International Journal on Applications in Mechanical and Production Engineering
Volume 1: Issue 2: February 2015, pp 1-5. www.aetsjournal.com

Analysis And Performance Enhancement Of Intercooler In Two Stage Reciprocating Air Compressor Using CFD

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Abstract— Compressors are intended to compress a substance in a gaseous state. Almost all the multi stage compressor applications, air will be cooled between thestages which are also known as intercooling.Intercooling of a compressor is necessary for an efficient process.With intercooling, the compression is more closely to an isothermal compression with resulting lower power requirement. Intercooler is basically a heat exchanger, which is used to cool the compressed air between the stages. In the present work,the circular cross section pins are inserted normal to the flow direction of air in existingfinned tube heat exchanger(intercooler)of two stage reciprocating air compressoris to increase the convective surface contact area and create the turbulenceresulting in an increase the rate of heat transfer.CFD analysis has been done on in this intercooler and comparing them using FLUENT software. The experimental data are taken asthe reference for CFD analysis. From this analysis the rate of heat transfer increase and work requirement lowered when compared with the existing one.

Keywords— Air compressor, Intercooler, Performance enhancement,CFD analysis.

I. Introduction

A reciprocating compressor or piston compressor is a positive displacement compressor that uses pistons driven by a crankshaft to deliver gases at high pressure. The intake gas enters the suction manifold, then flows into the compression cylinder where it gets compressed by a piston driven in a reciprocating motion via a crankshaft, and is then discharged. Applications include oil refineries, gas pipelines, chemical plants, natural gas processing plants and refrigeration plants. In the study of heat transfer, a fin is a surface that extends from an object to increase the rate of heat transfer to or from the environment by increasing convection. The amount of conduction, convection or radiation of an object determines the amount of heat it transfers. Increasing the temperature difference between the object and the environment, increasing the convection heat transfer coefficient or increasing the surface area of the object increases the heat transfer. Sometimes it is not economical or it is not feasible to change the first two options. Adding a fin to an object, however, increases the surface area and can sometimes be an economical solution to heat transfer problems[1].Industrial plants use compressed air throughout their production operations, which is produced by compressed air units ranging from 5 hp over 50,000hp. It is worth noting that the running cost of a compressed air system is far higher than the cost of a compressor itself [2]. The ranges between 5 to 30 horsepower are commonly seen in automotive applications and are typically for intermittent duty [3].The US department of energy (2003) reports that70% to 90% of compressed air is lost in the form of unstable heat friction, misuse and noise. For this reason, compressors and compressed air systems are important areas to improve energy efficiency at industrial plants. For improving efficiency compression is done in more than one stage and between each stage intercoolers provide [4].

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Vijay F.Pipalia[3] investigated that improving the efficiency of two stage reciprocating air compressor by providing water cooling source , radiator coolant and Ethylene glycol and results are compared .. The experiments of a two double-cylinder reciprocating compressor system with air, water and different intercoolants were performed. The equations representing the volumetric and isothermal efficiency were solved and the predicted results compared with the experimental data and theoretical data of water, other cooling sources and air cooling showing good agreement.

Pawan kumar gupta[4] described that the modeling of heat exchanger which is based on minimization of heat transfer area using MATLAB. Shell diameter, baffle spacing, number of tube-side pass are varied. In this work, pressure drop for both sides is trying to reduced with proper spacing of baffle and baffle cut and also tube diameter and tube length.

Sikindar Baba.Md, Nagakishore.S ,Prof.M.Bhagvanth Rao[2]they are investigated that the thermal analysis has been done on finned tube heat exchanger (Intercooler of two stage air compressor). Experimental analysis was done on the intercooler (Finned tube heat exchanger) model for the particular pressure ratio. For the finned tube, inside and outside convection heat transfer coefficients are estimated based on the experimental data. Theoretical analysis was done to estimate the heat transfer rate at different sections of the bare tube as well as at the sections where the fins are present. Modified Bessel's functions of the first and second kind were calculated for the annular fin of rectangular profile model and temperature distribution over each fin was calculated. Finite Element Analysis was done using ANSYS software. Temperature distribution at different sections and total heat flow is estimated for the finned tube with fins of rectangular profile and with fins of triangular profile. A comparison has been made among experimental data, theoretical data and finite element analysis.

