CONVECTIVE FLOW OF POWER-LAW FLUIDS ACROSS A PAIR OF TANDEM CIRCULAR CYLINDERS IN CONFINED ARRANGEMENT

In partial fulfillment for the award of degree

of

MASTER OF TECHNOLOGY

in

CHEMICAL ENGINEERING

(With specialization in Computer Aided Process Plant Design)

Submitted by

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JUNE 2013

DECLARATION

I hereby declare that the work being presented in the dissertation report entitled “convective flow of power-law fluids across a pair of tandem circular cylinders in confined arrangement” in partial fulfilment of the requirements for the award of the degree of Master of Technology in Chemical Engineering (specialization in Computer Aided Process Plant Design) and submitted to the Department of Chemical Engineering of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during the period from May 2012 to June 2013 under the supervision of Dr. R.P. Bharti, Department Of Chemical Engineering, Indian Institute Of Technology Roorkee, Roorkee, India.

The contents presented in this report has not been submitted by me for the award of any other degree of this or any other institute

Place: Roorkee   Sharad Tiwari

Date: 14/06/2013   Enrollment.No.11514020

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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Date-14-june, 2013

ACKNOWLEDGEMENT

I wish to express my sincere gratitude and appreciations to Dr. R.P. Bharti, Department of Chemical Engineering, Indian Institute of Technology Roorkee, Roorkee for providing me an opportunity to work under his guidance. Their valuable guidance with enriched knowledge, regular encouragement and invaluable suggestions at every stage of the present work has proved to be extremely beneficial to me. I consider myself fortunate to have had the opportunity to work under his able guidance and enrich myself from their depths of knowledge.

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ABSTRACT

In this work the steady flow of power law fluids across a pair of circular tandem cylinder has been studied numerically. The governing equations has been solved by FVM based solver FLUENT. In this work the effects of Power Law Index (0.2 to 1.8), Reynolds Number (1 To 40), Prandtl Number (1 to 100), Gap Ratio (2 to 10) and Richardson number (0 to -3) and their effect on local ang global characteristics such as streamlines, vorticity profile, isotherm velocity between two cylinder and pressure coefficient has been studied numerically. With increase in the shear thinning effect that is increasing the n the separation of flow took a longer time whereas the early flow separation occurred in case of power law index equal to 1 or less than 1.the pressure coefficient on the surface of cylinder showed a close relation with power law index, Reynolds Number and gap ratio but the effect of Richardson Number did not alter it significantly. The nusselt Number showed a close correlation with the Reynolds Number and Prandtl Number. The changes in Prandtl Number affected Nusselt Number significantly but it's effect on other coefficient such as Drag Coefficient and pressure coefficient were not significant precisely it did not alter these values a little bit but when Richardson Number Became negative it showed a little change. The drag coefficient values of individual cylinders came out to be smaller than the values of single Cylinder. The downstream cylinder was critically afeected by the changes in Gap Ratio. As the gap ratio was kept smaller i. e. 2 or four the effects of upstream cylinder was high on downstream cylinder but for higher values of gap ratio the downstream cylinder started behaving like individual circular cylinder. The effect of change of Richardson number can be easily seen in the streamline, vorticity and isotherm profiles.

Chapter-1

INTRODUCTION

1.1 MOTIVATION

In past time scholars have studied Newtonian and non-Newtonian fluids across a circular cylinder or across other geometries because of its practical applications. For the prediction of design outlet of an instrument or an assembly of instruments or engineering structure like ocean pipelines, heat transfer instruments like heat exchanger distillation column etc. In polymer melt operation also the flow characteristics and forces acting on bodies immersed in fluids are also needed to design or an appropriate design outlet is needed for the construction of an optimum economical instrument or operation. Moreover, this geometrical numerical method has also been used to validate numerical solution methodologies and to assess the efficiency of various numerical algorithms. Over the past few decades, several excellent reviews and even entire books have been written on this geometric configuration (e.g., Ghosh et al., 1994; Zdravkovich, 1997, 2003, etc.).

This simple flow can be studied in wide variety of forms for example laminar, turbulent, uniform and non-uniform. And geometries incorporated in the flow also varied and its effect on the flow profile depends on its size, geometries (circular or noncircular), physical characteristics of flow (Reynolds number, Prandtl number, Richardson number), flow configuration (confined or unconfined) and on fluid behavior (Newtonian or non-Newtonian).

Moreover In addition to this, the type of boundary layer i.e. constant wall temperature (CWT) or uniform heat flux (UHF) also affect the rate of heat transfer from cylinder to streaming fluid. It is well known that many materials exhibit a range of non-Newtonian flow

1.2 NEWTONIAN FLUIDS

When stress versus strain curve is linear for a fluid and it also passes through the origin then it is called Newtonian fluid. And the slope of the curve passing through origin is called the Newtonian viscosity and this slope of the curve is independent of shear rate or shear stress at a given temperature and pressure. Examples are air and other different gases, water and most of the substances having low molecular weights and organic liquids.

1.3 NON-NEWTONIAN FLUIDS

The fluids whose flow properties vary from that of Newtonian fluids are known as Non-Newtonian fluids. In other words, for these type of fluids stress versus strain curve is not constant at a given temperature and pressure. Slope of the shear stress versus shear strain curve is not constant, i.e., the viscosity is not independent that of shear rate or shear stress. A detailed literature is available on the non-Newtonian fluids and their classification in various texts (Chhabra and Richardson, 2005).

1.4 TIME-INDEPENDENT FLUIDS

The fluids that are function of shear rate and do not follow Newton's Law of Viscosity comes under this category. These types of fluids are called as time independent fluids. These types of fluids can be further divided into following classes on the basis of stress strain curve.

(a) Shear–thinning or pseudo plastic

In shear-thinning fluids apparent viscosity decreases with decrease in shear rate. The pseudo plasticity increases as slope of curve decreases. The examples of pseudo plastic fluids are high molecular weight polymers (solutions, melts, blends) and multiphase mixtures (solutions, melts, blend, etc.).

(b) Shear – thickening or dilatant

In shear-thickening fluids the apparent viscosity increases with increase in shear rate. Only some fluids such as corn flour in water, kaolin in water, suspensions of beach sand, etc. exhibits this kind of behavior.

(c) Viscopelastic fluids

These type of fluids have a unique property by virtue of that minimum stress developed must exceed before fluid starts to deform. If this stress surpasses the yield stress then flow curve may be linear or non-linear, but it will not pass through origin. The property exhibit by the fluid as solid or liquid is depend upon the distribution of shear stress and yield stress that means if former is greater than the later if yield stress is greater than shear stress and vice-versa. Examples of viscoplastic fluids include chocolates, meat extract, carbopol solutions, paints, foams, etc.

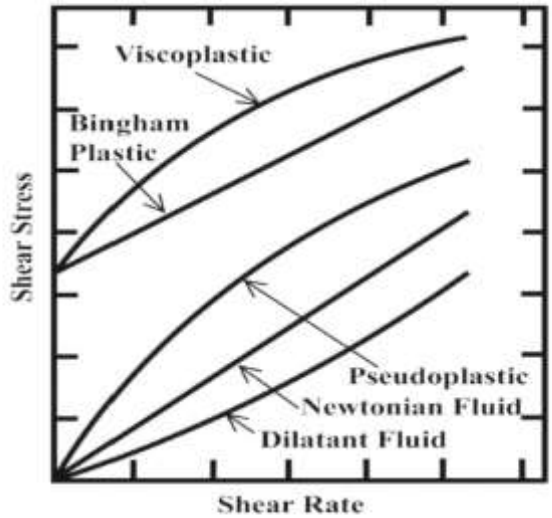

Figure 1 Rheogram for non-Newtonian fluids (Chhabra and Richardson, 1999)

1.5 PROBLEM STATEMENT

In this problem we considered here a pair of circular cylinder in tandem arrangement in which the cylinders are at constant temperature. The temperature of the cylinder is greater than the temperature of the fluid flow in confined arrangement. The temperature change is related to density means a significant change of temperature may change the density significantly. So in this case because the fluid is liquid so we can assume density dependency on temperature by Boussinesq approximation as $\rho = \rho_0[1-\beta(T-T_0)]$, where β is the coefficient of volumetric expansion at a constant pressure and ρ_0 is the density at a reference temperature which is T_0 I this case. The temperature difference between the fluid and two cylinders is kept constant that is 10 ^{o}C. The fluid viscosity is dependent on the temperature gradient between the cold fluid and hot cylinder and in this case the temperature has been kept less than desired so it would be appropriate to take viscosity constant. So it is justified to neglect the variation of the physical properties notably density and viscosity with temperature. CWT condition is maintained at the cylinders that mean a constant temperature throughout the operation and CHT condition that is constant heat flux condition has been maintained at parallel walls i. e. upper and lower wall. D is the diameter of the cylinders and the gap between two cylinders is represented by G (G=L/D), H is the height of confined arrangement that is the distance between two parallel walls, L is the distance between the centers of two cylinders and L_u is the distance from inlet to first cylinder.

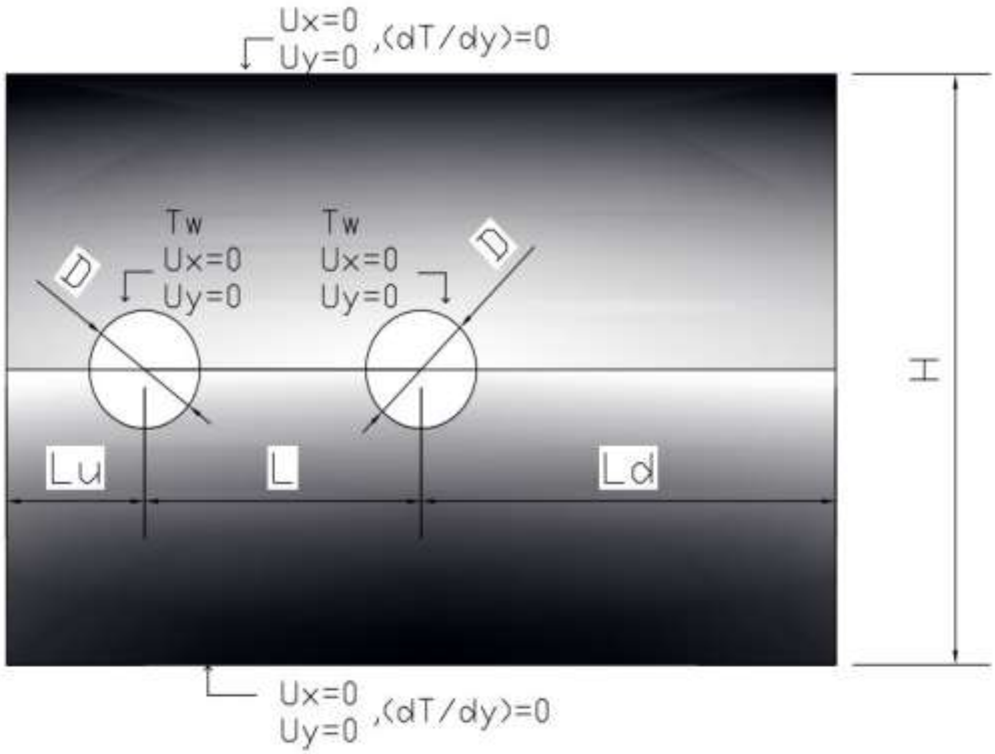

Fig.2 Schematic of the confined circular cylinders in tandem arrangement

u_x, u_y *x*- and *y*-components of the velocity, m/s

T_o Temperature of the fluid at the inlet, K

T_w Temperature of the surface of the cylinder, K

L_u Distance of first cylinder from inlet

L_d Distance of second cylinder from outlet

H Distance between upper and lower wall

L Distance between two cylinders

D Diameter of two cylinders

1.5 ORGANIZATION OF DISSERTATION

This dissertation is divided into five chapters. The introduction part and detailed description of fluids is given in Chapter 1. Chapter 2 deals with the previous work which is available in different papers and literature thar has been done to study the momentum and heat transfer characteristics of flow of fluid across a cylinder. In Chapter 3 that is named as numerical methodology and where the governing equations are presented with boundary conditions along with solution methodology. In chapter 3 development of model using GAMBIT and further solution procedure in FLUENT has also been discussed. In Chapter 4, the model has been validated with the results given in literature and then final results with detailed explanation are given. And in last chapter that is in chapter 5 conclusions are given along with the recommendations for future study.

CHAPTER 2

LITERATURE REVIEW

This chapter presents an overview of various aspects including the flow regimes associated with the flow past a circular cylinder, which helps in the basic understanding of the flow phenomena. It is further followed by a brief literature review available for the flow and heat transfer across a cylinder in different configurations.

2.1 BLUFF BODY

Bluff Bodies are the bodies around which streamlines are not continuous and break with sharp changes in parameters for example velocity. Bluff bodies may have sharp edges such as flat plates, rectangular, and polygonal cylinders or bluff bodies may also have round structure like spheres and circular, elliptical cylinders.

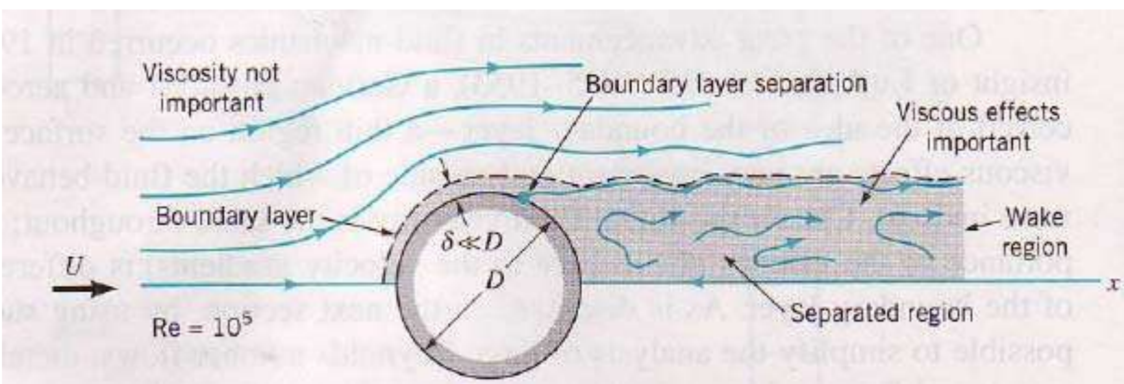

Fig.3: Bluff body flow: flow around bluff bodies with flow separation. (ref. 58:160 Intermediate Fluid Mechanics Professor Fred Stern Fall 2009)

2.2 STREAM LINE BODY

A Streamline Body is a body in which the drag force resulted directly from the viscous or skin friction of the fluid on the body. A thin flat parallel plate on to the oncoming flow is a streamline body since the flow is attached to the surface and skin friction accounts for up to 90 per cent of the total drag.

