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Design and Development of a Heating System to Control Windshield Fog

Yogesh S. Patil, Nikesh Gaukar, Abhishek Chavan, Mahadev Patil, Preetam Rangari, Dhanraj Akki

Abstract

Road visibility in passenger vehicle is of major concern for the car manufacturers and safety design engineers. Water film (Fog) that forms on the windshield during winter times would reduce and disturb the driver’s visibility. Extreme weather condition can make a difference while driving. One may experience the wide range of challenges during driving. The factors which mostly affected the visibility can be rain, fog, ice, snow, dust, etc. Due to such factors, it becomes very tough for driver to have a clear view of front side. Rear view is possible with the help of left and right view mirror fitted outside the front doors. Visibility of rear view mirror depends upon the visibility of the front side window glasses. Driving through rain, produces more challenging situation when water droplets on outsides surface of front window glass obstruct the vision. This problem becomes more dangerous when light gets scattered through water droplets and obstruct the vision during rainy night.

The main objective of this work is to find the possible solution for removing the fog from a specific area of front and rear windshield to have a clear view to avoid the accidents. In the present work, hot water and silicon fluid utilized to impinge on the front and rear glasses with the help of converging nozzle and fluid inside the two windshields. The various combination of outlet water and silicon temperature is used for obtaining maximum clearing area. Computer simulated results are verified with the experimental results.

1. Introduction

Road transport remains the most favored mode of transport for both freight and passenger movement in India. The fast growing population, exceptional rate of motorization coupled with the ever growing urbanization has made people vulnerable to frequent road accidents resulting in fatalities, injuries/disabilities. Road accidents in India kill almost 1.5 lakh people annually. Accordingly, India accounts for almost 11% of the accident related deaths in the World.[9] Accidents are termed as unwanted occurrences which lead to injuries, loss of production, fatalities, or damage to property and possessions. Road accidents are undoubtedly the most prevalent and, in general, the reason behind most of the damage. Road accidents have been and will continue to be one of the greatest health hazards [2] [3]. As per Government of India report nearly 12000 people died in road accidents in 2018 because of foggy and misty weather condition. It is nearly 8% of total people killed in road accidents [9]. Weather conditions like snow, mist, rain, fog, hail, etc. makes it difficult for drivers to run their vehicles cautiously, severely rise travel times, and significantly lessen roadway capacity. Society, especially the transportation sector, has been adversely affected, both in terms of cost and setbacks, due to fog [2]. Fog is itself self- explanatory, but generally recorded when its occurrence hinders visibility noticeably. Fog formation is linked to the natural processes as radiative, microphysical, thermo-dynamic and aerosol processes [4]. Occurrence of fog is witnessed when air chills down below its dew point. The difference between temperature and dew point is mostly less than 2.5°C or 4.5°F. Across India, fog is categorized into two types as: a) Radiation Fog b) Advection Fog.

Radiation fog (sometimes called Ground fog) is formed after sunset (evening time) when there is change of seasons from summer to fall and winter [10] [4]. Advection Fog is wind directed fog formation. It is formed by the passage of warm humid air over a cool surface with the aid of wind. The term “advection” scientifically denotes “the movement of fluid”. Fog is measured with respect to visibility distance. In Meteorology, Visibility is explained as a measure of the distance at which an object or light can be surely anticipated [5]. The visibility scale which depicts the link between fog and visibility is shown in Fig. 1. [1]

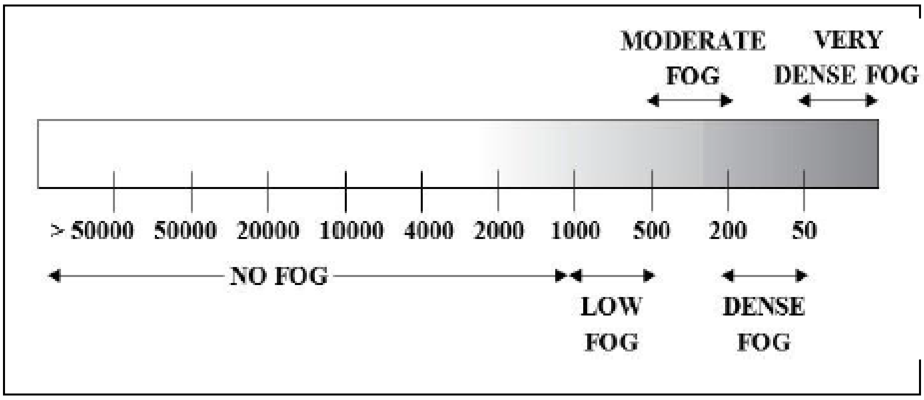


Fig.1.Visibility scale (in meter)

Fog data is represented in form of visibility codes as in Table 1. [1]