II. EXPERIMENTAL ANALYSIS

A. Experimental setup

ThePhotographic view of the experimental setup is shown in the Figure 1. The experiment was carried out in a two-stage reciprocating air/gas compressor mounted in a Vshape with two separated cylinders, as shown in the figure1.

Fig.1 Photographic view of two stage reciprocating compressor

The compressor, manufactured by Coimbatore compressor engineering corporation private limited.(Model type ELT 600), is capable of producing about 12 Kg/cm^2 maximum output pressure and 4.5 Kg/cm^2. The compressor was mounted in tandem that the second stage was driven directly from the rear of the first stage. The air is firstly drawn into the intake tank via a measuring nozzle that is used to determine the intake volume. The intake tank acts as a calming zone and housing for the measuring sensors of the intake state, i.e., pressure transducer and manometer. Between the first stage and the second stage, there is a small pressure vessel for intermediate cooling. After the second stage, the compressed air is forced into a storage tank via a cooling tube. To achieve a steady operating state, the compressed air is blown off via a bleeder valve with sound absorbing. Safety and pressure regulator valves, which are compulsory components in any compressor, are installed for safety and control.

Table 1. Observation Data Of Compressor With Existing Intercooler Connected To The Pipeline

T_1	T_2	T_3	T_4	P_1	P_2	P_3	P_4	W	N
[K]	[K]	[K]	[K]	[kg/ cm^2]	[kg/ cm^2]	[kg/ cm^2]	[kg/ cm^2]	[kW]	[rpm]
307	379	367.7	369.4	1.0	2.29	3.0	2.87	2.473	1116
307	385	382.4	384.1	1.0	2.25	4.0	4.49	2.473	1041
307	390	387.5	391.9	1.0	2.25	5.0	5.19	2.498	1058
307	408	395.7	398.9	1.0	2.29	6.0	6.23	2.498	1041

All electrical controls and displays are fitted into a switch cabinet as shown in the figure 1, the master switch, emergency stop switch, and digital displays for whole measuring variables. It also displays the electrical output data, and the electric motor switch for compressor. Switch cabinet is connected to a PC (computer) via USB cable for displaying and recording the measured data.

Table 2. Calculated Data Of Compressor With Existing Inter Cooler Connected To The Pipeline

S. No	**Delivery Pressure**	**Actual Volume**	**Swept Volume**	**Volumetric Efficiency**	**Isothermal Work done**	**Shaft Power**	**Isothermal Efficiency**	**Rate of Heat Rejection**
	[kg/ cm^2]	[m^3/s]	[m^3 /s]	[%]	[kW]	[kW]	[%]	[kW]
1	3	0.0063	$4.55X10^{-3}$	76.7	0.594	1.99	30.10	0.2447
2	4	0.0064	$4.53X10^{-3}$	77.78	0.602	1.98	30.40	0.2540
3	5	0.0065	$4.55X10^{-3}$	79.14	0.652	1.97	33.09	0.2724
4	6	0.0067	$4.55X10^{-3}$	82.8	0.68	2.01	33.83	0.2970

B. Calculation

1) Swept volume = $\frac{\pi \times D2 \times L}{4 \times 60}$

Where

D = Bore diameter

L = Stroke length

N = Number of revolution

2) Volumetric Efficiency = $\frac{\text{Actual volu}}{\text{Swept volu}}$

3) Isothermal Work done = P_1 x Q_{actual} x ln

Where

P1 = Inlet pressure

P3 = Delivery pressure

4) Shaft power = Motor power x Motor efficiency

5) Re_d = $\frac{4 \times}{\pi \times D}$

Where

Re_d= Reynolds number

m = Mass flow rate

µ = Absolute viscosity

6) Nu = 0.023 x Re_d^n x Pr^n

r(or)

Nu = $\frac{h}{}$

Where

Nu = Nusselt number

Pr = Prandtl number

7) Q = h x A x

Where

h = Heat transfer coefficient

A = Fins Area

= Temperature difference

III. Specification Of Intercooler

The specification is measured directly from the existing intercooler component and Specification of new intercooler is same as per the existing intercooler, but additionally circular pins are inserted in the intercooler, as shown below figure 2 & 3.

