Performance Improvement in Single phase Tubular Heat Exchanger using continuous Helical Baffles

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ABSTRACT

Heat exchangers are important heat & mass exchange apparatus in oil refining, chemical engineering, environmental protection, electric power generation, etc. Among different types of heat exchangers, shell-&-tube heat exchangers (STHXs) have been commonly used in industries. About 35–40% of heat exchangers are of the STHXs, & this is primarily due to the robust construction geometry as well as easy maintenance & possible upgrades of STHXs. Segmental baffles are most commonly used in conventional STHXs to support tubes & change fluid flow direction. But, conventional heat exchangers with segmental baffles in shell-side have some shortcomings resulting in the relatively low conversion of pressure drop into a useful heat transfer.
The Helixchanger - a heat exchanger with shell side helical flow eliminates principle shortcomings caused by shell side zigzag flow induced by conventional baffle arrangements.

Both hydrodynamic studies & testing of heat transfer & the pressure drop on research facilities & industrial equipment showed much better performance of helically baffled heat exchanger when compared with conventional ones. The new design reduces dead zones within the shell space. These results in relatively high (Heat transfer co-efficient/Pressure drop) & low shell side fouling.

Thus, the helixchanger exhibits much more effective way of converting pressure drop into a useful heat transfer than conventional heat transfer. This project is basically gives the performance of shell & tube heat exchangers with helical baffles.

*Keywords:***Heat transfer coefficient, helical baffle, helix angle, pressure drop, shell & tube heat exchanger**

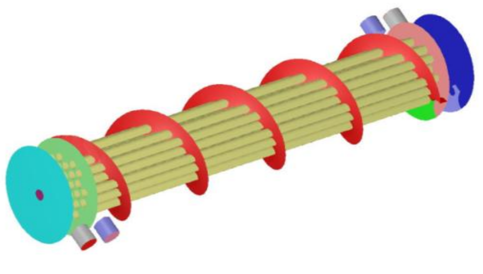
1. INTRODUCTION

Shell & tube heat exchangers (STHXs) are widely used in many industrial areas, such as power plant, chemical engineering, petroleum refining, food processing, etc. According to B.I. Master et al. [5], more than 35-40 % of heat exchangers are of the shell & tube type due to their robust geometry construction, easy maintenance & possible upgrades. Rugged safe construction, availability in a wide range of materials, mechanical reliability in service, availability of st&ards for specifications & designs, long collective operating experience & familiarity with the designs are some of the reasons for its wide usage in industry.

Baffle is an important shell side component of STHXs. Besides supporting the tube bundles, the baffles form flow passages for the shell side fluid in conjunction with the shell. The most commonly used baffles is the segmental baffle, which forces the fluid in a zigzag manner, thus improving the heat transfer but with a large pressure drop penalty. This type of heat exchanger has been well developed [2-5] & probably is still the most commonly used type of the shell & tube heat exchanger. The major draw backs of the conventional shell & tube heat exchangers with segmental baffles are threefold: firstly it causes a large side pressure drop; secondly it results in a dead zone in each component between 2 adjacent segmental baffles, leading to an increase of fouling resistance; thirdly the dramatic zigzag flow pattern also causes high risk of vibration failure on tube bundle. To overcome the above mentioned drawbacks of the conventional segmental baffle, a number of improved structures were proposed for the purposes of higher heat transfer coefficient, low possibility of tube vibration & reduced fouling factor with a mild increase in pumping power [5-10].However, the principal shortcomings of the conventional segmental baffle still remain in the above-mentioned studies, even though the pressure drop across the heat exchanger has been reduced to some extent. A new type of baffle, called helical baffle, provides further improvement. This type of baffle was first proposed by D. Kral&Nemcansky [12], where they investigated the flow field patterns produced by such helical baffle geometry with different helix angles. They found that these flow patterns were much close to plug flow conditions, which was expected to reduce shell side pressure drop & to improve heat transfer performance. PetrStehlik et al. [9] compared heat transfer & pressure drop correction factors for a heat exchanger with an optimized segmental baffle based on the Bell Delaware method [2-4] with those for a heat exchanger with helical baffles. D. Kral et al. [12] discussed the performance of heat exchangers with helical baffles based on test results of various baffles geometries. A comparison between the test data of shell side heat transfer coefficient vs. shell side pressure drop was provided for five helical baffles & one segmental baffle measured from a water-water heat exchanger. The case of 40° helix angle behaved the best. For the convenience of manufacturing, up to now all helical baffle used in STHXs are of non-continuous type made up of four elliptical sector-shaped plates joined end to end. In this type, the triangular zone between sectors shaped plates resulted in high degree of back mixing. Therefore it is essential to develop a new type of STHXs using continuous type of baffle, which can have the following attributes:

- Improvement of shell side heat transfer.
- Less pressure drop for a given mass flow rate.
- Reducing of bypass effects in shell side.
- Decreasing of fouling in shell side.
- Prevention of bundle vibration.

2. Helical Baffle Heat Exchanger



The concept of helical baffle heat exchangers was developed for the first time in Czechoslovakia. The Helical baffle heat exchanger, also known as Helixchanger, is a superior shell-and-tube exchanger solution that removes many of the inherent deficiencies of conventional segmental-baffle exchangers. Helical baffle heat exchangers have shown very effective performance especially for the cases in which the heat transfer coefficient in shell side is controlled or less pressure drop and less fouling are expected. It can also be very effective, where heat exchangers are predicted to be faced with vibration condition. Quadrant shaped baffle segments are arranged at an angle to the tube axis in a sequential pattern that guide the shell side fluid to flow in a helical path over the tube bundle. Helical flow path of the shell-side fluid can also be achieved by a continuous helix shaped baffle running throughout the length of the shell and tube heat exchanger.

The helical flow provides the necessary characteristics to reduce flow dispersion and generate near plug flow conditions. It also ensures a certain amount of cross flow to the tubes to provide high heat transfer coefficient. The shell-side flow configuration offers a very high conversion of pressure drop to heat transfer.

The Helixchanger design provides:-
1. Enhanced Heat transfer performance/ Shell-side pressure drop ratio.
2. Reduced fouling characteristics.
3. Effective protection from flow-induced tube vibrations.
4. Lower capital costs, reduced operating costs, lower maintenance costs and consequently, significant lower total life cycle costs.
5. For existing plants, the Helixchanger design helps to increase the capacity while lowering maintenance cost, plot space and energy costs.

It is better to consider the Helixchanger option when investigating the following:-
a) Plant upgrade with replacement tube bundles.
b) Capacity expansion with limited plot space.
c) Reduction of fouling problems and frequent downtime.

The performance of helixchanger depends on helix angle which determines pressure drop on shell side, i.e. pumping power required. The heat transfer per unit pressure drop is a good metric for comparing the performance. We know that heat exchangers are widely used equipments in various mechanical, chemical, power generation and refrigeration industry. The present well established process design trend requiring high degree of heat recovery usually results in installing a larger heat exchanger area. However adding a few more heat exchangers causes an increase in pressure loss together with a greater pumping power requirement.

On the shell side the conventional segmental baffles exhibit rather high-pressure difference to produce sufficiently high heat transfer rate. Therefore fresh look into the baffle arrangement is needed. So, use of helical shaped baffles is proposed.

The fluid flow pattern, particularly within the shell, may significantly influence the heat exchanger efficiency. The development of shell and tube exchanger focuses on better conversion of pressure drop into heat transfer by improving the conventional baffle design.

