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Flow diagnosis in a domestic radiator

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1 Introduction: -

Domestic and industrial heating systems constitute a big industry in cooler countries, globally. Radiators in central heating systems have been a primary source to provide domestic heating in the UK for several decades. In a typical central heating system, water is heated at a central node (boiler) and is then pumped through the pipe work to individual radiators. The radiators act as heat exchangers. This system has several drawbacks including little flexibility, limited controllability and poor expandability. A standalone system overcomes the drawbacks of a central heating system by having closer monitoring and control of heat and flow.

Radiators have been analysed for their performance by various researchers [1-7]. Peach, Walters and Ward [1]-[3] have found that the aspect ratio (length vs. height) of the radiator has a direct influence on radiator heat output. About 30- 50 % of the radiator heat output is emitted by radiation and the remainder through convection. Emissivity of the surface affects the performance and studies recommend an oxidized metallic surface for best performance. Beck et. Al, [4] have carried out extensive investigation to analyse the working of radiator panels in a central heating system. They have reported that the output of radiators can be increased by optimizing the location of the radiators within the room. Also decreasing the height above the ground and by increasing their spacing from the wall would improve the air flow characteristics over the radiator. The attachment of convector fins to the panel radiators increases the surface area and hence the convective heat transfer. They also concluded that different combinations of fluid entry and exit positions can affect radiator performance. However, form the literature it has been found that no analysis has been carried out to diagnose the flow structure within the radiator. Hence in this paper numerical analysis has been carried out to diagnose the flow structure within the stand alone radiator in iso-thermal condition at various flow rates with two different outlet configuration.

2 CFD model and set up: -

Three dimensional geometry of a commonly used radiator has been numerically modelled in Ansys work bench. For simplicity only the fluid zone in Geometry has been created as shown in figure 1. Length and width of the radiator has been set to 600 mm and 300 mm respectively. Inlet of the radiator has been placed at the bottom of the right corner of the radiator while outlet has been placed at the top and bottom of the left side of the radiator to simulate BTOE and BBOE configuration. The diameter of both, inlet and outlet have been made 12 mm. As shown in the figure 1 radiator consists of two rows and 18 columns. Width of each row has been considered as 25 mm and whereas columns has been set to 10 mm.

Tetrahedral mesh has been selected for meshing the flow domain. The element size of 2mm has been selected for this study resulting in total number of elements of 2 million. For the numerical simulation, commercial ANSYS CFD- Fluent has been used. The analysis has been carried out in steady state with the working fluid through the radiator is assumed to be water. The shear stress turbulent (SST) model has been implemented, which can accurately analyse wall shear and provide the accurate prediction of the onset and size of the separation zone. Turbulent intensity of 5% has been considered for this study. Mass flow inlet and pressure outlet has been considered as an inlet and out let boundary conditions respectively with hydraulic diameter 0.012m.

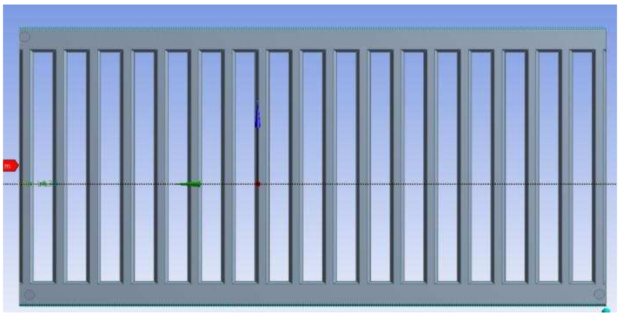


Figure 1 Radiator geometry

3 Results: -

A numerical analysis has been carried out on the 600 mm X 300 mm radiator with 18 columns and 2 rows. The analysis has been carried out for both BBOE and BTOE configuration for 5 different flow rates. These flow rates correspond to an inlet velocity in the range of 1.1 m/s to 1.75 m/s. Flow 1 corresponds with the elast velocity where as flow 5 correspond with the maximum velocity. Figure 2 depicts the mass flow rate distribution in the column of the radiator for various flow rates in BBOE (left) and BTOE (right) configuration. Figure illustrates higher flow rate in the inlet zone (far right in both cases) of the radiator. Figure also indicates that there is very less flow in the columns. Minimum flow rate can be seen at the middle column of the radiator. However, flow rate in the column increases as it approach the outlet (far left in both cases). Negative flow in case of BBOE indicates that flow is going downwards unlike in case of BTOE.

