CFD STUDY ON THE HEAT TRANSFER IN VERTICAL RIFLED TUBE WITH DIFFERENT HELICAL ANGLES

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Abstrak

Dalam penyelidikan ini, kajian “Computational Fluid Dynamics (CFD)” tentang pemindahan haba dan pemantauan aliran bendalir pada tabung laras menegak dengan dua sudut heliks (30^o and 45^o) yang berbeza telah dilaksanakan. Tabung laras menegak tersebut mempunyai diameter luar sebanyak 25mm, diameter dalaman maksimum sebanyak 18.8mm; diameter dalaman minimum sebanyak 17.50mm, ketebalan tetulang sebanyak 9.25, dan jumlah permulaan adalah empat. Simulasi CFD ini dijalankan ke atas orientasi menegak bagi tabung laras besi di bawah enam halaju masuk yang berbeza; 0.893, 1.765, 2.38, 2.897, 3.57, 4.166 m/s. Bendalir yang digunakan adalah air dan suhu awalnya adalah 298K. Objektif kajian ini adalah untuk menentukan pemindahan haba dan penurunan tekanan tabung laras dengan sudut heliks (30^o and 45^o) dibandingkan dengan keputusan tabung laras pada 60^o sudut heliks. Keputusan tabung laras pada 30^o sudut heliks menunjukkan suhu yang lebih tinggi untuk halaju masuk yang lebih rendah. Perbezaan suhu antara tabung masuk dan tabung luar adalah bersamaan 10.19K bagi 0.893 m/s halaju masuk. Sementara itu, bagi halaju masuk sebanyak 4.166 m/s, perbezaan suhu adalah 2K. Pola yang sama dijumpai bagi keputusan tabung laras pada sudut heliks 45^o. Tambahan pula, perbezaan keputusan bagi tabung laras 30^o dan 45^o dengan tabung laras bersudut heliks 60^o menunjukkan hanya sedikit penyimpangan. Penurunan tekanan bagi tabung-tabung bersudut heliks $30^o$and 45^o pada halaju masuk yang lebih tinggi adalah masing-masing 17277.2 Kpa dan 19426.44Kpa. Sementara bagi kedua-dua tabung pada halaju masuk yang rendah masing-masing bersamaan dengan 1295.9 Kpa, 1444.088Kpa. Keputusan tersebut menunjukkan penurunan tekanan yang semakin rendah adalah untuk halaju masuk yang semakin rendah. Perbandingan keputusan menunjukkan penurunan tekanan bagi sudut heliks 30^o and 45^o sentiasa tinggi berbanding sudut heliks 60^o untuk semua keadaan. Keseluruhannya, ini boleh disimpulkan bahawa kenaikan sudut heliks bagi tabung laras tidak memberikan kesan ke atas pemindahan haba tetapi memberi kesan dalam penurunan tekanan.

Abstract

In this research, computational fluid dynamics (CFD) study of heat transfer and fluid flow monitoring of vertical rifled tubes with two different helical angles (30^o and 45^o) has been carried out. The rifled tube has an outer diameter of 25mm, maximum inner diameter of 18.8 mm; minimum inner diameter of 17.50mm, rib width of 9.25, and the number of starts is four. The CFD simulation were conducted on a vertical orientation of the steel rifled tube under six different inlet velocities; 0.893, 1.765, 2.38, 2.897, 3.57, 4.166 m/s. The fluid used is water and the initial temperature is 298K. The objective of this study is to determine the heat transfer and drop pressure of rifled tubes with helical angles (30^o and 45^o) compared with rifled tube result at 60^o helical angles. The results of rifled tube with 30^o helical angle show higher temperature for lower inlet velocity. The temperature difference between the inlet and outlet of the tube is equal to 10.19 K for inlet velocity of 0.893 m/s. For inlet velocity of 4.166 m/s on the other hand, the temperature different is 2K. Similar patterns are found for results of rifled tube with 45^o helical angle. In addition, comparison of results for $30^o$and 45^o rifled tubes to rifled tube with 60^o helical angle yield only slight deviation. The pressure drop of the tubes with $30^o$and 45^o helical angles at higher inlet velocity is 17277.2 Kpa and 19426.44Kpa, respectively. While for both tubes at low inlet velocity, there are equal to 1295.9 Kpa, 1444.088Kpa, respectively. The results show lower pressure drop in the rifled tube for lower inlet velocity. Comparison of results shows that the pressure drops for 30^o and 45^o helical angle always higher than the 60^o helical angle for all cases. Consequently, it can be concluded that the increase in the helical angle for the rifled tube gives no effect on heat transfer but it does in drop pressure.

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LIST OF SYMBOLS AND ABBREVIATION

CFD	Computational Fluid Dynamics
K	Kelvin
^{o}C	Degrees Celsius
CHF	Computation Heat Flux
α (^{o})	Helix angle
w	Width
C_p	Specific heat
ρ	Dansity
P	Prssuer
τ_w	Wall Shear Stress
u_τ	Friction Velocity
ν	Kinematic viscosity
U_e	Velocity
Re	Reynolds Number
$\overline{C_f}$	Skin Friction Coefficient
Δp	Pressure Drop
μ	Dynamic Viscosity
k	Thermal Conductivity
u, v, w	Velocity component in(x, y ,z) coordinates system
$\bar{u}$	Average velocity

$\acute{u}$	Fluctuating velocity
$\bar{p}$	Average pressure
f	Force component in(x, y ,z) coordinates system
Φ	The viscous dissipation term
t	The Time
e	Internal energy of mixture, per unit mass
q	Heat Flux

LIST OF APPENDICES

CHAPTER 1

CFD STUDY ON THE HEAT TRANSFER IN VERTICAL RIFLED TUBE WITH DIFFERENT HELICAL ANGLES

INTRODUCTION

The study will describe a computer based software study and its results, analysing heat transfer and fluid flow in rifled tubes. The software used for the study is called GAMBIT and FLUENT. GAMBIT is a general-purpose pre-processor for CFD analysis, which allows engineers access into the CFD world is used to draw the objects FLUENT, the world leader in computational fluid dynamics software, is used to analyze the results.

