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Research paper

Design and Analysis of a Plate Heat Exchanger in the View of Performance Improvement and Cost Reduction

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Abstract

Redesigning of a system is a modification of existing system for reducing the disadvantages over the system and improves the features for getting more output that are desired. For redesigning the existing conventional heat exchanger by the new designed heat exchanger. Conventional heat exchanger has a major disadvantage consuming more space, high cost and maintenance is difficult. Plate heat exchanger has a major advantage over a conventional heat exchanger are that the liquid are exposed to main larger surface area because the liquids spread out over the plate. It is a specialized design well suited to transferring heat between low pressure liquids. The plate produces an extremely large surface area which allows for the fasten possible transfer and studying the plate material, gasket material, chevron angle, and surface enlargement angle. Design a plate heat exchanger by according more advantages and evaluate the cost of newly designed heat exchanger and compared to existing heat exchangers and validate the designs by flow analysis.

Keywords: *Heat exchanger, performance improvement, materials, analysis, CATIA.*

1. Introduction

A warmth exchanger is a gadget that is utilized to exchange warm vitality (enthalpy) between at least two liquids, between a strong surface and a liquid, or between strong particulates and a liquid, at various temperatures and in warm contact. In warm exchangers, there are typically no outside warmth and work communications. Normal applications include warming or cooling of a liquid stream of concern and dissipation or buildup of single-or multi-part liquid streams. In different applications, the target might be to recoup or dismiss warm, or sanitize, purify, fractionate, distil, think, solidify, or control a procedure liquid. In a couple of warmth exchangers, the liquids trading heat are in coordinate contact. In most warmth exchangers, warm exchange between liquids happens through an isolating divider or into and out of a divider in a transient way. In numerous warmth exchangers, the liquids are isolated by a warmth exchange surface, and in a perfect world they don't blend or break. Such exchangers are alluded to as immediate exchange compose, or basically recuperators. Interestingly, exchangers in which there is irregular warmth trade between the hot and chilly liquids—by means of warm vitality stockpiling and discharge through the exchanger surface or network—are alluded to as roundabout exchange write, or basically regenerators. Such exchangers more often than not have liquid spillage from one liquid stream to the next, because of weight contrasts and lattice revolution/valve exchanging. Regular cases of warmth exchangers circular segment shell-and tube exchangers, car radiators, condensers, evaporators, air preheaters, and cooling towers. On the off chance that no stage change happens in any of the liquids in the exchanger, it is at times alluded to as a sensible warmth exchanger. There could be interior warm vitality sources in the exchangers, for example, in electric radiators and atomic fuel components. Burning and concoction response may happen inside the exchanger, for example, in boilers, let go radiators, and fluidized-bed exchangers. Mechanical gadgets might be utilized as a part of a few exchangers, for example, in scratched surface exchangers, unsettled vessel and mixed tank reactors of the working liquid. Warmth move in the isolating mass of a recuperate for the most part happens by conduction. In any case, in a warmth pipe warm exchanger, the warmth pipe goes about as an isolating divider, as well as encourages the exchange of warmth by buildup, dissipation, and conduction inside the warmth pipe. The ordinary warmth exchanger utilized as a part of KMML has many problems such as its complicated design, high maintenance cost and need more space. These problems lead to decrease in company profit. For reducing the problems by redesign a new heat exchanger with same effect as existing and also reducing the problems such as space, maintenance cost and complicated design. To study the existing heat exchanger system. To analyze the scope for improving efficiency by developing a new heat exchanger design. To analyze the scope for cost reduction by replacing the conventional with new design.

2. Literature Review

A literature review is necessary to analyze, the theories and methodologies involved in design and cost estimation of a plate heat exchangers. Various articles were reviewed regarding the same.

Olga P. Arsenyeva , Leonid L. Tovazhnyansky a, Petro O. Kapustenko , Gennadiy L. Khavin [1], revieved the developments in design theory of plate heat exchangers, as a tool to increase heat recovery and efficiency of energy usage.

Vishal R. Naik, V.K. Matawala [2], reviewed the experimental study of heat transfer plates and corrugated plate heat exchangers have larger heat transfer surface area and increased turbulence level due to the corrugations.

Jogi Nikhil G., Assist. Prof. Lawankar Shailendra M, [3], explains corrugated plate heat exchangers have larger heat transfer surface area and increased turbulence level due to the corrugations. In this study, experimental heat transfer data will obtain for single phase flow (water-to-water) configurations in a corrugated plate heat exchanger for symmetric chevron angle plates.

