Thermohydraulic Analysis on Shell-And-Tube Helical Baffles Heat Exchanger

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Abstract- *In the paper a 3D numerical arrangement of two genuine shell-and-cylinder heat exchangers, with various kind of astounds, segmental and pseudo-helical, is introduced, using business codes, so as to assess the impact of the bewilders type on heat exchanger execution. The parameters to be assessed, which impact the effectiveness of the warm trade and the support and siphoning costs, are the weight drops, the warmth move coefficient and the fouling opposition. The liquid powerful investigation of the shell-and-cylinder heat exchanger is directed under stationary stream conditions. In the paper, moreover, the consequences of the thermohydraulic examination, performed under stationary stream conditions, increasingly "helical confuses" exchangers, with various puzzles helix point, are introduced. Exchangers with pseudo-helical bewilders slanted by 7°, 20°, 30°and 40°are dissected. The reenactments are done thinking about a genuine liquid, roughly incompressible, under laminar stream conditions..*

Keywords- Heat exchanger, Segmental baffles, Helical baffles, Thermo-hydraulic analysis.

I. INTRODUCTION

The well-mounted tendency to improve and optimize the recovery of warmth, in the course of the layout of latest system, includes steady research for revolutionary technical answers, which make certain higher overall performance with much less warmness trade floor place [1, 2]. Also, there may be situations in which there's a positive predicament on providing more warmth exchanger floor region, in particular within the case of revamping of current system, where the pumping capability and the general dimensions may be already fixed [3].

This layout fashion requires heat exchangers which use as little of the technique stream momentum as viable in drift-thru equipment. Precisely to differ the speed and turbulence at the shell facet and consequently the heat switch coefficient, baffles can be used, if you want to result in the fuid at the shell facet to tour a tortuous route. The baffles have, similarly, an vital mission from the mechanical point of view; they aid, in reality, the tubes of the package, preserving them equally spaced, and preventing the vibrations of the tubes themselves. On the shell facet, the traditional segmental baffle exhibits large strain differences to provide a sufficiently high heat transfer rate, low performance zones, combined glide, pass or recirculated currents. Therefore new sorts of baffles, consisting of helical baffles, were proposed.

A shell-and-tube warmth exchanger with pseudo-helical baffles, commonly called “helical baffles” warmth exchanger, is a possible opportunity to the conventional warmness exchanger with segmental baffles. It succeeds, in truth, in reconciling an increase in gadget overall performance with a rather simple production and installation technology. This sort of baffle is represented by circular region plates positioned sequentially, with each horizontal and vertical attitude, that allows you to impart a helical path to the fluid, at the shell side. “Helical baffles” warmness exchangers are typically used in oil and gas plants and refineries inside the petrochemical and chemical industries [4, 5].

In the paintings, a 3D numerical simulation of a actual warmth exchanger was done, thinking about first the type with segmental baffles and, later, the only with pseudo-helical baffles, through the usage of industrial codes, as a way to evaluate the overall performance of the 2 types taken into consideration. Moreover, the overall performance of “helical baffles” heat exchanger with one of a kind baffles helix attitude have been studied.

CFD simulations results, in the end, were in comparison with those obtained by means of the software of some correlations available inside the literature [6].

II. SHELL AND TUBE HEAT EXCHANGERS

Shell-and-tube warmness exchangers consist of expanded or welded tubes on two tube plates, placed in the shell. In preferred, the baffles are placed in the shell, that's of the perforated plates which have the twin intention of supporting the tubes and of creating the external fluid to the tubes (the shell side) skip a more tortuous course. In this manner, they enhance the velocity, growth the turbulence, and therefore, the warmth transfer coefficient. As already cited, the baffles have, further, an critical task from the mechanical point of view; they guide, in truth, the tubes of the package deal, preserving them similarly spaced, and preventing the vibrations of the identical. The conventional segmental baffle (Figure 1) reveals as an alternative high pressure differences to supply a sufficiently high warmth switch fee, useless zones, combined float, pass or recirculated currents (Figure 2). Therefore new forms of baffles, together with helical baffles, have been proposed.