2.1Advantages of Helixchanger

1. Thermal & Hydraulic Performance

Elimination of the shell-side back and forth flow path with a more unidirectional flow yields a much higher heat transfer coefficient per unit of pressure drop. Typically, heat transfer coefficients are 40% higher for the same pressure drop or, conversely, pressure drops are halved for the same heat transfer coefficient. Moreover, the tube-side swirl induced flow enhances the coefficients by an amount similar to that of twisted tape or tabulator inserts in a plain round tube. The overall effect of this is a substantial reduction of heat transfer area for a twisted tube exchanger compared with a conventional exchanger for the same duty. Alternatively, significant improvements in the performance of an existing exchanger can be achieved by replacing a conventional bundle with a Twisted Tube bundle.

2. High Thermal Effectiveness

The closer approach to pure plug flow on the shell-side means that designs achieving higher thermal effectiveness, more typical of plate type exchangers, are possible with Twisted Tube exchangers

3. Lower Fouling & Cleaning ability

The elimination of dead spots on the shell-side and the increased turbulence, both on the shell-side and the tube-side results in reduced fouling. Particulate fouling is reduced by the scouring action. Other types of fouling such as scaling and chemical reaction products are prevented by the removal of hot spots. Fouling characteristics are therefore, more typical of those found in plate exchangers rather than shell and tube type exchangers. The lower shell side pressure drop for a given flow means that higher velocities are possible, thereby reducing clogging and plugging with fibrous materials. Should fouling occur, the twist alignment in the twisted tube exchanger provides cleaning lanes even though the bundle is constructed using triangular pitch tube layout. Hence, the cleaning ability of a conventional square pitch layout is combined with heat transfer area density of a triangular layout.

4. Vibration Elimination

Flow induced vibration can occur in conventional exchangers although special precautions such as "no tubes in window" are available to overcome the problem by providing more tube support. The most damaging vibration arises from fluid-elastic instability that can lead to damage within a few hours of operation. The possibility of such vibration in twisted tube exchangers is completely eliminated by axial flow and because the tubes are supported approximately every two inches along the tube length. Clearly, there is some cross-flow at the inlet and outlet regions but good tube support effectively mitigates this potential for failure. Further, the cleaning lanes provide additional smooth paths with a flow entering and exiting the bundle.

5. Cost Saving on Total Life Cycle Basis

Surface savings, lower fouling and consequently higher service life of tube bundles. Lower shell side pressure drop saves operating costs when using the Helixchanger designs. Longer run lengths with helical baffles translates into lower maintenance costs and longer operating life of tube bundles saves the disposal costs during the life span of the heat exchanger units. As a result, in new installations, the Helixchanger option significantly lowers the Total Life Cycle Costs of the heat exchanger banks.

6. Improving Plant Run Length

Helixchanger heat exchanger with its low fouling characteristics offers much longer run length as compared to a conventionally baffled heat exchanger in identical service. The drop in performance over an operating cycle is much slower in services.

3. Numerical Studies of Helixchanger&Segmental Baffle Heat Exchanger

Now days, computerized analysis methods are used all over Industries, Research Fields and Educational purposes. There are lots of solutions for a single problem and for selecting optimum solution lots of testing is done. So for analyzing them all lot of time energy and money required plus disposal or reuse of non-required specimen is again became issue. To overcome these all problems computerized methods are used.

In field of Fluid Flow and Heat Transfer analysis Mesh HTRI software is used. There application is becoming wide, because HTRI can be used to improve understanding of test field, Evaluate new technology performance, provide conceptual designs, Identify potential operational problems and Guide experiments. Also HTRI is more cost-effective than physical testing; HTRI provides more complete information than experimental testing; HTRI does NOT make decisions for engineers, but help them be more informed.

HTRI ***Xchanger Suite***, the most advanced tool for the design, rating, and simulation of heat exchangers, brings our rigorous research to end users in an integrated graphical environment. With the addition of our latest component—***Xspe***—HTRI's premier technology and expertise are available in a full complement of products for all your engineering needs.

From the experimental Set up accordingly we have decided the geometrical parameters of helixchanger& segmental baffled heat exchanger & did the thermal analysis in HTRI.

