Theoretical Analysis of Automotive Refrigeration System by Waste Heat Recovery

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***Abstract*—The title "Theoretical analysis of Automotive Refrigeration System by WHR" has the objective to utilize the waste heat rejected from the vehicle exhaust of an automobile in an economical way. The waste heat is recovered using the Pre heater system. Pre heater receive a heat from exhaust and delivery a heat to inlet of the compressor. There is a transfer of heat from the exhaust of IC engine to the pre-heater system depends on the velocity, pressure, temperature of the exhaust. The extracted heat from the exhaust is used to increase the temperature of the refrigerant entering the compressor before compression process. The increase of the refrigerant temperature before compression reduces the work of the compressor. The reduction of compressor work by the WHR system , results in reduction of work input to the compressor, which improves the refrigeration effect. The implementation of the WHR system has increased the COP. the work done (W_C) by the compressor is reduced and utilize the certain amount of waste heat (Q) .**

Keywords- Vapour compression refrigeration, Waste heat, COP, Compressor work, Preheat

I. INTRODUCTION

A rapid changing environment and atmospheric effect, the air conditioning of the moving vehicle has become a necessity. In the same time consumers are incapable to bear the increasing operating cost of the vehicle due to continuous raise in fuel prices, component cost and maintenance costs associated with vehicles. More recently, several new philosophies for manufacturing improvement have been developed and implemented in various sectors. In this paper, an exploration has been done to research the possibility of waste heat recovery and its subsequent utilization in air conditioning system of a vehicle without increasing the component cost, weight, number of component and bring improvement in vehicle by making luxurious. Automotive air conditioning is the process by which the air is cooled and cleaned, the humidity lowered and the air circulated. The quantity and quality of the air is also controlled. Under ideal conditions the air conditioning system can be expected to accomplish all these tasks at the same time. The best temperature for the inside of car is between **20°C** to **22°C**. This is equivalent to climatic load the "comfort range". When a car drive under Strong sunlight **40°C** . the interior temperature increases more than **15°C** may be it reaches **60°C to 70°C** because ambient air heat, sunlight heat, engine heat, road heat, exhaust heat added inside of cabinet. Heat pumps offer the advantages of reducing energy consumption, improving heating performance and reducing the negative effects on the environment compared with other heating methods [1]. Larger capillary tube decreases the tendency of refilling of evaporator but offers less 'evaporator temperature' effective in lower range of refrigeration temperature. Shorter capillary tube ensures higher COP initially but which deteriorates at a faster rate in lower temperature range [2]. The main objective in this study was to obtain performance of the refrigeration system in term of Refrigeration Capacity, Compressor work and COP by determining three important parameters during in operating mode which are temperature, pressure and refrigerant flow rate. The average COP of the refrigeration system using the refrigerator test rig was about 2.7 [3]. The heat exchange coefficient h of exhaust in the engine pipe, According to the Strouhal number St varies between 0.089 and 0.43. $Nu = 0.33581\ Pr^{0.33} Rd^{0.52376}$ insignificant. at low Reynolds number the CAF is almost two times more than the Colburn correlation in the steady state conditions, due to the pulsating effect of exhaust gas, at medium Reynolds number CAF decreases from 1.8 to 1.1 approximately, at high Reynolds number CAF is almost the same as the steady state conditions due to the high frequency of exhaust, and similar to the turbulence flow in the steady state conditions [8].

II. PREHEAT AUTOMOTIVE REFRIGERATION SYSTEM

A. The process of automotive refrigeration system

A circuit consists of compressor, condenser, expansion valve, evaporator. The vehicle engine drives the belt by means of the ribbed V-belt. The belt pulley follows on freely when the compressor is switched off. When the compressor is connected, voltage is present at the magnetic coil. A magnetic force field is created. The compressor runs on. The low temperature, low pressure vapour is compressed by a compressor to high temperature and pressure vapour. This vapour is condensed into high pressure vapour at in the condenser and then passes through the expansion valve. The vapour is throttled down to a low pressure liquid and passed on to an evaporator, where it absorbs heat from the Surroundings