Helical baffles are pseudo-circular shaped plates established inside the coat sequentially, just so the shell side go with the flow follows a helical direction. Each baffle occupies one quadrant of the go-phase and has a sure inclination with the centerline of the exchanger. Four baffles make one set baffle and the fluid returns to its beginning state of affairs after crossing the set. Helical baffles encompass two most important sorts [7]:non-stop helical baffles that are not generally used because of difficulties in design and production;non-non-stop helical baffles, made of a triangular-fashioned plate with elliptical area base, which also can be designed through subtracting a triangular formed plate from an elliptical plate (Figure 3). These types of baffle are the difficulty of take a look at of the existing work.

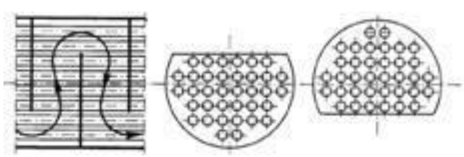

Figure 1. Single-segment baffles

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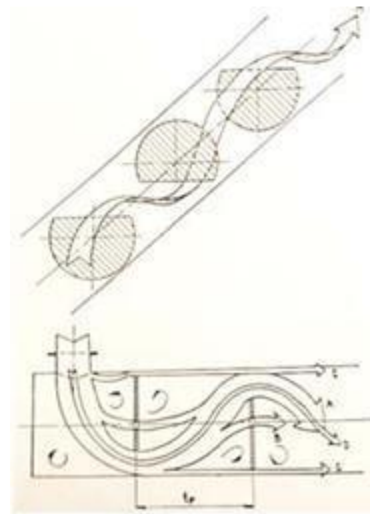

Figure 2. Flow pattern for the segmental baffles arrangement [3]

A accurate association of pseudo-helical baffles in shell and tube heat exchangers appears to offer two blessings. First, because the shell aspect flow sample is similar to the plug flow circumstance, there might be tremendous upgrades of the temperature due to the reduction of back mixing; 2nd, an incidence of the shear speed profile generated via the vortex core growing a vortex which favorably and markedly influences the film warmth switch coefficient.

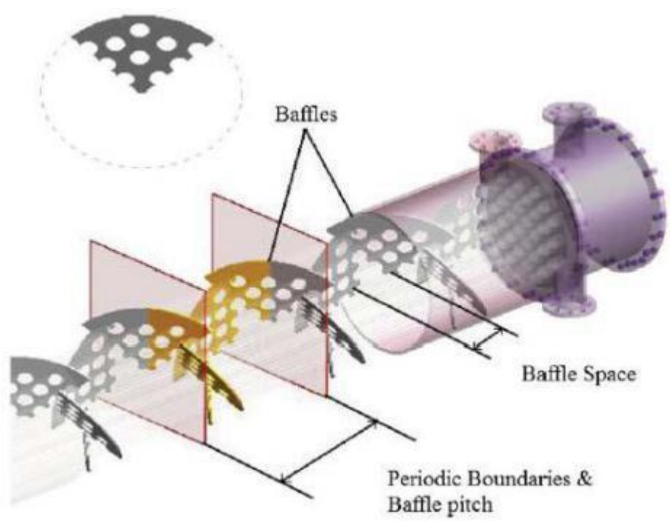

Figure 3. Positions of periodic boundary, baffle pitch and baffle space [8]

Figure four suggests the flow sample for pseudo-helical baffles. In designing shell and tube warmth exchangers with pseudo-helical baffles, pitch perspective, baffle association, and the space between two baffles with the equal function are important parameters. Baffles pitch attitude s is the attitude among float and perpendicular floor on exchanger axis and Hs is area between following baffles with the equal state of affairs (Figure 5).

