IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
ISSN: 2278-1684, PP: 07-14
www.iosrjournals.org

An Overview of Radiator Performance Evaluation and Testing

Prof. A. R. Khot [1], Prof. D.G. Thombare [2] Prof. S. P. Gaikwad [3]
Prof. A. S. Adadande[4]
[1,3,4]*(Mechanical, JJMCOE JSP, India)*
[2]*(Automobile, RIT Sakhrale, India)*

Abstract - *In this paper various methods for radiator performance evaluation and testing of the radiator are considered because all internal combustion engines produce heat as a byproduct of combustion and friction. This heat can reach temperatures up to 1925°C (3500°F) and can have catastrophic affects on engine components. Pistons, valves and cylinder heads must be cooled to reduce the risk of detonation. Cylinder temperatures need to be controlled so lubricating oil can maintain a protective film on the cylinder surfaces and the lubricating oil should be cooled to ensure its integrity. In addition to overheating, overcooling can have negative effects on the engine. Overcooling can reduce engine performance and shorten the engine's service life. Cooling systems are used to manage engine heat. Cooling systems must be properly designed, operated and maintained for proper engine operation and service life [5].*

***Keywords**:-* *(LMTD) Log Mean Temperature Difference (ε-NTU) Effectiveness - NTU method*

I. EXISTING EVALUATION METHODS FOR ENGINE COOLING SYSTEMS

Existing methods employed in the automotive industry worldwide are classified into three approaches; analytical and experimental, computational methods. Out of these two methods are discussed in this paper [01]

1.1 Analytical Methods

According to theory of heat exchanger, radiator performance can generally be determined using either one of the following approaches;

The Log Mean Temperature Difference method (LMTD)
The Effectiveness - NTU method (ε-NTU)

1.1.1 Log Mean Temperature Difference

In this method specific radiator operating condition, including coolant flow rate, inlet temperatures and intended outlet temperatures of both fluids are considered, the LMTD method can be conveniently used to calculate the correct size (the heat transfer area) of the radiator core in order to achieve the required outlet temperatures. The heat transfer equation for cross-flow heat exchangers using the LMTD method is given by,

$$Q = UAF\,\Delta T_{log\text{-}mean}$$

Where Q = overall heat transfer rate of the radiator
U = overall heat transfer coefficient of the radiator
A = surface area for heat transfer
F = the correction factor
ΔTlog-mean = log mean temperature difference (LMTD) of the two fluids for a
Counter-flow heat exchanger

$$\Delta Tlog - mean = \frac{(Th,i - Tc,o) - (Th,o - Tc,i)}{In[(Th,i - Tc,o)/(Th,o - Tc,i)]}$$

Here T = temperature; subscripts h = hot fluid (coolant) c = cold fluid (air)

1.1.2 Effectiveness – NTU

In comparison with the LMTD method, this method is more effective when the radiator geometry, the coolant flow rate and the inlet temperatures of both fluids are known for a particular radiator. The outlet temperatures in association with the heat transfer rate of the radiator are subsequently calculated. This approach involves several dimensionless parameters to be calculated it consisting of Number of Heat Transfer Units

(NTU), Effectiveness (ε) and Capacity Ratio (Cmin/Cmax). In this method each parameter affects the performance of the heat exchanger and has its own physical significance.

A general relationship between the parameters is expressed by the following formula,

$$\varepsilon = f(NTU, \frac{C_{min}}{C_{max}}, flow\ arrangement)$$

Once the radiator effectiveness (ε) is determined, the heat dissipation rate (Q) from the radiator can be obtained by applying the following equation;

$$Q = \varepsilon C_{min}\,(T_{hi} - T_{ci})$$

1.2 Experimental Methods

Experimental evaluation method is carried out by on-road and wind-tunnel testing. On road testing offers a direct assessment of the true behavior of engine cooling performance as well as providing airflow over the vehicle under “real” conditions. However, weather conditions, particularly the inability to control atmospheric winds (and associated turbulence) and ambient temperatures, prejudice repeatability and accuracy of on-road testing. On the other hand, wind tunnels provide an approximation of on-road flow conditions that are replicated in controlled environments (involving a stationary vehicle with respect to movement of air). The main advantage of wind-tunnel testing is that the tests can be conducted more conveniently, time-effectively and accurately. Two types of wind tunnels are currently employed in aerodynamic development for automotive vehicles; aerodynamic wind tunnels and climatic wind tunnels. These have been used by vehicle manufacturers worldwide for many years. Aerodynamic wind tunnels provide good external aerodynamics, and are used for assessing the forces and moments on the vehicle and, increasingly, wind noise. On the other hand, climatic wind tunnels are facilities that were designed to replicate thermal characteristics experienced on the road, providing the capability of controlling ambient air temperature and humidity as well as simulating engine loads on a chassis dynamometer. It is recognized that the flow quality in climatic wind tunnels is generally not as good as that in aerodynamic wind tunnels.