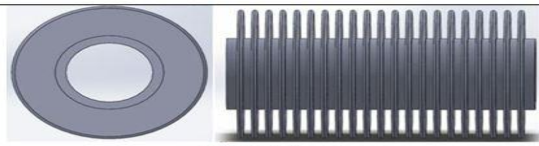


Fig 2: Existing intercooler

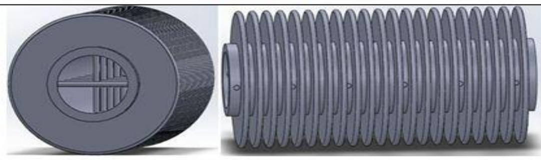


Fig 3: Modified intercooler

Table 3 specification of intercoolers

	Existing intercooler	Modified intercooler
Tube material	Aluminium	Aluminium
Inner diameter of bare tube	35mm	35mm
Outer diameter of bare tube	45mm	45mm
Length of the intercooler	165mm	165mm
No.of fins	21	21
Thickness of each fins	3mm	3mm
outer diameter of fins	85mm	85mm
Height of the fins	20mm	20mm
Types of fin	Circular fin of rectangular cross section	Circular fin of rectangular cross section
Diameter of the pin	-	3mm
No. of pins	-	11

IV. CFD ANALYSIS OF INTERCOOLER

Computational Fluid Dynamics (CFD) is the science of predicting fluid flow, heat transfer, mass transfer, chemical reactions and related phenomena by solving mathematical equations that represent physical laws using a numerical process. CFD is simply the use of computers and numerical techniques to solve problems involving fluid flowand it is the simulation of fluids engineering systems using modeling (mathematical physical problem formulation) and numerical methods (discretization methods, solvers, numerical parameters and grid generations, etc.,).

Theintercooler models have been modeled using SOLIDWORKS 2013 software as shown in the fig 2 and fig 3. They have been meshed using ICEM CFD software. The meshed models have been exported into the FLUENT 14.5 version software and the solution is initialized and calculations have been obtained by applying boundary conditions.

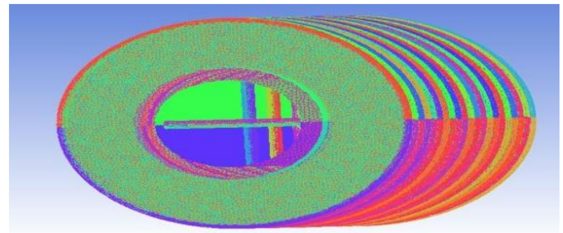
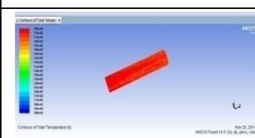
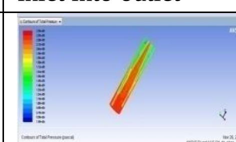
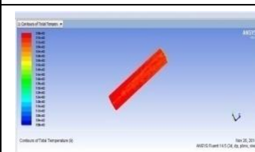
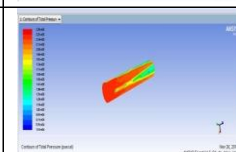
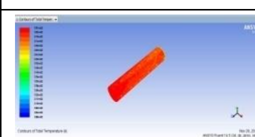
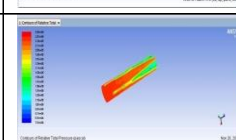
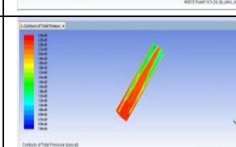


Fig 4 Meshing of modified intercooler

Mesh details
Total no of elements = 5636604
Total no of nodes = 972759
Surface mesh
No of shells = 5533480
Volume mesh
No of cells = 553380

Table 5 Temperature and pressure contours of existing intercooler

Boundary conditions
Boundary condition 1 = (T_2= 379 K, P_2= 2.29 kg/cm^2),
Boundary condition 2 = (T_2= 385 K, P_2= 2.25 kg/cm^2),

Boundary condition	Temperature variation in intercooler from inlet into outlet	Pressure variation in intercooler from inlet into outlet
Boundary condition 1		
Boundary condition 2		
Boundary condition 3		
Boundary condition 4		

Boundary condition 3 = (T_2= 390 K, P_2= 2.25 kg/cm^2),
Boundary condition 4 = (T_2= 400 K, P_2= 2.29 kg/cm^2).