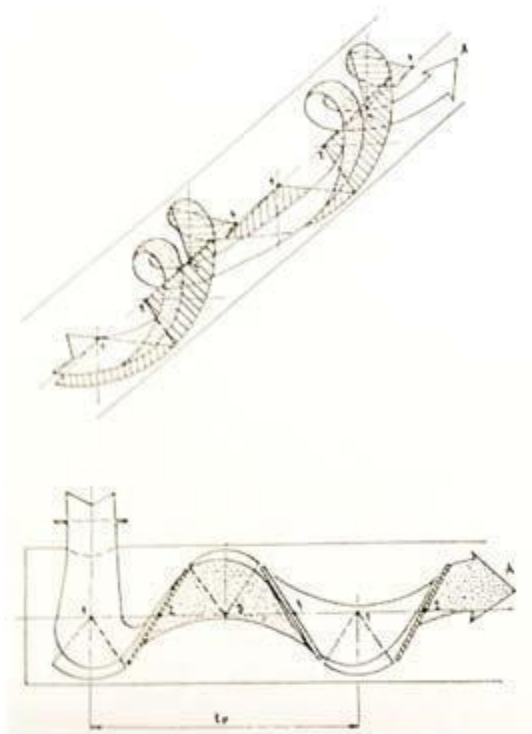

Figure 4. Flow pattern for pseudo-helical baffles [3]

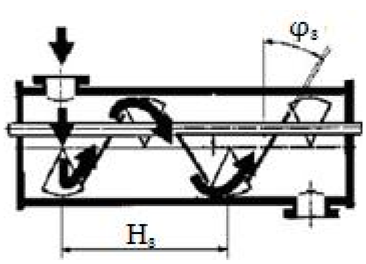

Figure 5. A schematic of heat exchangers with pseudo-helical baffles [9]

III. THERMOHYDRAULIC ANALYSIS

The fluid dynamic have a look at of the shell-and-tube warmth exchangers is carried out, in maximum cases, underneath situations of desk bound glide and, also inside the case of warmth exchangers with non-continuous helical baffles, the same evaluation can be performed.

In the paper a thermohydraulic evaluation changed into performed, executed beneath desk bound waft situations, with extra "helical baffles" exchangers and with unique baffles helix perspective (7°, 20°, 30°and forty°).

The geometric parameters of the analyzed exchangers are given in Table 1.

Table 1. Geometric parameters of the analyzed exchangers

Element	Size and description
Shell side parameters	
D_i [mm]	200
Material	SA 516 Gr.70
Tube parameters	
d_e [mm]	19
Length [mm]	1,092
Number	37
Pitch [mm]	25.4
Material	SA 213 T5
Baffle parameters	
Thickness [mm]	3

It is appropriate that the type of shell-and-tube warmness exchanger with segmental baffles have to provide for a baffle area of no longer much less than 1/5 of the inner diameter of the shell, in keeping with layout practice, as shown in Figure 6. Segmental baffles of the "cut 25 %" type have been considered for the thermal-hydraulic evaluation.

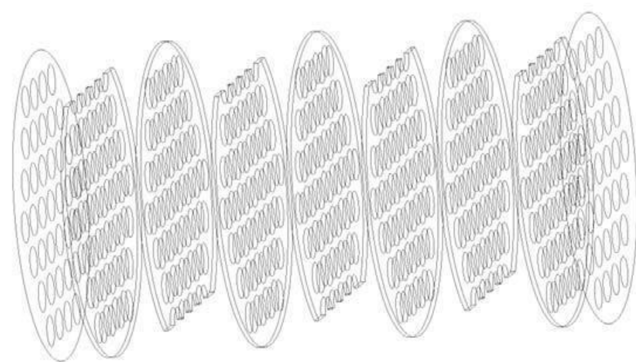

Figure 6. Segmental baffles with pitch greater than 1/5*Di*

By distinctive feature of the period of the tubes used, the analyzed exchangers are made up of seven segmental baffles and of seventy two, 24, 12, 12 pseudo-helical baffles, respectively, for a pitch attitude of 7°, 20°, 30°and forty°.