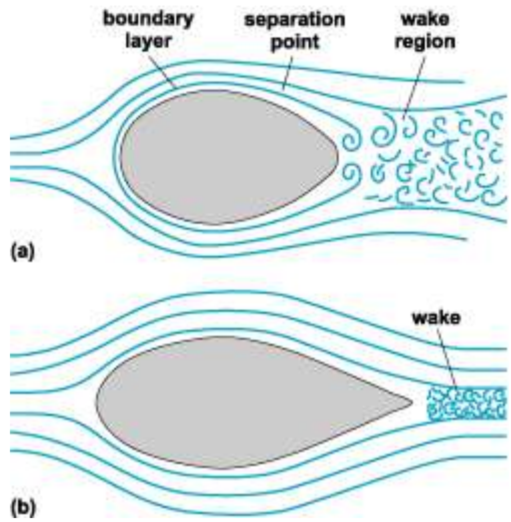

Fig.4 Streamline Flow (ref. Unitech labs)

2.3 GOVERNING PARAMETERS

A detailed description of all governing parameters will be provided in this section. All dimensionless number which has a relation with this study will be discussed in this section along with their numerical formula.

Reynolds Number (Re): It is a dimensionless number which is the ratio of inertia force to that of viscous force. Reynolds number generally signifies the velocity of the flowing fluid if the other variables are constant. So it is an important governing parameter in fluid flow.

$$\mathrm{Re} = \frac{\rho D^n U_{avg}^{2-n}}{m}$$

Prandlt Number (Pr): It is a dimensionless number which is the ratio of viscous diffusion rate to the thermal diffusion rate. It does not have length variable in its formula hence it is constant for constant physical parameters where the length is changing.

$$pr = \frac{C_p m}{k} \left(\frac{U_{avg}}{D}\right)^{n-1}$$

Nusselt Number (Nu): it also belongs to the group of dimensionless number and is the ratio of convective to conductive heat transfer.in case of laminar flow the value of Nusselt number approaches to unity.

$$Nu = \frac{hD}{k}$$

Peclet Number (Pe): it is also a dimensionless number which is important in the study of transport of heat and mass energy. In case of transport of heat energy it is product of Reynolds number and Prandtl number and in case of transport of mass energy it is product of Reynolds number and Schmidt number**.**

$$Pe = \mathrm{Re} \times \mathrm{Pr} = \frac{\rho C_p U_{avg} D}{k}$$

Grashof Number (Gr): it is a dimensionless number which is the ratio of buoyancy force to the viscous force.

$$Gr = \frac{g\beta \Delta T \rho^2 D^3}{m^2} \left(\frac{U_{avg}}{D} \right)^{2(1-n)}$$

Richardson Number (Ri): it is dimensionless number which represent the gravity effect on the flow. If the Richardson number is less than unity the gravity effect can be neglected**.**

$$Ri = \frac{Gr}{\mathrm{Re}^2} = \frac{g\beta \Delta T D}{U_{avg}^2}$$

2.4 REFFERED LITERATURE

Although the information on momentum and heat transfer from a pair of tandem cylinder in confined arrangement is not available extensively but a wide range of study has been done for single cylinder in confined and unconfined arrangement for steady flow regime (for instance, see Bharti et al. 2005, 2006, 2007; Patnana et al. 2010; Sivakumar et al. 2006). Recent studies have done with several modifications like several studies have done for some other type of geometries for instance square cylinders, hexagonal cylinders. Certain studies have also done for vortex dynamics and drag and heat transfer characteristics of power law fluid in unconfined and confined flow configuration for wider range of Reynolds numbers (40<Re<140), Power Law Index (0.4<n<1.8), and Prandtl numbers (1<Pr<100) i.e. (Patnana et al., 2009, 2010).

Besides that, several scholars around the globe have done various studies on mixed convection flow across a circular cylinder submerged in power-law fluid (for instance Soares et al.,2005). A concise study of several papers has been done on mixed and forced convection convective flow across a single and a pair of tandem circular cylinder is presented below:

Juncu et al. (2004) has analyzed in his paper which was published in 2004 for the unsteady state heat and mass transfer characteristics of a circular cylinder placed in flowing fluid. He carried out numerical study for Re (2 to 20) for different value of Prandtl numbers. The ADI method was used to solve the heat and mass balance equation in cylindrical coordinates. In his investigations he analyzed that there were two types of fluid profile i. e. for Re<5 the flow was steady and there was no separation but for Re>5 two symmetric vortices formed behind the cylinder.

Chakraborty et al. (2004) has analyzed numerically the steady flow of an incompressible flow in his paper which was published in 2004. In his paper he studied Newtonian incompressible fluid across a circular confined cylinder in a plane and rectangular channel with the help of FLUENT 6.3 and carried out steady state analysis for different values of Re for uniform inlet velocity. He carried out his analysis for quite high value of Reynolds number (0.1 to 200) that were mostly avoided by many researcher at the initial period of CFD research. He also varied blockage ratio extensively (for instance 1 to 20). In his research he found out that the Drag coefficient decreased with increase in Reynolds number and increase in pressure drag with increase in blockage ratio was more significant than friction drag. And hence an expression for C_D as a function of the blockage ratio was developed.

Bharti et al. (2005) has analyzed forced convection heat transfer in his paper for non-Newtonian power law fluids across a cylinder (circular geometry). The arrangement was kept unconfined means the vicinity around cylinder tend to have infinite area. Cylinder was placed symmetrically within two boundaries. The boundaries were parallel and the flow regime was cross. He studied forced convection heat transfer for wider range of physical parameters such as Reynolds number upto 40, Power law index (0.8, 1, and 1.2), Prandtl number (1 to 10) and he also studied the streamlines, isotherms, vorticity and viscosity pattern on the surface of the cylinder. All governing equations were solved by semi implicit FVM and QUICK scheme.

Bharti et al. (2006) published a paper in 2006 in which he kept a circular cylinder in unconfined arrangement across which a power law fluid was flowing. The physical parameters were settled so that a cross flow regime was maintained. He solved the momentum equation for the above explained assembly. He investigated the whole process by finite volume method. He presented the process for the following values of parameters such as he varied Reynolds number from 5 to 40, Power Law Index from 0.6 to 1.8 and a wide range of prandtl number. In his study he found out that wake formation drastically influenced the value of drag coefficient. He also calculated pressure coefficient, vorticity on the surface of the cylinder.

Sivakumar et al. (2006) published a paper in 2006 in which he kept a circular cylinder in unconfined arrangement across which a power law fluid was flowing. He solved numerically the momentum and energy equation with the help of solver FLUENT 6.3. in his study he investigated the conditions which causes the formation of wake. He also observed the effect of Power Law Index on Reynolds number, Strouhal number for a wider range of Power law index. In his study he varied power law index from 0.3 to 1.8.

Bharti et al. (2007) published a paper in 2006 in which he kept a circular cylinder in unconfined arrangement across which a power law fluid was flowing. The conditions were settled for the occurrence of forced convection i. e. the effect of gravity was kept negligible in the investigation. He used Finite Volume Method for his study. He varied the physical parameters for a wider range which are as follows: Re (10 to 45), Pr (0.7 to 400). He also developed the correlation on Nusselt number with other dimensionless parameters. He found out in his study that as he increased the Reynolds number and Prandtl number the rate of heat transfer also get increased. One interesting thing also noticed by the study is that the for constant values of Reynolds number, constant heat flux condition showed a higher value of heat transfer coefficient in comparison of constant temperature condition.

Bharti et al. (2007) published a paper in 2006 in which he kept a circular cylinder across which a incompressible power law fluid was flowing. Flow in this case was a Poiseuille flow. They placed the circular cylinder symmetrically in between two plates. They solved continuity and momentum equation for the flow. He analyzed the results for a wider range of physical parameters such as he varied Reynolds number from 1 to 40 and Power Law Index from 0.2 to 1.9. While the study he found out that for constant value of blockage ratio drag coefficient get increased. As we know that for Power law index less than one the process is shear-thinning and for Power law Index greater than one the process is shear-thickening. This thickening and thinning effect prevailed for low value of Reynolds numbers only and as they increased the value of Re this effect diminished. Although the process was confined but the pressure profile was quite similar to that of unconfined flow. A decreasing wake size with increase in the value of Power Law Index was observed. The wall effects on the flow was quite high and it was due to wall effect the wake formation was delayed.

Diman et al. (2007) in this process they studied a heated square cylinder across which Newtonian Power law fluid was flowing and the condition was mixed convective. Buoyancy effect was simulated with boussinsq approximation. They formed a non-uniform grid structure and used semi implicit finite volume method. They varied the physical parameters on wider range which are as follows: Re (1 to 30), power-law index: (0.8 to 1.5), Prandtl number (0.7 to 100) and Richardson number from (00.5). in this study they found out that the effect of Prandtl number and Power Law index was more significant than Richardson number. The effect of Richardson's number on total drag was also found to be weak.

Soares et al. (2009) they studied circular cylinder across which power law fluid was flowing. The flow conditions were mixed convection heat transfer. The continuity, momentum, and thermal energy equations were solved numerically. They used a second order finite difference method for solution of these differential equations. The local and average surface values of Nusselt Number were obtained for following ranges of conditions: Power law index (0.6, 0.8, 1, 1.6), Prandtl number (1 to 100), Reynolds number (1 to 30) and Richardson number from (0, 1, 3). They found out that the drag coefficient decreased as they increased the value of Reynolds number.

Srinivas et al. (2009) they established a mixed convection heat transfer condition across an isothermally heated circular cylinder across which incompressible power law fluid was flowing. The buoyancy force and flow was in same direction that is the condition was settled as aiding buoyancy condition. The momentum and energy equations were solved numerically using finite volume based FLUENT solver. The physical parameters were varied as follows: Richardson number ($0 < Ri < 2$); Power-law index ($0.2 < n < 1.8$) and Reynolds number ($1 < Re < 40$). They noticed that the wake size decreases with increase in the value of Richardson number.

Singh et al. (2010) have published their paper in 2010 in which they studied the flow across a circular cylinder which was placed symmetrically. They generated an unstructured grid for numerical calculation. They used Navier–Stokes solver. They varied the physical parameters as follows: Reynolds Number (45, 100, 150, 200 and 250), (H/ D) from (2.0 to 8.0). The effect of walls was significant in this case which resulted for the transition of steady flow to unsteady flow. As the height of the channel increased the effect of sidewalls became weak. The effect of sidewalls was most prominent for the H/D ratio 4. With increase in channel height the value of Strouhal number and drag coefficient get decrease

Patina et al. (2010) has studied in their paper a circular cylinder in unconfined arrangement. The arrangement was two dimensional and grid was non uniform. He solved the momentum and energy equation using FVM based FLUENT solver. He varied the physical parameters as follows: Power law index ($0.4 < n < 1.8$), Reynolds number ($40 < Re < 140$), Prandtl number ($1 < Pr < 100$). He noticed that floe transition occur in between the following values of Reynolds number i. e. (33 to 50).

Rao 2011) et al. (they investigated the numerical result for a square cylinder which was kept in flowing fluid. A numerical solution of momentum and energy solution was also provided. The emphasis was given to evaluate the Reynolds number at which the floe separation occurs. He varied the physical parameters for the following range: Re ($0.1<Re<40$), Pr ($0.7<Pr<100$), Power Law Index ($0.2<n<1.4$). the effect on Nusselt number by the other physical parameters was studied extensively.

Chandra et al. (2012) they investigated a submerged semicircular cylinder across which a power law fluid was flowing. The study state was maintained throughout the process. The energy and momentum equations were solved for a wider range of physical parameters. He varied Richardson number from 0.0.6 to 2, Power law index from 0.2 to 1.8, Reynolds number from 1 to 30 and

Prandtl number from 1 to 100. The free and forced convection was studied with the help of streamlines and isotherm contours. They did a numerical analysis of average Nusselt number and pressure coefficient on the surface of semicircular cylinder. The value of Nusselt number for low Reynolds numbers observed to be higher at corners. It was observed that the average Nusselt number showed a direct relationship with Reynolds number**.**

Sharma et al. (2012) they studied the mixed flow condition across a square cylinder submerged in the flowing fluid was entitled to aiding buoyancy condition. Semi implicit finite volume method was adopted for the numerical analysis. The flow separation was observed to be increased Reynolds number as the value of Richardson number for example the flow separation occurred for Re 0-1 at zero Richardson number but for Ri 0.5 the separation occurred at Re2-3. As the Richardson number increased it was observed that the values of drag coefficient, total drag coefficient and pressure coefficient get increased. The detailed study was done for heat transfer with the help of local and average Nusselt number.

CHAPTER 3

NUMERICAL METODOLOGY

3.1 MATHEMATICAL FORMULATION & GOVERNING EQUATIONS

In this chapter we described the mathematical equations which are used in this work and other governing equations such as boundary conditions. The geometrical and configurational details of the flow along with the simplifying assumptions, followed by the governing differential equations and the appropriate boundary conditions has been also described.

3.2 MATHEMATICAL EQUATIONS

The flow and heat transfer characteristics are governed by momentum and energy equations. So in the following equations are given here as follows:

1. Continuity Equation

$$\frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}=0$$

2. Momentum Equation:

(a) (x-component)

$$\rho\left(u_x\frac{\partial u_x}{\partial x}+u_y\frac{\partial u_x}{\partial y}\right)=-\frac{\partial p}{\partial x}+\left(\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{yx}}{\partial y}\right)$$

(b) (y-component)

$$\rho\left(u_x\frac{\partial u_y}{\partial x}+u_y\frac{\partial u_y}{\partial y}\right)=-\frac{\partial p}{\partial y}+\left(\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}\right)+\rho_0 g\beta(T_w-T_0)$$

3. **Energy Equation**

$$\rho c_p\left(u_x\frac{\partial T}{\partial x}+u_y\frac{\partial T}{\partial y}\right)=k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)$$

Ux: Velocity in x direction (m/s)

Uy: Velocity in y direction (m/s)

ρ: Density of fluid (kg/m3)

k: Thermal Conductivity (W/m2K)

T: Temperature (K)

p: Pressure (Pa)

Cp: Heat Capacity (J/kg K) τ: Shear Stress (Pa)

3.3 BOUNDARY CONDITIONS

The boundary walls are stationary and a constant heat flux condition has been maintained at both walls. The velocity profile at the inlet is parabolic and kept as constant. The fluid is entering from left hand opening and is named as INLET in gambit and inlet properties has been settled for fluid there. A constant temperature conditions has been maintained at two cylinders and no slip condition is there. The symbolic representation of all boundary conditions and equations used are as follows:

Boundary conditions at inlet

$$U_x = U_\infty;\ U_\infty = 0; T = T_\infty$$

Because there is no slip and constant temperature condition at the surface of of cylinders which are as follows:

Dirichlet boundary conditions

At the surface of cylinders

$$U_x = 0;\ U_y = 0;\ T = T_w$$

Neumann boundary condition

Exit boundary condition

$$\frac{\partial U_x}{\partial y} = 0;\ \frac{\partial U_y}{\partial y} = 0;\ \frac{\partial T}{\partial y} = 0$$

Viscosity relation with temperature has been taken from (Soares et al., 2010) and is as follows

$$\mu = Ae^{\frac{E}{R\theta}}$$

Where:

θ (K) is the temperature E is activation energy

R the molar gas constant

In our case the activation energy has to be independent of viscosity and in general most of the fluid obeys this rule for wider range of temperature.

