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Investigation of Air Conditioning System by Vapour Compression Refrigeration Cycle Using Waste Heat Energy from the Engine Exhaust

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Abstract*:. *The heat energy from the vehicle exhaust can be used to run the Vapour compression Refrigeration System (VCRS), hence reducing the work lost by the engine to run the VCRS compressor. Keeping this in mind, this paper researches the possibilities of utilizing the VCRS in moving vehicles using the waste exhaust gas. Refrigerator is a device used for cooling of products for both domestic and commercial purposes by utilizing mechanical vapour compression Cycle in its process. The main objective of this work is to investigate the performance of the VCRS system using the waste heat from the exhaust tail pipe and evaluate the energy required in the exhaust to run the compressor. To attain this objective a turbocharger is incorporated in the new VCRS system to run the compressor. The rotational energy of the turbocharger is converted into electrical energy and then a step down transformer is used to obtain the required voltage. The obtained energy is used to run the compressor of the VCRS system [1-2].

Keywords*: *Step down transformer, Turbocharger, Refrigeration, VCRS.

I. INTRODUCTION

Refrigeration is the process in which work is done to remove heat energy from a space, or from a substance. The objective of using a refrigeration system is to reduce the temperature of the enclosed system to a desired level and then maintain the lower temperature of the system as compared to the surroundings. The main objective of this project is to develop a VCRS system for automobiles by lowering the temperature of a small space inside the vehicle by using waste heat and exhaust gases from the engine. Most of the domestic refrigerators today are functioning based on the vapour compression refrigeration system. The vapour compression refrigeration system consists of four main components which are compressor, evapourator, throttling device, and condenser.

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II. MATERIAL AND METHODS

A. Vapour Compression System

Vapour compression refrigeration cycle is a famous refrigeration and air conditioning cycle in the world. This is due to the factors like highly efficient, inexpensive and compact system. This system mainly consists of four major components namely: a compressor, condenser, thermal expansion valve and an evapourator. A refrigerant is allowed to move inside the system to absorb the heat and thus lowering the system temperature. The refrigerant enters the compressor as a saturated vapour at stage 1 in figure 1. Whenever the refrigerant gas is compressed it increases the temperature and pressure leaving the compressor as a superheated vapour. Then the superheated vapour will enter the condenser, at stage 2, which is normally a heat exchanger kind of setup which uses air or water for cooling. Now the refrigerant passes heat to the surrounding by convection ,phase change takes place from superheated vapour to saturated liquid. The liquid is then sent to the throttling valve, as indicated by stage 3, where there is a sudden drop in pressure which causes sudden evapouration which changes the saturated liquid to a saturated vapour causing subsequent drop in temperature of the refrigerant, which is caused due to the sudden drop in pressure due to the throttling valve. In the throttling process only partial evaporation takes place because its temperature is lowered from the saturation temperature. The low temperature and partially evapourated refrigerant then moves to the stage 4, where it absorbs surrounding system heat and becomes saturated vapour. This is the last stage in the process, in which cooling is produced in the refrigeration cycle [3].

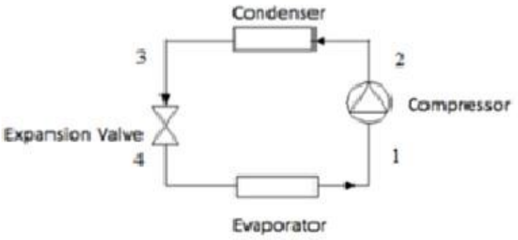

Fig 1 – Vapour Compression Cycle [3]

B. Energy Output from Various Engine

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By looking at all the reference data it is found that,
Exhaust waste =30%
Cooling system loss=30%
Radiation losses=5%
It is found that only about 35% of the energy is used as brake power.