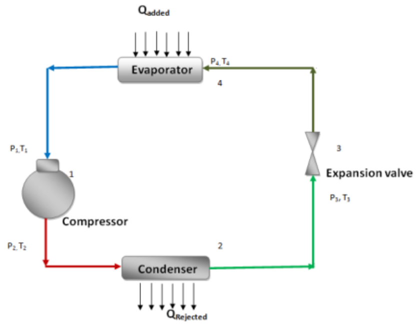


Figure 1. Layout of automotive refrigeration

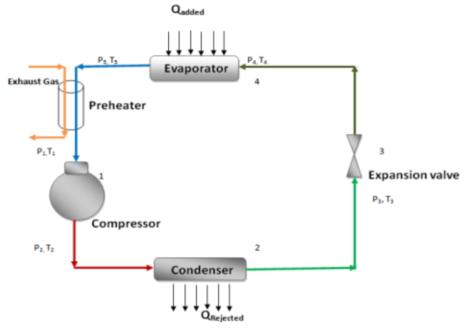
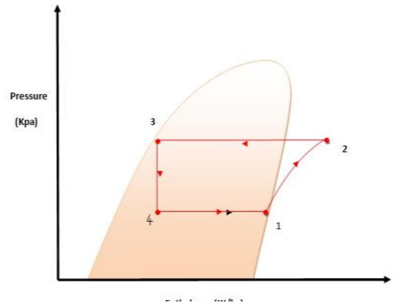


Figure 2. Layout of reheating automotive refrigeration



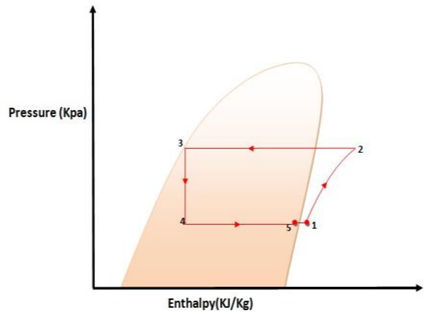


Figure 4. Preheat Vapour compression refrigeration cycle

from the circulating fluid and vapourizes into low pressure vapour. Figure 1. The cycle repeats continuously.

The present invention involves a system and method for preheating the refrigerant gas in a motor vehicle air conditioning system in order to minimize the amount of work required to be performed by the compressor. In an embodiment of the present invention, the refrigerant gas is diverted through the exhaust manifold immediately before passing through the compressor. As the refrigerant gas passes through this tube passing through the exhaust mani fold, it is Preheated by the surrounding hot exhaust gases. Figure 2.

In an existing system Figure 3. due to the continuous adding and removing of heat in a refrigerant, compressor work done is increased so we reduced a work done by treatment of refrigerant in preheating process from exhaust heat. if preheated is high that optimal value its expands so again its compress in compressor unit its need high work done. so preheating value should be perfect for cycle from Figure 4. reference air temp 20°C is compressor inlet point is lie inside of saturation line for that point temperature of refrigerant is 27°C. In a pressure and enthalpy case studies of R134a is preheated 40° a refrigerant volume ratio is not affected above 40°C volumetric compression is increased 20 %.so finally we conclude a preheated maximum up to 35°C so temperature adding is 8 °C.

B. Length of Preheating

A length of preheating is very essential for preheating process because preheating process depends on exhaust condition of the automotive vehicle in my analysis of exhaust condition.

Heat transfer coefficient of our exhaust condition find by using Woschni relation.

$$U= 3.26\ (b^{-0.2})\ (P^{0.8})\ (T^{-0.55})(V^{0.8})$$

Heat Supplied from exhaust to refrigerant

$$Q= m\ C_P\ (T_{co}-T_{ci})$$

Area of Preheating

$$Q=UA\ (LMTD)$$

where,

$LMTD = (Z_o – Z_i) / (In\ (Z_o/Z_i))$

$Z_o= T_{ho}-T_{co}$

$Z_i= T_{hi} - T_{ci}$

In our exhaust condition Temperature = 200°C, Velocity = 10 m/s.

we find a values of $U=76.81\ W/m^2°C$, Q = 46.8 W, LMTD = 168.96°C, A= 0.003645 m^2, D_i=0.04m, D_o= 0.06m, L=0.2317m.

III. ANALYSIS OF AUTOMOTIVE REFRIGERATION SYSTEM

It consists of three cycles each cycle depends on reference atmospheric temperature values initial reference value is 36°C constant, final atmospheric reference value is changed each process from 26°C to 20°C. In blue color cycle at a on reference atmospheric temperature value is 26°C. In yellow color cycle at a on reference atmospheric temperature value is 23°C. In blue color cycle at a on reference atmospheric temperature value is 20°C. Figure 5.

