DESIGN OF HEAT PIPE TO PROVIDE REFRIGERATION AND AIR CONDITIONING IN AUTOMOBILES

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Abstract This paper presents the necessity of a efficient heat exchanger to transfer energy from one location to another, Heat pipes can be effectively used as heat transfer modules to recover waste heat from the coolant of the I.C. Engine. The evaporator is arranged in the coolant of the I.C.Engine (where 33% of total heat is rejecting to atmosphere). By arranging the heat pipe in an I.C. Engine it is possible to run a vapour absorption refrigeration system (VAR) and the COP of the VAR system can be proved to be equal to 2. By using this system in I.C.Engines the vehicle can be run continuously throughout while providing Refrigeration and Air Condition in the hot Countries.

INTRODUCTION

Every Internal combustion engine will generate the heat and rejection of this heat is imminent for its optimum and reliable operation. As internal combustion design higher throughput in smaller packages, dissipating the heat load becomes a critical design factor. Many of today's internal combustion engines require cooling beyond the capability of standard metallic heat sinks. The heat pipe is meeting this need and is rapidly becoming a main stream of thermal management tool.

Only in the past few years, however, the steam boiler contained heat pipes are reliable and indeed cost-effective solutions for high end cooling applications. The purpose of this article is to explain the basic heat pipe operation, review key heat pipe design issues, and to discuss current heat pipe for application to I.C.Engine cooling.

During the process of combustion, the cylinder gas temperature often reaches quite a high value. A considerable amount of heat is transferred into the walls of the combustion chamber. Therefore, it is necessary to provide proper cooling especially to the walls of the combustion chamber. Due to the high temperatures, chemical and physical changes in the lubricating oil may also occur. This causes wear and sticking of the piston rings, scoring of cylinder walls or seizure of the piston. Excessive cylinder-wall temperatures will therefore cause the rise in the operating temperature of piston head. This in turn will affect the strength of piston seriously.

In addition, overheated cylinder head may lead to overheated spark plug electrodes causing preignition. The exhaust valve may become hot enough to cause preignition or may fail structurally. Moreover, preignition would increase the cylinder head temperature further until engine failure or complete loss of power results. As the last part of the charge to burn is in contact with the walls of the combustion space during the burning period, a high cylinder wall or cylinder head temperature will reduce the delay period and may cause knocking. In view of the above, the inside surface temperature of the cylinder walls should be kept in a range which will ensure correct clearances between parts, promote vaporization of fuel, keep the oil at its best viscosity and prevent the condensation of harmful vapors. Therefore, the heat that is transferred into the walls of the combustion chamber is continuously removed by employing a cooling system. Almost 30 to 35 per cent of the total heat supplied by the fuel is removed by the cooling medium. Heat carried away by lubricating oil and heat lost by radiation amounts to 5 per cent of the total heat supplied.

Heat transfer occurs when a temperature difference exists. As a result of combustion, high temperatures are produced, inside the engine cylinder as compared to the surroundings. Considerable heat flow occurs from the gases to the surrounding metal walls. In addition to this the shearing of the oil film separating the bearing surfaces transforms available energy into internal energy of the oil film. This increases the temperature of oil film and results in heat transfer from the oil to the bearing surfaces. However, the heat transfer on this account is quite small. Hence, the cylinder walls must be adequately cooled to maintain safe operating tempe ratures in order to maintain the quality of the lubricating oil. The two main parts of the heat not available for work are the heat carried away by the exhaust gases and the cooling medium as shown in fig.1

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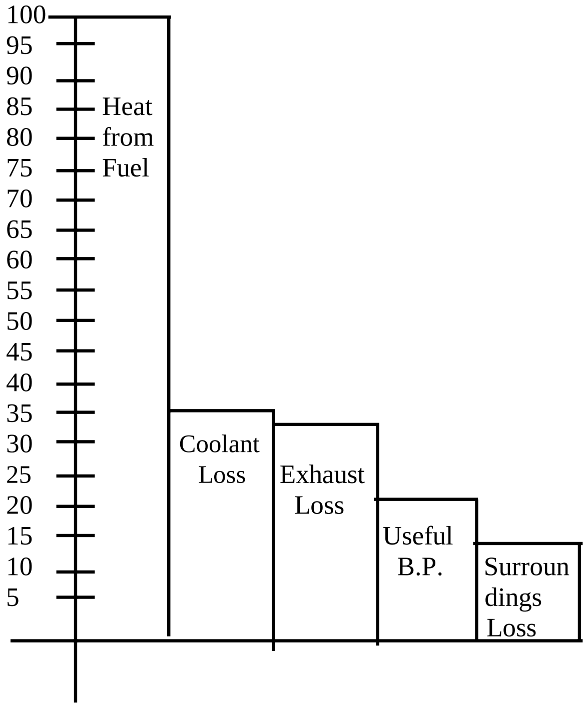