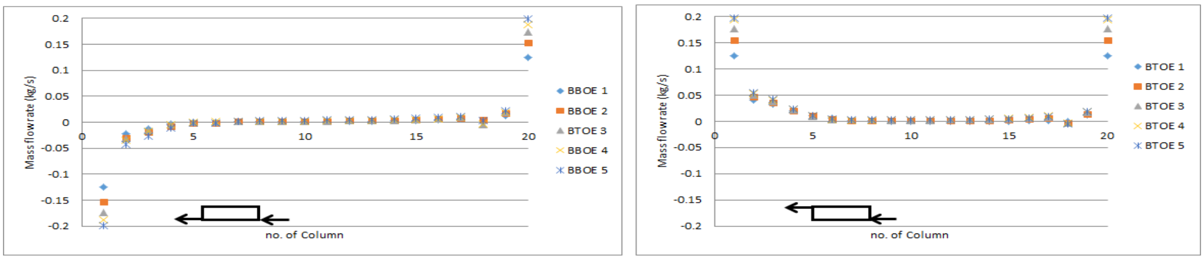
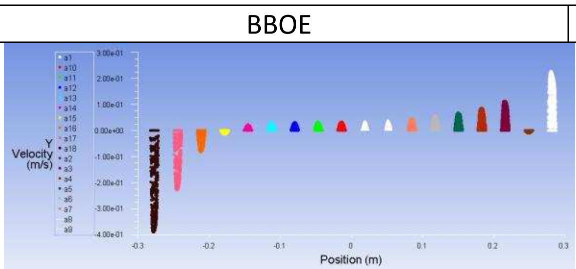
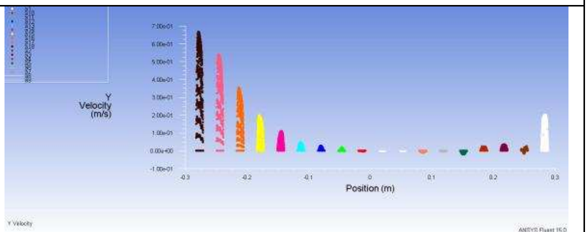
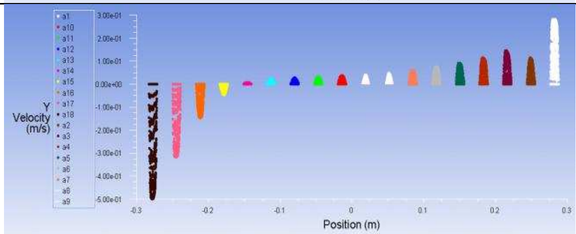
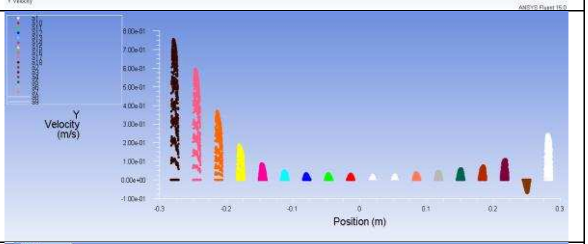
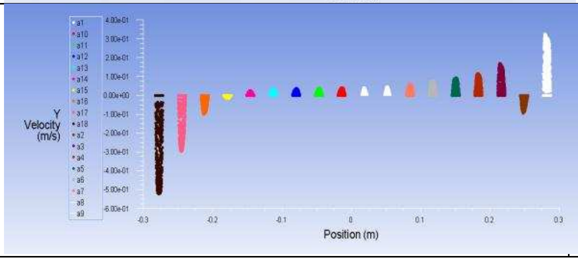
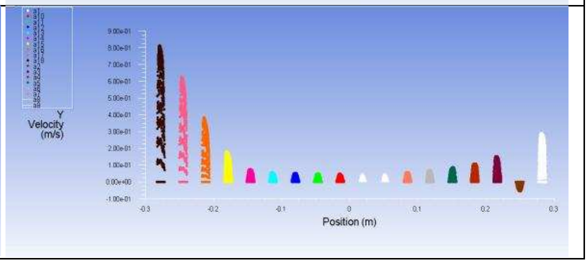


Figure 2 Mass flow rate distribution in a radiator left) BBOE and right) BTOE

Figure 3 depicts Y component velocity profile in each column of the radiator for both radiator configuration (BBOE and BTOE). Results have been presented for 5 different flow conditions for both configurations. Figure shows that for all the flow conditions, in each column, velocity in the middle of each column is higher than that of wall region. Furthermore, figure also indicates that the velocity is higher in in initial columns of the radiator and tends to decreases as it approaches the middle of the radiator. However, velocity starts to increases as it approaches outlet of the radiator. Negative velocity in BBOE indicates that the water is flowing downwards where as in case of BTOE in most of the channels water is flowing in upward direction.

