Experimentation & CFD Analysis of Intercooler Fins in Two Stage Reciprocating Air Compressor

Pravin T. Nitnaware, Gayatri J Kale, Premendra J. Bansod, Manoj D. Hambarde, Sanjay R. Deodas

Abstract—This paper shows comparison of Aluminum and Copper fin tube intercooler used in multistage reciprocating air compressor. Results are validated with ANSYS – Fluent - 18.2 software. The experimentation is done on the Copper fin tube length 1090mm with helically wounded strip width of 6mm and 8 numbers of fins per inch. Volumetric efficiency increases and work input decreases for Copper fin tube with air velocity of 5 m/s. The results shown increase in heat transfer with decreasing air temperature.

Index Terms—Aluminum tube, Copper finned tube, ANSYS – FLUENT-18.2, Air Compressor, intercooler.

I. INTRODUCTION

This paper provides CFD analysis of intercoolers of Aluminum tube and Copper finned tubes also shows comparison with experimental results of temperature throughout. To enhance the intercooler design to increase heat transfer rates through it by changing materials of tubes also by increasing the surface area of intercooler by addition of fins. To reduce work required to run air compressor is achieve by using copper finned tube. With best design i.e. Copper tube of length 1090mm with helically wounded strip width of 6 mm and 8 fins per inch used, analyzed and tested experimentally, temperature recorded by thermocouple and infrared thermometer at various length. Result from this analysis is increase in heat transfer rate from copper finned tube than existing Aluminum tube.

II. LITERATURE OVERVIEW

A. Falavand et al [1] had experimentally shown the effect of fins per inch on heat transfer from intercooler and pressure fall through it he did study on circular and hexagonal fins. For more heat transfer and less pressure drop FPI 8 – 12 would be good selection. For more FPI than this causes less heat transfer.

To increase heat transfer we used fins per inch no. 8 - 12 on intercooler.

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A. Nuntaphan et al [2] had been experimentally investigated that by using crimped fins structure more heat transfer can be obtain. Also crimped spiral configuration used in heat exchanger give effect with of pipe diameter, fin space, tube pitch is study. Author had been shown base on the tentative comments, the following results ware concluded as fin spacing increases heat transfer rate reduce. By means of proper fin space heat transfer can be increase. If Pitch lowers it gives high heat transfer coefficient.

Sikindar et al, [3] had done numerically and analytically thermal analysis of intercooler made of aluminum tube with aluminum fins wounded of cross section rectangular and triangular. At particular pressure ratio intercooler used in air compressor by analytically analysis he conclude that triangular fins are more effective that rectangular fins and but larger manufacturing cost required for triangular fins than rectangular fins.

Amit Panchal et al, [4] have been experimentally investigated to improve air side performance on spiral fin and tube heat exchanger. He has worked by reducing weight and size of heat exchanger so that to make it compact in size heat exchanger. He has modified various configurations of fins and with various tube arrangements. Also operating conditions has been investigated to improve performance.

N. Senthil Kumar et al. [5] has done modification and analysis of compressor intercooler fins used in turbocharger, analysis by FEM. The validation analysis performed with optimum control parameters which show improved heat transfer.

S.Gil et al.[6] has been investigated thermal analysis of transverse fins by placing in form of helical spring which functions as radiator on pipe. With respect to natural and forced convection he has been carried out investigation. MAG welding technology used to weld the fins on tube helped him in good heat transfer but a defective weld due to its rapid erosion may lead reduced performance.

Pawan Kumar et al. [7], studied design of air compressor in which design and performance analysis of existing and modified model by using finite element analysis tool.

Jignesh et al. [8] conclude that the Overall heat transfer rate of finned tube heat exchanger is greater than without finned tube heat exchanger.

Min Zeng [9] experimentally investigated that by using internally finned tubes and annuli are among the earliest tube-side enhancement geometries. The early versions used extruded aluminum insert devices, which provide full height fins. The first integral, internal fin tubes were made of copper using a cold swaging process. He concluded that the performance can be improved by forming the fins at a helix angle, e.g., up to 25°. Although the copper tubes provide high performance, they are quite expensive.