1.2.1 Measurement of Radiator Airflow

There are several constraints existing that make measurements of cooling airflow very difficult. These constraints are;

- The compactness of engine compartments;
- The complexity of air velocity, pressure and temperature fields in engine compartments;
- The airflow velocities through radiators are typically low (in the order of a few meters per second);
- The unknown flow directions (in some cases there are major separations and flow reversals);
- The cooling system location in an enclosed area making measurement access difficult.

1.2.2 Thermally-based Systems

The basic principle of HWA is that it determines an air velocity by identifying the heat lost from an exposed hot wire. In general, there are two ways of heating the wire; by supplying a constant current (the constant-current type) or maintaining a constant temperature (the constant temperature type). In either type, the heat lost to airflow is a function of the air velocity. By measuring the change in wire temperature under constant current, or the current required to maintain a constant wire temperature, the heat lost can be obtained. The heat lost can then be converted into a fluid velocity.

1.2.3 Propeller-Based Systems

This is the most common industrial practice for airflow measurement is to employ banks of propeller-based anemometers. The rotation speed of each propeller gives an indication of the average velocity over a circular area. The anemometers need prior calibration on a flow stand over a wide range of flow rates, and often require recalibration

1.2.4Optically-based Systems

In this method the airflow measurement are carried out optically with the help of Laser Doppler Anemometry (LDA) and Particle Image Velocimetry (PIV) technologies. They are considered as state-of-the-art, precise and non-intrusive techniques and do not need re-calibration. Without disturbing the flow, LDA provides fluid velocity data at a single point while PIV offers velocity data in a plane, with reasonably high frequency response and resolution. However, their complexity in experimental setups and high cost limit applications of the optically-based systems in industrial flow measurement. Further disadvantages for measurement in an engine compartment involve the need for transparent vehicle panels and the necessity for seeding tracer particles.

1.2.5 Pressure-based Systems

This method is based on relating pressure vectors measured in a flow field to a flow velocity at a certain point. In pressure based system based method *Pitot-static Tubes* is well-proven which is a classical and reliable method for measuring airflow velocity. There are two sets of pressure tapping in the head of the Pitot-static tube. The pressure tap for the total pressure in the flow (which is equal to the dynamic pressure plus the static pressure) is located at the foremost (stagnation) point. Another set of pressure taps for the static pressure in the flow consists of a series of orifices located about a distance of six to eight tube diameters back from the foremost point). By knowing the dynamic pressure (the difference between the total and the static pressures in the flow), the flow velocity at a point can easily be calculated.

1.2.6 Multi-hole Pressure Probes

Multi-tube pressure probes, with suitable calibration, have been conveniently used to determine the magnitudes and the orientations of mean velocity vectors within acceptance angles of about ±45°. Despite LDA, PIV and HWA offering measurement of mean velocities and sometimes flow directions, multi-hole pressure probes provide additional measurement of static pressure in three-dimensional flow fields. Thus these enable total pressure, dynamic pressure, flow directions (including pitch and yaw angles) to be determined at a small volume in the flow by relating the pressure field at the probe heads to three-component velocities and static pressures.

1.3 Performance Parameters

Because of the difficulty in using any of the known techniques for accurately measuring radiator airflow (and in fact no existing technique can provide fully satisfactory measurement of cooling airflow), the automotive manufacturers have sought alternative methods of inferring aerodynamic performance of cooling systems.

There are two parameters commonly found in the literature that are used as efficient ways for evaluating engine cooling performance and optimizing vehicle front-end configurations. These are Specific Dissipation (SD) and Air-to-Boil (ATB)

1.3.1Specific Dissipation

In contrast to ATB, SD offers a much more time-effective way to assess the cooling system performance where SD testing can be conducted under both stable and slowly changing vehicle operating conditions and is relatively insensitive to changes in ambient and coolant temperatures. SD is a radiator's effectiveness related parameter, and is defined as the heat dissipation rate of a radiator divided by the overall temperature difference across the radiator.

$$SD = \frac{Q}{Tci - Tai}$$

Where

Q = heat dissipation rate of the radiator (W)

Tci = coolant radiator inlet temperature (°C)

Tai = ambient temperature (°C)