Srbislav B. Genic, Branislav M. Jacimovic , Dragan Mandic , Dragan Petrovic, [4], correlates the results of experimental research on 8 plate heat exchangers. The main achievement of this research was that the fouling factors were determined experimentally, and the found values can be used further on in design of plate heat exchangers in district heating systems.

ZhenHua Jin et. al., [5] designed and estimated the pressure drop of PHE. His investigation verified that the pressure drop in PHE is comparatively lesser than the shell and tube heat exchanger.

Aydın Durmus et. al., [6] investigated the heat transfer in plate heat exchanger and he found that the heat transfer rate in plate heat exchanger is much more than that of conventional heat exchangers.

Kukulka and Devgun [7] conducted on analytical study of velocity and pressure distribution in both the intake and exhaust conduits of PHE, that plate heat exchanger can be designed with equal flow distribution regardless of the number of plates.

Pignotti and Tamborenea [8] developed a computer program to solve the system of linear differential equations for the numerical calculation of the thermal effectiveness of arbitrary flow arrangements in a PHE.

Wright and Heggs [9] shown how the operation of a two stream PHE can be approximated after the plate rearrangement has been made, using the existing PHE performance data. Their method can help when adjusting PHE, which is already in operation, for better satisfaction to required process conditions.

Marriot [10] the effect of varying plate corrugation pattern is achieved by combining chevron-plates with different corrugation inclination angle in one PHE. The design approach and advantages of such a method were shown by for a one pass counter-current arrangement of PHE channels.

From the literature reviews, it was found that for designing a new heat exchanger from existing heat exchanger the different properties of a plate material are taken. The plates corrugation and all the dimensions are needed. The effectiveness is high for a plate heat exchanger. These reviews may be torchlight in this project work ahead.

3. Methodology

After reviewing the different materials for manufacturing plate heat exchanger by suitable plate material has been selected. Using conventional design procedure the heat duty of the heat exchanger is theoretically calculated. For determining the theoretical calculation is same by calculating the design procedure in analytical method. For obtaining the theoretical and analytical calculations are same. Then the further design calculations can simply calculated by analytical method through Ansys. Then study of different plate materials used in plate heat exchanger and design a new heat exchanger with three different plate materials are selected. First taking the stainless steel plate material and the theoretical and analytical methods are calculated.

The analytical and theoretical calculations are valid, that is obtained previously. Then the theoretical calculation of three plate material is analytically calculated and constructed the final plate. Then cost analysis of existing and newly designed heat exchanger is calculated.

4. Design and Analysis of Existing Heat Exchanger

Material Selection

Materials selection for plate heat exchangers focuses primarily upon the plates and gaskets. Since these items significantly affect first cost and equipment life, this procedure should receive special attention. One of the features which make plate-type heat exchangers so attractive for geothermal applications is the availability of a wide variety of corrosion-resistant alloys for construction of the heat transfer surfaces. Most manufacturers offer the alloys listed below:

304 Stainless Steel, 316 Stainless Steel, 317 Stainless Steel, Titanium, Tantalum, Incaloy 825, Hastelloy, Inconel, Aluminium Bronze and Mone

In addition to these a larger number if optional alloys are available by special order. Most manufacturers will quote either 304 or 316 stainless steel as the basic material. For direct use geothermal applications, the choice of materials is generally a selection between 304 stainless, 316 stainless, and titanium. The selection between 304 and 316 is most often based upon a combination of temperature and chloride content of the geothermal fluid. At temperature/chloride concentrations which fall into the region below the curve, the particular alloy in question is considered safe to use. Combinations of temperature and chloride content that are located above the curve offer the potential for localized pitting and crevice corrosion, fluid characteristic above the curve for a particular alloy do not guarantee that corrosion will absolutely occur.

However, this curve, based on oxygen-free environments, does provide a useful guide for plate selection. Should oxygen be present in as little as parts per billion (ppb) concentrations, the rates of localized corrosion would be significantly increased (Ellis and Conover, 1981). Should the system for which the heat exchanger is being selected offer the potential for oxygen entering the circuit, a more conservative approach to materials selection is recommended. Titanium is only rarely required for direct use applications.