Above mentioned equations are solved using fluid dynamics software (FLUENT) on an appropriate grid arrangement. The solution of these equations has been solved for streamlines, drag coefficients and Nusselt number which are analogous to velocity pressure and temperature.

.3.4 NUMERICAL SOLUTION METHODOLOGY

The above mentioned equations have been solved in fluent on a non-uniform grid structure by QUICK scheme. The non-uniform grid was generated in the GAMBIT.

3.5 MESH GENRATION

The unstructured quadrilateral and triangular cells of non-uniform The unstructured "quadrilateral" cells of non-uniform grid spacing were generated using the commercial grid tool GAMBIT 2.3.16. Meshing near the cylinder has been done fine so that the effect near the cylinder can be observed vividly. The region away from two cylinders has been generated coarser as compared to cylinders to save the time and computations.

The following boundaries are assumed as:

Wall	Upper Wall, Lower Wall and two Cylinders
Velocity inlet	Inlet
Outflow	Outlet

The mesh which was generated in GAMBIT contained the boundaries and these boundaries has to be named in GAMBIT as explained previously. After classification of boundaries and zones, the grid has to be exported to FLUENT. The formed grid in pictorial form has been represented in the following figure.

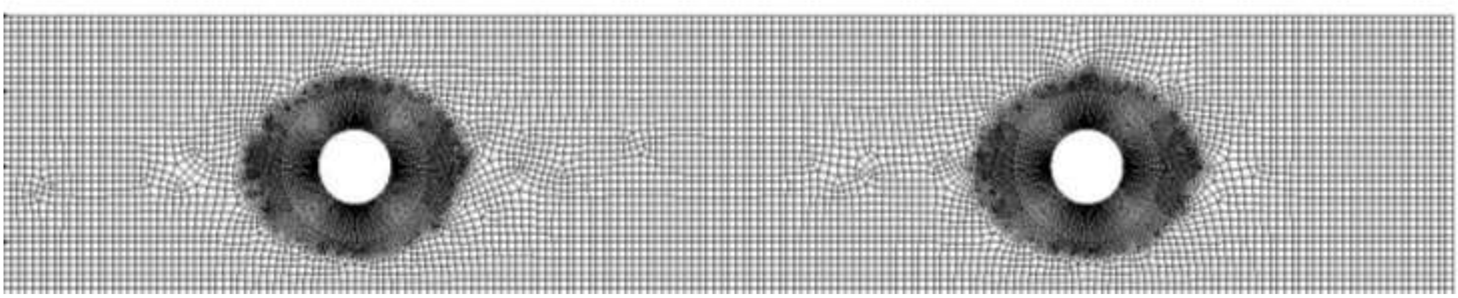

Fig. 5 mesh generated in GAMBIT.

3.6 SIMULATION METHOD ADOPTED IN FLUENT

After importing the case file in fluent from gambit we set the case for the desired values of physical parameters. In fluent we adopted the methods and values of governing parameters according to the requirement, for example if we want to simulate for laminar flow regime we have to set the value of Reynolds number such that the flow maintained a laminar regime and these values are determined by manual calculations. After given all values several approximations are done to simplify the calculations for example to diminish the effect of temperature boussinesq approximation is done in this work. For numerical solution of pressure equation SIMPLE ALGORITHM has been used and for the solution of momentum and energy equation QUICK scheme has been used.

CHAPTER 4

FINAL RESULTS AND DISCUSSION

This chapter has been divided in four parts. In first part domain independence test has been done to fix the grid size and the numerical results have been given in tabular form. In second part grid independence test has been described in detail. In third part the results has been validated with some standard results. And in fourth and last part the final results have been given in tabular form as well as their pictorial description is also given to elucidate the changes and outcomes of the work. The discussion of the results has been described next to every plot and table.

4.1 DOMAIN INDEPENDENCE TEST

Domain independence test is done to fix the domain size of geometry. As there are two cylinders in assembly, the distance between inlet to upstream cylinder is Ld and distance from downstream cylinder to outlet is Lu. So we divide the this test in two parts.

1.In first part we fixed the value of Lu by taking three values of Lu i.e. (10,20 and 30) and take arbitrarily fixed value of Ld i.e. (100). The value of Ld has taken in such a manner so that it is sufficient to settle the disturbances created by cylinders. In this work shift from Lu=20 to Lu=10 and Lu=30 did not show any significant change and hence the value of Lu has been fixed as 20.

2. In second part we did the test to fix the value Ld and after analyzing the results by following same criteria adopted in previous test it has been fixed to 100.

Table. 1 dimension selected for grid independence test.

DOMAIN	Lu	Ld
1.	10	50
2.	20	100
3.	30	150
FIXED VALUE	**20**	**100**

Once the domain get fixed we shift our concentration to fix other variables which are important parameters of the physical dimension of the grid i. e. the number of study points in cylinder, the mesh size which directly depends on the spacing we opted for the mesh generation. And for this a grid independence test has done which will be described in detail in next topics.

Table2: The effect of change of distance of first cylinder to the inlet on drag coefficient, pressure coefficient and on total drag has been given in numerical data form.

GAP RATIO 2										
Lu	Re(n)	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf
10	40(1)	4.8554	4.5618	9.4172	3.1904	2.9897	6.1801	1.6650	1.5721	3.2371
20	40(1)	4.8512	4.5611	9.4124	3.1872	2.9893	6.1765	1.6640	1.5718	3.2358
30	40(1)	4.8587	4.5645	9.4233	3.1925	2.9916	6.1841	1.6662	1.5728	3.2391
10	40(1.8)	6.0371	5.5198	11.5569	3.3754	3.0718	6.4473	2.6617	2.4480	5.1096
20	40(1.8)	6.0376	5.5215	11.5591	3.3755	3.0731	6.4487	2.6620	2.4484	5.1105
30	40(1.8)	6.0404	5.5255	11.5658	3.3766	3.0752	6.4518	2.6637	2.4502	5.1139
10	40(0.2)	3.3085	3.2916	6.6001	2.7730	2.7576	5.5306	0.5355	0.5340	1.0695
20	40(0.2)	3.3073	3.2857	6.5931	2.7719	2.7523	5.5243	0.5354	0.5333	1.0688
30	40(0.2)	3.3096	3.2890	6.5986	2.7740	2.7552	5.5292	0.5356	0.5337	1.0694
GAP RATIO 10										
10	40(1)	5.0629	4.7687	9.8316	3.3810	3.1797	6.5607	1.6819	1.5889	3.2708
20	40(1)	5.0609	4.7639	9.8247	3.3798	3.1771	6.5570	1.6810	1.5867	3.2677
30	40(1)	5.0680	4.7716	9.8396	3.3848	3.1816	6.5664	1.6832	1.5900	3.2700
10	40(1.8)	7.6477	7.0713	14.7190	4.3940	4.0521	8.4460	3.2537	3.0193	6.2730
20	40(1.8)	7.6460	7.0725	14.7185	4.4002	4.0539	8.4540	3.2558	3.0185	6.2743
30	40(1.8)	7.6531	7.0837	14.7369	4.3972	4.0596	8.4568	3.2559	3.0241	6.2800
10	40(0.2)	1.9972	1.9773	3.9746	1.6688	1.6513	3.3202	0.3284	0.3260	0.6544
20	40(0.2)	1.9871	1.9740	3.9611	1.6594	1.6482	3.3076	0.3277	0.3258	0.6535
30	40(0.2)	1.9885	1.9753	3.9638	1.6605	1.6492	3.3097	0.3280	0.3260	0.6541

DESCRIPTION

In the above table the values of drag coefficient, pressure coefficient and total drag coefficient has been provided which are the outcome of domain independence test. The values of Prandtl number is taken as constant as 100. The Power law index has been varied from 0.2 to 1.8 and two values of Gap ratio has taken as 2 and 10.

Table.3: The effect of change of distance of first cylinder to the inlet on drag coefficient, pressure coefficient and on total drag has been given in numerical data form.

GAP RATIO = 2										
Lu	Re(n)	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf
10	40(1)	4.8327	2.6866	7.5193	3.2147	1.6759	4.8906	1.6181	1.0106	2.6287
20	40(1)	4.8289	2.7060	7.5349	3.2128	1.6898	4.9026	1.6160	1.0161	2.6322
30	40(1)	4.8328	2.6892	7.5219	3.2151	1.6782	4.8933	1.6177	1.0110	2.6287
10	40(1.8)	6.1077	3.6685	9.7762	3.4951	2.0252	5.5204	2.6126	1.6432	4.2558
20	40(1.8)	6.1010	3.9697	10.0706	3.4872	2.1985	5.6857	2.6138	1.7710	4.3849
30	40(1.8)	6.1357	3.9733	10.1090	3.5159	2.2121	5.7280	2.6199	1.7612	4.3811
10	40(0.2)	1.7851	1.1822	2.9673	1.4799	0.9326	2.4125	0.3053	0.2496	0.5549
20	40(0.2)	1.7755	1.1767	2.9522	1.4704	0.9260	2.3964	0.3026	0.2532	0.5558
30	40(0.2)	1.7765	1.1777	2.9559	1.4717	0.9281	2.3998	0.3048	0.2512	0.5561
GAP RATIO = 10										
Lu	Re(n)	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf
10	40(1)	4.6203	2.4167	7.0371	3.0241	1.4621	4.4863	1.5961	0.9546	2.5508
20	40(1)	4.6192	2.4220	7.0412	3.0234	1.4658	4.4892	1.5958	0.9562	2.5520
30	40(1)	4.6179	2.4203	7.0382	3.0226	1.4648	4.4874	1.5954	0.9555	2.5509
10	40(1.8)	6.9603	4.3738	11.3341	3.8829	2.3654	6.2483	3.0774	2.0085	5.0859
20	40(1.8)	6.9602	4.3730	11.3313	3.8849	2.3645	6.2494	3.0762	2.0057	5.0819
30	40(1.8)	6.9562	4.3762	11.3324	3.8805	2.3670	6.2475	3.0757	2.0092	5.0850
10	40(.2)	2.9945	1.8799	4.8745	2.4925	1.4842	3.9767	0.5021	0.3957	0.8977
20	40(.2)	2.9952	1.8823	4.8775	2.4898	1.4862	3.9760	0.5015	0.3950	0.8965
30	40(.2)	2.9945	1.8831	4.8776	2.4924	1.4872	3.9797	0.5020	0.3959	0.8979

DESCRIPTION

In this table the values of drag coefficient and pressure coefficient has been provided and their variation with Lu has been taken into account. The values of Prandtl number is taken as constant as 100. The Power law index has been varied from 0.2 to 1.8 and two values of Gap ratio has taken as 2 and 10.

4.2 GRID INDEPENDENCE TEST:

In grid independence test we take two independent spacing's and three different set of points on cylinders After simulating all results we analysed the pattern of changes in all conditions. There are six sets of combinations of points and spacing. We checked these six pairs by dividing the whole process in two following parts. And in outside region to check the effect of changing this value of on the forces such as drag forces.

Table. 4 domains selected for grid independence test.

Points	GRID	re(n)	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf
120	G2	40(1)	1.9752	0.8721	2.8472	1.2862	0.5036	1.7897	0.6890	0.3685	1.0575
240		40(1)	1.9757	0.8737	2.8494	1.2862	0.5038	1.7899	0.6896	0.3699	1.0595
120	G2	1(1)	38.9364	38.5570	77.4934	20.8999	20.7184	41.6184	18.0365	17.8386	35.8751
240		1(1)	38.9544	38.5805	77.5349	20.8934	20.7153	41.6086	18.0611	17.8652	35.9262
120	G2	40(1.8)	2.4960	1.4521	3.9481	1.3658	0.7633	2.1291	1.1302	0.6889	1.8190
240		40(1.8)	2.4981	1.4551	3.9532	1.3634	0.7629	2.1263	1.1347	0.6922	1.8269
120	G2	1(1.8)	54.6466	54.5000	109.1466	26.4645	26.3996	52.8641	28.1821	28.1004	56.2824
240		1(1.8)	54.6711	54.5340	109.2051	26.3722	26.3132	52.6853	28.2990	28.2208	56.5198
120	G2	40(.2)	1.4155	0.3494	1.7648	1.2537	0.2458	1.4996	0.1618	0.1035	0.2653
240		40(.2)	1.4135	0.3467	1.7602	1.2544	0.2457	1.5002	0.1591	0.1010	0.2601
120	G2	1(0.2)	24.8226	23.3087	48.1313	16.6515	15.2932	31.9447	8.1710	8.0155	16.1866
240		1(0.2)	24.8371	23.3234	48.1605	16.7257	15.3758	32.1015	8.1114	7.9477	16.0590

1. In first part we have taken different points on cylinders and taken one fixed set of spacing in outside region and on cylinders. When all results came we took other set of spacing and repeated the process for all spacing.
2. In second part we fixed the spacing and changed the number of points on cylinders to check the effect of change of change of number of points on cylinders on forces.

After analysing the results we select the grid which show no change or insignificant change when we move from that particular grid to another grid.

Table. 5 domain selected for grid independence test.

Points	GRID	re(n)	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf
120	G10	40(1)	2.0563	1.9142	3.9704	1.3426	1.2451	2.5877	0.7136	0.6691	1.3827
240	G10	40(1)	2.0521	1.9094	3.9614	1.3390	1.2413	2.5804	0.7130	0.6681	1.3811
120	G10	1(1)	42.3415	42.3472	84.6888	22.8434	22.8467	45.6902	19.4981	19.5005	38.9986
240	G10	1(1)	42.3619	42.3602	84.7221	22.8267	22.8255	45.6522	19.5353	19.5346	39.0699
120	G10	40(1.8)	2.5825	2.3281	4.9106	1.4153	1.2700	2.6853	1.1672	1.0580	2.2253
240	G10	40(1.8)	2.5831	2.3273	4.9103	1.4113	1.2658	2.6771	1.1718	1.0615	2.2333
120	G10	1(1.8)	56.2967	56.3029	112.5996	27.0632	27.0661	54.1292	29.2335	29.2368	58.4703
240	G10	1(1.8)	56.3330	56.3270	112.6600	26.9564	26.9524	53.9088	29.3766	29.3746	58.7512
120	G10	40(.2)	1.4592	1.4492	2.9085	1.2935	1.2828	2.5764	0.1657	0.1664	0.3321
240	G10	40(.2)	1.4570	1.4478	2.9048	1.2941	1.2842	2.5783	0.1628	0.1636	0.3265
120	G10	1(0.2)	29.0180	29.0103	58.0283	19.8714	19.8642	39.7357	9.1466	9.1460	18.2926
240	G10	1(0.2)	29.0490	29.0436	58.0926	19.9595	19.9548	39.9143	9.0894	9.0888	18.1782

4.3 RESULT VALIDATION

For the validation of the results an unconfined grid was created while keeping all other data same as the data was used for standard result and the results has been validated with the result of Patil et al. 2008. For result validation we made a confined grid with a long channel height to neglect the wall effects because patil et al. an unconfined grid was created. The other change is done with velocity in which we used a constant velocity profile in Y direction as it prevails in unconfined arrangement. The result of validation is that the values of drag coefficient and pressure coefficient are almost comparable with the results of patil et al. and hence we can move further with the same grid by assuming that our grid which is outcome of the domain and grid independence test is optimum. The detailed results are given in following table.

