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Experimental Investigation of Micro-Gas Turbine Performance at Reduced Air Inlet Temperature

Mior Azman Said[1, a)], Suhaimi Hassan[1] and M Faizairi M Nor[1]

[1]Mechanical Engineering Dept.,
Universiti Teknologi PETRONAS,
32610 Bandar Seri Iskandar, Perak, Malaysia

[a)]Corresponding author: miorazman@utp.edu.my

Abstract. Gas turbines have long been utilized as the main device for power generator. High temperature of ambient air flowing into inlet can reduce their performance. The objective of this study is to investigate the performance of a 1.5 kW micro-gas turbine at reduced inlet temperature using dry-ice as the cooling elements. Dry-ice is placed surrounding the outer wall of contained in a net-like holder at the inlet before the compressor and the inlet air temperature found to be decreased till 13ºC from the ambient temperature. Comparison test was performed with a baseline result, which is the operation without the dry-ice cooling unit and the results shows that the power output decreases linearly with the increase of inlet air temperature. It was recorded that increase power output of 8.5% achieved from reduction of temperature of 7.5%. The power output was found also to be decreased with time, due to the inlet duct exposed to the heat form the combustion chamber. This indicates better insulation or adapted data recording approach is needed.

INTRODUCTION

Gas turbines is an important device in generating electricity, mobility and other engineering usage in industry. Higher thermal efficiency is one of the aspects that researchers look to achieve. In improving the gas turbine cycles, ambient temperature, pressure and humidity are the factors that can influence the gas turbine power output. However, according to El-Hadik [1], ambient temperature is the highest influence to the gas turbine power output, where as high as 1 K in temperature increase can produce 0.6% power increase and 0.18% thermal efficiency increase.

Due to the volatility of fossil fuel energy prices, researchers in inlet air cooling system for gas turbines to increase performance has escalated recently. Most research works on the inlet air cooling system can be categorized into these following classes based on their cooling systems: (1) Mechanical vapor compression or absorption chillers (2) Evaporation (3) Spray or fogging. For absorption chiller system, it is recorded that the gas turbine power output can be increased till 20% and efficiency by 2% but this has the highest cost compared to other two systems. Evaporation system consists of porous element like wood wool fibers where water inside it is evaporated when inlet air flows against it. For spray and fogging system, there are classified into two sub-category: (1) saturated air (2) overspray. The difference in both sub-category is the use of saturated air only before compressor for saturated air fogging system while for overspray system, is the use of high volume of water droplets in the spraying system [2].

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LITERATURE REVIEW

Temperature plays a role in determining the efficiency of a gas turbine, therefore change in the inlet temperature will affect the efficiency and the power output of a gas turbine . Early et al. [3] mentioned that the amount of electrical power produced by the gas turbine or electric generator depends on the temperature of air at the inlet. In general the lower the temperature the higher the p is power output. Erdem and Sevilgen [4] have produced an equation of monthly electricity production:

$$E_m = N \cdot LF_m \cdot G \cdot 24 \tag{1}$$

where N is the power, LF is the monthly load factor and G is the number of days in the particular month. The power N, is calculated by the formula

$$N = \frac{P_1}{R_a} V \left[\frac{W_t}{T_1} - \frac{c_{pa}}{\eta_{cis}} \left(P_{rc}^{\frac{k_a - 1}{k_a}} - 1 \right) \right] \tag{2}$$

where P_1 is the inlet pressure and R_a is air ideal gas constant, V is the volumetric flow rate, W_t is the turbine work, T_1 compressor inlet temperature, c_{pa} is air specific heat at constant presssure, η_{cis} is the compressor isentropic efficiency. K_a is the air specific heat ratio and P_{rc} is the compressor pressure ratio.
Based from the study, it was shown that the electricity production, E_m decreases on the months that have a relatively higher T_1 temperature (the summer season between May to September), which shows that low temperature increases the power output.