	BBOE	BTOE
Flow 1		
Flow 2		
Flow 3		

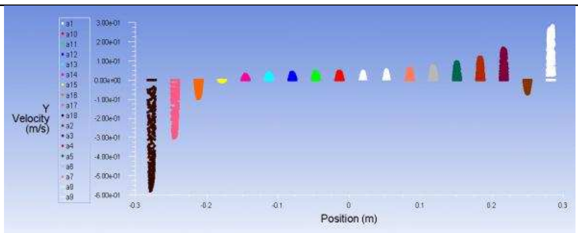
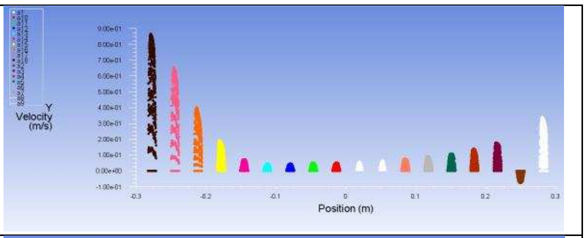
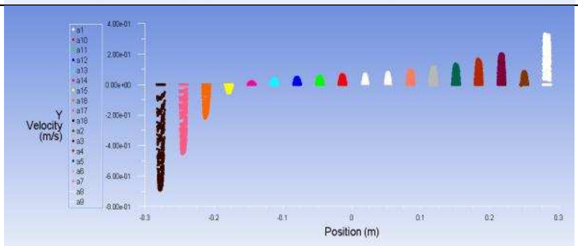
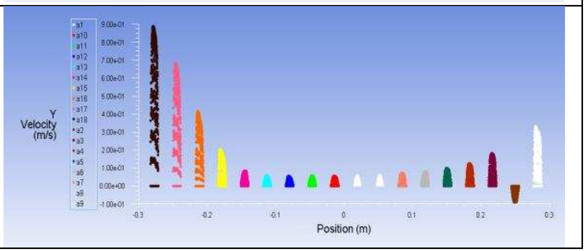
Flow 4		
Flow 5		

Figure 3 Y-component velocity profiles in each column

Figure also indicates that the velocity in each column increases as the flow rate increases. In some cases it can been seen that in second column water flows downwards.

Loss coefficients in radiator:-

The pressure values measured at the inlet and outlet of the radiator were used to compute the pressure drop, which in turn was used to compute the loss co-efficient based on following equation.

$$K = \frac{H_f\,2\,g}{V^2} = \frac{2\Delta P}{\rho V^2} \qquad (1)$$

The following results compare the non-dimensional loss co-efficient for different pipe configurations.

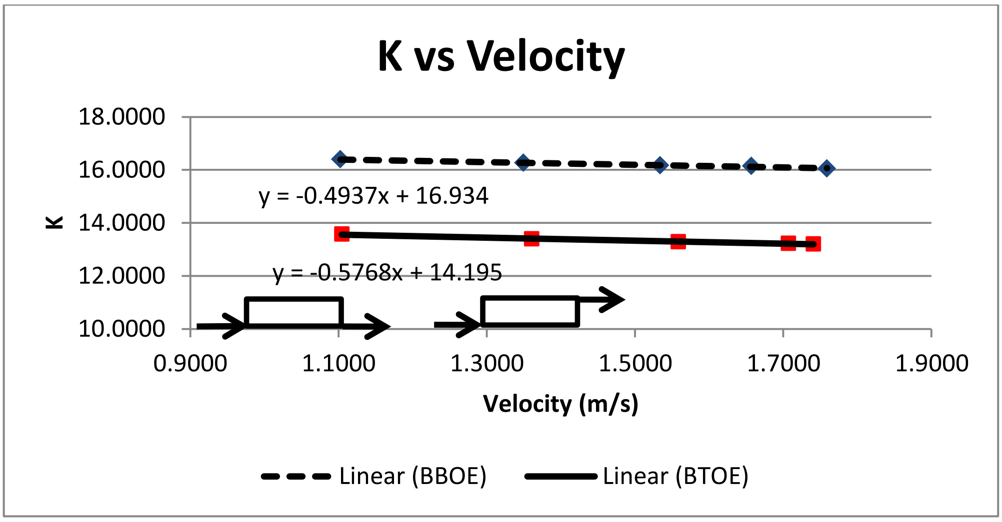


Figure 4 Loss coefficients against velocity trend for BBOE and BTOE

Loss co-efficient against velocity has been illustrated in figure 4 to study the trend for the two pipe layouts in a single panel radiator. From the figure it can be seen that, both BBOE and BTOE configurations have similar trends, where the value for the loss co-efficient K drops with the increase in velocity. Furthermore, it can also be seen that overall BBOE configuration has a higher loss co-efficient than BTOE. K at flow 1 in a BBOE layout has been found to be 16.39 and 13.57 for a BTOE layout. The loss co-efficient has been found to be 16.05 and 13.19 at 100% flow rate for BBOE and BTOE configurations respectively. Further analysis has been carried out develop a functional relationship for loss coefficient as a function of Reynolds number.

