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NUMERICAL INVESTIGATION OF HEAT TRANSFER UNDER IMPINGING ANNULAR JETS

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Abstract

In the present work, numerical investigations have been done to predict the transport phenomena and heat transfer characteristics of laminar annular jets impinging on a surface. For analysis purpose, the characteristics of an annular jet has been compared with that of a circular jet at the same Reynolds number with same amount of mass and momentum efflux at the nozzle exit. The Reynolds number of the jet is defined on the basis of width of the annular part. The distribution pattern of the Nusselt number over the impinging surface scales with $Re^{0.54}$.

Keywords
Heat transfer, Impingement, Numerical methods, annular jet, Laminar flow.

1. Introduction

Jet impingement is flow capable of achieving the maximum heat transfer rate between a fluid and a solid wall. Transport phenomena and heat transfer on a surface by impinging jets are of great interest among the researchers for solving problems of fluid flow and also it is very much important in various industrial applications. The applications of impingement of jets are on heating, cooling and drying body as well as in paper and textile industries, metals manufacturing, food processing, combustors of gas turbines, and waste heat recovery through water-driven steam injector (Chattopadhyay, H. et. al. 2004, 2007, 2011, Travnicek Zdenek et. al. 2004 and Zhang Zhao et. al. 2012) among others.

The study on the characteristics of heat transfer of annular jets is extremely scarce though extensive research activities has taken place with regard to circular jets (Jambunathan, K et. al. 1992 and Martin. H, 1990).

A study on the laminar annular jet has been performed by Chattopadhyay , H (2004) with jet location at r = 0.5–0.707 and the Nusselt number distribution model on the impinging surface scales with $Re^{0.55}$. It was establish that about 20% heat transfer more from the circular jet compared with the annular jet.

The annular portion area is considered to be equal to the area of circular portion with the diameter as characteristics length. A transition SST based model is used to solve the governing equations of mass, momentum and energy for simulating the flow phenomena.

Figure 1 shows the computational domain of annular jet. For solving momentum, mass and energy equations an axi-symmetric formulation has been used with SIMPLE algorithm.

Reynolds number has been varied from 100 to 50000; and the jet location of the annular zone has been varied for three ranges (r = 0.5-0.707, r = 1.0-1.11803 and r = 1.5-1.5811) for a fixed height (h=1.0). The distribution of Nusselt number and skin friction coefficient has been found to be strongly influenced by these parameters. The total heat transfer reduces for the case of annular jets and the distribution of heat fluxes over the surface becomes relatively uniform compared to circular jet. The flow transition to periodicity at higher Reynolds number has also been reported.

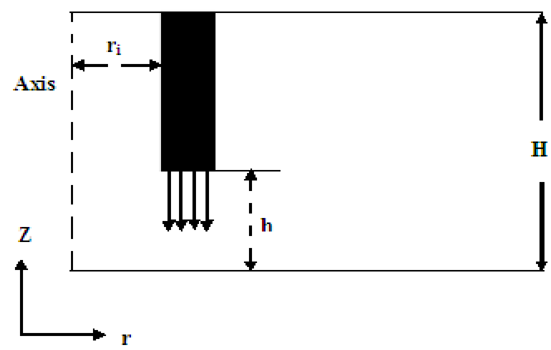

Figure 1: Computational domain of annular jet.

2. Mathematical Formulation

In the present study, working fluid is taken as air (Pr = 0.71) and jet flow is considered incompressible with constant properties.

With rotational symmetry the no-dimensional equations are:

Continuity equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(ru)+\frac{\partial w}{\partial z}=0 \tag{1}$$

Momentum equation in radial direction:

$$u\frac{\partial}{\partial r}(u)+w\frac{\partial}{\partial z}(u)-\frac{u^2}{r}=-\frac{\partial p}{\partial r}+\frac{1}{\mathrm{Re}}(\nabla^2 u) \tag{2}$$

Momentum equation in axial direction:

$$u\frac{\partial}{\partial r}(w)+w\frac{\partial}{\partial z}(w)=-\frac{\partial p}{\partial r}+\frac{1}{\mathrm{Re}}\nabla^2 w \tag{3}$$

Energy equation:

$$u\frac{\partial T}{\partial r}+w\frac{\partial T}{\partial z}=\frac{1}{\mathrm{Re}.\mathrm{Pr}}\nabla^2 T \tag{4}$$

The SIMPLE formulation (Patankar, S.V., 1980) using the commercial code FLUENT 15.0 was used to solve all the relevant equations.

