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Design of Air Conditioning System by Using Air Refrigeration Cycle for Cooling the Cabinet of Truck

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Abstract: *Increase in energy demand as well as environmental considerations such as ozone layer depletion forces the human being to think over the safe alternatives for refrigerants used in air conditioning systems. In this paper, waste exhaust gases of truck engine is used to cool the air .here the air conditioning system is based on Reversed Brayton cycle. The use of air as refrigerant overcomes the all environmental disadvantages of refrigerant like R12, R22, etc., which affects the ozone layer depletion. With the advancement of turbo-machinery, we can increase the* **COP** *of Reversed Brayton cycle. Turbocharger is used to extract energy from waste exhaust as well as to compress atmospheric air along with heat exchanger. Further a turbocharger is used as turbo-expander to cool the air and work of turbine is used to deliver compressed air to the engine.*
Keywords: *Turbocharger,* **COP**.

I. Introduction

Now a days most of the automotive air conditioning systems in use are based on the vapour compression refrigeration cycle, and the required power to the system is provided to the compressor by the vehicle engine through a magnetic clutch. Such power supply to compressor has a significant impact on engine fuel consumption and power transfer to tires, particularly for economic class cars. Air conditioning system uses refrigerants. Dichloro difloro methane (R12), Trichloro monofloro methane (R11), Monochloro trifloro methane (R13), Carbon tetra florite (R14) are some commonly used refrigerants which are responsible for ozone layer depletion, and greenhouse effect. To overcome these mentioned disadvantages force the human being to think over the safe alternatives for refrigerants used in air conditioning systems. In this project, we have used Air (R729) as a refrigerant. The goal of this work is to design and develop a preliminary analysis on the feasibility of using an alternative automotive air conditioning system based on the Brayton cycle to be assembled using a turbo compression intercooling system configuration available in the market which runs on the exhaust gases from truck engine. The goal of this project is to demonstrate that an air conditioning system can be manufactured from existing automotive turbocharger components and provide acceptable cooling with a minimal performance penalty.

II. Literature Survey

To provide air cooling for the driver of a truck is never given importance in India, the basic reason is the use of available methods of air cooling affects the fuel consumption and the initial cost of the truck. However the earliest attempt at developing a mechanical comfort cooling system for a vehicle is attributable to William Whiteley, who in 1884 suggested placing blocks of ice in trays under horse drawn carriages and blowing air inside by attaching a Fan to the axle.For automobile air conditioning normally vapour compression refrigeration cycle is used. The cycle run on engine power and consumes around 10% of the total power produced by the engine and thereby increases the fuel consumption.[2]The work of this paper depends upon the Air Refrigeration cycle. The machine working on this are called Air Cycle Machines (ACM).The idea of using air-cycle air conditioning for this type of application is well-founded by theory, but practical limitations in implementing the system can considerably decrease the performance of an ACM. A research group at Queen’s University, Belfast, has designed and implemented a supercharger based ACM for refrigerated trailers in road transport applications.[3][11] The group implemented a two-wheel bootstrap cycle similar to the one in this project. The primary compressor is gear driven from the crankshaft, and it feeds compressed air to the typical bootstrap ACM. The supercharger is dedicated to supply air to the ACM. The turbocharger-based differs from the supercharger-based unit because there is energy available that would have been wasted during the turbine bypass process, waste-gating, without the presence of the ACM. Instead of wasting this energy, it can be utilized for powering the ACM without any additional cost to the engine. This is essentially free cooling, or infinite COP. Since the use of a turbocharger as the air source allows increased upper limits of performance than the supercharger-based system, there is an improved likelihood of success.

