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PERFORMANCE ANALYSIS OF SHELL AND TUBE HEAT EXCHANGER WITH DIFFERENT TUBE AND BAFFLE DESIGNS: THREE-DIMENSIONAL COMPUTATIONAL FLUID DYNAMICS (CFD) AND TWO-WAY FSI ANALYSIS

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ABSTRACT

In this study, a three-dimensional numerical analysis has been done to investigate the heat transfer, pressure drop in the shell side and vortex shedding, tubes deformation due to fluid induced vibrations in the shell and tube heat exchanger (STHX). Three-dimensional CFD and two-way FSI has performed with the commercial software ANSYS. To examine the thermo-hydraulic performance and induced vibrations in shell-and-tube heat exchangers with segmental/ helical/ clamping anti-vibration baffles and cylindrical/twisted tubes, numerical simulations are carried out. The numerical models show the thermo-hydraulic performances for the heat exchangers with segmental, helical and novel clamping anti-vibration baffles with cylindrical and square twisted tubes. The result shows that the use of square twisted tubes result in higher heat transfer rate as compared to cylindrical tubes. As far as pressure drop is concerned, it is also greater in the shell and tube heat exchangers with square twisted tubes for segmental, helical and anti-vibration baffles. The deformation in the tubes, velocity of the tubes and vortex shedding formation is minimum in STHX with clamping anti-vibration baffles than in STHXs with helical and segmental baffles.

Keywords: numerical simulation, shell and tube heat exchanger, vortex shedding, fluid induced vibrations, clamping anti-vibration baffles, square twisted tubes

NONMENCLATURE

Abbreviations

STHX	Shell and Tube Heat Exchangers
SGCT	Segmental Baffles with Cylindrical Tubes
SGSTT	Segmental Baffles with Square Twisted Tubes
HBCT	Helical Baffles with Cylindrical Tubes
HBSTT	Helical Baffles with Square Twisted Tubes
CBCT	Clamping anti-vibration Baffles With Cylindrical Tubes
CBSTT	Clamping anti-vibration Baffles with Square Twisted Tubes
WT	With tube-to-baffle-hole clearance
WOT	Without tube-to-baffle-hole clearance

1. INTRODUCTION

Heat exchangers are popular for many applications. Shell and tube heat exchangers are being used extensively as they are diverse, flexible and multipurpose as per [1]. Enriched performance of STHXs being considered to preserve energy [2]. To enhance thermal performance baffles shapes inside STHXs play a vital role, not only that but they also ensure support to the tube bundles [3].

The commonly used baffles are the “segmental baffles”, the circular shape of the baffle with a cut termed ‘baffle cut’ as shown in Figure 1(c). There are some downsides of conventional segmental baffles, pressure drop in all across the shell, fouling resistance, low efficiency in heat transfers for the reason of flow stagnation, operation time of the STHXs reduced due to strong induced vibrations [4].

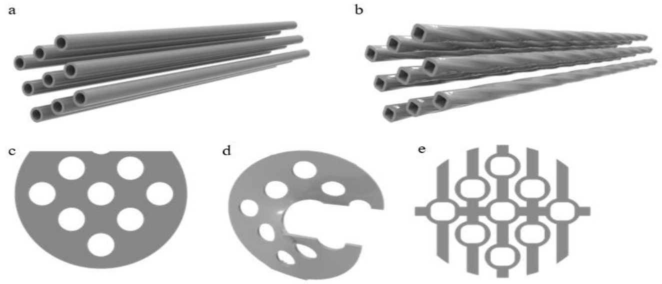

Fig 1 Models of tubes and baffles (a) cylindrical tubes; (b) square twisted tubes; (c) segmented baffle; (d) helical baffle; (e) clamping anti-vibration baffle

Helical baffle as shown in Figure 1(d) causes less shell-side fouling, improved rate in heat transfer/pressure drop ratio in the shell-side, averting flow induced vibrations and less maintenance [5, 6].

An innovative Clamping anti-vibration baffle as shown in Figure 1(e) is used to eradicate flow induced vibrations and helps effectively to eliminate stagnant turbulent fluid flow zones, as fluid flow longitudinally through the gaps in the baffles.

