International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Experimental Analysis and Investigation for Thermal Behaviour of Ventilated Disc Brake Rotor using CFD

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Accepted 20 Sept 2014, Available online 01 Oct 2014, **Vol.4, No.5 (Oct 2014)**

Abstract

In recent years a trend towards faster vehicles with powerful engines has developed. Heavy braking force & high retardation leads to high temperature at disc brake. An upper limit on the temperature of the brake assembly is dictated by certain material properties. Hence heat energy has to be disposed of more efficiently. Possibilities of increasing conduction and radiation are restrained by material properties and temperature limits. Therefore the focus is on convection. Different ventilated disc brake rotors are analyzed with CFD and the most optimum ventilated disc rotor is found for automobile industry. Various disc brake designs are used to describe a method for calculating temperatures of disc brakes. For the calculations a CFD code is employed that determines distributions of local temperatures in the flow field as well as on the disc brake rotor. In a ventilated disc brake rotor air must be circulated through the rotor to provide adequate cooling. The passages formed by the radial vanes between the braking surfaces, act as a centrifugal fan, facilitating the required air flow for cooling. To improve the performance of a ventilated disc brake rotor, radial vanes are modified and analysis is done for the same. After the CFD analysis the experimental verification is done with actual experimental setup. The CFD results are verified with the experimental results obtained on test rig.

Keywords: *Disc Brake, Heat Transfer, CFD, Number of Vanes.*

1. Introduction

The brakes are one of the most important aspects of a vehicle since it fulfills all the stopping requirements. As trivial as brakes may appear to be, many issues surround their heating characteristics when it comes to their development, including material choice, contact region properties, development of hot spots, associated physical geometry, and thermo-elastic deformations. Braking is a process which converts the kinetic energy of the vehicle into mechanical energy which must be dissipated in the form of heat. During the braking, the frictional heat generated at the disc-pads interface may lead to high temperatures.

The heat dissipation and thermal performance of ventilated brake discs strongly depends on the aerodynamic characteristics of the air flow through the rotor passages. The objective of the research was to develop an understanding of how aerodynamics could be used to improve the cooling of automotive disc brakes.

This paper describes current research its limitations and findings the best disc brake among all. For this different disc brake rotors namely the Ventilated Disc Brake Rotor (VDBR) of Mahindra Xylo, Mahindra Scorpio, Volkswagen Polo, Tata indica and Ford Ikon are analysed on CFD. Also the results of the CFD analysis are verified by the experiments.

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Objectives

- Study and investigation of thermal behaviour of disc brake rotor.
- To find the optimum disc brake geometry for maximum cooling and minimum thermal stresses.

2. CFD Analysis

Present braking system may have the problems like Thermo-Mechanical Distortions / Warping, Cracking, Hot Judder, Brake Fading, Overheating of Braking Fluid, Seals and Other Components, Plastic Yielding, Contact Region, High thermal stresses, Thermo-Elastic Instability, Influence of third body.

All these problems are due to poor heat transfer rate from VDBR. In order to remove these problems heat transfer rate from VDBR must be enhanced. And the temperature of the disc should remain within a limit. Heat transfer rate can be increased by conduction, convection or by radiation. Out of which conduction mode of heat transfer leads to overheating of braking fluid, seals and other components also it have some limitations. Radiative mode of heat transfer becomes effective at higher temperature. But the disc temperature should not go till that temperature. So the only way remaining is convection mode of heat transfer.

When brakes are applied, the kinetic energy of the vehicle is converted into heat energy; the power developed by the braking action at disc caliper interface is expressed in equation (1).

$$P = F . V \quad (1)$$

Where,
P: The power developed by the braking action [W],
F: The braking force at road/tyre interface [N],
V: Longitudinal vehicle speed [m/s].
This heat is dissipated in three modes the role of each mode is given in the fig. 1.