The theory behind effects of temperature on the air is that temperature causes the change in air density. The density hot air is lighter, while cooled air is much denser. The dense air will give turbine a higher mass flow rate, which requires more power to compress the air but on the other hand it also results to an increase in turbine output and efficiency[5]. Ameri and Hejazi [5] stated in their study that the amount of increase in turbine power output due to higher mass flow rate outweigh the drop in power that may occur to compress the air. Previous studies have shown there are noticeable losses in terms of thermal efficiency and power output with the increase of ambient air temperature, where the latter's effect is much more substantial than the first. As documented by Erdem and Sevilgen [4], depending on the temperature variations, the production loss ranges from 1.32% up to 7.85%. In locations where the ambient temperature is above 15°C, especially in the summer, the production loss ranges between 1.67-7.22%. The increase in ambient temperature in hot regions will cause decrease in electricity production and also increases the fuel consumption rate per unit electricity produced. When the inlet air is cooled, the augmentation of power production is about 0.37 -7.59%.

In a study conducted by Ameri and Hejazi [5], it was found that there is relationship between air inlet temperature and the efficiency of a gas turbine. Due to the fact that cooler air is denser compared to hot air, cooler air will cause higher mass flow rate and results to an increase in turbine output and its efficiency. Thus, it was found that each 1°C increase of ambient air temperature, the power output will decrease by 0.74%. While the average power output, can be increased up to 11.3% when the inlet air inlet air cooled. The same pattern of deviation of performance also recorded by Sa and Zubaidy [6], in their study on the performance of gas turbine at varying ambient temperature, as shown in Figure 3 and Figure 4 respectively, stating for every K rise in ambient temperature above the ISO condition, the themal looses 0.1%, while the lost in power output is as high as 1.47 MW.

METHODOLOGY

The main equipment used in the study is a two shaft gas turbine unit, TGT .5 kW, placed at the energy laboratory in Universiti Teknologi PETRONAS. First, data collection is performed for the normal operating condition of gas turbine. This data will be used as a control before the modification of an air cooling unit is made. Next, the sizes of the inlet filters and air inlet will be measure for fabricating purposes.

In order test the effects of cooling towards the system, net like-holder will be mounted to the air filter of the compressor during the fabrication stage. This net-like holder will be used to old dry ice while following air to pass through, hence allowing the process of heat transfer, making the air entering the gas turbine via air inlet of the compressor to cool down. Another cooling will be attached at the piping of the gas turbine, right after the first stage of compression. The test will be conducted by first using only one point of cooling – either the inlet or the piping cooling method – and it then both the points will be used to evaluate the cooling effects. In order to control the cooling load, the amount of dry ice used will vary in terms of mass for each run of experiment. This eases the process of finding the relation between the air temperature and power output of gas turbine. Hence, making it possible to observe the effect of decreased in air temperature on the performance of the gas turbine.

The data will be tabulated and compared with the control data, to observe the deviation in performance before the air is cooled and after the cooling system is installed.The amount of deviation and the data collected will also be compared to the ISO standards and the results from previous studies that have been conducted on the performance of gas turbine with varying air inlet temperature.

Equipment

The main equipment in the study is a two-shaft micro-gas turbine with maximum power output of 1.5 kW. The gas turbine is equipped with temperature probes, pressure gauge and speedometer. Data measured can be gathered through readings on the display panel. The gaseous fuel used is propane. The specifications of the gas turbine are displayed in TABLE 1.

TABLE 1. *Specifications of Two-Shaft Micro-Gas Turbine*

Parameter	Specification
Centrifugal ventilator flow rate	500m3/h
Compression ratio of compressor	1.2 – 3
Flow rate of compressor	100 – 700 kg/h
DC generator maximum speed	3750 rev/min
DC generator maximum power	1.5 kW

The cooling element that used in the study is solid carbon dioxide or known as dry-ice. Air flows against the dry-ice is cooled via sublimation process where the solid evaporates into gas. Dry-ice is placed around the outside diameter of the inlet pipe before the compressor. The properties of dry-ice is shown in **TABLE 2**.

TABLE 2. *Properties of Solid Carbon Dioxide*

Parameter	Specification
Molecular weight	44011 kg/kmol
Sublimation point	-78.9^{o}C at 1 bar
Density	1977 kg/m^3
Triple point	-56.6^{o}C at 5.18 bar bar
Critical temperature	31^{o}C

Experimental Procedure

The procedure to perform the experimental investigation is as follows: (1) The main power supply, tap water and compressor are switched on. (2) LPG tank is connected to the gas turbine using a hose. (3) The gas turbine unit is turned on. Initial readings will be displayed on the display panel. (4) Air inlet from compressor and amount of fuel

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gas enters the gas turbine unit are adjusted. The pressure of gas inlet is set to 1 bar. (5) Manual restart button is turned on. (6) Air inlet and amount of fuel gas enters the gas turbine unit is adjusted to obtain stable combustion in the combustion by observing the flame. (7) Once, the flame is steady, all readings on the panel is taken.

