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Design and Fabrication of Evaporative Cooling Air Conditioner in Tractor Cabin

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ABSTRACT

The Evolution of automotive air conditioning was a remarkable milestone in the history of mankind. It has played an important role in human comfort and to some extent in human safety during vehicle driving in varied atmospheric conditions. Present work focuses on providing comfort conditioning of a tractor cab which is a key factor in ensuring optimum working performance of the driver. A closed tractor cab acts like a greenhouse and its interior could become unbearable and sometimes even dangerous. Conventionally, vapour compression refrigeration systems are the standard for air conditioning in automobiles and account for up to 25 % of fuel consumption in the cooling season. Apart from conventional vapour compression technology, the work explores applicability of evaporative cooling in comfort conditioning of a tractor cabin which is an economical and eco-friendly alternative. The results procured are positive lower cabin temperature close to acceptable limit with less than 10 % of energy consumption compared to vapour-compression units when tested under similar hot-dry conditions.

***Keywords:** Automotive air Conditioning, Tractor Cabin, Vapour Compression, Refrigeration System*

1. INTRODUCTION

A low-cost safety tractor cab with external side shades and wet pad evaporative cooling system was developed to improve the working efficiency and lengthen the effective working time of farmers during the summer who cannot afford to buy an expensive air-conditioned cab. The cab is cooled by passing air through a wet evaporative surface made up of 5 cm thickness of honey comb. The evaporative surface is kept continuously wet with recirculation of water by a low-capacity, submersible water pump installed at the bottom of a water tank. The air cooled by evaporation of water from the evaporative surface is sucked into the cab through a duct by a fan located at the centre of the cab roof.

The motor of the pump and fan are energized by a 12-V DC battery of the tractor. To protect the glass portion of the cab from direct solar radiation, external side shades of white painted plywood are installed on all sides of the cab. At the tractor speed of 5 km/h, relative air velocity at the face of the pad was about 65 m/min. Dry bulb temperature inside the cab was lowered from 34°C to 29° C with relative humidity 54 to 66% (giving thermal sensation in comfortable zone) under worst climatic conditions of Chennai (outside dry bulb temperature of 34.5° C with relative humidity 54%).

2. VAPOUR COMPRESSION SYSTEM

The simplest explanation of this system is a heat engine working in reverse, technically referred to as reverse Carnot engine. In other words, it is the transfer of heat from a cold reservoir to a hot one. Clausius Statement of the Second Law of thermodynamics states:"It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body". Since the vapour compression cycle is against the Second Law of Thermodynamics, some work is necessary for the transfer to take place. The Vapour Compression Refrigeration Cycle involves four components: compressor, condenser, expansion valve/throttle valve and evaporator. It is a compression process, whose aim is to raise the refrigerant pressure, as it flows from an evaporator. The high-pressure refrigerant flows through a condenser/heat exchanger before attaining the initial low pressure and going back to the evaporator. Second, they control the amount of liquid refrigerant entering the evaporator.

2.1 Solution for the Problem in Evaporative Cooling

Evaporative cooling can turn out to be one of the feasible alternatives to this problem and can address to the major cooling needs in the world. It is mechanically and operationally simpler, because it does not require a compressor or a refrigerant. Evaporative cooling systems consist of fans or blowers to move the air around the space to be cooled and water pump to pump water over the pad.

3. DESIGN FEATURES OF TRACTOR CABIN

An overview related to design features of the thermal processes and HVAC characteristics was carried out using relevant technical documentation and by analyzing the design of several agricultural tractors. Majority of tractors have power ranging from 40.5 to 155 kW. The outer length of their cabs is between 1.40 and 1.77 m, the cab width is between 1.38 and1.70 m, and the cab height is between 1.45 and 1.80 m. The basic materials for tractor cab frames are steel profiles, which primarily must provide mechanical protection of the operator. Frames of the cabin usually have six pillars, although there are designs with four pillars.

The floor is made of a steel sheet supported by a steel frame. The transmission system or power train of typical tractors is positioned beneath the cab. In the interior, rubber or polymer flooring is used. Sometimes, foam is used as insulation material between the flooring and the floor. Composite materials are used for heat and sound insulation beneath the floor. Cab roofs are made of polymers, and the cab can be equipped with a roof window. The components of the ventilation system and the air conditioning are generally placed in the roof. Cabin glass is generally tempered and tinted.