The study about the various tube designs is done to analyze optimal and efficient configurations, to be used in water boilers. A boiler is a closed vessel in which water is heated. The heated or vaporized fluid exits the boiler for use in various processes or heating applications. In water-tube boilers the water tubes are arranged inside a furnace in a number of possible configurations: often the water tubes connect large drums, the lower ones containing water and the upper ones, steam and water; in other cases, such as a mono-tube boiler, water is circulated by a pump through a succession of coils. This type generally gives high steam production rates, but less storage capacity than the above. Water tube boilers can be designed to exploit any heat source and are generally preferred in high pressure applications since the high pressure water/steam is contained within small diameter pipes which can withstand the pressure with a thinner wall.

The boiler system consists of circuits, pressure grids and connecting tubes. Therefore, the study of temperature history (heat transfer), change in pressure, steam velocity and fluid flow in a vertically rifled tube are essential for the safety and efficiency of the tube boiler. Prediction of liquid one-phase flow frictional pressure drop in flow boiling process is of key importance in designing thermal process equipment in various industries such as thermal energy plant, refrigeration and heat pump system, chemical process engineering and others. On one hand, if a fixed flow is required, the pressure drop in a system determines the power input of a pumping system. If, on the other hand, the available pressure drop in a system is fixed, the relationship between the pressure drop and the resultant system velocity is of importance in determining velocity-dependent parameters, such as heat transfer coefficient, mass flux and heat flux limitation. However, the prediction of vapour liquid one-phase frictional pressure drop in flow boiling still needs investigation because it is usually greater and usually very difficult to estimate.

In this research, software based studies will be carried out on the fluid flow in a vertical rifled tube (one-phase), considering 3 different helical angles.
The specifications of the angles in the tubes are as follows:

1. Rifled tube with 60 degree angle (results are available from previous studies and will be used as comparison baseline)

2. Rifled Tube with 30 degree helical angle

3. Rifled Tube with 45 degree helical angle

The study will be conducted and comparisons made between the two rifled tubes and the standard setting. The study will analyze flow rate and pressures, in order to determine the time required to reach the boiling point. The results will be illustrated graphically in a temperature – time diagram.

With the development of enhanced heat transfer technology over the last decades, various enhanced heat transfer tubes have been developed for the purpose of improving heat transfer coefficients and saving energy consumption. However, in general, heat transfer is increased in the enhanced heat transfer tubes by accompanying an increase of one-phase frictional pressure drop whereby the most efficient angle will be determined during the study.

Spirally internally rifled tube is one of these types of enhanced heat transfer tubes which can enhance flow boiling heat transfer and critical heat flux (CHF) development of science and technology. Enhanced heat transfer technology has achieved great development and found wide applications in various industries over the past decades. Enhanced heat transfer is generally called the second generation heat transfer technology and it plays a very important role in the development, utilization, and saving of energy (Wedd *et al 2009).* Whether for practical use or for theoretical value, the study of enhanced heat transfer elements is of great significance. For that aspect of flow boiling which involves heat transfer enhancement, quite a few studies have been conducted to improve heat transfer rate and energy efficiency. An exhaustive compilation of the relevant literature has been presented (Almeida.*et al.,2008)* , Enhanced heat transfer Technology is generally classified as active, passive, and compound heat transfer enhancement technologies, respectively, which combines at least two heat transfer enhancement methods. Passive heat transfer enhancement technology is more practical and is easily implemented because it does not consume external power. Various flow boiling heat transfer enhancement methods have been developed over the past years, for example, rough surface, electrostatic field, additives for fluids and so on (Mott *et al .,2006)* Of these, the spirally internally rifled tube is a type of enhanced tube which is able to enhance flow boiling heat transfer and critical heat flux (CHF).

Attaining a good level of understanding of enhanced boiling in tubes is still a task due to the effect of each change in the enhanced geometry on the flow boiling process and pressure drop. The introduction of roughened surfaces obtained with internal helical ridging or transverse ribbing, has revealed a successful method in enhancing heat transfer in tubes and, therefore, in reducing the heat a number of studies of flow boiling in internally rifled tubes have been carried out over the past years in this study Numerical analysis will be carried out on vertical rifled tubes to determine the fluid flow properties, the heat transfer and pressure drop across the tubes in the different models. Heat will be supplied electrically. Heat transfer rate will be determined by calculations with the software as well as the velocity of the fluid. The fluid flow velocity will be controlled as input parameter in the software. The pressure drop in the tube and the heat enhancement factor of ribbing the tube will also be determined by software analysis.

1.1 OBJECTIVES OF STUDY

1. To determine the flow rate and pressure characteristics in a vertical positioned rifled tube helical angle 30°, 45° and 60°.
2. To determine the heat transfer in a vertical rifled tube (determine the time required to reach the boiling point).

3. To determine the pressure drop in a vertical rifled tube.

1.2 SCOPE OF STUDY

Computer analysis will be used to determine the characteristics of fluid flow in the rifled tube. Table 1.1: shows the dimensions of the rifled tube the scope of study are:-

i. Water will be used as the fluid medium (one-phase).

ii. Riffled tube will be analyzed with two different helical settings; 30° and 45° degrees and compared with previously studied of 60 degrees.

iii. The analysis will be conducted with tube placed vertical.

Table 1.1: The dimensions of the rifled tube.

Tube type	Outer diameter, OD (mm)	Max inner diameter, ID (mm)	Min inner diameter, ID (mm)	Rib height, t (mm)	Rib width, w (mm)	Helix angle, α (°)	Number of starts
Steel	25.00	18.80	17.50	0.6835	9.25	30°,45° &60°	4

1.3 Expected Results.

At the end of this study, the fluid flow characteristics, pressure drop and heat transfer across a vertical rifled tube will be determined by CFD. Also optimum helical angle will be chosen.

