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"A Proposed Methodology for Air Cooling of LCV by Vortex Tube Refrigeration"

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ABSTRACT

The vortex tube, also known as the Ranque-Hilsch vortex tube, is a mechanical device that separates a compressed gas into hot and cold streams. The main objective is to create a Refrigeration system in Low Commercial Vehicles without using air conditioner. The refrigerants used in VCRS have ozone depleting potential (ODP) and global warming potential (GWP) and are toxic. Leakage of the refrigerant during accidents is also a problem causing deaths due to its inhalation. The high pressure created in the air compressor, which is run through engine shaft, is used as inlet to a vortex tube which is placed inside the vehicle cabin. The cold air from the vortex tube is used to cool the vehicle cabin and the hot air is exhausted to atmosphere. The expected result will be a drop of 10 degrees in the temperature inside the car. This will result in a cooling system which doesn't use the Freon utilizing system. The societal impact of the project will be the absence of a Freon consuming cooling system. Thus it will help in reducing the ozone depletion and global warming.

Key words: *- Vortex Tube, VCRS, LCV, ODP & GWP*

I. INTRODUCTION

The vortex tube was discovered in 1930 by French physicist Georges Ranque. Vortex was the first company to develop this phenomenon into practical, effective cooling solutions for industrial applications. Fluid that rotates about an axis - like a tornado - is called a vortex. A vortex tube creates a vortex from compressed air and separates it into two air streams - one hot and one cold. Compressed air enters a cylindrical generator which is proportionately larger than the hot (long) tube where it causes the air to rotate. Then, the rotating air is forced down the inner walls of the hot tube at speeds reaching 1,000,000 rpm. At the end of the hot tube, a small portion of this air exits through a needle valve as hot air exhaust. The remaining air is forced back through the center of the incoming air stream at a slower speed. The heat in the slower moving air is transferred to the faster moving incoming air. This super-cooled air flows through the center of the generator and exits through the cold air exhaust port. Vortex tube products have been solving industrial cooling problems for years. Using only filtered, factory compressed air as a power source, they convert ordinary compressed air into two air streams - one hot and one cold. At 100 PSIG (6.9 Bar) and 70° F (21°C) inlet temperature, a vortex tube can produce refrigeration up to 6000 BTUH (1512 kcal/H) or temperatures to -40° F (-40° C).

II. OBJECTIVE OF PROJECT

This project will ensure air cooling in low commercial vehicles up to a temperature drop of 10^0C or above without the use of any kind of refrigerant.

III. PROPOSED METHODOLOGY

To run the system some power from the vehicle engine shaft is diverted by a pulley arrangement to run an air compressor. The high pressure created in the air compressor is used as inlet to a vortex tube which is placed inside the vehicle cabin. The cold air from the vortex tube is used to cool the vehicle cabin and the hot air is exhausted to atmosphere.

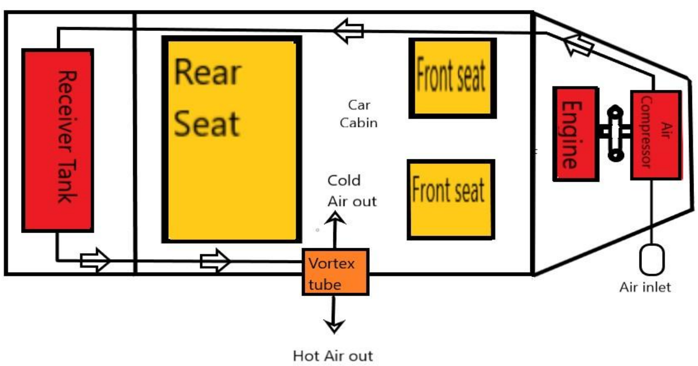

Fig1. Experimental setup

The experimental set up is having

1. Air inlet pipe with air filter
2. Vehicle Engine

3. Single cylinder, single h.p Reciprocating Air-Compressor.
4. Vortex tube assembly.
5. Pressure reducing valve with two side connectors along with pressure gauge and air filter.
6. Belt
7. Air receiver tank (40 lts) with safety valve and pressure gauge
8. Air delivery pipe

The atmospheric air is compressed in a reciprocating air compressor run by the vehicle engine shaft. The compressed air is stored in storage tank which is set up in back side of the vehicle. Air is supplied in to vortex tube at various pressures to get the required comfort air temperatures.

An analysis of the vortex tube has been done below:
Vortex tube gets high pressure air from an air compressor through a tangential nozzle. Assume suffixes i, h, c stands for inlet to the nozzle, hot end and cold end, respectively then the mass and energy conservation of control volume given by

Mass balance $m_i = m_c + m_h$ 1

Steady flow energy balance

$m_i*hi = m_c*h_h + m*.h_h$ 2

Assuming the kinetic energies are negligible.
The cold gas temperature difference or the temperature drop of the cold air tube is defined as

$\Delta T_c = T_i - T_c.$ 3

The hot gas temperature difference or the temperature raise of the hot air tube is defined as

$\Delta T_h = T_h - T_i$ …4

If the system is isentropic then the heat lost by the cold stream is equal to heat gained by hot stream,

$m_c (T_i - T_c) = m_h (T_h - T_i) = (m_i - m_c)*(T_h - T_i)$

$T_i - T_c = [(m_i/m_c)-1].(T_h - T_i) = (\mu-1)^{-1}.(T_h - T_i)$ 5

where μ is the ratio of cold air to the air supplied, called as cold mass fraction.

