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Numerical and experimental analysis on shell side thermo-hydraulic performance of shell and tube heat exchanger with continuous helical FRP baffles

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A R T I C L E I N F O

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A B S T R A C T

The present work deals with the numerical and experimental investigation of heat and fluid flow in shell and tube heat exchanger with continuous helical baffles on shell side. Seven helix angles, namely 10°, 19°, 21°, 25°, 30°, 38°, and 50° are investigated numerically by modeling a full length continuous helical baffled shell-and-tube heat exchanger for different mass flow rates and inlet temperature conditions. Results revealed that the larger helix angles (30°, 38° and 50°) adds to lower heat transfer and lower pressure drop, and smaller helix angles (10°, 19°and 21°) resulted in higher heat transfer as well as higher pressure drop. The experiments were carried out on shell and tube heat exchanger for helical baffles with 25° helix angle and results were compared with segmental baffles. New baffle material, FRP (Fiber Reinforced Plastic) is introduced on the shell side of the proposed heat exchanger. For material comparison between FRP and stainless steel, the deviation of heat transfer coefficient is 8–10%, which can serve as a potential replacement for conventional baffle material, thereby reducing the capital and operating cost of the tubular heat exchanger.

1. Introduction

Heat exchangers such as shell-and-tube, plate type and finned tube are used in various industries for different applications such as heating, cooling, condensation or evaporation process. Most of the modern day heat exchangers are provided with baffles which help in enhancing the heat transfer. Baffles also helps in providing structural rigidity for tubes and preventing corrosion and acts as guide ways for the flow across bundles of tube to obtain higher heat transfer rate. In the case of segmental baffles the flow along the shell side is very complex due to back mixing, bypass flow and cross flow phenomenon. Also segmental baffles effect in a significant pressure drop transversely to the heat exchanger due to rapid change in direction, expansion, and contraction. To overcome these difficulties of segmental baffle heat exchanger various deflectors, rod baffles, sealing strips are used, however drawbacks of the segmental baffle structure still exist [1–7]. In recent years a novel type of heat exchanger with helical baffles on the shell side is proposed [8,9]. Fig. 1(a–e) shows the various types of helical baffles used by different researchers. Helical baffles provides enhancement in heat transfer as compared to the conventional heat exchangers. Due to the significant advantages of the helical baffles over segmental baffles number of experimental and numerical studies are carried out using helical baffles.

Lutcha and Nemcansky [10] in their investigation on heat and fluid flow in a helical baffle heat exchanger concluded that appropriate selection of baffle inclination angle will result in enhancement of overall temperature by the reduction in back mixing. Kral et al. [11] found the overall performance of the heat exchangers with different helical baffle configurations.

Table 1 shows the research carried out on heat exchangers by varying baffles angles and implementing different baffle styles.

Having realized the advantages of helical baffles, many researchers tried to study the heat exchanger for coming up with an optimum design solution which will give maximum heat transfer coefficient for a unit pressure drop. Basically, researchers tried to analyze the design of the heat exchanger by adopting various approach. Initially after invention of the helical baffle, much of the analysis was carried out experimentally. However experimental analysis was not always a feasible approach as it was rigid, time consuming and costly method. Therefore, there was a need for different approach which led to numerical analysis using CFD software. Since then many researchers tried to analyze the heat and fluid flow in heat exchangers consisting different baffle configuration and arrangements.

Peng et al. [13] using Doppler anemometry determined the flow

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Nomenclature

A	heat transfer area, m^2
A_{min}	minimum transverse area, m^2
B	baffle Pitch of 1 cycle
Cp	specific heat, J/kg K
D	tube diameter, mm
d_{it}	inner diameter of tube, mm
d_{ot}	outer diameter of tube, mm
D_{is}	inner diameter of shell, mm
d_e	characteristics dimension, mm
f	friction factor
F_s, F_t	fouling resistance [m^2K/W]
h	heat transfer coefficient, W/m^2K
j_i	Colburn j-factor for an ideal tube bank
Nu	Nusselt number
P_t	tube pitch, mm
Re_s	shell side Reynolds number
T_{hi}	temperature of hot inlet fluid (°C)
Th_o	temperature of hot outlet fluid (°C)
Tc_i	temperature of cold inlet fluid (°C)
Tc_o	temperature of cold outlet fluid (°C)
U	overall heat transfer coefficient [W/m^2 -K]
V	shell side velocity, m/s