V.RESULTS AND DISCUSSION

The CFD analysis of existing intercooler without pipe line is shown in thetable 4. Experimental data of compressor with existing intercooler connected to the pipe line were taken as the reference for CFD analysis. Outlet pressure [P_2] and temperature [T_2]of the low pressure cylinder were taken as the input of the intercooler and also input boundary condition for CFD analysis.

5.1 Temperature contours of existing intercooler

In the existing intercooler, the exit pressure [P_3]equal to the inlet pressure [P_2] that indicates (P2=P3) no pressure drop through length of intercooler because there is no any obstacle to fluid flow inside of the tube. But in the modified intercooler 11 numbers of circular pins were inserted normal to the fluid flow direction so pressure drop may occur in the modified intercooler (P2≠P3).

The same boundary conditions are taken as the reference for both the existing and the modified intercooler and it is found experimentally in two stage reciprocating air compressor by using existing intercooler between the stages. The temperature and pressure contours of modified intercooler are shown in the table 5.

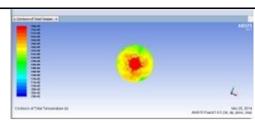
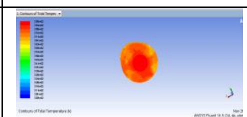
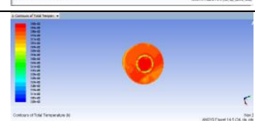
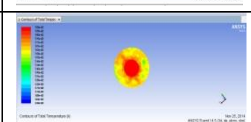
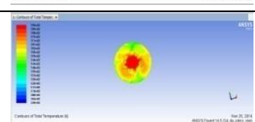
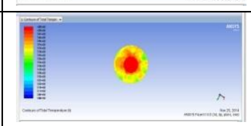
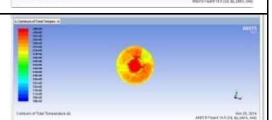
Boundary condition	Inlet of intercooler	Outlet of intercooler
Boundary condition 1		
Boundary condition 2		
Boundary condition 3		
Boundary condition 4		

Table 6 Temperature and pressure contours of Modified intercooler

5.2 Temperature and pressure contours of modified intercooler

From the temperature contours modified intercooler shows that when comparing exit temperature of modified intercooler is lower than that of existing intercooler by applying same boundary condition. In the modified intercooler the circular cross section pins are inserted to increase the surface contact area and create turbulence for increases the rate of heat transfer (Q). Why need of turbulence means the middle flow air need to contact with tube surface.

4.1 Result from CFD analysis

Table 6 Outlettemperatures and pressure of both intercoolers from CFD analysis at various input boundary condition.

Boundary condition	Inlet Temperature of intercooler [T_2]	Inlet pressure of intercooler[P_2]	Outlet Temperature of Existing intercooler [T_3]	Outlet Temperature of Modified intercooler [T_3]	Outlet pressure of intercooler[P_3]
	[K]	[kg/cm^2]	[K]	[K]	[kg/cm^2]
Boundary condition 1	379	2.29	372	370	2.26
Boundary condition 2	385	2.25	378	376	2.20
Boundary condition 3	390	2.25	380	373	2.22
Boundary condition 4	408	2.29	397	393	2.23