Fig. 1 Heat Losses from Fuel

Heat pipes are particularly useful in energy – conservation equipment one such example is that hot gases are used to run a waste heat recovery boiler.

A high latent heat of vaporisation is desirable in order to transfer large amounts of heat with a minimum fluid flow and hence to maintain low pressure drops within the Heat pipe. The thermal conductivity of the working fluid should also perferably be high in order to minimise the radial temperature gradient and to reduce the possibility of nucleate boiling at the wick/wall interface.

The resistance to fluid flow will be minimised by choosing fluids with low values of vapour and liquid viscosity. A conventional means of quickly comparing fluids is provided by the merit number.

Lithium has a higher merit number than most metals including sodium, however its use requires a container made from an expensive lithium – resistant alloy, where as sodium can be contained in stainless steel, it may therefore be cheaper and more convenient to accept a lower performance heat pipe made from sodium/stainless steel.

Stainless steel is a suitable container and wick material for use with working fluids such as acetone, ammonia and liquid metals from the point of view of compatibility. Its low thermal conductivity is a disadvantage and copper and aluminum are used where this feature is important.

Tests in excess of 8000 hrs with ammonia/aluminum were reported but only 1008 hrs had been achieved in case of aluminum / acetone combination.

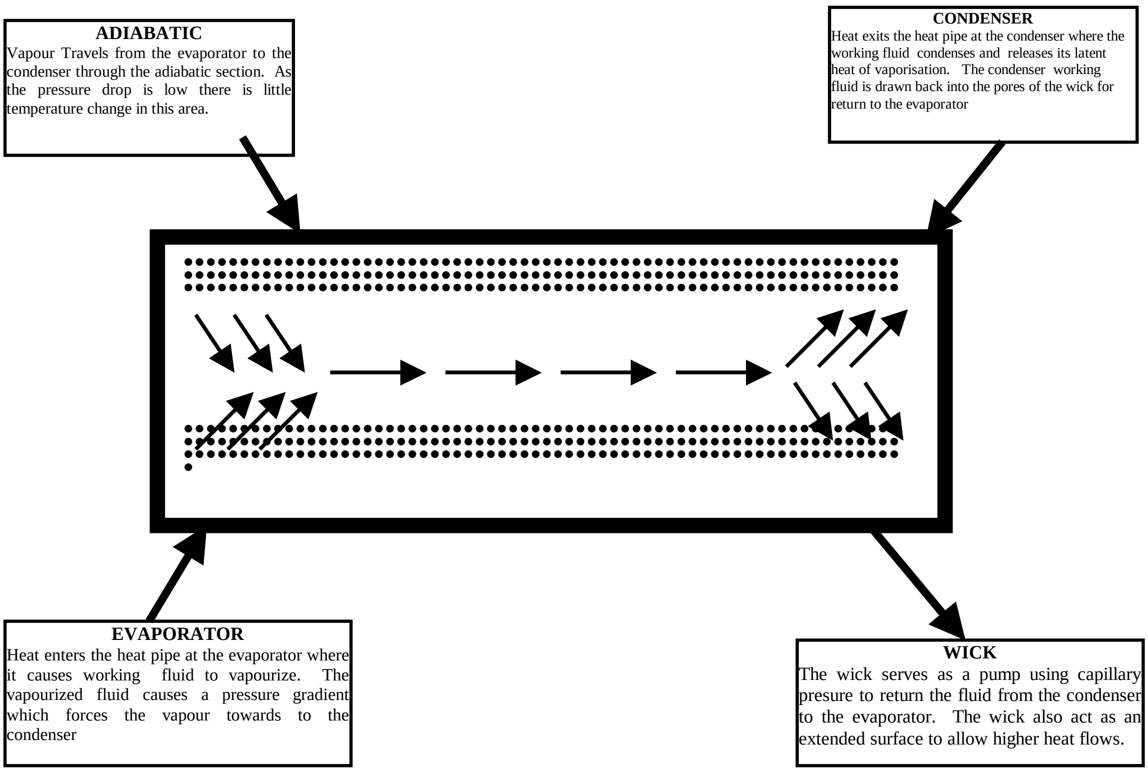

Fig. 2. Heat Pipe Operation

The tests indicated that copper/water heat pipes could be operated without degradation over long periods (now exceeded 20,000 hrs). Ref. (2), Ref. (6).