3. Results and Discussion

All the simulations that have been done and the results obtained in this work are based on the model sketch of the annular jet as described in figure 1.

The skin friction coefficient (C_f,) is:

$$C_f = \frac{\tau_s}{\frac{1}{2}\rho w_\infty^2}$$

Where**Error! Reference source not found.** is the shear stress on the impinging surface?

In this work, for the non- dimensionalization that we have considered, the skin friction coefficient can be finally expressed in terms of the velocity gradient, i.e, **Error! Reference source not found.**

The Nusselt number that can be calculated by the local gradient of temperature using $Nu = -\frac{\partial T}{\partial Z}$ measures the heat transfer performance whereas the average of Nusselt number is obtained by Nu_{av} = -Nu(r) ∂r/L, where L is the length of the computational field in r direction.

Figure 2 shows the trends of Nusselt number with increase in Reynolds number for both circular and annular jet though for annular jet Nusselt number comparatively lesser with increasing r_i than that of circular jet. It has been observed that heat transfer of the annular jet at about 30% less compared to the circular jet.

In Figure 3 the transition zone is predicted for an annular jet with r= 1.5–1.5811. It was found that the range of transition is from Re = 700 to 6000.

Figure 4 shows distribution of Nusselt number for jet impingements with different Reynolds numbers. From the study, it can be understood that the value of Nusselt number at first increases and becomes maximum at the value of inner radius of nozzle (r = 0.5-0.707) of 0.8 for the annular jet and then reduces monotonically. The effect of jet height and jet location on the performance of global and local heat transfer is studied.

The allocation of the skin friction coefficient of an annular jet and circular jet at the Reynolds number of 750 has been presented in Figure 5. Here the distance of the jet is, h = 1.0. It is evident from the Figure that at all locations, C_f value for the circular jet is higher which indicates higher shear stress for circular jets. For such a circular jet, the value of C_f at first increases and then reduces consistently. In case of an annular jets, C_f distribution has two local minima, one at the axis (r=0.0) and the other at the stagnation point. The distribution curve then increases and then reduces continuously.

The distribution of C_f at different Re of the annular jets with r = 0.5-0.707 is depicted at Figure 6 that shows that the profile becomes analogous.

The difference of heat transfer is presented at Figure 7. For annular jets the entire peak value occurs with more value of r compared to each and other.

In Figure 8, the distribution of velocity vector at inlet of the annular jets with r = 1.0–1.118 at Re=1000 is presented.

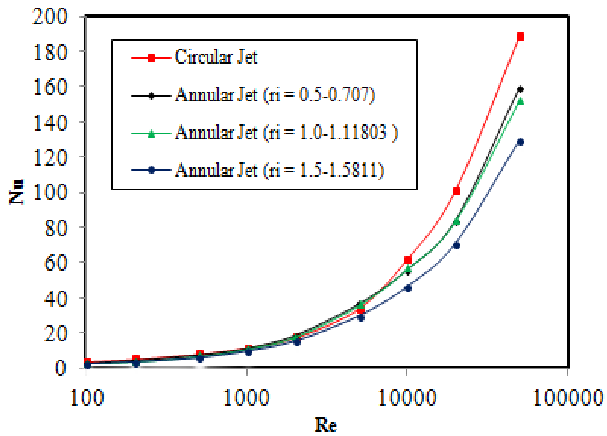

Figure 2: Variation of Nu with Re for Circular Jet and Annular Jet (with different r)

