

# ANALYSIS OF INLET AIR TEMPERATURE EFFECT ON GAS TURBINE COMPRESSOR PERFORMANCE

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**Abstract-** The air compressor in Gas turbine plant plays an important role as it supplies the air under desired pressure to combustion chamber of the plant. The inlet air temperature also effects on the performance of the plant and power output. Normally cooling effects are provided better performance in the gas turbine plant. This task must be carried out with the possible minimum of pressure leaks and with the maximum possible release of heat respect the limited space available.

The air entering into the compressor will have higher temperatures which intern effects the efficiency of the compressor hence the temperature should be lowered by coolers and then allowed into compressor the effects are measured practically in the gas turbine power plant and the conditions are considered for the analysis.

In this present work a 3D model of the compressor outer case done in Unigraphics-Nx software. The generated 3-D model imported into ANSYS using the parasolid format and flow analysis done on the compressor outer case at different temperatures which are obtained in the actual plant at a time duration of 10 hours. Present analysis the temperatures considered are 300K, 295K and 290K the compressor efficiencies are approximately equal in both the cases ie actual plant measured values and values obtained in the analysis. Cooling effect the efficiency and lower temperature of inlet air to the compressor shows the maximum efficiency and maximum power output.

**Keyword-** Air Compressor, Inlet air temperature, Unigraphics-Nx, Ansys.etc..

## 1. INTRODUCTION

### 1.1. INTRODUCTION TO GAS TURBINE PLANT

Gas turbine engines derive their power from burning fuel in a combustion chamber and using the fast flowing combustion gases to drive a turbine in much the

same way as the high pressure steam drives a steam turbine.

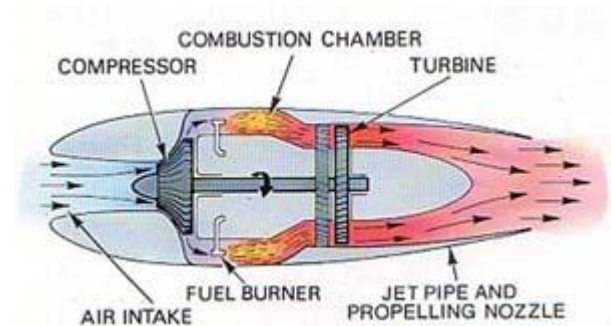


Fig.1.1.Gas turbine working priciple

One major difference however is that the gas turbine has a second turbine acting as an air compressor mounted on the same shaft. The air turbine (compressor) draws in air, compresses it and feeds it at high pressure into the combustion chamber increasing the intensity of the burning flame. It is a positive feedback mechanism. As the gas turbine speeds up, it also causes the compressor to speed up forcing more air through the combustion chamber which in turn increases the burn rate of the fuel sending more high pressure hot gases into the gas turbine increasing its speed even more. Uncontrolled runaway is prevented by controls on the fuel supply line which limit the amount of fuel fed to the turbine thus limiting its speed.

The thermodynamic process used by the gas turbine is known as the Brayton cycle. Analogous to the Carnot cycle in which the efficiency is maximised by increasing the temperature difference of the working fluid between the input and output of the machine, the Brayton cycle

efficiency is maximised by increasing the pressure difference across the machine. The gas turbine is comprised of three main components: a compressor, a combustor, and a turbine. The working fluid, air, is compressed in the compressor (adiabatic compression - no heat gain or loss), then mixed with fuel and burned by the combustor under constant pressure conditions in the combustion chamber (constant pressure heat addition). The resulting hot gas expands through the turbine to perform work (adiabatic expansion). Much of the power produced in the turbine is used to run the compressor and the rest is available to run auxiliary equipment and do useful work. The system is an open system because the air is not reused so that the fourth step in the cycle, cooling the working fluid, is omitted.

### 1.2. AIR COMPRESSOR

An **air/gas compressor** is a mechanical device that increases the pressure of a air/gas by reducing its volume. An air compressor is a specific type of gas compressor. Compressors are similar to pumps: both increase the pressure on a fluid and both can transport the fluid through a pipe. As gases are compressible, the compressor also reduces the volume of a gas. Liquids are relatively incompressible; while some can be compressed, the main action of a pump is to pressurize and transport liquids.



Fig.1.2. Air compressor inlet

## 2. FLOW CALCULATIONS FOR GAS TURBINE COMPRESSOR EFFICIENCY

### 2.1. Gas turbine industrial data and calculations:

A 12 MW gas turbine generator is required to operate at sea level with an ambient temperature  $T_1$  of 20°C and a combustion temperature  $T_3$  of 950°C. The following data apply.

