PERFORMANCE AND STRUCTURAL ANALYSIS OF PLATE AND FRAME HEAT EXCHANGER

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ABSTRACT: The plate and frame heat exchanger was first developed about 100 years ago. But it gained increasing interest during the last two decades, primarily due to the development of methods of manufacturing plate and frame heat exchanger. The major advantages of plate and frame heat exchangers are their extremely compact design and efficient use of the construction material.

The plate and frame heat exchangers are used regularly in the heating, ventilating, air conditioning, and refrigeration industry. Recently new application fields in the chemical, processing of milk and allied industries are opened up due to their numerous advantages. Heat transfer coefficients are generally higher in plate and frame heat exchangers than in conventional shell and tube heat exchangers.

The objective of this project is to fabricate an experimental set up and conduct performance analysis of plate and frame heat exchanger .Using this set up, a test is conducted to evaluate the performance of heat exchanger at varying flow rates and inlet temperatures, for optimal effectiveness-NTU and Log Mean Temperature Difference relationships, under steady state operation and also to determine the heat transfer rate of pasteurization unit, apart from this test a structural analysis is conducted to identify the weak points caused due to heavy weight of the plates resulting in the breakage of the supports of the system .

A plate and frame heat exchanger is analyzed here for structural stability (stress optimization) using finite element method. So WHRU is analyzed by finite element analysis method at working boundary conditions for identifying weak points in it. Modifications are made on weak points to reduce stress value is analyzed for same. The results are validated with the experimentation carried with thermal test equipment on the model.

I. INTRODUCTION

India is currently the largest producer of milk in the world, a status it has maintained since the late nineties. Further, India is also self-sufficient in milk. This has been largely achieved through a combination of favourable policies and an institutional network that has helped support millions of rural households in pursuing their livelihoods through small scale dairy farming.

The dairy industry in India is going through major changes with the liberalization policies of the government and the restructuring of the economy. This has brought greater participation of the private sector. This is also consistent with global trends, which could hopefully lead to greater integration of Indian dairying with the world market for milk and milk products. Today, India is the world's largest and fastest growing market for milk and milk products with an annual growth rate of about 4.5%.

India is witnessing winds of change because of improved milk availability, a change-over to market economy, globalization, and the entry of the private sector in the dairy industry. The value addition and variety in the availability of milk products are on everybody's agenda. There is an increasing demand for new products and processes. The main reasons are:- an increase in disposable incomes; changes in consumer concerns and perceptions on nutritional quality and safety; arrival of foreign brands; increasing popularity of satellite/cable media; and availability of new technologies and functional ingredients.

Problem Statement: This is a stress optimization problem. In this a stacked Plate & frame heat exchanger with the provided dimensions is to be analyzed for structural stability using FEA software (ANSYS).

We can calculate the mechanical stresses developed in heat exchanger but thermal behaviour (stresses and deformation) is very difficult to obtain accurately because of uninformed distribution of temperature in the body. Many parts of the heat exchanger may fail because of thermal loading. So, safe working of stacked heat exchanger without failure due to excessive stresses is necessary because safety is our prime importance. Analyze the current design for stress optimization (structural analysis) using FEA. Identify weak points and suggest remedies for them.

PASTEURIZATION PROCESS

Processing of milk

The function of a dairy plant is the blending, processing, standardizing, packing and distribution of milk and its products for safe human consumption.

Most of the dairy plants receive milk from several dairy farms and collection of centers located in near by villages. This milk is usually mixed, then processed by separation and blended to produce milk, which will contain a uniform butter fat as required. Pasteurization is an important step in the processing procedure as a means of destroying undesirable bacteria and for prolonging the milk life with its quality. Proper pasteurization will kill all pathogenic type of bacteria and nearly all other objectionable organisms but other heat resistant types of bacteria will continue to survive unless the milk is cooled promptly after the pasteurization process. The life of the milk can be prolonged to even 15 days provided with proper processing and cooling procedure applied to it.

Pasteurization methods

This process was developed by Louis Pasteur. It has been described as the process of heating the milk to such temperature i.e., 72°C and holding it at that temperature for 30 minutes and rapidly cooling it to below 4°C.

The primary purpose of heat treatment is to kill all microorganisms capable of causing disease. Pasteurization of milk must be free from pathogens. A part from pathogenic organism, milk also contains other substances and microorganisms which may spoil the taste and shelf life of the milk products. The secondary purpose of pasteurization is therefore to destroy as many as possible of these organism and enzymic system in order to safe guard the product quality.

Intensive heat treatment of milk is desirable from the micro biological point of view. But such treatment also involves a risk of adverse effects on the appearance, taste and nutritional value of milk. In the dairy, milk is almost pasteurized in the continuous HTST process.

HTST pasteurizers

The HTST process involves heating the milk 72°C -75°C with 15 seconds holding time before it is cooled.

The main process involved as the milk passes through the HTST systems are

1. Regeneration
2. Heating
3. Cooling
4. Holding

COMPACT HEAT EXCHANGERS

Introduction

The transfer of thermal energy between fluids is one of the most important and frequently used processes in engineering. The transfer of heat is usually accomplished by means of a device known as a heat exchanger.

“A heat exchanger is any device used for affecting the process of heat exchange between two fluids that are at different temperatures.”

Common applications of heat exchangers in the nuclear field include boilers, fan coolers, cooling water heat exchangers, and condensers. The basic design of a heat exchanger normally has two fluids of different temperatures separated by some conducting medium.

The most common design has one fluid flowing through metal tubes and the other fluid flowing around the tubes. On either side of the tube, heat is transferred by convection. Heat is transferred through the tube wall by conduction.

