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CFD Analysis on Heat Transfer Enhancement in Horizontal Tube by Forced Convection with Inserts

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Abstract:

There is a continued research to increase heat transfer rates in industrial heat exchangers. Particularly at moderate Reynolds numbers in pipe flow the augmentation methods are divided into two types viz., passive techniques and active techniques. Placing different types of inserts in tubes serve as passive techniques. Active techniques, in which external power input is used, such as power work, are less preferred. In the present study experiments are conducted to augment heat transfer rates in turbulent flow to a horizontal tube using a square rod insert to which spiral, square, rectangle and pyramid blocks are welded.

The Reynolds numbers ranged from 6000 to 14000. Five different inserts are used. They are (1) plain rod (2) spiral over rod (3) spiral and square blocks over rod, (4) spiral and rectangle blocks over rod and (5) spiral and pyramid blocks over rod. Analysis data obtained is used for calculation of Friction factor and Nusselt number in the presence of inserts. Among five inserts tested, spiral-rectangle blocks insert gave maximum heat transfer advantage. Since an increase in heat transfer coefficient is associated with an increase in pumping work.

1.INTRODUCTION:

Heat exchanger is a device used for the process of heat exchange between the two fluids that are at different temperatures. The heat exchange process in heat exchangers can be described by the principles of evaporation or condensation, conduction, radiation and convection. Heat exchangers are useful in many engineering processes like those in air conditioning systems and refrigeration, food processing systems, chemical reactions, and power systems.

When two systems are bought into contact through some kind of energy transfers such as work and heat take place between them. The transfer and conversion of energy from one form to another is basic to all heat transfer processes and hence they are governed by the first as well as the second law of thermodynamics. Thermodynamics deals with systems in equilibrium so it cannot be expected to predict quantitatively the rate of change in a equilibrium which results from non-equilibrium states. Heat transfer is commonly associated with fluid dynamics and it also supplements the laws of thermodynamics by providing additional experimental rules to establish energy transfer rates.

Increase in thermal performance of heat exchangers, thereby effecting energy, cost and material savings have led to development and use of many techniques termed as “Heat Transfer Augmentation”. These techniques also referred as “Heat Transfer Enhancement or Intensification”. Augmentation techniques increase convective heat transfer by reducing the thermal resistance in a heat transfer.

By using heat transfer enhancement techniques lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. Thus, when designing a heat exchanger using any of these techniques, pressure drop and analysis of heat transfer rate has to be done.

Mainly experiment was concentrated on heat transfer by convection which occur when a temperature difference exists between a solid and a fluid flowing past it. It is essentially a process of energy transport affected by the circulation or mixing of a fluid medium which may be a liquid, a powdery substance, or a gas. The transport of heat transfer during convection is directly linked with the transport of the medium itself, and as such convection presents a combined problem of conduction, fluid flow and mixing.

The energy transfer in convection is predominantly due to the bulk motion of the fluid particles, though the molecular conduction within the fluid itself also contributes to some extent.With respect to the cause of fluid circulation or flow, two types of convection distinguished

1.1.1 Free Convection
1.1.2 Forced Convection

1.1.1 Free Convection:

Circulation of bulk fluid is caused by changes in fluid density resulting from temperature gradients between the solid surface and mass of fluid. The stagnant layer of fluid in the immediate vicinity of the hot body gets thermal energy by conduction. Because of temperature raise, these particles become less dense and hence lighter than the surrounding fluid particles. The lighter fluid particles move upwards to a region of low temperature where they mix with and transfer a part their energy to the cold particles. Simultaneously, the cool heavier particles descend downwards to fill the space vacated by the warm fluid particles. The circulation pattern, upward movement of the warm fluid and the downward movement of the fluid, is called convection currents. These currents are set up naturally due to gravity alone and are responsible for free convection.

Ex: Heat treatment processes like Quenching, normalizing, Heat transfer from transmission lines etc.

1.1.2 Forced Convection:

If the fluid motion is principally produced by some superimposed velocity field (like a fan, blower or a pump), the energy transport is said to be used to forced convection. The convection heat is affected to an appreciable extent by the nature of fluid flow.

Ex: Cooling of I.C engine cylinder, Refrigeration coils etc.

