) [3]:

$$\dot{Ex}_{F,k} = \dot{Ex}_{P,k} + \dot{Ex}_{D,k} \qquad (13)$$

where Ex is the exergy transfer associated with the subscript F for fuel, P for product and D for destruction. Exergy of fuel represents the expended resources used to generate the product and exergy of product represents the desired results produced by the system [23].

Thus, exergetic efficiency associated with fuel and products is expressed as in Equation (14) [23]:

$$\varepsilon_{(j)} = \frac{\dot{E}_{P(k)}}{\dot{E}_{F(k)}} \qquad (14)$$

For the development of the exergoeconomic model, the following assumptions were adopted:

i. The gas-fueled DC system operated at a steady state in which all the properties of the system remained unchanged with time.

ii. In the operation of the GT, the complete combustion took place in the combustion chamber.

iii. There was negligible heat loss for all the subcomponents of the GT as the process was adiabatic.

iv. The HRSG consisted of the evaporator and economizer.

v. The mass flow rate of the exhaust gas was equal to the mass flow rate of the combustion product from the combustion chamber in the GT.

vi. The mass flow rate of the exhaust gas entering the HRSG was equal to the mass flow rate of the exhaust gas leaving the HRSG.

vii. The mass flow rates of the cooling water entering the SAC were similar to the mass flow rates of cooling water leaving the SAC.

viii. The mass flow rates of the chilled water entering the SAC were similar to the mass flow rates of chilled water leaving the SAC.

RESULTS AND DISCUSSION

For the exergoeconomic evaluation, the results of the cost rate of the generated electricity from the gas-fueled DC system was calculated to be RM660.06/h for stream 4. This means that the product of the specific cost of stream 4 was RM47.50/GJ and the electricity production was 3.86 MW.

As shown in Table 2, the specific cost of fuel of the overall gas-fueled DC system was RM14.41/GJ, while the construction and operation of the gas-fueled DC system resulted in a cost increase of RM55.80/GJ. This could be taken as the estimated specific costs of the products which are power (stream 4) and chilled water (stream 14) of the overall gas-fueled DC system. If the product is only power, the specific cost would be RM47.50/GJ. The results also indicated that the gas-fueled DC system was able to achieve a higher profit due to the price of electricity being greater than the price of natural gas. These results are in agreement with those in [24].

The influence of the energy and exergetic efficiencies of the GT on the unit cost of power could be observed from Figure 2(a) and Figure 2 (b). The trends of these two results indicate the higher the energy and exergetic efficiencies, the lower the unit cost of power obtained. This was proved by the higher generation of power corresponding to the higher energy efficiency of the GT, resulting in lower unit cost of power.

Another factor was the exergetic efficiency in the GT demonstrated by the percentage of fuel exergy provided to the gas-fueled DC system. The higher the exergetic efficiency, the higher the useful energy of fuel provided in the generation of power. Therefore a higher maximum work of fuel was achieved. The results of this study showed that the unit cost of power represents the true cost of the quality of energy from the GT.

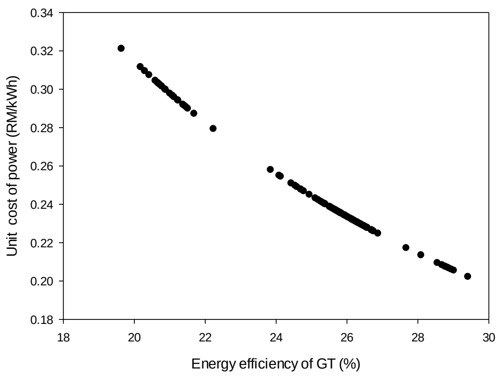

Figure 2 (a): Variations of unit cost of power with energy efficiencies of GT.

