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CFD Assessment of Flow Maldistribution in Plate Fin and Tube Heat Exchangers

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Abstract: **The primary goal of this work is to use CFD assessment simulating framework is to anticipate the impact of injecting air flowing mal-distribution on heat exchanger architecture and thermal flow characteristics. Using CFD (computational fluid dynamics) simulation-studies, determine the impact of air intake flow unequal distribution or mal-distribution on the complete redesign as well as high - temperature hydraulic performing ability of HEX (heat exchangers). The findings demonstrate that a plate as well as tube fin heating element consisting of an elongated tubular setup slanted by 30 degrees can achieve the highest temperature transmission, having a heat transfer ability of 23.22 percent greater than a (SPHEX) spherical pipe heat exchanger.**

Keywords: Heat Exchangers, Plate Fin And Tube Heat Exchangers, Flow Maldistribution

I. INTRODUCTION

The PFTHEX (plate-fin-and-tube) heat exchanging device is a cross-flow heat transferring device that employs plates as fins as shown in (Figure 1), resulting in undifferentiated flow outside the tubes. It's often referred to as a compact heat exchanger because of its higher heat transfer surface area to volume ratio. Because of its size reduction and reduced weight, the PFTHEX are expansively employed in numerous sectors, particularly aviation. Other fin designs, including louvre, convex-louver, and wavy, exist in addition to the plate; nonetheless, the plate fin seems to be the highest in terms of performance and various construction efficiency [1].

PFTHEXutilize either circle-shaper or elliptical tubular architecture. Experimentation were used in the number of research using PFTHEX.

Figure 1 Plate Fin And Tube Exchanger

The fin-and-tube heat exchanger (FTHE) (Fig. 2) is a common component in HVAC&R (Heating, Ventilation, Air Conditioning, and Refrigeration) systems, and many other implementations requiring gas-to-liquid heat transfer wich is smaller in size, such as power and also chemical engineering. The exchangers design has a large surface area per unit volume and a highly competitive heat transfer rate per unit pumping power. Related to the physiological characteristics of gases, the latter requirement is crucial for most implementations requiring gas heat exchange. On the gas side, it is consequently critical to optimise heat exchanger shape for maximal heat transfer per unit pumping power.

Flow maldistribution in tubes connected to the header of heat exchangers can be produced by exchanger geometric elements of design or realistic operational parameters. Heat exchanger efficiency and effectiveness will be greatly reduced if flow rate is unevenly distributed throughout tubes. Furthermore, the unequal flow distribution would cause non-uniformity in the supplementary side fluid's inner temperature distribution [2].

In terms of contact region per unit volume, the PFHX is 4 times higher than a spiral-type heat exchangers and five times greater than a shell–tube heat exchanger. Furthermore, the PFHX can operate with a multiphase operating fluid. An essential method of evaluating the architecture of the PFHX header/distributor arrangement is an equitable distribution of operating fluid with low head loss. Among the most important factors affecting the thermal performance of a plate-fin heat exchanger is the flow distributions in the header/distributor segment [3].

The primary goal of this study is to use three - dimensional CFD experiments to predict the impact of inlet air flow unequal distribution on heat transfer design and temperature flow characteristics.design a novel PTFHEX for batter heat transfer using varied tube pitches. And to run multiphase flow simulations to see how inlet air flow unequal distribution affects new heat transfer design and temperature hydrodynamic conductivity.

II. LITERATURE REVIEW

The heat-transfer efficiency of plate–fin heat exchangers (PFHEs) is severely influenced by the misdistribution of gas–liquid combinations, that has a negative impact on the steady and smooth production of a gas processing facility. As a result, it's crucial to look into the phase distribution performance of PFHEs and how it affects natural gas liquefaction. A two-phase flow distribution experimental setup was constructed for this research in order to explore the flow distribution features of a PFHE under various working situations [4].On the gas–liquid distribution, the impacts of gas–liquid ratio, tilt angle, and sloshing were investigated. A dditionally, the Aspen Muse software was used to investigate the effects of feed gas maldistribution, N2 refrigerant, and mixture refrigerant (MR) on heat transfer as well as natural gas liquefaction performance. The findings confirmed and the more the gas–liquid proportion and tilt angle were increased, the more unequal the liquid flow distribution became. On comparison to the horizontal situation, the MR rate of production was lowered by 5.2 percent to 18.5 percent in the tilt condition.