In the realms of fluid mechanics, essentially two types of fluid flow are characterized.

a.) Laminar Flow
b.) Turbulent Flow

a.) Laminar Flow:

The fluid particles moving flat or curved un-mixing layers are steams and follow a smooth continuous path. The paths of fluid movements are well defined and the fluid particles retain their relative positions at successive cross section of the flow passage. There is no transverse displacement of fluid particles, the particles remain in an orderly sequence in each layer.

b.) Turbulent Flow:

The motion of fluid particles is irregular, and it proceeds along unpredictable and erratic paths. The stream lines are intertwined and their change in position from instant to instant.

Fluctuating transverse velocity components are superimposed on the main flow, and the velocity of individual fluid elements fluctuate both along the direction of flow and perpendicular to it.

1.2 Enhancement Techniques:

Heat transfer enhancement techniques refer to the improvement of thermo hydraulic performance of heat exchangers. The techniques can be classified into two types and they are as follows:

1.2.1 Active Techniques:

which require external power.

i. Mechanical aids
ii. Surface vibration
iii. Fluid vibration
iv. Electrostatic fields
v. Injection
vi. Suction
vii. Jet impingement

1.2.2 Passive Techniques:

which require no direct application of external power.

i. Treated surfaces
ii. Rough surfaces
iii. Extended surfaces
iv. Displaced enhancement devices

v. Swirl flow devices
vi. Coiled tubes
vii. Surface tension tubes
viii. Additives for liquids
ix. Additives for gases

Of these, passively enhanced tubes are relatively easy to manufacture, cost effective for many applications where as active techniques, such as vibrating tubes are costly and complex.The heat transfer rate can be improved by introducing a disturbance in the fluid flow there by breaking the viscous and thermal boundary layer. In this process pumping power may increase significantly and ultimately the pumping cost becomes high. Therefore to achieve a desired heat transfer rate in an existing heat exchanger at economic pumping power, several techniques have been proposed in recent years.

The intent of the present experiment is to investigate the enhancement in heat transfer rate in a tube due to inclusion of the inserts.These tube inserts are believed to enhance convective heat transfer by creating one or more combinations of the following conditions which increase the heat transfer coefficient.

1. Continuously interrupting the development of the boundary layer of the fluid flow and increasing the degree of flow turbulence.
2. Continuously increasing the effective heat transfer area.
3. Continuously generating secondary flow.

Heat transfer enhancement is usually accompanied by increased pressure drop and therefore higher pumping power. By forcing the fluids through the tubes at higher velocities, the heat transfer can be increased, but this higher velocity results in larger pressure drop and thus larger pumping costs. So there must be a compromise between enhancement of heat transfer and pumping costs.

2: INTRODUCTION TO CAD

Computer-aided design (CAD), also known as computer-aided design and drafting (CADD), is the use of computer technology for the process of design and design-documentation. Computer Aided Drafting describes the process of drafting with a computer.

CADD software, or environments, provide the user with input-tools for the purpose of streamlining design processes; drafting, documentation, and manufacturing processes. CADD output is often in the form of electronic files for print or machining operations. The development of CADD-based software is in direct correlation with the processes it seeks to economize; industry-based software (construction, manufacturing, etc.) typically uses vector-based (linear) environments whereas graphic-based software utilizes raster-based (pixelated) environments.

CADD environments often involve more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions. CAD may be used to design curves and figures in two-dimensional (2D) space; or curves, surfaces, and solids in three-dimensional (3D) objects.

CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals. The modern ubiquity and power of computers means that even perfume bottles and shampoo dispensers are designed using techniques unheard of by engineers of the 1960s. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry.

The design of geometric models for object shapes, in particular, is often called computer-aided geometric design (CAGD).Current computer-aided design software packages range from 2D vector-based drafting systems to 3D solid and surface modellers. Modern CAD packages can also frequently allow rotations in three dimensions, allowing viewing of a designed object from any desired angle, even from the inside looking out. Some CAD software is capable of dynamic mathematic modeling, in which case it may be marketed as CADD — computer-aided design and drafting.

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CAD is used in the design of tools and machinery and in the drafting and design of all types of buildings, from small residential types (houses) to the largest commercial and industrial structures (hospitals and factories).

2.1: INTRODUCTION TO PRO/ENGINEER:

Pro/ENGINEER Wildfire is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design while ensuring compliance with your industry and company standards. Integrated Pro/ENGINEER CAD/CAM/CAE solutions allow you to design faster than ever, while maximizing innovation and quality to ultimately create exceptional products.Customer requirements may change and time pressures may continue to mount, but your product design needs remain the same - regardless of your project's scope, you need the powerful, easy-to-use, affordable solution that Pro/ENGINEER provides.

