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Heat Exchanger Performances Comparison Using Two Variance ANOVA Method

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Abstract- Helically coiled heat exchangers are used in order to obtain a large heat transfer area per unit volume and to enhance the heat transfer coefficient on the inside surface. The enhancement in heat transfer due to helical coils has been reported by many researchers by experimental setups for the estimation of the heat transfer characteristics. In this thesis the experimental results are compared with the calculation results using the software package CATIA used by the many researchers. Further a computational study has been accomplished to determine the effects of heat transfer in the helical coiled heat exchanger by considering the parameters like pitch length of helical coil and mass flow rate of fluids in helical coil heat exchanger. It is concluded that the analysis results fairly matches with the Experimental Results. A comparison with experimental results and simulations has proved that by decreasing the pitch length of helical coil and relative velocity of fluids in helical coil heat exchanger, increases heat transfer rate.

Keywords: Helical Coil Heat Exchanger, Computational Fluid Dynamic (CFD), CATIA, Heat Transfer Rate, Heat Transfer Coefficient.

I. INTRODUCTION

Heat exchangers are used to transfer heat between two sources. The exchange can take place between a process stream and a utility stream (cold water, pressurized steam, etc), a process stream and a power source (electric heat), or between two process streams resulting in energy integration and reduction of external heat sources. Typically, a heat exchanger is used with two process streams.

However, mutli-stream heat exchangers are sometimes used with energy extensive processes, such as LNG processing, to reduce capital cost. The term heat exchanger applies to all equipment used to transfer heat between two streams. However, the term is commonly used to equipment in which two process streams exchange heat with each other.

In the other hand, the term heater or cooler is used when the exchange occurs between a process stream and a plant service stream.

Other terms used to describe heating equipment include: vaporizer and re-boiler (for vaporization) and evaporator (for stream concentration). Exchangers can also be classified as fired (heat source is fuel combustion) and unfired exchangers.

II. HELICAL COIL HEAT EXCHANGER

Fig. 1 gives the schematic of a helical coil. The pipe has an inner diameter 2r. The coil has a diameter of 2Rc (measured between the centers of the pipes), while the distance between two adjacent turns, called pitch is H. The coil diameter is also called pitch circle diameter (PCD).

The ratio of pipe diameter to coil diameter (r/Rc) is called curvature ratio, The ratio of pitch to developed length of one turn (H/2rRc) is termed non-dimensional pitch, A.

Consider the projection of the coil on a plane passing through the axis of the coil. The angle, which projection of one turn of the coil makes with a plane perpendicular to the axis, is called the helix angle, Similar to Reynolds number for flow in pipes; Dean Number is used to characterize the flow in a helical pipe.

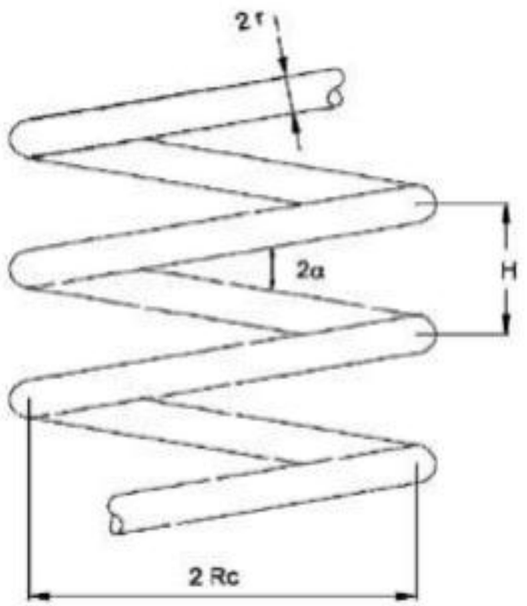

Fig 1. Basic geometry of a helical pipe.

1. Heat Transfer Coefficient:

Convective heat transfer is the transfer of heat from one place to another by the movement of fluids due to the difference in density across a film of the surrounding fluid over the hot surface. Through this film heat transfer takes place by thermal conduction and as thermal conductivity of most fluids is low, the main resistance lies there.

Heat transfer through the film can be enhanced by increasing the velocity of the fluid flowing over the surface which results in reduction in thickness of film. The equation for rate of heat transfer by convection under steady state is given by

Q=ha (Tw-Tatm)

Where, h is the film coefficient or surface coefficient A is the area of the wall, TW is the wall temperature, Tatm is surrounding temperature.