The focus of this [5] was on a double flow plate-fin heat exchanger (PFHE) with an offset mismatched fin heat transfer component. The thermodynamic features of a full-size PFHE were investigated using a porous media technique and numerical simulations. The impacts of viscous forces and the positions of the inlet and exit tubes on flow distribution as well as pressure loss of the PFHE were investigated using the numerical model. The results revealed that raising the density and viscosity enhanced the flow distribution of the PFHE.As a result, under diverse inlet velocity conditions, the interaction among flow distribution as well as pressure drop was investigated, and a correlation among flow distribution, pressure loss, and Reynolds number was discovered. Lastly, a middle-based technique for improving PFHE flow distribution was developed and quantitatively proven.

A unique model for MSPFHE simulation is provided in [6]. The relevance of the algorithm is that researchers have represented the entire MSPFHE domain, which is impossible to simulate using modern CFD techniques at a reasonable computing cost. Furthermore, many varieties of fins can be employed in this manner. Only the heat transfer coefficient and friction factor correlations, as well as the surface geometric properties of fins, need be modified for this purpose.The temperature distribution across the fluid flows was calculated using characteristics of modelling cryogenic heat exchangers including inlet mass flow maldistribution, physical property variations, conduction inside the partitioning plates, cap plates, as well as side plates, heat spillages from cap plates, or rather side plates, and temperature fluctuations anywhere along depth of the heat exchanging devices [6]. The thermal modeling was used to determine the temperature distribution all across the solid matrix of an MSPFHE. The heat transfer rate first from top and bottom separation plates of the fins has been calculated using the proposed algorithm, which considers transverse heat conduction and through fins.

The influence of flow maldistribution in PHE evaporators on the cycle thermodynamic & economic strength is evaluated using a combination of plate heat exchanger (PHE) - heat pump modelling approach presented in [7]. To demonstrate how the simulation software may be used, a real world example of heat pump incorporation for waste heat recovery in datacentres was selected. The coolants were CO2/dimethyl ether (DME) (0.2,0.8) and the clean fluids butane and propane, as well as the zeotropic mixes propylene/butane at (0.5,0.5) mass composition and CO2/dimethyl ether (DME) (0.2,0.8).In the heat exchanger models, including liquid/vapour maldistribution and the influence of end plates are taken into account. Butane is the most vulnerable to maldistribution, with a maximal Coefficient of Performance (COP) loss of 5.9%, while propane has the least COP lowering of 2.5 percent. The evaporator design, coolant pressure loss, and fluid characteristics were discovered to be connected to the varying sensitivity of the operating fluids to maldistribution. Finally, when maldistribution effects are taken into account, the economic analysis showed that higher specific cost of heat is obtained.

A few of the reasons of performance problems in air-to-refrigerant heat exchangers has been recognized as air flow maldistribution. Full heat exchanger computations employing CFDapproaches, that are generally significantly more computationally more extended price than classic lumped variables or bounded volume dependent heat exchanger representations, are required to accurately anticipate precisely a non-uniform air circulation profile. Because of the high computating price of CFD, investigating the effects of many variables on air circulation allocation and heat exchanger effectiveness in a broad context is difficult. Based on a momentum resistance model, a computationally accurate and efficient combined CFD modelled heat exchanger approach is proposed in [8].

Numerically and practically, spaced finned rotating and orbicular tube bundle exchangers were explored in [9] to show the simplification of previously discovered optimized design combinations for highest heat transfer rate under a constant volume limitation. In the research lab, two air conditioning systems with extended surfaces ellipsoidal and slightly curved tubes have been built, and six test runs had been performed in a split air conditioner using turbulent forced convection. When convective heat transfer resistances are at their lowest, the microstructural evolves optimal way in the available space, i.e., builds models design, the above is at its best. The identification of suitable nondimensional groups enabled broad meaning of the outcomes to circular and elongated tube and brazed plate heat exchanger.