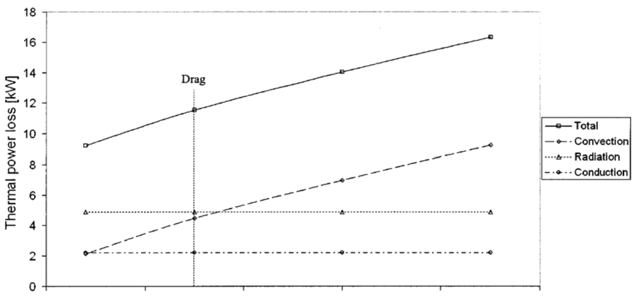

Fig. 1 Heat dissipated by each mode of heat transfer at 600 °C

Conduction & radiation modes of heat transfer are having some limitations and are being constant with respect to speed. So convection is the remaining way. Also it increases with the speed of the wheel. Taking convection into consideration different VDBR are analysed with CFD. The VDBR of Mahindra Xylo, Mahindra Scorpio, Volkswagen Polo, Tata indica and Ford Ikon are analysed on CFD. While these analysis different geometrical parameters are varied and mass flow rate & heat transfer rate are calculated.

1. Mahindra Xylo: The present VDBR of Mahindra Xylo has 36 numbers of vanes. While CFD analysis, numbers of vanes are varied from 32 to 56. The fig. 2 shows the meshed geometry of one of the vane of VDBR of Mahindra Xylo.

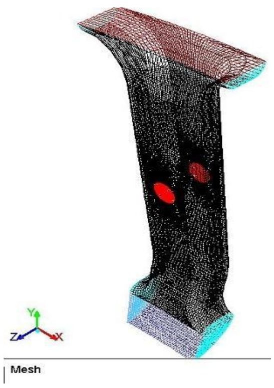

Fig. 2 Meshed geometry vane of Xylo VDBR.

In the analysis for the number of vanes; It has been found that the mass flow rate and also the heat transfer rate is maximum at about 44 number of vanes than that of the existing 36 numbers. The heat transfer rate in case of 44 numbers of vanes is found to be 3.18 % more than that of 36 numbers of vanes. It can be seen from the fig- 3 and fig. 4.

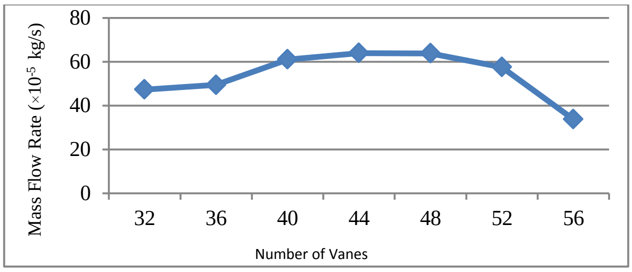

Fig. 3 Mass flow rate Vs number of vanes

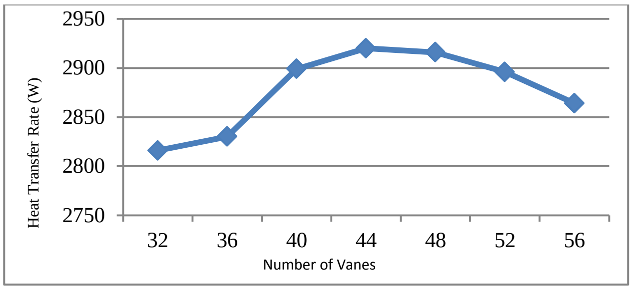

Fig. 4 Heat transfer rate Vs number of vanes

Effect of cross drill: There is considerable effect of presence of cross drill on the heat transfer rate through VDBR. This is due to the reason, the fresh air is induced in the vane passage due to the presence of the cross drill. But it has been found that the heat transfer rate is not changing considerably with respect to the change in number of cross drills. Also there is no much effect on the mass flow rate of the air due to cross drill. The cross drills are very helpful in removal of the third body like wear out particles, rain drops and dust particles etc.