III. METHODOLOGY

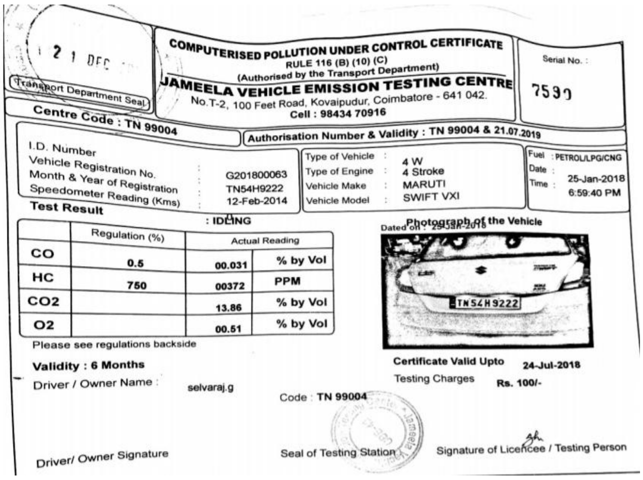
A. Energy Test

In order to get the most approximate amount of energy that is released from the exhaust of the engine the emission test was performed on Maruti-Suzuki swift vehicle and the data from the emission test were used to perform the energy calculations.

B. Procedure

When the vehicle starts the unused exhaust gas is produced the exhaust heat taken from the tail pipe is then transferred to the turbocharger, from which electric energy is produced. The produced energy is then stepped down to run the VCRS compressor.

Emission Certificate



21 DEC
Transport Department Seal

COMPUTERISED POLLUTION UNDER CONTROL CERTIFICATE
RULE 116 (B) (10) (C)
(Authorised by the Transport Department)
JAMEELA VEHICLE EMISSION TESTING CENTRE
No.T-2, 100 Feet Road, Kovaipudur, Coimbatore - 641 042.
Cell : 98434 70916

Serial No. : 7590

Centre Code : TN 99004
Authorisation Number & Validity : TN 99004 & 21.07.2019

I.D. Number : G201800063
Vehicle Registration No. : TN54H9222
Month & Year of Registration : 12-Feb-2014
Speedometer Reading (Kms) :

Type of Vehicle : 4 W
Type of Engine : 4 Stroke
Vehicle Make : MARUTI
Vehicle Model : SWIFT VXI

Fuel : PETROL/LPG/CNG
Date : 25-Jan-2018
Time : 6:59:40 PM

Test Result : IDLING

	Regulation (%)	Actual Reading	
CO	0.5	00.031	% by Vol
HC	750	00372	PPM
CO2		13.86	% by Vol
O2		00.51	% by Vol

Please see regulations backside

Photograph of the Vehicle
Dated on : 25-Jan-2018

Validity : 6 Months
Driver / Owner Name : selvaraj.g

Certificate Valid Upto 24-Jul-2018
Testing Charges Rs. 100/-

Code : TN 99004

Driver/ Owner Signature
Seal of Testing Station
Signature of Licencee / Testing Person

Fig 2 – Emission Certificate

For the tests a swift petrol car with 83.1 bhp was used. The vehicle was fitted with an engine of the displacement of 1200 cc [4].

C. Parameter and Values

Parameter	Value
Ignition	Spark ignition
Displacement	1200cc
Number of cylinders	4
Maximum power output	85.8bhp@6000rpm
Maximum torque	114Nm@4000rpm
Emission standard	EEV
After treatment	PPF

Table 1 - Characteristics of the tested car [4]

IV. MEASUREMENT SYSTEM

For the measurement of the exhaust velocity and temperature the **Anemometer** and **K-Type Thermocouple** were used.

A. Anemometer

An anemometer is an instrument that measures velocity of air or any gas. Here anemometer was used to perform the velocity calculations of the exhaust gases coming out of the tail end of the exhaust pipe.

B. K-Type Thermocouple

A **Thermocouple** is a device made by two different wires joined at one end, called junction end. The two wires are called thermo-elements, thermo-elements are distinguished as positive and negative. Here thermocouple is used to measure the temperature of the exhaust gas that is thrown out of the exhaust pipe [5].