From equation 2.3 we get.

$\mu (T_i - T_c) = (1 - \mu)*(T_h - T_i)$

$\mu [(T_i - T_c) + (T_h - T_i)] = (T_h - T_i)$

$\mu = (T_h - T_i)/[(T_i - T_c) + (T_h - T_i)]$

$\mu = \Delta T_h/(\Delta T_h + \Delta T_c)$

$\mu = m_c/m_i$ 6

If the process had undergone an isentropic expansion from inlet pressure Pi to atmospheric pressure Pa at the cold end then the static temperature drop due to expansion is given by

$\Delta T'_c = T_i - T'_c = T_i\ [1\text{-}(P_a/P_i)(\gamma\text{-}1)/\gamma]$ 7

The temperature drop occurred in vortex tube is $\Delta T'_c$. The ratio of ΔT_c to $\Delta T'_c$ is called Relative Temperature drop

$\Delta T_{rel} = \Delta T_c/\Delta T'_c$ 8

The product of μ and ΔTrel represents the adiabatic efficiency of the vortex tube because it is defined As,

$$\eta_{ab} = \frac{\text{actual cooling gained in vortex tube}}{\text{cooling possible wit adiabetic expansion}}$$

$\eta_{ab} = (m_c \Delta T_c C_p)/(m_i \Delta T'_c C_p) = \mu \Delta T_{rel}$

$\eta_{ab} = [\Delta T_h/(\Delta T_h + \Delta T_c)]*(\Delta T_c/\Delta T'_c)$ ...9

The C.O.P of the vortex tube is defined as the ratio of the cooling effect to the work input to the air compressor.

Cooling effect = $m_c \Delta T_c C_p$

Work input to air compressor = $(C_p m_i T_i)[(P_i/P_a)(\gamma\text{-}1)/\gamma\text{-}1]/\eta_{ac}$

where η_{ac} is the adiabatic efficiency of the compressor.

$$COP = \frac{Cooling\ Effect}{Work\ input}$$

C.O.P = $[(m_c \Delta T_c C_p).\eta_{ac}]/(C_p m_i T_i)[(P_i/P_a)(\gamma\text{-}1)/\gamma\text{-}1]$

C.O.P = $\mu(\Delta T_c.\eta_{ac})/\{T_i[(P_i/P_a)(\gamma\text{-}1)/\gamma\text{-}1]\}$ 10

Substituting the value of Ti from equation 2.5 in equation 2.8

$$COP = \frac{\{\mu(\Delta Tc.\eta ac)\}}{\{(\Delta T'c/[1-(Pa/Pi)(\gamma-1)/\gamma])[(Pi/Pa)(\gamma-1)/\gamma-1]\}}$$

C.O.P = $\mu.(\Delta T_c/\Delta T'_c)\eta_{ac}.[(P_a/P_i)(\gamma\text{-}1)/\gamma]$ 11

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Substituting the value of μ ($\Delta T_c/\Delta T'_c$), from equation 2.7

$$C.O.P = \eta_{ab}.\ \eta_{ac}.\ \left(\frac{p_a}{p_i}\right)^{\frac{\gamma-1}{\gamma}} \qquad ....12$$

3.1 Cooling load calculations (No. of occupants - 4)

The following assumptions were made in quantifying the amount of heating load on a car.

- Heat conducted from the outside through the glass is considered.
- Heat conducted through the firewall into the passenger compartment has been neglected. It is assumed that enough insulation is provided to minimize this heat transfer.

The following calculations estimate the heat gain loss via glass, from occupants, and infiltration.

$Q_{load} = Q_{glass} + Q_{inf} + Q_{occ}$ …..1

❖ Heat gain via glass (Q_{glass}) :

The heat gain through an automobile glass can be expressed as the sum of solar heat gain, due to transmitted and absorbed solar radiation and the heat conducted, due to the difference between outdoor and indoor air temperature.

$Q_{glass} = Q_{solar} + Q_{cond}$ …..2

Solar radiation varies temporally and spatially. The heat conducted through the glass depends on the solar heat gain, as the amount of absorbed radiation affects the temperature distribution of the glass. Heat loss from the car is taken as negative and heat gain is taken as negative.

✓ Solar Heat Gain ,(Q_{solar})

Solar heat gain is obtained by summing direct normal, diffuse horizontal and solar radiation due to ground reflection.

Q_{solar} = 1960 Watts.