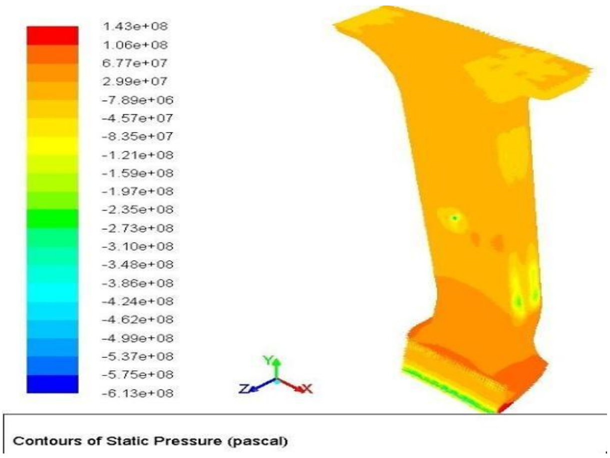

Fig. 6 Pressure contours of cross drilled vane

CFD analysis clearly shows us that the pressure at the region of hole is less than that of other region in the vane. As the air flows through the vane, the pressure of the air drops, the cross drill in vane passage connects this low pressure region to the outside atmosphere, causing the outside air to flow into the vane passage. The CFD analysis clearly shows that the pressure at the region of cross drill is lower than that of the outside atmospheric pressure. Also the velocity of the air at cross drill is more that surrounding. The pressure contours and the velocity contours are shown in the fig. 6 and fig. 7

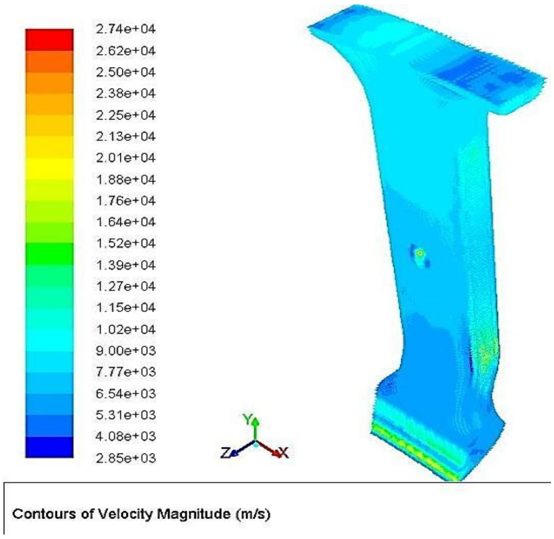

Fig. 7 Temperature contours of cross drilled vane

Turbulence is created at the region of cross drill and hence that is the reason for increased heat transfer rate even for the similar mass flow rate. Fig. 8 shows the streamlines for the air flow through the vane passage.

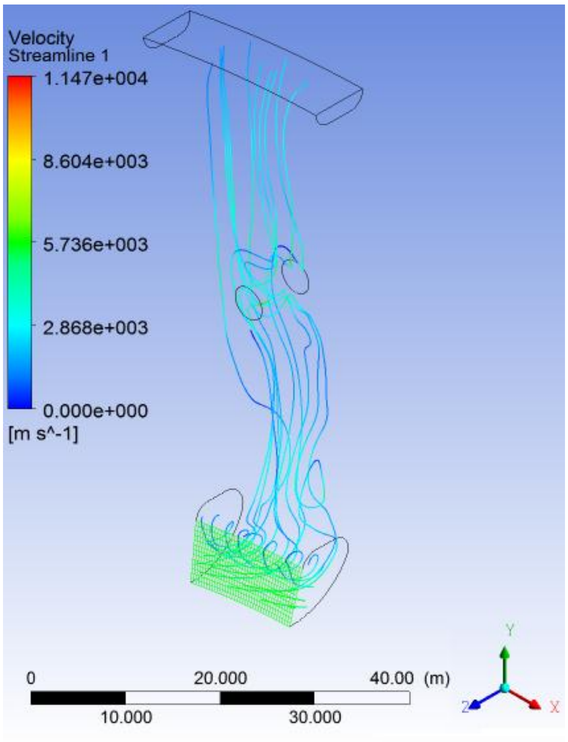

Fig. 8 Streamlines through the cross drilled vane

The velocity vector at the cross drill shown in fig. 9 indicates that the fresh air is get induced into the vane.