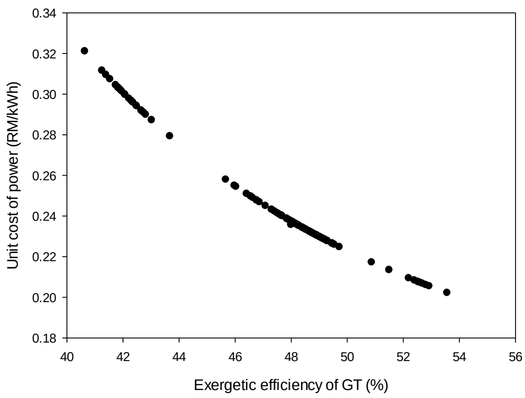

Figure 2 (b): Variations of unit cost of power with exergetic efficiencies of GT

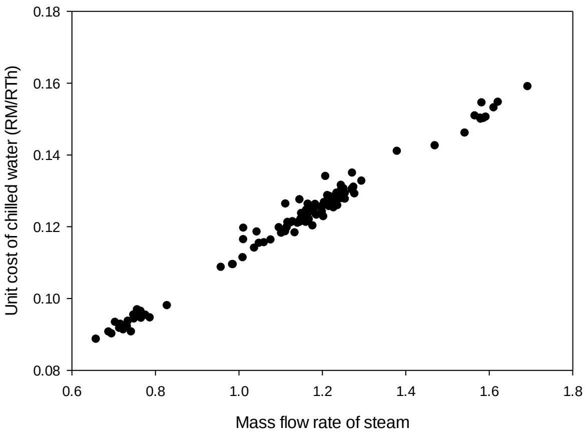

Figure 3: Variations of unit cost of chilled water with mass flow rate of steam.

Since steam is the main input in the chilled water process, the influence of the mass flow rate of steam was investigated. Figure 3 shows the results of the mass flow rate of steam against the unit cost of chilled water. The values shown in this graph were calculated from the exergetic cost rate model for chilled water. Figure 3 indicates that an increase of mass flow rate of steam resulted in the higher unit cost of chilled water from the gas-fueled DC system.

One of the possible reasons for this result is the higher mass flow rate of steam increased the exergetic efficiency of the SAC, resulting in the positive linear proportionality of the exergetic efficiency of the SAC to the mass flow rate of steam. Therefore, the increase in the mass flow rate of steam which in turn affected the unit cost of chilled water.

Theoretical calculations were performed in order to obtain the correlation between the model and utility charges for unit cost of power and chilled water. The DC system which was used in this study consists of one 4.2 MW of GT, one HRSG with 12 tons/h steam flow and one 1250RT capacity of SAC. The results show the cost rate of power approximately RM0.17 / kWh and RM0.11/RTh for chilled water. The data from the utility system were taken from literature.

For the case of unit cost of power, it is approximately 34% lower compared to public utility charges which charged RM0.26/kWh. The results of the industry rate of power were based on those of Malaysia’s Independent Power Producer (IPP). The main reason for the deviation between the exergoeconomic model and the industrial rates could be due to the method which took into account the economic concept. These exergoeconomic model results concurred with the method adopted from the model developed by Mehmet et al. [3]. The model was developed with the thermodynamic and economic points of view. In their study, the values obtained from the exergoeconomic analyses were the costs of power and steam. The findings indicate that an exergoeconomic analysis is useful for identifying and evaluating the actual costs of the product generated. This analysis was also used to highlight the possible improvement of the power plant. In the case of the IPP, the calculation involved an analysis of CAPEX, OPEX and other financial factors. This explains the reasons of the results of the IPP were higher when compared to the results from the exergoeconomic model.

For the unit cost of chilled water, the GDC Malaysia sold the chilled water in the range of RM0.34/RTh, the cost of which was based on OPEX and CAPEX [25]. The results indicated the utility charges were higher than those obtained from the exergoeconomic model. One possible reason for the higher rate is OPEX and CAPEX which depend on the design capacity of the electricity, steam and chilled water for the gas-fuelled DC system. As OPEX and CAPEC increased, the estimated cost of chilled water increased.

CONCLUSION

The findings indicate that an exergoeconomic analysis is useful for identifying and evaluating the actual costs of the power and chilled water generated. It could assist in identifying areas for possible improvement of the DC plant. It is noted that the evaluated cost rates for both power and chilled water from the exergoeconomic model are lower than the commercial rates. One possible reason is that the commercial entities include other financial factors besides the OPEX and CAPEX in their costing. Since the model did not include other financial factors besides CAPEX and OPEX, the results from the model could not be used as basis for comparison with commercial rates. For future works other financial costs besides OPEX and CAPEX to be incorporated in the model

ACKNOWLEDGEMENTS

Authors would like to acknowledge the support of Universiti Teknologi PETRONAS and Ministry of Education for supporting this research study.

REFERENCES

[1] Hua, B., Q.L. Chen, and P. Wang, New Exergoeconomic Approach for Analysis and Optimization of Energy Systems. Energy, 1997. Vol. 22(11): p. 1071-1078.