Table.6 numerical data for validation.

	Patil et al, 2008		**Present result**	
Power law index	Cdp1	Cdp2	Cdp1	Cdp2
n=0.6	6.4787	5.0369	6.5936	5.0061
n=1	3.8272	2.0420	4.0105	2.0838
n=1.4	2.8120	0.9804	2.9948	1.0227
Power law index	Cfp1	Cfp2	Cfp1	Cfp2
n=0.6	5.3976	4.5785	5.5073	4.8126
n=1.0	3.9621	2.4548	4.3293	2.8953
n=1.4	3.2293	1.4545	3.5643	1.5098

Table.7: the effect of gap ratio, Reynolds number for the constant values of Pr (100), Ri (0) and power law index (1) has been given in

G	Re	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf	Nu1	Nu2
2	1	38.9542	38.5803	77.5346	20.8933	20.7153	41.6087	18.0609	17.8650	35.9259	4.7636	2.9453
	2	19.6726	19.2677	38.9403	10.5701	10.3700	20.9401	9.1025	8.8977	18.0002	6.0099	3.7023
	5	8.2642	7.7128	15.9771	4.4990	4.1931	8.6921	3.7653	3.5197	7.2850	8.2707	4.9199
	10	4.6237	3.8280	8.4517	2.6011	2.1154	4.7165	2.0226	1.7126	3.7352	10.7090	5.9596
	20	2.8702	1.8527	4.7230	1.7169	1.0468	2.7637	1.1533	0.8060	1.9593	14.4010	7.1123
	40	1.9757	0.8737	2.8494	1.2862	0.5038	1.7900	0.6896	0.3699	1.0595	18.8050	9.9068
4	1	42.2970	42.3294	84.6264	22.8041	22.8309	45.6350	19.4929	19.4984	38.9913	4.9733	3.7336
	2	21.2866	21.3101	42.5967	11.5009	11.5231	23.0240	9.7858	9.7870	19.5728	6.2664	4.8649
	5	8.8684	8.8414	17.7098	4.8556	4.8488	9.7044	4.0128	3.9926	8.0054	8.5803	6.9743
	10	4.9022	4.7485	9.6507	2.7706	2.6853	5.4559	2.1316	2.0632	4.1948	11.0220	9.0047
	20	2.9955	2.6237	5.6192	1.7967	1.5630	3.3598	1.1988	1.0607	2.2595	14.4880	11.1420
	40	2.0257	1.4550	3.4807	1.3209	0.9286	2.2495	0.7048	0.5264	1.2312	19.7330	13.4890
6	1	42.4468	42.4493	84.8961	22.8831	22.8843	45.7674	19.5637	19.5651	39.1288	4.9814	4.0026
	2	21.3717	21.3750	42.7467	11.5475	11.5494	23.0969	9.8242	9.8256	19.6498	6.2770	5.1460
	5	8.9150	8.9145	17.8294	4.8827	4.8829	9.7656	4.0323	4.0315	8.0638	8.5982	7.2422
	10	4.9365	4.8977	9.8341	2.7917	2.7696	5.5612	2.1448	2.1281	4.2729	11.0530	9.4760
	20	3.0248	2.8588	5.8836	1.8158	1.7113	3.5271	1.2090	1.1474	2.3565	14.5170	12.3310
	40	2.0512	1.7080	3.7592	1.3387	1.1032	2.4419	0.7124	0.6048	1.3173	19.5980	15.8930
8	1	42.4415	42.4428	84.8843	22.8803	22.8813	45.7616	19.5612	19.5616	39.1227	4.9811	4.1529
	2	21.3701	21.3708	42.7408	11.5465	11.5470	23.0935	9.8235	9.8237	19.6472	6.2769	5.3354
	5	8.9150	8.9152	17.8301	4.8827	4.8829	9.7655	4.0323	4.0323	8.0646	8.5984	7.5303
	10	4.9372	4.9278	9.8650	2.7921	2.7867	5.5789	2.1451	2.1410	4.2861	11.0530	9.9267
	20	3.0264	2.9500	5.9764	1.8168	1.7690	3.5858	1.2096	1.1810	2.3906	14.5180	13.1530
	40	2.0544	1.8379	3.8923	1.3409	1.1924	2.5334	0.7134	0.6455	1.3589	19.5940	17.4760
10	1	42.4429	42.4444	84.8873	22.8806	22.8816	45.7622	19.5623	19.5628	39.1251	4.9813	4.1530
	2	21.3703	21.3710	42.7413	11.5466	11.5471	23.09366	9.8237	9.8239	19.6476	6.2769	5.3354
	5	8.9150	8.9153	17.8304	4.8827	4.8829	9.7656	4.0323	4.0324	8.0647	8.5984	7.5304
	10	4.9372	4.9278	9.8650	2.7921	2.7867	5.5789	2.1451	2.1410	4.2861	11.0530	9.9265
	20	3.0264	2.9498	5.9762	1.8168	1.7688	3.5857	1.2096	1.1810	2.3905	14.5180	13.1530
	40	2.0521	1.9094	3.9615	1.3391	1.2413	2.5804	0.7130	0.6681	1.3811	19.6010	18.1470

Table.8 : the effect of gap ratio, Reynolds number for the constant values of Pr (100), Ri (-0.5) and power law index (1) has been given in tabular form.

G	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf	Nu1	Nu2
						Re1	Pr100	n1			
2	38.9542	38.5803	77.5346	20.8933	20.7153	41.6087	18.0609	17.8650	35.9259	4.7636	2.9453
4	42.2970	42.3294	84.6264	22.8041	22.8309	45.6350	19.4929	19.4984	38.9913	4.9733	3.7336
6	42.4468	42.4493	84.8961	22.8831	22.8843	45.7674	19.5637	19.5651	39.1288	4.9814	4.0026
8	42.4415	42.4428	84.8843	22.8803	22.8813	45.7616	19.5612	19.5616	39.1227	4.9811	4.1529
10	42.4429	42.4444	84.8873	22.8806	22.8816	45.7622	19.5623	19.5628	39.1251	4.9813	4.1530
						Re5	Pr100	n1			
2	8.2642	7.7128	15.9771	4.4990	4.1931	8.6921	3.7653	3.5197	7.2850	8.2707	4.9199
4	8.8684	8.8414	17.7098	4.8556	4.8488	9.7044	4.0128	3.9926	8.0054	8.5803	6.9743
6	8.9150	8.9145	17.8294	4.8827	4.8829	9.7656	4.0323	4.0315	8.0638	8.5982	7.2422
8	8.9150	8.9152	17.8301	4.8827	4.8829	9.7655	4.0323	4.0323	8.0646	8.5984	7.5303
10	8.9150	8.9153	17.8304	4.8827	4.8829	9.7656	4.0323	4.0324	8.0647	8.5984	7.5304
						Re10	Pr100	n1			
2	4.6237	3.8280	8.4517	2.6011	2.1154	4.7165	2.0226	1.7126	3.7352	10.7090	5.9596
4	4.9022	4.7485	9.6507	2.7706	2.6853	5.4559	2.1316	2.0632	4.1948	11.0220	9.0047
6	4.9365	4.8977	9.8341	2.7917	2.7696	5.5612	2.1448	2.1281	4.2729	11.0530	9.4760
8	4.9372	4.9278	9.8650	2.7921	2.7867	5.5789	2.1451	2.1410	4.2861	11.0530	9.9267
10	4.9372	4.9278	9.8650	2.7921	2.7867	5.5789	2.1451	2.1410	4.2861	11.0525	9.9265
						Re20	Pr100	n1			
2	2.8702	1.8527	4.7230	1.7169	1.0468	2.7637	1.1533	0.8060	1.9593	14.4010	7.1123
4	2.9955	2.6237	5.6192	1.7967	1.5630	3.3598	1.1988	1.0607	2.2595	14.4880	11.1420
6	3.0248	2.8588	5.8836	1.8158	1.7113	3.5271	1.2090	1.1474	2.3565	14.5170	12.3310
8	3.0264	2.9500	5.9764	1.8168	1.7690	3.5858	1.2096	1.1810	2.3906	14.5180	13.1530
10	3.0264	2.9498	5.9762	1.8168	1.7688	3.5857	1.2096	1.1810	2.3905	14.5180	13.1530
						Re40	Pr100	n1			
2	1.9757	0.8737	2.8494	1.2862	0.5038	1.7900	0.6896	0.3699	1.0595	18.8050	9.9068
4	2.0257	1.4550	3.4807	1.3209	0.9286	2.2495	0.7048	0.5264	1.2312	19.7330	13.4890
6	2.0512	1.7080	3.7592	1.3387	1.1032	2.4419	0.7124	0.6048	1.3173	19.5980	15.8930
8	2.0544	1.8379	3.8923	1.3409	1.1924	2.5334	0.7134	0.6455	1.3589	19.5940	17.4760
10	2.0521	1.9094	3.9615	1.3391	1.2413	2.5804	0.7130	0.6681	1.3811	19.6010	18.1470

Table.10 : the effect G and Re for the constant values of Pr (100), Ri (-0.5) and power law index (1) has been given in tabular form.

G	Re	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf	Nu1	Nu2
2	1	38.9542	38.5803	77.5346	20.8933	20.7153	41.6087	18.0609	17.8650	35.9259	4.7636	2.9453
	2	19.6726	19.2677	38.9403	10.5701	10.3700	20.9401	9.1025	8.8977	18.0002	6.0099	3.7023
	5	8.2642	7.7128	15.9771	4.4990	4.1931	8.6921	3.7653	3.5197	7.2850	8.2707	4.9199
	10	4.6237	3.8280	8.4517	2.6011	2.1154	4.7165	2.0226	1.7126	3.7352	10.7090	5.9596
	20	2.8702	1.8527	4.7230	1.7169	1.0468	2.7637	1.1533	0.8060	1.9593	14.4010	7.1123
	40	1.9757	0.8737	2.8494	1.2862	0.5038	1.7900	0.6896	0.3699	1.0595	18.8050	9.9068
4	1	42.2970	42.3294	84.6264	22.8041	22.8309	45.6350	19.4929	19.4984	38.9913	4.9733	3.7336
	2	21.2866	21.3101	42.5967	11.5009	11.5231	23.0240	9.7858	9.7870	19.5728	6.2664	4.8649
	5	8.8684	8.8414	17.7098	4.8556	4.8488	9.7044	4.0128	3.9926	8.0054	8.5803	6.9743
	10	4.9022	4.7485	9.6507	2.7706	2.6853	5.4559	2.1316	2.0632	4.1948	11.0220	9.0047
	20	2.9955	2.6237	5.6192	1.7967	1.5630	3.3598	1.1988	1.0607	2.2595	14.4880	11.1420
	40	2.0257	1.4550	3.4807	1.3209	0.9286	2.2495	0.7048	0.5264	1.2312	19.7330	13.4890
6	1	42.4468	42.4493	84.8961	22.8831	22.8843	45.7674	19.5637	19.5651	39.1288	4.9814	4.0026
	2	21.3717	21.3750	42.7467	11.5475	11.5494	23.0969	9.8242	9.8256	19.6498	6.2770	5.1460
	5	8.9150	8.9145	17.8294	4.8827	4.8829	9.7656	4.0323	4.0315	8.0638	8.5982	7.2422
	10	4.9365	4.8977	9.8341	2.7917	2.7696	5.5612	2.1448	2.1281	4.2729	11.0530	9.4760
	20	3.0248	2.8588	5.8836	1.8158	1.7113	3.5271	1.2090	1.1474	2.3565	14.5170	12.3310
	40	2.0512	1.7080	3.7592	1.3387	1.1032	2.4419	0.7124	0.6048	1.3173	19.5980	15.8930
8	1	42.4415	42.4428	84.8843	22.8803	22.8813	45.7616	19.5612	19.5616	39.1227	4.9811	4.1529
	2	21.3701	21.3708	42.7408	11.5465	11.5470	23.0935	9.8235	9.8237	19.6472	6.2769	5.3354
	5	8.9150	8.9152	17.8301	4.8827	4.8829	9.7655	4.0323	4.0323	8.0646	8.5984	7.5303
	10	4.9372	4.9278	9.8650	2.7921	2.7867	5.5789	2.1451	2.1410	4.2861	11.0530	9.9267
	20	3.0264	2.9500	5.9764	1.8168	1.7690	3.5858	1.2096	1.1810	2.3906	14.5180	13.1530
	40	2.0544	1.8379	3.8923	1.3409	1.1924	2.5334	0.7134	0.6455	1.3589	19.5940	17.4760
10	1	42.4429	42.4444	84.8873	22.8806	22.8816	45.7622	19.5623	19.5628	39.1251	4.9813	4.1530
	2	21.3703	21.3710	42.7413	11.5466	11.5471	23.09366	9.8237	9.8239	19.6476	6.2769	5.3354
	5	8.9150	8.9153	17.8304	4.8827	4.8829	9.7656	4.0323	4.0324	8.0647	8.5984	7.5304
	10	4.9372	4.9278	9.8650	2.7921	2.7867	5.5789	2.1451	2.1410	4.2861	11.0530	9.9265
	20	3.0264	2.9498	5.9762	1.8168	1.7688	3.5857	1.2096	1.1810	2.3905	14.5180	13.1530

Table. 11: the effect n and Re for the constant values of Pr (100) and Ri (0) and G (2) has been given in tabular form.