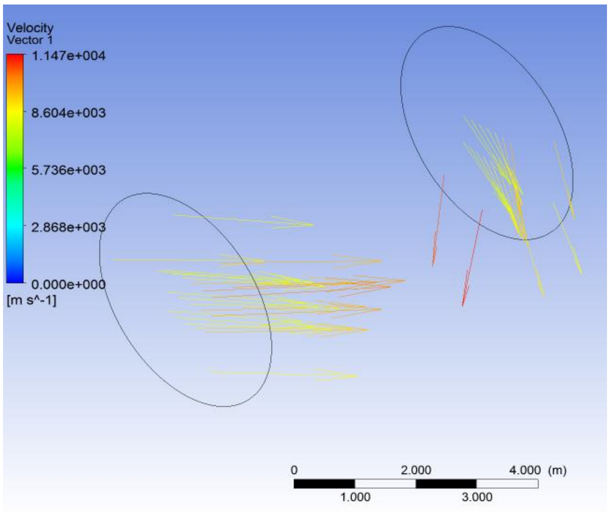

Fig. 9 Velocity vector at cross drill.

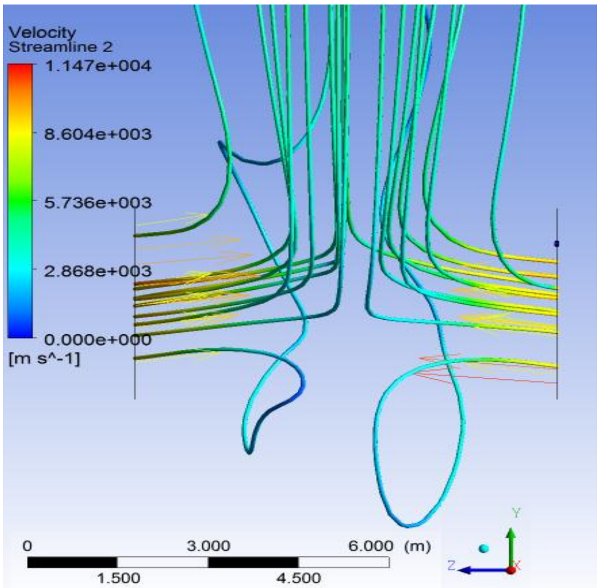

Fig. 10 Velocity vector and streamline at cross drill

The fig. 10 shows the velocity vector and the streamline both at the region of cross drill. All these leads to the increased heat transfer rate from the VDBR.

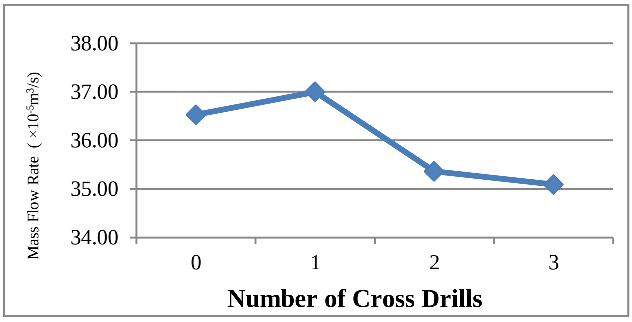

Fig. 11 Variation of mass flow rate respect to no. of cross drill

The variation of mass flow rate with respect to the number of cross drills is shown in the fig. 11.

The variation of heat transfer rate through cross drilled with respect to the number of cross drill of a VDBR is shown in fig. 12.

