PERFORMANCE EVALUATION OF A SINGLE PHASE BRAZED PLATE HEAT EXCHANGER

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Abstract— **Brazed plate heat exchanger (BPHE) is one of the most efficient and compact type amongst all of the heat exchangers. The geometry and the geometrical parameters play a very important role on the design and on the performance of the BPHE. Therefore, a slight change in the geometry of the BPHE can vary the performance adversely. Hence, a good and efficient mathematical method is necessary to capture the true performance which would be unique for that particular geometry of the BPHE. The BPHE performance parameters include thermal performance and hydraulic performances. The thermal performance measures the rate of heat transfer or the heat transfer efficiency and the hydraulic performance measures the pressure drop over the BPHE. The present report is on modeling the heat transfer efficiency of the heat exchanger by optimizing the Calculated Overall heat transfer coefficient in accordance with the Required Overall heat transfer coefficient. The RequiedOHTC is calculated from the actual temperature program, heat transfer area available and the heat load on the heat exchanger. The developed method relates the parameters or non-dimensional numbers influencing the heat transfer and pressure drop against Reynolds number. The constants developed from this relation are unique for the specific tested BPHE model and Reynolds number region. However, the prediction can be extended for different heat transfer areas, temperature programs and varying heat loads but for the specified Reynolds number region and the BPHE. The pressure drop modeling involves only the pressure drop in the channels of the BPHE but not the entire pressure drop that occurs between the inlet and outlet of the BPHE which might include the pressure drop in the pipes, pipe bends, connections etc. The pressure drop in the fluid channels influences the heat transfer area requirement in case of applications where there is strong dependence of fluid properties on local pressure.**

Keywords— **Thermal, hydraulic, performance evaluation, Brazed plate heat exchanger**

I. INTRODUCTION

Heat exchanger is a component that facilitates heat transfer between two or more fluids either between solid surface and a fluid or between solid particulates and a fluid at different temperatures usually in thermal contact and normally without external work and heat interactions

Brazed plate heat exchanger is a plate type heat exchanger which is constructed as a package of corrugated channel plates with a filler material between each plate. The filler material along with the two corrugated plates is vacuum brazed. During vacuum-brazing process, the filler material forms a brazed joint at every contact point between the plates forming complex flow channels. There are four ports provided on each plate which facilitates the flow of heat transfer fluid into and out of channels. The port design and the plates are arranged such that alternatively the hot and the cold fluids enter the channels and the fluids do not mix with each other.

The BPHE consists of the channel plates, cover plates, zero hole plates and connections in the front and rear end. The cover plate consists of sealing plates, blind rings. As shown in the figure, the channel plates are arranged such that patterns for each plate are pointing in opposite directions with the start plate facing upwards. The connections can be customized to the requirements but, the selection or the design of the connections also depends on the port diameter on each of the models

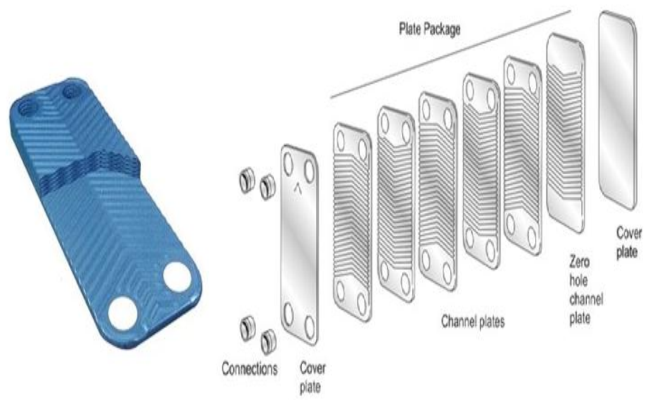

Fig. 1 Corrugated channel plate and plate package of BPHE

In-between two plate's one channel is created and the number of plates required to be built depends on the heat transfer area required to meet the application demands. Hence, the total heat transfer area for a unit with certain number of plates is defined as the area of a plate multiplied by (NOP-2) where NOP is the number of plates.

The plate area is defined as the length (from bottom port centre to top port centre on the same side) multiplied by its width. So, based on the application requirement, different sizes of BPHE are designed and manufactured.

II. FLOW ARRANGEMENT IN BPHE

The BPHE is tested with water as heat transfer fluids on both sides and for a counter current flow arrangement.