In applications where the temperature/chloride requirements are in excess of the capabilities of 316 stainless steel, titanium generally offers the least cost alternative. As with plate materials, a variety of gasket materials are available. Among the most are shown in the table:

Table 1: Gaskets Materials

Material	Common Name	Temperature Limit
Styrene Butadiene	Buna-S	185
Neoprene	Neoprene	250
Acrylonitrile – Butadiene	Buna-N	275
Ethylene	EPDM	300
Fluorocarbon	Viton	300
Resin-Cured Butyl	Resin-Cured Butyl	300
Compressed Asbestos	Compressed Asbestos	500

Frame, Tie Bolts, and Fluid Connections

The frame of most plate heat exchangers is constructed of carbon steel. This is generally painted with an epoxy based material. Tie bolts are of nickel-plated carbon steel. Alternative materials are available (stainless steel), though these are generally unnecessary Bar geothermal applications. Standard connections are 250-lb flange-type of carbon steel construction (2-1/2 in. and larger). Connections of 1-1/2 in. and smaller are generally threaded. Alternate materials and configurations (threaded, grooved end, plain end, etc.) are available.

The heat exchangers are of two types, a small heat exchanger and one big heat exchanger. The analysis of two heat exchanger has to be calculated. Then, the designing of a new heat exchanger. There are two heat exchangers are used in existing, one big and one small heat exchanger by combining these two heat exchangers and redesign a new heat exchanger with the same effect of existing heat exchangers.

Determination of Heat Duty of Existing Heat Exchanger

Heat Duty Analysis of Heat Exchangers

Existing
Hot Side = slurry
Slurry Inlet Temperature, Tsi = 90°C
Slurry Outlet Temperature, Tso = 68°C
Cold Side = Cooling water from cooling tower
Cooling Water Inlet Temperature, Tci = 34°C
Cooling water Outlet Temperature, Tco = 52°C

LMTD (Counter)
LMTD = [(Tsi-Tco)-(Tso –Tci)]/ In [(Tsi-Tco)/(Tso-Tci)] = 35.96°C
Heat Load; Q = 4.03 l x 105 K Cal/hr
Reynolds's Number
Re= (De x M/Ap)/μ = 77000 kg/hr m^3
Where, M - mass flow rate of fluid
μ = dynamic viscosity = 1 centi poise = 3.6kg/m
Re = 0.647 x (77000/0.52588)/3.6; Re = 26315.153; Re<200000

Overall Heat Transfer Coefficient (U)
At = Q/ (U x LMTD x F) = 0.98

Parameters for Small Heat Exchanger
n = 70 (No of Plates)
Area of plate Ap= 0.52588 m^2
Total effective heat transfer area, At = 36.806 m^2
U = 311.218 K cal/hr m^2°C
LMTD = 35.90°C
Cost Analysis of Existing Heat Exchanger
Considering six heat exchangers
Downtime loss = 8 x 6 = 48 hrs
Per hour is assumed by = Rs. 7,500/-
So for 8 hrs = 7500x48; = Rs. 3, 60,000/-

Labour Cost for Maintenance for Existing Heat Exchanger
For One Worker = 500/hr; For 5 Worker = 5x48x500; =1.20, 000/-

Cost Estimation
Cost of Alfa Laval Heat Exchanger = Rs. 4, 93,000/-
Cost of one plate of a Alfa Laval Heat Exchanger = Rs. 3750/-
Cost of Spondex Heat Exchanger = Rs 4, 53,000
Number of plates used in Alfa Laval Heat Exchanger = 84
So, total cost of Alfa Laval Heat Exchanger = 84 x 3750 = Rs. 3, 15,000/-
Number of plates in Spondex Heat Exchanger = 70
So, total cost Spondex Heat Exchanger = 70 x 3500 = Rs. 2, 45,000/-
So, total cost both Heat Exchangers (Existing = 3, 15,000 + 2, 45,000 = Rs. 5, 60,000/-

Proposed
G = mass flow rate = 231000kg/hr
Hot side (slurry); Slurry Inlet, Tsi = 87.5°C
Slurry outlet, Tso = 68°C
Cold Side (Cooling water from cooling tower)
Cooling water inlet, Tci = 32°C
Q = mCp (Tsi– Tso) = 10.72 x 105 Kcal/hr
Tco = Tci + Q/mCp
Tco = 32 + (10.72 x 105/231000 x 0.238)
Cooling water outlet, Tco= 51.49°C
LMTD - [(Tsi – Tco) - (Tso – Tci)]/ ln [(Tsi – Tco) / (Tso – Tci)] = 36ºC