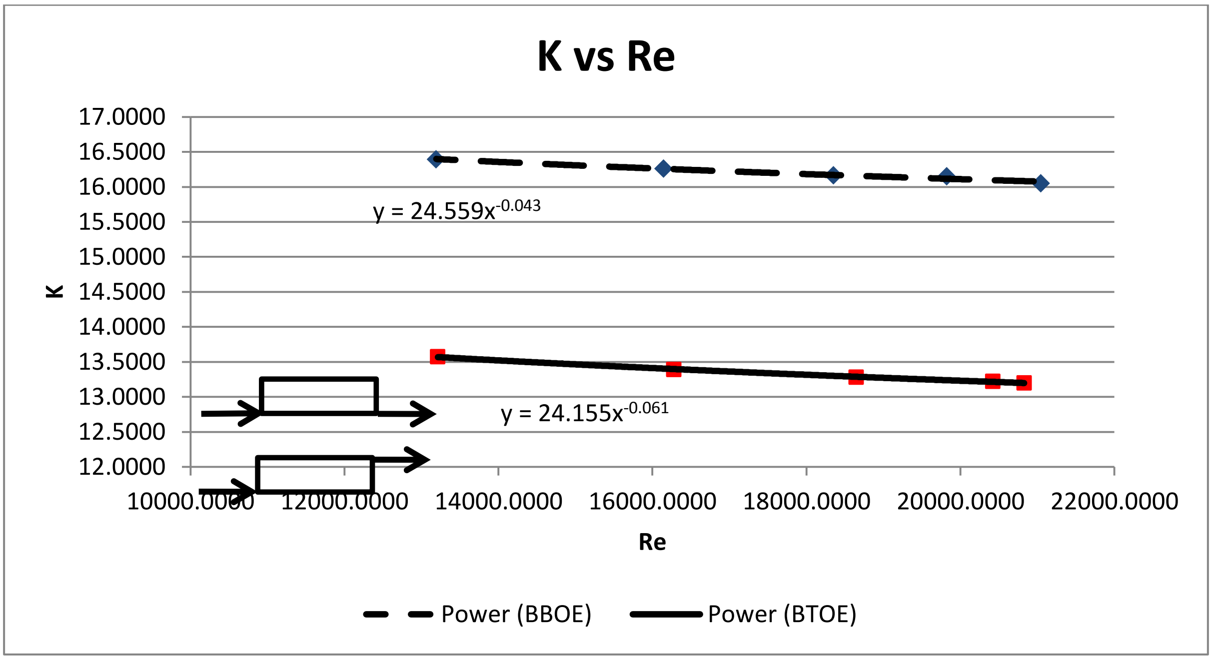


Figure 5 Loss coefficients against Reynolds number trend for BBOE and BTOE

Figure 5 depicts loss coefficient as a function of Reynolds number for single panel radiator with both pipe configuration. Figure illustrates that both BBOE and BTOE have similar trend as the Reynolds number increases loss coefficient decreases. Furthermore figure also indicates that in BBOE configuration the loss coefficient is 16.39 at 13191 Reynolds number and is 16.04 at 21043 Reynolds number.

The loss coefficient for the BBOE configuration can be expressed as a function of Reynolds number by following equation.

$$K = \frac{24.55}{Re^{0.043}} \qquad (2)$$

Where as in BTOE configuration the loss coefficient is 3.57 at 13213 Reynolds number and is 13.19 at 20827 Reynolds number. The loss coefficient for the BTOE configuration can be expressed as a function of Reynolds number by following equation:-

$$K = \frac{24.15}{Re^{0.061}} \qquad (3)$$

4 Conclusions: -

Numerical simulations have been carried to analyse flow distribution within a domestic radiator with dimensions of 300mm by 600mm containing 18 columns and 2 rows. The study was carried out on a radiator with BBOE and BTOE configuration at various flow rates. Flow distribution on the radiator has been presented in this paper. Relationships between loss coefficient and velocity have been quantified, which shows similar trend for both configurations, and shows the loss coefficient decreases as the velocity increases. Relationship between loss coefficients as a function of Reynolds number has also been developed in this study for both BBOE and BTOE configurations.

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