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Performance investigation of axial flow compressor at different climatic conditions

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Abstract: This paper discusses the effect on axial-flow compressor, when climatic conditions are changing. Ensuring compressor run at maximum effectiveness is a primary aim for operators. In the existing economic climate, whatever that increases productivity, and hence profit, is obviously welcome. From climate point of view, it is also significant that compressor run as efficiently and produces as insufficient emissions as possible for optimum performance of gas turbine engine. The performance characteristics of axial flow compressor depend on the ambient and operating condition, influenced by pressure ratio, ambient temperature, and relative humidity (RH). Social activity makes a stress on the environment in every area of land, water and air are overcome with the bad effects of industry. Atmospheric circumstances affect the performance of the engine after the density of the air will be changed under different conditions. At inlet condition of the compressor spray coolers and variable inlet guide vanes are also used for enhancing the power and the efficiency of the gas turbine power plant, however, it works more efficiently at hot and dry climatic conditions. Economic Conditions that Affect Fuel Strategy by variation of climate conditions. The performance of the axial flow compressor is reliant on the mass of air incoming the engine.
Keywords: climate condition, axial flow compressor, ambient temperature, relative humidity, variable inlet guide vane.

I. INTRODUCTION

The compressor always play an important role in overall performance of the gas turbine power plant at various phase. The compressors in most gas turbine power plants applications especially ones of 5 MW or more usage axial flow compressors [11]. In an axial flow compressor, the flow arrives the compressor in an axial direction as parallel to the axis of rotation. The axial flow compressor compresses the occupied fluid by firstly accelerating the fluid and then diffusing it to get a pressure increase. The fluid is augmented by a row of rotating blades rotor, and then diffused in a row of fixed blade stator. The diffusion in the stator transforms the velocity increase added in the rotor to a pressure increase. Compressors consist have many stages, where one stage is reflected a rotor monitored by a stator. An axial flow compressor of one or more rotor gatherings that convey blades of airfoil section mounted between bearings in the casings that include the stator vanes. The axial flow compressor is a multi-stage unit as the quantity of pressure increase by each stage, consists of a row of rotating blades monitored by a row of stator vanes.

During action the rotor is turned at top acceleration by the cause so that air is continuously induced into the compressor, which is again accelerated by the alternating blades and swept rearwards regulate the adjacent row of stator vanes. The burden acceleration after-effects from the activity imparted to the air in the rotor, which increases the air velocity. The air is again decelerated (diffused) in the afterward stator access and the active activity translated into pressure. Stator vanes as well serve to actual the bend accustomed to the air by the rotor blades prior to entry.

A. Basic Performance parameters For Compressor

Deliberating to the ISO standards 3977-2 (Gas Turbines - Procurement - Part 2: Standard Reference Conditions and Ratings) the ISO ambient conditions for the gas turbine are designated in table 1.

Table 1: ISO ambient Condition for industrial gas turbine engine [4]

Ambient temperature	15 ^{0}C/59 ^{0}F
Relative humidity	60 %
Ambient pressure	1.013 bar/14.7 psi

The above cited parameters are directly related to the density of air. Therefore, the deviation of ambient conditions from the above

ISO ambient conditions results in change in the air density. As a result of that the amount of air mass enters the gas turbine changes.

B. *Effect of Intake on Compressor Performance*

The result of intake air on compressor performance should not be underestimated. Intake air that is polluted or hot can harm compressor performance and result in excess energy and maintenance prices. If humidity, dust, and other contaminants are existing in the intake air, such contaminants can build up on the interior components of the compressor, such as valves, rotors, and vanes. Such build-up can source premature wear and reduce compressor capacity.

When inlet air is cooler, means denser. As a result, mass flow and pressure capability increase with falling intake air temperatures, particularly in axial flow compressors. Conversely, as the temperature of intake air increases, the air density decreases and mass flow and pressure potential reduce. The resulting decrease in capacity is often addressed by operating further compressors, thus increasing energy consumption.