Uavg = 1 / [1 /H x X/K x 1/He + dFc]
Eliminate. 1/He, dFc; Re (avg) = 34030.5
H = 0.742 x Cp x G x[(Re (avg)-0.62) x (Pr (avg)-0.667]
Where Pr = μ x Cp/K
Where K = 0.58446 K cal/hr m^2°C
Pr = (3.6 x 0.238)/0.58446 = 1.565
H= 0.742 x 0.238 x (231000/1.02) x (34030.5)-0.62 x (1.565)-0.667; H= 49.26 K cal/hr m^2°C;
U= 275.50 K cal/hr m^2°C

Overall Heat Transfer Coefficient (U)
At = Q/ (U x LMTD x F) = 0.98
No. of plates N = 115
Area of heat exchanger, At = 110m^2
Overall-heat transfer coefficient, U = 275.50K cal/ hr m^2ºC
LMTD = 36ºC; Slurry Inlet, Tsi = 87.5°C
Slurry outlet, Tso = 68°C
Cooling water inlet, Tci = 32 °C
Cooling water outlet, Tco = 51.49°C
Cost Analysis of Existing Heat Exchanger
Considering three heat exchangers there would be three maintenance schedules, three for each heat exchanger
So, downtime loss = 8 x 6 = 48 hrs
Per hour is assumed by = Rs. 7,500/-
So for 8 hrs = 7500x48 = 3, 60,000/-
Considering new heat exchangers at an average of 3 maintenance schedule
So downtime loss would be = 8x3= 24hrs/
Per hour loss assumed to be = Rs. 7500/-
=24*7500 =1, 80,000
Labour Cost for Newly Designed Heat Exchanger
For one worker = 500/hr
For 5 worker = 500x 24x 5 = 60,000
Saving from downtime cost = Rs 3, 60,000 - Rs 1, 80,000 = Rs 1, 80,000/-
Saving from Labour cost =Rs 1, 20,000-Rs 60, 000 = Rs 60,000/-
Cost of Alfa Laval Heat Exchanger = Rs. 4, 93,000/-
Cost of one plate of a Alfa Laval Heat Exchanger = Rs. 3750/-
Cost of Spondex Heat Exchanger = Rs. 4, 53,000/-
Number of plates used in Alfa Laval Heat Exchanger = 84
So, total cost of Alfa Laval Heat Exchanger = 84 x 3750 = 3, 15,000
Number of plates in Spondex Heat Exchanger = 70
So, total cost Spondex Heat Exchanger = 70 x 3500 = 2, 45,000
So, total cost both Heat Exchangers (Existing HE) = 3, 15,000 + 2, 45,000 = 5, 60,000
Number of plates used = 115
So, the total cost of newly designed heat exchanger = 115 x 3750= Rs 4, 31,250/-
Cost of existing Alfa Laval Heat Exchanger = Rs 5, 60,000/-
Reduction in Cost = 5, 60,000-4, 31,250
= Rs 1, 28,750/-
Maintenance cost per hours loss = Rs 7500/-
Total time = 8 hrs for cleaning
Labour = 5 people (Rs 500/hr)
Total reduction in cost = 128750 + 60000+ 1, 80,000 =Rs. 3, 68,750/-

5. Newly Designed Layout

The current stream of heat exchangers has many problems regarding space, cost, maintenance etc.; in order to overcome these it is design a new heat exchanger which can replace the two heat exchangers in two second stream.

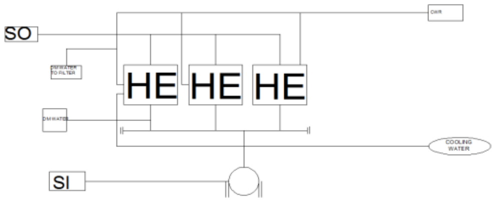

Figure 1: Newly designed layout of heat exchanger

The Figure 1 shown above is the layout of newly designed Heat Exchanger. In the above layout, only three heat exchangers are used instead of six. But the effect obtained is equal as existing heat exchanger.

6. Analysis Of Plate Used In Heat Exchangers

In this section the newly designed heat exchanger is considered and different plate materials are selected for heat exchanger. The different plate materials are Stainless Steel, Titanium and Aluminium Bronze are considered and analysis has been carried out by applying boundary conditions.