The value of „h" depends upon the properties of fluid within the film region; hence it is called "Heat Transfer Coefficient". It depends on the different properties of fluid, dimensions of the surface and velocity of the fluid flow (i.e. nature of flow).

The overall heat transfer coefficient is the overall transfer rate of a series or parallel combination of convective and conductive walls. The "overall Heat Transfer Coefficient" is expressed in terms of thermal resistances of each fluid stream. The summation of individual resistances is the total thermal resistance and its inverse is the overall heat transfer coefficient, U.

2. Applications:

Use of helical coils for heat transfer applications:

- Helical coils are used for transferring heat in chemical reactors and agitated vessels because heat transfer coefficients are higher in helical coils. This is especially important when chemical reactions have high heats of reaction are carried out and the heat generated (or consumed) has to be transferred rapidly to maintain the temperature of the reaction. Also, because helical coils have a compact configuration, more heat transfer surface can be provided per unit of space than by the use of straight tubes.
- Because of the compact configuration of helical coils, they can be readily used in heat transfer application with space limitations, for example, in steam generations in marine and industrial applications.
- The helically coiled tube is eminently suited for studying the characteristics of a plug flow reactor in reaction kinetic studies because the secondary motion present in the helical coil destroys the radial concentration gradient.
- The existence of self induce radial acceleration field in helical coils makes helical coils most desirable for heat transfer and fluid flow applications in the absence of gravity field, such as for space ships in outer space. Helical coiled tubes have been and are used extensively in cryogenic industry for the liquefaction of gases.

Although double-pipe heat exchangers are the simplest to design, the better choice in the following cases would be the helical-coil heat exchanger (HCHE):

- The main advantage of the HCHE, like that for the Spiral heat exchanger (SHE), is its highly efficient use of space, especially when it's limited and not enough straight pipe can be laid. [20]
- Under conditions of low flow rates (or laminar flow), such that the typical shell-and-tube exchangers have low heat-transfer coefficients and becoming uneconomical. [20]

- When there is low pressure in one of the fluids, usually from accumulated pressure drops in other process equipment. [20]

When one of the fluids has components in multiple phases (solids, liquids, and gases), which tends to create mechanical problems during operations, such as plugging of small-diameter tubes. [21]

Cleaning of helical coils for these multiple-phase fluids can prove to be more difficult than its shell and tube counterpart; however the helical coil unit would require cleaning less often.

III. SHELL TUBE HEAT EXCHANGER

In intercoolers, boilers, pre-heaters and condensers inside power plants as well as other engineering processes, heat exchangers are utilized for controlling heat energy. Heat exchangers are devices that regulate efficient heat transfer from one fluid to another.

There are two main types of heat exchangers. The first type of a heat exchanger is called the recuperative type, in which heat are exchanged on either side of a dividing wall by fluids; The second type is regenerative type, in which hot and cold fluids are in the same space which contain a matrix of materials which work alternately as source for heat flow.

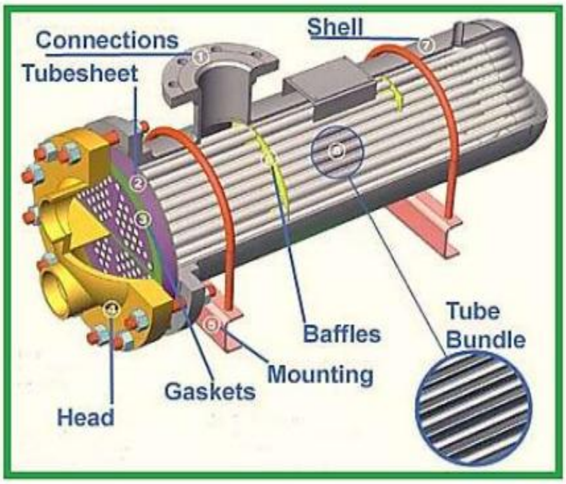

Fig 2. Text Here Your Fig Title.