CHAPTER 2

LITERATURE REVIEW

2.1 Significance and background of heat transfer enhancement.

Heat transfer, heat flow, heat exchange or transfer of thermal energy all implies to the movement of heat from one place to another. Heat transfer occurs when an object has temperature different to that of its surroundings and this happens until temperature of both reaches to equilibrium. The heat transfer always occurs in the direction from high temperature to low temperature region which is accordance with the second law of thermodynamics. In engineering, energy transfer by heat between objects is classified as either heat conduction, also called diffusion, of two objects in contact, by fluid convection, which is the mixing of hot and cold fluid regions, and by thermal radiation, the transmission of electromagnetic radiation described by black body theory (Loomis and Maris, 1994). However, engineers also consider the transfer of mass of differing chemical species, either cold or hot, to achieve transfer of heat.

Heat exchange has its application in various fields like aviation and space systems; energetic, chemical and petroleum refining, food industries, refrigerating, air-conditioning and cryogenic engineering; materials, steel, iron and metallurgical industries and heating and hot water supply systems *etc*.(Kakaç and Liu, 2002). The investigation and development of the better heat transfer performance of heat exchangers is denoted as heat transfer enhancement. This is nothing but the increase in the heat transfer coefficient. This area of enhancement of heat transfer has gone through hasty and noteworthy growth in recent years and is of extreme significance in heat exchanger strategies. The fact that the enhanced heat transfer exchangers can provide more compact, lightweight and less expensive exchangers has been the backbone of this growth.

Enhancement techniques are characteristically set apart into two groups: ‘passive’ and ‘active’ techniques. In passive techniques special surface geometries or fluid additives are used for enhancement. In the active enhancement there are techniques like heated surface rotation, surface vibration, fluid vibration, electrostatic fields and suction at the heated surface. The active techniques are efficient in dropping the wall superheat and augmenting the critical heat flux, but the practical applications are confined, possibly due to the difficulty in providing the mechanical or electrical effect (Bergles, 1997). Utilization of two or more of these techniques concurrently can produce an enhancement that is greater than the specific techniques applied discretely.

2.2 The critical heat flux (CHF)

Critical heat flux (CHF) is the heat flux at which a boiling crisis happens accompanied by an abrupt raise of the heat transfer surface or decreasing the efficiency of the heat transfer rate. The CHF inflicts a limit in constructing and accomplishing boiling heat transfer machinery in macroscopic heat transfer excahangers in power manufacturing units like the nuclear, fusion and fossil power stations. Besides in microscopic heat transfer devices like heat pipes and micro channels for cooling electronic chips. Therefore, a raise in the critical heat flux could add to the safety factor and permits for more economical devise and operations at elevated heat fluxes (Chang et al., 2006). The higher the capacity of the nuclear power plant or the fossil boilers is the more will be the requisite heat load per unit transfer area. The utmost heat flux may be elevated more than 10 MW/m^2 and hence special heat transfer maneuvers are mandatory. Nucleate boiling is the most effectual heat transfer process and the upper boundary of this is stipulated by the CHF. Henceforth, attempts have been discharged to explicate the regime of nucleate boiling. The enhancement of the CHF is thus an important element in the domain of heat transfer;

having substantial research of related work accounted in the literature (Chang et al., 2006).

From the past studies and recent researches, it has been found that the main thermal resistance to the convective heat transfer is because of the existence of laminar sub-layer on the heat-transferring surface. The ribs break the laminar sub-layer and produce local wall turmoil because of the flow separation and reattachment among the consecutive ribs, that diminishes the thermal resistance and very much improves the heat transfer. Anyhow, the artificial roughness used may result in higher friction and thus higher pumping power necessities. For that reason, it is advantageous that the turbulence ought to be created in the vicinity of the wall, i.e. only in the laminar sub-layer region, which is accountable for thermal resistance. That's why, the pains of researchers have been intended towards discovering the roughness shape and arrangement that could break the laminar sub-layer and improve the heat transfer coefficient to the maximum with the least amount pumping power penalty (Kamali and Binesh, 2008).

There were investigations on the effects of rib height, rib spacing, and Reynolds number. The friction factor is shown to be directly proportional to the rib height and inversely proportional to the rib spacing in the range investigated. Dipprey and Sabersky formulated a friction similarity law and a heat momentum transfer analogy for flow in rough tubes (Dipprey and Sabersky, 1963). Webb and Eckert also contributed by developing the heat transfer and friction factor correlations for turbulent air flow in tubes having repeated rib roughness (Webb et al., 1971). The heat transfer enhancement was investigated and Zhang et al. reported that the addition of grooves in between adjacent square ribs could enhances this capability of the surface greatly with almost same pressure drop penalty (Zhang et al., 1994). The aid of artificial roughness in the form of repeated ribs in these respects has been established to be an proficient technique of enhancing the heat transfer to fluid flowing in the duct. Katto has broadly studied CHF for forced convection boiling in various case of working conditions based on dimensional analysis. He collected CHF data by means of seven different fluids and the data were sorted out into four flow regimes and the analogous correlations were framed according to the flow regime (Katto, 1978).

Tubes that have a transverse repeated-rib roughness with rectangular cross section have been examined first by Webb et al. (Webb et al., 1971). With the aid of the law of the “wall similarity” and heat-momentum analogy he put forth a few correlations where the friction factor is expressed as a function of the dimensionless geometric parameters and the Reynolds number, wheras the Stanton number is expressed as a function of the same variables and the Prandtl number together. This study was extended to the effect of the rib helix angle by Gee and Webb (Gee and Webb, 1980). Based on the heat-momentum transfer analogy, Withers (Withers, 1980) developed correlating equations for the heat transfer and pressure drop in tubes comprising simple and multiple helical ridges inside. These correlations were derived by experimental data attained with water in the Reynolds number range 10000-120000 and Prandtl number range 4-10. Heat transfer enhancement of up to 2.5 to 3 was accounted. A similar study of heat transfer enhancement was conducted by Yampolski using a spirally fluted tube (Yampolski, 1983). He illustrated that the swirl in the flow owing to the helical flutes augments turbulent exchange on both interior and exterior of the tube with no substantial increase in the friction factor. Turbulent flow investigations dealing with pressure drop and heat transfer coefficient in the doubly-fluted tubes were also performed by Richards et al (Richards et al., 1987). In the study, out of the twelve different geometries that were analyzed only some of them yield an enhanced performance, expressed by the authors in terms of heat exchanger volume diminution.

