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Flow and Heat Transfer in A Pipe Containing A Disk.

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ABSTRACT

A numerical investigation was made of steady laminar flow and convective heat transfer in a pipe constricted by a coaxially rotating disk. The analysis was done with aluminium oxide nanofluid of different concentrations as the working fluid and compared with the results of water obtained by Janusz Wojtkowiak. Calculations were made for the through-flow Reynolds numbers in the range of 10-150, and for the disk-to-pipe radius ratios of 0.9-0.99. The pressure drop coefficient, length of wall and disk recirculation regions, local and average Nusselt numbers, temperature distributions are presented. The results show that the temperature and flow characteristics are substantially affected due to the rotation of the disk. This affect is more when aluminium oxide nanofluid is passed through the pipe compared to distilled water, the base fluid of al_2o_3 nanofluid.
Keywords: Nanofluid, Reynolds number, Laminar flow, Nusselt number

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INTRODUCTION

In the present work, initially a plane pipe without any obstructions was taken. Simulations were carried out for laminar fully developed flow with varying mean axial velocity .since our case is a constant wall temperature fully developed laminar flow, Nusselt number is a constant.

Next the same pipe, having a stationary disk inside was taken and test cases were run for different Reynolds number. Next test runs were made to compute the local pressure drop coefficient for stationary disk in a pipe. Test cases were also run by varying the disk radius inside the pipe.

Further work is concentrated on using nanofluids with varying concentrations as working fluids inside the pipe. Properties of al_2o_3nanofluid with varying particle concentrations are collected. The thermal conductivity of metallic liquids is much greater than that of non metallic liquids. Therefore, the thermal conductivities of fluids that contain suspended solid metallic particles could be expected to be significantly higher than those of conventional heat transfer fluids [1-10].

EXPERIMENTAL

- In the present work, a straight pipe of length $l_1+l_2+l_d$=55 cm is considered.
- Test cases were run for laminar fully developed flow with various Reynolds number (10<Re<150).
- Test cases were run for laminar fully developed flow with various disk-pipe radius ratio (N_{rd}=0.9 - 0.99).
- The same test cases were run by introducing nanofluids
- in to the pipe instead of water.
- The range of parameters pertinent to practical applications are identified and the local pressure fields, velocity profiles and nusselt number distributions are exhibited.

RESULTS AND DISCUSSION

In Figs.2 and 3 plots of the numerically constructed stream functions are exemplified. From these graphs it can be observed that as Re increases, the flow structure on the upstream side of the disk is unaffected, whereas the flow on the downstream side undergoes conspicuous changes. For low values of Reynolds number i.e., for Re=10, the flow patterns are qualitatively similar on both sides of the disk, i.e., no separation, and no recirculation zones are visible. Physically, for a very low Reynolds number, the inertial forces have not induced separation. As Re increases from 10 to 100, an annual wall jet is formed, and one large recirculation region on the downstream face of the disk can be observed. With further enhancement of Reynolds number from 100 to 150, a new recirculation region begins to form on the pipe wall due to adverse pressure gradient caused by the sudden expansion. On the downstream side of the disk, the increasing pressure slows down the wall flow and pushes the fluid backwards .The disk recirculation region is principally due to abrupt change in the flow geometry. As Re increases, an elongated separation bubble is formed on the pipe wall and a strong interaction between the disk and the wall recirculation regions is noticeable. The size of the wall bubble increases and the length of the disk recirculation zone is reduced. Simultaneously changes in the internal structure of the disk region are evident.

Wall and disk recirculation regions

The forgoing observations based on the numerically constructed visualizations are summarized to represent a quantitative portrayal of the two principal flow elements, i.e., the disk recirculation zone and the wall recirculation zone. In Figs. 4 – 7 the variation in x and y with Re are shown plotted. When the wall recirculation region is formed, the disk recirculation zone shrinks in size. Also, the wall recirculation region grows relatively fast as Re or N_{rd} increases. Figs. 4 and 5 illustrates that the effect of N_{rd} and rd on wall recirculation region length. The mechanism of the formation of the wall recirculation zone is the presence of a positive pressure gradient in the downstream side of the disk. The pressure gradient increases with Re and N_{rd}.

Local pressure drop coefficient

In Fig. 8 the relationship between the local pressure drop coefficient and Re for different working fluids is presented. It is observed that there is no change in f with varying working fluids. In Fig .9 the dependence of f on N_{rd} is presented. It is observed that f increases with increasing N_{rd}.

Heat transport characteristics

Heat transport characteristics are mentioned in Figs.10-18.The axial profiles of local Nusselt number on the pipe wall and the variations of the fluid bulk temperature are shown plotted. At the inlet, a uniform temperature profile is specified, which gives a large value of Nu. As the fluid reaches the disk region, the fluid is accelerated. The fluid impinges on the cold pipe wall, which leads to a sudden and extremely localized increase in Nu. Downstream of this disk region, Nu generally drops off sharply to a very low value, which is caused by reduced fluid velocities leaving the pipe at the outlet. When the wall recirculation region begins to form, some decrease in Nu is visible. This is due to the fact that the wall recirculation zone causes the main through-flow to move away from the pipe wall. The minimum value of the Nusselt number occurs in the vicinity of the separation point of the wall recirculation region. For downstream close to the exit, Nu tends to settle down to the value for a fully developed pipe flow.