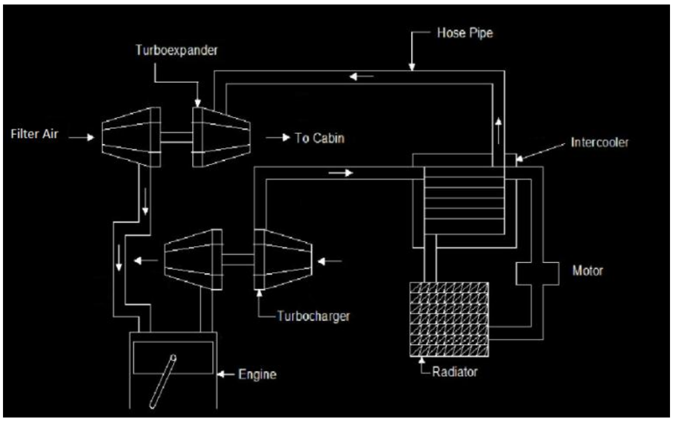

Fig.3.1 Basic Block Diagram of Refrigeration Cycle

The exhaust gases coming out of engine runs the turbocharger and expelled out to the atmosphere. The turbocharger sucks fresh air from atmosphere, compresses it. The compressed air has high temperature and pressure. The compressed air is then send it to intercooler. The intercooler is water cooled. In intercooler the heat is rejected at constant pressure to circulating water. The hot water is sent to radiator where it is cooled by air flow. The water pump is used to circulate water again in the intercooler. The high pressure and low temperature air is send to another turbocharger which is used as a turbo-expander where it runs the turbine of expansion side. The compressed air gets expanded due to which its temperature again decreases. This cooled air then carried to truck cabin via ducts. The compressor side of turbo-expander sucks the atmospheric air, compress it and sends to engine.

III. Thermodynamic Analysis

Thermodynamic analysis includes the study of the basic air refrigeration cycle, the study of the performance of the components and cooling load estimation.

IV. Air Refrigeration Cycle

Reverse brayton cycle is an important cycle frequently employed in air cycle refrigeration systems. This may be thought of as a modification of reversed Carnot cycle, as the two isothermal processes of Carnot cycle are replaced by two isobaric heat transfer processes. This cycle is also called as Joule or Bell-Coleman cycle. Fig (a) and (b) shows the schematic of a closed, reverse Brayton cycle and also the cycle on T-s diagram. As shown in the figure, the ideal cycle consists of the following four processes.[6]

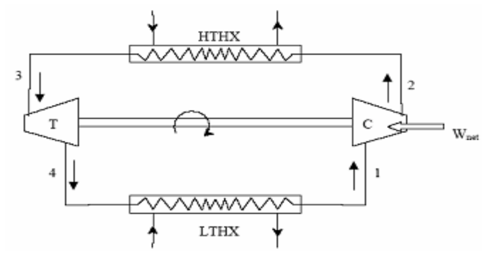

Fig.4.1 Schematic of a closed reverse Brayton cycle

Process 1-2: Reversible, adiabatic compression in a compressor
Process 2-3: Reversible, isobaric heat rejection in a heat exchanger
Process 3-4: Reversible, adiabatic expansion in a turbine
Process 4-1: Reversible, isobaric heat absorption in a heat exchanger

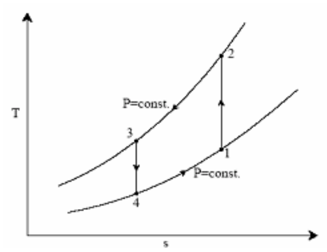

Fig2. Reverse Brayton cycle in T-s plane

4.2 Theory and Methodology

The theory and general methodology is developed based upon known temperatures, boost pressure, and driving conditions. Heat needs to be removed from the compressed air before it enters the turbo-expander. Heat needs to be removed from the water after it exits the intercooler. Basic heat exchanger analysis is used to analyse both the intercooler and radiator. The steps are followed to complete the analysis as below [5]

1. Analyse the compressor flow rate
2. Analyse the water-air radiator and analyse the intercooler
3. Analyse the temperature drop in turbo-expander
4. Cooling load estimation
5. COP calculations

To perform a thermodynamic analysis for an Air conditioning system, the mass and energy balance equations are applied to each component in the system. With reference to the figure and applying the heat balance, the operating conditions are obtained from the system. The limiting conditions are decided. The atmospheric air at 40^0C and inlet temperature of water in intercooler is 50 ^{0}C.Considering the temperature of intercooler and radiator, the pressures are decided. The other pressures and temperature are decided based on data from references and practical conditions. Values of enthalpy are obtained from Steam Table The configuration of an air conditioning system is shown in table 1 below. The system is to operate under following conditions

Table 1: System Observations

Parameters	Symbols	Value
Inlet Temp. of air in Intercooler	t_1	133 ^{0}C
Outlet Temp. of air in Intercooler	t_2	100 ^{0}C
Inlet temp. of water in radiator	T_1	70 ^{0}C
Outlet temp. of water in radiator	T_2	50 ^{0}C
Atmospheric temp.	T_a	40 ^{0}C

The various parameters are calculated with the help of standard formulas for all the components which are shown in table 2. calculations are done using Jenelle Pope's work on Analysis of Turbocharger.[5]