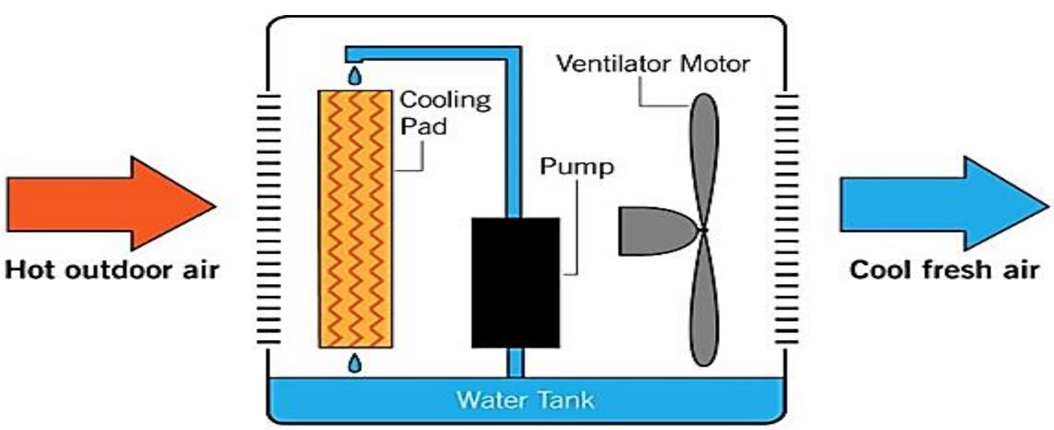

Fig 1. Working of Evaporative Air Conditioner

The cooling load for a closed tractor cab in hot environment, under the steady-state conditions, consists of the following:

1. Heat transfer through the cab roof caused by solar radiation,
2. Heat gain through the cab envelope due to the temperature difference. Solar radiation transmission through glazing, Sensible and latent heat released by the operator, and Heat gain from the power train.

Heat load by infiltration will turn out to be zero due to the pressurization of the tractor cab. In order to maintain the interior temperature constant, the heat removal by the air conditioning should be equal to the heat gain. Total thermal load of the cab under chosen moderate summer conditions will be depending on the size of the cab and on its orientation in relation to the sun. Worst case from the heat gain and direct influence of the solar radiation on the operator could be the case when the largest side of the cab is faced to the sun. Roughly, this could be approximately 1/4 of glazed area, e.g., around 1.5 m^2, which gives solar heat load of order of 1100 W. Rest of area faced to the environment (app. 7 m^2) would transfer up to 700 W of heat, and estimated heat gain from the power train would be 200 W. In total, without the heat released from the operator, estimated heat load of the cab is around 2 kW. Based on performance curve of a typical automotive air conditioner, the approximate compressor power consumption is 1.4 kW for the cooling load of 2 kW on vehicle cabin