#### Compressor:

Pressure ratio of the compressor  $r_{pc}$  1.5  
 Compressor efficiency  $\eta_c$  0.85  
 Ratio of specific heats for compression  $\gamma_c$  1.4

Specific heat at constant pressure  $C_{pc}$  1.005  
 kJ/kg°K

Ambient pressure 1.0 bar

#### Turbine

Pressure ratio of the turbine  $r_{pt}$ , nominal 11.0

Turbine efficiency  $\eta_t$  0.87

Combustion pressure drop  $P_{23}/P_{23}$  0.04

Ratio of specific heats for expansion  $\gamma_t$  1.33

Specific heat at constant pressure  $C_{pt}$  1.147  
 kJ/kg°K

Heat rate 15.750 MJ/kWh

There are various definitions of efficiency when it comes to compressors and turbines. Any efficiency is going to be a function of what you put in divided by what "get out". A common definition is something like

$$\eta = \frac{\dot{W}_{in}}{\Delta h_{in}}$$

Or basically, the ratio of the work we're inputting divided by the enthalpy rise in the stage. It can be written as

$$\eta = \frac{T\omega}{\dot{m}c_p\Delta h}$$

Where  $T$  is the input torque and  $\omega$  is the rotational speed, combined they are the work per unit time (power) of the motor. On the bottom we have total enthalpy. Certainly one doesn't measure enthalpy, so typically I've seen the enthalpy term written out in terms of total temperature and change in total pressure, which you should be able to measure with what you have. So, we can use isentropic definitions for pressure and temperature to convert the previous equation to

$$\eta = \frac{T\omega}{\dot{m}c_p T_{T1} \left[ \left( \frac{P_{T2}}{P_{T1}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]}$$

Where the total pressure is defined as:

$$P_T = p + \frac{\rho V^2}{2}$$

And the total temperature defined as:

$$T_T = T + \frac{V^2}{2c_p}$$

So, it will need to use the temperature at the inlet and outlet planes to compute a gamma (ratio of specific heats). It will also need to compute density. This can be done from tabular lookup or from an empirical relation. From density, area, and the measured airflow you can compute velocity.

From velocity and measure pressure/temperature you can compute total properties (you'll also need to look up specific heat at constant pressure cp similar to gamma). Once total pressure and temperature at both inlet and outlet planes, you can compute an efficiency given your mass flow and input from your motor. Note that it will need a few conversion factors depending on the units of power from the motor.

**2.2. Compressor efficiency**

The efficiency on a compressor map, which are called isentropic (or adiabatic) efficiencies. They are calculated this way:

$$\eta_c = \frac{T_{out\ th} - T_{in}}{T_{out} - T_{in}}$$

Where:

$\eta_c$  is Compressor efficiency

$T_{in}$  is Inlet temperature

$T_{out}$  is Outlet temperature

$T_{out\ th}$  is Theoretical outlet temperature

**2.3. Industrial Data (Calculated & Measured)**

**2.3.1. Without cooling effect**

S.No.	Time (hours)	Inlet air temperature(K)	Power output (MW)
1	10	297	8.5
2	10	298	7.8
3	10	300	7.5

Table.2.1. Inlet air temperature and power output without cooling

**2.3.2. With cooling effect**

S.No.	Time (hours)	Inlet air temperature(K)	Power output (MW)
1	10	295	9.5
2	10	290	11
3	10	288	11.8

Table.2.2. Inlet air temperature and power output with cooling

**2.3.3. Analysis consideration values:**

For validation and comparison from the above conditions it considered as given below

S.No.	Time(hours)	Inlet air temperature (K)	Compressor efficiency $\eta_c$	Power output (MW)	Condition of inlet air
1	10	300	61.05	7.5	Without cooling
2	10	295	62.11	9.5	With cooling
3	10	290	63.32	11	With cooling

Table.2.3. Inlet air temperature, compressor

**3. 3D MODELING OF GAS TURBINE COMPRESSOR OUTER CASE**

In the present study NX\_CAD software is used for 3D modeling of gas turbine compressor outer case, ANSYS CFD package software's shall be used for the flow simulation. Perform flow analysis of gas turbine compressor outer case for different inlet air flow temperatures using ANSYS Fluent software to determine the outlet temperatures, pressure and compressor efficiency.