The selection process must take a number of factors, all of which are related to the specific application. These factors include the following:

1. Thermal and hydraulic requirements
2. compatibility with fluids and operating conditions
3. Maintenance
4. Availability
5. Economic factors

Classification of compact heat exchangers

Classification According to Fluid Flow

- ➢ Parallel flow heat exchanger
- ➢ Counter flow heat exchanger
- ➢ Cross flow heat exchanger

Classification According to Surface Compactness

- ➢ Gas-to-fluid exchangers
- ➢ Liquid-to- Liquid and Phase Change Exchangers

Classification According to Construction Features

A. Tubular Heat Exchangers

- ➢ Shell and Tube Heat Exchangers
- ➢ Double Pipe Heat Exchangers
- ➢ Spiral Heat Exchangers

B. Plate Type Heat Exchanger

PLATE AND FRAME HEAT EXCHANGER

Introduction

The plate and frame heat exchanger (PFHE) was introduced in Germany in the 1930^s to meet the hygienic demand of the dairy industry. The plate and frame heat exchanger consists of a number of thin rectangular metal plates sealed around the edges by gaskets and held together in a frame as shown as fig.5.1.

Since the 1930^s, plate heat exchangers increasingly have been used in the chemical and food processing industries. Most plate heat exchangers are fitted with gasket seals, and the material has to be selected to be compatible with the fluid being processed. Plate heat exchangers are used mainly for liquid-to-liquid heat exchange, but are also suitable for some liquid-to-gas and liquid-to-condensing vapour combinations.

Design Procedure for Plate and Frame Heat Exchanger

There are only a few correlations and a limited amount of data available in the open literature on the design of PFHE's. They use design correlations and methodologies developed on the basis of their data. The corrugated design is pretty common in the PFHE's as it helps to create a high degree of turbulence even at a low Reynolds number. The critical Reynolds number of a PFHE ranges between 10 to 400 depending upon the type of plate.

The Reynolds number is defined as

$$Re = U D_e \rho / \eta$$

The Nusselts number is defined as

For $R_e P_r D/x >$ when $0.5 < P_r < 16000$

$$Nu = 1.86 (R_e P_r)^{0.33} (D/x)^{0.33} (\mu/\mu_w)^{0.14} \quad \text{(since Re<2300)}$$

$$Nu = 0.26 (R_e)^{0.65} (P_r)^{0.4} (\mu/\mu_w)^{0.14} \quad \text{(since Re>2300)}$$

Where

x = length of the pipe

D= diameter of the pipe

The general design procedure is as follows:-

➢ Calculate the heat load, volumetric flow rates of the streams, terminal temperatures across the exchanger, and LMTD.

➢ Select the specific construction of the plates suitable for the required service (for example a wider gasketed plate for cooling of a viscous liquid such as 50% caustic soda solution).

➢ Select suitable pass and flow arrangement on the basis of allowable pressure drop for either stream.

➢ From an estimated flow rate per passage, the clean overall heat transfer coefficient and pressure drop per passage can be directly obtained from the plate characteristic curves.

➢ Select fouling resistance and obtain the dirty overall heat transfer coefficient. Calculate the total area requirement from the known heat load, calculated LMTD, and the dirty overall heat transfer coefficient.

➢ Determine the effective number of plates from the known heat transfer area per plate. Then, calculate the number of plates required which is one more than the effective number of plates.

Methods of thermal performance evaluation

A single – pass heat exchanger with a large number of plates is the simplest case and is dealt with first. Their application to counter current flow is described in detail because this is the most common form as shown in fig.Here, the hot fluid condenses in down flow in alternate passages and the coolant flows in upward flow in the other alternate passages, sub cooling of the condensate is conveniently obtained by arranging for the bottom part of the channels in which the condensation is occurring to be flooded with the condensate.

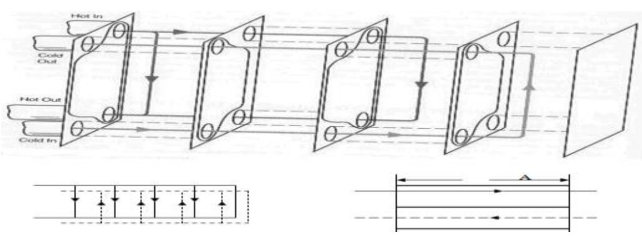


Plate and frame heat exchanger configurations with single pass counter current flow

This single pass arrangement avoid thermally induced maldistribution of the type possible in two pass arrangements ,but, for high hot fluid velocities, pressure changes along the entry ports can give uneven pressure drop across the respective condensing channels and hence no uniform flow. This problem is the more severe the higher the hot fluid velocity and, hence, the lower the pressure.

Where

L = length of each plate in the direction of flow

A = Total heat exchanger area

Methodology:

Design of Plate and Frame Heat Exchanger has been based on kern correction method. In the beginning of the design process, the geometric dimensions of the plate and frame heat exchanger are determined based on kern correction method. The model development is subjected to the following underlying assumptions.

1. The heat exchanger operates under steady – state conditions.
2. The overall heat transfer coefficient is constant throughout the heat exchanger.
3. Fluid temperatures and velocities are uniform across the channel.
4. Heat is not conducted in the direction of flow.
5. The fluids are equally distributed between the channels.
6. Heat losses are negligible.

II.EXPERIMENTAL SET UP DESCRIPTION

Plate and Frame Heat Exchanger

An existing plate and frame heat exchanger is taken and modified to suit the experimentation. The selected unit has a pack of fifty three plates and gaskets arranged for multi operation with passes in series (Pattern of holes in the plates and shape of the gaskets determine the direction of flow through the exchanger) as shown in fig 6.1.The following is the technical data.