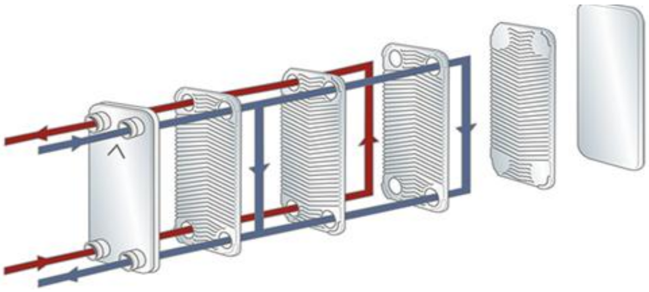

Fig. 2 Counter current flow arrangement in BPHE

From the figure 2, the red lines and blue lines shows the warm and cold fluids flow in the alternate channels of the BPHE. The ports are generally named F1, F2, F3 and F4 on the front side and P1, P2, P3 and P4 on the rear side of the BPHE.

So, for a counter-current flow arrangement, the warm fluid enters at F3 and exits at F1. Similarly the cold fluid enters at F2 and exits at F4. Also the two fluids flow in opposite directions in the alternate channels. The below figure shows the temperature profile for a counter current flow

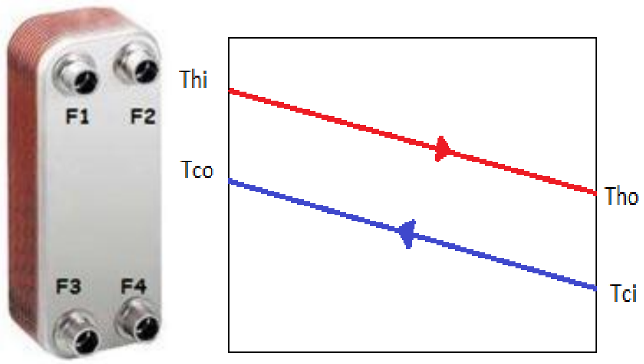

Fig. 3 Ports on the heat exchanger model and temperature profile

The advantage of a counter current flow arrangement is that a close temperature approach can be obtained which implies higher LMTD and higher heat transfer.

III. WORKING AND GEOMETRY OF BPHE

WORKING: The BPHE consists of corrugated plates arranged one after the other in the opposite direction of the channels corrugations. Each plate has 4 ports for the fluid flow and the arrangement of the channel plates and port design ensures the warm and cold fluids to flow in alternate channels. However the fluid direction can be controlled according to the requirement.

In the course of the fluid flow, heat transfer takes place between the warm fluid to the plate wall and then to the cold fluid. The driving force for heat transfer is the temperature difference between the warm and the cold fluids. The corrugations on the plate offer more turbulence to the fluid flow. The chevron angle of the pattern can be varied to offer more turbulence. Designing different patterns on the plates and also by changing the chevron angle, pressing depth, length etc depending on the requirement, the rate of heat transfer and pressure drop can be controlled. The rate of heat transfer depends on the geometry of the plates, velocity of the fluid flow and thermodynamic properties of the fluids.

GEOMETRY: The plate geometry plays a vital role in the overall performance of the heat exchanger. The rates of heat transfer and pressure drop are directly related to the geometry and hence the selection of the geometrical parameters becomes more important in designing a brazed plate heat exchanger. The following figure shows some of the important geometrical parameters of any BPHE plate.

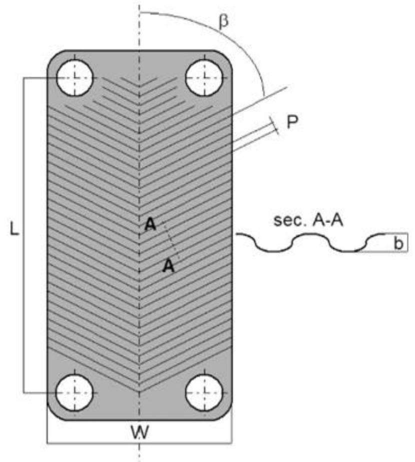

Fig. 4 Geometry of a BPHE channel plate

L → Length of the plate which is usually measured from the port Centre's
W →Width of the plate.
β → Chevron angle
P → Pitch of the corrugations
b → Pressing depth

Based on the chevron angle, the plate design is basically divided into three types namely,

- High Theta (H)
- Medium Theta (M)
- Low theta (L)

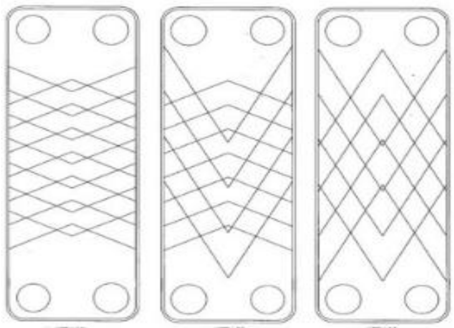

Fig. 5 Different patterns on a channel plate

H-Theta plate: This plate pattern allows more turbulence for fluids and hence more heat transfer rate. Also the resistance for fluid flow is also high and hence pressure drop increases.