Table I. Visibility Codes

Sr. No.	**Visibility in meter**	
	Visibility code	Visibility
1.	90	0-50
2.	91	50-200
3.	92	200-500
4.	93	500-1000

5.	94	1000-2000
6.	95	2000-4000
7.	96	4000-10000
8.	97	10000-20000
9.	98	20000-50000
10.	99	>50000

Research conventions are progressing not only on fog detection, but also on visibility enhancement to minimize the count of road crashes. In rainy and winter season, while travelling by vehicle there is rise in relative temperature between inside and outside of vehicle. Owing to differences in air temperature, windshield glass often fogs up. It can be a real menace for drivers as it decreases visibility. Fogged windshields obstruct the driver's line-of-sight and cause difficulty in driving. Defrosting mechanism in the form of an air stream directed against the side view mirror of a vehicle as well as an air stream directed against the side window of the vehicle adjacent to the side view mirror [7][8][13].

Fogging on the windshield occurs when the glass temperature falls below the dew point of air. Two major reasons for windshield fogging are dirt and moist air. The difference in the temperature between the inside and the outside of the car can cause moisture to build upon the windshield. The condensation happening due to the difference in air temperatures causes the formation of small droplets that settle on the surface of the windshield. Moreover, if the humidity levels in the air are high, fogging will occur indefinitely [6] [11]. Even the breaths of passengers sitting inside the car will be enough to cause windshield fogging. When the windshield is dirty, the fog will settle more readily on the surface. If windshield is steamed up with fog, driving will be extremely dangerous. The following are some of the common fogging scenarios found in a vehicle: [6]

- Fogging that occurs below the start of engine due to trapped moisture in the passenger compartment and external temperature drop.
- Flash fogging at the start of the engine due to pre-existing evaporator condensate from AC operation.
- Fogging that occurs after engine start due to excess moisture introduction by the passengers who have just showered, got rained on, stepped through snow, etc.
- Sudden windshield temperature drop using driving, such as caused by a heavy rainfall during warm day.

- Fogging due to steady vapour stream generation by passengers of the vehicles during driving in cold ambient conditions.
- Highly humid tropical conditions with air saturated at 100% humidity.

With the increased use of air recirculation, fogging is becoming more of a concern. Air recirculation prevents the discharging of moisture out of the passenger compartment and accentuates fogging through the accumulation of moisture from various sources such as perspiration, respiration, wet clothing, melting of deposited snow on floor mats, etc.[6].

2. Design of Heat Exchanger

Automatic temperature controller (ATC) is used to measure two variables cabin air temperature and ambient (outside) temperature. ATC signal is used to control climate inside cabin [12] [14]. Effective control of climate is possible with proper heat exchanger. The heat exchanger used for the experimental setup is required for increase the temperature of the water which is afterward sprayed on front windshield for increase its temperature. There are two heat exchanger used for the particular water heating purpose which are connected to tank. Material used for the heat exchanger is copper tube. For rear windshield required to be heat the silicone fluid which increase the rear windshield temperature.

2.1 Overall Heat Transfer Coefficient U

Consider energy balance in a differential segment of a single-pass heat exchanger shown schematically in fig.2. The rate of heat transfer in this segment is

$(dq) = UA\Delta T$… (1)

Where U is the overall heat transfer coefficient, ΔT is the local temperature difference between the hot and cold fluids, and d_A is the contact area in the differential segment. The overall heat transfer coefficient is inversely proportional to the total resistance R to the heat flow. The latter is the sum of

(1) Resistance $R_{conv,\,h}$ to convective heat transfer from the hot fluid to the partition between the fluids

(2) Resistance R_p to thermal conduction through the partition, and

(3) Resistance $R_{conv,c}$ to convective heat transfer from the partition to the cold fluid. Therefore

$$U = \frac{1}{R_{tot}} = \frac{1}{R_{conv,h} + R_p + R_{conv,c}}.$$

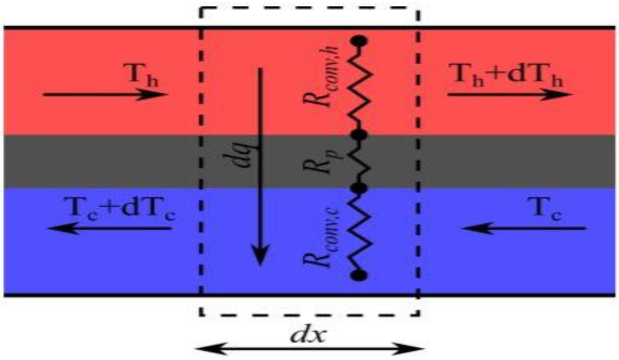


Fig.2: Energy balance in a differential element of a single pass heat exchanger

2.2 Relationships between Overall Heat Transfer Coefficient and the Inlet and Outlet Fluid Temperatures.

Heat exchangers are usually analyzed using either the Logarithmic Mean Temperature Difference (LMTD) or the Effectiveness – Number of Transfer Units (ε-NTU) methods. The LMTD method is convenient for determining the overall heat transfer coefficient based on the measured inlet and outlet fluid temperatures. The ε-NTU method is more convenient for prediction of the outlet fluid temperatures if the heat transfer coefficient and the inlet temperatures are known. LMTD method is suitable for current analysis since inlet and outlet water temperature is measured directly using device system. The analysis presented is based on following assumptions