The use of perforated fins to improve air-side thermal performance in finned-tube heat exchangers (FHEXs) with large fin baseballs has been mathematically investigated in the present study. At various large fin pitches, the effects of penetration size and number on the plane j major consideration and heat transmission rate of the FHEX are investigated in depth. The obtained from the numerical level processes that an optimised penetration design can be achieved to obtain the highest increase in the j component for the punctured FHEX when compared to the plate FHEX without tiny holes. It is also found that the enhancement of the j factor increases with the rising air-side Reynolds number from 750 to 2350. For the perforated FHEX with fin pitch of 10.0 mm, the j factor increases by 0.3% at Re = 750 and 8.1% at Re = 2350, respectively, with the optimal perforation design [10].

In [11], researcher used Computational Fluid Dynamics (CFD), a Multilayer Perceptron (ANN) of the Group Method of Data Handling (GMDH) type, and the Non-Dominated Sorting Metaheuristic Optimization II to perform a multi-objective optimization (MOO) of wavy frame heat exchanger (NSGA-II). The goal of this number of co maximisation is to maximise heat transfer while minimising drop in pressure.For this purpose, the considered objective functions, Colburn factor (j) and friction factor (f) are optimized with regards to the design variables (four variables). Experimental results are used to validate the CFD results. Based on the CFD results, basis functions of the GMDH type neural net are established.

A three-dimensional CFD computational domain of the temperature dependent character traits of a typically on the order wavy fin-and-elliptical tube (SWFET) exchangers with three new kinds of vortex generators (VGs), namely rectangular trapezoidal winglet (RTW), angle rectangular winglet (ARW), and curved angle rectangular winglet (CARW), has been planned and carried out in [12]. This research looked at a number of variables. There is a significant impact on thermal properties achievement. In additament, the results are analyzed using the field synergetic concept, which emphasizes that the primary mechanism for improving thermal performance is to reduce the synergetic angle among both velocity and fluid thermal diffusivity.These parameters include: Reynolds number (based on the hydraulic diameter, ReDh¼ 500—3000), geometric shape of VGs, attack angle of VGs (aVG = 15–75°), placement of VG pairs (up- or/and downstream), tube ellipticity ratio (e = 0.65–1.0) and wavy fin height (H = 0.8–1.6 mm). The thermal performance of the SWFET heat exchanger is improved by increasing Prandtl number and curly entails higher while lowering the tube ellipticity ratio.

In terms of developing co - relation for flow and thermal interfacial character traits in louvred fin and tubular exchangers, simulation studies of 3D turbulent flow were used. On the effects of Prandtl number, fin fastball, latitudinal tube pitch, and longitudinal tube ball on guidelines j/j0 and f/f0, a thorough sensitivity analysis was performed in [13]. The advanced correlation coefficients are based on the ratio of the Colburn and contact pressure factors of a louvred fin exchanger to those of a flat fin exchanger (j/j0 and f/f0), which are much relatively simple than other correlation coefficients. Also, when the louvre angle reaches zero (flat fin), the parameters j/j0 and f/f0 reach one, as expected. Inclusion of technology correlation coefficients do not show this strategy.Within 15% of the 186 numerical simulated results, the advanced correlation coefficients can describe 100% and 86 percent of the parameters j/j0 and f/f0, respectively. Using the advanced correlation coefficients, a machine learning model was used to find the optimal louvre angle.

As it can be seen in literature work that many researchers have focused on different design to enhance the performance of heat exchanger but still there are some limitations when it comes to the maldistribution or unequal distribution of air circulation in plate and fin tube heat exchanger, by varying the pitches of the tubes used in fin and tube heat exchangers.

III. METODOLOGY

PFHEX is a form of heat exchanger that transfers heat across liquids using plates with fin compartments. The PFHEX is employed in a variety of manufacturing sites, containing aircraft because of its tiny size and illuminating qualities, and cryogenics because of its ability to move heat across small temperature variations.

The energy equation for the mixture takes the following form:

$$\frac{\partial}{\partial t}\sum_{k=1}^{n}(\alpha_k\rho_k E_k) + \nabla.\sum_{k=1}^{n}\left(\alpha_k\vec{v}_k(\rho_k E_k + p)\right) = \nabla.\left(k_{eff}\nabla T\right) + S_E$$