Bulk temperature

The profiles of the bulk temperature *t* are included in Figs 10 and 11. A monotonic decrease in *t* is seen in the upstream region of the disk. In the disk gap region, a rapid decrease in *t* is visible. In the downstream region, a mild decrease in t is evident. In general, the rate of decrease in t becomes more pronounced as Re decreases. Minor irregularities in the bulk temperature plots, which are noticeable on the disk upstream-side and on the disk downstream-side, are attributable to the existence of the upstream side, and the downstream side wall recirculation regions. A combination of the reverse flow in these regions with the main flow produces the bulk temperature peaks, are shown in the graphs.

Average Nusselt number

In Fig.18 the relationship between average Nusselt number and Re for various working fluids is shown. It is observed that, as the nanofluids particle concentration increases, the average Nusselt number increases with increasing Re.The percentage increase in the average Nusselt number when 0.5% aluminium oxide nanofluid is used in the case of stationary disk is 5.13%.The percentage increase in the average Nusselt number when 0.8% aluminium oxide nanofluid is used in the case of stationary disk is 9%.

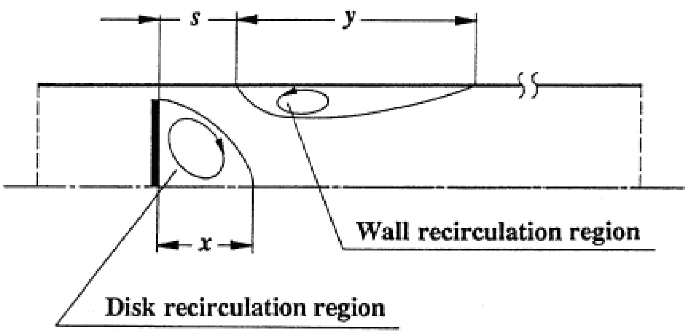

Fig 1: Schematic of the Principle Flow Elements.

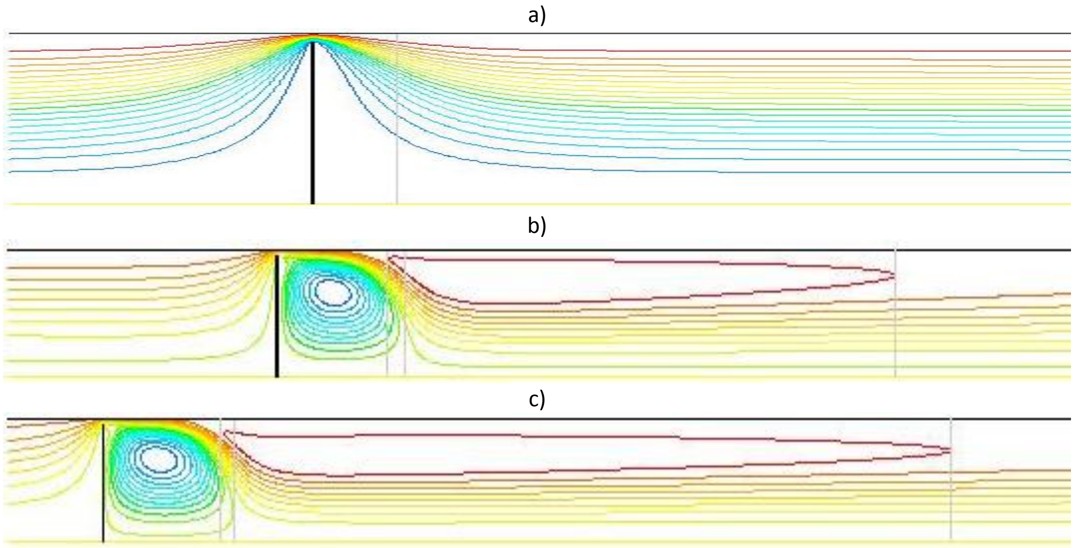

Fig. 2. : Plots Of The Meridional Stream Function For The Case N_{rd}=0.95 And Re_{ω}=0:
a) Re=10; b) Re=100; c) Re=150 For WATER