V. RESULTS OF MEASUREMENT

Observing and recording the flow parameters form the chosen vehicle through experiments.

CONDITIONS	VELOCITY m/s	TEMPERATURE ˚C
Idling(no load) RPM-1000	2.6	39.1
During full throttling	7.1	49

Table 2 – Results from Exhaust

List of Symbols

m’	Mass flow rate (kg/s)
C_p	Specific heat capacity (kJ/kgK)
$T_{Exhaust}$	Temperature of Exhaust (K)
T_{Amb}	Ambient temperature (K)
ρ	Density (kg/m^3)
Δp	Pressure difference (N/m^2)
D	Diameter of exhaust pipe (m)
L	Length of exhaust pipe (m)
H_f	Head loss due to friction (m)
f	Friction factor
R	Radius of curvature of pipe (m)

A. Calculations

ENERGY RATE AVAILABLE AT EXHAUST = $M'(C_P)_{EXHAUST}*(T_{EXHAUST} - T_{AMB})$

From the equation,

$$C_8H_{18} + 12.5(O_2+3.76N_2) \rightarrow 8CO_2 + 9H_2O+(12.5*3.76)N_2$$

$(C_p)_{Exhaust}$=
$[8/(8+9+(12.5*3.76)*(C_p)_{Co2})]+[9/(8+9+(12.5*3.76)*(C_p)_{H2o})]+$
$[12.5*3.76/(8+9+(12.5*3.76)*(C_p)_{N2})]$
$=0.1505+0.5987+0.7638$

$(C_p)_{Exhaust}$ =1.503 kJ/kgk.
$(M')_{exhaust}$=Area of exhaust pipe *

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$[((velocity)_{Co2}+(velocity)_{H2o}+(velocity)_{N2})*(\rho)_{Co2}+(\rho)_{H2o}+(\rho)_{N2}]$

$(vel)_{co2} = [8/(8+9+(12.5*3.76))] * (vel)_{Exh}$
$(vel)_{H2o} = [9/(8+9+(12.5*3.76))] * (vel)_{Exh}$
$(vel)_{N2} = [(12.5*3.76)/(8+9+(12.5*3.76))] * (vel)_{Exh}$
Subs, $(vel)_{exh} = 2.6$ m/s;
$(vel)_{co2} = 0.325$ m/s
$(vel)_{H2o}=0.365$ m/s
$(vel)_{N2} = 1.909$ m/s
$(\rho)_{Co2} = 0.04\ Kg/m^3$
$(\rho)_{H2o} = 1000\ Kg/m^3$
$(\rho)_{N2} = 1.7201\ Kg/m^3$
$(M')_{exhaust} = \pi/4 *(7*10^{-2})^2*[0.013+635+3.2836]$
$(M')_{exhaust} = 1.416$ Kg/s

At Idling Condition:
Energy rate available at exhaust = $M'(C_p)_{exh}(39.1-30)$

$(C_p)_{Co2} =1.204$ KJ/KgK
$(C_p)_{H2o} = 4.186$ KJ/KgK
$(C_p)_{N2} =1.040$ KJ/KgK

$(C_p)_{exh}=[(8/8+9+(12.5*3.76)*1.204)]+[(9/8+9+(12.5*3.76)*4.186)]+[((12.5*3.76)/8+9+(12.5*3.76)*1.040)]$
$(C_p)_{exh} =1.503$ KJ/KgK

Energy rate available at exhaust =1.416*1.503(9.1)
$Energy_{exh}$=19.37 KJ/s

Pressure calculations:
Frictional pressure loss:
Rearranging the fanning's equation we get,
$\Delta p=(0.01422*c^{1.852}*L)/D^{1.269}$
$P_2-P_1= (0.01244*2.6^{1.852}*3.410) / (7*10^-2)^{1.269}$
$P_2-P_1=8.3129\ N/m^2$

Friction factor in the pipes:
$H_f=\Delta p/(\rho * g) =0.573$
$= fLV^2/(2*g*d) = 0.573$
We get,
f=0.03411.