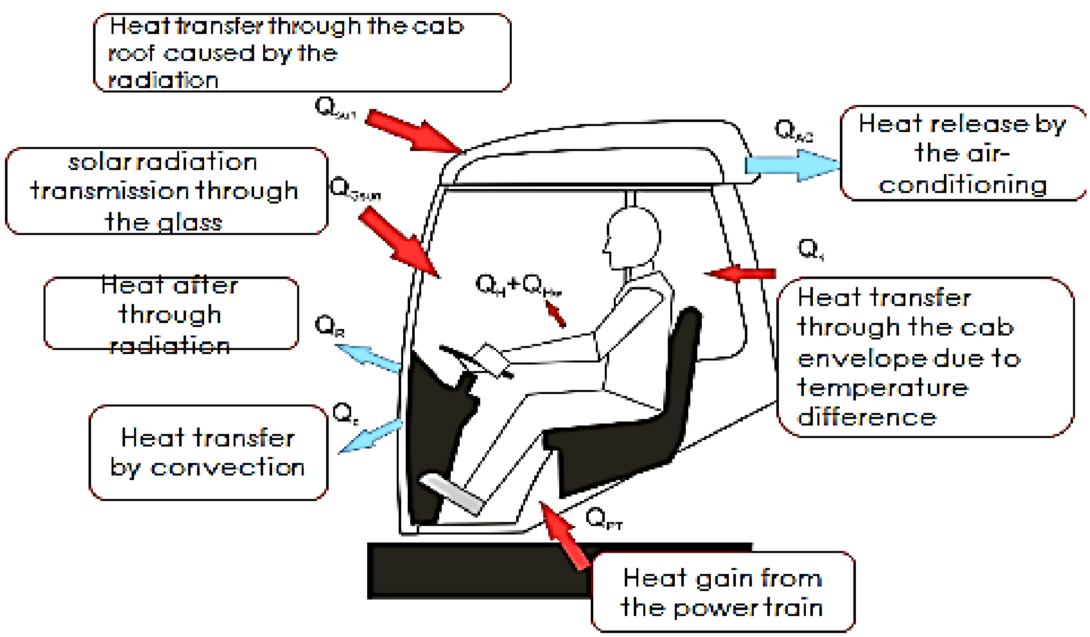

Fig 2. Thermal processes between a tractor cabin and hot environment

4. FABRICATION OF THE PROTOTYPE

As per the guidelines of the cabin geometry discussed above, the cabin for this project was fabricated with suggested dimensions having approximate volume of 2.5 m^3. The evaporative cooling unit was installed on the roof of the cabin. Table gives details of the fabrication. Evaporative unit consist of hollow box-type structure which has cooling pads being fitted at all four vertical faces. The top face is covered permanently by a metal sheet and bottom face is kept open. The system is mounted on the roof of the vehicle cabin such that the hollow bottom face coincides with the roof level of cabin. A circular hole is being provided on the roof of the cabin for blowing air in the cabin from the unit. The bottom face includes a fan unit for this purpose. The fan unit axially blows air on top of the driver head and around the periphery of the body in accordance with the design considerations discussed above. When the fan turns on, the ambient air passes through the wetted pads which gets evaporative cooled and is blown into the cabin space by the axial fan. The system has a small pump unit which discharges water to the cooling pads through a delivery pipe which is further connected to the pipe distribution circuit.