In this study, we will be executing three different kinds of baffle and two different kinds of tubes as shown in Figure 1(a, b) to analyze their effect on the thermo-hydraulic performance of STHX. By using CFD and two-way FSI, heat transfer characteristics and shell side flow induced vibrations have been examined in this paper.

2. GEOMETRIC CONFIGURATION

The shell has an external diameter of 50 mm, a length of 200 mm. More details are listed in Table 1.

Table 1. Structural parameters of the STHXs

Material: stainless steel	Tube number: 9
Tube internal diameter: 4 mm	Number of Baffles: 4
Tube external diameter: 6 mm	Baffle thickness: 1 mm
Tube effective length: 186 mm	Baffle cut: 22%
Shell internal diameter: 44mm	Baffle spacing:35.6mm

3. DOMAIN DETAILS AND BOUNDARY CONDITIONS

Study comprises modeling of six different computational domains and meshes to study each individually. The purpose is thoroughly study and analyze each keeping in mind the two fluid domains (tube and shell side with water) and one solid domain i.e. baffles and tube bundles.

The boundary condition applied for shell and tube sides includes pressure outlet and velocity inlet. The pressure at outlets was set to 0 Pa. All the walls are imagined to be non-slip condition. The shell wall is also assumed to have zero heat flux thermal boundary condition.

4. RESULTS AND DISCUSSIONS

4.1 Model validation

For shell side heat transfer rate previously published results [7] and for pressure drop Esso method [8] were used to validate the numerical model. Average deviation is found to be less than 10%.

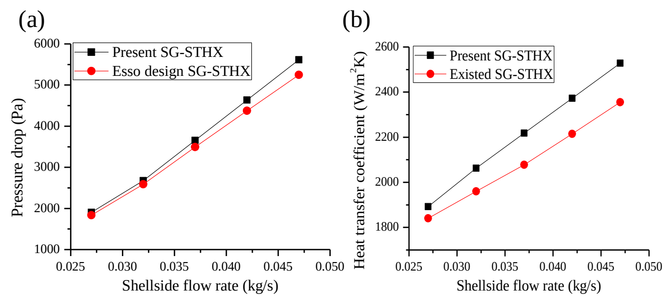

Fig 2 Model validation (a) Pressure drop and Esso design; (b) Heat transfer coefficient and already published work

4.2 Pressure drop

As pumping cost is greatly linked with pressure drop, less pressure drop results in less operating cost. Figure 3(b, d, f) illustrates that recirculation zones with lot of dead zones are formed by square twisted tubes as compared to cylindrical tubes as shown in Figure 3(a, c, e).

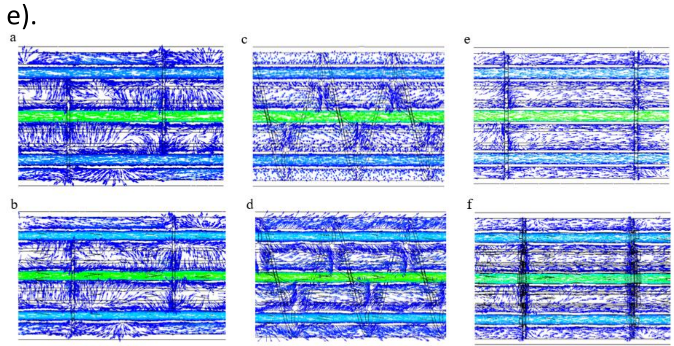

Fig 3 Velocity vectors (a) SGCT-STHX; (b) SGSTT-STHX; (c) HBCT-STHX; (d) HBSTT-STHX; (e) CBCT-STHX; (f) CBSTT-STHX

Fluid recirculation, dead zones and higher maximal velocities are the main causes of increase in pressure drop. It can be observed that the square twisted tubes cause more fluid recirculation, ultimately more pressure drop. Flow circulation is better and dead zones almost eliminate in clamping anti-vibration baffle as shown in Figure 3(e, f).