Type of plate:-Chevron plate

- Plates are manufactured from AISI 316 stainless steel.
- Number of active plates: 51
- Plate overall dimensions: 250mm x 750mm
- Plate thickness: 5 mm
- A gap 1.5mm (0.0015m) between each plate approximately.

Refrigeration unit details:

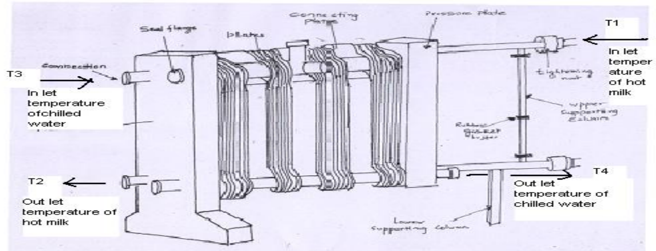
The refrigeration system is used to provide the cooling in the cooler section. Ammonia is the refrigerant chosen and brine (Ethylene Glycol) is used as a secondary refrigerant. A 130 H.P single acting, twin cylinder reciprocating compressor with motor speed of 1440 R.P.M is recommended for the experiment. The condenser recommended is a vertical shell and tube type of condenser, with water as readily available cooling medium. The evaporators designed are shell and tube type .the expansion devices selected are thermostatic expansion valves. The capacity of the system has comes to 127 tons of refrigeration. The primary refrigerants of ammonia are used in the milk dairy.

The hot and cold fluid paths are arranged in such a manner to allow counter current to co-current operation. The complete set up is supported by a frame and column construction. The following instrumentation is provided to collect data.

- Provision is made for temperature measurement at four points, two at the inlets and two for outlets of fluid paths.
- Temperatures are measured using type K thermocouples with miniature plug for direct connection electrical console on HT30X.
- A Rota meter is provided in chilled water line.
- A tapping is provided to measure milk collection /time.
- A Stop watch.
- Measuring can of 50 ltr.

Operation of plate and frame heat exchanger

- Milk enters into the upper portion of plate and frame heat exchanger with an inlet temperature of 28°C.
- The chilled water enters into the lower portion of plate and frame heat exchanger with an inlet temperature of 0.5°C.This chilled water flows in counter flow direction to the milk flow.
- The chilled water absorbs the heat of milk.
- The temperature of chilled water is gradually increased and also the temperature of milk is reduced along their flow paths.
- Milk leaves the heat exchanger with an out let temperature of 4°C.
- Also the chilled water leaves the heat exchanger with an outlet temperature of 5°C.



Experimental setup of Plate and Frame Heat Exchanger

Conduct of the Experiment

Initially the pipe lines are cleaned of any debries.The chilled water (i.e., municipal-portable) is allowed slowly in steps up to 8000 ltr /hr in to plate and frame heat exchanger. Then the milk is let in to the heat exchanger and the flow rate is measured by collecting milk per 10 min. The flow rate of milk and chilled water are increased in steps to 500 and 15000 ltr /hr.

The different temperatures are noted down for every 5 min. The system is assumed to have come to steady conditions (i.e., about 50 min time) when three consecutive readings show the same temperatures are noted.

- observations on noted on date:22/4/2008

S. No	No. of Plates	Mass flow rateof chilled water (m_c) kg/s	Mass flow rate of hot milk (m_h) kg/s	$T_{milk\ in\ let}$ (°C)	$T_{milk\ out\ let}$ (°C)	$T_{chilled\ inlet}$ (°C)	$T_{chilled\ outlet}$ (°C)
1	51	15000	5000	28	4	0.5	5
2	51	15000	5000	31	4	1	10
3	51	15000	5000	35	4	1.5	13

The experiment is repeated on the second day again. Temperature and mass flow rate noted and tabulated.

- observations on noted on date:09/5/2018

S. No.	No. of Plates	Mass flow rate of chilled water (m_c)	Mass flow rate of hot milk (m_h)	$T_{milk\ in\ let}$ (°C)	$T_{milk\ out\ let}$ (°C)	$T_{chilled\ inlet}$ (°C)	$T_{chilled\ outlet}$ (°C)
1	55	16500	5500	28	4	0.5	5
2	59	18000	6000	28	4	0.5	5
3	63	19500	6500	28	4	0.5	5

- observations on noted on date:18/5/2018

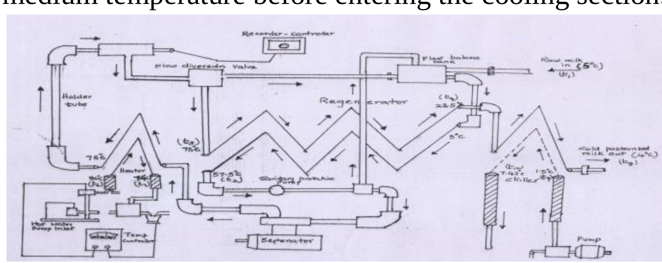
The experiment is repeated on the third day again. Temperature and mass flow rate noted and tabulated.

S. No	Mass flow rate of chilled water (m_c) kg/s	Mass flow rate of hot milk (m_h) kg/s	$T_{milk\ inlet}$ (°C)	$T_{milk\ outlet}$ (°C)	$T_{chilled\ inlet}$ (°C)	$T_{chilled\ outlet}$ (°C)
1	16500	5500	28	4	0.5	5
2	18000	6000	28	4	0.5	5
3	19500	6500	28	4	0.5	5

Pasteurization unit

Operation of pasteurization unit

For a plate and frame-type, high temperature short time pasteurization system as shown in fig 6.3, raw milk is first discharged into the float from the holding tank by gravity or by a pump with a uniform level having maintained in the float tank by means float valve. Milk from the float tank is drawn through the regenerating section at a partial vacuum to the suction of the milk pump. The pump will discharge either directly to the heating section or it may pass through filter, clarifier and a homogenizer before passing to the heating section. From the heating section the milk is forced through the holder tube to the flow diversion valve and if at the correct pasteurization temperature will pass through the regenerating section so that the cold raw milk coming into the unit will be heated by the pasteurized milk as it passes to the cooling section and the pasteurized milk will be cooled by the raw milk to a medium temperature before entering the cooling section.