II. INVESTIGATIVE APPROACH

Investigation facilities that use undefined atmospheric air must account for fluctuations in ambient compressor inlet circumstances to createa repeatable performance maps.
To investigate the effects of complex order similarity constraints on compressor performance, exit circumstances will be modified to normal, winter and summer day inlet settings for density and work coefficient. Inlet condensation can happen in high humidity surroundings due to air acceleration. This section outlines the analysis used for the climatic parameters which effect the performance of the compressor due to change in density of air and work coefficient correction, ambient temperature, pressure ratio and the calculation of thermodynamic properties in this study. All reference conditions assume dry air with the following properties:

$$\rho_{0,ref} = \frac{p_{0,ref}}{R_{ref}T_{0,ref}} \tag{1}$$

$$\rho_{0,ref} = 1\,atm = 14.7\,psi$$

$$T_{0,ref} = 518.67^0R = 288.15K \tag{2}$$

$$\gamma_{ref} = 1.4$$

$$R_{ref} = 53.36\frac{ft\,lb_f}{lb_mR} = 287.058\,J/kgK \tag{3}$$

Compressor investigation facilities that use undefined atmospheric air are subjected to changes in the fluid properties of the employed fluid with ambient circumstances: pressure, temperature, and humidity. The change of these atmospheric conditions make it expected that the compressor will unable to achieve the same pressure (density) rise as it would with the reference inlet conditions from eq. (2).Therefore, variable ambient conditions disturb the compression process, including the enthalpy rise (work input) and entropy rise (losses).
The performance of an axial flow compressor is very much reliant on on environmental circumstances. We will describe the influence of the different environmental parameters and their conclusion on performance below. The environmental parameters that influence the performance of compressor are:

- Relative Humidity
- Temperature effect on tip clearance
- Inlet pressure
- Reynold number effect
- Ambient temperature

To understand the impact of these parameters, we have to look at the performance curves of a axial flow compressor and see how performance of axial flow compressor is impacted with changing environmental parameters or climatic conditions.

A. *Relative Humidity Effect*

Relative humidity (RH) is the amount of the water vapor's partial pressure to its saturated pressure at a specific temperature. RH is stated as a percentage and is usually used to describe ambient air humidity. The disadvantage of using RH is that it is heavily reliant on temperature. For illustration, if RH is 85% and the temperature 20°C, a reduction in the air temperature of only 2°C fluctuations the RH to 96%. Optimal control needs precise humidity data.At high inlet humidity, the drop in static pressure throughout acceleration of the air concluded the compressor will rise dust adhesion on the blades because of the condensing water.

Figure 2.1 shows the percent difference in total enthalpy, (h_o), total density (ρ_0), and ratio of specific heats (γ), compared to air at reference conditions for a diversity of inlet pressures, temperatures, and relative humidity (RH) values that could occur throughout a typical climate circumstances.

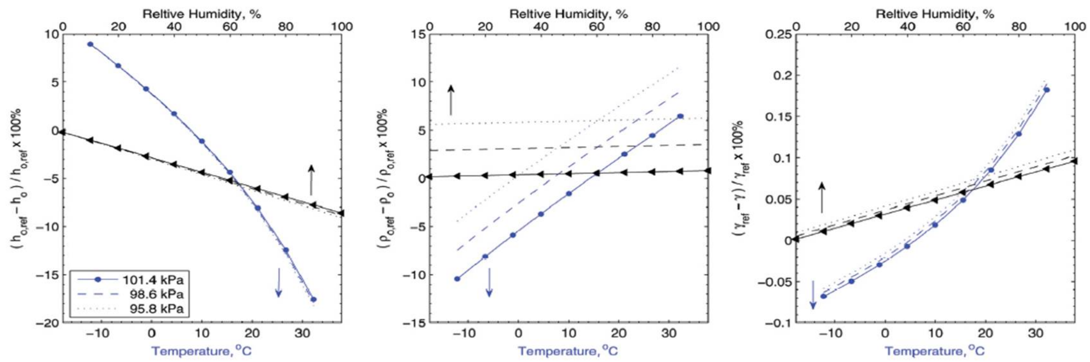

Fig.2.1 Effects of temperature ambient pressure, & RH change on enthalpy, density, and ration of specific heat of air [6]

B. Temperature effect on Tip Clearance

The inlet temperature of the air in has an impact on the density of the air at the intake of the compressor and will manipulate the kinetic energy transferred by the blades to the air. Increased density at lower intake temperatures will effect in a higher free air delivery and also higher power utilization of the compressor.