Figure 4 depicts that the pressure drop go from lowest to highest in the following order: CBCT, CBSTT, HBCT, SGCT, HBSTT and SGSTT.

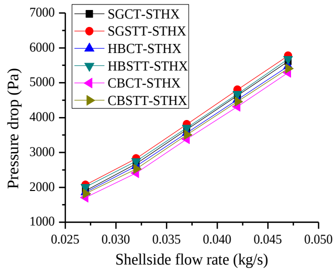

Fig 4 Pressure drop: pressure drop comparison of three STHXs; with cylindrical tubes and with square twisted tubes

Clamping anti-vibration baffles offer less pressure drop, because the flow direction doesn't change fiercely.

4.3 Heat transfer performance

Figure 5 shows the shell-side heat transfer coefficient for six STHXs. STHX with helical baffles has greater heat transfer coefficient.

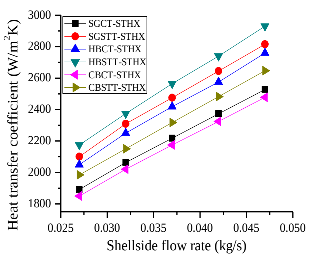

Fig 5 Heat transfer coefficient: heat transfer comparison of three STHXs; with cylindrical tubes and square twisted tubes

It also represents that the STHXs with STT have greater heat transfer capacity as compared to STHXs with CT, heat transfer rate is highest in STHX with HBSTT than other types of STHXs. It is because in the STHX with STT the shell-side fluid and the tube-side fluid has greater contact area for the transference of heat.

4.4 Vortex shedding

Finite element method is used for the tube bundles to determine the natural frequencies and vibration modes of the tubes. Vortex shedding could direct to flow induced vibrations, this may drive to unplanned maintenance and possible performance penalties.

To find the maximum amplitude of the vortex shedding, Fast Fourier Transform (FFT) analysis has been performed by developing MATLAB code. STHXs with SGCT, HBCT and CBSTT have better thermo-hydraulic performances as compared to others. That's why these STHXs have been chosen for further vibration analysis.

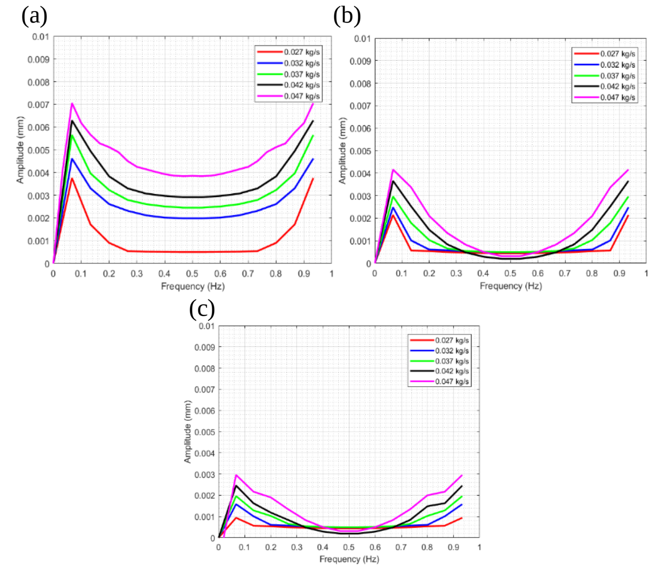

Fig 6 Maximum amplitude of vortex shedding: (a) SGCT-STHX; (b) HBCT-STHX; (c) CBSTT-STHX

STHX with clamping anti-vibration baffles has minimum amplitude of vortex shedding than other two designs as shown in the Figure 6. Because of less vortex shedding, induced vibrations are also less in CBSTT-STHX.

4.5 Total velocity of tubes

Velocity produced in the tubes of heat exchangers due to vortex shedding can be seen in Figure 7. As the vortex shedding is less in the CBSTT-STHX, velocity produce in the tubes of CBSTT-STHX is also less.