A circular pipe has a layer of wicking material covering the inside surface, with a hollow core in the center. A condensable fluid is also contained in the pipe, and the liquid permeates the wicking material by capillary action. When heat is added to one end of the pipe (the evaporator), liquid is vaporized in the wick as shown in Fig. 2 Ref. (7), Ref. (8).

The type of energy used in the conventional vapour compression refrigeration (VCR) system is of high grade type (mechanical shaft work) and hence costly and possesses less abundantly available energy.

Whenever there is a waste heat available which is otherwise to be rejected to atmosphere like heat rejected from condenser of steam plant, solar heat, and heat from Biomass, vapour absorption refrigeration system is preferred for which little shaft work is required.

EXPERIMENTAL SETUP

The experimental apparatus is shown schematically in fig.3 On application of heat to the solution present in generator NH3 vapour is driven out from the solution and this NH3 vapour travels upwards, since some water particles may also travel with this vapour, Concentration of Ammonia per Kg of vapour is not equal to 1. Therefore analyser helps to remove these water particles, so that concentration increases. The counter flow of rich solution in the analyser will pull down the water particles to generator. During this process, vapour encounters heat and mass exchanger with falling rich solution. The Result is concentrated vapour leaves the analyser. The plates (buffels) which are present analyser obstruct the passage of vapour in the path and therefore water particles do not get a free passage, where as dry vapour can move through the gaps, Ammonia vapours are driven off from the solution leaving weak ammonia solution in generator.