Experimental set up of High Temperature – Short Time Pasteurization Unit.

III. INTRODUCTION TO SOFTWARES

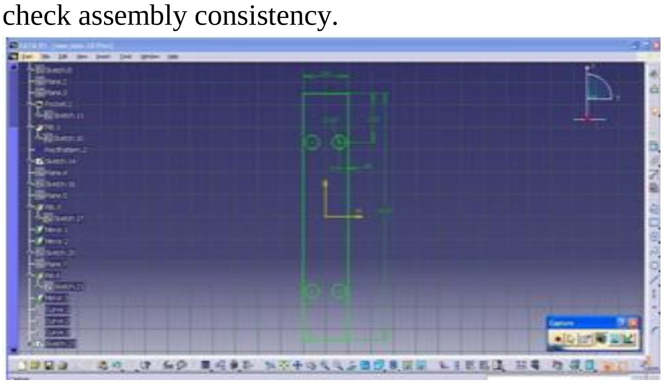
Computer Aided Design:

Computer aided design helps to assist in the creation, modification, analysis, or optimization of a design using cad software. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD is used as follows:

- To produce detailed engineering designs through 3-D and 2-D drawings of the physical components of manufactured products.
- To create conceptual design, product layout, strength and dynamic analysis of assembly and the manufacturing processes themselves.
- To prepare environmental impact reports, in which computer-aided designs are used in photographs to produce a rendering of the appearance when the new structures are built.

About CATIA:

CATIA means Computer Aided Three Dimensional Interactive Application. CATIA is a 3D product Lifecycle Management software suite developed by the French Company Dassult Systems. CATIA facilitates collaborative engineering across disciplines with its 3D experience platform. CATIA allows the user to create parts in highly productive and intuitive environment. CATIA enriches existing product design with basic part and surface design tools, easily establish assembly constraints, automatically positions parts and check assembly consistency.



Profile of Plate in Catia V5

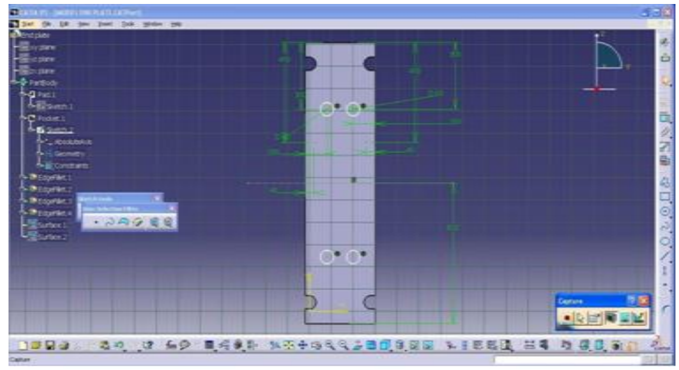


Fig 7.3: Solid model of Plate in Catia V5

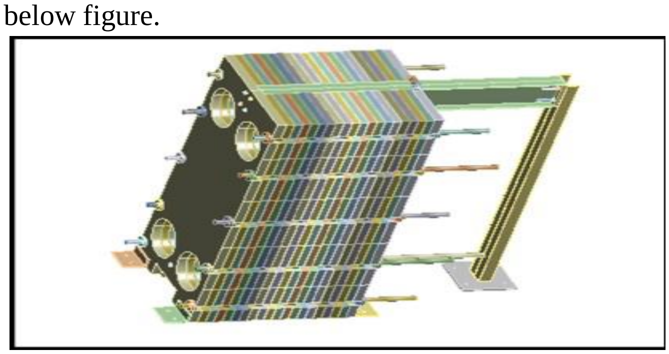
Making an Assembly:

Start the Assembly Design Workbench by clicking Start > Mechanical Design > Assembly Design or select New > Product which will automatically brings you to the Assembly Design Workbench. (If it's not, try the first step).

In the Assembly Design Workbench, you'll see a product tree on the top left corner with Product1 as the parent. You can change the name by modifying the properties.

Now right click on the Product1 tree and select Components > Existing Components or select Insert > Existing Components or click on the Insert Existing Component Icon .

A File Selection box will appear and select all the parts to be assembled. The assembled model is shown in below figure.



Catia model of stacked plate & frame heat exchanger

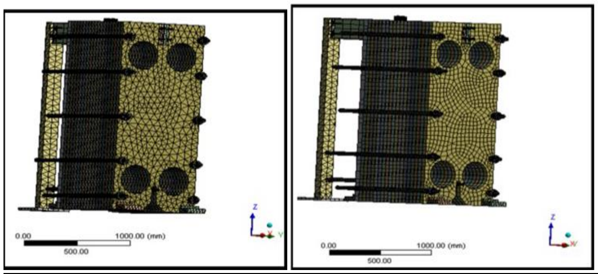
The required boundary conditions for the analysis of heat exchanger are as follows