Where, k_{eff} = effectual conductivity

S_E= volumetric heat sources

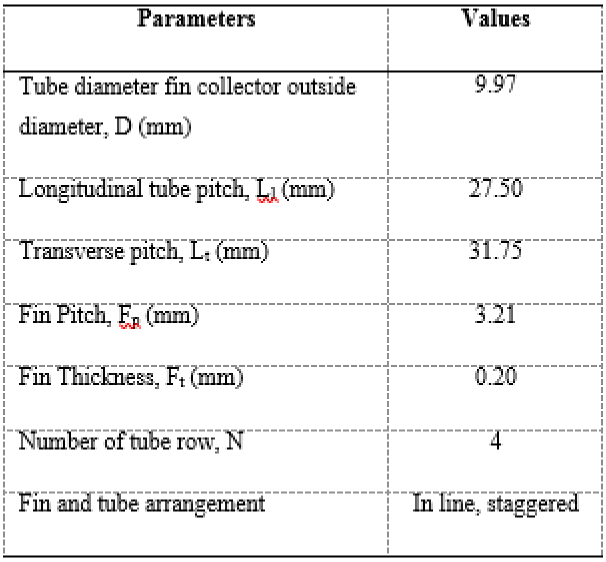
$$E_k = h_k - \frac{p}{\rho k} + \frac{v_k^2}{2}$$

Where

$E_k = h_k$ for an incompressible stage and h_k= sensible enthalpy for stage k

$$\frac{\partial}{\partial t}(\rho \in) + \frac{\partial}{\partial x_i}(\rho \in v_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\in}\right)\frac{\partial \in}{\partial x_j}\right] + C_{1\in}\frac{\in}{k}(G_k + C_{3\in}G_b) - C_{2\in}\rho\frac{\in^2}{k} + S_\in$$

Table 1Variations of PFTHEX have the following geometric properties:



Parameters	Values
Tube diameter fin collector outside diameter, D (mm)	9.97
Longitudinal tube pitch, L_1 (mm)	27.50
Transverse pitch, L_t (mm)	31.75
Fin Pitch, F_p (mm)	3.21
Fin Thickness, F_t (mm)	0.20
Number of tube row, N	4
Fin and tube arrangement	In line, staggered

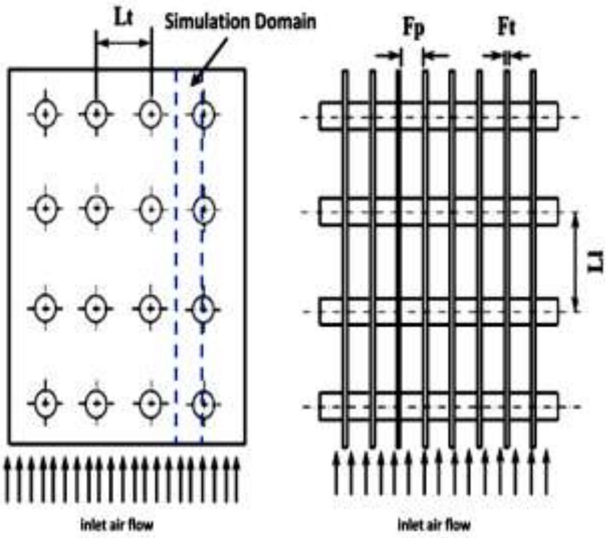


Figure 2 Design in physical form with uneven placement

Only a fraction of the domain needs to be modelled due to the symmetrical of the tube bank architecture. Figure 3 depicts the mathematical model in outline.