Another study by Garimella et al.(Garimella et al., 1988) expressed the performance of spirally enhanced tubes in terms of a single non dimensional geometric parameter, the severity. Here also the turbulent flow is considered and it has shown that for severity values between 0.001 and 0.01 the heat transfer increase is escorted by moderately low friction factor increase, hence proving the competence of similar variety of geometries. Garimella and Christensen (Garimella and Christensen, 1993) have inspected the fluid flow in annuli produced by inserting spirally fluted, indented and ribbed tubes within a smooth outer tube. In order to have better understanding of the development of the swirl in the bulk flow, thorough temperature profile measurements and flow visualization tests were carried out for the laminar, transitional and turbulent flow. As a result, it was established that the fluted inner tubes are the most proficient in promoting the secondary flow and consequently in improving the convective heat transfer.

Several attempts were made by the researchers to enhance the CHF by maneuvering the internal flow and changing the fuel assembly. According to (Gambill et al., 1960) when the flow in a tube is directed by twisted tape, a helical coil or a grooved surface (rifled tube), a swirl flow can be generated. By the centrifugal force generated by the swirling motion of the fluid, liquid is forced to flow on the tube surface and vapor is forced to flow along center line of the tube. Consequently, local velocity of the flow is increased compared to that in a smooth tube under the same mass flux. Therefore, the swirl motion of the flow can contribute to enhancement of the CHF. (Gambill et al., 1960) were the first to study the effect of flow swirling on heat transfer and its effect on the CHF. They attained high CHFs, 118 MW/m^2 for water and 28 MW/m^2 for ethylene glycol. The experiements of CHF under a subcooled boiling region were also performed by some others later (Araki et al., 1989; Celata et al., 1994). Further, CHF experiments for one-sided heating were also conducted to study the effect of a one-sided heat load in a PFS like divertor in fusion reactors (Boscary et al., 1999).

So many literatures are available with the data presenting the rifled tube yields, which have significant enhancement in heat transfer and CHF (Cheng and Xia, 2000; Nishikawa et al., 1972; Swenson et al., 1962; Whalley, 1979). The chief application of rifled tubes consists of coal fired boilers and fusion divertors. Investigations with experiments on boiler application are conducted at high pressure and high quality (~22 MPa, $x>1$). In the spiral internally rifled tubes, the CHF can be enhanced by a factor of 1.3–1.6 when compared to a smooth tube (Cheng and Xia, 2002; Kim et al., 2005). On their study on four headed rifled tube with an average inner diameter 17 mm, Iwabuchi et al., (1982) found that at a pressure beyond 20.6 MPa, the improvement of the CHF vanished. Cheng and Xia, (2002) performed a parallel study and found that the enhancement effect is evident from 10 MPa to 19 MPa. Anyhow, there was no noticeable enhancement at 21 MPa. When the pressure reached a critical pressure of approximately 22 MPa, the ratio of liquid water density to vapor density was reduced and approached 1. With a low (~1) density ratio, the swirl flow cannot provide strong centrifugal force to the liquid water and the effect of the swirl flow on the CHF is decreased. For the fusion divertor applications, the works are conducted at low pressure and low quality (~ 1 MPa, $x<0$)(Boscary et al., 1999).

2.3 Rifled tube

During the 1970s and near the beginning 80s, the cost of the energy began to increase spectacularly. As a result, the demand for energy-efficient air conditioning products also enlarged. In the early 1980s, the heat exchanger industry's contributed to the commercialization of rifled-tube heat exchangers. Ahead of introduction of rifled tubes, the designer normally added more heat exchanger surface to hoist the effectiveness of an air conditioner (Shinohara et al., 1987). At present, due to the improved heat transfer characteristics of rifled tubing, designers can amplify efficiency without expanding the size of air conditioning components. The rifled tubing was developed to augment the performance of evaporators and condensers in two-phase refrigerant flow applications. The enhancement in heat transfer is due mainly to the 50% to 60% increase in internal surface area over plain tube, in this manner plummeting the liquid refrigerant film thickness (Kim et al., 2005).

As a result of reduced film thickness, there is an increased effective temperature difference among the tube wall and the refrigerant gas-liquid interface, and offers further heat transfer potential. In addition, in evaporator coils (depending on refrigerant velocity), the rifled tube facilitates in promoting the annular flow, that results in the increase in the amount of wetted surface area for evaporation. The tube-side heat transfer coefficient for rifled tubing is as much as two and one-half to three times as compared to that of plain tube for condensing and evaporating settings.

The design of the ridges in rifled tubing is provided to improve performance in both condensers and evaporators; however, should have enough strength to diminish deformation when the tube is stretched into the fins (Paul Jr and Decourcy, 2001). Other factors that contribute to the performance enhancement include the ridge height, apex angle, and helix angle. Under the tow-ohase flow conditions also the rifled tubing has proven to be effective (Lee and Chang, 2008). When compared to the condenser that has has desuperheating and subcooling sections, the evaporator coil has a higher percentage of its internal surface area in two-phase flow.

The research on rifled tube has been since long time and many researchers published article on the use of it in the heat exchange behavior (Lee and Chang, 2008; Smith et al., 1968; Yang et al., 2010). Tucakovic *et* al., (2007) used the evaporating tubes in the steam boilers with the intention of increasing the steam–water mixture turbulization and to prevent the burnout of tubes walls. The rifled evaporating tubes and the working fluid forced circulation are applied in the steam boiler at the Thermal Power Plant "Kolubara B" that is being built by the Electric Power Utility of Serbia. Lee and Chang, (2008) performed a study of post-dry out heat transfer with a directed heated smooth tube and rifled tubes using vertical R-134a up-flow to look into the heat transfer distinctiveness in the post-dryout region. Three types of rifled tube that have dissimilar rib height and width were used to study the effects of rib geometry and match up with the smooth tube, using a mass flux of 70–800 kg/m^2 s and a pressure of 13–24 bar (corresponding to an approximate water pressure of 80–140 bar). The same study also showed that the heat transfer correlation for rifled tubes was also obtained as a function of rib height and width with the amendment of the smooth tube conjunction.