Kuldeep et al. [10] studied of improved two stage reciprocating air compressor and its industrial usage. He reviewed that the air compressor is device which used to convert electrical power into potential energy by forcing air into a smaller volume cylinder resulting in increasing its pressure. The compressed air is then stored in tank called air receiver. This compressed air will utilized for further application in various industries.

Sahiti et al. [11] has been done analytical, experimental investigation on heat exchanger with pin fins of wavy, strip and louvered fins which shows due to increase in surface area there is increase in heat transfer rate and heat transfer coefficient through it.

Vijaykumar et al. [12] reviewed on production and maintenance in industrial application, compressed air can be used from range of power 5 HP to 50000 HP. He has been concluded that running cost is high than manufacturing cost of compressor. Problem facing during compression is temperature goes on higher at inlet port in high-pressure cylinder results in high temperature raise at outlet port of cylinder. This causes damage of tube used in between low-pressure cylinder to high-pressure cylinder.

Ramakrishna et al. [13] has been experimentally investigated, design and CFD analysis of shell and tube heat exchanger using plain tube and corrugated tube. He has been concluded by Numerical and experimental study that corrugated tube more capable to do heat transfer than plain tube.

Vishal et al. [14] has been developed a test rig of single stage reciprocating air compressor to check various parameters like FAD, isothermal power required, volumetric efficiency, specific power requirement on two compressors and concluded that volumetric efficiency will vary with vary in motor RPM and piston specifications.

In multistage compressor heat exchanger or intercooler is required which plays important role due to which temperature difference between two stages affect on increase in volumetric efficiency of compressor. Pressure ratio need to be limited as it depend on inlet temperature. Material selection plays vital role in heat transfer process.

III. METHEDOLOGY

- To increase heat transfer rate by changing material and increasing surface area by adding fins on tube intercooler.
- Experimental and analytical compare in existing Aluminium tube.
- Numerical Design of fins per inch to use on tube.
- Computer Added Design of finned tube in software CREO 3.0.
- Analysis on new designed Copper fin tube intercooler by using ANSYS-FLUENT 18.2.
- Compare the results from CFD analysis and Experimental analysis of new designed Copper fin tube with existing Aluminium tube intercooler.

IV. DESIGN CALCULATIONS

A. Design for Fins per inch (FPI):

Heat transfer by extended surface, relation between fin efficiency and effectiveness

- Governing equation for convection heat transfer is

$$Q = h\,A\,(T_b - T_\infty)$$

- Fin efficiency

$$\eta = \frac{Qfin}{Qfinmax} = \frac{\text{Actual transfer of heat through fin}}{\textit{Ideal heat transfer from fin tube}}$$

$$\eta = \frac{\sqrt{\text{h P k Afin}}\ (\text{Tb} - \text{T}\infty)}{h\ \text{Afin}\ (\text{Tb} - \text{T}\infty)}$$

- Fin effectiveness (ε_{fin}),

$$\varepsilon\text{fin} = \frac{Qfin}{\text{Qnofin}}$$

$$\varepsilon\text{fin} = \frac{Qfin}{h\,Ab\ (\text{Tb} - \text{T}\infty)}$$

- Fin effectiveness can be enhanced by,
  - Choice of material of high thermal conductivity. Ex. Aluminium, Copper
  - Increasing ratio of area to the perimeter of the fins. The use of thin closely placed fins is more suitable than thick fins.
  - Low values of heat transfer coefficient (h).