1. There is no energy loss to the environment
2. Heat exchanger is at a steady-state
3. There are no phase changes in the fluids
4. Heat capacities of the fluids are independent of temperature
5. Overall heat transfer constant is freelance of the fluid temperature and position within the heat exchanger. Since all heat exchangers considered in this experiment have a single pass for both the hot and cold fluids, the discussion below is limited to single-pass heat exchangers.

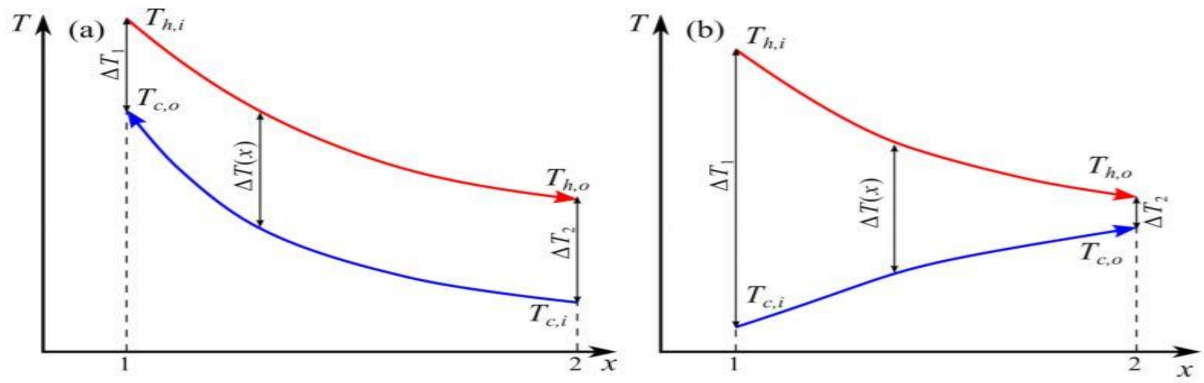


Fig. 3: Temperature profiles in (a) counter-flow and (b) parallel flow single pass heat exchangers

2.3 Logarithmic Mean Temperature Difference (LMTD) Method:-

The total heat transfer rate is

$$q = \int_1^2 \mathrm{dq}$$

Where dq is given by Eq. (1) and points 1 and 2 are defined in Fig.3.4. This integral cannot be computed by a direct integration of Eq. (1), since ΔT typically varies with position in the heat exchanger, as shown in Fig.3.

However, it is possible to obtain q by combining Eq. (1) with energy balances in differential segments of the heat exchanger,

$dq = -C_h dT_h = C_c dT_c$

Here, dT_k is the temperature change of fluid k (k = c or h) in the interval under consideration, and C_k is the heat capacity rate of fluid k

$C_k = \dot{m}_k c_k$, $k = c$ or h

Where $\dot{m}\,k$ and c_k are the mass flow rate and heat capacity of fluid k, respectively. This analysis yields

$q = UA\, \Delta T_{lm}$

Where A is the total contact area and ΔT_{lm} is the logarithmic mean temperature difference (LMTD)

$\Delta T = \frac{lm\Delta T1 - \Delta T2}{\ln(\Delta T1/\Delta T2)}$

Here, ΔT_k refers to temperature difference between the hot and cold fluids at point k (k = 1 or 2), i.e.

For the counter-current flow and

$\Delta T_1 = T_{h,} - T_{c,}$ and $\Delta T_2 = T_{h,} - T_{c,}$

For the parallel flow.

