# Effect of Haze on Gas Turbine Output

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## SUMMARY

The occurrences of haze in Malaysia are usually attributed to forest fires during prolong period of dry spells in weather condition. Close monitoring of gas turbines' outputs at Kuala Langat Power Plant (KLPP) during such haze period indicated their outputs are affected; the reduction of output is greater the higher is the haze as measured using the Air Pollution Index (API). The output reductions could reach as much as about 3% during normal running of the gas turbines even when the outputs are corrected for ambient temperature, atmospheric pressure and relative humidity. Base upon our observation from monitoring data recorded during such haze periods in the past, we are of the opinion that this is primarily due to incomplete combustion and change to the specific heat ratio of air, arising from the change in air composition.


## INTRODUCTION

Since 1990, Malaysia has experience the occurrences of haze during prolong dry spells of weather condition. Such occurrences are usually attributed to forest fires. Haze from biomass smoke contains a large and diverse number of chemical components that many also consider to have some health implications upon the general population. Numerous air pollution indices have been developed as a way to warn the general public on prevailing condition of the atmosphere. In Malaysia, API is used to indicate the degree of such air pollution. This index is based on the measurement of five pollutants; namely, carbon monoxide, sulphur dioxide, nitrogen dioxide, ozone and $PM_{10}$ (small particles). The values for each pollutant are then converted to a scale ranging from 0 to 500. The highest value among the scales so converted for the five pollutants would then be taken as the API value for the day.

In KLPP we operate a block of gas turbine combined cycle plant. As part of the block configuration, it has three Alstom 13E2 gas turbines; each rated at 165 MW, gross output under ISO conditions. Data arising from the operating the plant is closely monitored continuously. Their value together with site ambient conditions are recorded electronically for analysis should the need arises in the future.

During periods when haze were noticed, we observed that the outputs expected from the gas turbines, even after correcting to site weather conditions, did not reach to the level expected. This is in spite of the fact that we had taken into account normal degradation associated with such gas turbines. We suspected that this phenomenon could be directly associated with the occurrence of haze itself since the phenomenon disappeared together with the haze. This paper investigates how the gas turbine output is being affected by the onset of haze.

## DEGRADATION OF GAS TURBINE

Gas turbine power output is affected by site elevation, ambient temperature, relative humidity, ambient pressure. Besides these, the output is also affected by wear and tear, compressor fouling, fuel types and load conditions. Degradation attributable to compressor fouling, and wear and tear can be categorised under two categories: recoverable degradation and non recoverable degradation. The distinction between the two is that recoverable degradation is usually associated with compressor fouling and can be recovered through offline compressor washing whereas non-