a) Inlet temperature of hot fluid = 140ºC

b) Out let temperature of cold fluid = 1000C

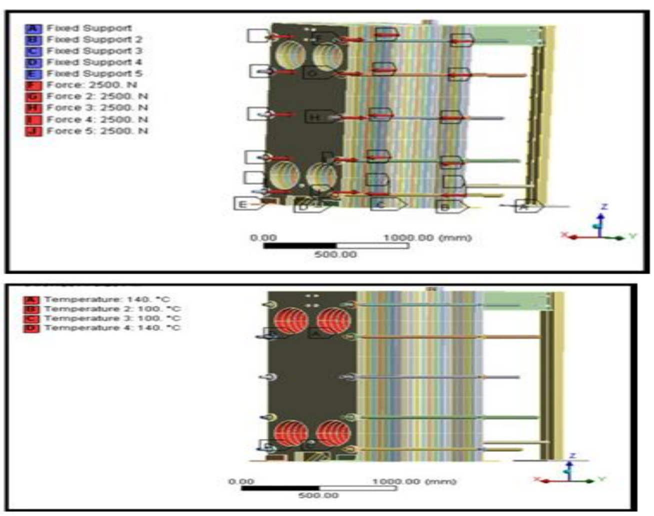
c) Bolt compressive load = 2.5 kN

For the meshing of the element hexahedron and tetrahedron elements are used in ANSYS workbench. The meshing images are shown in figure below.

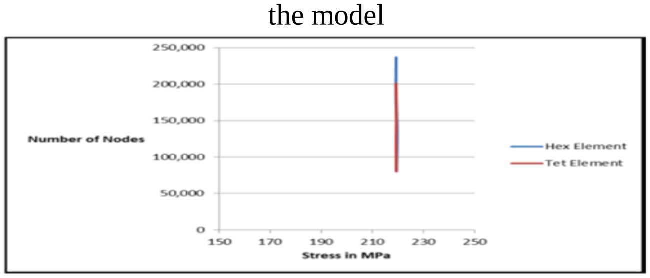


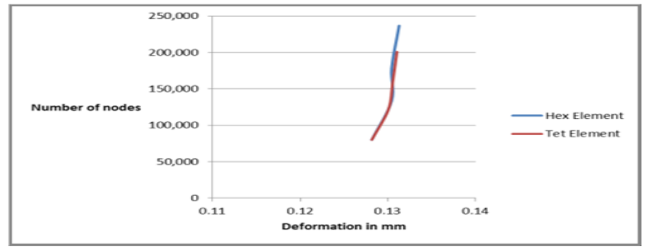
Meshing of the model with tetrahedron and hexahedron element

The bolting load acting (boundary condition) on the model and thermal boundary conditions are shown below in figure 3. The analysis results in the form of deformation and the value of stresses developed in the model for both tetrahedron and hexahedron element for different number of nodes are shown in graph 1 and 2 below.

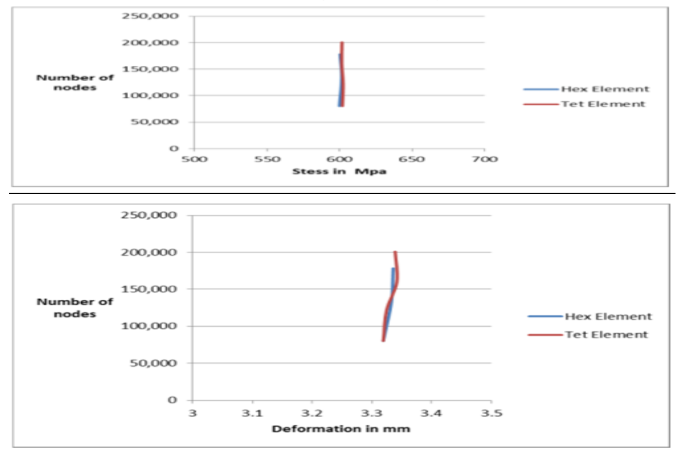


Bolting force and thermal boundary conditions acting on the model



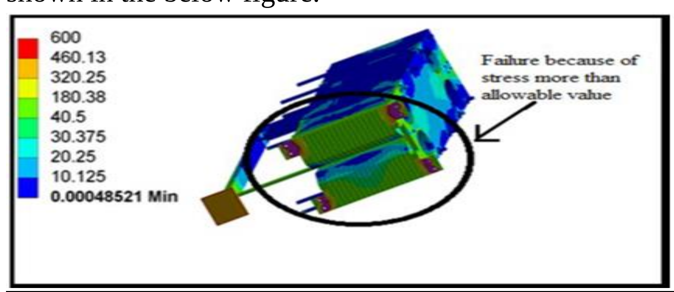


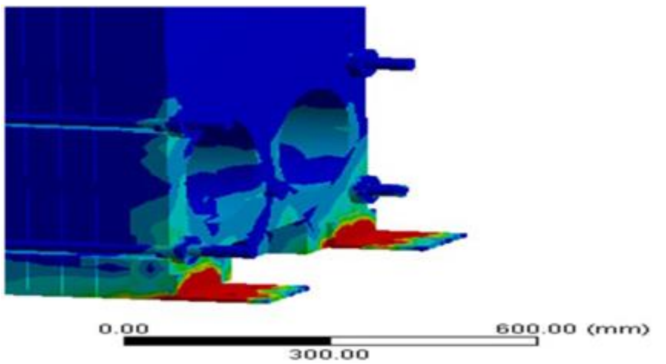
Comparison between hexahedron and tetrahedron element for bolting boundary conditions



Comparison between hexahedron and tetrahedron element for Thermal boundary conditions

After analysis we find that for thermal boundary conditions the model fails at supports due to the excessive stress value. This failure at the supports is shown in the below figure.