B. Parameters to Calculate in Two stage Air Compressor[15]:

- Work done

$$W = \frac{2n}{n-1} m\,R\,T1 \left[\left(\frac{P3}{P1}\right)^{\left(\frac{n-1}{2n}\right)} - 1\right]$$

- Isothermal Work

$$Isothermal\ Work\ (Piso) = m\,R\,T1\,ln\frac{P3}{\text{P1}}$$

- Isothermal Efficiency = $\frac{Isothermal\ Power}{Indicated\ Power}$

- Free air delivered (FAD) $FAD = \frac{m\,R\,T1}{P1}$

- Compressor Capacity: It is amount of actual air delivered by compressor in m^3 per minutes or m^3 per second.

- Actual Volume of air intake (Va),

$$\text{Va} = \text{Cd A}\sqrt{\frac{2\text{gHw}\rho\text{w}}{1000\ \rho\text{a}}}\quad m^3/s$$

- Theoretical Volume or Swept volume (V_s),

$$(V_s) = \frac{\pi\text{x DxDx Lx N}}{4}\quad m^3/s$$

- Volumetric Efficiency (η_{vol}): It is ratio of actual volume of FAD at standard atmospheric condition in one delivery stroke (actual air intake) to swept volume (theoretical air intake) by the piston during the stroke.

$$\eta_{vol} = \frac{\text{Va}}{\text{Vs}} = \frac{\text{FAD}}{\text{Vs}}$$

- Heat transfer in intercooler (T_2),

$$T_2 = T_1\left(\frac{P2}{P1}\right)^{\left(\frac{n-1}{n}\right)}$$

- Heat transfer by intercooler (Q),

$$Q = m \times C_p \times (T_2 - T_1)$$

$$\text{Where, } m = \frac{1.03 \times 10\ 4 \times Va}{29.3 \times (ta+273)}$$

t_a = room temperature.

V. COST ESTIMATION

Table I shows that cost of Aluminium tube is half of Copper finned tube. Though initial cost is more, with use of copper finned tube work done requirement will be less on compressor.

Table I: Estimated Cost Copper finned and Aluminium tube

Description	Copper		Aluminium	
	Rate	INR	Rate	INR
Tube				
Total input weight in Kg	0.64		0.19	
Rate of Copper per Kg (INR)	618		143	
Cost of tube		**397**		**225**
Finning				
Total Wt. of fin Material	0.77			
Rate of fin material in per Kg	78			
Cost of Finning Material	60			
Labour cost for fin per inch	62			
Brazing cost both Fins End Point	30			
Tube bending per Bend x 5 no	150		150	

VI. COMPUTATIONAL FLUID DYNAMICS (CFD)

A. CFD analysis for Aluminum tube

For analysis purpose meshing of tube is done on ANSYS 18.2. Solid model is meshed with 3 D solid elements. The mesh size is used as 2mm which is based up on mesh sensitivity analysis performed on the previous analyzed components of similar style. Total number of nodes and element observed are recorded as shown in table II.

At velocity 5m/s pressure drop of air is a 50pa from inlet to outlet. From this primary flow analysis we have derived the outlet pressure of intercooler is 50pa lesser than the inlet intercooler pressure, convective heat transfer is assume to be 10 W/m^2 k

Table II: Boundary condition Imposed for Analysis of Aluminum tube intercooler

Mesh nodes	49800
Mesh elements	83663
Inlet Pressure (Pascal)	300000
Inlet Temperature(⁰C)	154
Outlet Pressure (Pascal)	299950
At Pipe wall convection(w/m2-k)	10
Free Stream temperature (⁰C)	29

Temperature plot for fluid through Aluminum tube

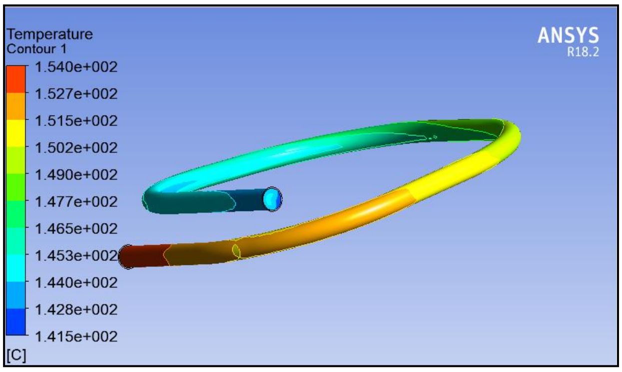

Fig 1: Temperature plot of fluid through Aluminum tube intercooler

Fig 1 is plot shows minimum temperature observed is 141.5 °C at outlet. Average temperature at outlet observed experimentally is 146°CTemperature plot for tube