n	Re	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf	Nu1	Nu2
						Re 1						
0.2	1	26.9147	26.9085	53.8232	18.4301	18.4247	36.8548	8.4846	8.4838	16.9684	5.5958	4.2742
0.4	1	32.3554	32.3511	64.7065	20.3517	20.3484	40.7001	12.0037	12.0027	24.0064	5.8730	4.5928
0.6	1	35.7696	35.7684	71.5379	21.0850	21.0842	42.1692	14.6845	14.6841	29.3687	5.4683	s
0.8	1	39.1291	39.1300	78.2591	21.9541	21.9543	43.9084	17.1751	17.1756	34.3507	5.1848	4.1421
1.2	1	45.7851	45.7889	91.5740	23.8560	23.8580	47.7140	21.9291	21.9309	43.8600	4.8305	3.8970
1.4	1	49.1998	49.2038	98.4035	24.8679	24.8701	49.7380	24.3319	24.3337	48.6656	4.7150	3.8147
1.6	1	52.7434	52.7464	105.4899	25.9237	25.9256	51.8493	26.8197	26.8209	53.6406	4.6243	3.7491
1.8	1	56.4653	56.4661	112.9315	27.0331	27.0337	54.0669	29.4322	29.4324	58.8646	4.5515	3.6958
						Re 2						
0.2	2	13.5706	13.5615	27.1321	9.3287	9.3211	18.6498	4.2419	4.2405	8.4823	7.2982	5.6633
0.4	2	16.4264	16.4235	32.8499	10.4160	10.4138	20.8298	6.0104	6.0097	12.0201	7.5847	6.0323
0.6	2	18.0875	18.0870	36.1745	10.7170	10.7167	21.4337	7.3705	7.3703	14.7408	6.9819	5.6337
0.8	s	19.7341	19.7358	39.4699	11.1093	11.1103	22.2196	8.6248	8.6255	17.2503	6.5667	5.3501
1.2	2	23.0270	23.0313	46.0583	12.0181	12.0205	24.0386	11.0089	11.0108	22.0197	6.0658	4.9935
1.4	2	24.7254	24.7294	49.4548	12.5145	12.5168	25.0313	12.2109	12.2126	24.4235	5.9056	4.8754
1.6	2	26.4916	26.4938	52.9854	13.0369	13.0380	26.0749	13.4548	13.4557	26.9105	5.7806	4.7816
1.8	2	28.3490	28.3480	56.6970	13.5883	13.5876	27.1759	14.7607	14.7604	29.5211	5.6807	4.7056
						Re 5						
0.2	5	6.3916	6.3843	12.7760	4.5778	4.5712	9.1490	1.8139	1.8131	3.6270	12.4380	9.8358
0.4	5	7.0385	7.0386	14.0771	4.6070	4.6072	9.2142	2.4315	2.4314	4.8629	10.9340	8.8597
0.6	5	7.6698	7.6715	15.3413	4.6618	4.6635	9.3254	3.0080	3.0080	6.0160	9.8088	8.1060
0.8	5	8.2911	8.2922	16.5833	4.7553	4.7568	9.5121	3.5357	3.5355	7.0712	9.0830	7.5953
1.2	5	9.5530	9.5489	19.1020	5.0376	5.0355	10.0731	4.5154	4.5134	9.0288	8.2566	9.9864
1.4	5	10.2151	10.2048	20.4199	5.2145	5.2084	10.4229	5.0005	4.9964	9.9969	8.0048	6.7921
1.6	5	10.9093	10.8912	21.8004	5.4097	5.3984	10.8081	5.4996	5.4927	10.9924	7.8120	6.6393
1.8	5	11.6435	11.6163	23.2599	5.6217	5.6044	11.2261	6.0219	6.0120	12.0338	7.6599	6.5164

n	Re	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf	Nu1	Nu2
						Re 10						
0.2	10	3.0300	3.0306	6.0606	2.1819	2.1824	4.3643	0.8481	0.8482	1.6963	14.2990	11.5370
0.4	10	3.9354	3.9454	7.8808	2.7018	2.7104	5.4122	1.2337	1.2350	2.4686	14.5650	12.0480
0.6	10	4.2935	4.2870	8.5804	2.7279	2.7246	5.4525	1.5655	1.5623	3.1279	12.9930	10.8970
0.8	10	4.6215	4.5982	9.2197	2.7552	2.7417	5.4969	1.8663	1.8565	3.7228	11.8370	10.0570
1.2	10	5.2515	5.1981	10.4496	2.8434	2.8129	5.6563	2.4081	2.3851	4.7933	10.5130	9.0651
1.4	10	5.5754	5.5079	11.0833	2.9104	2.8713	5.7817	2.6650	2.6365	5.3015	10.1260	8.7631
1.6	10	5.9143	5.8334	11.7477	2.9914	2.9435	5.9349	2.9229	2.8899	5.8128	9.8379	8.5330
1.8	10	6.2732	6.1796	12.4528	3.0852	3.0283	6.1134	3.1880	3.1513	6.3393	9.6158	8.3527
						Re 20						
0.2	20	2.1398	2.0888	4.2287	1.7602	1.7020	3.4621	0.3797	0.3869	0.7665	19.1390	16.0310
0.4	20	2.3484	2.2732	4.6217	1.7364	1.6664	3.4028	0.6120	0.6068	1.2189	18.1320	15.1670
0.6	20	2.5960	2.4839	5.0799	1.7685	1.6822	3.4507	0.8275	0.8017	1.6292	16.8230	14.0870
0.8	20	2.8207	2.6780	5.4987	1.7942	1.6967	3.4909	1.0265	0.9813	2.0078	15.5690	13.1120
1.2	20	3.2162	3.0320	6.2481	1.8381	1.7286	3.5666	1.3781	1.3034	2.6815	13.6860	11.7320
1.4	20	3.4013	3.2023	6.6036	1.8638	1.7490	3.6128	1.5375	1.4532	2.9908	13.0470	11.2790
1.6	20	3.5855	3.3741	6.9597	1.8954	1.7746	3.6700	1.6901	1.5996	3.2897	12.5590	10.9360
1.8	20	3.7730	3.5512	7.3241	1.9333	1.8058	3.7391	1.8397	1.7454	3.5851	12.1830	10.6640
						Re 40						
0.2	40	1.4500	1.2365	2.6864	1.2878	1.0666	2.3544	0.1621	0.1698	0.3320	23.1460	18.6740
0.4	40	1.5736	1.3376	2.9112	1.2904	1.0584	2.3488	0.2832	0.2792	0.5624	22.4530	17.9200
0.6	40	1.7246	1.4609	3.1855	1.2870	1.0639	2.3510	0.4376	0.3970	0.8345	21.5340	17.1690
0.8	40	1.8943	1.5854	3.4797	1.3155	1.0832	2.3988	0.5787	0.5022	1.0809	20.5290	16.4820
1.2	40	2.1962	1.8290	4.0253	1.3569	1.1230	2.4799	0.8393	0.7061	1.5454	18.7690	15.4000
1.4	40	2.3317	1.9484	4.2801	1.3751	1.1440	2.5191	0.9566	0.8044	1.7610	18.0450	14.9780
1.6	40	2.4600	2.0665	4.5265	1.3932	1.1652	2.5584	1.0668	0.9013	1.9681	17.4150	14.6140
1.8	40	2.5836	2.1840	4.7676	1.4121	1.1865	2.5986	1.1716	0.9974	2.1690	16.8830	14.3170

Table.12: the effect n and Re for the constant values of Pr (100) and Ri (0) and G (10) has been given in tabular form.

n	Re	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf	Nu1	Nu2
						Re 1						
0.2	1	29.0475	29.0352	58.0827	19.9583	19.9474	39.9057	9.0892	9.0878	18.1769	6.3868	5.2555
0.4	1	32.3338	32.3355	64.6693	20.3389	20.3404	40.6793	11.9949	11.9951	23.9900	5.8682	4.8949
0.6	1	35.7159	35.7166	71.4325	21.0459	21.0467	42.0925	14.6700	14.6700	29.3400	5.4648	4.6073
0.8	1	39.0556	39.0549	78.1105	21.9019	21.9017	43.8036	17.1536	17.1533	34.3069	5.1820	4.4000
1.2	1	45.6885	45.6856	91.3741	23.7938	23.7919	47.5858	21.8946	21.8937	43.7883	4.8281	4.1343
1.4	1	49.0907	49.0868	98.1775	24.8002	24.7976	49.5978	24.2905	24.2892	48.5796	4.7128	4.0460
1.6	1	52.6227	52.6177	105.2404	25.8514	25.8481	51.6995	26.7713	26.7696	53.5409	4.6222	3.9759
1.8	1	56.3334	56.3274	112.6608	26.9565	26.9525	53.9090	29.3769	29.3749	58.7517	4.5494	3.9193
						Re 2						
0.2	2	14.8334	14.8265	29.6598	10.2896	10.2834	20.5731	4.5438	4.5430	9.0868	8.4104	7.0323
0.4	2	16.4120	16.4123	32.8243	10.4049	10.4052	20.8101	6.0071	6.0071	12.0142	7.5800	6.4427
0.6	2	18.0595	18.0597	36.1192	10.6979	10.6981	21.3959	7.3617	7.3616	14.7233	6.9763	5.9979
0.8	2	19.6978	19.6973	39.3951	11.0835	11.0832	22.1667	8.6143	8.6141	17.2284	6.5631	5.6862
1.2	2	22.9798	22.9781	45.9579	11.9876	11.9864	23.9740	10.9922	10.9916	21.9839	6.0633	5.2985
1.4	2	24.6724	24.6701	49.3426	12.4816	12.4800	24.9616	12.1909	12.1901	24.3810	5.9034	5.1720
1.6	2	26.4332	26.4303	52.8635	13.0018	12.9999	26.0017	13.4314	13.4304	26.8618	5.7786	5.0725
1.8	2	28.2854	28.2818	56.5672	13.5514	13.5491	27.1006	14.7339	14.7327	29.4666	5.6789	4.9924
						Re 5						
0.2	5	6.3917	6.3902	12.7820	4.5775	4.5762	9.1537	1.8142	1.8141	3.6283	12.4380	10.6840
0.4	5	7.0312	7.0312	14.0624	4.6007	4.6007	9.2013	2.4305	2.4305	4.8611	10.9280	9.5504
0.6	5	7.6599	7.6595	15.3194	4.6543	4.6541	9.3084	3.0056	3.0054	6.0110	9.8032	8.6838
0.8	5	8.2775	8.2771	16.5546	4.7454	4.7451	9.4905	3.5321	3.5320	7.0641	9.0787	8.1120
1.2	5	9.5352	9.5342	19.0694	5.0258	5.0252	10.0510	4.5093	4.5090	9.0184	8.2536	7.4409
1.4	5	10.1951	10.1939	20.3890	5.2019	5.2012	10.4031	4.9932	4.9927	9.9859	8.0022	7.2320

1.6	5	10.8875	10.8862	21.7737	5.3964	5.3956	10.7920	5.4911	5.4906	10.9817	7.8097	7.0709
1.8	5	11.6200	11.6186	23.2386	5.6079	5.6070	11.2149	6.0121	6.0116	12.0237	7.6579	6.9426
						Re 10						
0.2	10	3.5601	3.5604	7.1205	2.6810	2.6811	5.3621	0.8791	0.8793	1.7584	16.1590	14.3110
0.4	10	3.9317	3.9304	7.8621	2.6983	2.6973	5.3956	1.2334	1.2331	2.4664	14.5590	13.0210
0.6	10	4.2882	4.2857	8.5739	2.7235	2.7218	5.4453	1.5647	1.5639	3.1286	12.9870	11.7580
0.8	10	4.6150	4.6122	9.2272	2.7501	2.7484	5.4985	1.8649	1.8638	3.7287	11.8320	10.8100
1.2	10	5.2431	5.2395	10.4826	2.8375	2.8355	5.6730	2.4056	2.4041	4.8096	10.5110	9.6972
1.4	10	5.5661	5.5614	11.1275	2.9042	2.9014	5.8057	2.6619	2.6599	5.3218	10.1250	9.3655
1.6	10	5.9044	5.8974	11.8018	2.9850	2.9809	5.9660	2.9193	2.9165	5.8358	9.8365	9.1142
1.8	10	6.2627	6.2521	12.5148	3.0787	3.0723	6.1510	3.1840	3.1798	6.3638	9.6145	8.9175
						Re 20						
0.2	20	2.1425	2.1412	4.2837	1.7625	1.7602	3.5227	0.3800	0.3810	0.7610	19.1460	17.5870
0.4	20	2.3487	2.3404	4.6891	1.7363	1.7281	3.4644	0.6124	0.6123	1.2247	18.1330	16.6870
0.6	20	2.5950	2.5773	5.1723	1.7674	1.7538	3.5212	0.8276	0.8235	1.6511	16.8200	15.5340
0.8	20	2.8186	2.7914	5.6101	1.7923	1.7739	3.5662	1.0263	1.0175	2.0438	15.5650	14.4350
1.2	20	3.2126	3.1627	6.3753	1.8354	1.8057	3.6410	1.3773	1.3570	2.7343	13.6800	12.7700
1.4	20	3.3972	3.3322	6.7294	1.8607	1.8231	3.6838	1.5365	1.5091	3.0456	13.0410	12.1980
1.6	20	3.5809	3.4993	7.0802	1.8921	1.8449	3.7370	1.6888	1.6544	3.3432	12.5540	11.7570
1.8	20	3.7681	3.6694	7.4375	1.9299	1.8723	3.8021	1.8383	1.7971	3.6354	12.1790	11.4150
						Re 40						
0.2	40	1.4570	1.4483	2.9053	1.2942	1.2846	2.5788	0.1628	0.1637	0.3265	23.4310	21.9820
0.4	40	1.5778	1.5423	3.1201	1.2939	1.2575	2.5513	0.2839	0.2848	0.5688	22.5540	20.9330
0.6	40	1.7274	1.6627	3.3901	1.2890	1.2329	2.5219	0.4384	0.4298	0.8682	21.5630	19.9960
0.8	40	1.8960	1.7922	3.6882	1.3166	1.2382	2.5548	0.5795	0.5540	1.1334	20.5360	19.0210
1.2	40	2.1965	2.0188	4.2153	1.3568	1.2439	2.6007	0.8397	0.7749	1.6146	18.7710	17.3860
1.4	40	2.3315	2.1234	4.4548	1.3747	1.2491	2.6237	0.9568	0.8743	1.8311	18.0500	16.7480
1.6	40	2.4595	2.2256	4.6851	1.3925	1.2565	2.6490	1.0670	0.9691	2.0361	17.4230	16.1900
1.8	40	2.5831	2.3273	4.9104	1.4113	1.2658	2.6771	1.1718	1.0615	2.2333	16.8950	15.7280