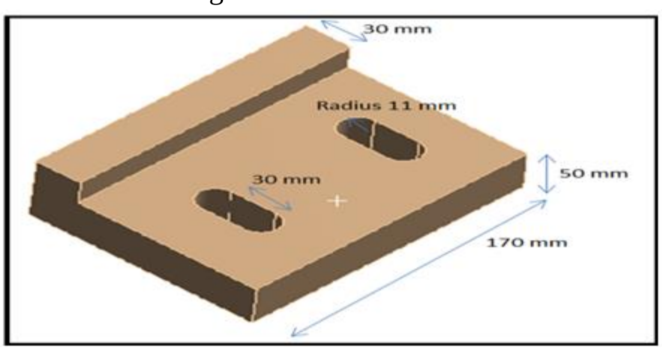




Failure at the support after thermal boundary conditions

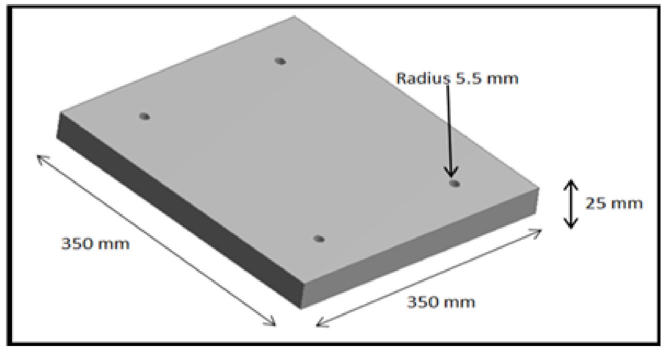
Remedies on the failure parts in thermal boundary conditions

The material used for analysis for fixing plate is structural steel. The value of allowable stress for fixing plate with structural steel according to ASME code section 8, part 5 is 412 Mpa. As stress value due to thermal loading that is temperature of the hot and cold fluids is more than allowable value, failure is occurred at fixing plate. So aim is to reduce (optimize) value of stress at fixing plate. Stresses can be reduced by increasing cross sectional area of the plate. So the new modified dimensions of the L shaped fixing plate for which the stress value is bellow allowable value are shown in below figure.



Modified geometry of L shaped fixing plate

Similar to L shaped fixing plate, square plate is also need to be optimized for stresses value as stress value is more than allowable value. The modified geometry of square fixing plate is given in below figure.



Modified geometry of square fixing plate

IV. RESULTS AND DISCUSSION

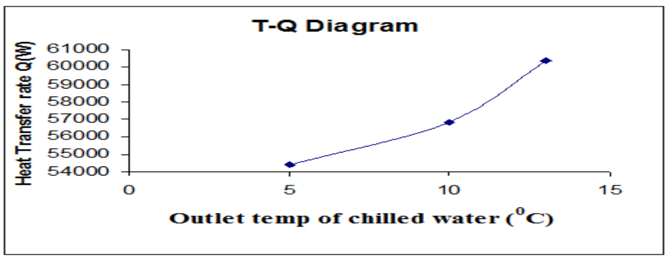
1. Plate and Frame Heat Exchanger

Heat transfer rate (Q) of heat exchanger depends on various parameters like inlet temperature and outlet temperature of chilled water and number of plates. There are three cases for analyzing heat transfer rate viz: - 1) Number of plates is fixed and varying temperature of the chilled water and milk 2) Number of plates variable and constant temperature of chilled water and milk 3) Varying the flow rate and constant temperature of chilled water and milk. These are discussed from the calculations obtained and are depicted in tables and plots in the following:

The following Plate and Frame Heat Exchanger table Illustrate the relation between constant number of plates Vs heat transfer rate with varying different temperatures of the chilled water and milk

S. No	No. of Plates	T_{milk} inlet (°C)	T_{milk} out let (°C)	$T_{chilled}$ inlet (°C)	$T_{chilled}$ outlet (°C)	Mass flow rate of chilled water (m_c)	Mass flow rate of hot milk (m_h)	□T_{lm} (°C)	U (W/m^{2-} k)	Q (watts) $x10^5$	NTU_{min}	Effectiveness (□)

						kg/s	**kg/s**					
1	51	28	4	0.5	5	15000	5000	10.36	546.80	0.543	2.316	0.855
2	51	31	4	1	10	15000	5000	9.85	601.17	0.568	2.943	0.909
3	51	35	4	1.5	13	15000	5000	9.51	660.78	0.603	3.469	0.938

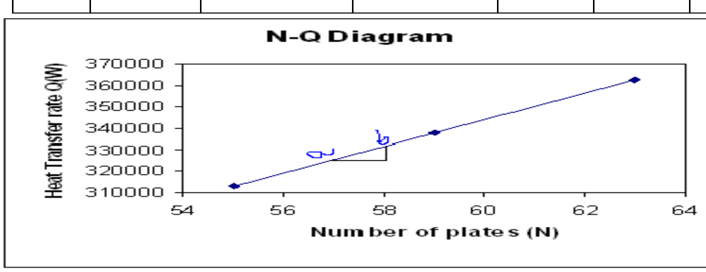


The plotted graph between outlet temperature of chilled water vs. Heat Transfer rate from the values obtained from the above table.

From the above figure above represents the variation of heat transfer rate with Outlet temperature of chilled water for plate and frame heat exchanger. It is observed that the heat transfer rate increases with increase in Outlet temperature of chilled water.

The following Plate and Frame Heat Exchanger table Illustrate the relation between varying number of plates Vs heat transfer rate with constant temperatures of the chilled water and milk .