The optimum thermal design of a shell and tube heat exchanger involves the consideration of many interacting design parameters which can be summarized as follows:

1. Process:
- Process fluid assignments to shell side or tube side.
- Selection of stream temperature specifications.
- Setting shell side and tube side pressure drop design limits.
- Setting shell side and tube side velocity limits.
- Selection of heat transfer models and fouling coefficients for shell side and tube side.

2. Mechanical:
- Selection of heat exchanger TEMA layout and number of passes.
- Specification of tube parameters - size, layout, pitch and material.
- Setting upper and lower design limits on tube length.
- Specification of shell side parameters – materials, baffles cut, baffle spacing and clearances.
- Setting upper and lower design limits on shell diameter, baffle cut and baffles spacing.

IV. ONE-WAY ANOVA VERSUS TWO-WAY ANOVA

There are two main types of ANOVA: one-way (or unidirectional) and two-way. There also variations of ANOVA. For example, MANOVA (multivariate ANOVA) differs from ANOVA as the former tests for multiple dependent variables simultaneously while the latter assesses only one dependent variable at a time.

One-way or two-way refers to the number of independent variables in your analysis of variance test. A one-way ANOVA evaluates the impact of a sole factor on a sole response variable. It determines whether all the samples are the same. The one-way ANOVA is used to determine whether there are any statistically significant differences between the means of three or more independent (unrelated) groups.

A two-way ANOVA is an extension of the one-way ANOVA. With a one-way, you have one independent variable affecting a dependent variable. With a two-way ANOVA, there are two independents.

For example, a two-way ANOVA allows a company to compare worker productivity based on two independent variables, such as salary and skill set. It is utilized to observe the interaction between the

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two factors and tests the effect of two factors at the same time.

V. RESULT AND SIMULATION

1. Design Software:
Regularly alluded to as 3D Product Lifecycle Management programming suite, CATIA bolsters different phases of item advancement (CAx), from conceptualization, plan (CAD), fabricating (CAM), and building (CAE). CATIA encourages community building crosswise over controls, including surfacing and shape outline, mechanical designing, hardware and frameworks designing.

CATIA gives a suite of surfacing, figuring out, and perception answers for make, adjust, and approve complex imaginative shapes. From subdivision, styling, and Class A surfaces to mechanical useful surfaces.

CATIA empowers the making of 3D sections, from 3D outlines, sheet metal, composites, and shaped manufactured or tooling parts up to the meaning of mechanical congregations. It gives devices to finish item definition, including useful resilience's, and in addition kinematics definition.

2. Helical Type Heat Exchanger Design And Analysis :

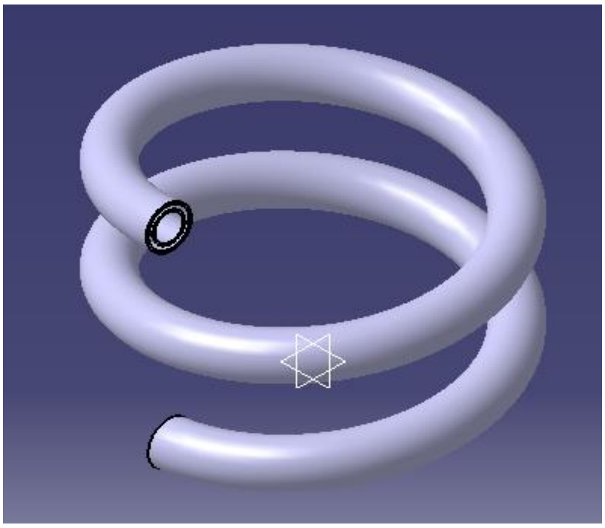

Fig 3. Helical type HE.

Fig 2 shows design of helical type HE in CATIA software. Given approach is simulation using FEM analysis method.

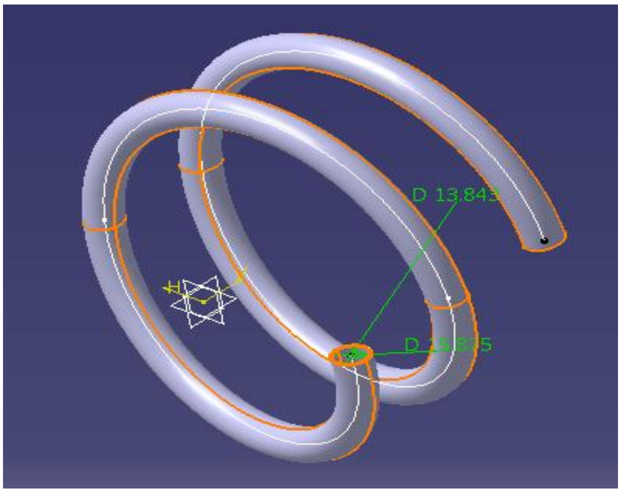

Fig 4. Design Specification.