Table. 13: The effect of change of gap ratio and Reynolds number for the constant value of Prandtl number(1), Power law index (1) and Richardson number (0)													
Gap Ratio	n	Re	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf	Nu1	Nu2
							Re 1						
2	1	1	38.9545	38.5799	77.5344	20.8934	20.7153	41.6087	18.0611	17.8646	35.9257	0.6519	0.1550
2	1	2	19.6727	19.2675	38.9402	10.5701	10.3700	20.9401	9.1026	8.8975	18.0001	1.0882	0.3752
2	1	5	8.2643	7.7127	15.9770	4.4990	4.1931	8.6921	3.7653	3.5196	7.2849	1.7437	0.8763
2	1	10	4.6237	3.8280	8.4517	2.6011	2.1154	4.7165	2.0226	1.7126	3.7351	2.2782	1.2426
2	1	20	2.8702	1.8527	4.7230	1.7169	1.0468	2.7637	1.1533	0.8060	1.9593	2.9593	1.5762
2	1	40	1.9757	0.8737	2.8494	1.2862	0.5038	1.7900	0.6896	0.3699	1.0595	3.8792	1.9719
							Re 2						
4	1	1	42.2970	42.3294	84.6264	22.8041	22.8309	45.6350	19.4929	19.4984	38.9913	0.6958	0.1277
4	1	2	21.2866	21.3102	42.5968	11.5009	11.5231	23.0240	9.7858	9.7871	19.5729	1.1574	0.3650
4	1	5	8.8684	8.8414	17.7098	4.8556	4.8488	9.7044	4.0128	3.9926	8.0054	1.8282	0.9970
4	1	10	4.9022	4.7485	9.6507	2.7706	2.6853	5.4559	2.1316	2.0632	4.1948	2.3579	1.5238
4	1	20	2.9955	2.6237	5.6192	1.7967	1.5630	3.3598	1.1988	1.0607	2.2595	3.0314	2.0051
4	1	40	2.0257	1.4550	3.4807	1.3209	0.9286	2.2495	0.7048	0.5264	1.2312	3.9614	2.5107
							Re 10						
6	1	1	42.4468	42.4493	84.8961	22.8831	22.8843	45.7674	19.5637	19.5651	39.1288	0.7041	0.1218
6	1	2	21.3717	21.3750	42.7467	11.5475	11.5494	23.0969	9.8242	9.8256	19.6498	1.1624	0.3658
6	1	5	8.9150	8.9145	17.8295	4.8827	4.8830	9.7656	4.0323	4.0315	8.0638	1.8315	1.0326
6	1	10	4.9365	4.8977	9.8341	2.7917	2.7695	5.5612	2.1448	2.1281	4.2729	2.3630	1.6358
6	1	20	3.0248	2.8588	5.8836	1.8158	1.7113	3.5271	1.2090	1.1474	2.3565	3.0395	2.2220
6	1	40	2.0512	1.7080	3.7592	1.3387	1.1032	2.4419	0.7124	0.6048	1.3173	3.9730	2.8404
							Re 20						
8	1	1	42.4429	42.4444	84.8873	22.8806	22.8816	45.7622	19.5623	19.5628	39.1251	0.7059	0.1200
8	1	2	21.3703	21.3710	42.7413	11.5466	11.5471	23.09366	9.8237	9.8239	19.6476	1.1636	0.3660
8	1	5	8.9150	8.9153	17.8304	4.8827	4.8829	9.7656	4.0323	4.0324	8.0647	1.8314	1.0400

8	1	10	4.9372	4.9278	9.8650	2.7921	2.7867	5.5789	2.1451	2.1410	4.2861	2.3631	1.6766
8	1	20	3.0264	2.9498	5.9762	1.8168	1.7688	3.5857	1.2096	1.1810	2.3905	3.0400	2.3339
8	1	40	2.0521	1.9094	3.9615	1.3391	1.2413	2.5804	0.7130	0.6681	1.3811	3.9749	3.0377
							Re 40						
10	1	1	42.3619	42.3602	84.7221	22.8267	22.8256	45.6523	19.5352	19.5346	39.0698	0.7082	0.1195
10	1	2	21.3299	21.3287	42.6587	11.5196	11.5188	23.0384	9.8103	9.8099	19.6202	1.1636	0.3669
10	1	5	8.8989	8.8982	17.7971	4.8716	4.8712	9.7428	4.0273	4.0270	8.0543	1.8306	1.0408
10	1	10	4.9289	4.9260	9.8549	2.7861	2.7844	5.5706	2.1427	2.1415	2.2843	2.3617	1.6926
10	1	20	3.0219	2.9843	6.0063	1.8135	1.7900	3.6034	1.2085	1.1944	2.4029	3.0385	2.3955
10	1	40	2.0521	1.9094	3.9615	1.3391	1.2413	2.5804	0.7130	0.6681	1.3811	3.9735	3.1611

Table.14: the effect of change of Reynolds number and Gap ratio while keeping constant values of Prandtl number (100), Richardson Number (-3).													
G	n	Re	Cd1	Cd2	Cd	Cdp1	Cdp2	Cdp	Cdf1	Cdf2	Cdf	Nu1	Nu2
2													
	1	1	39.1915	38.5906	77.7821	21.0711	20.7094	41.7805	18.1204	17.8812	36.0016	4.7852	3.1637
	1	2	19.9751	19.3266	39.3017	10.8071	10.4147	21.2218	9.1679	8.9119	18.0799	6.0802	4.5912
	1	5	8.5672	7.8814	16.4485	4.7604	4.3475	9.1079	3.8067	3.5339	7.3406	8.5199	7.4471
	1	10	4.8957	4.0269	8.9226	2.8480	2.2967	5.1447	2.0477	1.7302	3.7779	11.3270	9.8902
	1	20	3.0987	2.0353	5.1340	1.9251	1.2017	3.1267	1.1736	0.8336	2.0072	15.4670	12.9170
	1	40	2.1481	1.0438	3.1919	1.4383	0.6364	2.0747	0.7098	0.4074	1.1172	20.3460	17.1960
4													
	1	1	42.3769	42.4348	84.8118	22.8711	22.9154	45.7867	19.5057	19.5194	39.0251	4.9754	3.7439
	1	2	21.4053	21.4803	42.8856	11.6075	11.6672	23.2748	9.7978	9.8130	19.6108	6.2767	4.9186
	1	5	9.0811	9.1087	18.1899	5.0562	5.0869	10.1432	4.0249	4.0217	8.0467	8.6771	7.2173
	1	10	5.1608	5.0285	10.1893	3.0196	2.9446	5.9642	2.1411	2.0840	4.2252	11.4630	9.5842
	1	20	3.2253	2.8358	6.0611	2.0142	1.7600	3.7743	1.2109	1.0759	2.2868	5.6100	12.7540
	1	40	2.2055	1.5952	3.8007	1.4813	1.0498	2.5311	0.7242	0.5454	1.2696	20.4720	18.2880
6													
	1	1	42.5353	42.5571	85.0924	22.9571	22.9707	45.9279	19.5781	19.5864	39.1645	4.9844	4.0064
	1	2	21.5015	21.5459	43.0474	11.6632	11.6941	23.3574	9.8382	9.8517	19.6899	6.2902	5.1622
	1	5	9.1356	9.1785	18.3141	5.0897	5.1212	10.2109	4.0458	4.0473	8.1031	8.7027	7.3292
	1	10	4.8957	4.0269	8.9226	2.8480	2.2967	5.1447	2.0477	1.7302	3.7779	11.3270	9.8902
	1	20	3.2542	3.0439	6.2980	2.0338	1.9010	3.9349	1.2203	1.1428	2.3631	15.6820	13.3710
	1	40	2.2183	1.7781	3.9965	1.3895	1.1951	2.6846	0.7288	0.5831	1.3119	20.5830	17.9590
8													
	1	1	42.5327	42.5497	85.0824	22.9556	22.9660	45.9216	19.5771	19.5837	39.1608	4.9845	4.1564
	1	2	21.5013	21.5403	43.0416	11.6633	11.6897	23.3530	9.8380	9.8505	19.6885	6.2907	5.3498
	1	5	9.1371	9.1820	18.3191	5.0910	5.1223	10.2133	4.0461	4.0597	8.1058	8.7050	7.6261
	1	10	5.2043	5.2056	10.4099	3.0482	3.0483	6.0964	2.1562	2.1573	4.3135		
	1	20	3.2566	3.1501	6.4067	2.0356	1.9652	4.0008	1.2210	1.1849	2.4058	15.6920	14.1020
	1	40	2.2203	1.9388	4.1591	1.4909	1.2992	2.7901	0.7294	0.6396	1.3690	2.0624	18.6600

10	1	1	42.4543	42.4626	84.9169	22.9034	22.9080	45.8114	19.5509	19.5546	39.1055	4.9821	4.2514
	1	2	21.4636	21.4934	42.9570	11.6382	11.6580	23.2963	9.8254	9.8354	19.6608	6.2883	5.4787
	1	5	9.0116	9.0305	18.0421	4.9769	4.9898	9.9668	4.0347	4.0407	8.0753	8.6497	7.7745
	1	10	5.2032	5.2138	10.4169	3.0472	3.0534	6.1006	2.1559	2.1604	4.3163	11.5040	10.5170
	1	20	3.2587	3.2043	6.4630	2.0370	1.9996	4.0366	1.2216	1.2047	2.4263	15.6900	14.4420
	1	40	2.2195	2.0414	4.2609	1.4900	1.3677	2.8577	0.7295	0.6737	1.4031	20.6450	19.1110

Isotherm 1

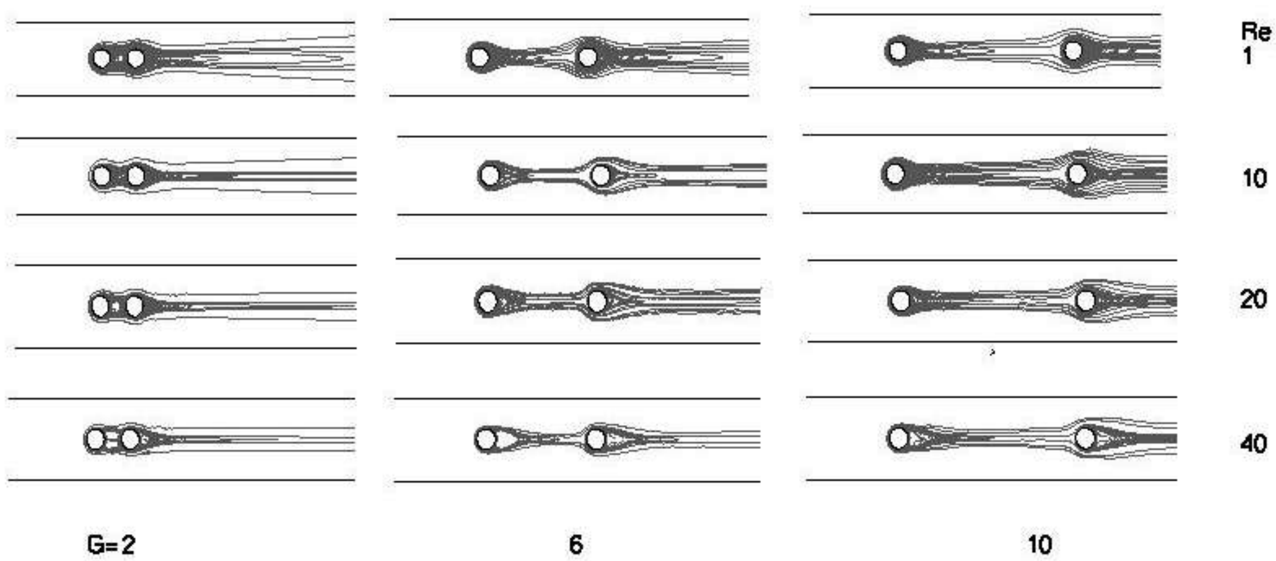

Figure.6 : isotherm profile for the different values of Reynolds number and gap ratio. The spacing betwwen two lines has been maintained at 0.5.

DESRIPTION

in this figure the effect of change of Reynolds number and gap ratio on heat transfer charactristic has been elucidated with the help of figure. As we can see that as Reynolds number increases the temprature distribution in fluid is less in comparision of low Reynolds number. And as the gap ratio increases from 2 to 10 the fluid get more space to settle in between two cylinder hence it can be concluded that for higher values of gap ratio the temprature is more distributed in between the two cyliders.

Isotherm 2

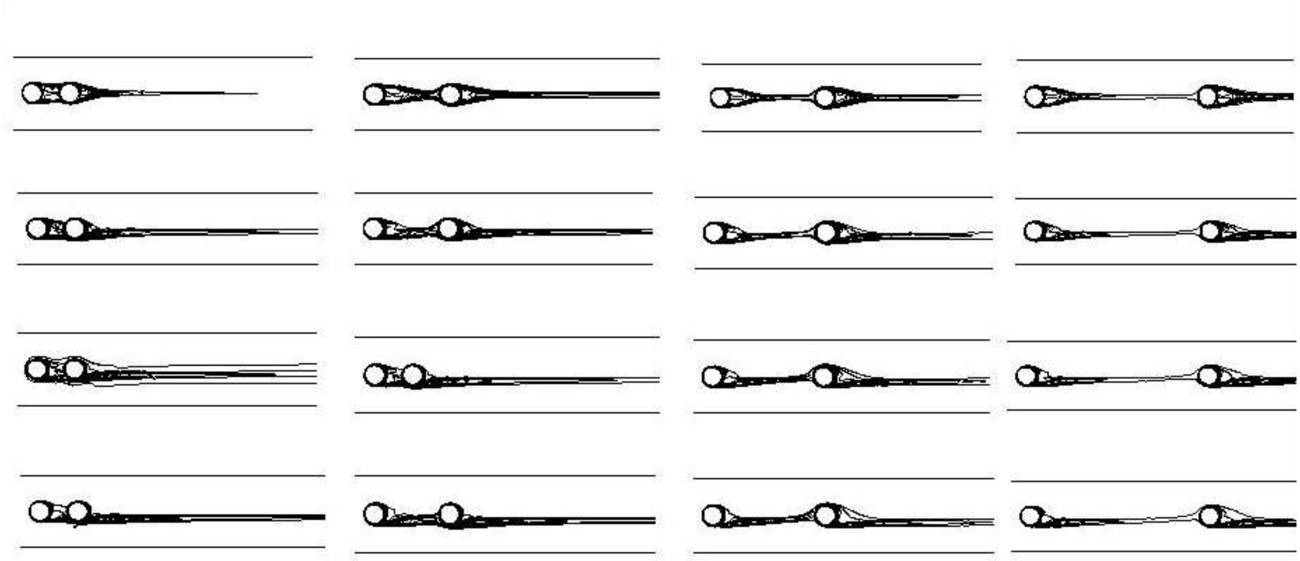

Figure.7 : in this figure isotherm profile for the different values of Reynolds number and gap ratio. The spacing betwwen two lines has been maintained at 0.5.

DESCRIPTION

In this figure the effect of change of Richardson number and gap ratio on heat transfer charactristic has been elucidated with the help of figure. As we can see that as Richardson number (negative numerical value) increases from top to bottom the gravity effect become significant. And hence the temprature is more distribulet beloe the cylinders. And as the gap ratio increases from 2 to 10 the fluid get more space to settle in between two cylinder hence it can be concluded that for higher values of gap ratio the temprature is more distributed in between the two cyliders.