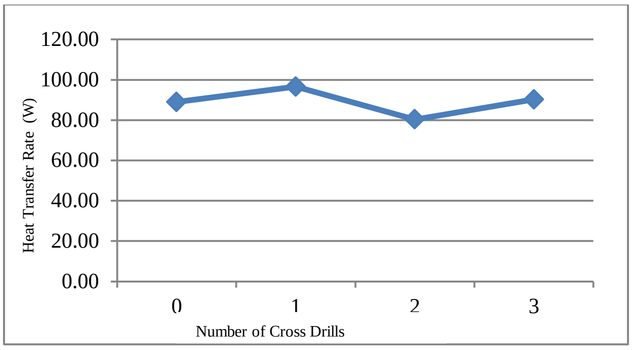

Fig. 12 Variation of heat transfer rate with respect to no. of cross drill

Ford Ikon: VDBR of Ford Ikon has the vane pattern of four short vanes after one long vane. This geometry is modified and different vane patterns of VDBR are generated namely, all short, all long, alternate long & short and one long & four short are analysed on CFD. It has been seen that the mass flow rate for VDBR with all long vane pattern is maximum and hence the heat transfer rate is. The mass flow rate & heat transfer rate for four different vane patterns (All short, all long, alternate long & short and one long & four short) is shown in fig. 13 and fig. 14.

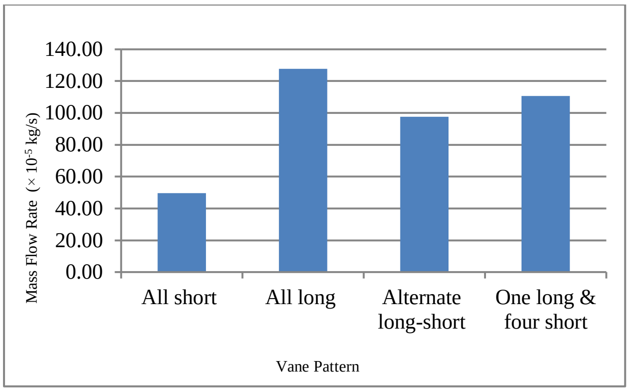

Fig. 13 Mass Flow Rate for various vane patterns

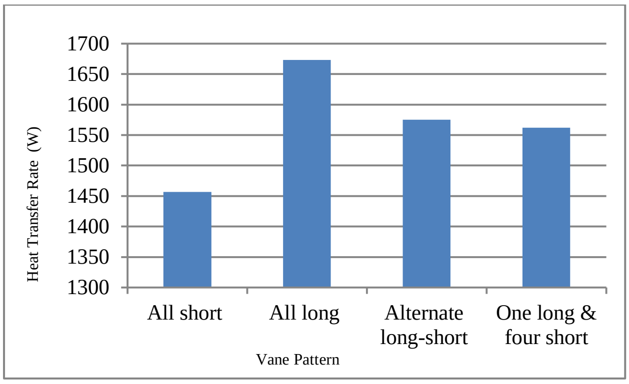

Fig. 14 Heat Transfer Rate for various vane patterns.

3. Experimental Analysis

All above VDBR are tested for mass flow rate and heat transfer rate through it. The experimental set up for the same is shown in fig- 15.

Fig. 15 Experimental set up.

Mass Flow Rate: VDBR of the vehicles mentioned below are tested for mass flow rate and heat transfer rate.

(1) Mahindra Scorpio: No. of vanes = 36, all radial. Special curvature at inlet is given to reduce pressure drop. Axial inlet & radial outlet.

(2) Tata indica: 31 pillars along each PCD. Three such PCD. Radial inlet and radial outlet.

(3) Volkswagen Polo: Angular vane backward inclination at 15^0. No. of vanes = 36 with holes for radial inlet. Inlet is both radial & axial with radial outlet.

(4) Ford Ikon: Four short vanes after one long vane. Total no. of vanes = 40. Radial inlet and radial outlet.