RESULTS AND DISCUSSION

A test was conducted on the gas turbine unit without the dry-ice cooling system; to be used as baseline results. The angular speed of motor was set as constant and also the other parameters of gas inlet temperature and pressure. The result of the experiment is taken to be controlled parameter, taking the mean readings of ten runs. The result is plotted in **FIGURE 1**. The figure indicates that the inlet air temperature affects the performance of the gas turbine. As the gas turbine operates the inlet temperature become increased due to the heating from combustion. **FIGURE 1** shows that the increased temperature of the inlet air to the gas turbine decreases the gas turbine power output.

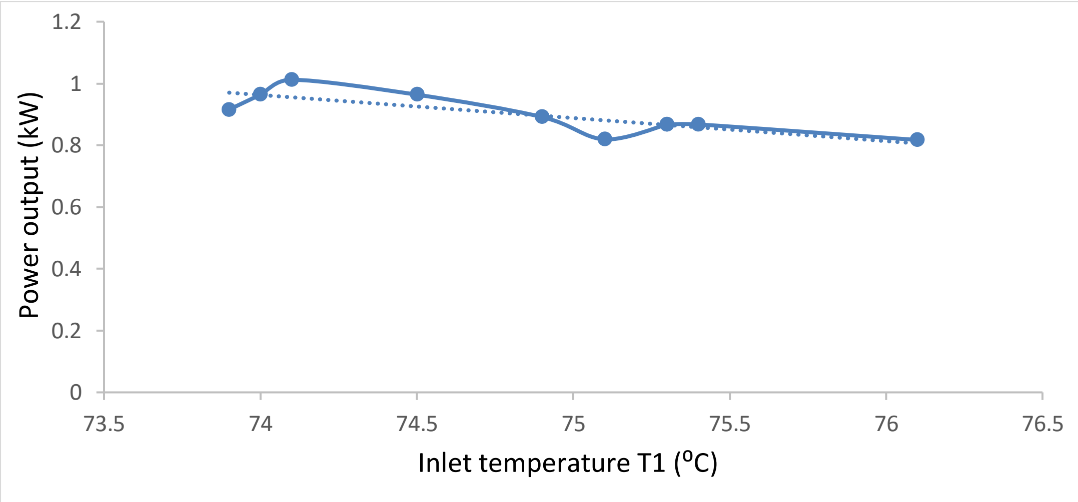

FIGURE 1. Power output vs inlet temperature for gas turbine test without dry-ice cooling.

With the installation of dry-ice cooling system in the inlet before the compressor of the gas turbine unit, the temperature decreases and the power output increases, as shown in **FIGURE 2**. The average temperature decreases from 74.9°C to 67.3°C and the power output increases from average power of 0.9 kW to 0.98 kW. These changes represent increase power output of 8.5% (0.8 kW) from reduction of temperature of 7.5% (15.6°C). This is coherent with the findings from [7] which states that Gas turbine output is a strong function of the ambient air temperature power output increase by 0.5-0.9% for every 1 °C decrement. The result also shows that the power output seems to be drecreasing with time, as the inlet air is being heated up due to the proximity to the combustion chamber.

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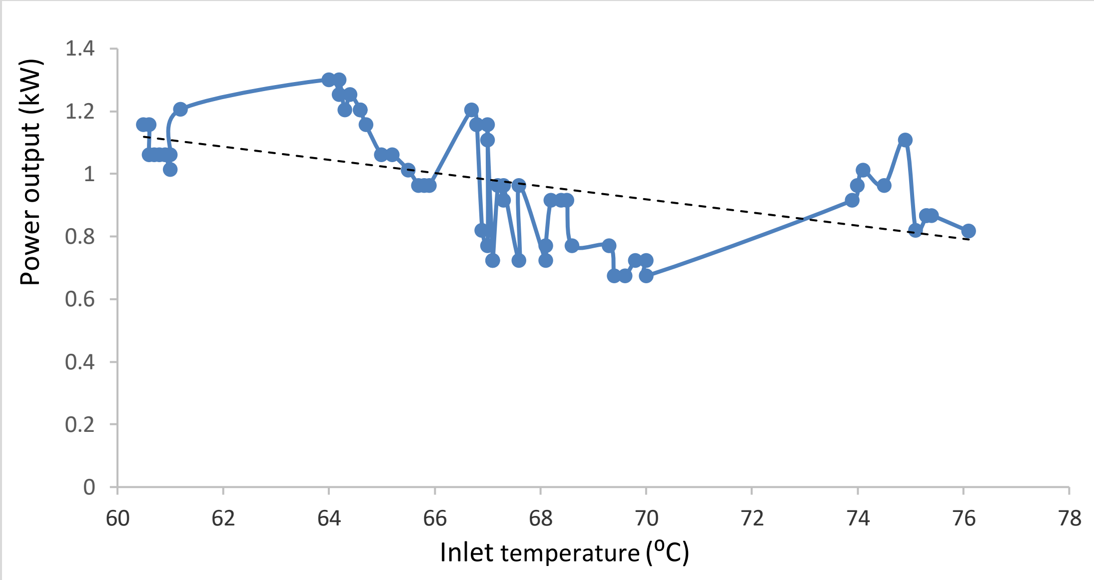