Streamline 1

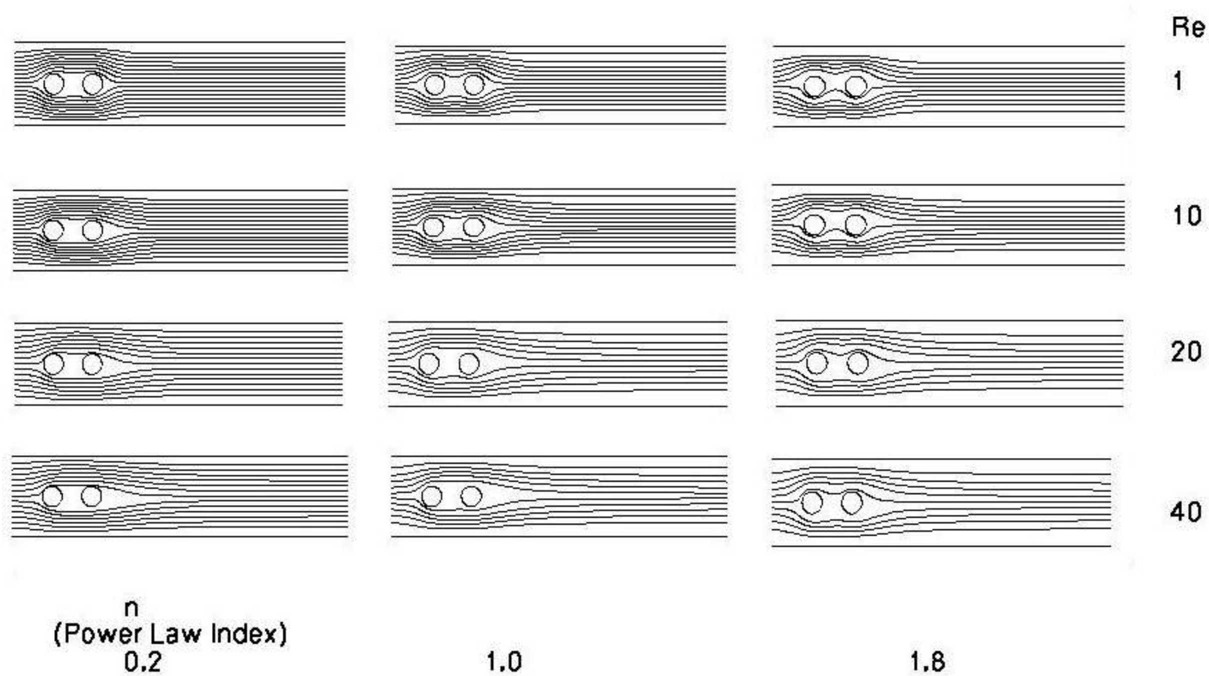

Figure. 8: streamline profiles for different values of Reynolds number and Power law indexat a gap ratio of G=2.

DESCRIPTION

In the above figure the streamline profiles has been plotted for the different values of Reynolds number and Power law index. As we can see that for higher values of Reynolds number the disturbnce created by the hinderance of cylinder takes more length to regain its path i. e. streamlines resume a long time to settle down. We can also see that the effect of Power law index is there and for higher values of n the streamline distortion is greater there.

Streamline 2

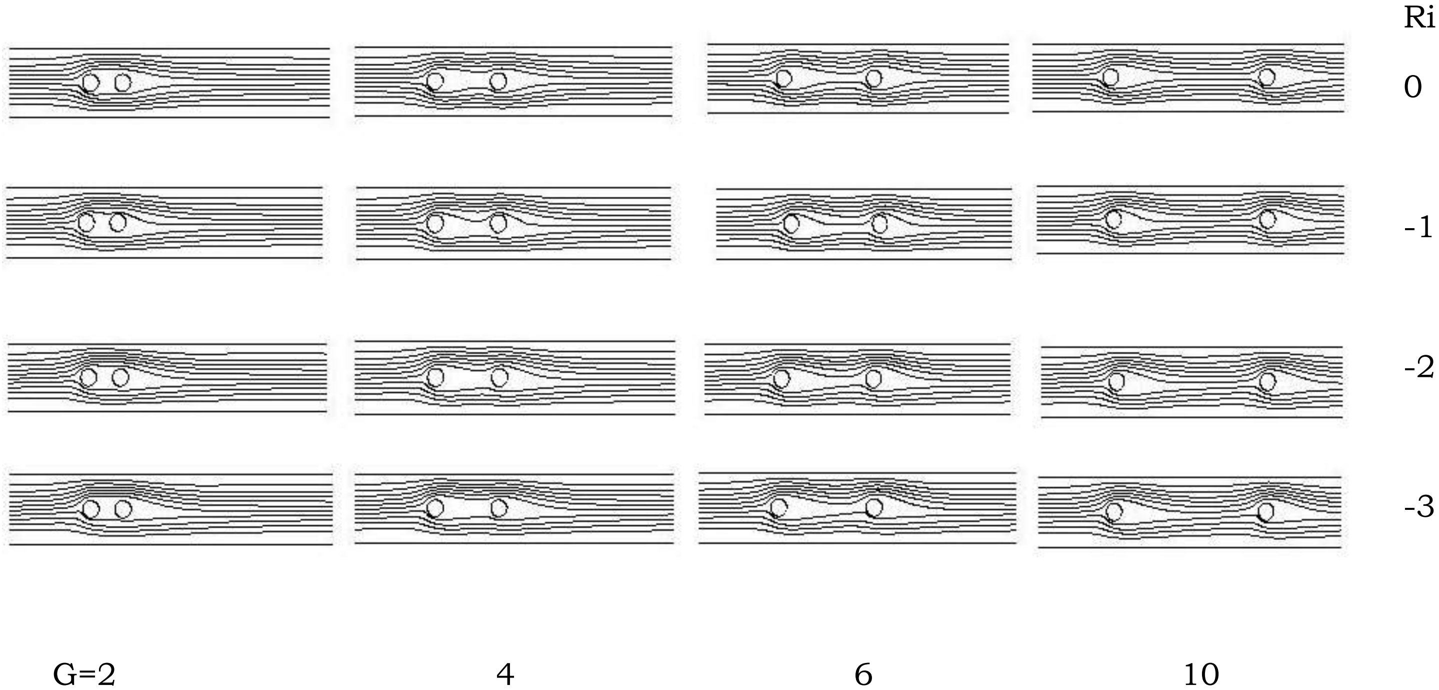

Figure.9: streamline profiles foe different values of Richardson number and gap ratio while keeping constant Power law index to 1 and Prandtl number to 100.

DESCRIPTION

In the above figure we have drawn streamline profile for Different values of Richardson number by keeping constant Prandtl number to 100, Reynolds number to 40 and the height of confined wall is 4. In the above figure it is seen from the figure that the effect of gravity is high numerical value of Richardson number i. e. for Ri -3 the streamlines below the cylinder are denser than streamlines above the cylinder. The effect of gap ratio is also significant because for the least value of G i. e. 2 the space between two cylinders is not enough that is why that region has not stream lines and as the gap ratio increased to 10 streamlines occupied the space between two cylinders. Absence of streamlines between two cylinders can be seen up to the value of gap ratio 4 but onwards gap ratio 6 they occupied the space between two cylinders.

Streamline 3

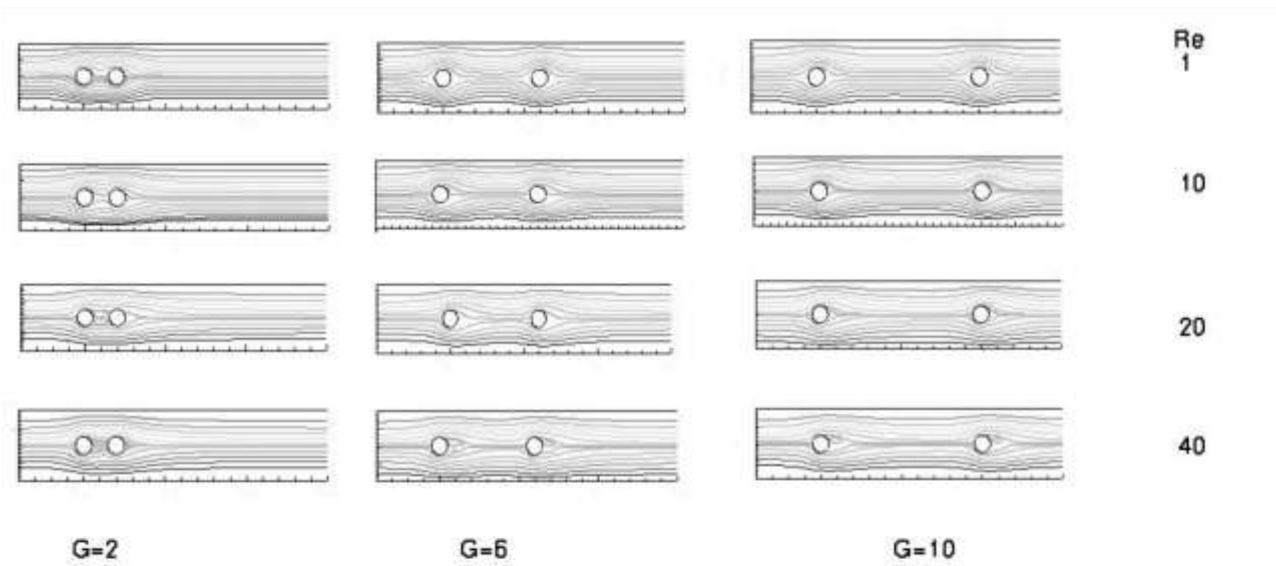

Figure.10 : in this figure streamlines has been plotted for the for the varying gap ratio and Reynolds number keeping Prandtl number and Richardson Number constant.

DESCRIPTION

As we can see from the figure, streamline profile for Different values of Reynolds number by keeping constant Prandtl number to 100, Richard number to 0 and the height of confined wall to 4. In the above figure it is seen from the figure that there is no effect of gravity. For the least value of G i. e. 2 the space between two cylinders is not enough that is why that region has not stream lines and as the gap ratio increased to 10 streamlines occupied the space between two cylinders. Absence of streamlines between two cylinders can be seen up to the value of gap ratio 4 but onwards gap ratio 6 they occupied the space between two cylinders. The effect of Reynolds number can be seen from the figure as the Re increases distortion of streamlines become more prevailing in the vicinity of walls and just because of high Reynolds number it take more time to regain its path.

Vorticity 1

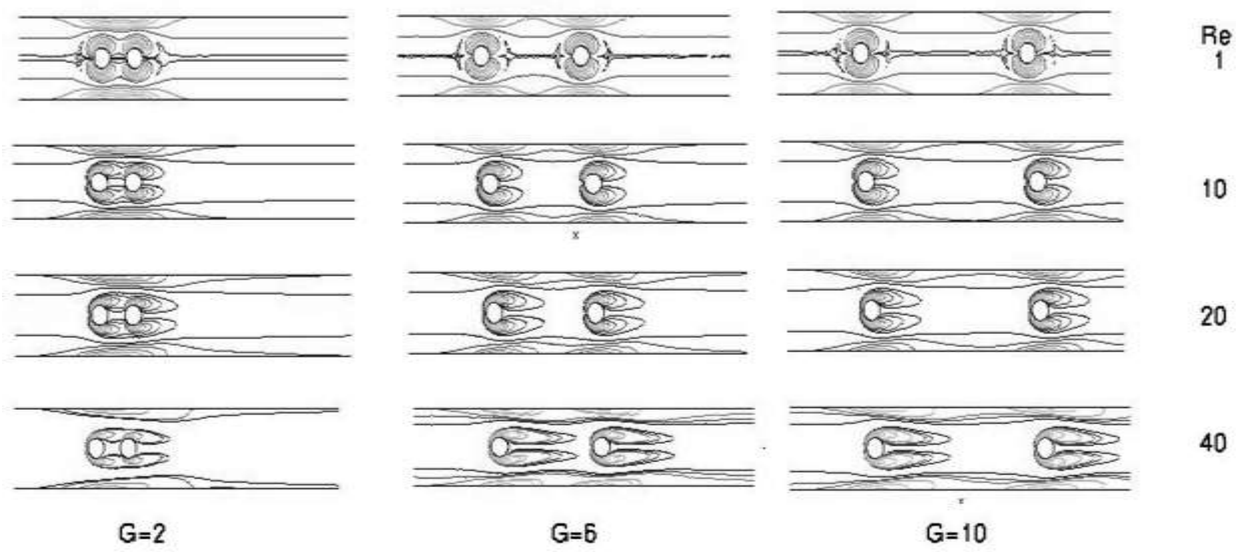

Figure.11: in the above figure the vorticity profile has been plotted with varying gap ratio and Reynolds number.

DESCRIPTION

In the above figure the vorticity profile has been plotted for different values of gap ratios and Reynolds number. As we can see from the figure the vorticity profile is significantly affected by the Reynolds number. As we know that n=1 is the case of Newtonian fluid hence the above profiles are for Newtonian fluid only. The vortex formation is also affected by gap ratio. We can see in the figure that when gap ratio is small the vortex on both cylinders is not separated but intermixed in to each other but as the gap ratio increased from 2 to six they get separated from each other.it is also concluded from the figure that when Reynolds number increased from 1 to 40vortex area around the cylinder get decreased and profile completely changes for Re 10 and higher values.

Vorticity 2

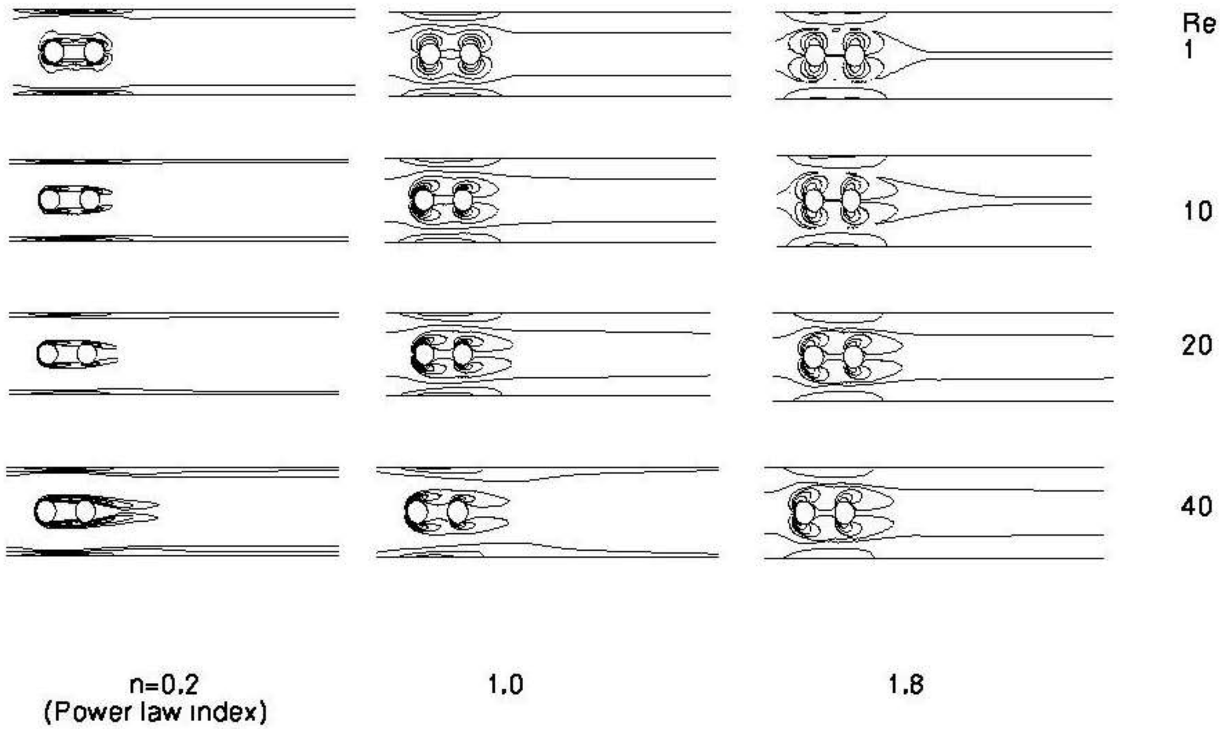

Figure. 12: in the above figure the vorticity profile has been plotted with varying Power law index and Reynolds number.