All these VDBR are tested for mass flow rate at experimental set up. The VDBR are fitted to the holding hub and fixed to the rotor of the variable speed electrical motor. The motor speed is increased step by step and corresponding air velocity at the exit of blower is measured with the aid of digital anemometer.

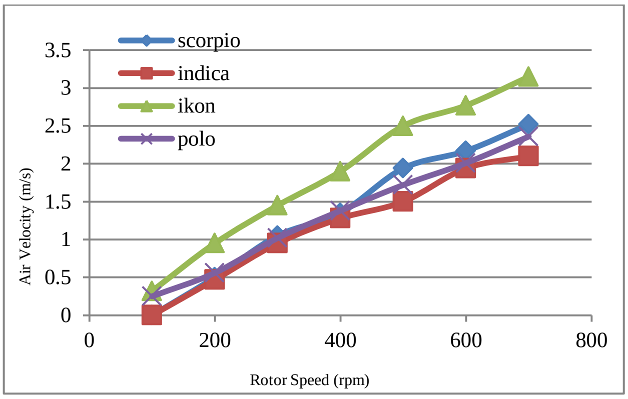

Fig. 16 Air velocity Vs rotor speed

The variation of mass flow rate in terms of air velocity for different VDBR is shown in the fig- 16.

Among all the VDBR the Ford Ikon VDBR is found to be the most efficient for mass flow rate. After that Mahindra Scorpio VDBR gives second highest mass flow rate for all the speed. But it is not necessary that the VDBR having maximum mass flow rate must have the maximum heat transfer rate.

For the heating of VDBR for its initial temperature, an electrical heater is used with a clamping device and an insulator shown in fig-17.

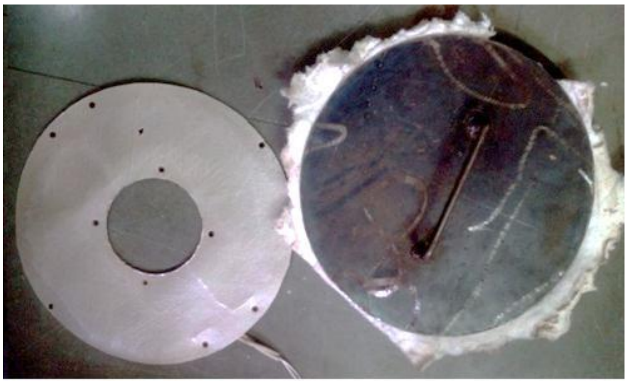

Fig. 17 Electric Heater & its holding plate

The temperature and the air velocity are measured with the aid of noncontact type thermometer and digital anemometer which are not shown in figure.

The VDBR is first heated till 100 ^{O}C then after uniform distribution of the temperature all over the disc it is then fitted to the motor shaft and rotated at constant speed and for a given period of time. The temperature drop in this five minute is noted and heat transfer rate of all VDBR is calculated.

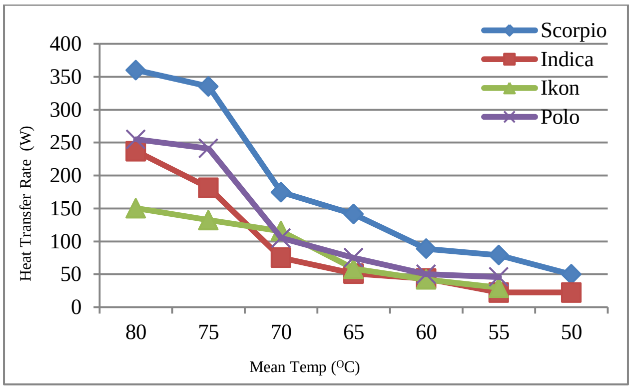

Fig. 18 Predicted heat transfer rate at mean temperature

The plot for the predicted heat transfer rate at different mean temperature is shown in the fig- 18. It is clear that the heat transfer rate of VDBR of Mahindra Scorpio is more than that of any other VDBR.

4. Results and Discussion

The comparison CFD results and experimental results for the mass flow rate of air through various VDBR are shown in the fig. 19.