M-Theta plate: This plate pattern has a chevron angle much lower than the H-plate and hence also has lower heat transfer rate and lower pressure drop compared to the H-theta plates

L-Theta plate: This plate has the lowest chevron angle in comparison to the H and the M plates which offer lower heat transfer and lower pressure drop.

Combination or mixing of H, M and L plates are also done in building the heat exchanger and the composition of each type of plates depends on the thermal duty required from the heat exchanger and the maximum allowable pressure drop. The mixing might be done either with 2 plate types or with all 3 plate types depending on the requirement. The standard chevron angles for H, M and L plate are defined as per individual company standards.

IV. TESTING OF BPHE

The BPHE is tested to evaluate the performance in its operating envelope. The operating envelope is specific for different models and applications. The test parameters, operating conditions and test specifications can be a standard setup or is usually decided by the lab test engineer.

The test parameters that are required to be defined before testing the BPHE is as follows

- Inlet temperatures of warm and cold fluids
- Minimum and maximum limits on Mass flow rates of warm and cold fluids
- Fluids used on warm and cold sides
- BPHE dimension parmeters
- Number of plates with which the BPHE is built

The heat exchanger performance is validated or measured in two regions i.e. Low Reynolds number region and High Reynolds number region. The ranges of operation of BPHE in these two regions are specific for different models. Normally, BPHE's are built to operate between Reynolds numbers of 10 to 10,000. However, this can be controlled based on the size of the heat exchanger, interest of operating range and application requirement. In our case study, the procedure is for testing the BPHE in the high Reynolds number region only. The different types of flows are defined based on Reynolds numbers for a BPHE and is as follows.

- Laminar flow: Re < 400
- Transition flow: 400 < Re < 1000
- Turbulent flow: Re > 1000

The BPHE is installed in the rig and the test is executed as per the set input parameters. The test data points are collected and the template of the lab test data file is shown below.

A	B	C	D	E	F	G	H	I	J	K	L	M
Point no	Mass flow warm kg/s	Temp in warm °C	Temp out warm °C	Pressure drop warm kPa	Mass flow cold kPa	Temp in cold °C	Temp out cold °C	Pressure drop cold kPa	Meas dP warm kPa	Pipe dP warm kpa	Meas dP cold kPa	Pipe dP cold kpa

Table 1 Test template for a single phase testing

The measured pressure drop columns "J and L" represents the pressure drop that is measured between inlet and outlet pressure sensors located on the pipes connecting to the BPHE. The column "E and I" represents the pressure drop only in the BPHE channels which is the actual pressure drop of interest. The actual pressure drop is calculated as follows.
Actual pressure drop = Measured pressure drop – (pipe pressure drop + port pressure drop)

V. EQUATIONS AND CALCULATIONS

HEAT TRANSFER EQUATIONS**:** In a BPHE, heat is transferred by convection from hot fluid to the wall and by conduction within the wall thickness and again by convection from the wall to the cold fluid. Since the fluids move in the BPHE with a certain velocity, the heat transfer takes place by forced convection. The heat transfer across the BPHE is shown in the below figure.

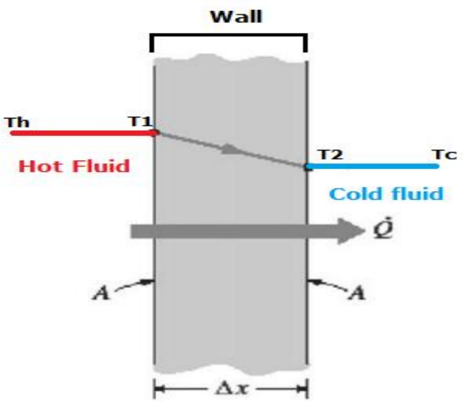

Fig. 6 Heat trasnfer across the wall

HEAT TRANSFER EVALUATION: The following equations are used in modeling the heat transfer.

$$Q = U \; x \; A \; x \; \Delta TLMTD$$

Q → Heat transfer by convection
U → Required Overall heat transfer coefficient
A → Heat transfer area
ΔT LMTD → Logarithmic mean temperature difference