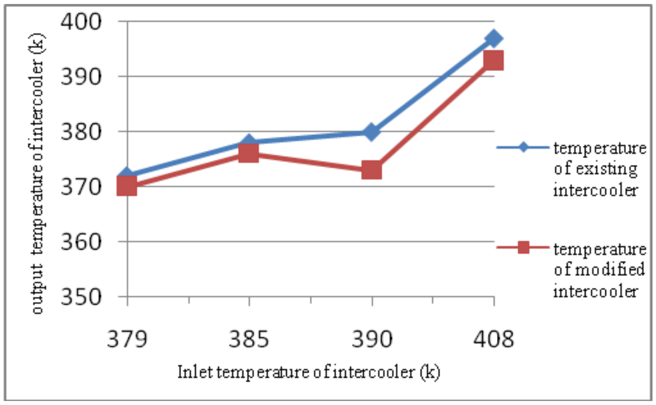
4.2 Theoretical calculation

Table 7Theoretical calculation of intercoolers

Outlet temperature of H.P cylinder in exist intercooler [T_4]	Outlet temperature of H.P cylinder in modified intercooler [T_4]	Outlet pressure of H.P cylinder in modified intercooler [P_4]	work required for compressor in existing intercooler [W]	work required for compressor in modified intercooler [W]	Rate of heat transfer in existing intercooler [Q_e]	Rate of heat transfer in existing intercooler [Q_m]
[K]	[K]	[kg/cm^2]	[kW]	[kW]	[kW]	[kW]
457	455	5.633	1.152	1.141	0.204	0.262
464	462	5.523	1.148	1.143	0.204	0.2728
467	458	5.535	1.151	1.147	0.219	0.375
488	483	5.623	1.195	1.182	0.237	0.438

5.3 Outlet temperature [T_3]

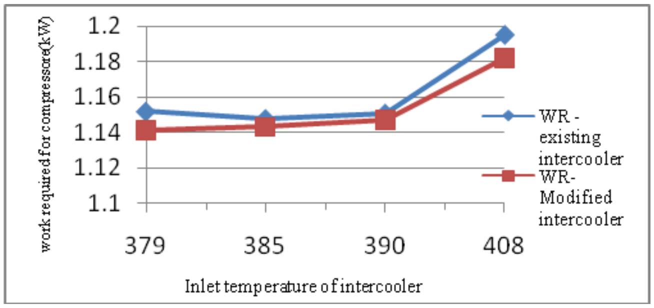
The output temperature of the modified intercooler is lower than that of existing intercooler it is shown in the graph 1.



Graph1comparison of output temperature intercooler with respect to the input temperature of intercooler

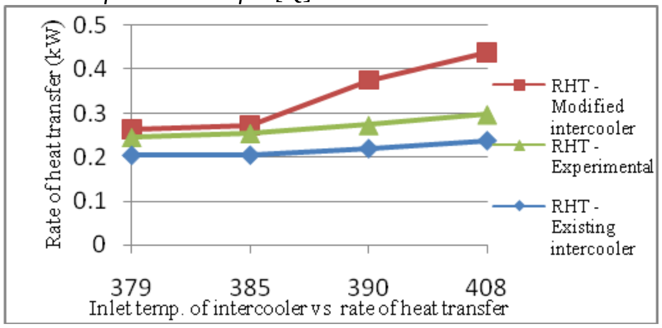
5.4 Work requirement of compressor [W]

Graph.2 shows that the work requirement of compressor by using modified intercooler is reduced when with comparing existing intercooler.



Graph 2Comparison of work requirement of compressor with respect to the inlet temperature of intercooler\

5.5. Rate Of Heat Transfer [Q]



Graph 3 comparison of heat transfer rate with the inlet temperature of intercooler

The rate of heat transfer increased by using modified intercooler it shown in graph 3.

VI. CONCLUSION

Thus the analysis and comparison of the proposed intercooler and existing intercooler of two stage reciprocating air compressor using CFD software, it has been known that the outlet temperature of the modified intercooler has been decreased by inserting the circular cross section pins normal to the flow direction of air. This modification is resulting in reduction of work required for the compressor and improvement in the rate of heat transfer. The rate of heat transfer has been increased in modified intercooler to 10-22% of the existing intercooler. The outlet temperature of the intercooler has been reduced to 1.5%-2.5% of the inlet temperature in the modified intercooler. Modified intercooler has 1% - 1.5% efficient than existing

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