[2] Yao, H., et al., Exergoeconomic analysis of a combined cycle system utilizing associated gases from steel production process based on structural theory of thermoeconomics. Applied Thermal Engineering, 2013. 51(1-2): p. 476-489.

[3] Mert, M.S., et al., Exergoeconomic analysis of a cogeneration plant in an iron and steel factory. Energy, 2012. 46(1): p. 78-84.

[4] Saidur, R., J. Ahamed, and H. Masjuki, Energy, exergy and economic analysis of industrial boilers. Energy Policy, 2010. 38(5): p. 2188-2197.

[5] Mousafarash, A. and M. Ameri, Exergy and exergo-economic based analyses of a gas turbine power generation system. Journal of Power Technologies, 2013. 93(1): p. 44--51.

[6] Sahin, A.Z., et al., Overall performance assessment of a combined cycle power plant: An exergo-economic analysis. Energy Conversion and Management, 2016. 116: p. 91-100.

[7] Seyyedi, S.M., H. Ajam, and S. Farahat, A new criterion for the allocation of residues cost in exergoeconomic analysis of energy systems. Energy, 2010. 35(8): p. 3474-3482.

[8] Ahmadi, P. and I. Dincer, Thermodynamic and exergoenvironmental analyses, and multi-objective optimization of a gas turbine power plant. Applied Thermal Engineering, 2011. 31(14–15): p. 2529-2540.

[9] Rismanchi, B., et al., Energetic, economic and environmental benefits of utilizing the ice thermal storage systems for office building applications. Energy and Buildings, 2012. 50: p. 347-354.

[10] Alexis, G.K. and P. Liakos, A case study of a cogeneration system for a hospital in Greece. Economic and environmental impacts. Applied Thermal Engineering, 2013. 54(2): p. 488-496.

[11] Ahmadi, P., I. Dincer, and M.A. Rosen, Exergy, exergoeconomic and environmental analyses and evolutionary algorithm based multi-objective optimization of combined cycle power plants. Energy, 2011. 36(10): p. 5886-5898.

[12] Ganjehkaviri, A., et al., Modelling and optimization of combined cycle power plant based on exergoeconomic and environmental analyses. Applied Thermal Engineering, 2014. 67(1–2): p. 566-578.

[13] Chang, Y. and Y. Li, Power generation and cross-border grid planning for the integrated ASEAN electricity market: A dynamic linear programming model. Energy Strategy Reviews, 2013. 2(2): p. 153-160.

[14] Shaharin, A., M. Amin A. Majid, Gas District Cooling in Malaysia. 2011.

[15] Kaushik, S., V.S. Reddy, and S. Tyagi, Energy and exergy analyses of thermal power plants: A review. Renewable and Sustainable Energy Reviews, 2011. 15(4): p. 1857-1872.

[16] Li, G., Energy and exergy performance assessments for latent heat thermal energy storage systems. Renewable and Sustainable Energy Reviews, 2015. 51: p. 926-954.

[17] Lee, Y.D., et al., Exergetic and exergoeconomic evaluation of a solid-oxide fuel-cell-based combined heat and power generation system. Energy Conversion and Management, 2014. 85(0): p. 154-164.

[18] Kaushik, S.C., V.S. Reddy, and S.K. Tyagi, Energy and exergy analyses of thermal power plants: A review. Renewable and Sustainable Energy Reviews, 2011. 15(4): p. 1857-1872.

[19] Ahmadi, P. and I. Dincer, Thermodynamic and exergoenvironmental analyses, and multi-objective optimization of a gas turbine power plant. Applied Thermal Engineering, 2011. 31(14-15): p. 2529-2540.

[20] Regulagadda, P., I. Dincer, and G.F. Naterer, Exergy analysis of a thermal power plant with measured boiler and turbine losses. Applied Thermal Engineering, 2010. 30(8–9): p. 970-976.

[21] Sullivan, W.G., E.M. Wicks, and J.T. Luxhoj, Engineering economy. Vol. 12. 2000: Prentice Hall London.

[22] Wheeler, A.J., et al., Introduction to engineering experimentation. 1996: Prentice Hall New Jersey.

[23] Bejan, A., G. Tsatsaronis, and M. Moran, Thermal design and optimization. 1996, New York: Wiley-Interscience.

[24] Xu, D. and M. Qu, Energy, environmental, and economic evaluation of a CCHP system for a data center based on operational data. Energy and Buildings, 2013. 67: p. 176-186.

[25] Conversation with GDC (M) Sdn. Bhd, 5th May 2015.