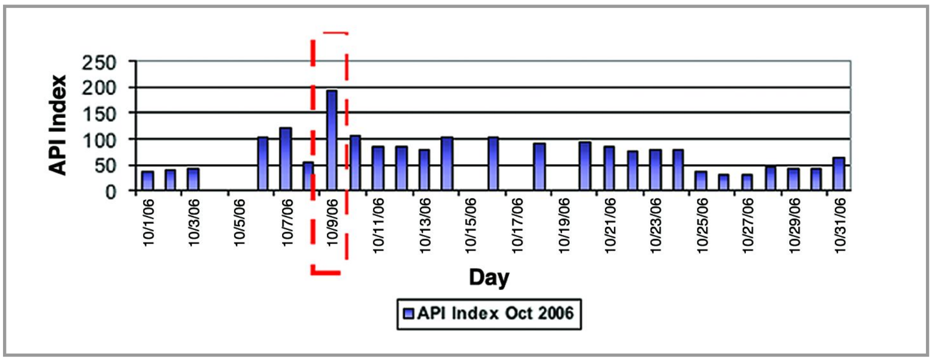


*Figure 1: API index October 2006 in Nilai*

Before Haze Period | ← Haze Period → | After Haze Period

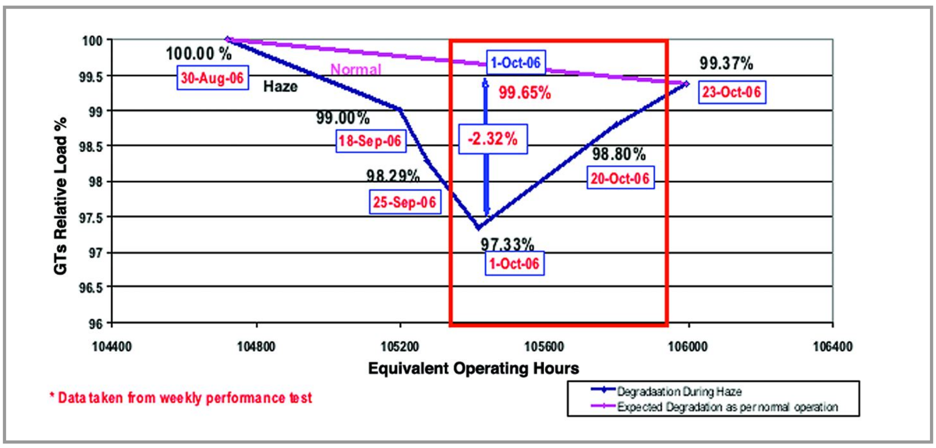


*Figure 2: GT1 power output degradation during 2006 haze period*

Before Haze Period | ← Haze Period → | After Haze Period

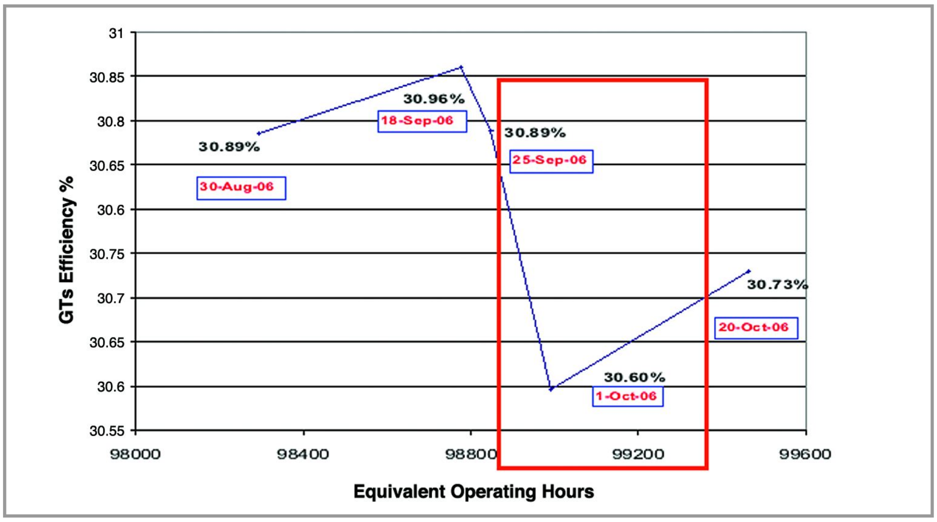


*Figure 3: GT3 efficiency during 2006 haze period*

Before Haze Period | ← Haze Period → | After Haze Period

recoverable degradation is mainly due to the increase in turbine and compressor tip clearances and change in surface finish which cannot be recovered through offline compressor washing but only through replacement of parts during inspection.

Degradation lowers both the gas turbine efficiency as well as its MW output which in turn compromises the commercial benefits that the power plant should bring. Therefore, in Kuala Langat Power Plant (KLPP), extra resources have been allocated to monitor the performance of each gas turbine. Output and efficiency checks are also conducted on a weekly basis and their values are corrected to reference site conditions so that gas turbine performances with respect to power output and heat rate degradation over time can be monitored.