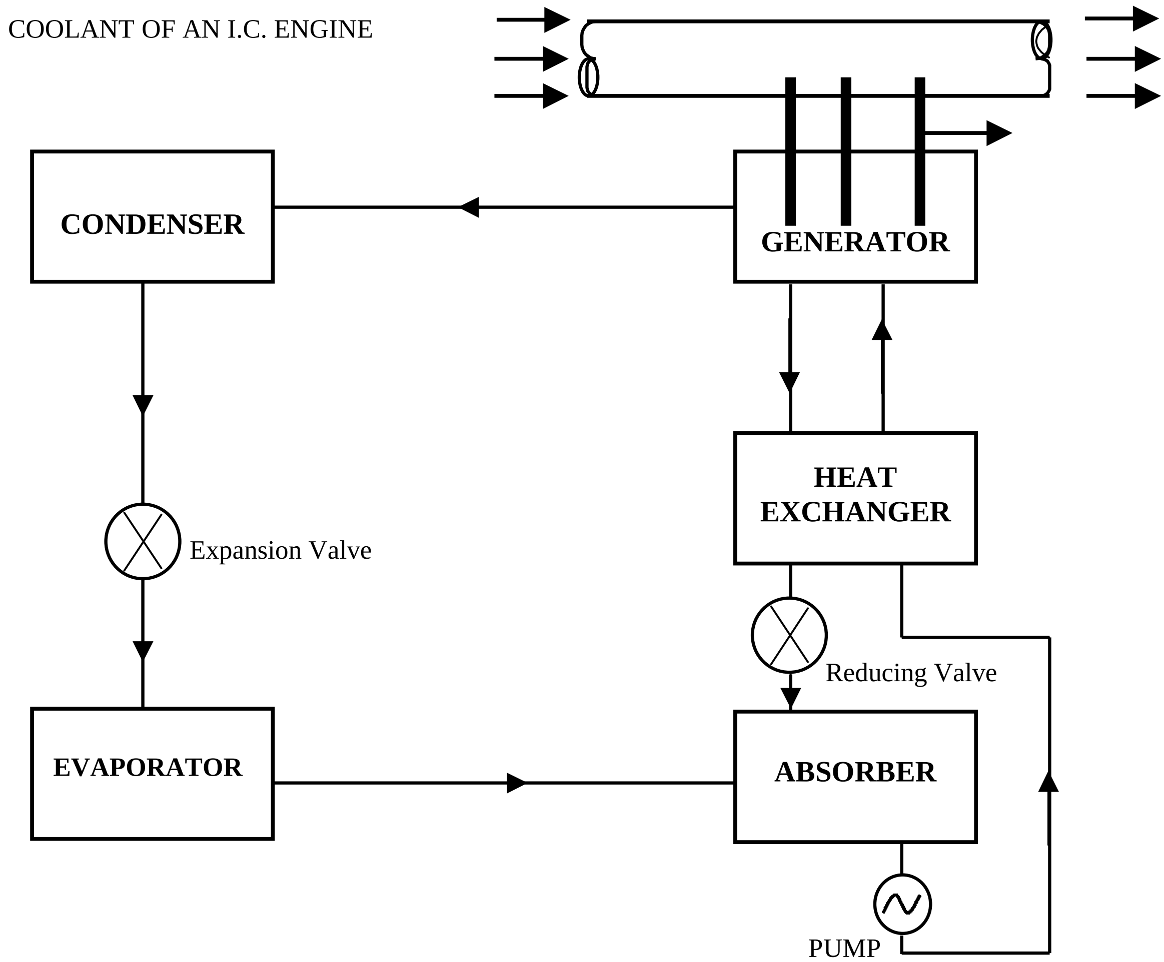

Fig. 3 Experimental apparatus
To provide refrigeration and Air conditioning
In Automobiles

This weak solution expands from condenser pressure to evaporator pressure while going to absorber via reducing valve. The NH_3 vapors are condensed in condenser at high pressure condensing into a saturated liquid. The dry Ammonia vapour leaving evaporator are absorbed by water forming strong Aqua - Ammonia solution at evaporator pressure. In the absorber, the strong solution is pumped from evaporator pressure to condenser pressure by requiring very little shaft work. Since the fluid that is being pumped is incompressible, it requires very less work.

DEVICE DESIGN

The device was made up of stainless steel. For the wick, water is used as the working fluid. If the operating temperature of the coolant in the I.C. engine is at 120^0C having a wick of 2 layers of 250 mesh. The heat pipe is 30cm long and has a bore of 1cm diameter and the evaporator is kept upwards at an inclination of 30^0C to the horizontal. The heat transport capability of such a system is found to be 19.5 W. If the 2 layers of 100 mesh are added to the 250 mesh wick due to the increase in liquid flow capability the heat transport capability will enhance to 363 W. Ref.(4).

The condenser of heat pipe is in contact with the generator of a vapour absorption refrigeration system. The ideal heat-operated refrigeration system that has a source temperate of 120^0C, a refrigerating temperature of 3^0C and an ambient temperature of 30^0C, the COP of the VAR system is 2.31. The plot between the generator temperature and evaporator temperature depicts the variation of COP as shown in fig.4. Ref.(9).

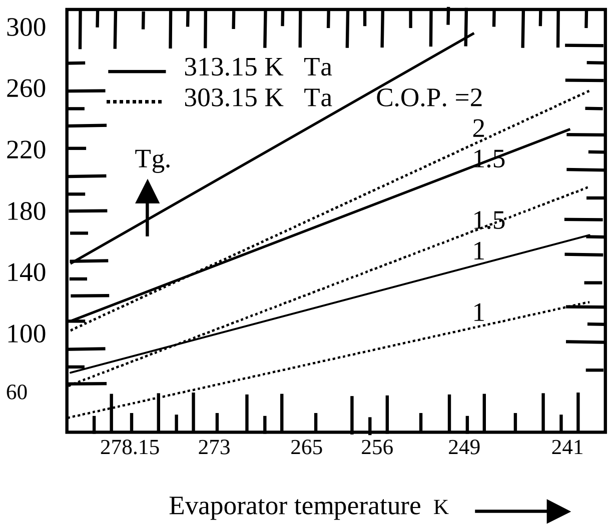

Fig. 4 Variation of COP with the generator temperature

CALCULATIONS

Sample Design of Heat Pipe

For finding the heat transport capability of a simple water heat pipe operating at 120^0C having a wick of 2 layers of 250 mesh against the inside wall, the heat pipe 30 cm long having a bore of 1 cm diameter and is operating at an inclination to the horizontal of 30^0, with evaporator above the condenser Ref. (4). Q, the maximum heat transfer is calculated from the following.