In order to investigate the heat transfer and friction behaviors of the rifled tube with vertical upward flow, Yang *et* al., (2010) from China used rifled tube in the water wall design of a 600MW supercritical CFB boiler. An in-depth experiment was conducted in the range of pressure from 12 to 30MPa, mass flux from 230 to 1200kg/(m^2s), and inner wall heat flux from 130 to 720kW/m^2. The wall temperature distribution and pressure drop in the rifled tube term were acquired from this experiment. Their experimental results demonstrate that the rifled tube can successfully avoid the incidence of Departure from Nucleate Boiling (DNB) and maintain the tube wall temperature in a acceptable range underneath the operating condition of supercritical CFB boiler (Yang et al., 2010).

The majority of the researchers focused on performing experimental based on a conventional rifled tube, rather than enhancing it. The recirculation of the fluid induced by the fins augments the heat transfer only for Prandtl number greater than 5. A numerical technique for predicting the friction factor and the heat transfer in spirally fluted tubes and this has been proposed by Iwabuchi et al., (1982). According to this technique the flute region is modeled as a porous substrate, with direction reliant permeability that influences the flow field in very much the similar way as the spiral flutes. The Nusselt number values obtained with the numerical simulation are in good agreement with their experimental data for Reynolds number below 500. Preliminary tests (Kohler and Kastner, 1986) confirmed that the presence of the helical ridging yields a noteworthy heat transfer intensification also in the laminar field and recommended the opportunity of additional study in this research, the fluid flow characteristic of the rifled tube will be carefully monitored and analyzed. In comparison to the smooth tube, the effect of the inner surface geometry of the tube on varying parameters will be intensively established.

2.4 Helix angle

In mechanical engineering, a helix angle is the angle between any helix and an axial line on its right, circular cylinder or cone (Geerts et al., 2002). General applications are screws, helical gears, and worm gears. The helix angle references the axis of the cylinder, differentiating it from the lead angle, which references a line perpendicular to the axis. The helix angle is the geometric complement of the lead angle and the angle is measured in degrees. According to (Webb et al., 1971) the range of geometric parameters were number of rib starts (18 to 45), helix angle (25 to 45 deg), and rib height (0.33 to 0.55 mm). These geometries supplies data on a new class of internal enrichment that is typical of commercially rough tubes currently utilized.

CHAPTER 3

METHODOLOGY

Develops sufficient background of the research based on past study by other researchers and therefore gains an insight into the challenges faced by the vertical rifled tube.

3.1 Study methodology

Figure 3,1 shows the stages of this study, where the process have been done through several steps, First came the background study and based on that define the problem statement and obtain the plan of the study and by planning can get the helical angle of the CFD study on rifled tube by 45° 30° and analyze the CFD results an compare the angles 45 and 30 and from the results we can conclude the right helical angle that provide the optimal heat transfer. For CFD analysis figure 3.2 illustrates the steps of running Gambit and Fluent software.