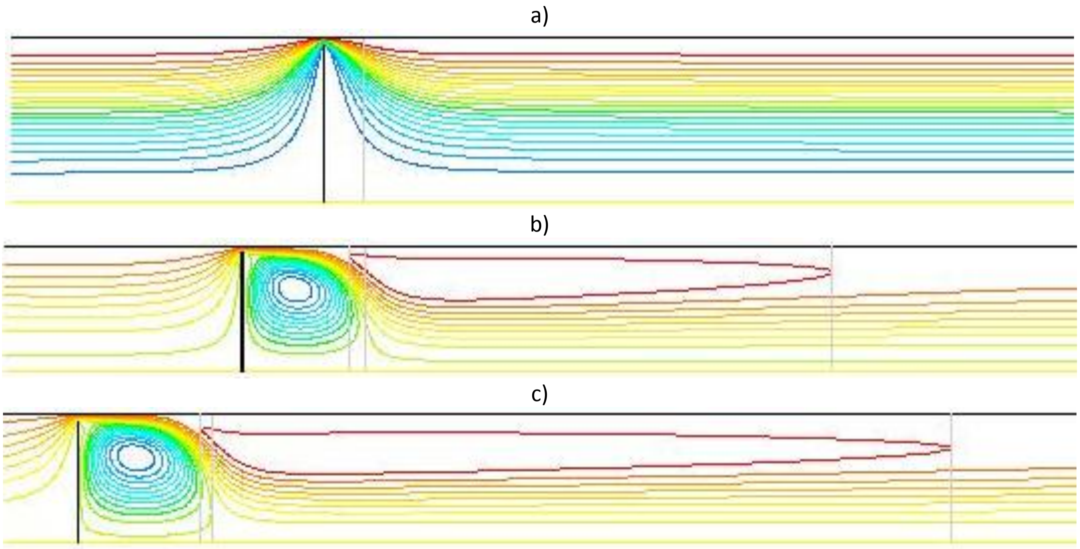

Fig. 3. Plots Of The Meridional Stream Function For The Case N_{rd}=0.95 And Re_{ω}=0:

a) Re=10; b) Re=100; c) Re=150 For 0.2 %Al_2o_3

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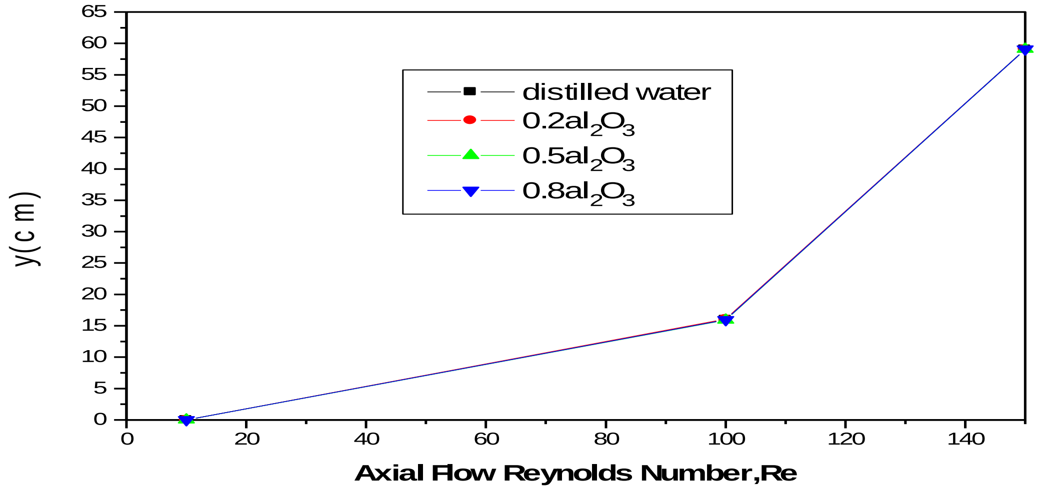