Temperature Distribution of Plates Materials

The temperature distribution of different plate materials are calculated. The inlet and outlet conditions are given to plate and obtain the temperature distribution in plates.

Temperature Distribution of Stainless Steel, Titanium and Aluminium Bronze Plates

The Figure 2 represents the temperature distribution of stainless steel plate. The red colour is the inlet and its temperature is high. The temperature is transformed from one side to another and the outlet colour is golden yellow, that is the temperature is get decreased. The blue colour represents very low temperature that is the cooling water temperature.

The Figure 3 represents the temperature distribution of Titanium plate. The red colour is the inlet of high temperature fluid and the opposite is the outlet of fluid. The temperature in the outlet is decreases and is shown by yellow colour. The blue colour represents the water temperature.

The Figure 4 represents the temperature distribution of Aluminium Bronze plate. The red colour is the inlet of high temperature fluid and in outlet the temperature get decrease. It can be shown by yellow colour. The temperature is decreases more in this plate.

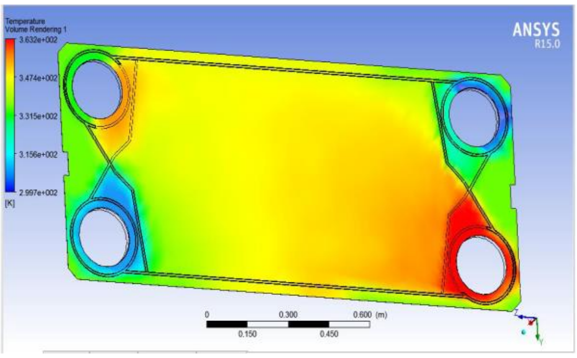

Figure 2: Temperature distribution of stainless steel plate

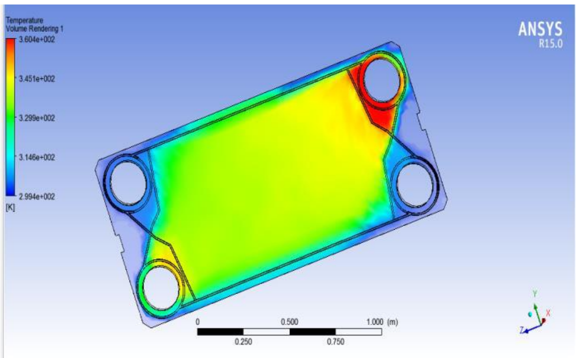

Figure 3: Temperature distribution of titanium plate

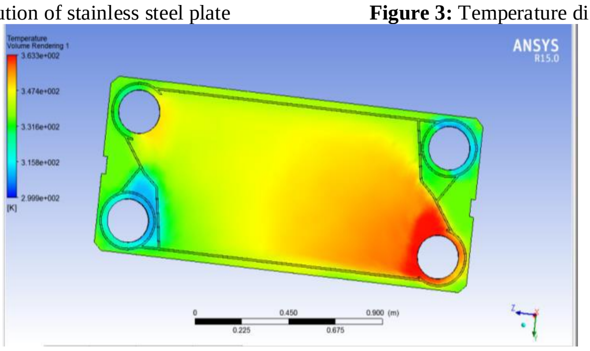

Figure 4: Temperature distribution of aluminium bronze plate

7. Slurry Temperature Distribution On Plates

The slurry temperature distribution of different plate materials are calculated. The inlet and outlet conditions are given to plate and obtain the temperature distribution in plates.

Slurry Temperature Distribution of Stainless Steel, Titanium and Aluminium Bronze Plates

The Figure 5 represents the slurry temperature distribution of Stainless Steel plate. The red colour is the slurry inlet of high temperature and flow through the surface of plate. The outlet where the temperature is decreases.

The Figure 6 represents the slurry temperature distribution of Titanium plate. The red colour is the slurry inlet of high temperature and flow through the surface of plate, the outlet where the temperature is decreases. The titanium slurry temperature distribution is less than stainless steel.

The Figure 7 represents the slurry temperature distribution of Aluminium Bronze plate. The red colour is the slurry inlet of high temperature and flow through the surface of plate, the outlet where the temperature is decreases. The slurry temperature distribution is high effective than Stainless steel and titanium plates.