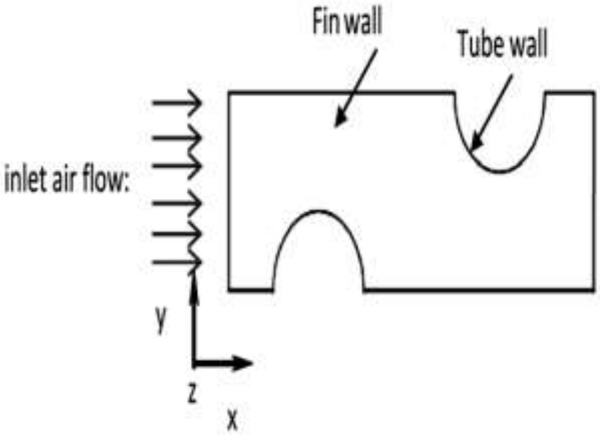


Figure 3 Fin tube heat exchanger computation region having multiple bounds

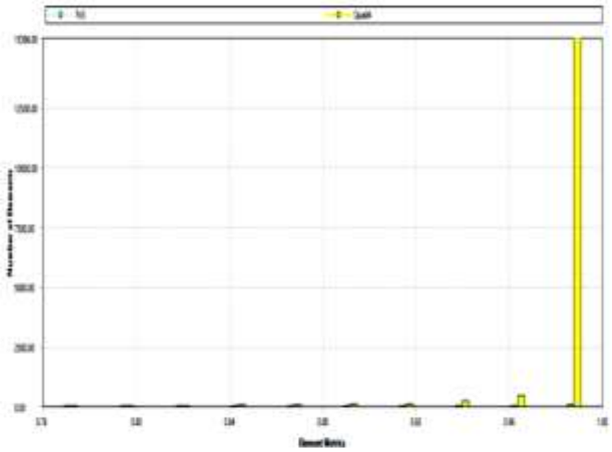


Figure 4 PFHEX having elliptical tube tilted at 30o have orthogonal mesh quality.

Figure 5 PFHEX having elliptical tubes tilted at 30o have various boundaries.

The temperature allocation well across plate fin having elliptical shaped tubular form is tilted at 30 degrees was noticed afterward conducting CFD assessment on the mentioned HEX (heat exchanger). The temperature distribution at PFTHEX was 353.1K to 268.9K, indicating an 84.2-degree temperature reduction.

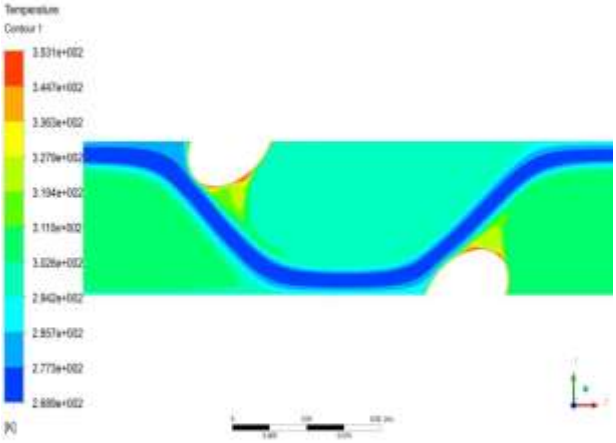


Figure 6 Temperature distribution along the PFHEX having an elliptical tube angled at 30 degrees.

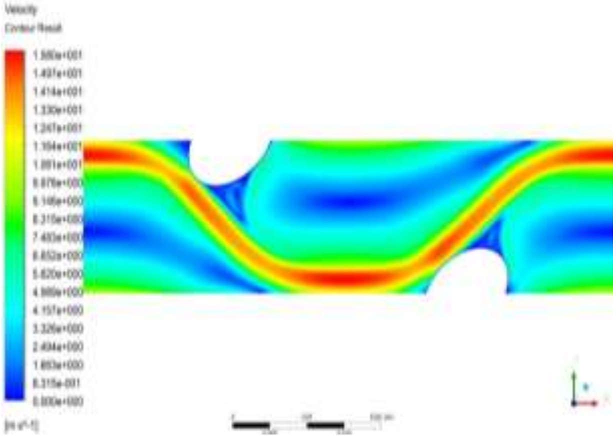


Figure 7HEX having elliptical tube tilted at 30 degree and velocity allocation across the plate fin

The greatest velocity determined at the plate-fin having the elliptical shaped tubular form is inclined at 30º HEX (heat exchangers) is 15.8 meter per sec. The maximum pressure measured above the plate fin in heat exchangers having an elliptical tube tilted at 30o is 89.69 Pa.

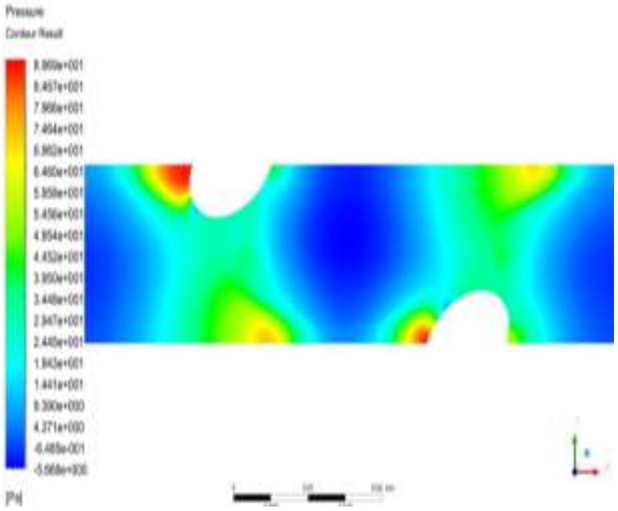


Figure 8HEX pressure distribution across plate fin having elliptical tube tilted at 30º