PRO/ENGINEER WILDFIRE BENEFITS:

•Unsurpassed geometry creation capabilities allow superior product differentiation and manufacturability

•Fully integrated applications allow you to develop everything from concept to manufacturing within one application

•Automatic propagation of design changes to all downstream deliverables allows you to design with confidence

•Complete virtual simulation capabilities enable you to improve product performance and exceed product quality goals

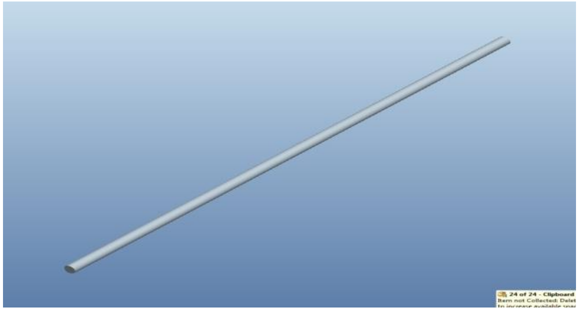
•Automated generation of associative tooling design, assembly instructions, and machine code allow for maximum production efficiency

Pro ENGINEER can be packaged in different versions to suit your needs, from Pro/ENGINEER Foundation XE, to Advanced XE Package and Enterprise XE Package, Pro/ENGINEER Foundation XE Package brings together a broad base of functionality. From robust part modelling to advanced surfacing, powerful assembly modelling and simulation, your needs will be met with this scaleable solution. Flex3C and Flex Advantage Build on this base offering extended functionality of your choosing.

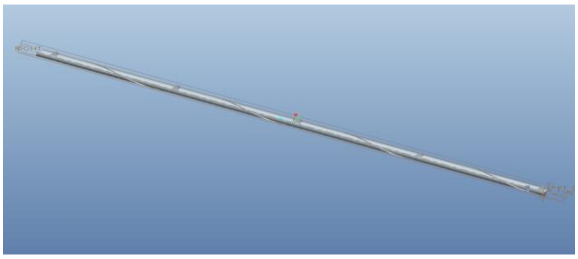
2.2: Different Modules in Pro/Engineer

- PART DESIGN
- ASSEMBLY
- DRAWING
- SHEETMETAL

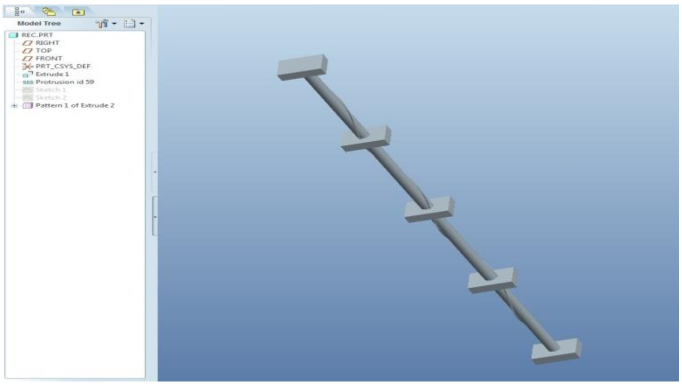
Plain rod



Spiral and pyramid blocks over rod



Spiral and rectangle blocks over rod



3: INTRODUCTION TO FEA

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variational calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Topp established a broader definition of numerical analysis. The paper centered on the "stiffness and deflection of complex structures".

By the early 70's, FEA was limited to expensive mainframe computers generally owned by the aeronautics, automotive, defense, and nuclear industries. Since the rapid decline in the cost of computers and the phenomenal increase in computing power, FEA has been developed to an incredible precision. Present day supercomputers are now able to produce accurate results for all kinds of parameters.

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

3.1 TYPES OF ENGINEERING ANALYSIS:

Structural analysis consists of linear and non-linear models. Linear models use simple parameters and assume that the material is not plastically deformed. Non-linear models consist of stressing the material past its elastic capabilities. The stresses in the material then vary with the amount of deformation as in.

Vibration analysis is used to test a material against random vibrations, shock, and impact. Each of these incidences may act on the natural vibrational frequency of the material which, in turn, may cause resonance and subsequent failure.