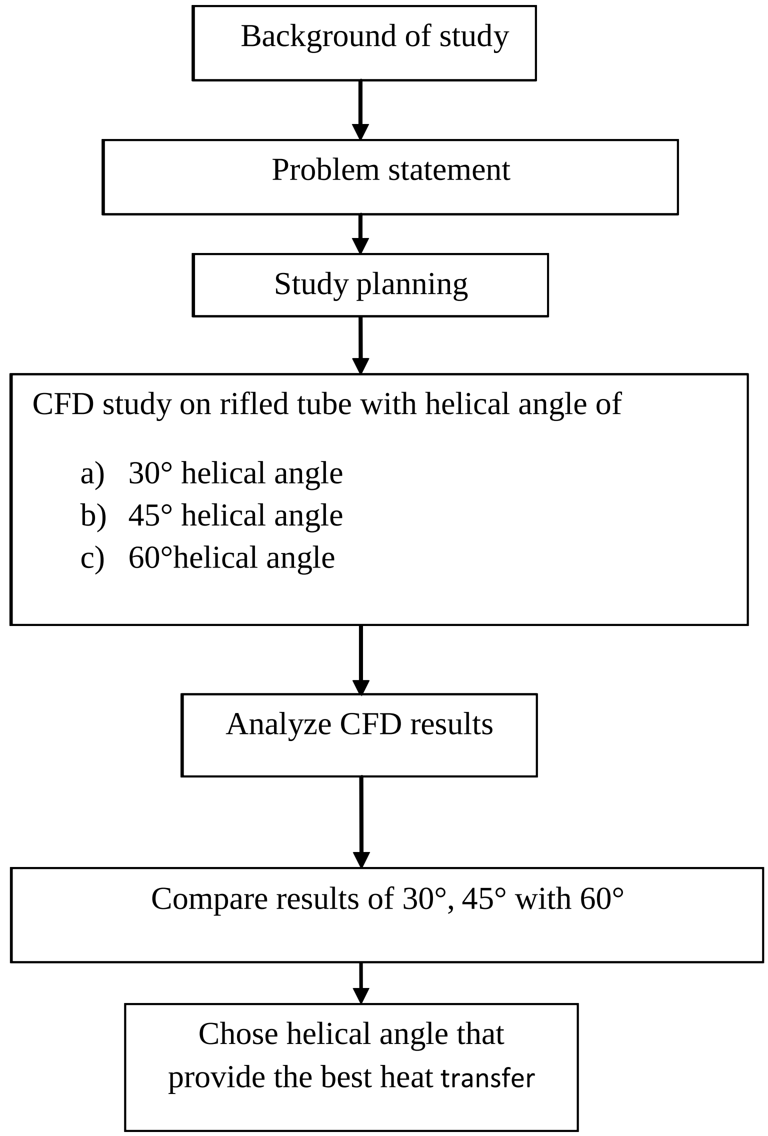

Figure 3.1: General flow chart of study

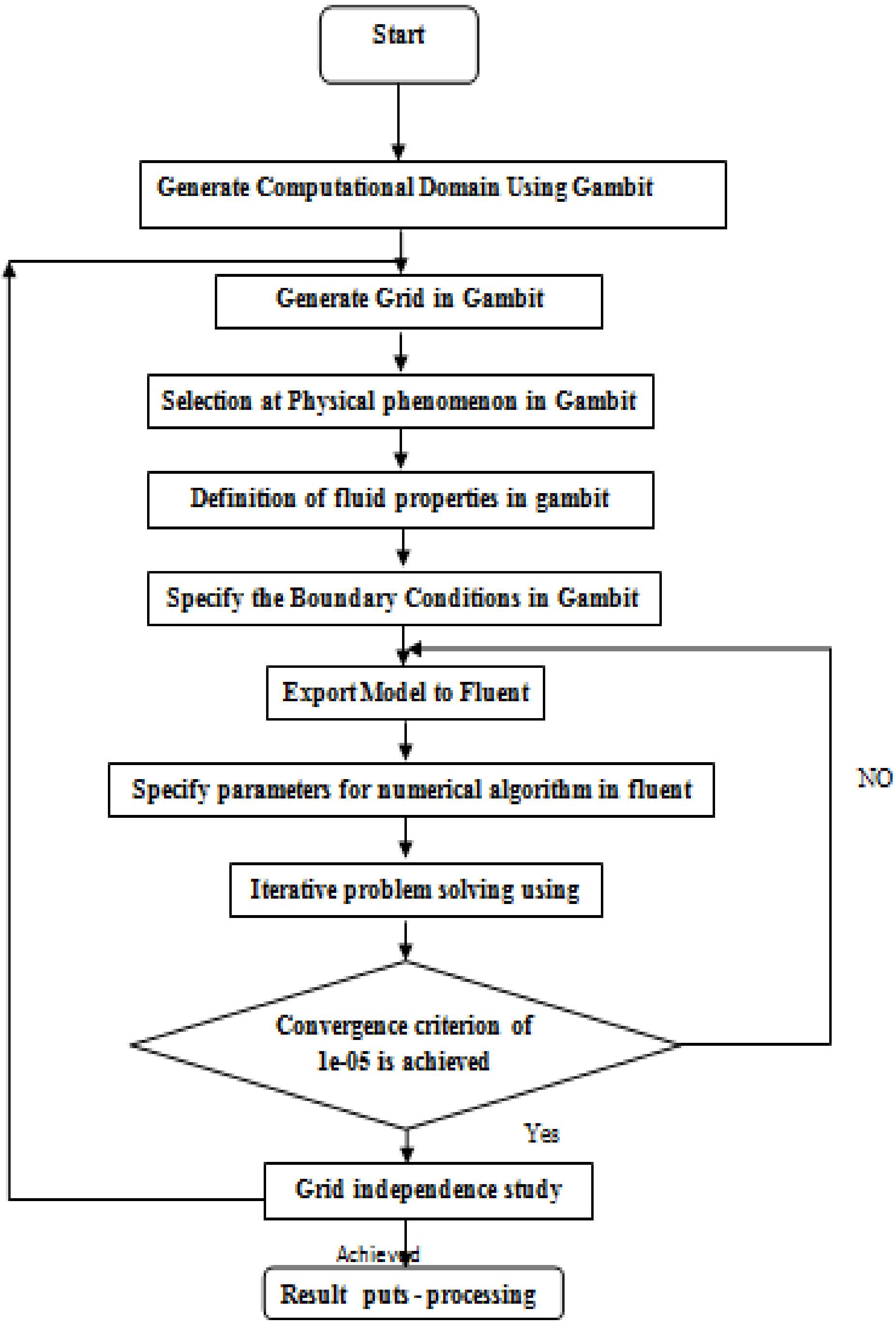

Figure 3.2 Flow chart for CFD works

Table 3.1 Gantt chart

Description		week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Background study	**Target planning**														
	Actual planning														
Problem statement	**Target planning**														
	Actual planning														
Study planning	**target planning**														
	Actual planning														
Writing report	**Target planning**														
	Actual planning														
Prepare for presentation	**Target planning**														
	Actual planning														

Table 3.1(continued)

Description			Week												
			1	2	3	4	5	6	7	8	9	10	11	12	13
Step	**Tasks**	**Planning**													
CFD Study on rifled tube with helical angle of 30° and 45°	Setup software and data	Target planning													
		Actual planning													
Calculations with CFD	Run calculations for the different angles (2 weeks each)	Target planning													
		Actual planning													
Analyze CFD Results; Compare results for 30° and 45° with 60°	Start of analyzis after the first 2 week; Compare results after both results are available	Target planning													
		Actual planning													
Chose helical angle that provide the best heat transfer		Target planning													
		Actual planning													
Write thesis		Target planning													
		Actual planning													
Prepare for Presentation		Target planning													

3.2 numerical methodology

3.2.1 Computational Domain

The commercial CFD code FLUENT (FLUENT, 6.3.) has been used to analyze the model flow characteristics of rifled tube. Modeling and mesh generation however have been performed in Gambit environment. Water has been taken as the fluid medium. Figure 3.3 shows the schematic diagram of the ribbed tube model. Table 3.2 on other hand, shows the dimensions of the rifled tube with the different helix angles. Also figure 3.6 shows the schematic diagram of computational domain, for schematic diagram of the Rifled tube has shown in figure 3.4. In additional to this, drawing of the Rifled tube which generated in GAMBIT shown in figure 3,5.

Table 3.2: The dimensions of the rifled tube.