Similarly CAD assessment were conducted on PFTHEX in 45̊, 60̊, and 90̊. Across the PFTHEX, the highest temperature distribution, Velocity Distribution, Pressure Distribution, Temperature Difference, Combine temperature distribution, was determined

IV. RESULT AND DISCUSSION

The primary purpose of this research is to investigate the best design of a plate fin heat exchanger utilising a computer-assisted dynamic fluids technique while maximising heat production. The CFD assessment was conducted on a total of five models of finned tube and plate heat exchangers in order to attain optimum heat transfer. Various CFD study's findings have been covered in this section employing table data and a graphical depiction.

Table 2Minimum Temperature Allocation over the PFTHEX

Design of Plate fin and tube heat exchanger	Temperature Distribution [K]
Base Paper Design	289.26
Elliptical pipe inclined at 30º	268.77
Elliptical pipe inclined at 45º	270.03
Elliptical pipe inclined at 60º	273.58
Elliptical pipe vertical	274.39

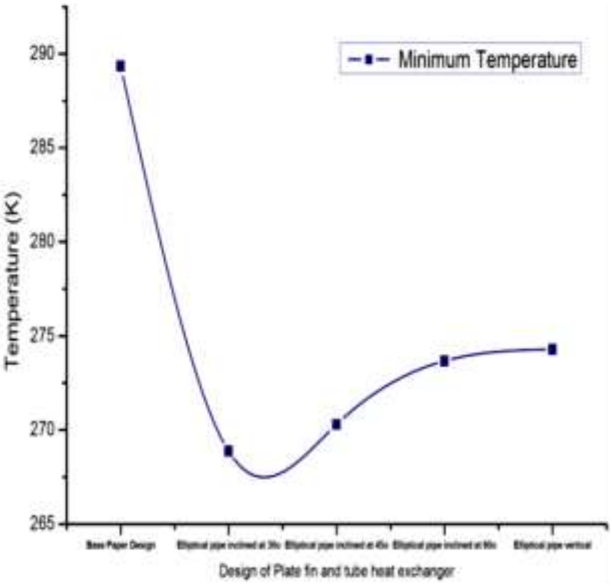


Figure 9 Along the PFHEX, the lowest temperature distribution

Table 3Along the PFHEX, highest temperature distribution

Design of Plate fin and tube heat exchanger	Temperature Distribution [K]
Base Paper Design	351.38
Elliptical pipe inclined at 30º	349.68
Elliptical pipe inclined at 45º	349.02
Elliptical pipe inclined at 60º	349.04
Elliptical pipe vertical	347.29

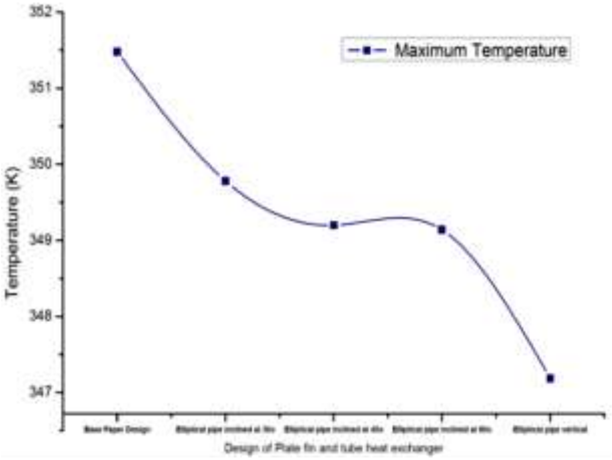


Figure 10 Along the PFHEX, highest temperature distribution

Table 4 Velocity Distribution across PTFHEX

Design of Plate fin and tube heat exchanger	**Velocity Distribution [m/Sec]**
Base Paper Design	14.86
Elliptical pipe inclined at 30°	15.85
Elliptical pipe inclined at 45°	18.69
Elliptical pipe inclined at 60°	21.37
Elliptical pipe vertical	22.45