Fatigue analysis helps designers to predict the life of a material or structure by showing the effects of cyclic loading on the specimen. Such analysis can show the areas where crack propagation is most likely to occur. Failure due to fatigue may also show the damage tolerance of the material. Heat Transfer analysis models the conductivity or thermal fluid dynamics of the material or structure. This may consist of a steady-state or transient transfer. Steady-state transfer refers to constant thermo properties in the material that yield linear heat diffusion.

3.2 INTRODUCTION TO ANSYS:

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated, or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

ANSYS is the standard FEA teaching tool within the Mechanical Engineering Department at many colleges. ANSYS is also used in Civil and Electrical Engineering, as well as the Physics and Chemistry departments. ANSYS provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping.

With virtual prototyping techniques, users can iterate various scenarios to optimize the product long before the manufacturing is started. This enables a reduction in the level of risk, and in the cost of ineffective designs. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effect of a design on the whole behavior of the product, be it electromagnetic, thermal, mechanical etc.

3.3 STEPS INVOLVED IN ANSYS:

In general, a finite element solution can be broken into the following these categories.

1. Preprocessing module:

Defining the problem the major steps in preprocessing are given below

- defining key points /lines/areas/volumes define element type and material /geometric /properties
- mesh lines/areas/volumes/are required The amount of detail required will depend on the dimensionality of the analysis (i.e. 1D, 2D, axis, symmetric)

2. Solution processor module:

assigning the loads ,constraints and solving. Here we specify the loads (point or pressure), constraints (translation, rotational) and finally solve the resulting set of equations.

3. Post processing module:

Further processing and viewing of results , In this stage we can see: List of nodal displacement Elements orcas and moments Deflection plots Stress contour diagrams

Thermal

ANSYS is capable of both steady state and transient analysis of any solid with thermal boundary conditions. Steady-state thermal analyses calculate the effects of steady thermal loads on a system or component. Users often perform a steady-state analysis before doing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis; performed after all transient effects have diminished. ANSYS can be used to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

- Convection
- Radiation
- Heat flow rates
- Heat fluxes (heat flow per unit area)
- Heat generation rates (heat flow per unit volume)
- Constant temperature boundaries

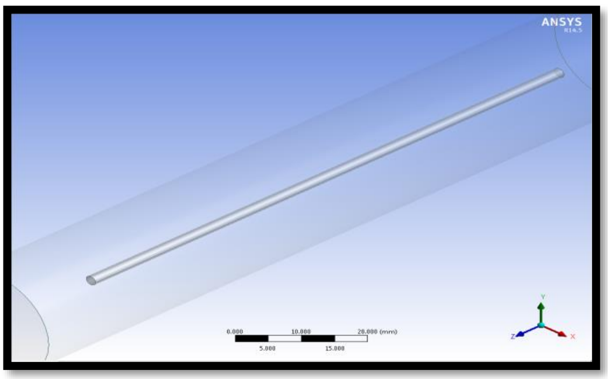
A steady-state thermal analysis may be either linear, with constant material properties; or nonlinear, with material properties that depend on temperature. The thermal properties of most material vary with temperature. This temperature dependency being appreciable, the analysis becomes nonlinear. Radiation boundary conditions also make the analysis nonlinear. Transient calculations are time dependent and ANSYS can both solve distributions as well as create video for time incremental displays of models.

3.4 INTRODUCTION TO CFD:

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial experimental validation of such software is performed using a wind tunnel with the final validation coming in full-scale testing, e.g. flight tests.

4. CFD ANALYSIS ON HEAT TRANSFER ENHANCEMENT IN HORIZONTAL TUBE WITH INSERTS

PLAIN ROD (Imported model)