$\Delta T_1 = T_{h,} - T_{c,}$ and $\Delta T_2 = T_{h,} - T_{c,}$

2.4 Calculation of heat-exchanger:-

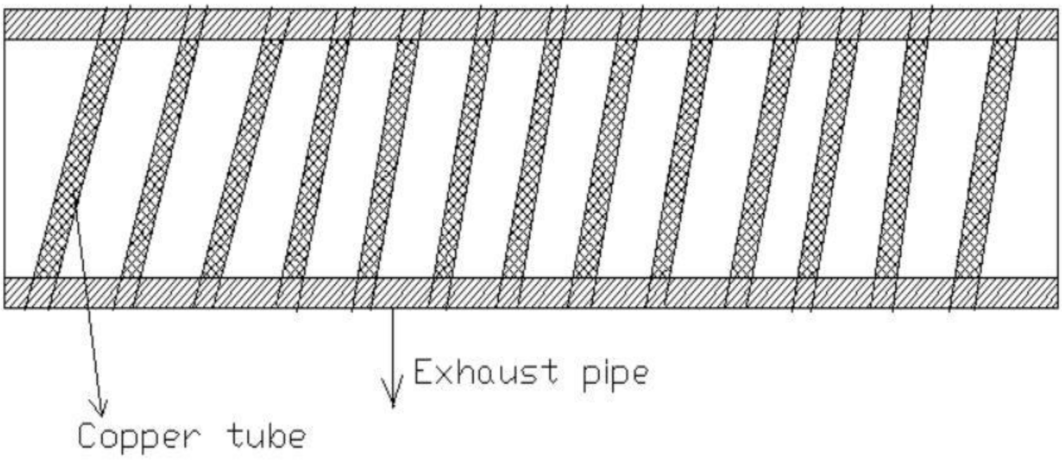


Fig.4 : Heat-exchanger

Exhaust parameter:-

1) Internal diameter: 0.034 m
2) Outer diameter: 0.04 m
3) Circumference inside: =0.1068 m^2
4) Circumference outside: =0.1256 m^2

- **Overall heat transfer coefficient [U] :**

$$U= \frac{1}{\frac{1}{h1\times A1}+\frac{\ln\left(\frac{D0}{Di}\right)}{2\prod LK}+x=\frac{\ln\left(\frac{D0}{Di}\right)}{2\prod LK}+\frac{1}{h2A2}}$$

U = 82.23 W/m²k

Mass flow rate of exhaust gas=$M_{Exhaust}$=0.0345 m^3/s (For 1200cc Engine)

Specific heat coefficient of cold water = C_{max}=0.06×4197=251.88 units

Specific heat coefficient of exhaust gas =C_{min}=0.035×1000=35 units

$$\frac{C_{min}}{C_{max}} = \frac{35}{251.88} = 0.1389$$

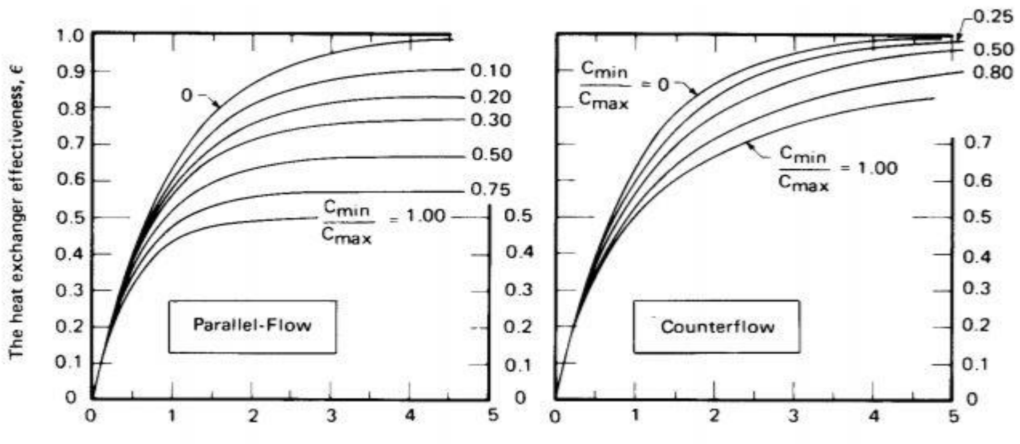


Fig.5 : Number of transfer unit (NTU) graph

From Graph NTU=4.67; Heat exchanger efficiency E=0.99

- **Rate of heat transfer (Q_{hot})**

$$Q_{hot} = E \times C_{min}[(T_h)_{in} - (T_h)_{out}] = 12.924\ KW$$

- **Exhaust gas temperature after heat exchanger (Th_{out}):**

$$\boldsymbol{T_{hout}} = T_{hin} - \left(\frac{Q}{C_{min}}\right) = 50.25^0C$$

- **Outlet temperature of water after heat exchanger (Th_{in}):**

$$\boldsymbol{T_{hin}} = T_{cin} + \left(\frac{Q}{C_c}\right) = 78.31^0C$$

Table 2:- Heat exchanger important parameters.

Sr. No.	Parameter	Value
1	Overall heat transfer coefficient (U)	82.23w/m^2 k
2	Mass flow rate of exhaust ($M_{exhuast}$)	0.0345 m^3/s
3	Specific heat of cold water (Cc)	251.88 w/K
4	Specific heat of exhaust gas (Ch)	35 w/K
5	Heat exchanger effectiveness (E)	0.99
6	Rate of heat transfer (Q_{hot})	12.924KW
7	Exhaust Outlet temperature	50.25^{0}C
8	Water outlet temperature	78.31^{0}C

3. Development of test setup

As the design of the proposed system is done the very next step is development of experimental setup, Development is nothing but bringing the paper work into reality. The fabrication started by defining the dimensions of each section from sketch to develop setup, the factor which are applicable during the finalizing dimension are:

1) Distance between two nozzles of car.
2) Angle of inclination of windshield.
3) Tank capacity(Volume) for silicon fluid as well as water
4) Pump size, SMPS size, Simmer-stat size etc.