S. No.	**No. of Plates**	**Mass flow rate of chilled water (m_c)**	**Mass flow rate of hot milk (m_h)**	**T_{milk} in let (°C)**	**T_{milk} out let (°C)**	**$T_{chilled}$ inlet (°C)**	**$T_{chilled}$ outlet (°C)**	**U (W/m^2 K)**	**Q (watts) x10^5**	**□P_h (N/m^2)**	**□P_c (N/m^2)**
1	55	16500	5500	28	4	0.5	5	549.35	3.1305	186.21	2155.80
2	59	18000	6000	28	4	0.5	5	552.36	3.3765	192.39	2226.04
3	63	19500	6500	28	4	0.5	5	555.24	3.6243	197.05	2291.29



The plotted graph between Number of Plates vs. Heat Transfer rate from the values obtained from the above table

From the above figure represents the variation of heat transfer rate with Number of plates for plate and frame heat exchanger. It is observed that the heat transfer rate increases with increase in Number of plates because of the Q= UA□T

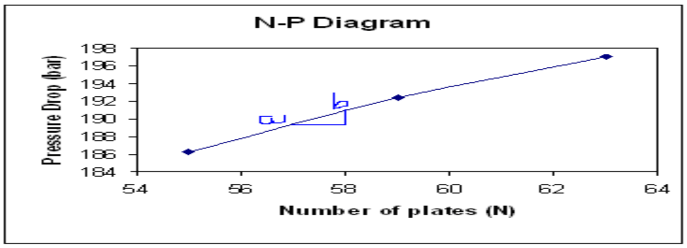
Q=U x N x a x □T

Calculating the slope of ab from the figure (8.2)

Slope of ab = $(y_2 - y_1) / (x_2 - x_1)$ = (331175 - 325000) / (58-57)

= 6175 W

The heat transfer rate will be increased 6175 W per each plate



The plotted graph between Number of Plates vs. Pressure drop from the values obtained from the above table.

From the above figure 8.3 represents the variation of pressure drop with Number of plates for plate and frame heat exchanger. It is observed that the Pressure drop increases with increase in Number of plates.

Calculating the slope of ab from the figure (8.3)

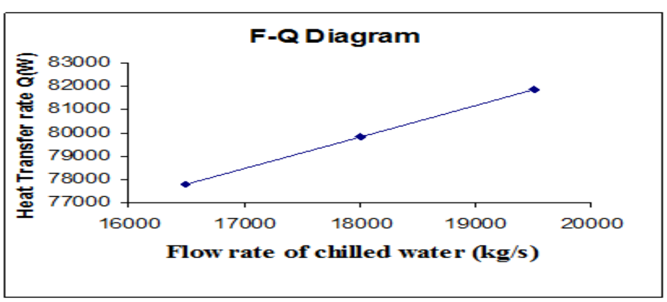
Slope of ab = $(y_2 - y_1) / (x_2 - x_1)$ = (190.55 - 189.2) / (58-57)

= 1.35 N/m^2

The Pressure drop will be increased 1.35 N/m^2 per each plate.

The following Plate and Frame Heat Exchanger table Illustrate the relation between varying flow rate Vs heat transfer rate with constant temperatures of the chilled water and milk in the PFHE.

S. No	**Mass flow rate of chilled water (m_c) kg/s**	**Mass flow rate of hot milk (m_h) kg/s**	**T_{milk} inlet (°C)**	**T_{milk} outlet (°C)**	**$T_{chilled}$ inlet (°C)**	**$T_{chilled}$ outlet (°C)**	**U (W/m^2K)**	**Q (watts) x 10^5**	**□P_h (N/m^2)**	**□P_c (N/m^2)**
1	**16500**	5500	28	4	0.5	5	**782.27**	**0.7780**	212.49	**2468.18**
2	**18000**	6000	28	4	0.5	5	**802.56**	**0.7982**	249.17	**2893.18**
3	**19500**	6500	28	4	0.5	5	**823.04**	**0.8186**	287.84	**3344.48**



The plotted graph between Chilled water flow rates vs. Heat Transfer rate from the values obtained from the above table.

From the above figure 8.4 represents the variations of heat transfer rate with flow rate for plate and frame heat exchanger. It is observed that the heat transfer rate increases with increase in flow rate for heat exchanger.

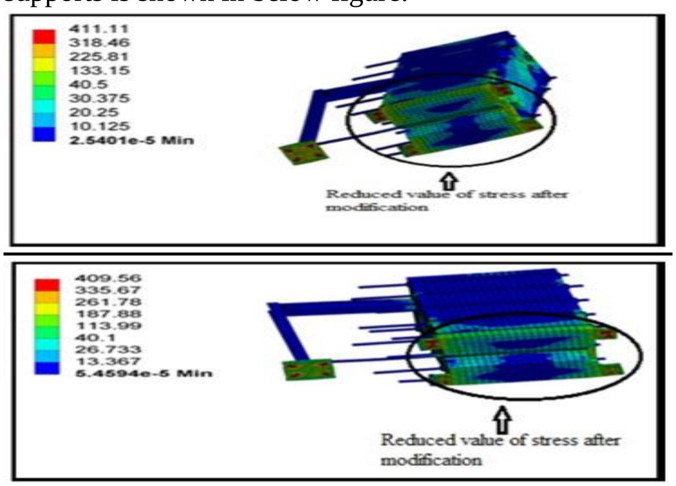
2. Pasteurization Unit:

The following Pasteurization table Illustrate the relation between Constant Number of plates Vs heat transfer rate with different temperatures of chilled water and milk.