FIGURE 2. Power output vs inlet temperature for gas turbine test with dry-ice cooling.

The drop in power output as the temperature increases as mainly due to drop in air density. This can be shown by **FIGURE 3**, which describe a linear decrease of density of the inlet air with respect to the increase of inlet temperature.

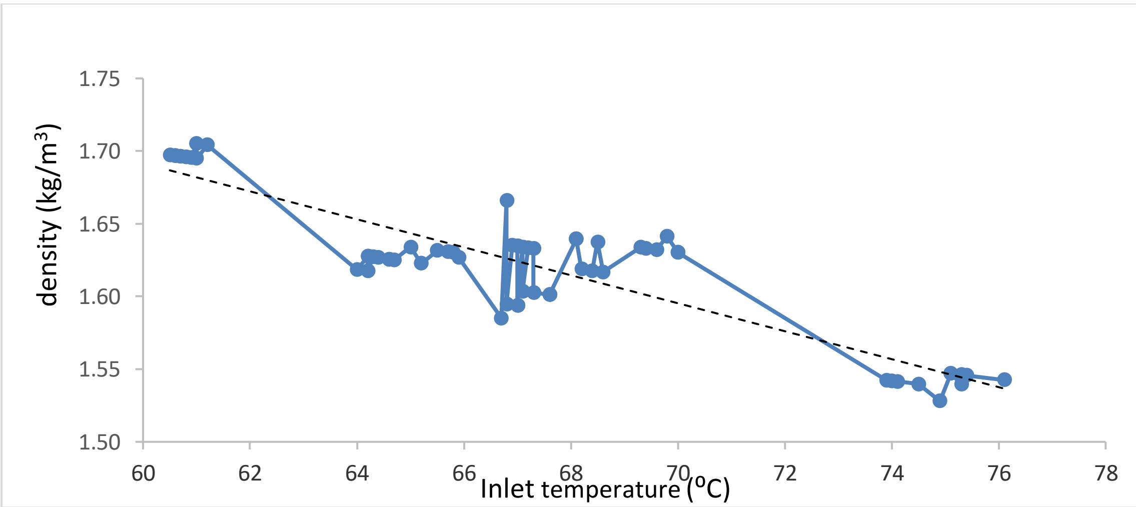

FIGURE 3. Density vs inlet temperature for gas turbine test with dry-ice cooling.

This is because as the hot air is lighter, lower mass flow rate, less amount of air goes to combustion. With same amount of volume, the air simply lighter compared to cold air, and thus tend to lower the combustion quality. This result concurs with other findings [4,8], which states that lower temperature resulted in higher air mass flow rate which correspond in higher density of the air.

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CONCLUSION

This study was performed to investigate the performance of a 1.5kW micro-gas turbine with reduced inlet air temperature. The cooling mechanism employed is the use of dry-ice cooling through sublimation process. Some conclusions that can be drawn from the results:

(1) Using dry-ice as cooling medium proves a good potential as it can reduced the temperature up till 13ºC from the ambient temperature.
(2) Power output decreases linearly with the increase of inlet air temperature. It was recorded that increase power output of 8.5% (0.8 kW) achieved from reduction of temperature of 7.5% (15.6ºC).
(3) Power output decreases with time, due to the inlet duct exposed to the heat form the combustion chamber. This indicates better insulation or adapted data recording approach is needed.

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