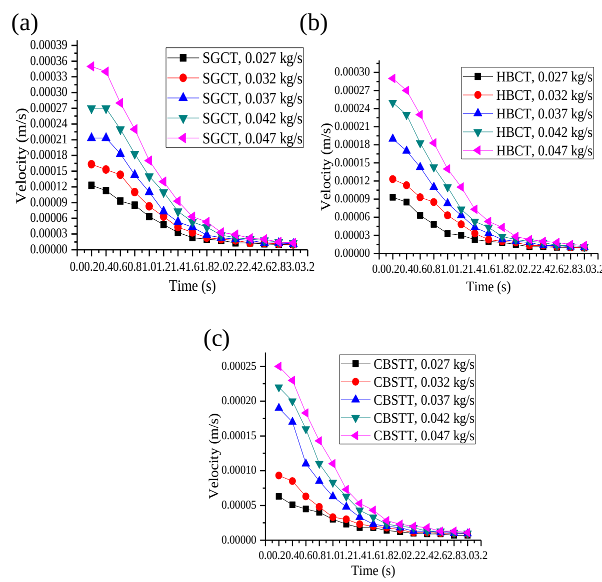

Fig 7 Velocity of tubes: (a) SGCT-STHX; (b) HBCT-STHX; (c) CBSTT-STHX

Figure 7 shows the velocity produced in the tubes of all three STHXs for 3 seconds.

4.6 Maximum Deformation

The maximum tubes deformation in STHXs can be seen in Figure 8, with and without tube-to-baffle-hole clearance. Figure 8(b) displays that STHX with tube-to-baffle-hole clearance has tubes deformation but Figure 8(a) illustrates that there is no deformation if there is no clearance between baffle and tube, as it does not allow the tube to vibrate.

(a) (b)

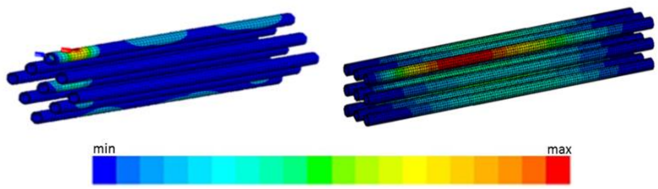

Fig 8 Maximum tubes deformation at 0.027 kg/s: (a) SGCT-STHX (WOC); (b) SGCT-STHX (WC)

Figure 9 displays that tubes deformation is greater in the STHX with traditional segmental baffles than two other heat exchangers.

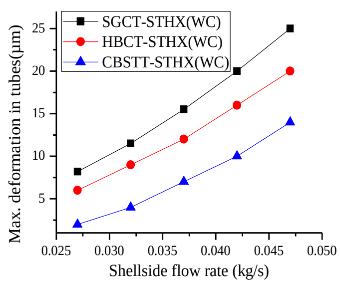

Fig 9 Maximum tubes deformation versus mass flow rate

The main reason of induced vibrations in segmented baffle design is that the total fluid flow passes through the tubes is cross flow, other than bypass streams and leakages.

5. CONCLUSIONS

STHXs are numerically analyzed to check the fluid induced vibrations and thermo-hydraulic performances. The conclusions are summarized as follows:

• Study proves that STHXs with SGCT, HBCT and CBSTT are better than other three STHXs. Because square twisted tubes with segmental and helical baffles cause large pressure drop and cylindrical tubes with clamping anti-vibration baffle cause very less heat transfer rate.

• CBSTT-STHX has less pressure drop than other two heat exchangers and has greater heat transfer rate than SGCT-STHX. It is because of pace with which the fluid flows and it's constant and consistent distribution produces less dead zones and reduces fluid recirculation in the shell-side of CBSTT-STHX.

• In segmented baffles the shell-side fluid crosses the tubes vertically, while in helical and clamping anti-vibration baffles it crosses the tubes at a certain angle relative to the axis. Thus the induced vibrations in SGCT-STHX are higher than the HBCT-STHX and CBSTT-STHX. Fluid flows longitudinally through the gaps in clamping anti-vibration baffles, eliminates dead and recirculation zones. For this reason flow induced vibrations, tubes deformation and vortex shedding are less in CBSTT-STHX than other two heat exchangers.

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