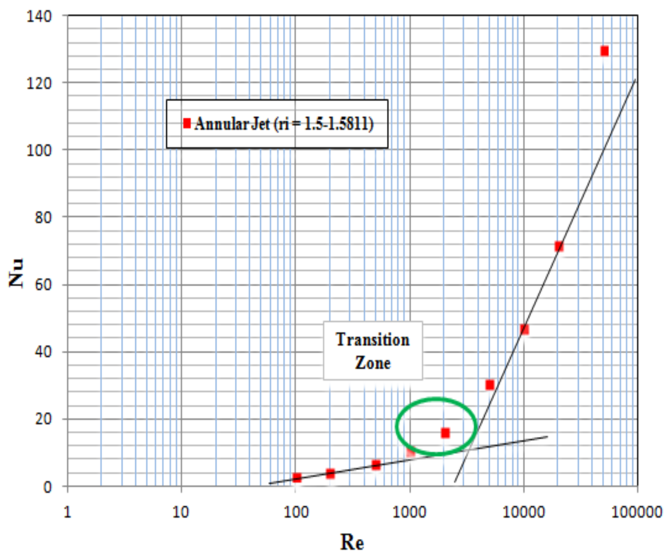

Figure 3: Predicting Transition of an Annular Jet with r= 1.5‑1.5811

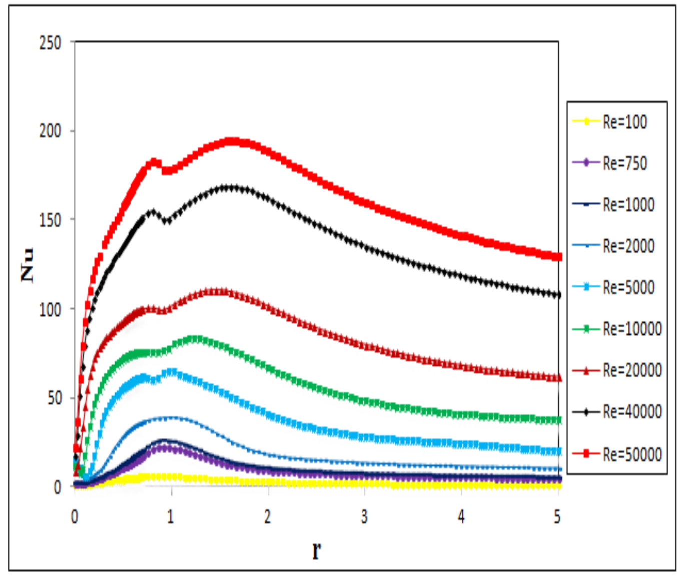

Figure 4: Allotment of Nu at different Re for an Annular Jet with r = 0.5‑0.707.

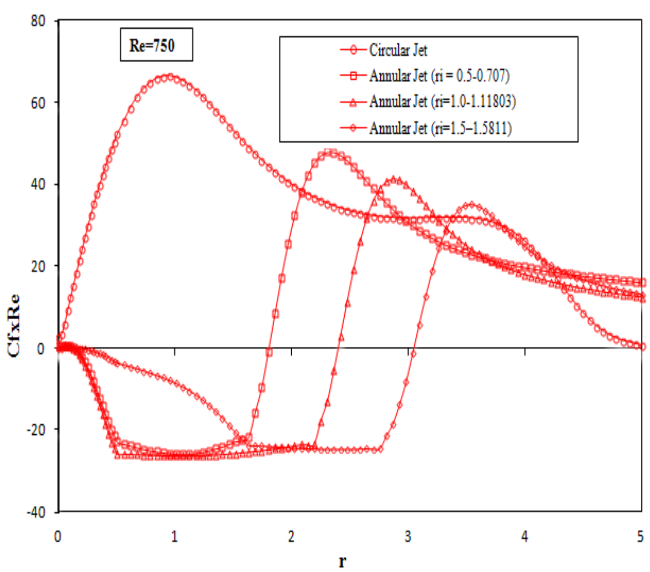

Figure 5: Distribution of C_f for Circular Jet and Annular Jet (with different r) at Re = 750