Fig.4 Wall Recirculation Region Length Vs. Re For Different Working Fluids

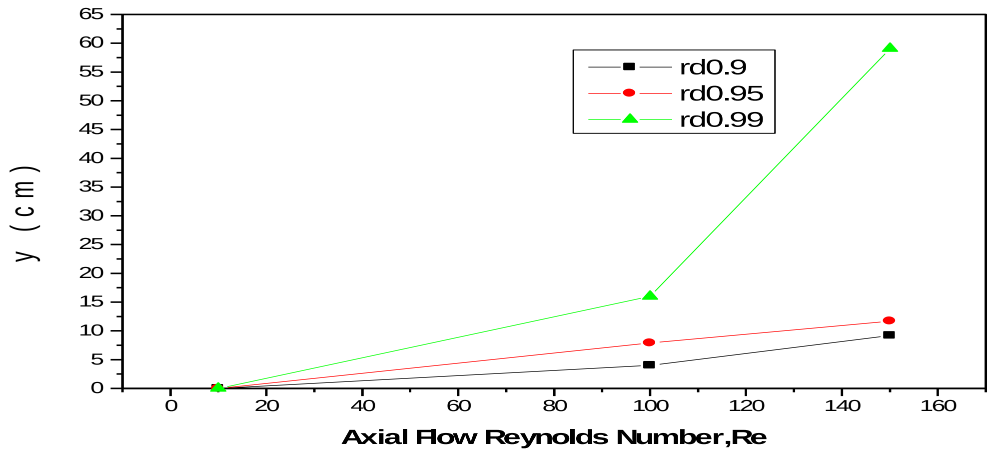

Fig. 5 Wall Recirculation Region Length Vs. Re For Different Disk Radii

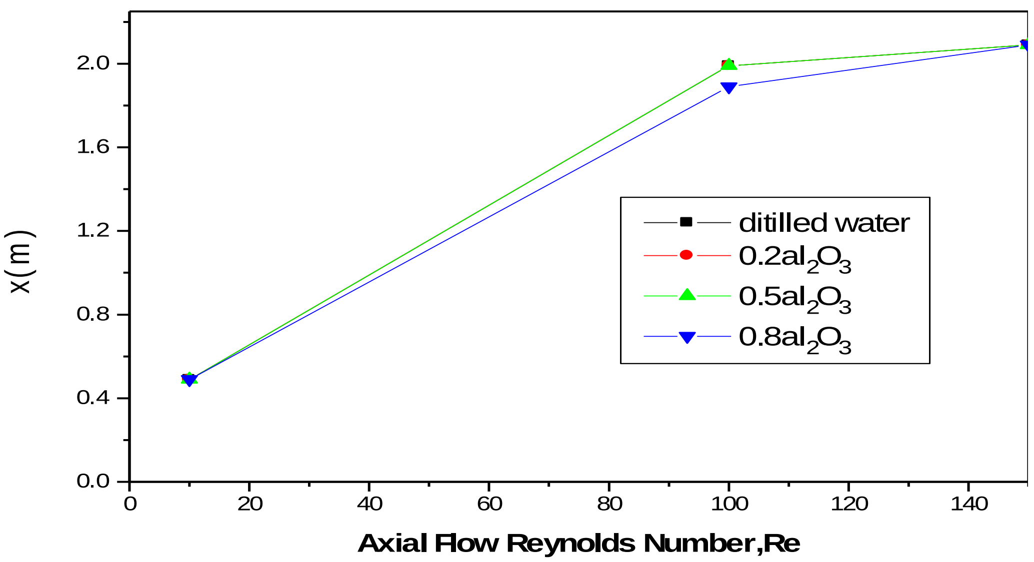

Fig. 6 Disk Recirculation Region Length Vs. Re For Different Working Fluids

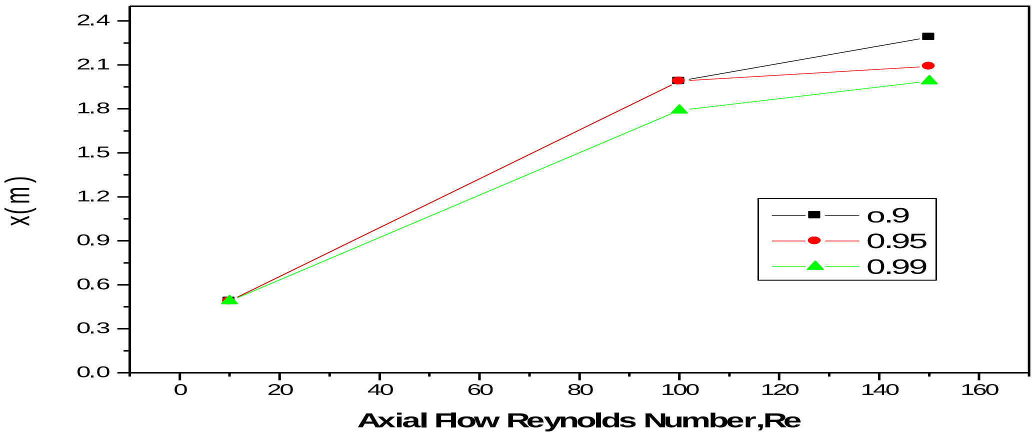

Fig. 7 Disk Recirculation Region Length Vs Re For Different Disk Radii

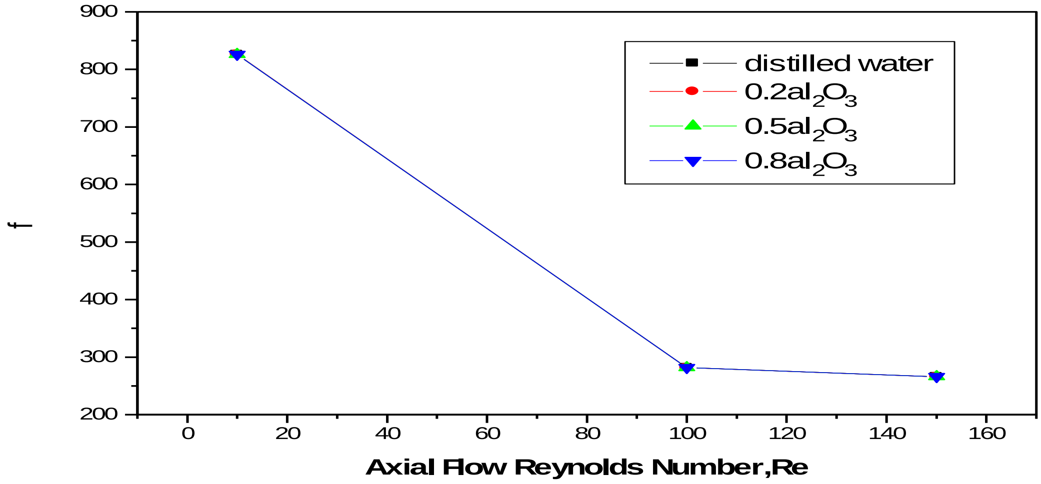

Fig. 8 Local Pressure Drop Coefficient Vs Reynolds Number For Different Working Fluids