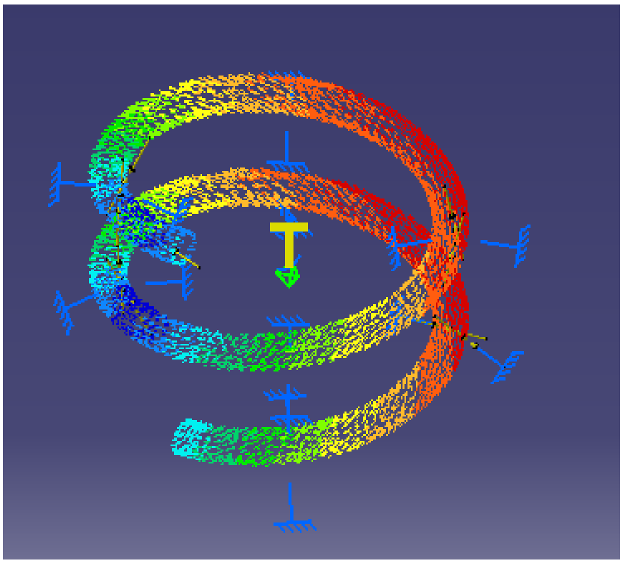

Fig 5. Temperature distribution.

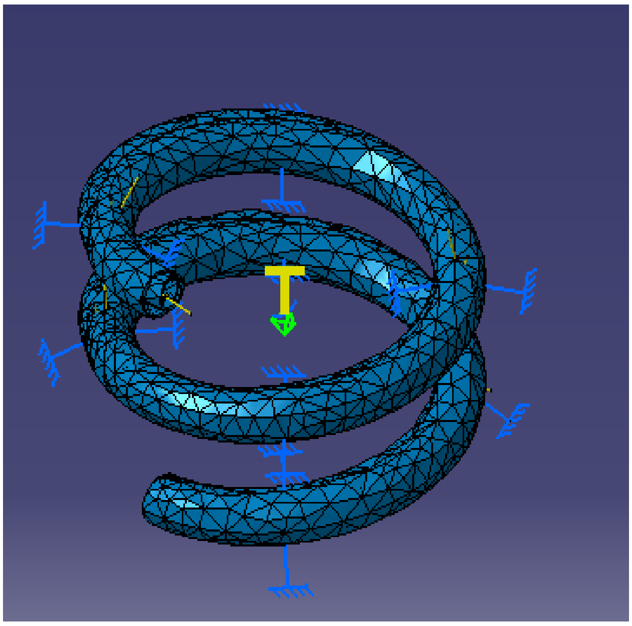

Fig 6. Pressure analysis.

Table 1. Mesh and node.

Entity	Size
Nodes	20799
Elements	10456

Table 5.1 is shows an node generation along the element. Given Node is boundary of design area in CATIA software. For Designing used FEM method to gives a better result in form of heat Stress level in helical type HE.

Table 2. Analysis Element Type.

Connectivity	Statistics
TE10	10456 (100.00%)

Table 5.2 TE is represent of Analysis statistics on total node 10456 complete 100%. Hence these are show analysis competition and boundary analysis node.

Table 3. Output Quality Specification

Criterion	Good	Poor	Bad	Worst	Average
Stretch	1514 (14.48%)	8942 (85.52%)	0 (0.00%)	0.067	0.224
Aspect Ratio	1601 (15.31%)	3857 (36.89%)	4998 (47.80%)	15.052	5.373

Table 5.3 are show Heat exchanger maximum pressure Stretch with respect to Aspect ratio. Given Performance evaluation observe in good, poor bad and Average criteria. Now these are indicate maximum node are effected on 8942 in poor region in helical type HE.

Table 4. Material specification.