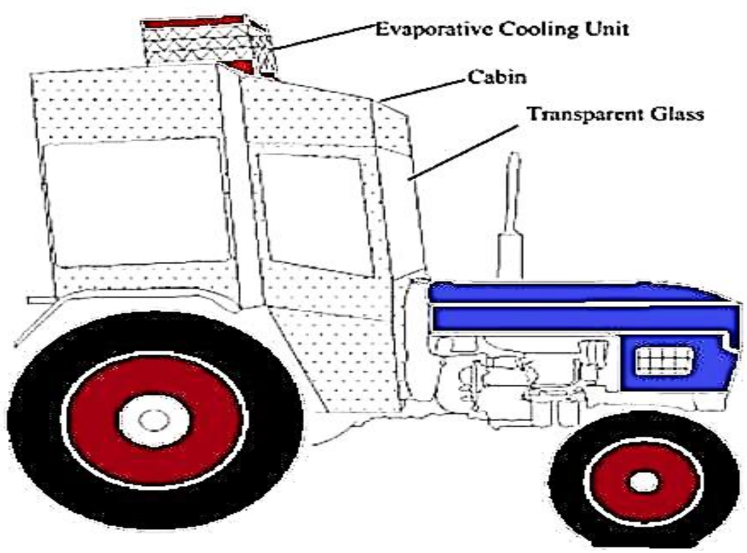

Fig 3. Mounting of Evaporative cooler in Tractor cabin

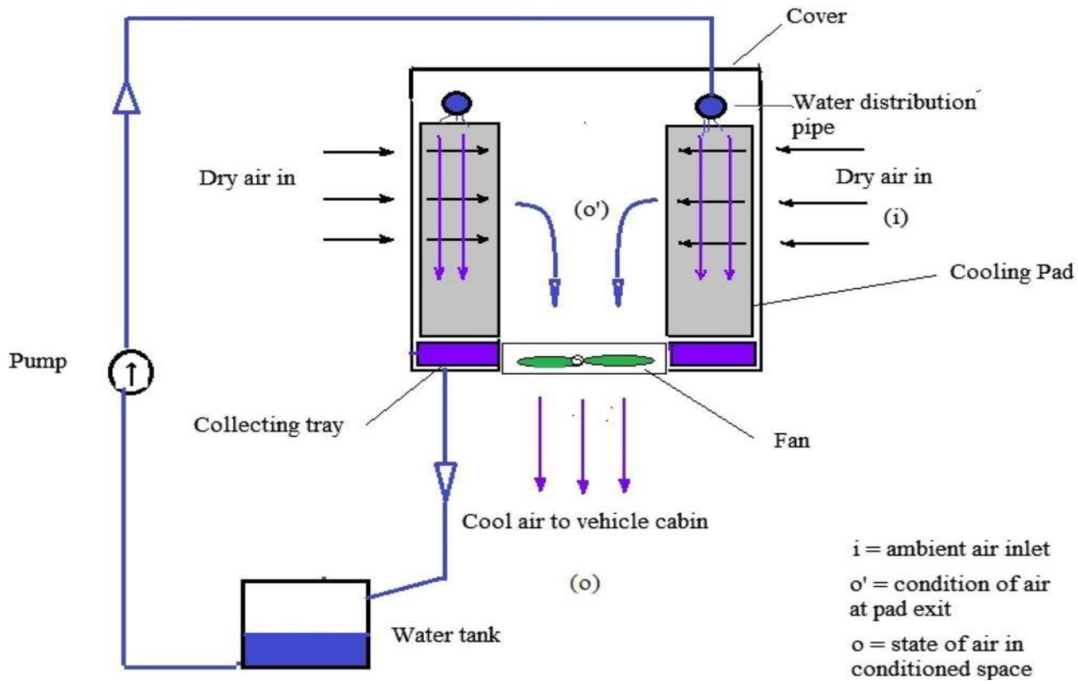

Fig 4. Working of Evaporative Cooling Unit in tractor cabin

This circuit comprises four horizontal pipes connected in series with end plug at end. They are arranged such that each pipe is fixed on top of each cooling pad. These pipes have multiple small holes oriented vertically so that water coming from the pump falls on top of each cooling pads through holes. The water trickles vertically down from the cooling pads and gets accumulated in a U-shaped channel and thereby goes to the sump through the drain pipe by gravity. The pump recirculates the sump tank water for regular wetting of the cooling pads, and the level in the sump is maintained by filling additional water periodically. The evaporative cooled air gets blown into the cabin space, where it pro- vides comfort to the occupants. The overall system consumes very small amount of energy in comparison to conventional vapour-compression systems and hence can be operated using the vehicle battery power.

Table1.Design of original tractor cabin

Unit	Dimensions
Evaporative unit	0.39 9 0.45 9 0.37 m^3
Total pad area	0.2184 m^2
Cabin volume	2.5 m^3
Cabin metal sheet area	5.18 m^2
Cabin glass area	2.47 m^2
Fan diameter, area (A)	0.3 m, 0.0706 m^2
Evaporative unit weight	13 kg
Water tank capacity	15 L

Table 2. Dimensions of fabricated tractor cabin

UNIT	DIMENSIONS	REMARK
Evaporative unit	$0.0123m^3$	
Total pad area	$0.042m^2$	Aspen wood 2^{00} pad
Cabin volume	$0.094m^3$	Approximate (the bottom surface is uneven)
Cabin metal sheet area	$0.31m^2$	
Cabin glass area	$0.75m^2$	
Fan diameter	0.115m	Circular hole is provided on the roof for blowing fan air in the cabin
Evaporative unit weight	7 Kg	
Water tank capacity	$0.0038m^3$	

5. DESIGN CALCULATIONS

5.1 Evaporative cooling

Before evaporative cooling (1)

Dry bulb temperature-34.6oC Wet bulb temperature-28.7oC

After evaporative cooling (2)

Dry bulb temperature-29oC

Wet bulb temperature-28.8oC

From the psychometric chart:

Before evaporative cooling (1)

Enthalphy-85KJ/Kg of dry air

Specific humidity-0.019kg/kg of dry air

After evaporative cooling (2)

Enthalphy-85KJ/kg of dry air

Specific humidity-0.022 kg/kg of dry air

5.1.2 Calculations

Heat added Q= m (h2-h1) =0 since{h1=h2}

Mass of water vapour added = m {Specific humidity(2)-Specific humidity(1)} Assuming mass (m) =1kg/sec.

Mass of water vapour added=0.003kg/s

Our project power requirements of Fan and pump

Fan Power=24V*1.5A=36W 46

Pump Power=18 W

Total Power =54 W

Now this approximate input output condition is assumed for vapour compression system and let us compare the result.

5.2 Vapour compression system

Before Vapour compression cooling(1)

Dry bulb temperature-34.6oC

Wet bulb temperature-28.7oC

After Vapour compression cooling(2)

Dry bulb temperature-29oC Wet bulb temperature-25oC

From the psychometric chart:

Before Vapour compression cooling (1)

Enthalphy-85KJ/kg of dry air

Specific humidity-0.019kg/kg of dry air

After Vapour compression cooling (2)

Enthalphy-76KJ/kg of dry air Specific humidity-0.018kg/kg of dry air

5.2.1 Calculations

Assuming mass (m) = 1kg/sec.

Heat added Q=m (h2-h1) = 9 KJ/kg of dry air

Q = 9KW = 9000W

Mass of water vapour added = m {Specific humidity (2)-Specific humidity (1)}

=0.001kg/kg of dry air

6. RESULT

Solar radiation on the operator could be approximately 1/4 of glazed area, e.g., around 1.5 m2, which gives solar heat load of order of 1100 W. Rest of area faced to the environment (app. 7 m2) would transfer up to 700 W of heat. Estimated heat gain from the power train would be 200 W. In total, without the heat released from the operator, estimated heat load of the cab is around 2 KW.

The temperature of hot air can be dropped significantly through the phase transition of liquid water to water vapour (evaporation). This can cool air using much less energy than refrigeration. In extremely dry climates, evaporative cooling of air has the added benefit of conditioning the air with more moisture for the comfort of tractor driver.

7. CONLUSION

The Results obtained are optimistic for the Safe design. Power consumed by evaporative air cooler Q=54W. Power consumed by vapour compression system Q=9KW. Thus power consumed is significantly reduced in evaporative cooling compared vapour compression system with very few disadvantages.

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