In Figure 7 and in Figure 8, the geometries, created with the aid of a commercial code, for an exchanger with segmental baffles and for exchangers with pseudo-helical baffles, are proven.

The fluid considered that circulates on the shell facet is Crude Oil, whose thermophysical houses are proven in Table 2.

A fluid flow charge of 50 kg/s become used.

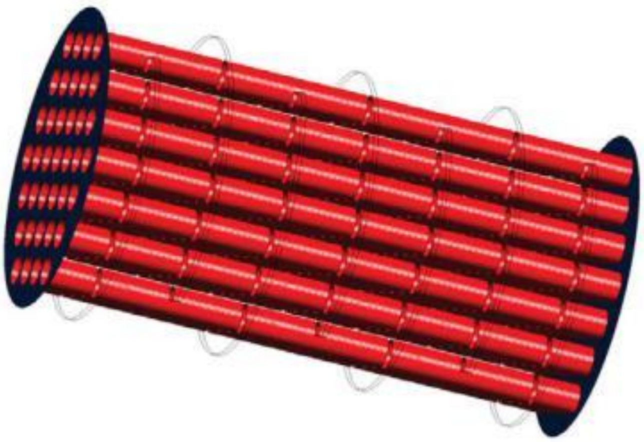

Figure 7. Heat exchanger with segmental baffles

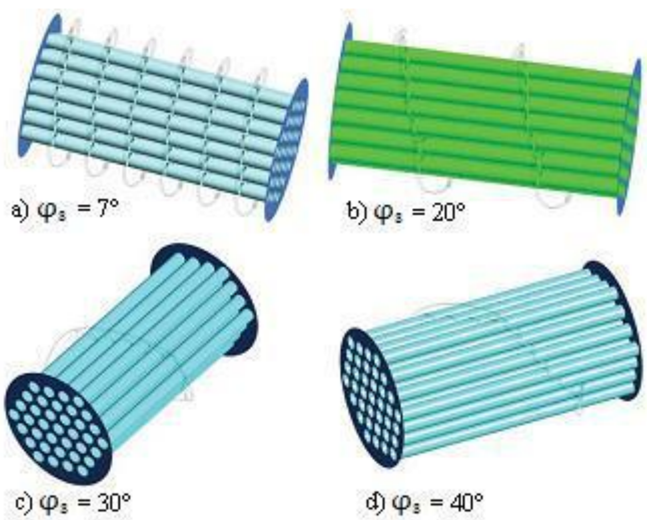

Figure 8. Heat exchanger with pseudo-helical baffles

Table 2. Thermophysical properties *of Crude Oil*

Properties	T=82°C	T=135°C
Density ρ [kg.m-3]	917	887
Specific heat c_p [J.kg-1.K-1]	2,050	2,260
Thermal conductivity k [W.m-1.K-1]	0.098	0.092
Viscosity μ [kg.m-1.s-1]	0.0393	0.00693

The simulations, accomplished using the 3-d double precision FLUENT code, had been completed considering a real fluid, about incompressible, below laminar waft situations. The gadget, due to the complicated geometry, gives the areas that could be involved in recirculation, especially in proximity to the baffles. Considering what has been said, it is natural to apply the stress-based solver, which determines the velocity area from the sphere of stress with the verification at the stress manipulate equation (continuity equation). In the calculation, the resolution of the strength equation is activated, considering the fact that it's miles a warmth switch hassle.

The running stress, within the case of incompressible glide, does not count on a good sized position, consequently, isn't used by software program inside the calculation of the density seeing that that is considered consistent.

To make a honest assessment the identical boundary situations have been laid, for all simulations: mass drift inlet for inlet section, outflow for outlet segment, wall for baffles and tube package deal. SIMPLE set of rules [10] is used and beneath-relaxation elements set were the following: strain zero.Three, density 1, frame 1, momentum The algorithm for the decision of the strain is Standard. The discretization of the momentum and power equations is occurred using a UpWind scheme of first order.