Meshed model

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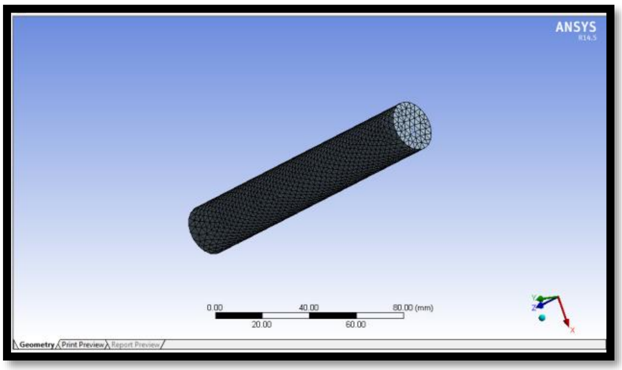
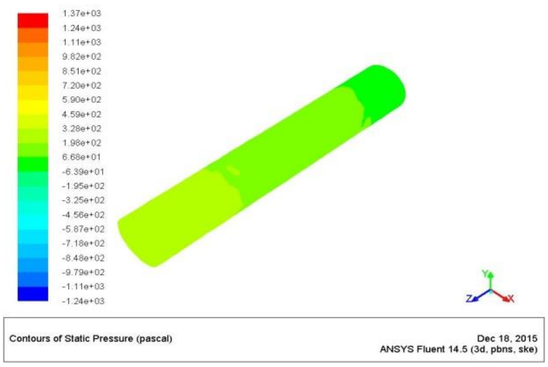


BOUNDARY CONDITIONS

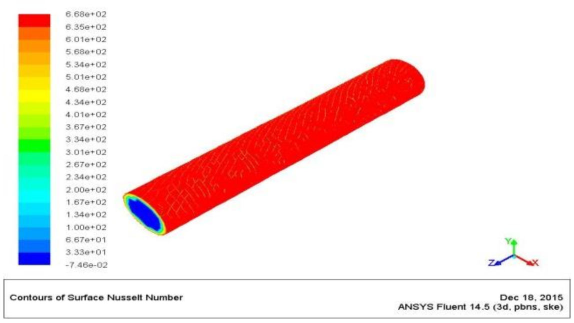
REYNOLD'S NUMBER – 6000

inlet temperatures(t)	331 k
inlet pressure(p)	101325 pa
inlet velocity(v)	43.822

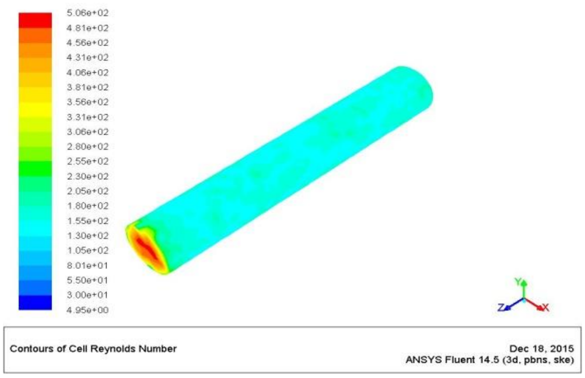
Pressure



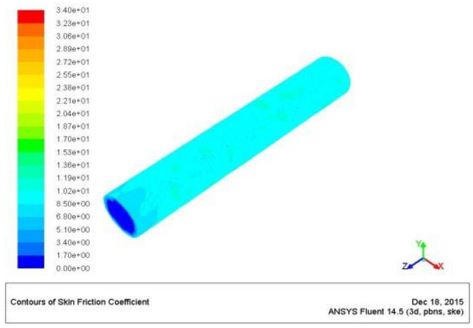
Nusselt number



Reynolds number



Friction coefficient



PLAIN ROD

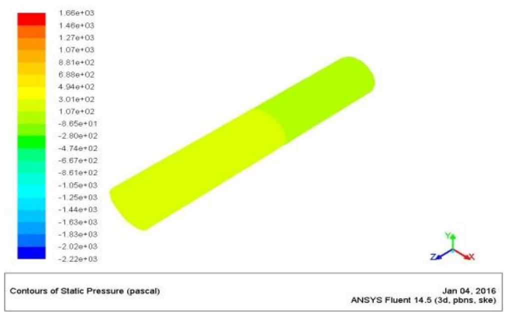
BOUNDARY CONDITIONS

REYNOLD'S NUMBER – 8000

inlet temperatures(t)	331 k
inlet pressure(p)	101325 pa
inlet velocity(v)	58.42938