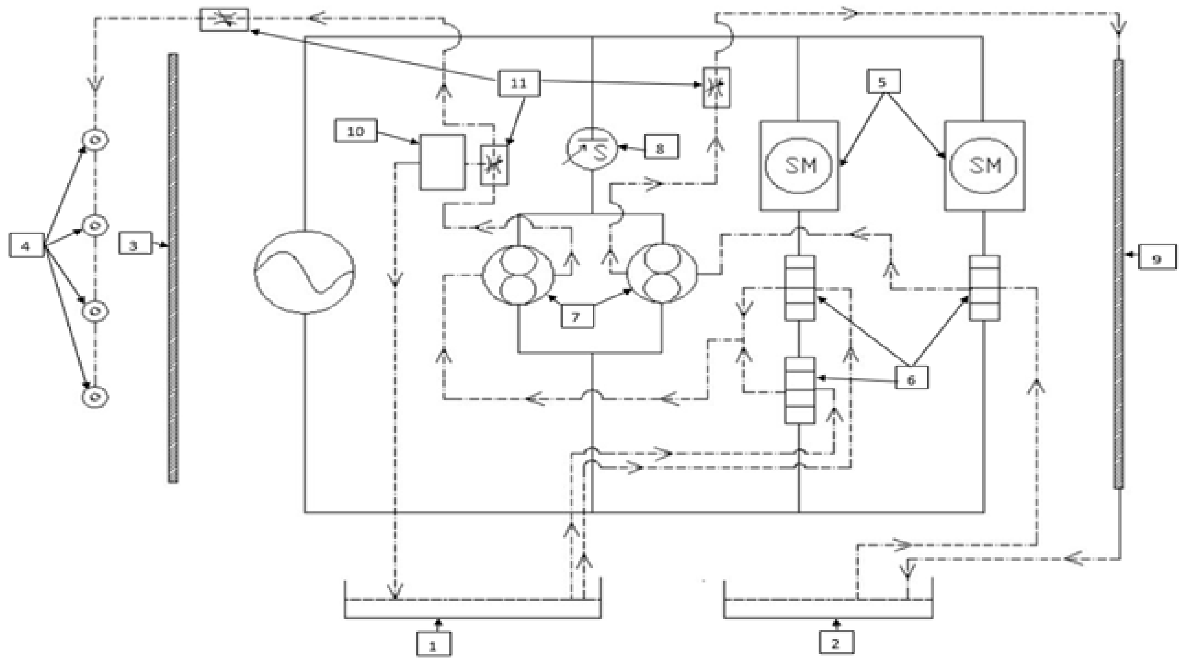
Table 3. List of Components for experimental setup

Sr.No.	Name of component	Specifications
1.	Water Pump	a) Pressure 6.5 bar. b) Voltage 12v. c) Discharge 4lit/min
2.	Front Glass Windshield	a) Material: toughened glass b) Thickness: 6mm c) Length: 6096mm d) Height: 3048mm
3.	Rear Glass Windshield	a) Material: toughened glass double layer. b) Thickness: 6mm c) Length: 6096mm d) Height: 3048mm
4.	Submersible pump for rain arrangement	a) Voltage: 165-230 V/50Hz b) Power: 20W c) Lifting height: 1.85 Meter
5.	Cartridge Heater	a) Voltage: 230 V b) Power: 500W
6.	Heat Exchanger	a) Material: copper b) Inner diameter: 8mm c) Outer diameter: 9.5mm d) No. Of turns: 11 e) No. of units: 3

7.	D.C. high speed fan for Air circulation	a) Voltage: 12 V b) Power: 2.4W c) RPM: 600
8.	Enclosure material	a) Pipe material: Cast iron b) Thickness of pipe: 2 mm c) Sheet Material: PVC Foam sheet d) Thickness of sheet: 6mm for outer covering and 3 mm for insulation of tank
9.	Silicone fluid Tank	a) Material: mild steel b) Diameter: 125mm (inner) and 135 mm (Outer) c) Length: 304mm
10.	Insulation	a) Material: Polyolefin (POF) Insulation (Tank) b) Asbestos (Heat exchanger)
11.	Simmer-stat	a) Input frequency: 40 – 60 Hz. b) Adjusting range: 7% to 93% c) Reactive load: 500VA d) Pilot switching: 125VA
12.	Tubes	a) Materials: composite plastic. b) Length: around 1500mm c) Temperature sustainability: 120-150 ^{0}C
13.	Nozzle	a) Diameter: 0.85mm b) No. of nozzle: 4 c) Temperature range: 120-150 ^{0}C
14.	Power supply Step down circuit (SMPS)	a) Input: 85-265 AC/50HZ/230V b) Output: 12 V
15.	Silicon Rubber Gel for glass adhesive.	a) Hardness: 70-80Shore A b) Heat Resistant: -75Degree C to + 480Degree C c) Water resistance
16.	Silicon Fluid	Thermal conductivity:-0.16 W/m-k Flash point: - 200^o C Pour point: - -55^o C Kinetic viscosity: - 15 m^2/sec Appearance: - Clear transparent