Material	Aluminium
Young's modulus	7e+010N_m2
Poisson's ratio	0.346
Density	2710kg_m3
Coefficient of thermal expansion	2.36e-005_Kdeg
Yield strength	9.5e+007N_m2

Table 5.4 are indicate on material properties on aluminum. These are representing on Young modulus on $7x10^{10}$ $N/m^{2,}$ poison ration 0.346, density is $2710kg/m^3$ and Heat transfer thermal expansion $2.36x10^{-5}$kdeg in helical type HE.

3. Shell and Tube Heat Exchanger:

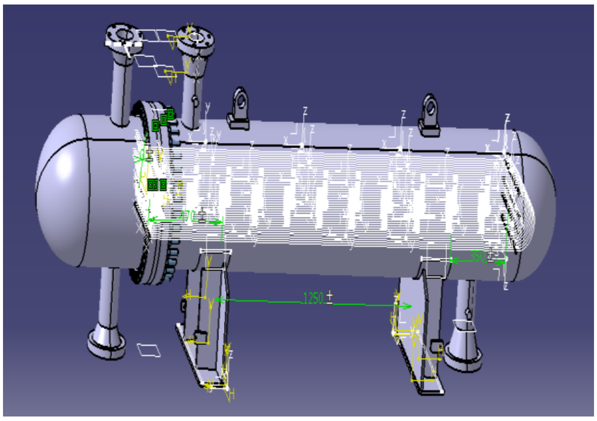

Fig 7. Shell and tube heat exchanger.

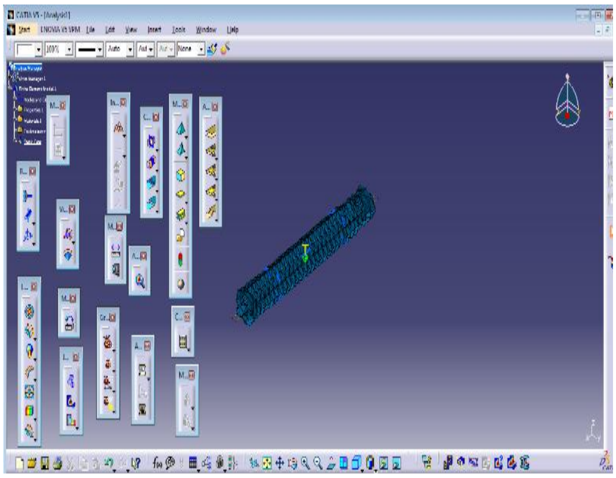

Fig 8. Catia v5 analysis.

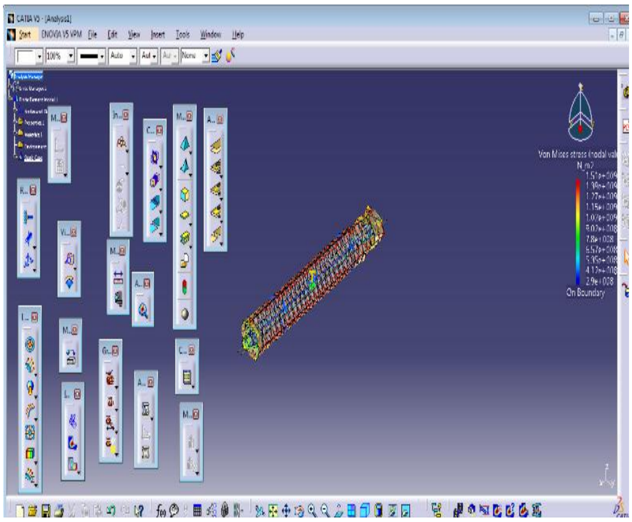

Fig 9. Pressure flow.

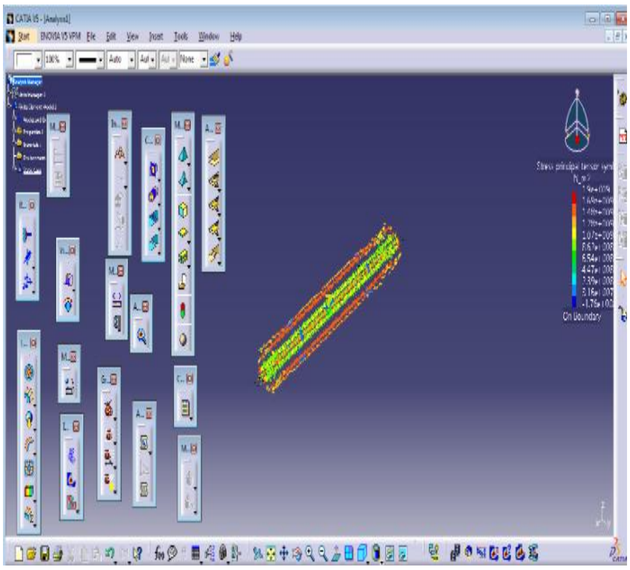

Fig 10. Pressure drop.