The simulations have been executed on grids described mesh impartial, or with a grid with an error less than five %, with respect to a grid with fewer elements. The mistakes among one of a kind grids is decided by using root imply squared blunders (RMSE), described via Eq.(1):

$$RMSE = \frac{1}{N} \times \sum_{i=1}^{N} \left(x_i - \hat{x}_i\right)^2$$

In which xi constitute the engineering significance of interest; inside the gift case, being additionally interested by the calculation of the strain drops, the pressure is the value of which the mesh independence may be achieved. RMSE has the same unit of degree of the value engineering taken as a reference, for which, in order that it can be calculated the share errors, beneficial to have at once an order of importance for the quantification of the error, it's far essential with a normalization appreciate to reference value. The software of this means that the vectors to be in comparison are of identical size. Since the grids of the unique variety of factors it has end up vital to the execution of an interpolation points the usage of the features of Matlab.

3.1 Grids generation

Grids technology became executed by the industrial code GAMBIT. On each grid the mesh independence was tested, and on every mesh independent the exceptional manage became executed. Particular importance of first-class control of the mesh have Aspect Ratio, which quantifies the deviation of an detail from the equilateral form, and Equiangle Skew, which offers a measure of the distortion of the detail [11, 12, 13].

In Table 3, depending on the form of warmness exchanger analyzed, the cells number constituting the grids for the mesh independence is mentioned. The following notation is used: S to indicate the warmth exchangers with segmental baffles and P.E to indicate the heat exchangers with pseudo-helical baffles.

In Table 4, relying at the type of warmth exchanger analyzed, the values of Aspect Ratio, Equiangle Skew and RMSE are proven. For the acquired outcomes, the grids can be defined as true

Table 3. Cells number constituting the grids for the mesh independence

Typology	Cells
S	2,356,000
P.E $\varphi_s = 7°$	2,431,400
P.E $\varphi_s = 20°$	958,984
P.E $\varphi_s = 30°$	1,959,980
P.E $\varphi_s = 40°$	2,345,000

Table 4. Values of Aspect Ratio, Equiangle Skew and RMSE

Typology	Aspect Ratio	Equiangle Skew	RMSE
S	< 4	< 0.85	2.10 %
P.E $\varphi_s = 7°$	< 20	< 0.85	3.00 %
P.E $\varphi_s = 20°$	< 4	< 0.85	4.50 %
P.E $\varphi_s = 30°$	< 4	< 0.85	2.50 %
P.E $\varphi_s = 40°$	< 4	< 0.85	2.35 %

3.2 Thermo-hydraulic results

The essential parameters to be decided are the movie warmness transfer coefficient and the pressure drop of the heat exchanger analyzed. For a more deepening of the fluid dynamic aspect, an analysis of the shell aspect pace profiles changed into additionally achieved, to have a further index of assessment

The movie heat switch coefficient h shell side is of fundamental importance for thermo-hydraulic evaluation of shell-and-tube warmth exchanger since it is the first-class index of the change itself. The code FLUENT lets in its evaluation through a surface integrals on area-weighted average; the values received for the heat exchangers analyzed are proven in Table 5.

Table 5. Heat transfer coefficient for the different studied exchangers

Typology	h [$W \cdot m^{-2} \cdot K^{-1}$]
Heat exchanger with segmental baffles	150.19
Heat exchanger with pseudo-helical baffles $\varphi_s = 7°$	156.09
Heat exchanger with pseudo-helical baffles $\varphi_s = 20°$	157.14
Heat exchanger with pseudo-helical baffles $\varphi_s = 30°$	162.79
Heat exchanger with pseudo-helical baffles $\varphi_s = 40°$	163.87

From Table five it is able to be determined that there may be an boom of the film warmth switch coefficient converting from a warmness exchanger with segmental baffles to one with pseudo-helical baffles. These increases, in percent phrases, as compared to the values acquired from a warmness exchanger with segmental baffles, are offered in Table 6