**The methodology followed :**

- Create a 3D model of the gas turbine compressor outer case using NX-CAD software.
- Create finite volume mesh for 3D model of gas turbine compressor outer case by using ANSYS ICEM CFD software and import into ANSYS FLUENT software.
- Perform flow analysis of gas turbine compressor outer case for different inlet air flow temperatures by using ANSYS Fluent software to determine the outlet temperature, pressure, velocity variations and compressor efficiency from inlet to outlet.
- The 3D model of the gas turbine compressor outer case is created using NX-CAD software from the 2D drawings. NX-CAD is the world's leading 3D product development solution. This software enables designers and engineers to bring better products to the market faster. It takes care of the entire product definition to serviceability.

**3.1. 2D drawing of Present gas turbine compressor outer case:**

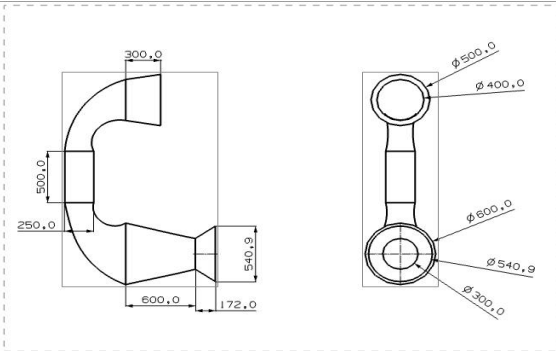


Fig.3.1.Compressor outer case 2D drawing.

**3.2. Isometric view of gas turbine compressor outer case:**

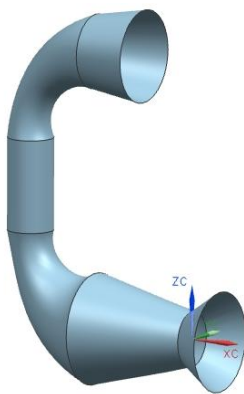


Fig.3.2. 3D model of gas turbine compressor outer case

**3.3. THE MODELING PROCESS:**

The modeling process consists of first taking the real world fluid geometry and replicating this in the virtual environment. From here, a mesh can be created to divide the fluid up into discrete sections. Boundary conditions must then be entered into the model to designate parameters. Conventional geometries, with their characteristics and applications of fluids to be modeled or the details of any solid edges or flow inlets/outlets. The simulation is then ready to be run and when a converged solution is found, it must be carefully analyzed to establish whether the mesh is appropriately modeling the flow conditions.

3D model of Gas Turbine compressor outer case is developed by using NX-CAD software to perform the gas flow simulation through compressor by taking industrial data.

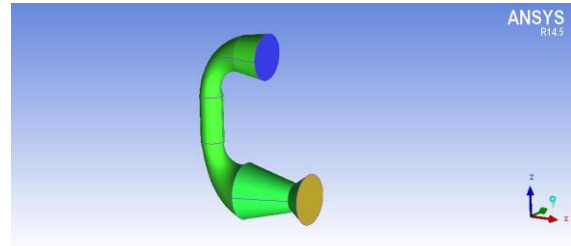


Fig.3.3. The Geometry of gas turbine compressor outer case

**3.4. CONSTRUCTING THE DOMAIN AND MESHING**

CFD allows virtual experimentation with and consequently optimization of the design parameters. It is very attractive to industry as it saves both time and effort during the design process when compared alongside traditional experimental methods. However, the degree of confidence in the results is dependent on many factors and as a result. For the flow analysis of the gas turbine compressor outer case are generated in NX-cad and mesh is created in the ICFM CFD software.

The domain was meshed using tetrahedral meshing technique. The geometry and meshing of the gas turbine compressor outer case is as below.

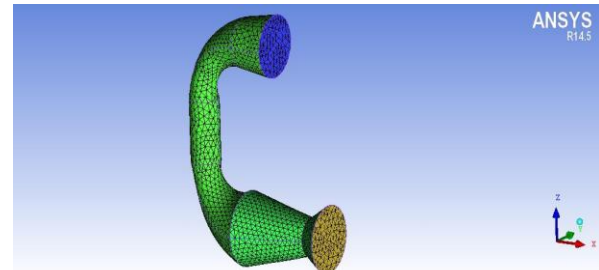


Fig.3.4. Gas turbine compressor outer case with volume Mesh and section view

**3.4.1. THE BOUNDARY CONDITIONS**

The CFX software comes with different boundary types which synchronize with the physical conditions. The CFX boundary model has been incorporated which uses the 'VELOCITY INLET' boundary types for hot air inlet. Temperature and flow velocity parameters are given to inlet boundary conditions. For the outlet, 'OUTLET VENT' boundary condition is used with atmospheric pressure. WALL boundary condition is used for the outer surface area.