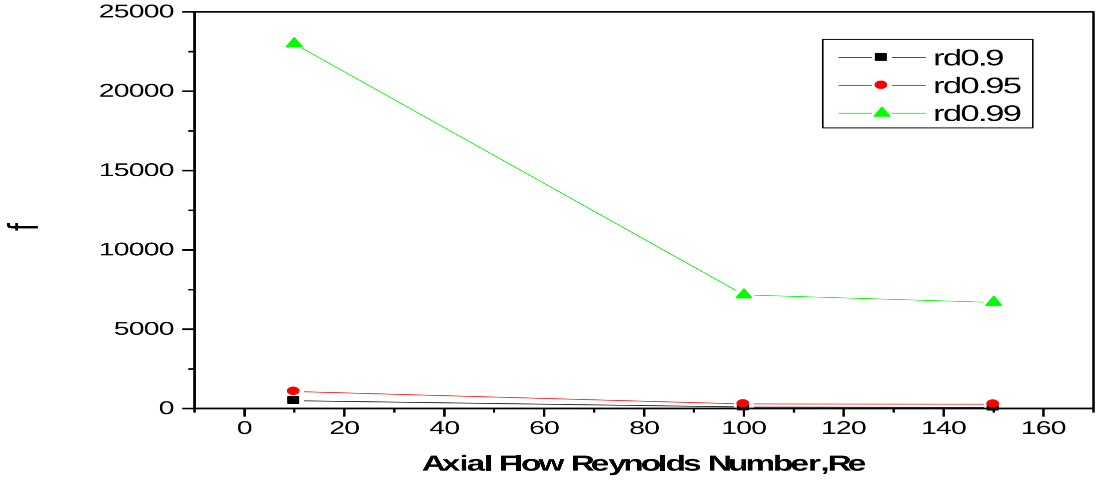

Fig. 9 Local Pressure Drop Coefficient Vs. Reynolds Number For Different Disk Radii

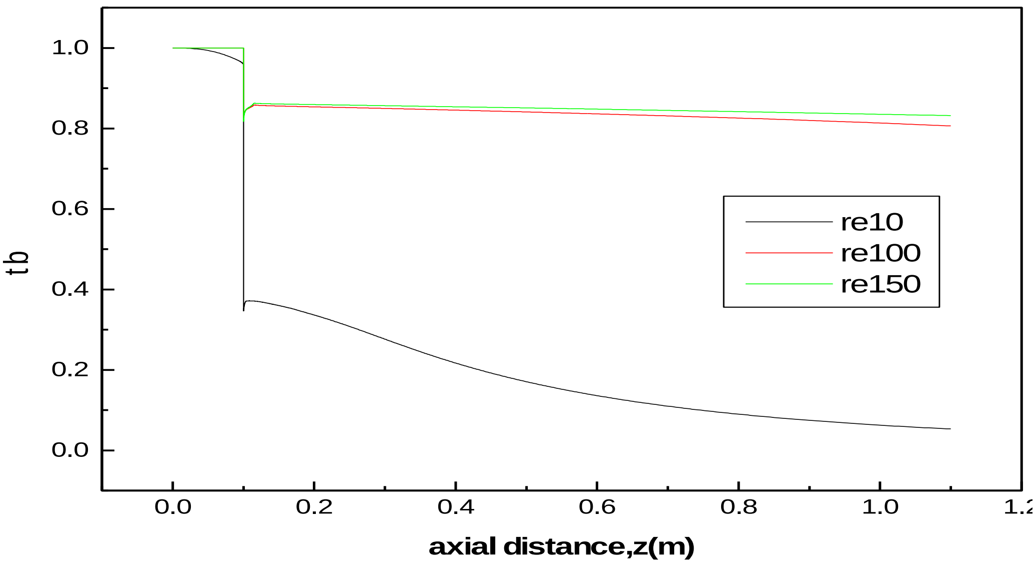

Fig. 10 Bulk Temperature Of The Fluid Vs Axial Distance For Different Flow Reynolds Numbers