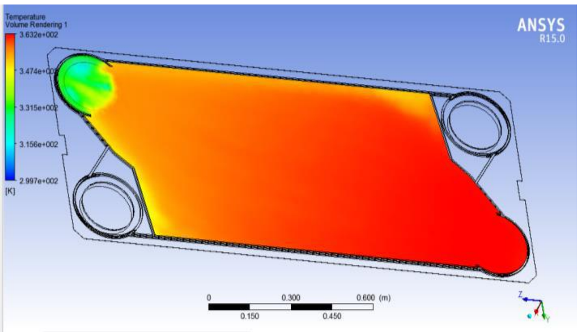

Figure 5: Slurry temperature distribution of stainless steel plate

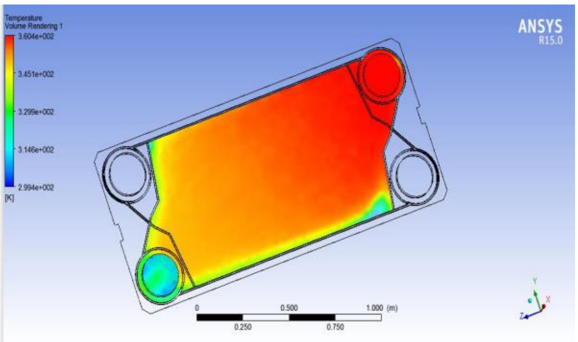

Figure 6: Slurry temperature distribution of titanium plate

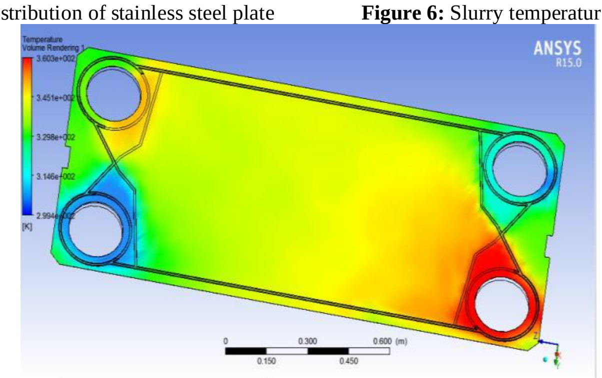

Figure 7: Slurry temperature distribution of aluminium bronze plate

8. Stream Line Velocity Distribution of Plates

The stream line velocity distribution of different plate materials are calculated. The inlet and outlet conditions are given to plate and obtain the temperature distribution in plates.

Stream Line Velocity Distribution of Stainless Steel, Titanium and Aluminium Bronze Plates

The Figure 8 represents the stream velocity distribution of stainless steel plate. The blue colour is the inlet of high temperature and flow through the surface of plate, the outlet where the temperature is increases. The increase in temperature is shown by green colour.

The Figure 9 represents the stream velocity distribution of Titanium plate. The blue colour is the inlet of high temperature and flow through the surface of plate, the outlet where the temperature is increases. The increase in temperature is shown by green colour.

The Figure 10 represents the stream velocity distribution of Aluminium Bronze plate. The blue colour is the inlet of high temperature and flow through the surface of plate, the outlet where the temperature is increases. It is more effective in velocity distribution than stainless steel and titanium plates.