1.3.2 Air-to-Boil

The parameter ATB has been commonly used by automotive manufacturers worldwide as an indication of the temperature margin from coolant boiling for a given operating condition (i.e. vehicle speeds, gears and engine loads). According to the Society of Automotive Engineers (SAE) standard J819, air-to-boil temperature is the ambient air temperature expected to cause the cooling system to boil when the vehicle is operated under specific conditions and modes of operation.
It has a simple definition that is expressed as;

$$ATB = Tbp - (Tci - Tai)$$

Where

Tbp = coolant boiling point (°C)
Tci = coolant radiator inlet temperature (top tank temperature) when the cooling system has stabilised (°C)
Tai = ambient temperature (°C)

II. TESTING OF THE RADIATOR

According to the IS code -13687 following parameters are considered for the testing of the radiator. [4].

Converted Heat Dissipation Rate

The heat dissipation rate of the cooling water (hereinafter referred to as "waterside"), which is converted to the state where inlet temperature difference between water and air is 60°C, and is expressed by the unit of kilocalorie per hour (kcal/h).

Heat Dissipation Rate on Waterside

The heat dissipation rate under test conditions, expressed as the quantity of heat which water loses under, and is expressed by the unit of kilocalories per hour (kcal/h).

Heat Reception Rate on Airside

The heat rate which the cooling air (hereinafter, referred to as "air" receives under test conditions and is expressed by the unit of kilocalories per hour (kcal/h).

Inlet Temperature Difference

The difference between the inlet temperatures of water and air expressed by the unit of degree Celsius (^{0}C).

Water Flow Rate

The flow rate of water which passes through the radiator expressed in liters per minute (l/mm). The flow rate of air passing through the radiator divided by the frontal area and is expressed in meter per second (m/s).

Pressure Loss of Waterside

The difference of static pressure between the water side inlet and outlet of the radiator which is measured at the test state and is expressed by the unit of mercury column height of millimeter (mm Hg).

Pressure Loss of Airside

The difference of static pressure between the airside inlet and outlet of the radiator, measured at the test state and is expressed by height of water column in millimeter (mm Aq).

Upstream End

Area before the radiator which permits entry of air into the radiator.

Downstream End

Area after the radiator which permits exit of air away from the radiator.

2.1 Test requirements

- The radiator must comply with IS 7611: 1993[6].
- The test room conditions shall be steady and at normal ambient temperature and humidity. The air flow shall be steady without large fluctuations.

- Unless otherwise specified the water used for test purposes shall be clear without suspended impurities and the radiator inlet water temperature maintained at 85 ±5ºC at the dissipation state. The temperature shall be recorded at steady state conditions and a variation of ±2ºC in the water inlet temperature is permissible between successive readings.
- The measuring equipment shall be calibrated before start of test.
- The test room shall be maintained, at steady atmospheric condition.

2.2 Testing and measuring- arrangements

The test apparatus is broadly divided into waterside **circuits** and airside (wind tunnel) circuits. The typical testing arrangement is shown in Fig. 1.

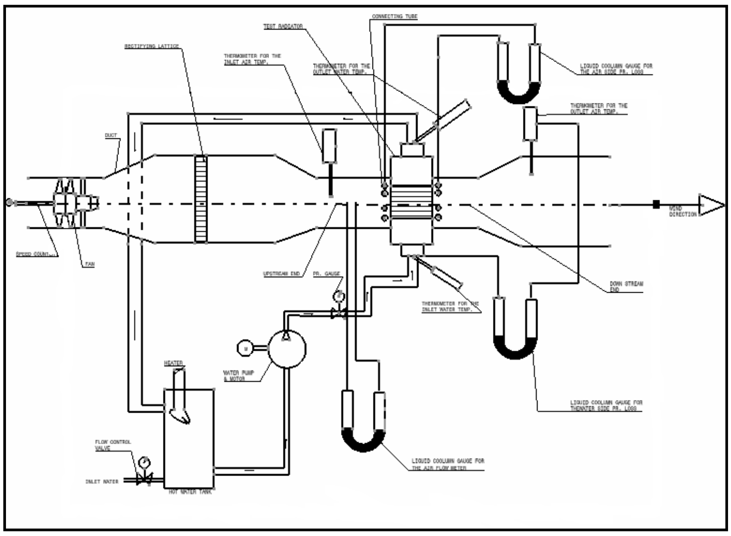

Fig. 1 Test set-up [4]

Waterside Circuit

The waterside circuit shall be equipped with separators in order to prevent mixing of air and vapour in the waterside circuit of the radiator. The hot water tank shall be so designed as to prevent air and vapour locking. The water pump may be connected, to either side of the inlet pipe or the outlet pipe of the radiator. Care shall be taken to avoid any cavitations. The rate of heat generation by hot water tank shall be enough to maintain heat dissipation rate and shall be adjustable in all ranges of heat dissipation.