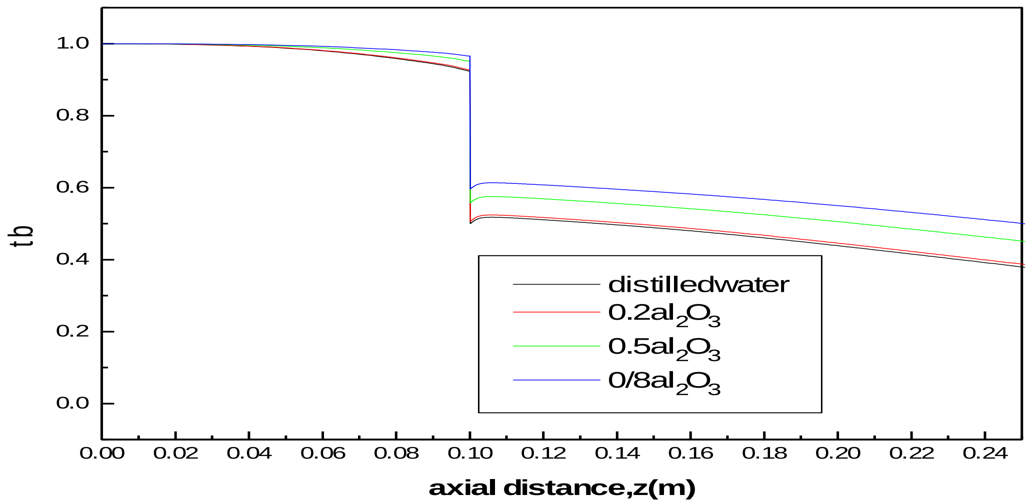

Fig. 11 Bulk Temperature Vs Axial Distance For Different Working Fluids

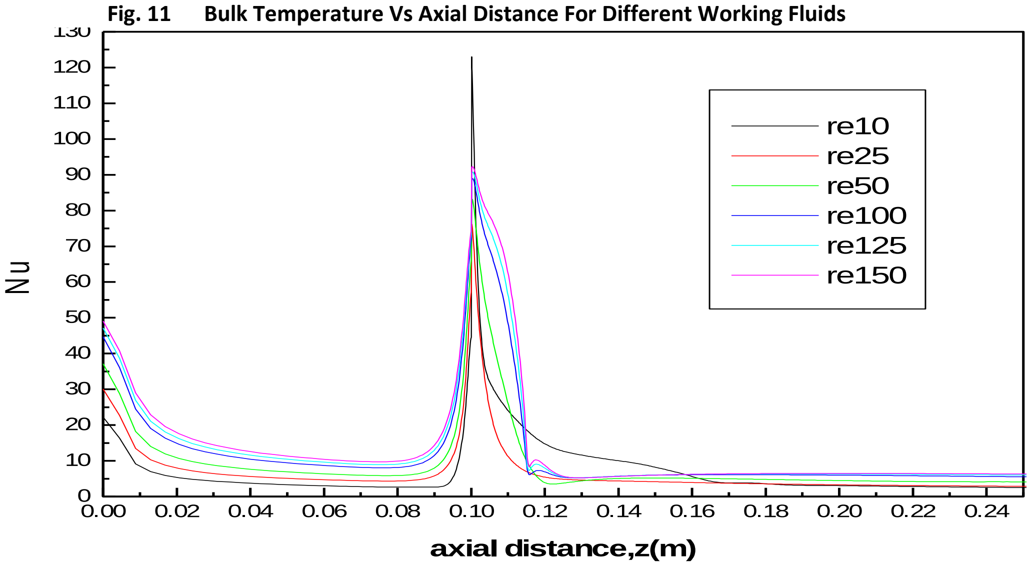

Fig .12 Local Nusselt Number Vs Axial Distance For Different Reynolds Numbers

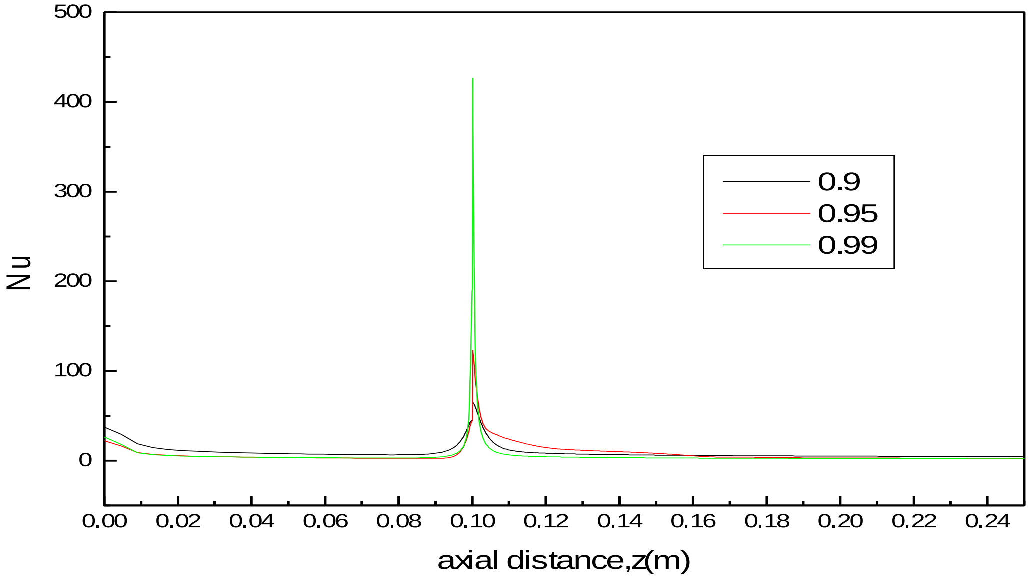

Fig. 13 Local Nusselt Number Vs Axial Distance For Different Disk Radii