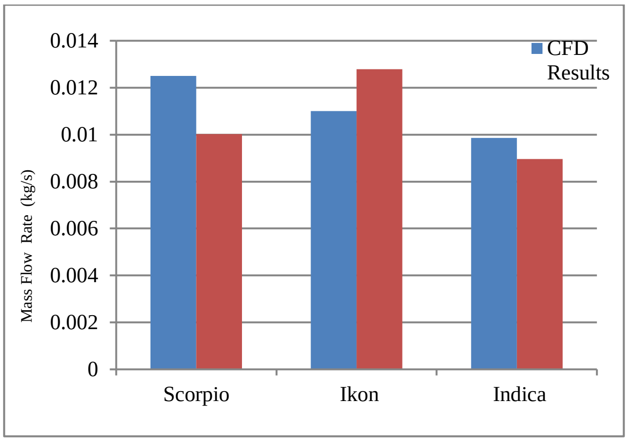

Fig.19 Comparison of Mass Flow Rate from CFD & Experimental Results

The comparison CFD results and experimental results for the heat transfer rate through various VDBR are shown in the fig. 20.

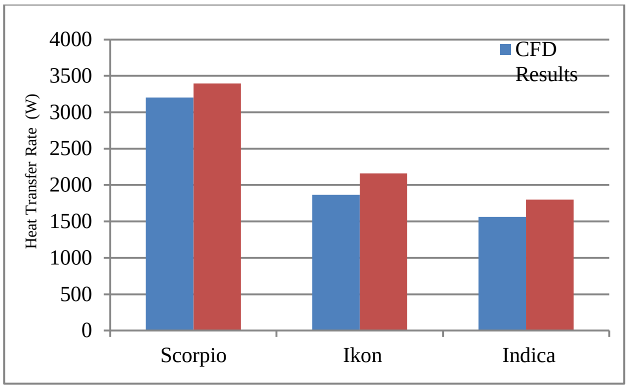

Fig. 20 Comparison of Heat Transfer Rate from CFD & Experimental Results

Conclusions

The heat transfer rate from VDBR can be increased through convection, which is by increasing the mass flow rate of the air flowing through the vanes. More is the mass flow rate; more will be the heat transfer rate. CFD analysis of various VDBR leads to the conclusion that;

1. VDBR with 44 numbers of vanes gives maximum heat transfer rate than that of existing 36 numbers of vanes. The heat transfer rate has increased by 3.18 %.
2. The presence of cross drill increases the heat transfer rate. This is due the reason, the fresh air is induced into the vane passage through the cross drill. There is no much effect of variation of number of cross drill into the vane passage on heat transfer rate. But the presence of the cross drill helps to remove the third body like wear out particles, dust particles & rain drops etc. Presence of third body may results into the lower coefficient of friction.
3. The mass flow rate for Ford Ikon VDBR with all long vane patterns is maximum patterns (Among all short, all long, alternate long & short and one long & four short.) and hence the heat transfer rate is.

4. Among all the VDBR the Ford Ikon VDBR is found to be the most efficient for mass flow rate. After that Mahindra Scorpio VDBR gives second highest mass flow rate for all the speed. But it is not necessary that the VDBR having maximum mass flow rate must have the maximum heat transfer rate. This is due to the reason of boundary layer formation in the vane passage of VDBR. This boundary layer formation can be reduced by modification of vane geometry. The VDBR of Ford Ikon gives maximum mass flow rate compared to the other brakes, but its heat transfer rate is poor than that of the Scorpio disc. It clearly indicated that the vane geometry of the VDBR of Ford Ikon must be changed to reduce the boundary layer formation.
5. Among all the VDBR analysed on CFD; the heat transfer rate of VDBR of Mahindra Scorpio in maximum followed by Volkswagen Polo, Ford Ikon and then Tata Indica. Out of which the results of Scorpio, Ikon & Indica are verified with the aid of experiments.

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