DESCRIPTION

In the above figure the vorticity profile has been plotted for different values of Power law index and Reynolds number. As we can see from the figure the vorticity profile is significantly affected by the Reynolds number. As we know that n=1 is the case of Newtonian fluid hence the above profiles are for Newtonian fluid only. The vortex formation is also affected by power law index significantly. We can see in the figure that when n is small the vortex on both cylinders is not distributed extensively in the vicinity. But as the power law index increased the extent of vortex formation also get increased in the vicinity.

Vorticity 3

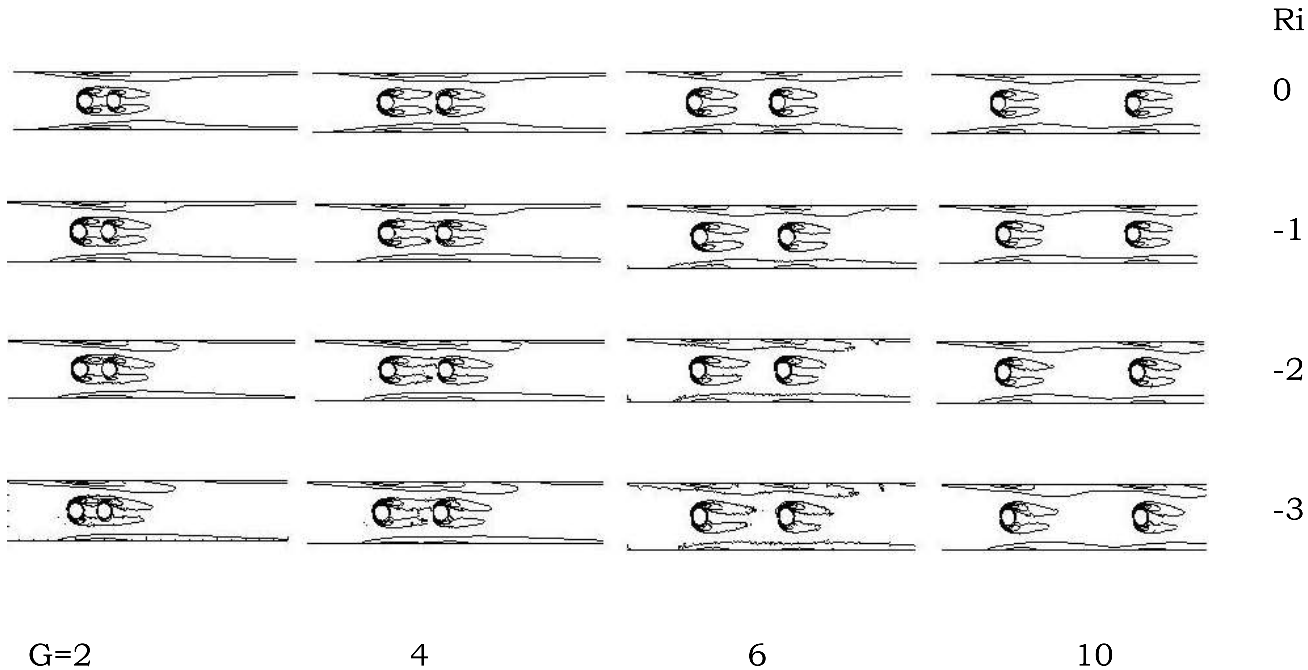

figure.13: **in the above figure the vorticity profile has been plotted with varying gap ratio and Richardson number.**

DESCRIPTION

In the above figure vorticity profiles has been plotted for different values of Richardson number and gap ratios such as in the above case the Richardson number has been varied from 0 to -3 and gap ratio has been varied from 2 to 10. We can see in the figure that when gap ratio is small the vortex on both cylinders is not separated but intermixed in to each other but as the gap ratio increased from 2 to six they get separated from each other. Richardson number also affected the above vortex profile significantly. As we know that for higher values of Richardson number the gravity effects are higher. So in our case as we increase Richardson number from 0 to -3 the vortex profile near the lower wall gets diminished in comparison of low Ri values profile.

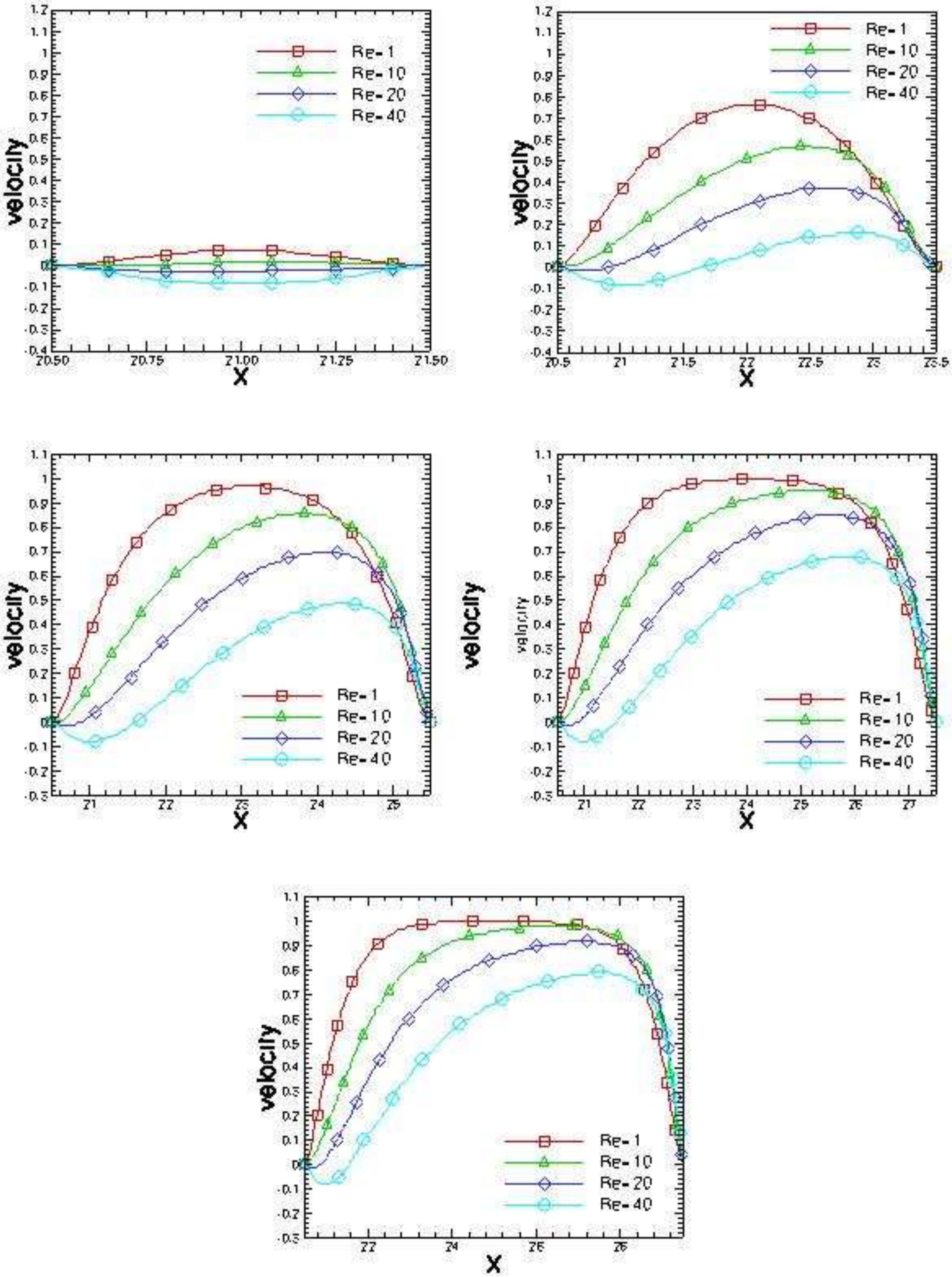

Figure.14: this is the plot of X velocity between two cylinders for different values of gap ratio i. e. for G= 2, 4, 6, 8, 10

DESCRIPTION FOR PREVIOUS FIGURE

In the above five figures for five values of gap ratio has been plotted for different values of Reynolds number. In the above figure the x-velocity versus x- coordinated has been plotted for different values of Reynolds number (1 to 40). As we can see in the figure that the value of x-velocity for higher values of Reynolds number is higher. For lower values of gap ratio fluid does not get required space in between two cylinders so its value is lower for low values of gap ratio.

The red color line represents Re 1 and it is clearly visible in the graph that x-velocity is higher for lower values of Reynolds number and vice-versa.

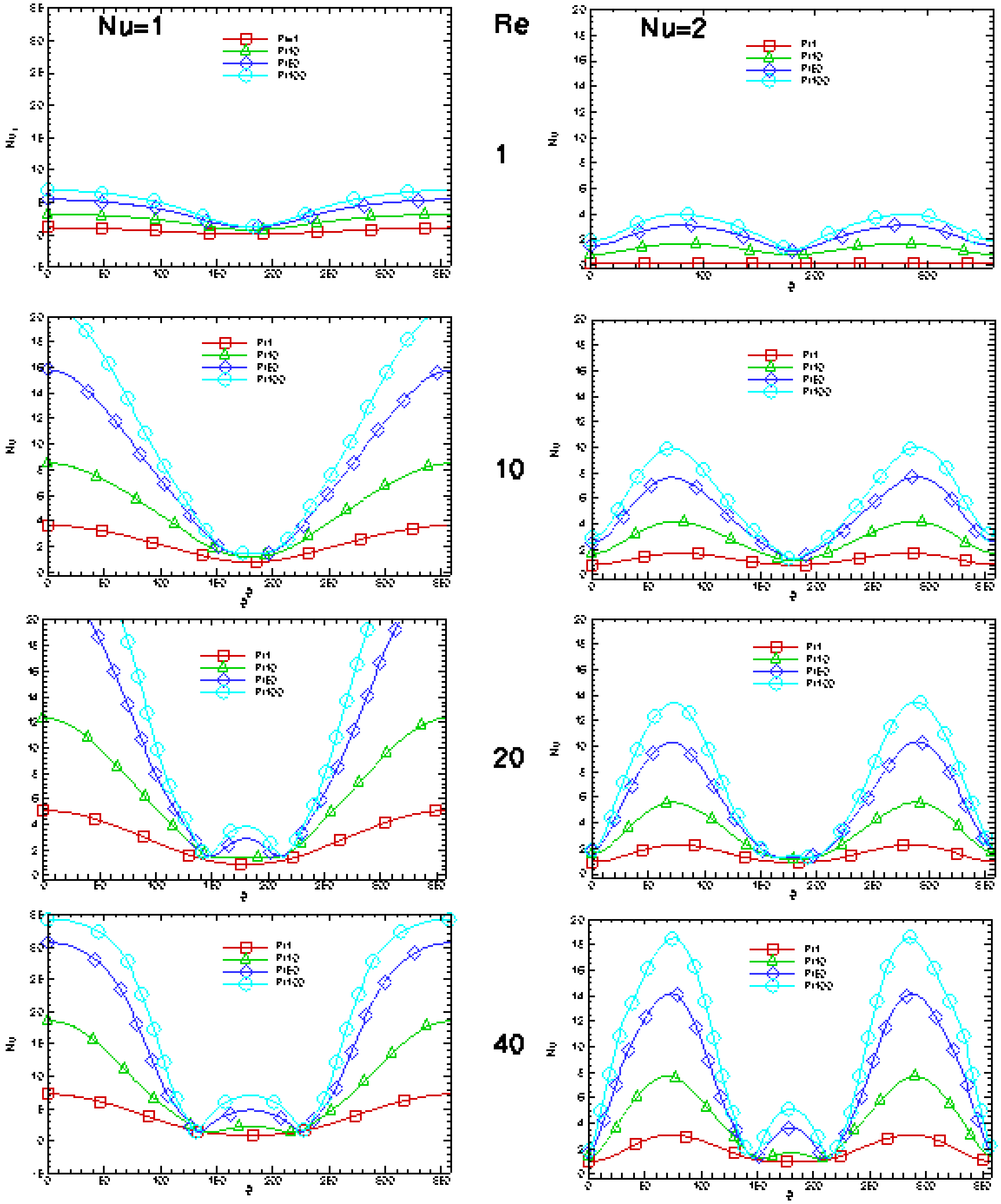

Figure.15: this is the plot of Nusselt number of two cylinders for different values of Reynolds Numbers i. e. for Re= 1, 10, 20 and 40.

DESCRIPTION TO PREVIOUS FIGURE

In the above figure the plot of Nusselt number versus angle made on the Centre of cylinder by radius has been plotted for different values of Prandtl number (1, 10, 50, 100). The right hand side represents the downstream cylinder and left hand side represents the upstream cylinder.

In x coordinate the perimeter of cylinder has been converted to angle by divided cylinder in to 240 points. Because we took 240 points on on cylinder for result analysis.

It can be seen from the graph that local Nusselt number increases with increase in the value of Reynolds number. For higher values of Prandtl number the values of Nusselt number are also higher.

CHAPTER 5

CONCLUSION AND RECOMMENDATION FOR FUTURE WORK

5.1 CONCLUSION

In this work, numerical solution has been calculated using Fluent. Heat and mass transfer equation has been solved for flow of power law fluid across a pair of circular tandem cylinder in confined arrangement. In this study the comparison of drag force, pressure drag and Nusesel number with changin parameters such as Richardson number (0 to -3), Reynolds number (1 to 40), Power law index (0.2 to 1.8), and Prandtl number (1 to 100).

It is seen from the numerical data the hydrodynamic drag force increases with increases in Richardson number irrespective of other parameters such as Reynolds number, Prandtl number and gap ratio.

For fixed value of Ri, Re and Pr the average drag force cofficient showed a increasing behaviour with incresing value of Power law index (n<1) and as power law index increases the value of drag cofficient increases significantly. The effect of Reynolds number also significant on drag forces, with increasing Reynolds number the values of drag forces decreses rapidly.

Nusselt number also shown a direct correlation with Reynolds number, with incresing value of Reynolds number the value of Nusselt number decreases drastically.

For better representation of effects isothermal profiles, streamline profiles and vorticity profile has been incorporated in this thesis.

5.2 RECOMMENDATION FOR FUTURE WORK

this thesis has been contributed for the understanding of fluid flow behavior across a circular cylinder in confined arrangement. For future work the following work can be done to extend this researc

h. 1. this work ha sbeen done for constant blockage ratio of 0.25, so in future work different blockage ratio can be incorporated to extend the present work.

2. this work has been done for laminar flow, in future numerical analysis can be done for turbulent flow also.

3. this work has been done for 2-D space but for real life practical application this work can also be done in 3-D model.

4. in this work a circular cylinder was taken, in future work other geometry such as square or elliptical cylinder can also be taken.

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