S.No.	Type of Process	No. of plates	$T_{milk\ inlet}$ (°C)	$T_{milk\ outlet}$ (°C)	$T_{chilled\ inlet}$ (°C)	$T_{chilled\ outlet}$ (°C)	U (W/m^2-k)	Q (watts) x10^5	A (m^2)	□T_{LM} (°C)
1	Regeneration	57	3	50	71	18	1583.18	3.0170	10.68	17.83
			4.5	54	73	21	1617.18	3.062	10.68	17.72
			5	57.5	75	22.5	1653.43	3.067	10.68	17.5
2	Heating	65	70	54	73	75	1266.11	1.618	12.18	10.48
			73	56	74	78	1312.09	1.624	12.18	10.15
			75	57.5	74.5	80	1485.66	1.806	12.18	9.81
3	Cooling	53	18	4	0.5	5	559.252	0.402	9.93	7.24
			20	4	1	6	590.23	0.4185	9.93	7.14
			22.5	4	1.5	7.5	789.95	0.547	9.93	6.979

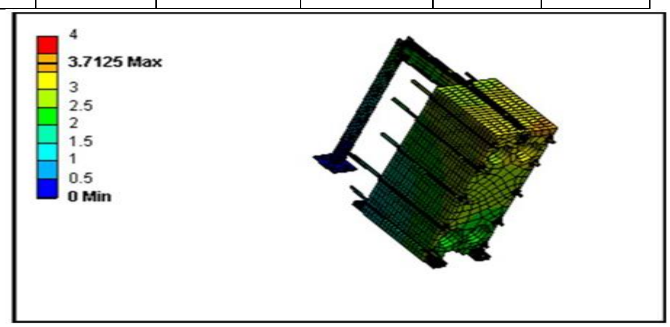
3. Analysis with modified Model

When modified model is used for analysis we get the results in which model is safe for given thermal boundary condition. The reduced value of stress at supports is shown in below figure.



Reduced value of stress after modifying support for thermal boundary condition

The deformation in the modified model for given thermal boundary condition is shown below in below figure



Deformation in the modified model

V. RESULTS

Model	Equivalent Stress in Mpa	Total Deformation in mm
Modification	409.56	3.7125

The above results are obtained in the Ansys Software for the structural analysis of the model after modifications. Both Equivalent stress and total deformation are obtained here which are allowable and required to reduce the risk of breakage of the supports due to heavy weight of the plates of the heat exchanger.

VI. CONCLUSION

Plate and frame type heat exchangers are gaining application in many areas of energy transfer. Dairy milk processing is chosen for the application of plate and frame type heat exchanger. Experimental investigation has been planned and conducted for a range of inlet temperatures. From the results and analysis made the following conclusions are made

1) The effectiveness of the heat exchanger varied from 0.855 to 0.938 for inlet temperatures from 28°C to 35°C.

2) The NTU minimum rose from 2.316 to 3.469 for an increase of inlet temperature from 28°C to 35°C.

3) The overall heat transfer coefficient increased from 546.80 to 660.78 W/m^2-K and subsequently the heat transfer rates increased from 0.543 $x10^5$ W to 0.603 $x10^5$ W for the same temperatures raise.

4) In another experiment the number of plates in the frame has been increased from 55 to 63 numbers in series. As expected the heat transfer increased by 10.3%.The pressure drop increased from 186.21 to 197.05 N/m^2

Further experimental data over wide range of temperature, pressure drop etc., are recommended to be able to optimize the plate and frame application for dairy industry.

After performance analysis of plate and frame heat exchanger, structural analysis is conducted to identify the weak points caused due to heavy weight of the plates resulting in the breakage of the supports of the system .It is difficult to find out stresses and deformation of the material under non uniform temperature distribution, so for this purpose finite element analysis methods is used. After performing structural analysis on stacked heat exchanger model for given bolting and thermal boundary conditions it is found that model is weak at its supports. When the supports are modified to reduce stresses, model is found safe for both boundary conditions. These results of analysis also matches with experimental analysis performed with thermal test equipment. In future there is also a scope for simulation of fluid flow through the heat exchanger using CFD or any modified simulation software for improving performance of heat exchangers.

REFERENCES

1. Cooper, A. and Usher, J.D.(1983),plate heat exchanger-design hand book, hemisphere publishing, newyork, chap 3.7
2. G.F.Hewitt, G.L.Shires, T.R.Bott. (1993), Process heat transfer. Library of congress cataloging-in-publication data, crc press. Boca Raton.New York
3. D.A.Reaay, David Reay & Associates (1999), Compact heat exchangers, enhancement and heat pumps. Pobox 25, whitely bay; Tyne &Wear.Ne26 1QT, UK.
4. Arthur W.Farrall. (1963)Engineering for dairy and food products.
   John Wiley & sons.Inc. New York.
5. Binay K.Dutta. (209), Heat transfer principles and applications Published by prentice –hall of India private ltd. M-97, New Delhi.
6. R.C.Sachdeva. (2003), Fundamentals of Engineering Heat and Mass transfer. New age international Publishers. New Delhi.
7. C.P.Kothandaraman, S.Subramanyan. (1989), Heat and mass transfer data book. New age international Publishers. New Delhi.
8. Arora .Domkundwar. (1973), A course in Refrigeration and Air conditioning, Dhanapat Rai &co.(P)Ltd. Publishers, Delhi.
9. Jamesr.lines,(1969)Asymmetric plate heat exchangers allow independent optimization of both fluids for maximum thermal efficiency and economic , Graham manufacturing co., New York
10. Mashelkar, R.A. (1988) Design considerations for heat exchangers handling non-Newtonian fluids in heat transfer equipment design, shah, R.K., subba rao. Hemisphere publishing. New York.
11. Foote, M.R. (1967), Effective mean temperature differences in multi pass plate heat exchangers, national engineering laboratory. Est. kilbrite.

12. Alfa Laval AB.(1969).Thermal hand book Sweden
13. Hall, C.W and Trout, G.M. Milk Pasteurization, The A.V.I.Pubi.Co., Inc. Westport, Connecticut (1968) .