Table 5. Mesh and node.

MESH:

Entity	Size
Nodes	1558
Elements	763

ELEMENT TYPE:

Connectivity	Statistics
TE10	763 (100.00%)

Table 5.5 is shows an node generation along the element. Given Node is boundary of design area in CATIA software in shell and tube heat exchanger.

Table 6. Output Quality Specification.

Criterion	Good	Poor	Bad	Worst	Average
Stretch	551 (72.21%)	212 (27.79%)	0 (0.00%)	0.241	0.337
Aspect Ratio	21 (2.75%)	742 (97.25%)	0 (0.00%)	4.520	3.592

Table 5.6 are show Heat exchanger maximum pressure Stretch with respect to Aspect ratio. Given Performance evaluation observe in good, poor bad and Average criteria. Now these are indicating maximum node are effected on 551 in good region in helical type HE.

Table 5.7 is indicating on material properties on aluminum. These are representing on Young modulus on $7x10^{10}$ N/m^2, poison ration 0.346, density is 2710 kg/m^3 and Heat transfer thermal expansion $2.36x10^{-5}$ k/deg in shell and tube heat exchanger.

Table 7. Material specification.

Material	Aluminium
Young's modulus	7e+010N_m2
Poisson's ratio	0.346
Density	2710kg_m3
Coefficient of thermal expansion	2.36e-005_Kdeg
Yield strength	9.5e+007N_m2

4. Anova Analysis:

Table 8. Helical HE ANOVA outputs.

Summary Output	
Regression Statistics	
Multiple R	0.369174461
R Square	0.136289783
Adjusted R Square	-0.151613623
Standard Error	39.83526445
Observations	5

Table 5.8 show ANOVA analysis result in Helical Type HE. These are shows on Regression result in term of various analysis parameters. Now Multiple R value is 0.36917, R square value is 0.136 and Standard Error is 39.83 in 5 observation samples.

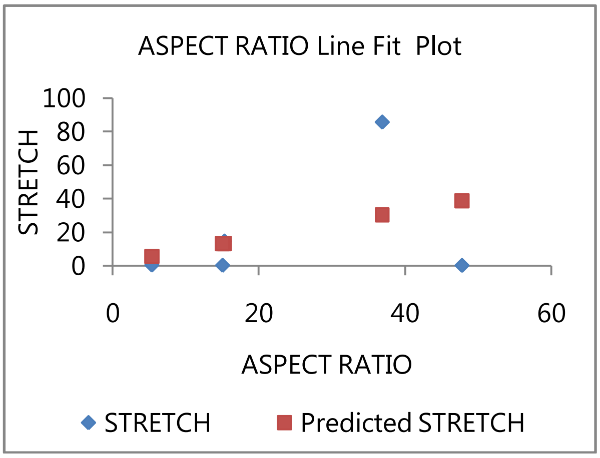

Fig 11. Helical HE Prediction outcomes.

Fig 11 show ANOVA stretch and Aspect ratio curve show. These are indicate on stretch predicted outcome almost linearly varies according to the aspect ratio. Hence maximum stretch is 40 in helical type HE.

Table 9. Shell and Tube HE ANOVA outputs.

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.136784008
R Square	0.018709865
Adjusted R Square	-0.308386847
Standard Error	36.00646003
Observations	5

Table 5.9 show ANOVA analysis result in **Shell and Tube HE ANOVA outputs**. These are shows on Regression result in term of various analysis parameters. Now Multiple R value is 0.13678, R square value is 0.01870 and Standard Error is 36.0064 in 5 observation samples.