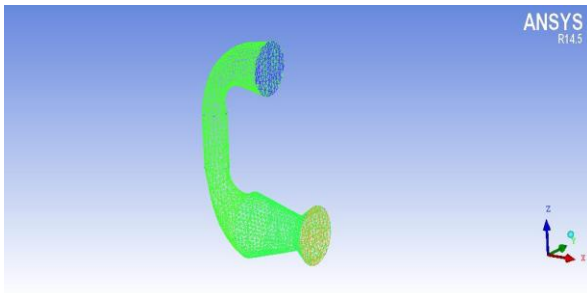


Fig.3.5. Inlet and outlet Boundary conditions of the gas turbine compressor outer case

### 3.5. THE SIMULATION APPROACH

After the meshing has been completed the model is then imported into ANSYS FLUENT pre-processor and suitable boundary types defined. The finite volume approach which is used in ANSYS FLUENT is used to create the solver. The governing equations are then integrated over the whole control volume.

#### FLUENT

Version: 3d, pbns, ske (3d, pressure-based, laminar)

Release: 13.0.0

#### Title: MODELS:

model	settings
Space	3D
Time	Steady
Viscous	Standard k-epsilon turbulence model
Heat Transfer	Enabled

#### MATERIAL PROPERTIES:

Material: air (fluid):

PROPERTY	UNITS	VALUES
Density	kg/m <sup>3</sup>	1.225
Cp (Specific Heat)	J/kg-k	1006.43
Thermal Conductivity	w/m-k	0.024
Viscosity	kg/m-s	1.78e-05
Molecular Weight	kg/kgmol	28.9
Thermal Expansion Coefficient	1/k	0
Speed of Sound	m/s	340

#### Compressor:

Wall Thickness (m)	0.005
Heat Generation Rate (w/m <sup>3</sup> )	0
Material Name	aluminum
Thermal BC Type	3
Temperature (k)	300
Heat Flux (w/m <sup>2</sup> )	0
Convective Heat Transfer Coefficient (w/m <sup>2</sup> -k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
External Emissivity	1
External Radiation Temperature (k)	300
Wall Roughness Height (m)	0
Wall Roughness Constant	0.5

#### Wall :

Wall Thickness (m)	0.005
Heat Generation Rate (w/m <sup>3</sup> )	00
Material Name	aluminum
Thermal BC Type	2
Temperature (k)	300
Heat Flux (w/m <sup>2</sup> )	0
Convective Heat Transfer Coefficient (w/m <sup>2</sup> -k)	1
Free Stream Temperature (k)	300



Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
External Emissivity	1
External Radiation Temperature (k)	300
Wall Roughness Height (m)	0
Wall Roughness Constant	0.5