Q_{solar_dffuse} = 43.69 Watts.

Q_{solar_ground} = 447 Watts.

∴ $Q_{solar} = Q_{solar\_direct} + Q_{solar\_dffuse} + Q_{solar\_ground}$

= 1960+44+447

= 2450 Watts. (approx)

✓ Conduction Load (Q_{cond}):-

The following assumptions have been made for calculating conduction load.

- Glass is in steady state (thermally).
- Clear glass with reflectance r_{glass}= 0.07; transmittance τ_{glass} =0.8 and absorptance β= 0.13 (for normal incidence).
- Most of the absorption takes place on the outer surface of the glass.

Solar heat gain is obtained by summing direct normal, diffuse horizontal and solar radiation due to ground reflection.

Q_{cond} = 513 Watts.

$\therefore Q_{glass} = Q_{solar} + Q_{cond}$ 3

= 2450 + 513

= 2963 Watts. (approx)

❖ Cooling load due to Infiltration:-

The heat gain due to infiltration has both sensible and latent components.

$Q_{inf} = Q_{inf\_sense} + Q_{inf\_lat}$ 4

1. Sensible load = 2000 Watts. (approx)
2. Latent load (Q_{inf_lat})= 426 Watts. (approx)

Hence, the total load due to infiltration is

$Q_{inf} = Q_{inf\_sense} + Q_{inf\_lat}$

= 2000 + 426

= 3099 Watts.

❖ Cooling Load due to Occupants:-

Similar to the cooling load due to infiltration, the occupant load also has both sensible and latent components given by

Q_{OCC} = 65 *4 persons

= 260 Watts

Q_{lat_occ} = Q_{lat_person}* Nocc

= 30 * 4 persons

= 120 Watts.

∴ Q_{OCC} = 260 + 120 = 380 Watts.

❖ Total Generated Heat Load (Qload):

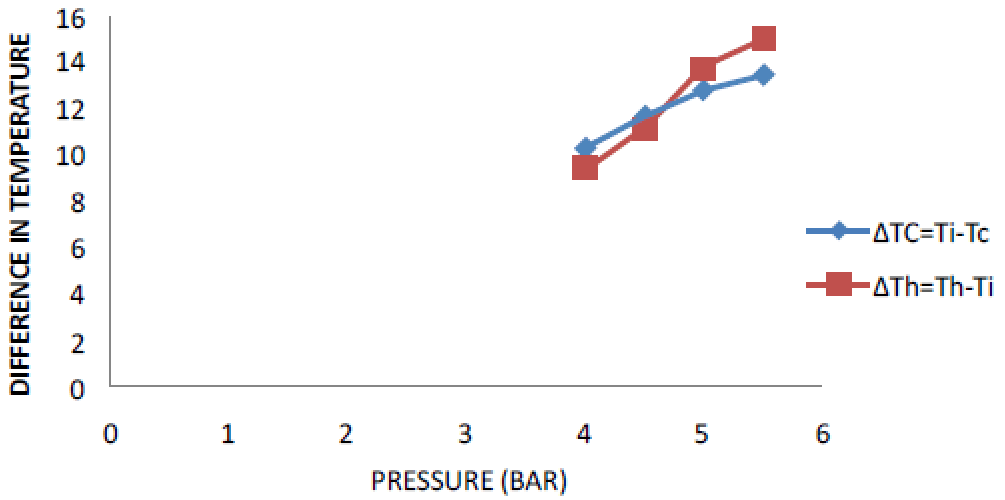
$Q_{load} = Q_{glass} + Q_{occ} + Q_{inf}$

$Q_{load} = Q_{solar} + Q_{cond} + Q_{occ} + Q_{inf}$

$Q_{load} = Q_{solar\_direct} + Q_{solar\_diffuse} + Q_{solar\_ground} + Q_{cond} + Q_{occ} + Q_{inf}$

Q_{load} = 6442 Watts.

A graph below shows the variation of temperature difference with respect to the pressure of air at the inlet of vortex tube.



IV. CONCLUSION

By installing the Vortex Tube Refrigeration System in LCV to get the required cooling conditions, the following conclusions will be observed:

1. The temperature drop inside the car cabin will be around 10^0 C or more.
2. Use of refrigerant won't be there as the working fluid is atmospheric air.
3. Global warming and Ozone depletion can be reduced once the setup is complete.
4. If there is any leakage due to an accident the passengers wouldn't pass away because no refrigerant is used hence no toxicity.
5. The passengers will feel comfortable inside the vehicle.

V. FUTURE SCOPE

Vortex Tube Refrigeration System is giving cooling conditions but not humidity conditions inside the vehicle cabin. For getting comfort conditions in the vehicle both cooling as well as humidity conditions are to be maintained. By installing humidifier along with the Vortex Tube Refrigeration System, the required comfort conditions i.e. temperature & humidity will be maintained in the vehicle cabin.

Thus the vehicle can not only be only cooled but can be conditioned too.

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