The Calculated Overall heat transfer coefficient is obtained by the following equation. (CalculatedOHTC)

$$U = \frac{1}{\frac{1}{h1} + \frac{1}{h2} + \frac{t}{K}}$$

U →Calculated Overall heat transfer coefficient
h1 → Individual heat transfer coefficient on warm side
h2 → Individual heat transfer coefficient on cold side
t → Wall or plate thickness
K → Thermal conductivity of plate

The individual heat transfer coefficients on the warm and cold sides (h1 and h2) are calculated by calculating the Nusselt number using the heat transfer correlation for forced convection.

$$Nu = C \; x \; Re^{n} \; x \; Pr^{y}$$

Nu → Nusselt number
Re → Reynolds number
Pr → Prandtl number
C and n → Constants
$y = \frac{1}{3} \; x \; e \; (\frac{6.4}{Pr + 30})$

The equations for Nu, Pr and Re are as follows

$$Nu = \frac{h \; x \; L/D}{k}$$

h → Individual heat transfer coefficient warm/cold side
D → Hydraulic diameter
k → Thermal conductivity of fluid

The individual heat transfer coefficient is unknown parameter in the above equation

$$Pr = \frac{\mu \; x \; Cp}{k}$$

μ → Dynamic viscosity
Cp → Specific heat capacity
k → thermal conductivity of fluid

$$Re = \frac{2 \; x \; \dot{m}}{W \; x \; \mu}$$

ṁ → mass flow rate of fluid per channel
W → Plate Width
μ → Dynamic viscosity

Dimensionless numbers are calculated for both warm and cold sides. The thermodynamic properties are calculated at reference temperature i.e. at the average temperature values of inlet and outlet on respective warm and cold sides.

By taking logarithm on both sides in the heat transfer correlation equation for forced convection

$$log\left(\frac{Nu}{Pr^{y}}\right) = log(C) + n \; x \; log(Re)$$

The above equation represents a straight line equation in the form of y = mx + C.
Assuming some values for C and n, a graph of log (Nu/Pry) vs log Re is plotted for both warm and cold side test points. Then from the above equation, the Nusselt number values for both warm and cold sides are calculated and hence h1 and h2 i.e. individual heat transfer coefficients of warm and cold sides are calculated using the equation for Nusselt number. Then the Overall heat transfer coefficient is calculated which is designated as CalculatedOHTC.

A parameter known as Margin is calculated as follows
Margin = 1 – (CalculatedOHTC / RequiedOHTC) in %

Then another curve of 'log (Nu/Pry) model' is plotted in the same graph. Log (Nu/Pry) model is calculated as log (Nu/Pry) Test ± Margin value of (log (Nu/Pry) model value obtained for individual test points.

The constants C and n are selected randomly for each iteration until the log (Nu/Pry) model and log (Nu/Pry) test values curves have a good agreement.

The below graph shows the plots for a test data and a model for some correlated C and n constants.

1st Iteration:

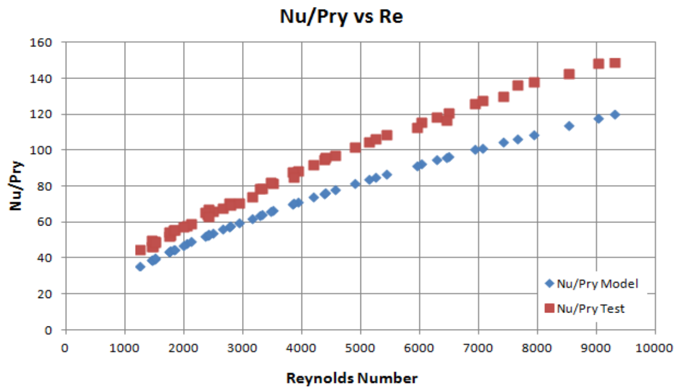

Fig. 7 Nu/Pry vs Re for 1st iteration

The model and test values have no good agreement for the assumed constant values.

2nd Iteration:

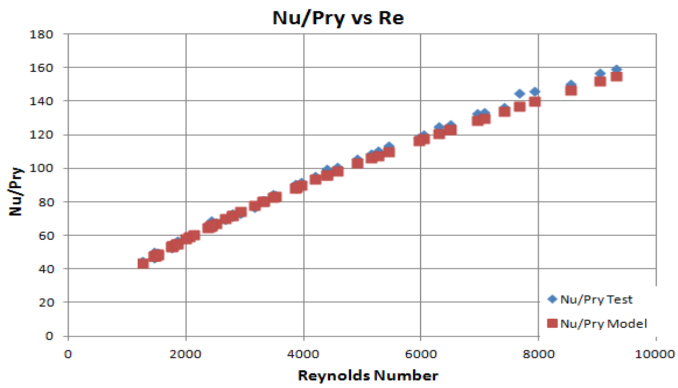

Fig. 8 Nu/Pry vs Re for 2nd iteration

Hence for the above assumed C and n values, there is a good agreement of the test and model values. Hence the assumed constant values are fixed for the particular BPHE model tested for heat transfer performance

PRESSURE DROP EVALUATION: The evaluation involves the pressure drop only that occurs in the channels of the BPHE but not the entire pressure drop.