Another main outcome of the modify in air or gas density is the available turndown of the compressor. That is the flow range where efficient regulation through use of inlet guide vanes is possible. From the illustrations below it is clear that with lesser temperatures a elevated turndown range is available.

Figures 2.2.1 show the effect of inlet temperature on the performance of turbo compressor.

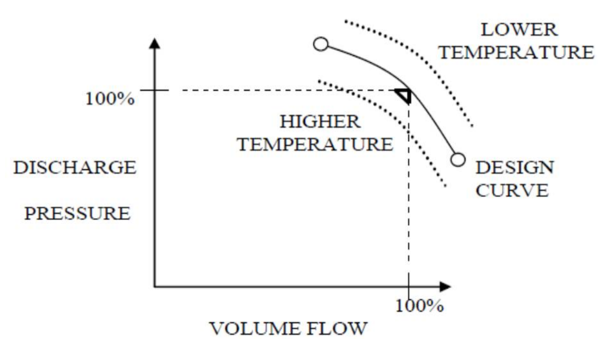

Fig. 2.2.1 Density of air increases with reduction of air temperature [19]

After incorporating humidity and real gas effects into modified inlet conditions for rotational speed and mass flow rate, there continue determinate and repeatable discrepancies between compressor performance on a cold and hot day. For compressor complete total pressure ratio (TPR) for the 3% and 4% at Tip clearance configurations. Corrected mass flow rate has been normalized by a nominal loading condition half way up the speed line. These data represent the average of a 20-point circumferential traverse and are repeatable for the similar inlet conditions.

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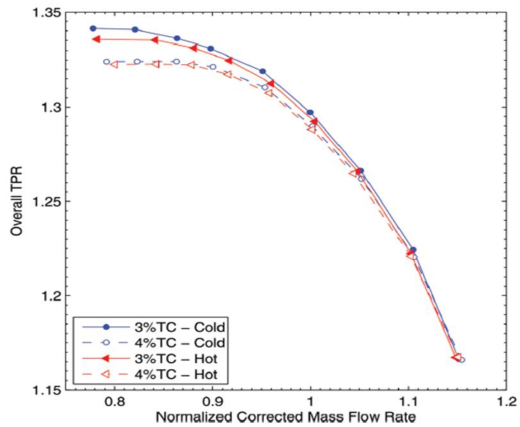

Fig. 2.2.2Differences in TPR between a hot and cold day [6]

This paper focus to investigate the performance of axial flow compressor at various environment circumstances in summer, average and winter condition. The performance parameter varies with respect to change in climate and affects the performance of the compressor.

C. Inlet Pressure

A decrease in inlet pressure will reduce the density of the air at the compressor intake. As with higher temperatures, it will result in lower free air delivery and power. Changes in inlet pressure can be caused by fouled inlet filters or changing barametric pressure. The same goes for the available turndown -lower intake pressure will result in smaller available turndown. (See Figure 2.3)

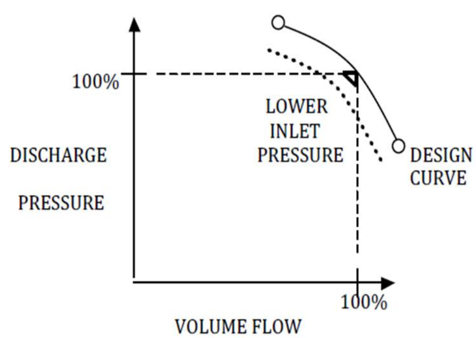

Fig 2.3 How lower inlet pressure impacts compressor performance [19]

D. Reynolds Number Effects

Large shifts in ambient conditions can cause the working fluid properties to change, therefore changing Reynolds number. Standard compressor testing procedures allow for Mach number similarity between the test and reference conditions through a correction process for rotational speed, but there is no prescribed method to also maintain Reynolds number similarity. Reynolds number effects are often considered small, and thus, they are often neglected. However, deviations from the Reynolds number at reference conditions can become large on significantly hot or cold days.

$$Reynold\ index = \frac{Re_{test}}{Re_{ref}}$$

It represent a ratio of test Reynold no corresponding to average days operation. Figure 2.4 represent the Reynolds index on the hot and cold days for the data present in figure 2. The Re_{test} number approaches a $\pm 10\,\%$ differences from Re_{ref}. A value which could become increasingly important for some compressors. The change in Re_{test} number arise from variable inlet conditions of temperature, pressure and relative humidity.