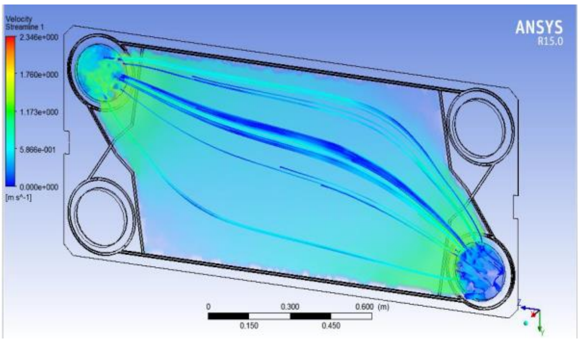

Figure 8: Streamline velocity distribution of stainless steel plate

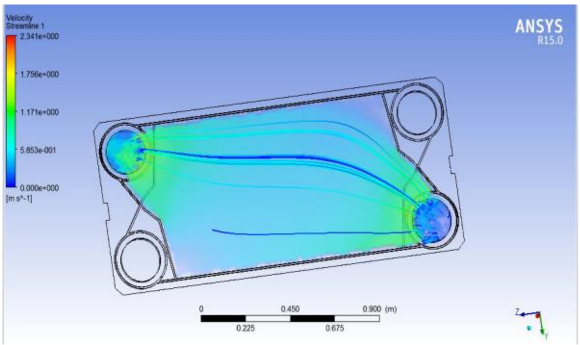

Figure 9: Stream line velocity distribution of titanium plate

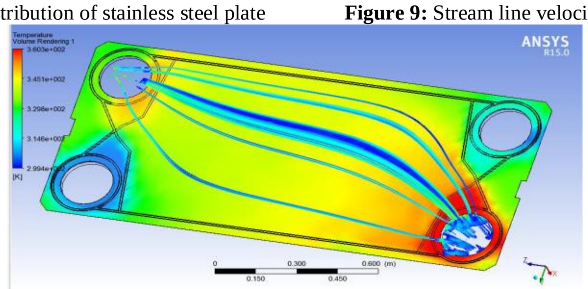

Figure 10: Stream line velocity distribution of aluminium - bronze plate

9. Water Temperature Distribution of Plates

The water temperature distribution of different plate materials are calculated. The inlet and outlet conditions are given to plate and obtain the temperature distribution in plates.

Water Temperature Distribution of Stainless Steel, Titanium and Aluminium Bronze Plates

The Figure 11 represents the water temperature distribution of stainless steel plate. The blue colour is the water inlet of low temperature and flow through the surface of plate, the outlet where the temperature is increases.

The Figure 12 represents the water temperature distribution of Titanium plate. The blue colour is the water inlet of low temperature and flow through the surface of plate, the outlet where the temperature is increases. It is poor in heat transfer between slurry and cooling water. There is no change in the colour of inlet and outlet of water temperature.

The Figure 13 represents the water temperature distribution of Aluminium Bronze plate. The blue colour is the water inlet of low temperature and flow through the surface of plate, the outlet where the temperature is increases. It is higher in heat transfer between slurry and cooling water. There is change in the colour of inlet and outlet of water temperature. The inlet of water is blue. In outlet the temperature increases and the colour is green.

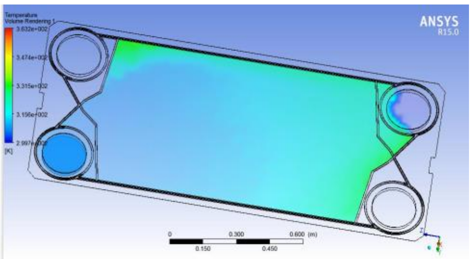

Figure 11: Water Temperature distribution of stainless steel plate

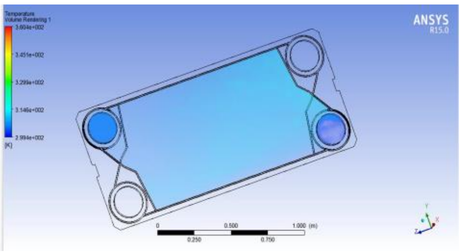

Figure 12: Water temperature distribution of titanium plate

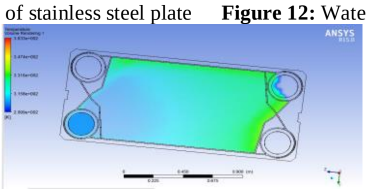

Figure 13: Water temperature distribution of aluminium bronze plate

10. Result and Discussion

Variation of Temperature Distribution, Slurry Temperature and Water Temperature Distribution of Stainless Steel, Titanium, Aluminium-Bronze

The Figure 14 shows the variation in temperature distribution from this graph it can be seen that the temperature of Stainless Steel and Aluminium Bronze has got good heat reduction capacity since its thermal conductivity is high than the Titanium plate.

Figure 15 shows the variation of slurry temperature in the plate. From this it can be understand that the temperature in the Stainless Steel and Aluminium bronze are more than the Titanium it shows that the Titanium is a bad metal for using in plates.

Figure 16 shows it can see that the heat absorbed by the water is more in Stainless Steel and Aluminium Bronze also Titanium has very less heat absorbing capacity and it cannot be used as a plate even though Aluminium Bronze is far better than the Stainless Steel but its availability is less and price is high so Stainless Steel is suitable.