m^0 = the maximum liquid flow rate in the wick. It is given by

$$m^0 = \frac{\rho_l K A_w}{\mu l\, l_{eff}} \left\{ \frac{2\sigma_1}{r_c} \cos\theta - \rho 1\, g\, l_{eff} \sin\phi \right\}$$

K = Permeability of 250 mesh
A_w = Wick cross sectional area
ρ_l = Liquid density
μl = Liquid Dynamic Viscosity
l_{eff} = Effective heat pipe length
σ_1 = Coefficient of Surface Tension
r_c = Core radius
θ = Contact Angle
ϕ = Inclination of Heat pipe

The wire diameter of 250 mesh is typically 0.0045 cm, Ref. (5), and therefore the thickness t_h, of 2 layers of 250 mesh considering 2 layers at the top and 2 layers at the bottom of heat pipe is

t_h = 2 x 2 x 0.0045 cm = 0.0180 cm.

The bore of the heat pipe is 1 cm,

$\therefore A_{wick} = 0.018 \times \pi \times 1 = 0.057\ cm^2$

Assuming perfect wetting ($\theta = 0^0$), the mass flow m^0 may be calculated using the properties of water at 120^0C, the following values are obtained from Ref. (10).

L	=	2.193×10^6 J/Kg
ρ_1	=	9434 Kg/m^3
μ_1	=	0.013 C.P
σ_1	=	53.73 mN/m

From the properties of 250 mesh the pore radius and permeability of 250 mesh are 0.002cm and 0.302×10^{-10} m^2

$$\therefore m^0_{max} = \frac{943.4\,(0.302 \times 10^{-10})\,(0.057 \times 10^{-4})}{(0.013 \times 10^{-3}) \times (0.3)}$$

$$= 4.1640 \times 10^{-11}\,(5373 - 1388)$$

$$= 1.659 \times 10^{-4}\ \text{Kg / Sec.}$$

The maximum heat transport in a heat pipe at a given vapour temperature may be obtained from the equation.

$Q_{max} = m^0_{max} \times L$ = Kg / Sec x J/Kg = W

Q_{max} Per heat pipe = $1.659 \times 10^{-4} \times 2.193 \times 10^6$ =363 W

And hence for 3 heat pipes the total heat transport

Q_{max} = 3x363 = 1089W

Simple absorption refrigeration does not consider rectification column and preheat in Heat Exchanger In such a aquo-ammonia cycle, evaporator, absorber, condenser & generator temperatures are 233 K, 303 K, 313 K and 373 K respectively. The properties of aqua-ammonia are as follows. Ref. (1).

	Concentration (Kg of NH/ Kg of Sol.)	Enthalpy (KJ/Kg)
1.Strong Solution leaving Absorber (H1)	0.421	30
2.Weak Solution leaving generator (H2)	0.375	340
3.Vapour leaving generator (H3)	0.945	1870
4. Liquid leaving condenser (H4)	0.945	470
5. Vapour leaving evaporator (H5)	0.945	1387.5

I. For 1 Ton Refrigeration capacity, determining the mass flow rate of solution in evaporator.

R.E = m $(H_5–H_4)$

1 TR = 3.5 KJ/Kg = m (1387.5 – 470)

m = 0.003815 Kg/Sec.

$$f = \frac{F}{D} = \frac{\text{Kg of rich solution}}{\text{Kg. of Vapour}}$$

f = Quantity of rich solution handled by the pump, i.e., supply to the generator per Kg. of vapour leaving the generator.

F= Kg of rich solution leaving the absorber and entering the generator.

D= Kg of refrigerant vapour leaves the generator.

$$= \frac{Cv – Cp}{Cr – Cp}$$

$$f = \frac{\text{[Kg of Ammonia per kg of vapour (Cv) - Kg of Ammonia per Kg of poor solution (Cp)]}}{\text{[Kg. Of Ammonia per Kg of rich solution (Cr) -Kg of Ammonia per Kg of poor solution (Cp)]}}$$

$$= \frac{0.945 – 0.375}{0.421 – 0.375}$$

f–1= Quantity of poor solution leaving the generator per Kg of vapour generated.