Table 2: System Calculation

	Parameters	Value
Turbocharger	RPM	2400
	CFM	620.141
Radiator	m_a	2.023
	m_w	0.26
	Q	16.35
	NTU	0.8129
	LMTD	18.26
	E	0.5
	UA	0.4336
Intercooler	m_a	0.328
	m_w	0.26
	Q	10.923
	NTU	1.9146
	LMTD	53.49
	E	0.8
	UA	631.83

The cooling load required for cabin cooling is calculated by using standard method of load calculation. The various factors of heat load like solar radiation (roofs, walls, glasses) normal heat gain through glass, normal heat gain through wall, air infiltration, number of persons in cabin sensible heat load, Latent heat load can be calculated using ASHRAE Hand book. [7]

Table 3: System Observations

Parameters	value
Cabin Dimensions	$(1.75\times2.24\times1.75)m^3$
Cabin Temperature without cooling	45 ^{0}C
Sensible heat conduction through cabin structure byconduction	0.395 kW
Solar heat gain (sensible) through outside Walls and roof	0.760 kW
Heat gain due to infiltration	1.33 kW

Heat gain from occupants	0.440 kW
Heat gain from engine bonnet	0..00628 kW
Heat gain from lighting equipment	0.0375 kW
Total heat gain	**2.96878 kW**

V. Result And Discussions

Brief summary of the parameters required for plotting the graph to determine the characteristics from the plot.

Table 4: CFM over varying RPM and Boost

Boost in PSI	Pr	500 RPM	1000RPM	1500RPM	2000RPM
1	1.06	55.19	110.3	165.5	220.7
5	1.34	69.25	138.5	207.7	277.0
10	1.68	86.83	173.6	260.5	347.3
15	2.02	104.4	208.8	313.2	417.6
20	2.36	121.9	243.9	365.9	487.9
22.5	2.53	130.7	261.5	392.3	523.1

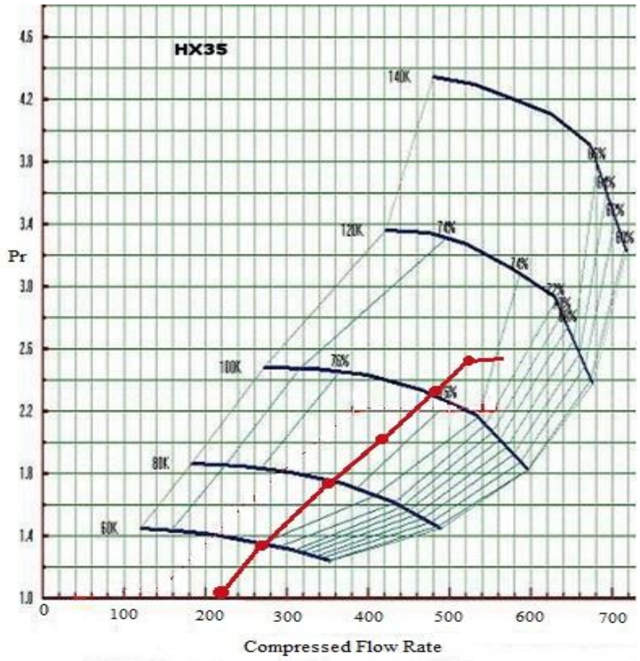

Fig 3 Pr vs Compressd Flow Rate[5]

1. The performance of turbocharger is shown in the graph plotted under Pr vs Compressed flow rate.
2. From the graph it is observed that the efficiency of the turbocompressor is between 75% to 76%.
3. It may be noted that the Pr no. increase as the increase in compressed flow rate.
4. The temperature of the truck is found to be decreased by 10-15 ^{0}C
5. From above, it can be concluded that, for providing cabin cooling for truck using engine exhaust air refrigeration cycle is can be used.

VI. Conclusion

The main purpose of this paper is to design the cooling system for the truck cabin by using the exhaust gases and atmospheric air. This paper also aims towards the possible modification to be done in the present automotive air conditioning system. Another objective includes the comfort cooling of the cabin to reduce the driver's fatigue.

By working on this project, we found out that the air conditioning system based on air refrigeration cycle can be designed, assemble and feasible to run on the truck engine without much affecting its performance.

As the refrigerants are the source of ozone layer depletion and greenhouse effect, the initiation of using air refrigerant cycle in automotive air conditioning is the best way to decrease the adverse effects of the refrigerants such as R12, R22 on environment. The use of air as refrigerant totally eliminates the use of refrigerants and subsequently reduces the ozone layer depletion. Therefore we finally conclude that use of Air Refrigeration Cycle in automotive air conditioning system will be the best way to design the Automotive Air conditioning System.

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