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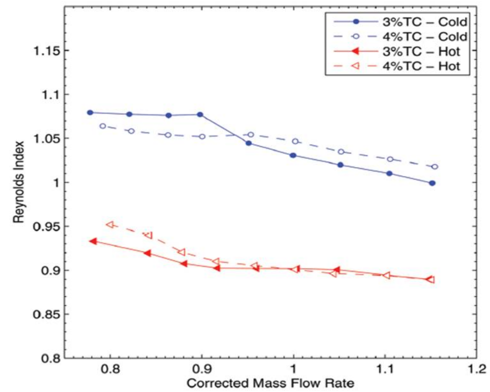

Fig 2.4 Reynolds number index on a hot and cold day[6]

E. Effect of ambient temperature

Efficiency of the gas turbine vary with vary ambient conditions [11]. The efficiency decreases as the compressor requires more power to compress air of higher temperature. The net power output is improved by 11%, when the gas turbine engine is provided with cold air at the inlet. At the ambient temperature of 30^0 the net power output increases by 11 % at ISO rated condition, accompanied by a 2 % rise in thermal efficiency and a drop in specific fuel consumption of 2 %.

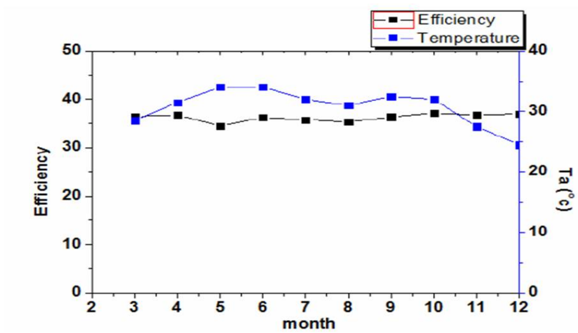

Fig. 2.5.1 Thermal efficiency and ambient temperature during the year (2006) [5]

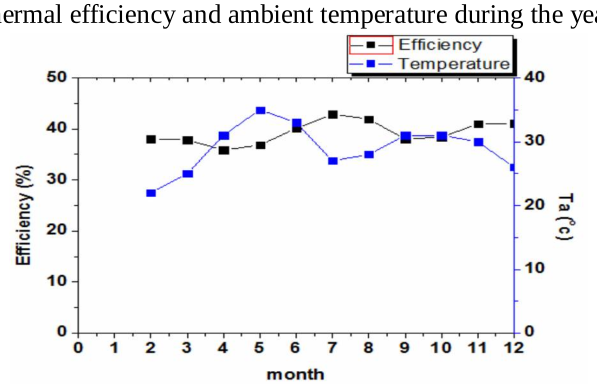

Fig. 2.5.2 Thermal efficiency and ambient temperature during the year 2007 [5]

Figure 2.5.1 illustrate that the variation of temperature and efficiency during the one year. In March month when the temperature is 28.5^0 C the corresponding efficiency is 36.48 %, for April month the efficiency nearly same as March, but when temperature rises the efficiency falls as shown in May and June (summer season). For remaining the month of the years the efficiency is observed as the temperature drops in those month.

Figure 2.5.2 the efficiency decreases gradually as the average temperature increases in February to April. In July the efficiency reach maximum value when ambient temperature is 28^0 C due to the rainy season. The efficiency the decreases again in September and October due to increasing in Temperature value. The efficiency again rises as the temperature drops in December (Winter Season).