B. CFD analysis for Copper Finned Tube

For analysis purpose meshing of Copper finned tube intercooler is done on ANSYS 18.2. Solid model is meshed with 3 D solid elements as shown in table 3.

Table III: Boundary Conditions Imposed for Analysis for Copper finned tube

Mesh nodes	49800
Mesh elements	207269
Inlet Pressure (Pascal)	300000
Inlet Temperature(⁰C)	154
Outlet Pressure (Pascal)	299950
At Pipe wall convection(w/m2-k)	10
Free Stream temperature (⁰C)	30

D. CFD Result Plots for Copper Finned Tube Intercooler

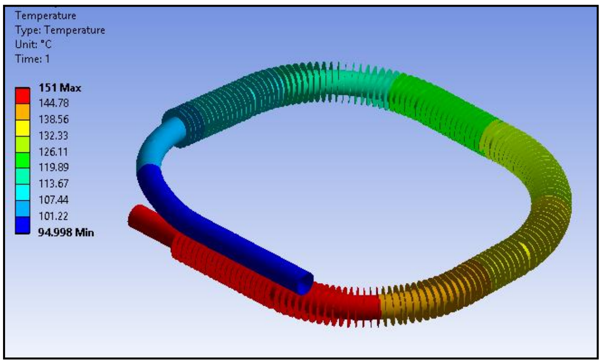

Fig 2: Temperature distribution plot along the length of Copper fin tube intercooler

From fig 2 we can see that the temperature at air outlet is reduced from 151 °C to 94.998°C due to convection Heat transfer between Fluid and Pipe.

VII. RESULTS AND DISCUSSION

A. Experimental Setup

Fig 3 shows experimental setup where Copper finned tube is mounted and temperature measured at end of low-pressure cylinder and at inlet of high-pressure cylinder.

Fig 3: Experimental setup

B. Experimental Result: Aluminum Tube Intercooler

Table IV: Experimental Result: Aluminum Tube intercooler

PHYSICAL PARAMETERS	VALUES
Material for tube and fins	Aluminum
External diameter of the pipe mm	19
Length of the pipe mm	1090
Free stream fluid	Air
Low-pressure cylinder outlet temp. (^{0}C)	154
High-pressure cylinder inlet temp. (^{0}C)	146
Velocity/s	5

Table IV shows temperature difference of 8 ^{0}C while from CFD analysis it shows 13 ^{0}C.

C. Experimental Results: Copper Finned Tube

Experimental result when Copper tube used shown in table V. Copper tube of length 1090mm with helically wounded strip width of 6 mm and 8 fins per inch used. With this the difference in temperature is 55°C and by CFD analysis it shows with difference in temperature is 59 °C.

Table V: Experimental results Copper Finned Tube

Physical parameters	Sensor readings			
working pressure (bar)	6	8	10	12
Amb Dry (^{0}C)	30	29.5	30	30
Amb Wet (^{0}C)	22.5	23	23	23
Air Filter Inlet (^{0}C)	37.7	38	37.3	37.5
LP Outlet Temperature (^{0}C)	155.2	155.1	154	155
HP inlet Temperature (^{0}C)	98	97.9	97.8	97
HP Outlet Temperature (^{0}C)	208.1	209.1	210.1	210.1
Receiver Tank Inlet Temp. (^{0}C)	101.2	101.4	101.1	102.1
Receiver Tank outlet Temp. (^{0}C)	48.9	48.9	49	49.1
Motor Suction Temp. (^{0}C)	34.3	33.9	34.2	34.1
LP / HP surrounding (^{0}C)	36	36.8	37.7	38.2
Motor RPM	2946	2942	2942	2942
Pump RPM	1035	1032	1031	1031
Power (kW)	4.34	4.35	4.42	4.42
Current (Amp)	7.53	7.56	7.63	7.63
Voltage (V)	408	408	410	410