SPIRAL OVER ON ROD

Pressure



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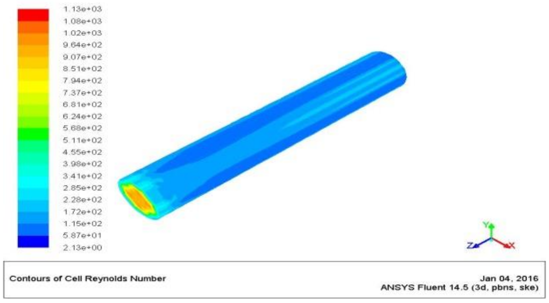
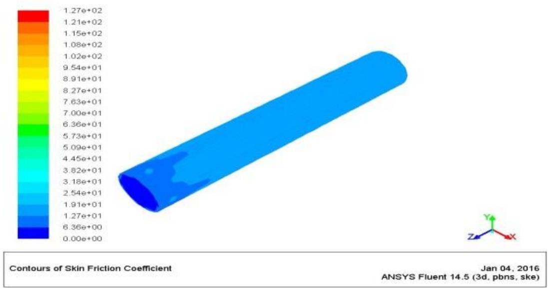
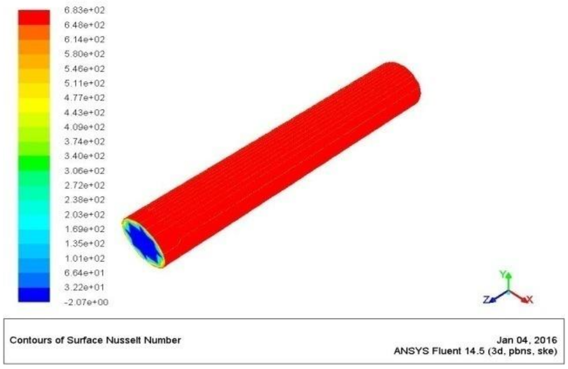
Reynolds number



Skin friction coefficient



Nusselts number

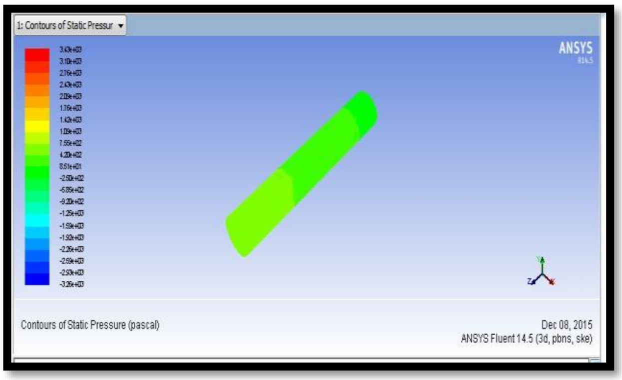


BOUNDARY CONDITIONS

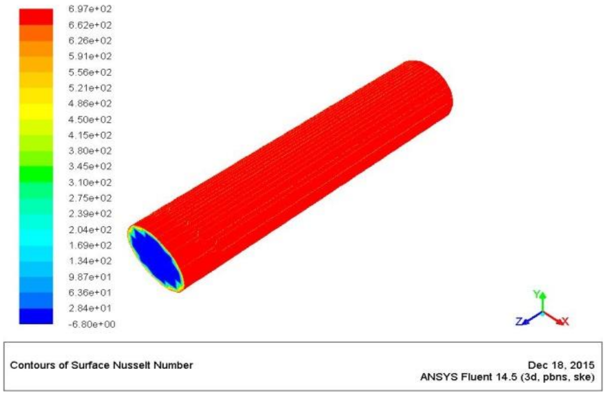
REYNOLD'S NUMBER - 12000

inlet temperatures(t)	331 k
inlet pressure(p)	101325 pa
inlet velocity(v)	87.64 m/s