3.4 Setup circuit diagram: -

The set up circuit diagram is as shown in fig.6. Numbers represent different components.



1. Water tank 2. Silicon fluid tank 3. Front windshield. 4. Nozzle. 5. Simmer-stat.
6. Heater and heat exchanger. 7. DC gear pump. 8. Switch mode power supply (SMPS)
9. Rear windshield 10. Fog generator. 11. Flow control valve.

Fig.6. Circuit diagram for front and rear windshield

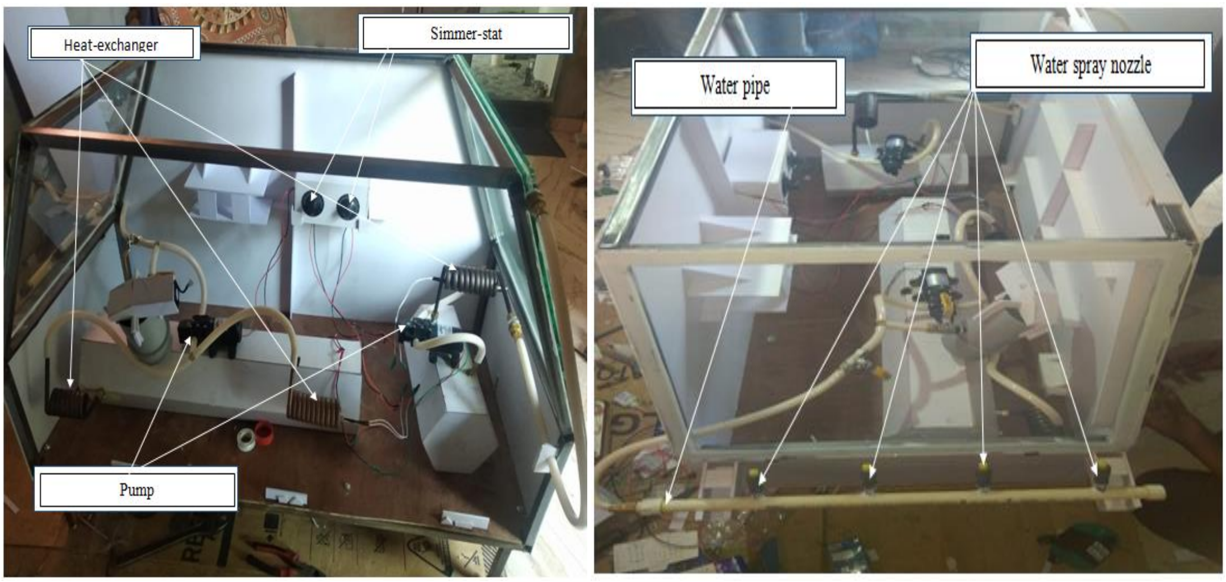


Fig.7 Actual Test set up during assembly

3.5 Analysis of front wind shield

A temperature of system varies from 50°C to 80°C. So it is necessary to carryout CFD analysis of windshield for this range. Temperature distribution plot for windshield is as shown in fig.8. The results are also shown in table 4