Table 6. Increases of coefficient h at variation of the baffles helix angle

φ_s	Increase
S	-
7°	3.93 %
20°	4.63 %
30°	8.39 %
40°	9.11 %

The heat exchanger type “helical baffles”, compared to the sort with segmental baffles, presents greater warmness exchange efficiency with an boom ranging among 4 and 9 %. Moreover, on the subject of Table 5, it is observed that the values of the movie heat transfer coefficient will increase with the angle of inclination of the baffles. Table 7 shows in percent terms, increases in coefficient h obtained from the assessment of different configurations with the one having a helix angle of 7 tiers.

For a entire analysis, the most fulfilling perspective of inclination for pseudo-helical baffles was estimated. Simulating a shell-and-tube “helical baffles” warmth exchanger with helix attitude of forty five°, in line with the formerly described geometric parameters, it denotes a reduction of nineteen % of the film warmness switch coefficient h as compared to the type with helix perspective of forty°. Therefore, increasing the perspective of inclination of the “helical baffles” increases the film heat transfer coefficient; this effect, however, for a helix angle greater than 40°is no longer valid.

Table 7. Increases of the coefficient h to vary the baffles helix angle

φ_s	Increase
7°	-
20°	0.67 %
30°	4.29 %
40°	4.98 %

Figure 14. Fluid course through shell facet

The fluid, in "helical baffles" warmth exchangers, follows a helical path, lots softer than that during a zigzag configuration, function of the traditional heat exchangers. Consequently to this, in the latter, there are significant recirculation phenomena related to a separation and a blending of the fluid after the passage of the baffle. A extra uniform path of the fluid also results in a less sedimentation of the stable debris and, consequently, in much less fouling in the heat exchanger [14].

Table 8 shows, furthermore, that the pressure drops of a shell-and-tube "helical baffles" warmth exchanger with helix attitude of seven°are more than orders of magnitude more as compared to that with a helix perspective of 20°. This is due to the growth of the passage location (Figure 15) because of the increase of the attitude of inclination of the "helical baffles" that creates a greater uniform route to the fluid.

IV. COMPARISON WITH EMPIRICAL CORRELATIONS

The results received from a CFD evaluation of the heat exchangers with pseudo-helical baffles had been as compared with the ones obtained from empirical correlations available in the literature. In specific, the Stehlik et al. Correlations [6] have been taken into account for a contrast of the heat switch coefficient (Table nine, Figure 21) and at the pressure drops (Table 10, Figure 22).

In the same tables also are given the differences between the 2 answers acquired

The results obtained from a CFD analysis of the heat exchangers with pseudo-helical baffles were compared with those obtained from empirical correlations available in the literature. In particular, the Stehlik et al. correlations [6] were taken into account for a comparison of the heat transfer coefficient (Table 9, Figure 21) and on the pressure drops (Table 10, Figure 22).

In the same tables are also given the differences between the two solutions obtained.

Table 9. Comparison between coefficient h obtained by CFD analysis and Stehlik et al. correlation

φ_s	h [$W \cdot m^{-2} \cdot K^{-1}$] CFD analysis	h [$W \cdot m^{-2} \cdot K^{-1}$] Stehlik correlation	Difference [%]
7°	156.09	151.29	3.17
20°	157.14	152.41	3.10
30°	162.79	156.98	3.70
40°	163.87	158.68	3.27

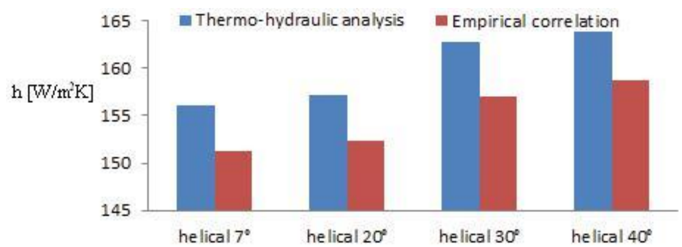

Figure 21. Comparison of coefficient h obtained by CFD analysis to the Stehlik et al. correlation