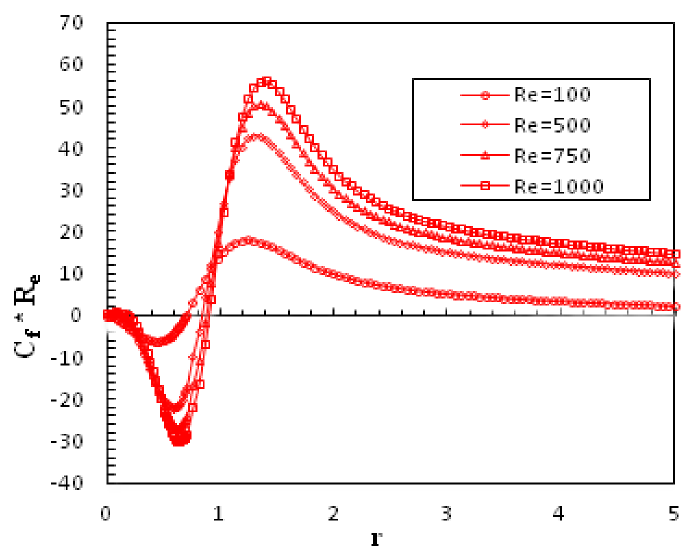

Figure 6: Allotment of C_f at different Re for an annular jet (location of annular jet at r = 0.5 ‑ 0.707).

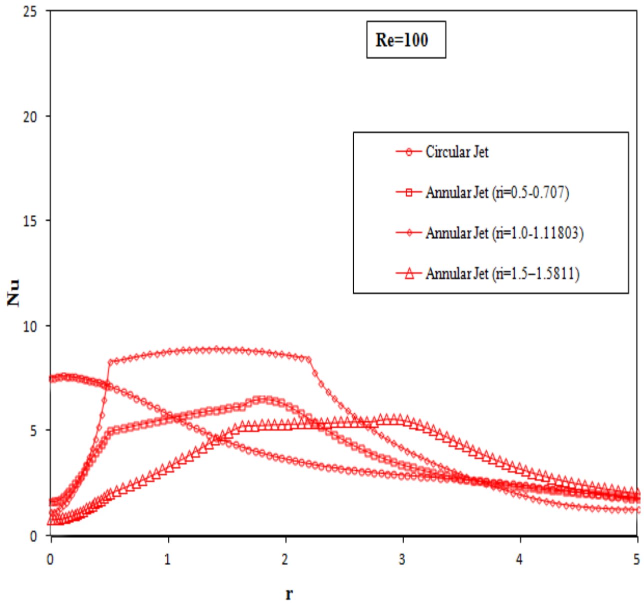

Figure 7: Distribution of Nu for Circular Jet an Annular Jet (with different r) at Re = 100

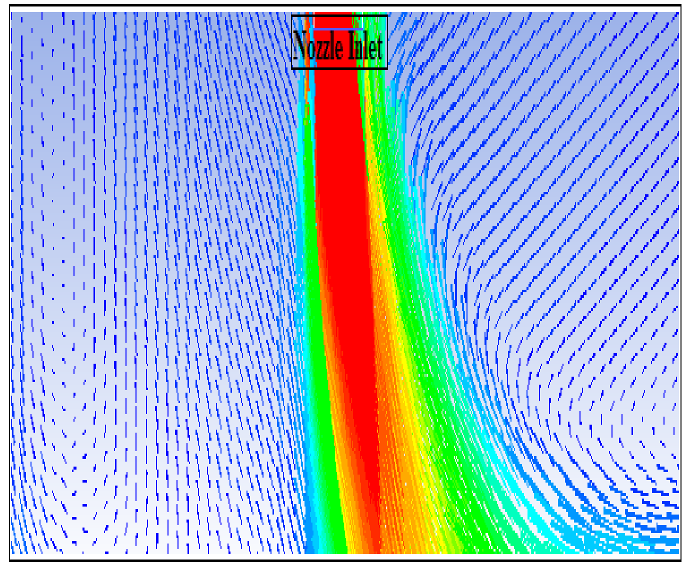

Figure 8: Velocity vector at inlet of Annular Jet (r= 1.0- 1.118) with Re=1000

4. Conclusion

In the present study, numerical investigations have been carried out to predict the transport phenomena of impinging laminar annular jets over a surface. With comparison between annular and circular jets at same value of Re and for fixed height at nozzle exit, it has been observed that the Nusselt number becomes lower compared to circular jets in our considered study. Therefore, it concludes that the heat transfer distribution may be lower in case of annular jets.

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