Airside (Wind Tunnel) Circuit

Wind Tunnel

The air flow passing through radiator shall be adjustable. The arrangement shall include fan, throttle devices such as orifice, shutter, and cone. The connecting tube between the main body of the wind tunnel and the radiator shall be interchangeable to take care of variations in size and shape of radiator: The shape of the connecting tube shall be such that the front of the radiator receives a uniform parallel flow, of air. All joints shall be totally airtight.

2.3 Measuring Equipments

Water Flow meter

The water flow meter used shall have an accuracy of + 2% of maximum scale.

Air Flow meter

The air flow meter used shall be based on Pitot tube or Orifice or Nozzle. The minimum scale for liquid column shall be 1 mm on 30’ inclined type manometer or that having a vertical column

Pressure Gauges

For waterside the liquid mercury column gauge shall have minimum one mm accuracy. For the airside to measure pressure loss, the liquid column gauge shall have at least 1 mm accuracy. For measuring atmospheric pressure, a Fortin's barometer is recommended.

Thermometers

For measuring the temperatures the thermometers used shall have at least ±l°C accuracy for waterside and l°C accuracy airside. For room temperature and humidity, a wet and dry bulb thermometer shall be used

2.4 Testing parameters

The airside circuit is completed by connecting the radiator and wind tunnel with the connecting tube. The waterside circuit of the test apparatus is connected to the inlet and outlet pipes of the radiator. When the radiator (see Fig. 8) reaches stable conditions with Specified rate of air and water flow, the heat transfer and pressure loss tests shall be conducted.

The following are measured:

a) Atmospheric pressure and humidity
b) Inlet and outlet water temperatures
c) Inlet and outlet air temperatures
d) Rate of air and water flow
e) Wind velocity
f) Pressure loss -Water and air sides.

Flow measurements shall be made after stable conditions are reached. When Pitot tube is used for air flow, only the control air velocity may be measured and the ratio of mean to centre velocity shall be used for computing the rate of airflow. The airflow is to be measured in the air inlet **side.**

2.5 Pressure Loss Measurements

The pressure loss measurement of waterside is to be made at the position as near as possible to the end of inlet and outlet pipe of radiator. The pressure loss measurement of airside is to be near the radiator at the upstream and downstream end both locations being equidistant from centre line of radiator core.

Temperature of water shall be measured as accurately as possible, near the inlet and outlet pipe of radiator. The measurement of air temperatures is to be made at the upstream and downstream end of the radiator. Inlet air temperature may be measured at the centre of core. In the case of outlet air temperature, measurements be made at least at four places covering entire core face and the mean temperature shall be calculated. The point of location of thermometer shall be such that it does not receive radiant heat from the radiator.

III. CALCULATIONS

From the results obtained, the heat dissipated on the waterside shall be calculated and this value shall be judged by heat received on airside simultaneously. The air velocity on the upstream side shall also be calculated.

3.1 Heat Dissipation on Waterside

It is calculated by the following formula:

$$Qw = Gw \times Cw\,[T_1 - T_2]$$

where

Qw = Rate of heat dissipated on the waterside(Kcal/h),

Gw = weight of water circulated through the radiator per hour (kg/h)

$Gw = Vw \times v \times 10^{-3} \times 60$

Vw= volume of water flow per minute in litres

V= weight of water per unit volume (kg/m^3)

Cw= specific heat of water, assumed as 1.0 ($kcal/kg^{O}C$)

T_1= inlet water temperature, ^{O}C

T_2= outlet water temperature, ^{O}C

3.2 Heat Received on Airside

$$Qa = Ga \times Ca\ (T_3 - T_4)$$

where

Qa = heat received out the airside, (kcal/h)
Ca = specific heat of air, kcal/kg^{o}C(assumed as 0.24 kcal/kg^{0}C)
T_3 = mean outlet air temperature, ^{O}C
T_4 = inlet air temperature, ^{O}C
Ga = weight of air passing through per hour,(kg/h)

$$Ga = Va \times A$$

Where

Va = rate of air, (m^3/h) (To be determined by Orifice/Pitot Tube methods)
A =weight of air per unit volume (kg/m^3)

3.3 Pitot tube Method

$$Va= 3\,600 \times S \times Vm$$

Where

s=cross-sectional area of wind tunnel at the measuring position, (m^2)
$v_{m=}$ Mean air velocity in the wind tunnel at the measuring positioning (m/s)