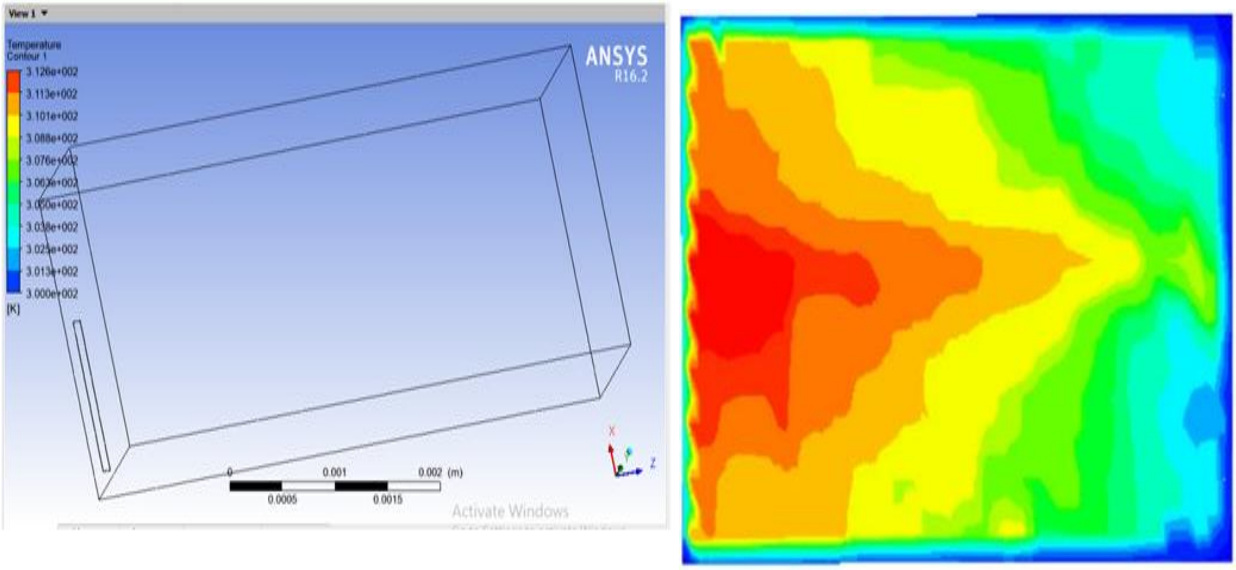


Fig.8 Temperature distribution of windshield

Table 4 CFD analysis result of temperature

Sr. no.	Input Temperature (^{0}C)	Minimum Value (^{0}C)	Maximum value (^{0}C)
1	50	18	30
2	55	22	34
3	60	23	39
4	65	27	43
5	70	32	48
6	75	37	51
7	80	40	56
8	85	44	61

4. Experimental results and discussion

In vehicles incorporating an automatic HVAC control system, it has been proposed to sense internal and external conditions to determine whether fogging is likely. Such known systems include a glass temperature sensor and a humidity sensor. The glass temperature sensor is affixed to an internal surface of the windshield glass, and the humidity sensor is disposed adjacent to the windshield glass. The system uses the sensed glass temperature and the sensed cabin humidity to determine whether a possible fogging condition exists, and actuates the HVAC system in response thereto. Unfortunately, such automated systems require additional sensors, which are expensive to purchase and require significant amounts of labor to install and electrically connect to the HVAC controller [14]. Current system is manually operated and is dependent upon driver's visibility (Ref. Table 1).

Experimental set-up (fig.7.) is used to analyze following parameters

4.1 Effect of type of Nozzle on fog removal

4.2 Comparison between test setup and actual system regarding time required for fog removal (Time study).

4.3 Temperature distribution on windshields of test setup.

Every parameter is discussed in detail below

4.1 Effect of type of Nozzle on fog removal

Three types of nozzles are used in car namely solid stream nozzle, double flat fan nozzle and flat jet nozzle. In experimental set up it is possible to replace nozzles easily so for every nozzle experimentation is carried out. For every nozzle time required to remove fog is recorded. It is shown in fig.9. It indicates time required for the solid stream nozzle to remove fog is 58 seconds. It is most effective nozzle because it provides continuous supply of single beam of water on windshield and it helps to increase the temperature of windshield more quickly. Same nozzle is used for further experimentation.

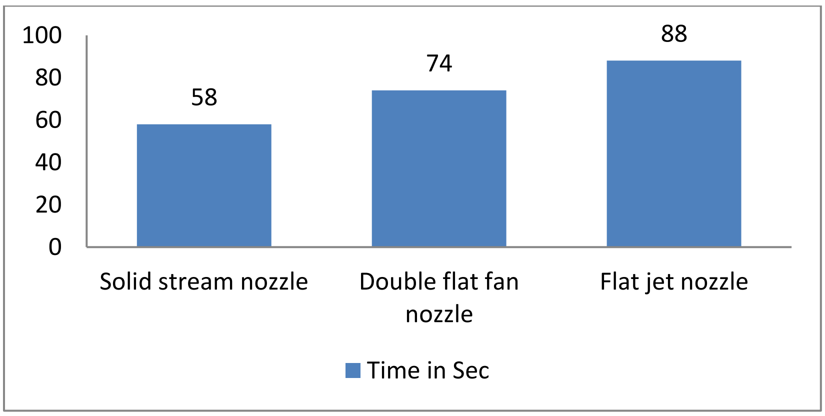


Fig.9. Comparison between Nozzles.