Tube type	Outer diameter, OD (mm)	Maximum inner diameter, ID_{max} (mm)	Minimum inner diameter, ID_{min} (mm)	Rib height, t (mm)	Rib width, w (mm)	Helix angle, α (^{o})	Number of starts
Steel	25.00	18.80	17.50	0.6835	9.25	45&30	4

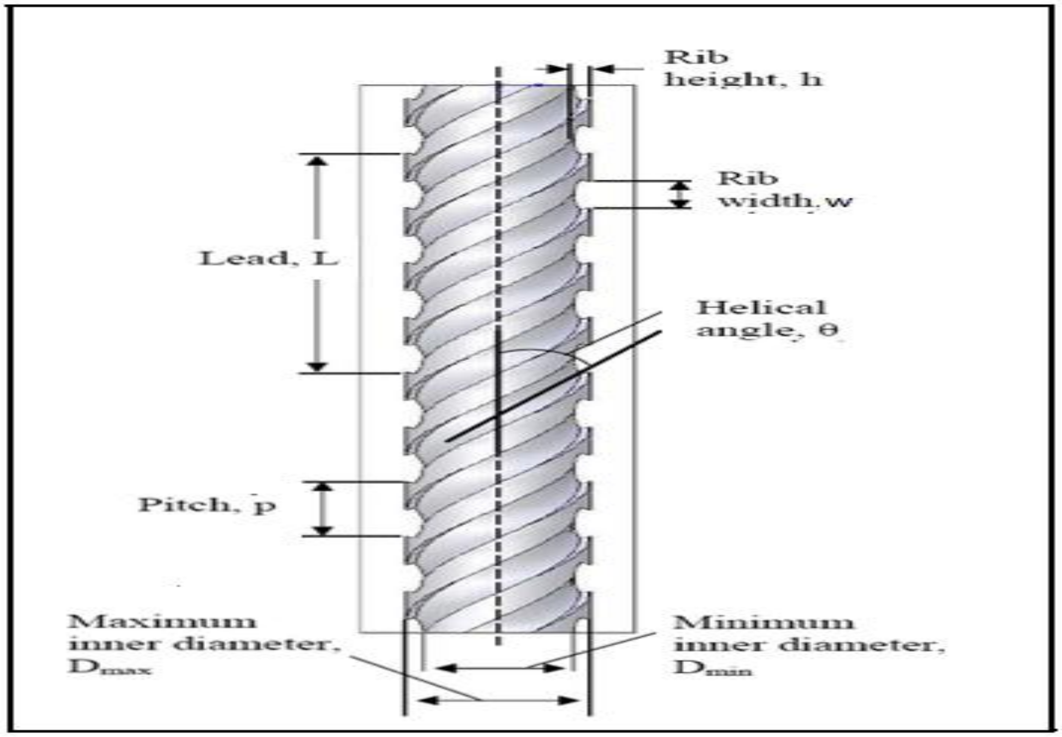

Figure 3.3: Computational domain.

Figure.3.4: Rifled tube.

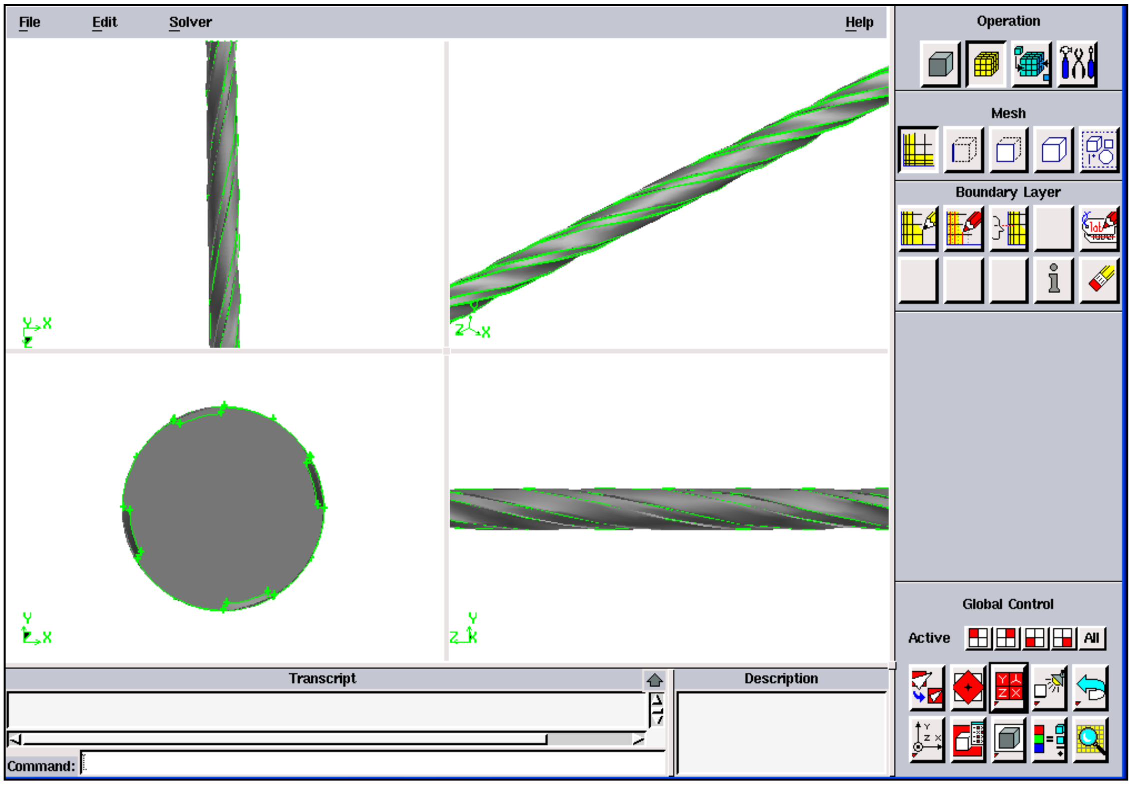

Figure.3.5A portion of the numerical domain generated in GAMBIT.

3.2.2Governing Equations

The following steady-state 3-D equations in Cartesian coordinates form will be use to solve numerically for a Newtonian, incompressible fluid.

Continuity Equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (3.1)$$

Conservation of Momentum Equations in three dimensions as:

x –component

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=\rho f_x-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \tag{3.2}$$

y -component

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=\rho f_y-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \tag{3.3}$$

z -component

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=\rho f_z-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \tag{3.4}$$

Based on literature review, the Standard k - ε Model will be used in this study.