It consists of three preheated cycles each cycle depends on reference atmospheric temperature values initial reference value is 36°C constant, final atmospheric reference value is changed each process from 26°C to 20°C. In blue color cycle at a on reference atmospheric temperature value is 26°C. In yellow color cycle at a on reference atmospheric temperature

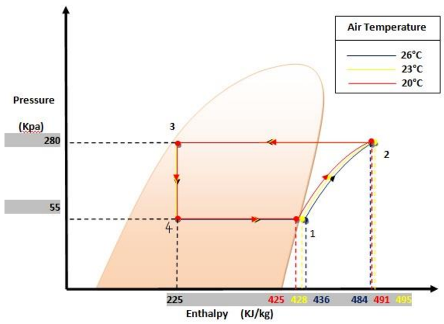


Figure 5. Analysis of vapour compression refrigeration cycle

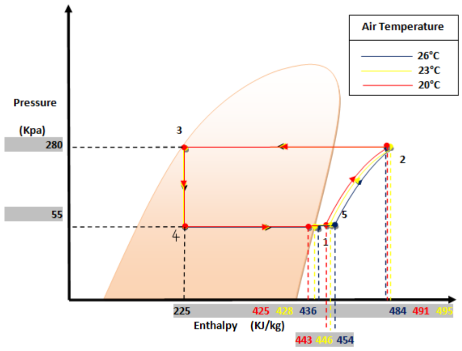


Figure 6. Analysis of Preheat vapour compression refrigeration

value is 23°C. In blue color cycle at a on reference atmospheric temperature value is 20°C. Figure 6.

A. Analysis of Vapour compression cycle

Temperature of air drop from 36°C to 26°C

In a first cycle blue color is drawn from observed reading of refrigerant properties at the inlet of compressor is present in superheated region so no moisture is present.

Temperature of air drop from 36°C to 23°C

In a second cycle yellow color is drawn from observed reading of refrigerant properties at the inlet of compressor is present in superheated region but compare than the previous one superheated region is reduced so very low level of cooling effect is added.

Temperature of air drop from 36°C to 20°C

In a third cycle red color is drawn from observed reading of refrigerant properties at the inlet of compressor is present inside of saturation region because due to the continuous process of cyclic heat addition and rejection in a refrigerant small quantity of cooling added in each stage.

B. Analysis of Preheat Vapour compression cycle

Temperature of air drop from 36°C to 26°C,23°C,20°C:

In a three cycles blue, yellow, red color is drawn from observed reading of refrigerant properties. The inlet of compressor is present in superheated region so no Cooling is added.

C. Analysis of W_C and COP using Ph Chart:

In a Figure 7. refrigerant inlet of compressor contains some moisture so generally compressor take high work done for our required output here work done of the compressor from area of the work done curve is

$W_{C(WOP)}$= area of (abcd)

$R.E_{(WOP)}$ = area of (adgh)

$$COP_{(WOP)}=\frac{Area\ of\ (adgh)}{Area\ of\ (adgh)}$$

In a Figure 8. refrigerant inlet to compressor is super heated condition by our preheating method so generally compressor takes low work done than moisture condition inlet. work done of the compressor from area of the work done curve is

$W_{C(WP)}$= area of(abcd) - area of (afed)

$R.E_{(WP)}$ = area of (adgh)

$$COP_{(WP)}=\frac{Area\ of\ (adgh)}{Area\ of\ (abcd)-\text{area of (afed)}}$$

Compare Figure 7. & 8.

i. work done $W_{C(WOP)} > W_{C(WP)}$ because $W_{C(WP)}$ is equal to the $W_{C(WOP)}$ - area of (afed). here some amount of area is subtracted from $W_{C(WOP)}$ area. so obviously $W_{C(WP)}$ work done is reduced

ii. Refrigeration effect is not vary in both conditions $R.E_{(WP)}$= $R.E_{(WOP)}$, here area of (adgh) is same for existing and proposed system.

iii. COP is defined as the ratio of refrigeration effect to work done here work done is reduce as discussed in (i. point). work done is inversely propositional to the cop so work done is reduced means cop is increased