Long radius elbow:
R=1.5*nominal diameter
=70*1.5
R=105mm
R/D =1.5

Dynamic pressure loss:
$\Delta p_d=k(\rho C^2/2)$
The value of K from the R/D ratio is found as,
K=0.24
$\Delta p_d=0.24*(1.48*2.6^2/2)$
$\Delta p_d=1.2N/m^2$ [6]

B. Cooling Load Calculation

CONDITIONS	HEAT IN KJ/hr
SOLAR RADIATION	300
HEAT GAIN TROUGH THE GLASS	200
HEAT GAIN THROUGH THE CAR WALLS	4300
AIR LEAKAGE	1000
PASSENGER INCLUDING THE DRIVER	1200
HEAT RADIATED FROM THE ENGINE	2000

Table 3 – Cooling Load Calculation

C. CFD

Computational fluid dynamics (**CFD**) is a branch of fluid mechanics that uses numerical **analysis** and data structures to analyse and solve problems that involve fluid flows.
In this project we have used ANSYS FLUENT as a CFD analysis software to analyse the exhaust pipe of the vehicle to get the require values using the boundary conditions provided.

D. Analysis of the Exhaust Pipe

This is the part diagram of the exhaust pipe of the SWIFT vehicle, used to analyse the fluid using the ANSYS WORKBENCH. The dimensions were taken from the exhaust pipe and drawn on CREO 4.0 software.