F-D= Mass of poor solution leaving the generator.

$$= \frac{Cv – Cp}{Cr – Cp} = \frac{0.945 – 0.375}{0.421 – 0.375} = 12.39 \text{ Kg.}$$

For 0.003815 Kg of refrigerant vapour, rich solution produced = 12.39 x 0.003815

= 0.0473 Kg/Sec.

(f – 1) = Kg of weak solution per Kg. of vapour generated

= (12.39–1)

= 11.39

For 0.003815 Kg of refrigerant vapour, weak solution produced = 11.39 x 0.003815

= 0.04345 Kg/Sec.

II. Considering energy balance for absorber and generator to find absorber Heat rejection and generator heat transfer, determination of heat rejection by condenser.

For absorber

Assuming 1 kg of a vapour

[1 Kg of vapour x vapour leaving evaporator + weak solution leaving generator x 11.35) = (12.39 x strong solution leaving absorber + Qa (heat rejected)]

As heat entering absorber = heat leaving absorber

1 Kg of vapour x 1387.5 + (340) x (11.39) =

(12.39) x 30 + Qa (heat rejected).

Hence Qa = 4888.4 KJ/Kg. of vapour

Heat rejected at absorber = 4888.4 KJ/Kg. of vapour

The heat balance for generator

[(12.39) x (Strong solution leaving absorber) + Q_G]

= [1xvapour leaving generator + weak solution leaving generator x (11.39)]

(12.39) (30) + Q_G = 1 x 1870 + (340) x (11.39)

Heat absorbed at generator

Q_G = 5370.9 KJ/Kg. of Vapour

The heat balance for Condenser

1x (vapour leaving generator – liquid leaving condenser)

= 1 x $(H_3 – H_4)$ = (1870 – 470) = 1400 KJ/Kg. of Vapour

Checking the over all energy balance neglecting pump work the C.O.P. is found thus.

Q_E , Heat absorbed at evaporator = 1 $(H_5 – H_4)$

= 1 (1387.5 – 470)

= 917.5

This is to show that the sum of heats at Generator and evaporator is equal to the sum of heat loss at condenser and absorber i.e.,

$Q_E + Q_G = Q_C + Q_A$

$Q_E + Q_G$ = 917.5 + 5370.9

= 6288.4 KJ/Kg. of Vapou

$Q_C + Q_A$ = 1400 + 4888.4

= 6288.4 KJ/Kg. of Vapour

$$\text{C.O.P.} = \frac{\text{Refrigeration effect}}{\text{Heat Supplied}} = \frac{Q_E}{Q_G}$$

9145

$$= \frac{}{5370.9}$$

$$= 0.171$$

An ideal heat operated refrigeration system that has a source temperature of 120^0C, a refrigerating temperature of 3^0C, and an ambient temperature of 30^0C.

$$\text{C.O.P.} = \frac{\text{Refrigeration rate}}{\text{Rate of heat addition at generator}}$$

Ts = Source Temperature
Tr = Refrigerating Temperature
Ta = Ambient Temperature.

$$= \frac{T_r (T_s - T_a)}{T_s (T_a - T_r)}$$

$$= \frac{(3 + 273.15)\,(120–30)}{(120 + 273.15)\,(30–3)}$$

$$= 2.\,31$$

LIMITATIONS

1. As T_s increases, the COP increases.
2. As T_r increases, the COP increases.
3. As T_a increases, the COP decreases.

CONCLUSIONS

A heat pipe system has been designed and fabricated to run a vapour absorption refrigeration system. The device allows simultaneous heat transport capability from the I.C. Engine coolant to the heat input of the generator of the vapour absorption refrigeration system. The C.O.P. of the VAR system is found to be equal to 2.31, consequently the coolant temperature of the I.C. Engine can be maintained constant and the vehicle can run continuously, besides the storage of some quantity of food and water in the evaporator of the VAR system, for preserving the food and water at low temperature. With this waste heat recovery system the heat that is to be rejected to the atmosphere is utilised more effectively and the temperature of pollutants in the atmosphere is reduced.

If a suitable blower is arranged in the evaporator coil of an VAR system it will deliver either coil air to room or sucks air from it before forcing through the evaporator coil which cools as well as dehumidifies the air. A thermostat is provided to maintain the desired temperature by means of on - off control of the VAR System. A damper is also used to regulate the fresh air supply. Ref. (9). This indicates the use of heat pipe in an automobile for providing Refrigeration and Air-conditioning with negligible increase in the cost.

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