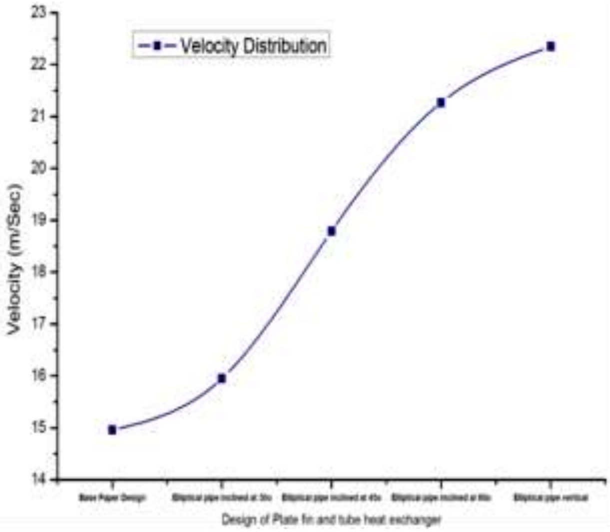


Figure 11Along the PFHEX, velocity distribution

Table 6 Pressure Distribution Across PTFHEX

Design of Plate fin and tube heat exchanger	**Pressure Distribution [Pa]**
Base Paper Design	50.76
Elliptical pipe inclined at 30°	59.79
Elliptical pipe inclined at 45°	140.04
Elliptical pipe inclined at 60°	193.06
Elliptical pipe vertical	220.08

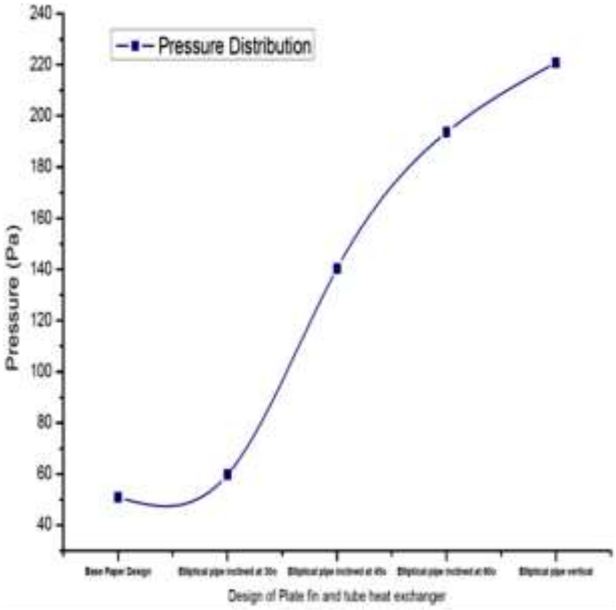


Figure 12 Along the PFHEX, pressure distribution

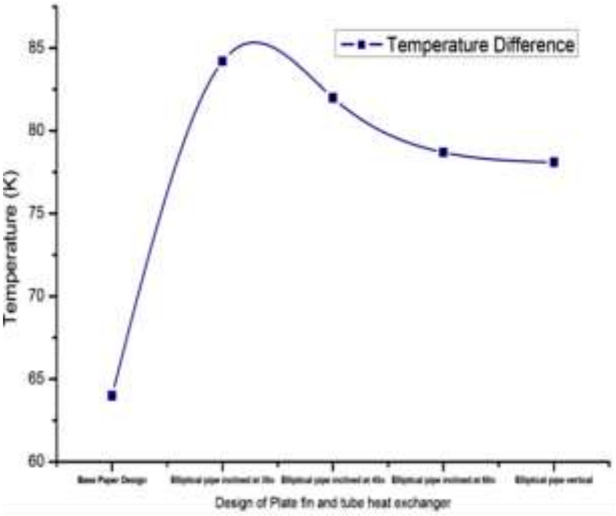


Figure 13 Along the PFHEX, temperature difference

Table 7 Temperature Difference across PTFHEX

Design of Plate fin and tube heat exchanger	**Temperature Difference [K]**
Base Paper Design	64.0
Elliptical pipe inclined at 30°	84.02
Elliptical pipe inclined at 45°	82.0
Elliptical pipe inclined at 60°	78.07
Elliptical pipe vertical	78.01