Also

$$V_{m} = \frac{\sqrt{2gpd}}{A}$$

Where

g =acceleration due to gravity, m/s^2(9.8 m/s^2)
Pd =dynamic pressure in Pitot tube (Arithmetic mean of pressure h_1, h_2 …..h_m)
= l/m (h_1+ h_2 …..h_m)
A = weight of air per unit volume (kgm^3)

3.4 Using the Orifice

$$Va= 3600 \times \alpha \times m \times \beta \times\sqrt{\frac{2gpx}{k}}$$

Where

α= Flow coefficient
β= correction coefficient by expansion of air
m= area of opening of Orifice (m^2)
px = pressure difference immediately in front and behind the Orifice (mm Aq)
K = weight of air per unit volume immediately in front of Orifice (kg/m^3)

3.5 Air Velocity of Front side Area (Vwf)

$$\mathbf{Vwf} = \frac{\mathbf{Va}}{\mathbf{F \times 3600}}$$

Where

Vwf= front side area air velocity, (m/s)
Va= rate of air
F = front side area, (m^2)

3.6 Weight of Air per Unit Volume (A)
It is Calculated from the Equation

$$A= \frac{1.293 \times H}{(1+0.00367\times ta)\times 760}$$

H= atmospheric pressure, nm of mercury (Room condition)

where

ta = atmospheric temperature, ^{O}C

IV. Review of case study-

In this study various parameters of radiator testing's are assessed for **MCR80-QP:** Swiftech's MCR80-QP which is a single row, single pass and two pass radiator. After experimentation following results were obtained which are shown graphically [2].

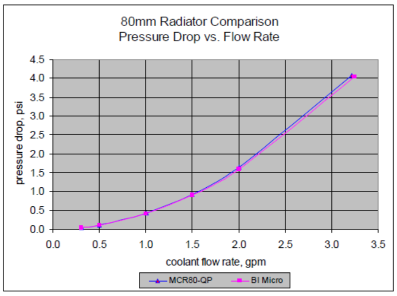

Fig2: Pressure drop increases with increase in flow rate

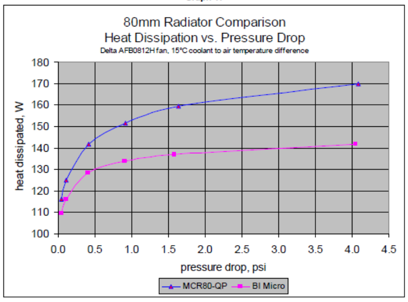

Fig4: Heat dissipation increases with increase in pressure drop

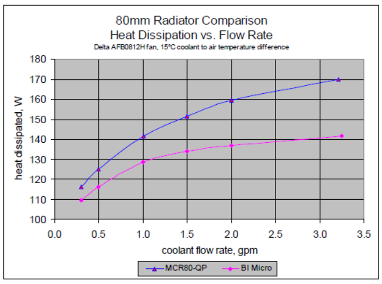

Fig 3: Heat dissipation increases with increase in flow rate

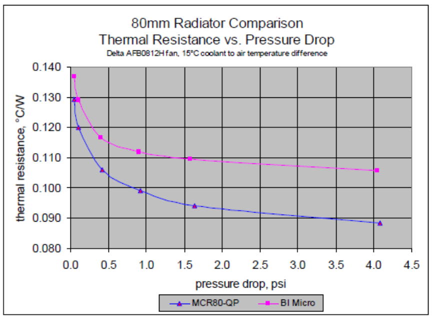

Fig 5: Thermal resistance decreases with decrease in pressure drop

IV. Conclusion

The demand for more powerful engines has created a problem of insufficient rates of heat dissipation in automotive radiators. To minimize the stress on the engine as a result of heat generation, performance of the automotive radiators must be tested to be more efficient while still maintaining high levels of heat transfer performance.

REFERENCES

[1] Eton Yat-Tuen NgVehicle Engine Cooling Systems: *Assessment and Improvement of Wind-Tunnel Based Evaluation Methods.Aug.2002* pp10-40

[2] Willams Adams *An assessment of radiator performance Rouchon Industries 2005* pp 1-15

[3] IS 13686 : 1993 Internal combustion engines - Radiators - Method of test.

[4] *IS 13687 : 1993 Internal combustion engines - Radiators - Heat dissipation performance -Method of test*

[5] P. S. Gill *Automobile Engineering Vol. 2 Katson publication*

[6] IS 7611 : 1993 *Internal combsion engines - Radiators – Specification*.