The pressure drop correlation is as follows

$$Fp = CFp\ x\ Re^{-xFp}$$

By Taking logarithm on both sides and simplifying the above equation to a straight line equation

$$\log(Fp) = \log(cFp) - xFp \cdot \log(Re)$$

A graph of log (Fp) vs log (Re) is plotted by assuming some values for cFp and xFp. This calculated value of Fp is designated as 'Fpmodel'.

The channel pressure drop in a BPHE is calculated using the equation

$$\Delta P_{channel} = \frac{Fp(Re) \cdot 1000}{\rho} \cdot \dot{m}^2$$

ΔP → Pressure drop in channel (Pa)
Fp → frictional pressure drop
ρ → density of fluid (kg/m^3)
$\dot{m}$ →Mass flow rate per channel (kg/sec)

The pressure drops in the channels on warm and cold side are known from the test data for each test point. From the above equation, the Fp for each test point on both sides can be calculated. These values are designated as 'Fptest'. A graph of log (FpTest) vs log (Re) is plotted.

The constants in the pressure drop correlation cFp and xFp are changed by iterative method until there is a good agreement between Fpmodel and Fptest values.

The below graph shows the plots for assumed values of the cFp and xFp constants

1st Iteration:

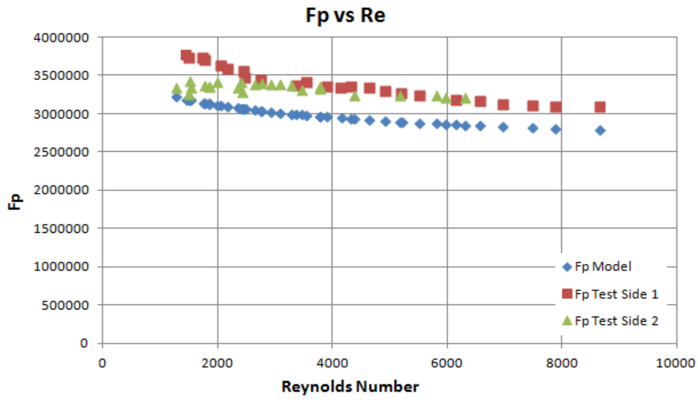

Fig. 9 Fp vs Re for 1st iteration

There is no good agreement of the model and the test values

2nd Iteration:

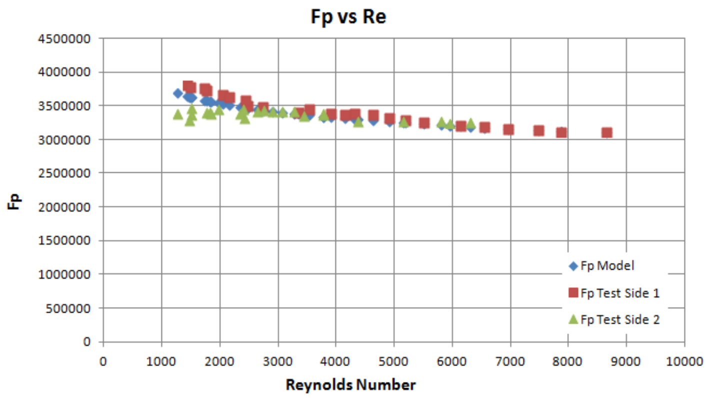

Fig. 10 Fp vs Re for 2nd iteration

There is good agreement of the model and the test values for the assumed constant values

VI. CONCLUSION

The performance evaluation of heat transfer and pressure drop for a heat exchanger is very important and should be done very accurately

1. The heat transfer performance predicted from the above described method has a good agreement with the real test data. The outlet temperatures calculated from this method in comparison to the test provided values have a deviation of lesser than 0.1K on both sides

2. The pressure drop prediction over the channels for different mass flow rates has good accuracy in comparison to the test measured values. The maximum deviation on both warm and cold sides for all test points on an average is ±5%.

REFERENCES

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