Fig.4.2. Vector temperature occurred on gas turbine compressor fluid demine

4.2. VECTOR TURBULENCE:

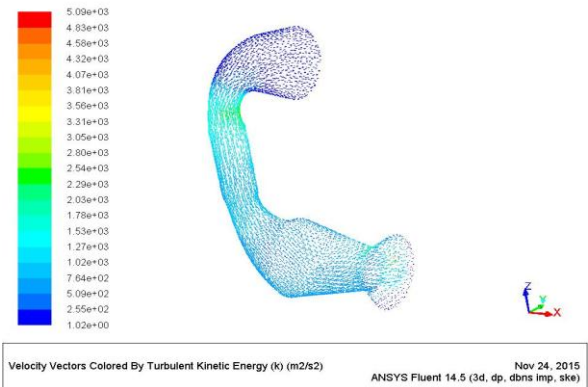


Fig. 4.3. Vector turbulence occurred on gas turbine compressor outer shell

4. RESULTS DISCUSSION

4.1. VECTOR TEMPERATURE:

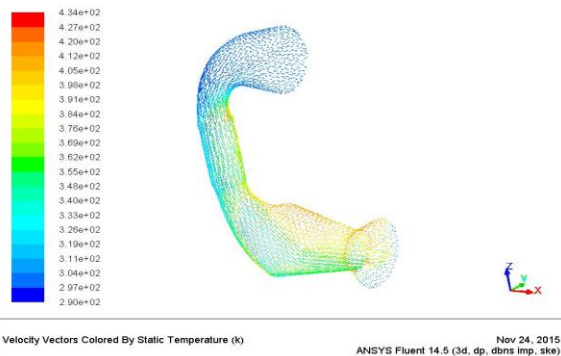


Fig.4.1. Vector temperature occurred on gas turbine compressor outer shell

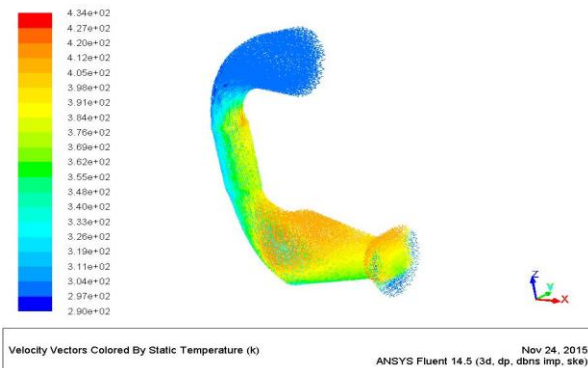


Fig.4.4. Vector turbulence occurred on gas turbine compressor fluid demine

From the above flow analysis results, it can observe that the average temperatures are 300K, 377K, 396K, and 360.4K respectively occurred on the inlet, wall, compressor and outlet surface areas of gas turbine compressor system. In this case we observed that the compressor efficiency by the average temperature calculations.

4.3. Compressor efficiency

It can calculate the compressor efficiency by putting into the above formula.

$$\eta_c = 0.615 * 100 = 61.5\%$$

#### 4.4. CASE-2 by changing the Inlet air temperature 295 K

##### 4.4.1. VECTOR TEMPERATURE:

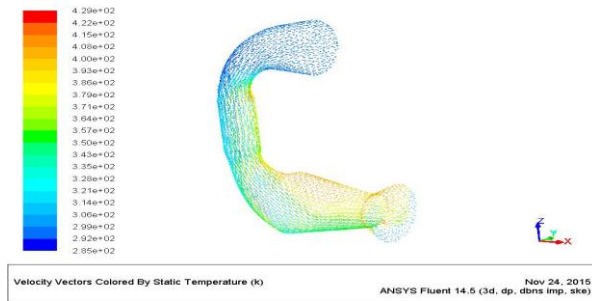


Fig.4.5. Vector temperature occurred on gas turbine compressor outer shell 295 k

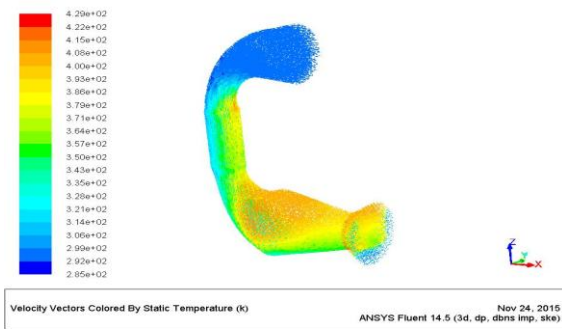


Fig.4.6. Vector temperature occurred on gas turbine compressor fluid demine 295 k

##### 4.4.2. VECTOR TURBULENCE:

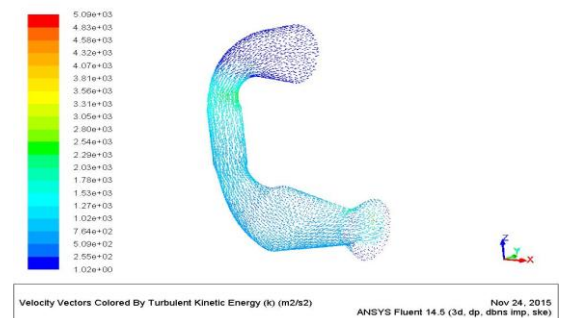


Fig.4.7. Vector turbulence occurred on gas turbine compressor outer shell

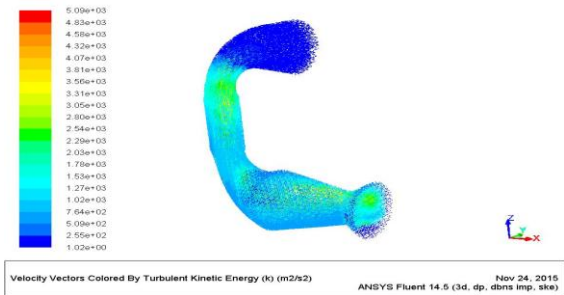


Fig.4.8. Vector turbulence occurred on gas turbine compressor fluid demine

From the above flow analysis results, we can observe that the average temperatures are 295K, 371K, 392K, and 353.6K respectively occurred on the inlet, wall, compressor and outlet surface areas of gas turbine compressor system. In this case we observed that the compressor efficiency by the average temperature calculations.