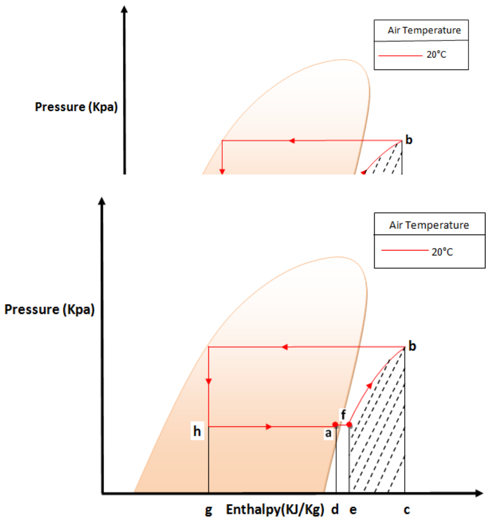


Figure 8. Analysis of Preheat Vapour compression cycle in Ph chart

D. Analysis of Performance Parameters:

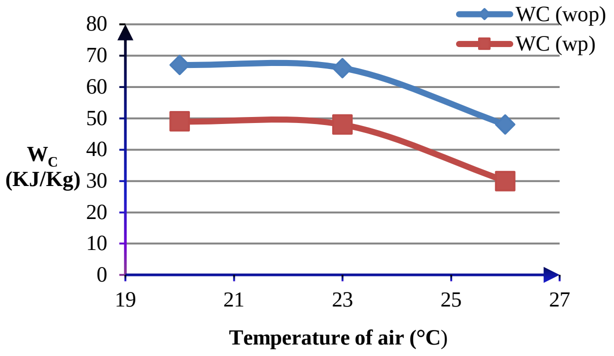


Figure 9. Comparison of work done

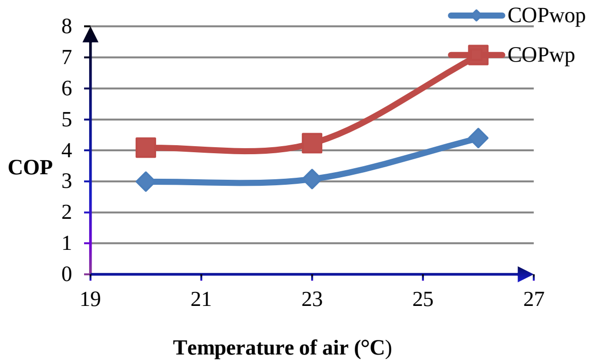


Figure 10. Comparison of COP

From above graphs we clearly understood COP of a refrigeration system is gradually decreases and compressor work done (W_C) is gradually increases. Figure 9. Refrigeration effect is decreases as shown in Figure 10. It clearly shows a reasons for increasing compressor work done. A moisture is added gradually to a refrigerant for continuous cyclic rotations so refrigerant need high work for compression required temperature output.

From above graphs we clearly understood COP of a refrigeration system is gradually decreases and compressor work done (W_C) is gradually increases. Figure 9. but compare than the existing system quantity of cop is high, Work done of compressor is low. In this theoretical analysis compressor inlet condition 8°C raise than existing system but in actual it is at an automotive vehicle exhaust initially low than maximum exhaust temperature 200°C. In refrigeration system COP is initially high so temperature adding less than 8°C. After some process, let reference temperature of air 20°C exhaust temperature is increased due to continuous running of engine so for that time 8°C is added to refrigerant 48.6W of heat transferred from exhaust gas to refrigerant. So in an experimental cases COP not decreases suddenly its obtains in a range of 4 to 5 compare than existing system it's high.

IV. ASSUMPTIONS

i. One dimensional heat flow
ii. Steady state heat dissipation
iii. Homogenous and isotropic material, thermal conductivity of the material is constant
iv. Uniform heat transfer coefficient from inlet to outlet
v. Adiabatic heat loss from pre heater pipe to surroundings.

V. CONCLUSION AND RECOMENDATIONS

In our theoretical analysis finally found a values for objectives and values again verified in simulations software ANSYS 14.5 , simulation also give a same results so finally

i. 46.8W Waste heat is utilized from total heat.
ii. 10.23 % of Stage wise increasing work done is reduced.
iii. Maximum 36.68 % of COP is increased.
iv. Maximum 26.28% of Work done is reduced.

This research fully based on an automotive air conditioning concepts also suitable for Industries large textile shops malls and hotels. Now, Experimental work are in progress.

VI. BENEFITS

By implementing a pre heater in an automotive refrigeration system the following benefits are achieved.

i. The power consumption in the compressor is reduced to minimum
ii. Better cooling effect can be achieved at minimum time.
iii. Fuel consumption of the engine is also reduced because of compressor work done.
iv. Low cost and easy construction

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