## OBSERVATION

Through the past ten years of operating the KLPP, we had noticed that whenever there is an occurrence of haze, the gas turbines' power outputs would affected quite significantly degrade: their outputs were reduced by an additional 1% to 3% as compared to operation during haze-free period. Initially we had surmised that compressor fouling had accelerated due to the haze. However, to our amazement, the additional power output loss would recover when the haze is cleared, even though neither offline compressor washing nor air intake filter replacements were performed. As similar behavior was observed on all the gas turbines we operate, we suspect there is correlation between the occurrence of haze and the additional degradation. Besides power output, the efficiency is also affected to some extent.

Figure 1 below records the API index for the month of October 2006 in Nilai, Negeri Sembilan when haze was observed in Peninsular Malaysia. The pollution index from this monitoring station is used as it is only a few kilometers from where the Kuala Langat Power Plant are located.

The power output and efficiency monitored during the same period are shown in Figures 2 and 3 respectively.

As haze has commercially implications, we have estimated that for one month of prolonged haze occurring, the additional losses in output and efficiency would amount to about RM9.3 million for by all the Independent Power Producers (IPPs) operating in Malaysia. Therefore, it is of great interest to gas turbine based power plant to investigate whether theres any correlation between occurrence of haze and additional degradation t gas turbine performances.

## INVESTIGATIONS

For our investigation, we have at first hypothesized that during the haze period, the oxygen concentration per volume of air could be lowered. Gas turbine combustion is normally pre-tuned to the optimal air-fuel ratio after scheduled maintenance and this would be carried out during haze-free period when oxygen level would be sufficient to achieve perfect or near perfect combustion. However during haze period, the air mass could contain less amount of oxygen the same optimal combustion to be sustained. This in turn would lead to greater amount of unburned carbon as well as greater concentration of carbon monoxide (CO) emitted from the gas turbine exhaust. The consequence of this would be the lowering of power output and efficiency. This hypothesis is surmised from