3.2.3 Energy equation

The modified form of the first law of thermodynamics applied to an element of fluid states that the rate of change in the total energy (intrinsic plus kinetic) of the fluid as it flows is equal to the sum of the rate at which work is being done on the fluid by external forces and the rate on which heat is being added by conduction,(P.K. Nagarajan et al,2009).

$$\rho\left(\frac{\partial e}{\partial t}+u\frac{\partial e}{\partial x}+v\frac{\partial e}{\partial y}+w\frac{\partial e}{\partial z}\right)+\frac{\partial q}{\partial t}=\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)$$
$$-p\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\Phi \tag{3.5}$$

Where Φ is known as the viscous dissipation term:

$$\Phi = \left\{2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 - \frac{2}{3}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)^2\right\}$$

3.2.4 Boundary Conditions

Flow is considered to be turbulent as the Reynolds number range between 10^4 to 5×10^4 were used. The properties of water were taken at temperature 25℃ (298 k), as show in table 3.3. The type of tubes used in this analysis is Steel and the properties for tube at 25^oC are show in table 3.4.The heat flux was applied to heat up the wall of rifled tube. Figure 3.6 shows the boundary conditions.

Where:-

V: is the velocity, the results have been got at six velocities (0.893, 1.786, 2.38, 2.976, 3.57, 4.166).

T: is the temperature (298k).

h: is the heat flux ($150KW/m^2$)

Table 3.3 .The properties of water at temperature (298 k).

Temperature *(k)*	Density ρ *(kg/m³)*	Specific heat *Cp (j/kg.k)*	Thermal conductivity *(w/m.k)*	Viscosity *(kg/m.s)*
298	997.1	4180	0.6055	0.000891

Table 3.4-The properties of Steel at 300 k.

Type of tube	Density ρ *(kg/m³)*	Specific heat *Cp (j/kg.k)*	Thermal conductivity *(w/m.k)*
Steel	8030	502.48	16.27

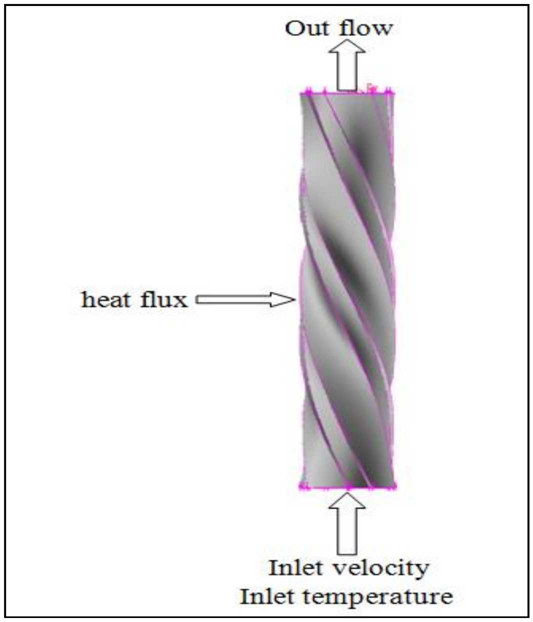

Figure.3.6: Boundary Conditions

3.2.5 Mash study

For standard wall functions, each wall-adjacent cell's centroid should be located within the log-law layer (figure 3.4).

$$y_p^+ \approx 30 - 300 \tag{3.6}$$

How to estimate the size of wall-adjacent cells before creating the grid:

$$y_p^+ \equiv y_p u_\tau / \nu \Rightarrow y_p \equiv y_p^+ \nu / u_\tau \;, \quad u_\tau \equiv \sqrt{\tau_w / \rho} = U_e \sqrt{C_f / 2} \tag{3.7}$$

Where:

τ_w is the Wall Shear Stress ($kg.s^{-2}.m^{-1}$)

u_τ is the Friction Velocity ($u_\tau = (\tau_w/\rho)^{1/2}$) ($m.s^{-1}$)

ρ is the Density (kg.m−3)

ν is the Kinematic viscosity ($m^2.s^{-1}$)

U_e is the velocity (m/s)

The skin friction coefficient ($\overline{C_f}$) for duct can be estimated from empirical correlations: :(www.Fluentusers.com)

$$\frac{\overline{C}_f}{2} \approx 0.039\,\mathrm{Re}_D^{-1/4} \tag{3.8}$$

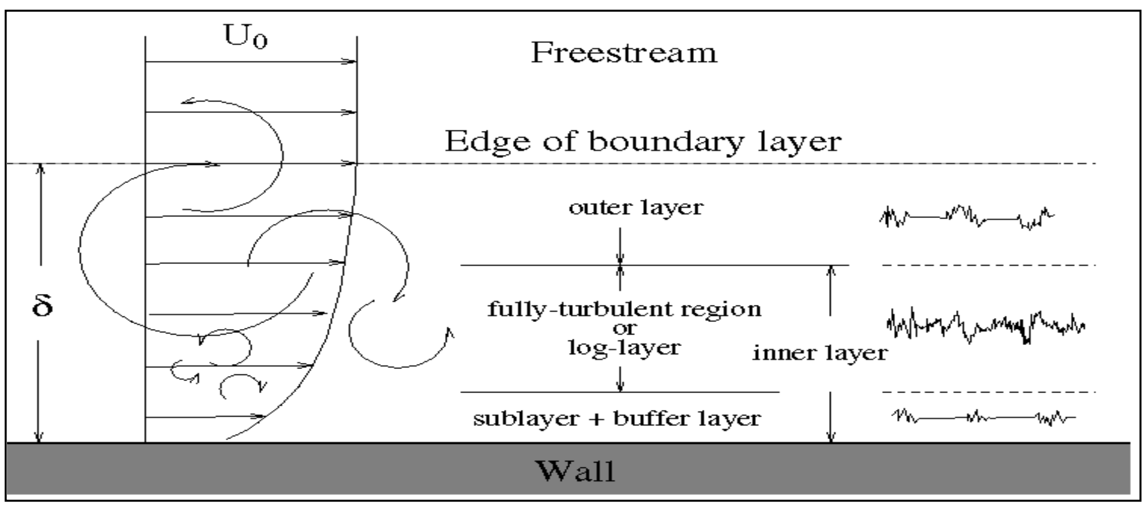

Figure 3.7 The structure of turbulent boundary layers in the near-wall region:

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