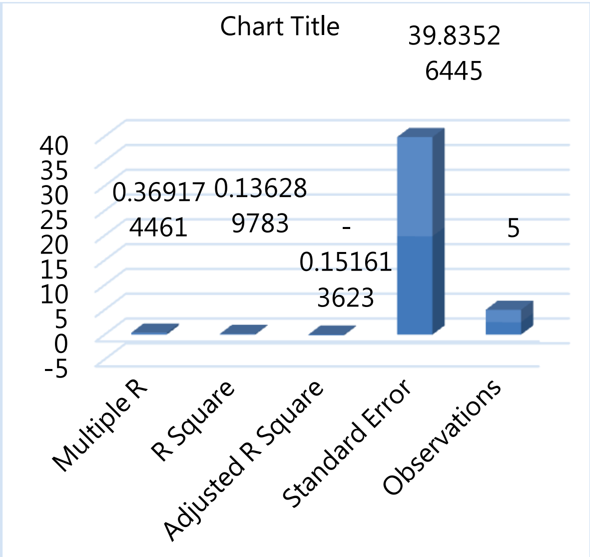

Fig 12. Helical HE error.

Fig 12 Helical HE error is depending on R square values. Hence prediction numerical outcomes are depending on material input parameters and pressure drop.

Fig 13. show ANOVA stretch and Aspect ratio curve show. These are indicate on stretch predicted outcome almost linearly varies according to the aspect ratio. Hence maximum stretch is 38 Shell and Tube HE.

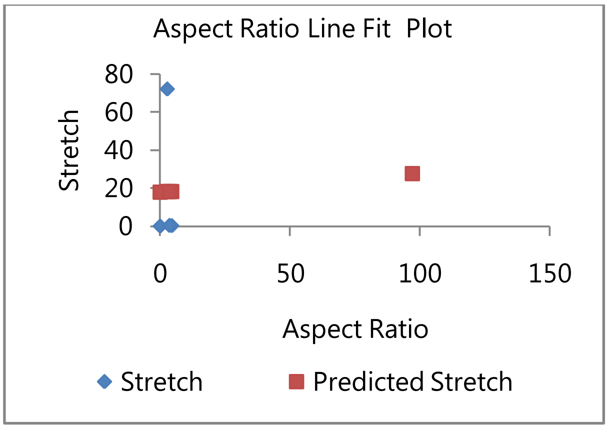

Fig 13. Shell and Tube HE Prediction outcomes.

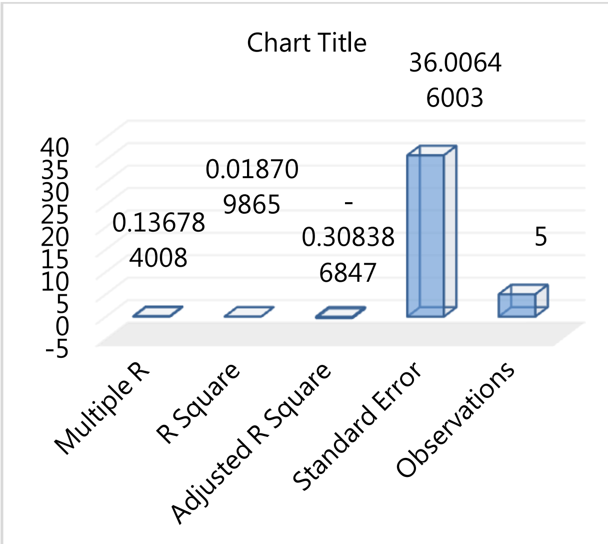

Fig 14. Shell and Tube error.

Fig 14. Shell and Tube error is depending on R square values. Hence prediction numerical outcomes are depending on material input parameters and pressure drop.

VI. CONCLUSIONS AND FUTURE SCOPE

In this work are give a comparison of two different type of HE using CATIA Software. In this work are found R square values like 0.13 and 0.0187 so identified helical type are best heat flow and lower pressure occurs in ANOVA method.

Since ANOVA can easily accommodate a large input and output parameters with sufficient training data, additional input and output parameters can be easily incorporated. These quantities are calculated by experimental correlations, and are best suited for ANOVA estimation.

With the current ANOVA calculations, the values of heat-exchanger heat transfer coefficient, pressure drop in tube and shell can be estimated rapidly. This method speeds up the thermal design iteration and in particular best thermal designs can be selected from a large number of preliminary trial and error designs.

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