D. Compare CFD Analysis with Experimental Results

Table VI: Results by CFD and Experimentally of Aluminum and Copper Finned Tube along length.

length (mm)	Aluminum tube results Temp(^{0}C)		Copper finned tube results Temp(^{0}C)	
	CFD	experiment	CFD	experiment
0	154	154.2	154	154.2
100	152	154.2	151	151
200	151	154	144	145
300	150	149.8	138	140
400	149	149	132	135
500	147	147	126	128
600	146	147	119	120
700	145	145	113	115
800	144	145	107	110
900	142	146	101	105
1000	141	146	95	99

In fig 4 shows plot when experimental and CFD analysis compare for Aluminum tube. By CFD temperature along length constantly decreasing while by experimentally it constant at starting then goes on decreasing. The percentage error in comparison is 3.

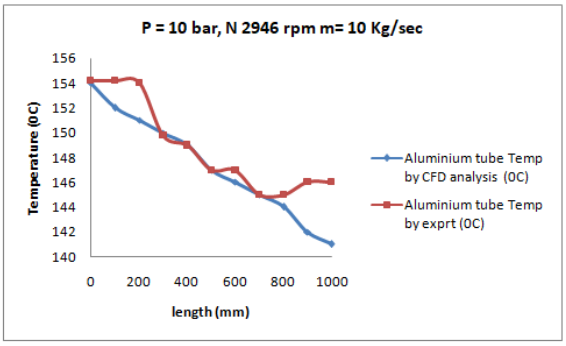

Fig 4: Aluminum Tube with CFD vs. Experimental Results

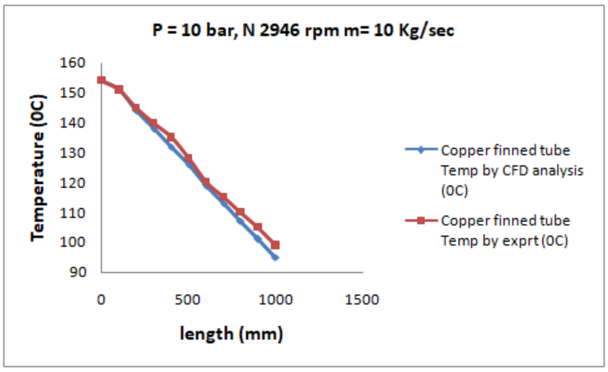

Fig 5: Copper Finned Tube with CFD vs. Experimental Results

Fig 5 Shows CFD and Experimental plot for Copper finned tube along length temperature variation. By both showing same result and percentage error is 3-4.

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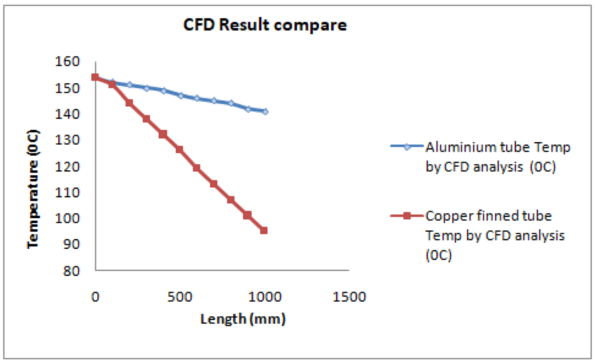

Fig 6: Al and Cu Tube compare with CFD Results

Fig 6 shows the comparison plot of temperature drop along the length in Aluminum tube and finned copper tube evaluated by CFD analysis. It can be noted that the temperature dropped is more in finned copper tube as compared to bare Aluminum tube. By use of copper finned tube instead of Aluminum tube the temperature drop is increased significantly by 32 percent.