Table 10. Comparison of *P* values obtained by CFD analysis to the Stehlik et al. correlation

s	P [kPa] CFD analysis	P [kPa] Stehlik correlation	Difference [%]
7°	126.43	115.6	9.37
20°	14.41	13.5	6.74
30°	5.4	5.1	5.88
40°	4.32	4.15	4.10

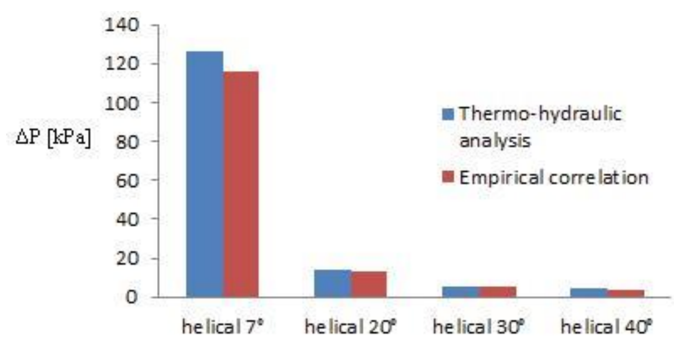

Figure 22. Comparison of *P* values obtained by CFD

analysis to the Stehlik et al. correlation

V. CONCLUSIONS

In the paper a 3D numerical solution of two real shell-and-tube warmness exchangers, with exceptional kind of baffles, segmental and pseudo-helical, has been provided, via using industrial codes, so one can compare the overall performance of the two types considered.

The thermal-hydraulic evaluation, finished under stationary drift situations, turned into carried out for numerous “helical baffles” exchangers, with specific baffles helix perspective. Exchangers with pseudo-helical baffles inclined by means of 7°, 20°, 30°and forty° have been analyzed. The simulations had been completed thinking about a actual fluid, approximately incompressible, below laminar glide situations.

CFD evaluation denotes that the usage of a “helical baffles” warmth exchanger, compared to a traditional exchanger (with segmental baffles), involves: an development of the efficiency of heat exchange, through distinctive feature of the boom within the movie heat switch coefficient (among four % and 9 %); decrease pumping charges, due to the discount of strain drops (among sixty four % and 99 %); lower maintenance fees, consequent to a decrease formation of fouling.

These consequences are tons extra obvious at more inclination of the angle of the baffle. It isn't encouraged, however, to have angles of inclination extra than 40°, on the grounds that for better angles there could be a lower of the heat transfer coefficient h. The use of a “helical baffles” heat exchanger with inclination perspective much less than 7°isn't always advocated either, because the strain drops could be too high. The choicest baffles helix perspective is forty°, despite the fact that marked blessings are already obtained at an attitude of 30°.

Finally, for the exchangers with specific attitude of inclination, a evaluation of the film warmness switch coefficient and the stress drops, with the correlations of Stehlik et al.[6]was performed. These correlations, in comparison to the results furnished by the CFD evaluation, present a deviation variable from three.10 % to 3.70 % at the film heat switch coefficient, and variable between 4.10 % and 9.37 % on strain drops.

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NOMENCLATURE

c_p	specific heat, J. kg-1. K-1
D_i	internal diameter of the shell, mm
d_o	external diameter of the tubes, mm
H_s	space between baffles with the same situation, mm
h	film heat transfer coefficient, W. m-2. K-1
k	fluid thermal conductivity, W. m-1. K-1
N	elements number of the mesh
P_{ing}	pressure in the inlet section, kPa
P_{out}	pressure in the output section, kPa
RMSE	root mean squared error
x_i	engineering magnitude of interest, kPa
$\hat{x}_i$	engineering magnitude of reference, kPa

Greek symbols

ΔP	pressure drops, kPa
μ	dynamic viscosity, kg. m-1.s-1
j_s	angle of inclination of the baffles, grad.
ρ	fluid density, kg. m-3