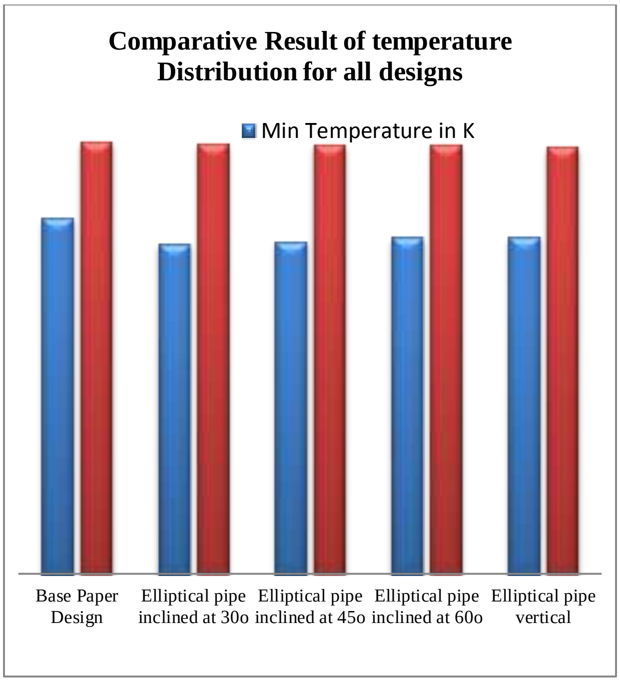


Figure 14 Temperature Distribution Comparison Outcome for All Designs

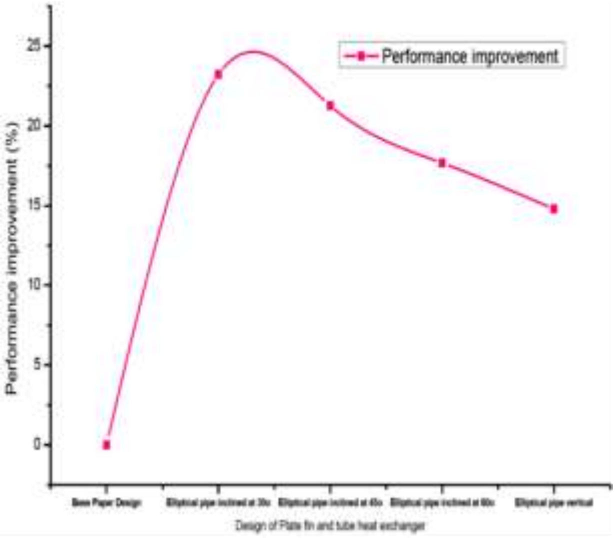


Figure 15 Improvements in performance for PFTHEX are compared.

HEX having fins-and-tubes having an organization of 45 degree tilted elliptical-shaped tubes were discovered at 349.68 K & 268.77 K, HEX having fins-and-tubes having an arrangement of elliptical tubes tilted at 60 degree were discovered at 349.04 K & 273.48 K, as well as heat exchangers with fins and tubes that had an positioning of elliptical-shaped tubes tilted at 90 degree were discovered at 347 K, as per the research results. HEX having fins-and-tubes by a 45-degree tilted elliptical-shaped tube configuration were witnessed at 349.68 K and 268.77 K, respectively, and HEX with fins and tubes with a 60-degree tilted elliptical tube configuration were observed at 349.04 K and 273.48 K, respectively. 347.39 K and 274.29 K are observed in HEX having fins-and-tubes consisting a configuration of elliptical-shaped tubes tilted at 90 degree.

V. CONCLUSION

The study's major goal is to find the conceptual quality for PFHEX using a computer based fluid-dynamic technique and maximize thermal power. The results obtained were reached after doing a computational fluid dynamics assessment on several plate as well as fin heat exchanger designs.The highest and lowest temperatures for HEX having plate-fins-and-tubes consisting of an elliptical-shaped tube tilted by 30 degrees were noticed at 349.68 K and 268.77 K, respectively, indicating a temperature fluctuation of 80, 91 degrees and improved heat transfer efficiency. The highest heat transfer may be acquired from a PTFHEX with an elliptical-shaped tube positioned astilted by 30 degrees, having a heat transfer capacity of 23.22 percent as much as a circular plate heat exchanger, rendering to the above findings. As a result, so rather than employing a circular tube configuration, it is recommended to use PTFHEX with antilted elliptical-shaped tube to achieve the heat transfer of the mixture.

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