4.2 Time study

In time study time required to remove fog by conventional AC duct method is noted and it is compared with experimental method. Both readings have been noted under same environmental conditions. The result of the experimentation is shown in fig.10. It indicates

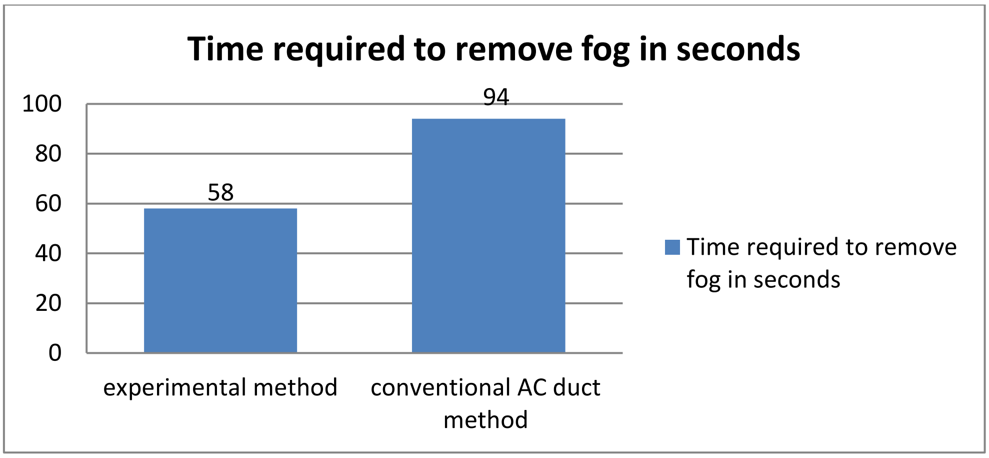


Fig.10. Comparison between two methods.

4.3 Windshield Temperature distribution

In experimental method hot water is spread on front windshield and silicone fluid is spread on rear windshield. It is necessary to note temperature of windshields after certain interval of time to check efficiency of a system. In experimentation hot fluid temperature is noted with temperature gun. Temperature of windshield is measured after certain interval of time and it is recorded. Time intervals chosen are 20 sec, 40 sec, 60 sec, 80 sec and 100 sec. All readings are shown in table. Readings were taken under following environmental conditions;

a) Windshield temperature: - 29 ^{0}C
b) Rain water temperature:- 20 ^{0}C
c) Air velocity:- 5m/s

Table 5:- Windshield temperature readings

Sr. no.	Temperature of fluid (^{0}C)		Time (Sec)	Windshield temperature (^{0}C)	
	Water	Silicone fluid		Front	Rear
1	60	57	20	30	32.3
			40	32.7	35.4
			60	35	39.6
			80	40.6	42
			100	43.9	44.7
2	65	63	20	34	36
			40	37.3	39.3
			60	39.8	42.9
			80	43	45.9
			100	47.4	48.8
3	73	70	20	36	36
			40	38.4	40.2
			60	42.3	45.7
			80	47	49.4
			100	52.2	54
4	79	74	20	35.8	36.3
			40	39	40.7
			60	44.4	45.3
			80	49.7	48.9
			100	55	56.3
5	84	78	20	35	36
			40	38.6	40.3
			60	43.7	44.6
			80	49.2	51.2
			100	57.4	58.5

Table 5 indicates there is sufficient amount of temperature rise with rise in inlet fluid temperature. This will help to remove fog more uniformly from windshields. Also temperature distribution on windshield is uniform it avoids possibility of windshield crack because of temperature difference.

5. CONCLUSION

Main purpose of work is to condense the moisture inside the vehicle. Proposed system uses heat form exhaust. This improves efficiency as well as it is more reliable. Windshield temperature increases with time. It helps to reduce moisture and fog. With proper nozzles proposed system is more effective than a conventional air conditioning duct system. Response time of system is 58 sec. with single beam nozzle and counter flow heat exchanger; this is the fastest response as compared with any other system available in market. CFD analysis also indicates there is even heat distribution on windshield. Above all factors shows proposed system is very efficient and useful for fog removal. In modern vehicles sensor based defogging systems are used. These systems are costly and require specialized manpower for installation and maintenance. In India vehicle cost plays an important role and common men avoid such costly assistance systems. The proposed fog control system is effective and less costly. As components involved in system are commonly used so no specialized manpower is required for its installation and maintenance.

6. FUTURE SCOPE

In present experimental setup silicon fluid circulation on rear windshield is used. Same can be used for the front windshield for removing the fog in less time. For this system a cavity of 1mm is required at front windshield. The silicon fluid will be poured inside cavity and whenever required it will be heated with copper material. As time required to heat silicone is less and it is transparent so it will give good results from visibility point of view.

CRediT authorship contribution statement

Yogesh S. Patil: Investigation, Experimentation, Data collection, Formal analysis, Visualization, Writing - original draft, Writing - review & editing. **Rajaram M. Shinde:** Conceptualization, Methodology, Software, Validation, Formal analysis, Writing - original draft, Writing - review & editing. **Aniket T. Suryawanshi:** Heat transfer analysis, Experimentation, Data collection, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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