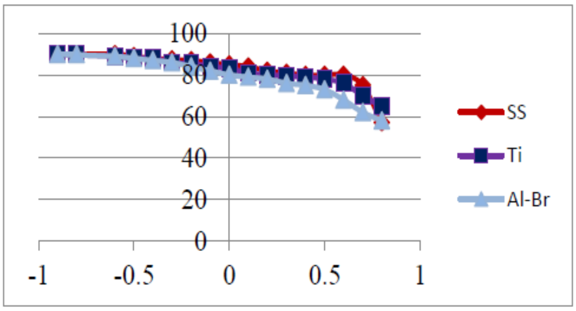

Figure 14: Variation of Temperature Distribution of Stainless Steel, Titanium & Aluminium - Bronze Plate

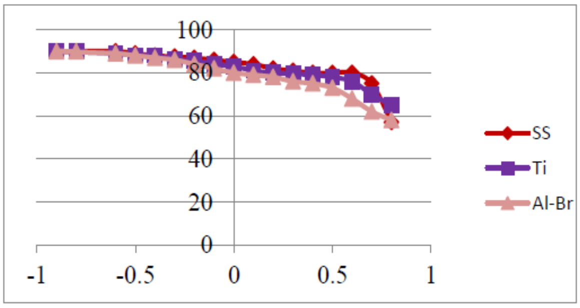

Figure 15: Variation of Slurry Temperature Distribution of Stainless Steel, Titanium and Aluminium Bronze Plate

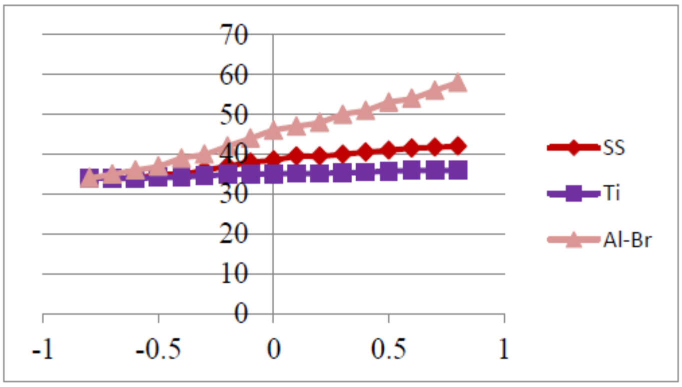

Figure 16: Variation of Water Temperature Distribution of Stainless Steel, Titanium & Aluminium-Bronze Plate

11. Comparison Result for Existing and Newly Designed Heat Exchanger

The Table 2 has shown the comparison result between existing heat exchanger and newly designed heat exchanger. From the Table 2 it can be shown that, by combining the small and big heat exchanger contains large space, area and cost. But for newly designed heat exchanger the space, area and cost are small.[10]

Table 2: Comparison between Existing and Newly Designed Heat Exchanger

Items	Small Heat Exchanger	Big Heat Exchanger	Newly Designed Heat Exchanger
Plates Used	70	84	115
Area(m^2)	36.808	85.65	110
Cost (Rs)	245000	315000	368750

12. Conclusion

Plan and improvement strategy for the PHE is exhibited which gives preferred arrangements over existing distributed techniques. It depends on scientific model representing the principle highlights deciding PHE warm and water driven execution. To get arrangement with insignificant warmth exchange zone for various process conditions is conceivable just for a sufficiently wide scope of plate writes and sizes. The advancement factors are: sort of plate, the quantities of goes for warm trading streams, the relative quantities of plates with various layering designs in one PHE. The proposed methodology of model parameters recognizable proof empowers to decide their qualities for business plates. It is made for an arrangement of plates with various geometrical qualities and types of folding. The heat exchanger used in the company facing many problems such as large space needed, high cost. By reducing this by redesign a new heat exchanger from existing heat exchanger has been completed.

The design procedure is first by theoretical method and then the same procedure is used in analytical method and both the result obtained is same. From this it can be conclude than for further design calculations, analytical method can be used. The different plate material study has been completed and selecting three different materials and analytic method is applied through ANSYS and obtain the result. From the result most suitable and effective plate material has to be selected and constructed the final plate. By replacing existing heat exchanger by newly designed heat exchanger, the space needed can be reduced. For increasing number of plates, the performance has been increased.

For the redesigning of heat exchanger reduces the overall cost. About Rs, 3, 60,000/- reduction in cost, which increase the company profit. It is the safe and secure method for implementing in an industry.

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