Greek Symbols

β	baffle inclination/helix angle, °
ΔP	pressure drop, Pa
K	thermal conductivity, W/mK
μ	dynamic viscosity, Pa-s
ρ	density, kg/m^3

Subscripts

In	inlet
Max	maximum
Min	minimum
Out	outlet

Abbreviations

HTC	heat transfer coefficient
FCHB	fiber continuous helical baffle
SB	segmental baffle
STHX	shell and tube heat exchanger

field in helical baffle heat exchanger and concluded that heat transfer enhancement depends upon Reynolds number as well as helix angle. Zhang et al. [7] experimentally studied effect of petal shaped helical baffles on pressure drop and heat transfer.

Numerical analysis on the continuous helical baffles in shell-and-tube heat exchanger is carried out by J-F Yang et al. [20] they concluded that CSSP-STHX provides better heat transfer performance. Prithviraj and Andrews [21] computed heat transfer and fluid flow in shell-and-tube heat exchangers using the distributed resistance method. Numerical investigation on shell-and-tube heat exchanger by Lei et al. [3] showed good agreement with experimental results. They used concept on distributed resistance with porous medium. Table 2 gives research carried out on different baffle types numerically.

From literature it is observed that only few investigators have carried out numerical analysis of heat and fluid flow in heat exchanger in shell and tube heat exchanger using full-length model. Also, no major efforts have been carried out to investigate the effect of baffle material on the performance of heat exchanger.

The present study examines the thermo-hydraulic performance of a shell and tube heat exchanger with single helical baffles using numerical and experimental methods for seven different helix angles ranging from 10° to 50°. The comparisons of the performance of seven heat exchangers with diverse baffle inclination angle are presented based on numerical results. Also the effect of baffle material is discussed.

1.1. Fiber reinforced plastic (FRP) baffles

Baffles are used to create the turbulence and hence enhance the heat transfer. In case of the helical baffle heat exchanger, the baffles used are of helicoids type which is three-dimensional geometry which makes its manufacturing a challenging task. FRP is a composite material consisting a polymer (the resin) and a ceramic. In FRP, the strength and stiffness is obtained due to presence of glass fibers while resin matrix provided the compressive strength, impact resistance and corrosive resistance. The manufacturing of the helical baffle with sheet metal (Steel or Aluminum) requires very complex die design. Whereas the manufacturing of the FRP baffle is much simpler and cost-effective with the help of a wooden pattern. The process of fabricating helical baffle using the wooden pattern is comparatively easier and cheaper. With large scale implementation of helical baffle, this process would turn out to be easy and cost effective.

The detail process of manufacturing the FRP Helical Baffle is as follows:

Material used: 20% Glass filled FRP with 5 mm thickness. (Fiber reinforced plastic)

Density of FRP: 1800 kg/m^3

Operating Temp: up to 90 ^{0}C

Step – 1) Creating the CAD model and draft drawing of helical baffle.

Step – 2) Preparation of the wooden pattern from drawing.

Step – 3) Making the mould from wooden pattern.

- Alternate layer Glass wool and adhesive is applied on the wooden pattern till the required thickness is achieved. Then it is kept for soaking for 24 h.
- After complete soaking the mould is removed from the pattern.
- Before applying the glass wool, thin layer of separator solution is applied on the surface of the pattern which does not allows the glass wool to stick to the pattern.
- Again the alternate layers of glass wool and adhesives are applied on the mould till the required thickness is achieved.
- Then it is kept for the soaking and after complete soaking it is removed from the mould.
- Here also before applying the glass wool thin layer of separator solution is applied on the surface of the moulds which does not allows the glass wool to stick to the pattern.
- Here the adhesive used for making the pattern is of very high quality compared to the adhesive used for making the final product.
- Thus the final product i.e. one helical baffle (one cycle) is produced from the mould.
- Depending on length of heat exchanger and pitch of helical baffle, several helical baffles are linked together to form a continuous helical baffles.

With this method, fabrication and mounting of helical baffle (any material) without the central tube is much simpler and cost effective.

Considering all the above facts, an attempt is made to fabricate a helical baffle of FRP material and consequently investigate its performance numerically as well as experimentally.

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