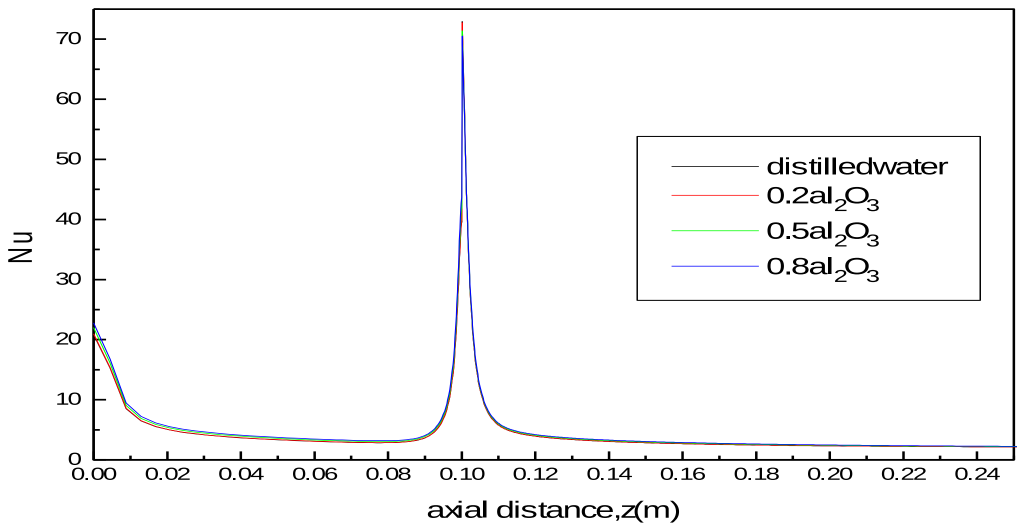

Fig. 14 Local Nusselt Number Vs. Axial Distance For Different Working Fluids

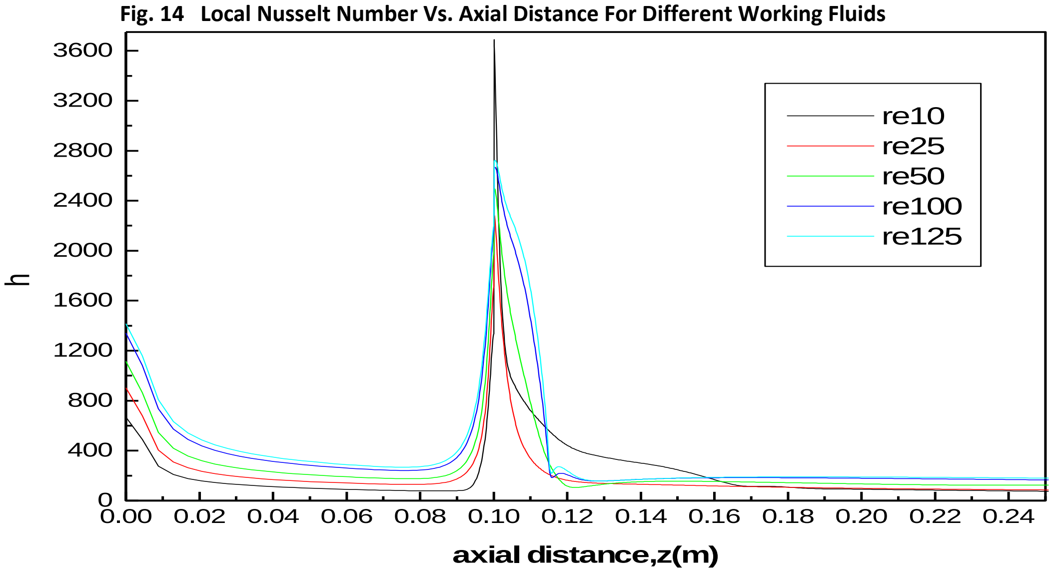

Fig. 15 Local Heat Transfer Coefficient Vs Axial Distance For Different Through Flow Reynolds Numbers

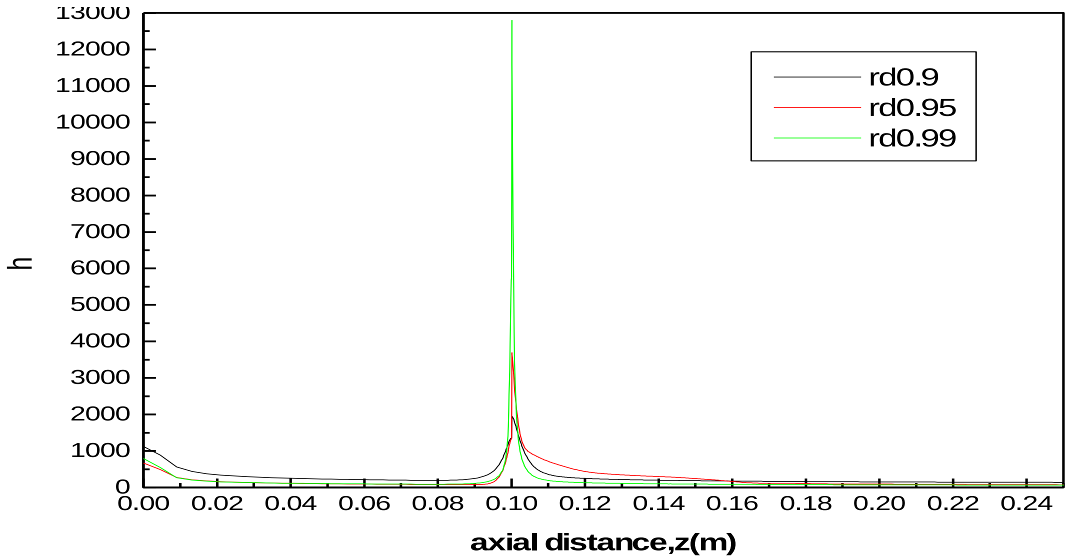

Fig. 16 Local Heat Transfer Coefficient Vs Axial Distance For Different Disk Radii