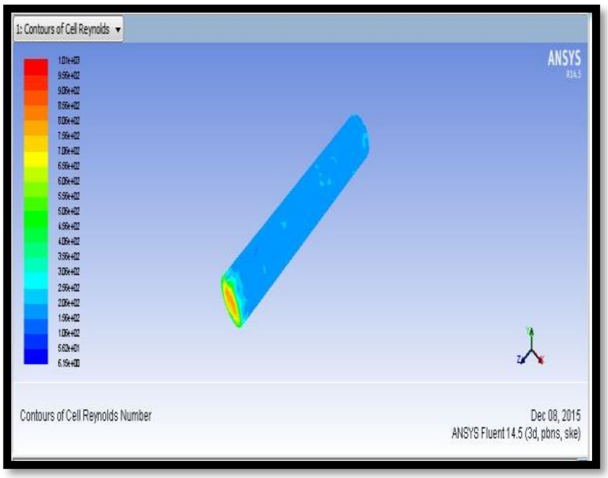
Pressure



Nusselt no



Reynolds number



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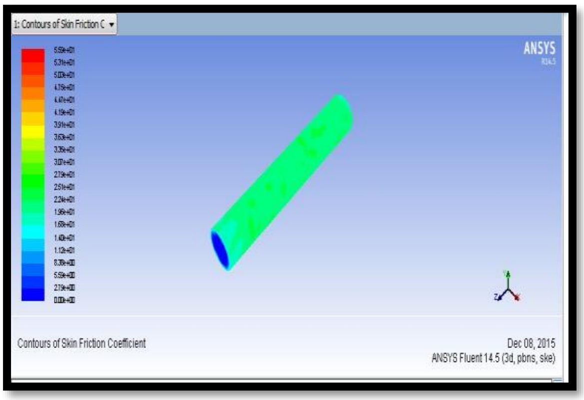
Friction coefficient



4.1 Analysis Tables:

By formulation and calculation, the Reynolds number, mass flow rates, Nusselt number and friction factor will be founded and listed in the following tables for different types of inserts used in the experiment.

Table 4.1: Plain Rod

Sl.no	Mass flow rate (kg/sec)	Reynolds number	Nusselt number	Friction factor
1	0.00226	6024.9	19.81	0.5456
2	0.00340	8353.4	25.7	0.54062
3	0.00412	10243.4	30.2	0.5376
4	0.00479	11834.6	34.0	0.5355
5	0.00542	13467.5	37.7	0.53370

Table 4.2: Spiral Insert

Sl.no	Mass flow rate (kg/sec)	Reynolds number	Nusselt number	Friction factor
1	0.00229	6206.4	20.2	0.5451
2	0.00341	8389.2	25.8	0.5405
3	0.00415	10212.4	30.21	0.5363
4	0.00488	12073.0	34.54	0.5344
5	0.00537	13201.8	37.1	0.5313

Table 4.3: Spiral-Square Blocks Insert

Sl.no	Mass flow rate (kg/sec)	Reynolds number	Nusselt number	Friction factor
1	0.00228	6753.4	21.7	0.5438

2	0.0034 4	8465.1	26.0	0.5404 2
3	0.0040 7	10384. 1	30.6	0.5374
4	0.0050 3	12361. 3	35.2	0.5349
5	0.0053 7	13303. 0	37.3	0.5338

Table 4.4: Spiral-Rectangle Blocks Insert

Sl.no	Mass flow rate (kg/sec)	Reynolds number	Nusselt number	Friction factor
1	0.00230	6943.3	22.19	0.5434
2	0.00346	8594.8	26.3	0.54020
3	0.00419	10405.8	30.67	0.5373
4	0.00486	12524.9	35.5	0.5347
5	0.005416	13465.6	37.7	0.5337

Table 4.5: Spiral-Pyramid Blocks Insert

Sl.no	Mass flow rate (kg/sec)	Reynolds number	Nusselt number	Friction factor
1	0.00229	6447.2	20.9	0.5445
2	`0.00344	8558.5	26.2	0.54026
3	0.004113	10134.9	30.03	0.5377
4	0.00486	12009.9	34.40	0.5353
5	0.005417	13363.1	37.4	0.5338

5. CONCLUSIONS & SCOPE FOR FUTURE WORK

5.1 Conclusions:

Analysis were conducted using five different types of inserts in a horizontal circular tube with Reynolds number 6000 to 14000 is shown. The investigations of the effects of parameters such as Reynolds number, Nusselt number, Friction factor and Mass flow rate are studied.The salient conclusions that can be drawn from the Analysis study are

1. The experimental data indicate an increase in friction factor while using the five types of inserts and are as follows (1) Plain rod (2) Spiral rod (3) Spiral-square blocks insert, (4) Spiral-pyramid blocks insert and (5) spiral-rectangle blocks insert.
2. With the increase in Reynolds number, Nusselt number increases and friction factor decreases.
3. Enhancement of heat transfer in comparison to plain tube is highest for Spiral-Rectangular blocks insert.

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5.2 Scope for future work:

1. The research work can be extended by changing the working fluid with water or any Nano fluid.
2. Analysis is done in turbulent region in the present work. Analysis study can also be accomplished in the laminar region.
3. The same Analysis study can also be carried with other geometric block shapes like circular shape, cylinder type, and star hexagonal type blocks attached over rod.
4. And also the same Analysis can be done with square blocks over rod, rectangle blocks over rod, pyramid blocks over rod i.e. without spiral.
5. By changing the dimensions of the insert rod, another experimental study can be done.

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