The Fig 7 shows the comparison plot of temperature drop (along the length) in bare Aluminum tube and finned copper obtained during experimentation. It can be clearly seen that the temperature dropped is more in finned copper tube as compared to bare Aluminum tube.

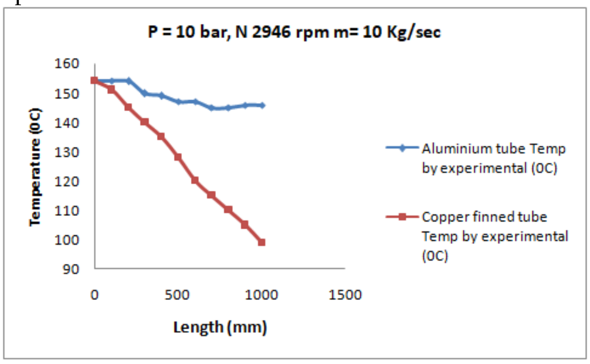

Fig 7: Al and Cu Tube compare with Experiment Results

E. Work Required for Compressor:

Table VII shows work required for compressor to run and experimental results compare between existing Aluminium intercooler and copper finned tube intercooler with theoretical.

Table VII: Work required for compressor

Delivery Pressure	Work required for compressor (kW)		
	Aluminium intercooler (kW)	Copper finned intercooler (kW)	By Theoretical calculation (kW)
6	2.473	2.123	1.956
8	2.473	2.12	2
10	2.49	2.23	2.1
12	2.5	2.25	2.2

Fig 8 shows work required for existing Aluminium Tube intercooler is more in compare with copper finned tube intercooler. When Compare on Theoretical and experimental, percentage error of 1 – 2 appeared.

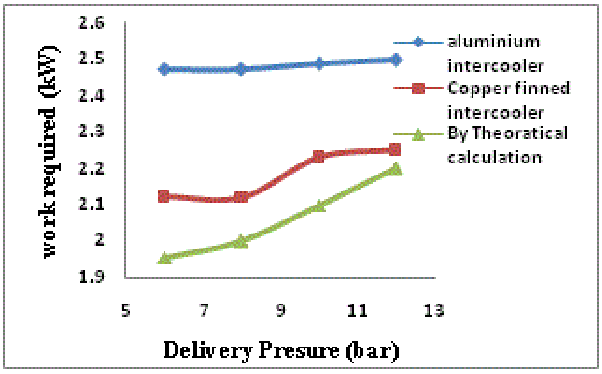

Fig 8: Work required for compressor Experimental and theoretical

VIII. CONCLUSION AND FUTURE SCOPE

Results shows in table VIII where T_{in} is temperature inlet at LP cylinder and T_{out} is at outlet of HP cylinder.

1) By using intercooler in between LP outlet and HP inlet, the error in the result between ANSYS Fluent and its experimental Result about is 3 % to 4 %.

2) The outlet temperature of fluid in aluminum bare tube was observed around 146^{0}C from CFD analysis and 141^{0}C experimentally so error in analysis is 3.4%.

3) The outlet temperature of fluid in copper fin tube is 95^{0}C from CFD analysis and 99^{0}C experimentally so error in analysis is 4%.

Table VIII: Result comparison of Temperature by CFD and Experimental.

No	Parameters	T_{in} ^{0}C	HP T_{out} ^{0}C		ΔT		Error analysis %
			CFD	Exp	CFD	Exp	
1	Aluminium tube intercooler	154	141	146	13	8	3.4
2	Copper fin tube intercooler	154	95	99	59	55	4

It is concluded that percentage drop in temperature increases significantly to almost 40% by using copper tube along with fins. Also, that the use of copper tube with fins has reduced the work required for compressor to run.

Future Scope:

- Can be checked with wire wound finned tubes of Copper or Aluminium material for wire and tube.
- Can be checked with helically wound Split or Serrated fin tube.

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