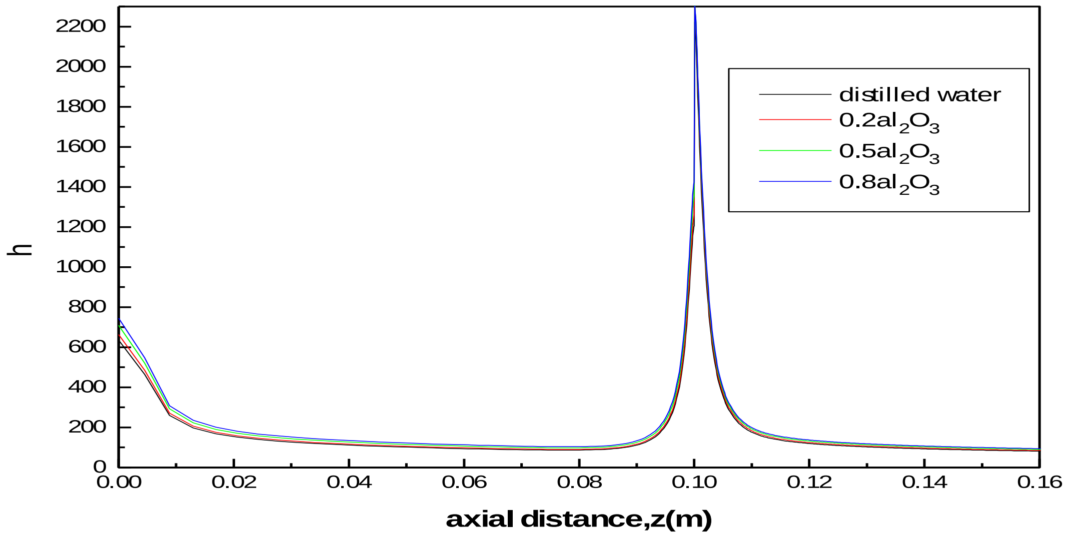

Fig. 17. Local Heat Transfer Coefficient Vs Axial Distance For Different Working Fluids

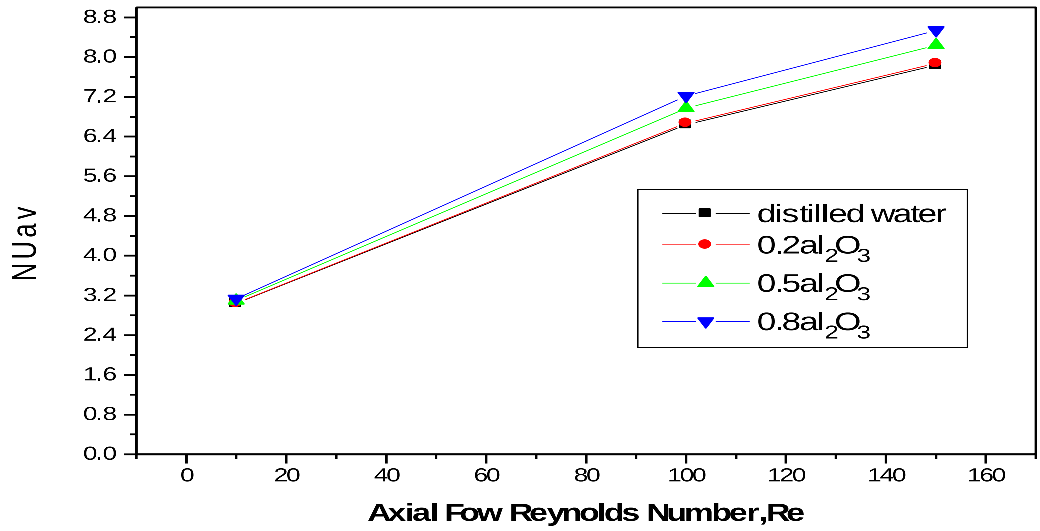

Fig. 18 Average Nusselt Number Vs Axial Flow Reynolds Number For Different Working Fluids.

Reynolds number	Average Nusselt number		Percentage increase in avg Nu	Avg Nu 0.5%al2o3	Percentage increase in avg Nu	Avg Nu 0.8%al2o3	Percentage increase in avg Nu
	water	0.2%al2o3					
10	3.042218	3.046626	0.14%	3.09296	1.66%	3.134219	3.0%
100	6.639875	6.673749	0.51%	6.970232	4.97%	7.217438	8.7%
150	7.835328	7.876901	0.53%	8.23728	5.13%	8.537573	8.96%

Table. 1 Enhancement in average Nusselt number with increasing aluminium oxide nanofluid particle concentration for different Axial flow Reynolds numbers

CONCLUSION

Numerical results have been obtained for steady laminar fluid flow and heat transfer in a pipe with disk and without disk. It is observed that the presence of the disk has profound impact on the flow and heat transfer characteristics especially in the downstream side of the disk. The percentage increase in the average Nusselt number when 0.5% aluminium oxide nanofluids is used in the case of stationary disk is 5.13%.The percentage increase in the average Nusselt number when 0.8% aluminium oxide nanofluids is used in the case of stationary disk is 9%.

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