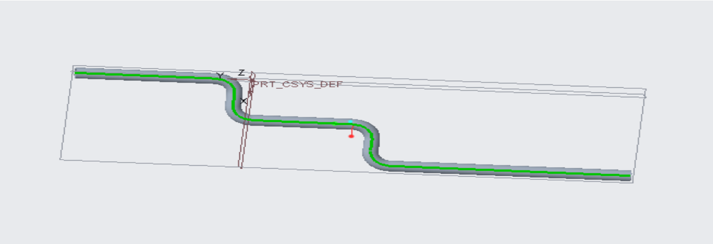

Fig 3 - Exhaust Pipe Part Diagram

Velocity in Boundary Layer

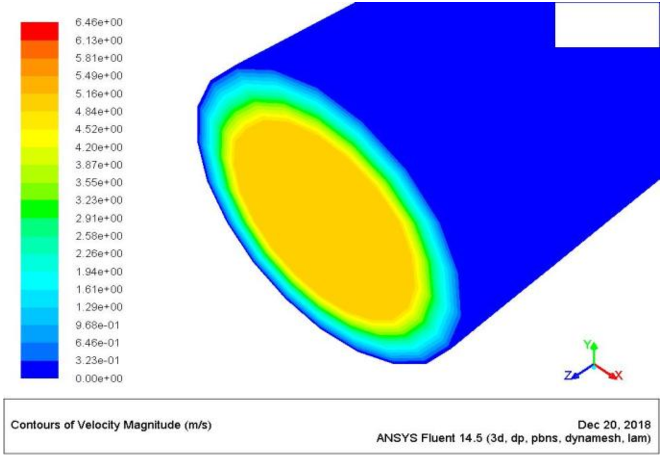

Fig 4 - Velocity Contour View

🟥 **-High Velocity**

🟨 **-Medium Velocity**

🟩 **-Intermediate Velocity**

🟦 **-Velocity between Intermediate and Low**

🟦 **-Low Velocity**

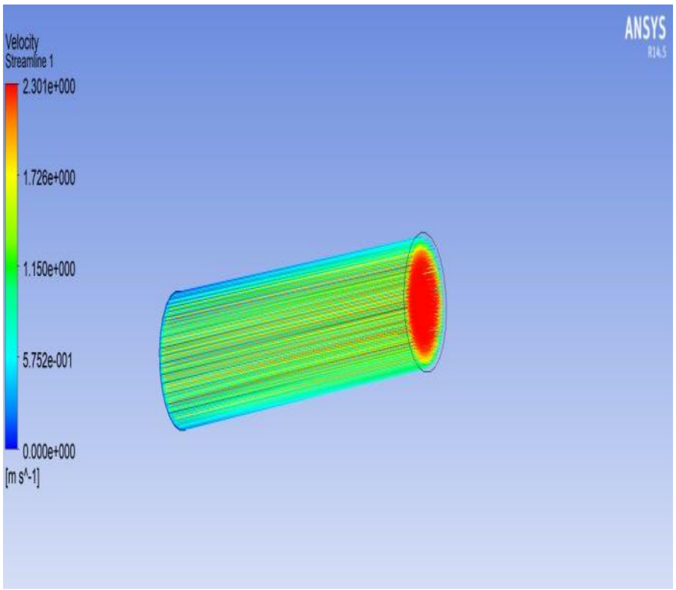

Fig 5 - Velocity Streamline

While doing the CFD analysis it was found that there is maximum velocity at the centre of the pipe and minimum at the edges of the pipe. The contour view has been shown in the fig 4. And then the velocity streamline showing the velocity difference between edges and centre of the pipe, Velocity Streamline has been shown in fig 5.

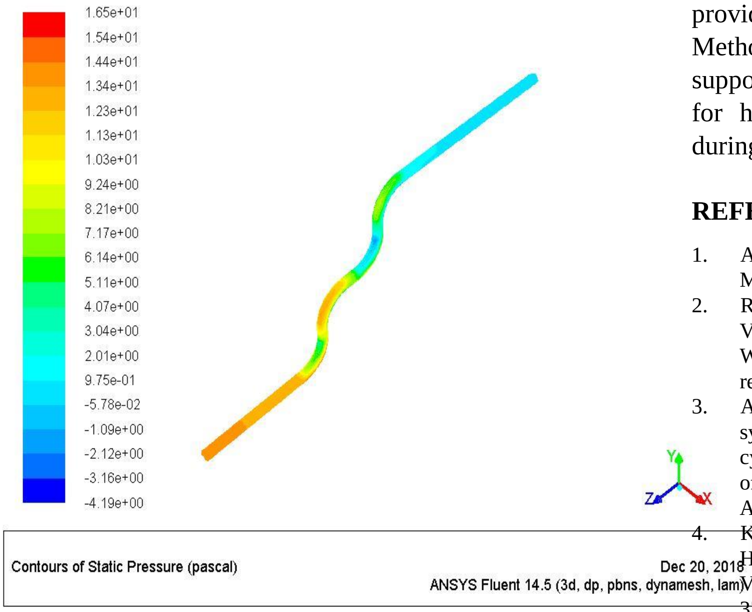

Fig 6 - CFD Diagram (pressure analysis)

🟧 **-Maximum Pressure**

🟨 **-Pressure between Maximum and Medium**

🟩 **-Medium Pressure**

🟦 **-Pressure between Medium and Low**

🟦 **-Low Pressure**

While doing the CFD analysis it was found that there is maximum Pressure at one end which is connected with engine the pipe and minimum at the edges of the pipe.

VI. CONCLUSION

We can see very easily 19.37 KW heat is minimally available at the exhaust. The cooling load calculations show that 1tonne refrigeration system can be installed. There would be only the installation charges after that there would be no running expenditure of Vapour compression refrigeration system. Also keeping in mind, the Environmental safety we have used Eco-friendly refrigerant which has **Ammonia** which is a natural gas which is not responsible for Green House effect or any ozone layer depletion [7-9]. By using this kind of exhaust reusing techniques approximately 35% to 40% waste heat is converted into useful mechanical work, the remaining heat is categorized under the non usable heat energy and thrown of the system which results in the rise in entropy. About 6 to 7% of the fuel efficiency can be increased by implementing VCRS using exhaust heat systems. Waste heat recovery using the exhaust gas is the best and the most efficient way to recover waste heat and increase fuel efficiency [10-11].

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