III. COMPARISON OF THE OVERALL PERFORMANCE CHARACTERISTICS AT DIVERSE CLIMATIC CONDITION

There are basically three operating conditions [7] for the axial flow compressor as shown in table 2:

Table 2 Details of the three operating conditions

Performance parameters	Units	Summer	Winter	Average
Inlet temperature	℃	30.3	16.0	8.1
Inlet pressure	kPa	88.0	90.0	89.0
Relative humidity (RH)	%	60	45	52
Mass flow rate	kg/s	78.36	62.28	72.15
Pressure ratio	psa	5.24	5.13	5.17
Rotational speed	r/min	5100		

The variable inlet guide vanes are used to achieve the optimum performance of the axial flow compressor by changing the stagger angle of the stator blade [7] to satisfy the demand under the different climatic conditions. Under summer operating situation, a huge amount of mass flow rate is required, while under the winter condition, the compressor working relative low mass flow rate.

The comparison of the overall performance characteristics at portion of the modes in different climatic conditions as summer, winter and average condition shown in figure 3.1, figure 3.2 and figure 3.3.

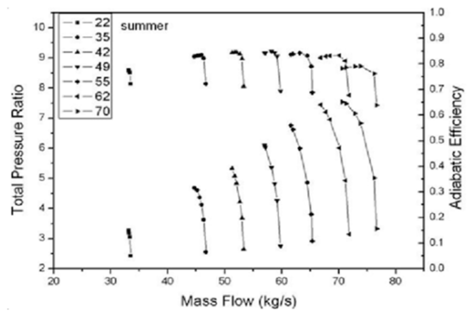

Fig. 3.1 Overall performances in summer condition [7]

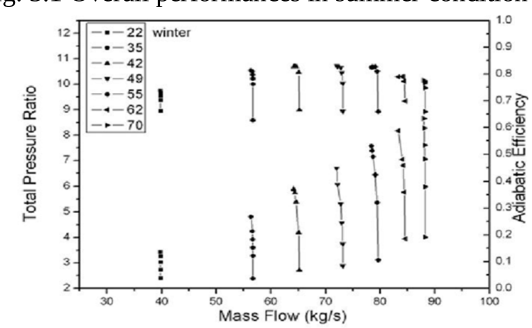

Fig. 3.2 Overall performances in winter condition [7]

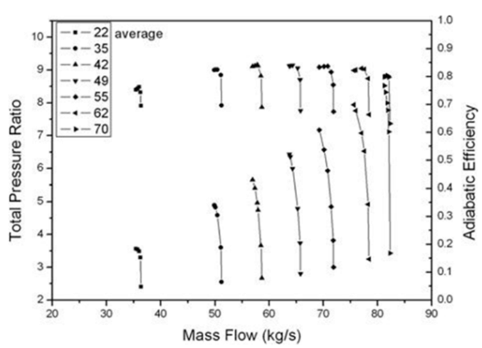

Fig.3.3 Overall performances in average condition [7]

In this paper different operating condition are discussed for varying climate conditions with respect to the various overall performance map of the compressor as shown in above figures.

As shown in figure 3.1, figure 3.2 and figure 3.3 the adiabatic efficiency of multistage axial flow compressor is at very high level. The highest efficiency of the axial flow compressor in summer and winter conditions is relatively a little bit low. As shown in figures, there is the identical tendency of the curve in summer and winter and average conditions, that the mass flow rate and total pressure ratio are enhanced with increase in stagger angles.

IV. CONCLUSION

The performance physical appearance are observed for a set of design and working parameters including relative humidity, ambient temperature, turbine inlet temperature and pressure ratio. From the various literature concluded that the performance of axial flow compressor vary with different ambient condition under, which a compressor operate have a noticeable effect on the both the power output and efficiency. There is variation in power and efficiency of the compressor in winter and summer season as a function of ambient temperature compared to the mention international organization for standards (ISO) condition at sea level and 32.78 ^{0}C.

They consume a substantial amount of power, producing a large drop in the overall plant performance. If the density of the air decreases, the equivalent volume of air will comprise less mass, so less power is produced by compressor. Similarly if the air density increases, power output also increases as the air mass flow rises for the equivalent volume of air. Climate circumstances affect the performance of the engine subsequently the density of the air will be different under diverse conditions. On a winter season, the air density is too high, so the mass of the air incoming the compressor is increased, as the result of higher horsepower is produced. Similarly in a summer season, or at high altitude, air density is decreased, resulting in a decrease of power. Cooler, denser air increases output and efficiency, similarly for hotter air decrease the output as well as efficiency of the compressor.

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