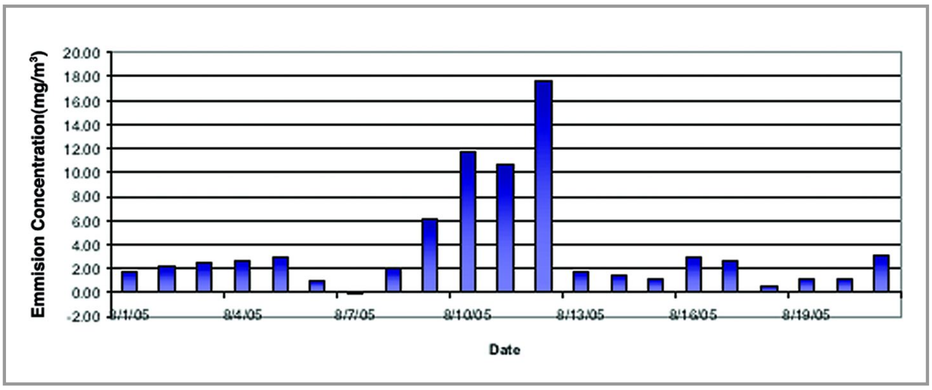


*Figure 4: CO emission level during haze period 2005*

Before Haze Period | Haze Period | After Haze Period

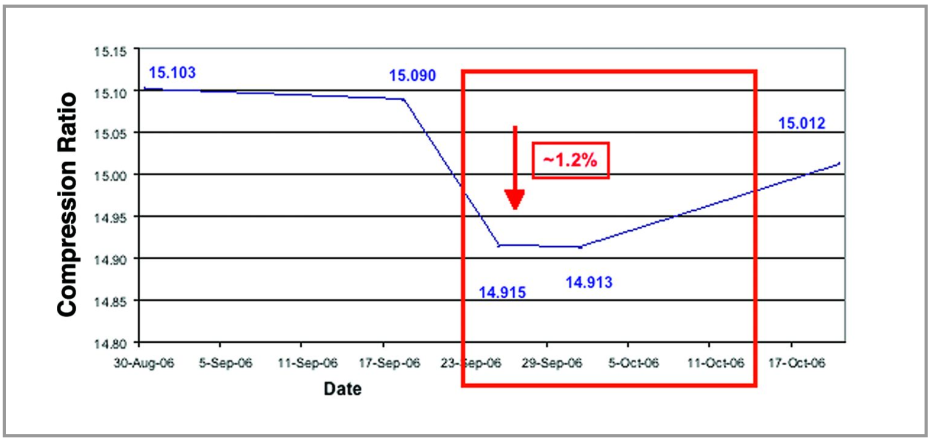


*Figure 5: GT compression ratio during haze period in 2006*

Before Haze Period | ← Haze Period → | After Haze Period

the following three equations where Equation (I) represents combustion equation for methane with theoretical 50% excess air, Equation (II) represents combustion equation arising from less than need excess air (drop from 50% to 15%), and Equation (III) correlates the energy loss with mass of unburned carbon (Mcarbon).

Equation (I). With a theoretical 50% excess air, the Combustion Equation for Methane is given by:

$$CH_4 + 2(1.50)\,O_2 + 2(1.50)\,(3.76)\,N_2 \longrightarrow CO_2 + 2H_2O + O_2 + 11.28N_2$$

Equation (II): However the excess air is reduced from 50% drop to, say 15% the equation would be reduced to:

$$CH_4 + 2(1.15)\,O_2 + 2(1.15)\,(3.76)\,N_2 \longrightarrow 0.95\,CO_2 + \mathbf{0.05CO} + 2\,H_2O + 0.325\,O_2 + 8.65\,N_2$$

Equation (III): As a result the energy loss of is given by

$$\text{Energy loss} = \frac{\text{Mcarbon x Heating Value kJ/kg}}{12}$$

The above equations show that CO concentration will increase if less oxygen is available during the combustion process. To substantiate our hypothesis, we also analysed the CO level at the gas turbine stack emission throughout the haze period. Our monitored records show that the CO concentration increased substantially during haze period but returned to normal level when the haze is over. The higher CO concentration at gas turbine exhaust would point towards a higher degree of incomplete combustion occurring during haze period. Such increase in CO level would also indicate an increase to the amount of unburned carbon which in turn results to a greater energy loss and therefore a reduction to the power output. The detail of CO emission level during haze period is shown in Figure 4.

## OBSERVATION

We also suspect that power output reduction during haze period could be due to multiple of factors. In extending our investigation, we observed that compression ratio was also reduced by 1.2% during such haze period but recovered when the haze subsided. Such reduction in compression ratio could also contribute to a reduction in power output (see Figure 5).

In thermodynamic isentropic compression equation below, compression ratio is proportional to the specific volume of air to the power of specific heat ratio, α:

$$\text{Compression ratio:} \quad \frac{P2}{P1} = \left[\frac{v1}{v2}\right]^{\alpha}$$

Where,

$$\alpha\text{, alpha} = \frac{\text{Cp, specific heat capacity for gas in constant pressure process}}{\text{Cv, specific heat capacity for gas in constant volume process}}$$

$P$ = Pressure
$v$ = Specific volume

Equation above depicts that compression ratio is affected by two factors i.e. the ratio of $v1$ over $v2$ and α; the ratio of specific heat (Cp/Cv). α is dependent upon air composition, where it is 1.40 for oxygen, 1.303 for carbon dioxide and 1.395. During haze period, the oxygen level is lower where carbon dioxide and fine particles would be higher. This change in air composition (as compared to normal air composition) would reduce the α and therefore reduce the compression ratio and hence the power output. Figure 5 shows the GT compression ratio before and after haze period.

## CONCLUSION

From our analysis above we believe that degradation of gas turbine performance during haze period is primarily due to incomplete combustion as well to change in the ratio of specific heat of air arising from the changes in air composition. ■