##### 4.4.3. Compressor efficiency

Compressor efficiency calculated as previous calculations in case -1 at temperature 300 K

$$\eta_c = 0.6196 * 100 = 61.9\%$$

#### 4.5. CASE-3 by changing the Inlet air temperature 290 K

##### 4.5.1. VECTOR TEMPERATURE:

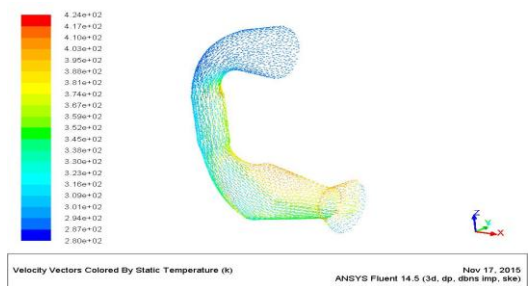


Fig.4.9. Vector temperature occurred on gas turbine compressor outer shell at 290K

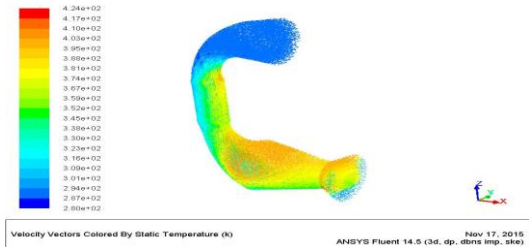


Fig. 4.10. Vector temperature occurred on gas turbine compressor fluid demine at 290K

4.5.2. VECTOR TURBULENCE:

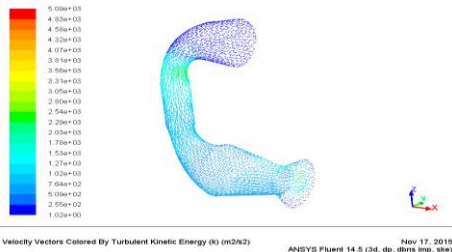


Fig.4.11. Vector turbulence occurred on gas turbine compressor outer shell at 290K

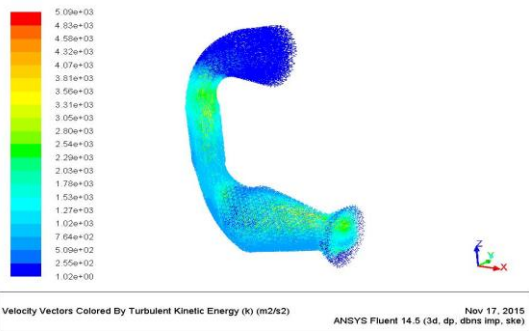


Fig.4.12. Vector turbulence occurred on gas turbine compressor fluid demine 290K

4.11. Compressor efficiency

From the above results,

We can calculate the compressor efficiency by putting into the above formula.

$$\eta_c = 0.625 * 100 = 62.5\%$$

5. CONCLUSION

- The Max Compressor efficiency obtained in the analysis without cooling is 61.5 % which is approximately equal to that of measured value of 61.05% at gas turbine plant.
- The Max Compressor efficiency obtained in the analysis with cooling at temperature 295 K is 61.9 % which is approximately equal to that of measured value of 62.11% at gas turbine plant.
- The Max Compressor efficiency obtained in the analysis with cooling at temperature 290 K is 62.5 % which is approximately equal to that of measured value of 62.32 % at gas turbine plant.
- Hence it is concluded that the Inlet air temperature of compressor in Gas turbine power generation plant effects the efficiency and also power output, hence the inlet air temperature should be low for which cooling effect should

be facilitated which improves the efficiency and power output.

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## BIOGRAPHIES



Hari Ganesh Played different roles from Site Engineer to Assistant General Manager level in Power plants( Coal & Gas plants) and visited Japan, Singapore, China (Twice), Malaysia, Uganda, South africa for various works like Inspections, Design review and commissioning activities of Power plant and its sub equipments.



Dr. N. Haribabu Professor of Mechanical Engineering obtained Ph.D in Engineering from Andhra University. Presently guiding M.Tech students under various projects.