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Final Results Page 1

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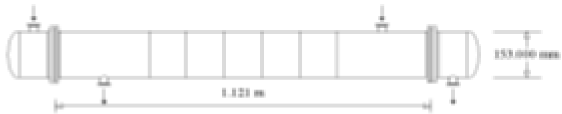
Simulation - Horizontal Countercurrent Flow TEMA BEM Shell With Single helix Baffles

Process Data		Cold Shellside		Hot Tubeside	
Fluid name		WATER		WATER	
Fluid condition			Sens. Liquid		Sens. Liquid
Total flow rate	(kg/s)		0.6660		0.1660
Weight fraction vapor, In/Out	(--)	0.000	0.000	0.000	0.000
Temperature, In/Out	(Deg C)	34.30	35.42	62.60	58.10
Temperature, Average/Skin	(Deg C)	34.9	37.67	60.4	55.19
Wall temperature, Min/Max	(Deg C)	42.38	44.80	42.46	44.90
Pressure, In/Average	(kPa)	0.000	0.000	0.000	0.000
Pressure drop, Total/Allowed	(kPa)	1.743		0.118	
Velocity, Mid/Max allow	(m/s)	4.537e-2		9.521e-2	
Mole fraction inert	(--)				
Average film coef.	(W/m2-K)		1045.16		779.13
Heat transfer safety factor	(--)		1.000		1.000
Fouling resistance	(m2-K/W)		0.001999		0.002998

Overall Performance Data

Overall coef., Reqd/Clean/Actual	(W/m2-K)	117.51 /	375.07 /	116.36
Heat duty, Calculated/Specified	(MegaWatts)	0.0031 /		
Effective overall temperature difference	(Deg C)	25.5		
EMTD = (MTD) * (DELTA) * (F/G/H)	(Deg C)	25.46 *	1.0000 *	1.0000

See Runtime Messages Report for warnings.



Exchanger Fluid Volumes

Approximate shellside	(L)	16.7
Approximate tubeside	(L)	12.0

Shell Construction Information

TEMA shell type	BEM		Shell ID	(mm)	153.000
Shells Series	1 Parallel	1	Total area	(m2)	1.073
Passes Shell	1 Tube	1	Eff. area	(m2/shell)	1.044
Shell orientation angle (deg)	0.00				
Impingement present	No				
Pairs seal strips	1		Passlane seal rods (mm)	0.000	No. 0
Shell expansion joint	No		Rear head support plate	No	
Weight estimation Wet/Dry/Bundle		156.76 /	128.10 /	17.21	(kg/shell)

Baffle Information

Type		Single helix	Helix angle	(deg)
Helical baffle sets		7	Baffle crossing fraction	
Central spacing	(mm)	112.000		
Inlet spacing	(mm)	265.194		
Outlet spacing	(mm)	265.194		
Baffle thickness	(mm)	0.000		

Tube Information

Tube type		Plain	Tubecount per shell	
Overall length	(m)	1.121	Pct tubes removed (both)	
Effective length	(m)	1.090	Outside diameter	(mm)
Total tubesheet	(mm)	30.600	Wall thickness	(mm)
Area ratio	(out/in)	1.3093	Pitch (mm) 22.5000	Ratio
Tube metal		Carbon steel	Tube pattern (deg)	

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Final Results Page 2

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Simulation - Horizontal Countercurrent Flow TEMA BEM Shell With Single helix Baffles

Shellside Performance

Nom vel, X-flow/window 8.561e-2 / 0.21

Pressure Drops (Percent of Total)

	Cross	Window	Ends	Nozzle	Shell	Tube
				Inlet	49.93	42.25
MOMENTUM			0.00	Outlet	49.92	26.82

Two-Phase Parameters

Method	Inlet	Center	Outlet	Mix F

H. T. Parameters		**Shell**	**Tube**
Overall wall correction		1.006	1.000
Midpoint	Prandtl no.	4.85	2.98
Midpoint	Reynolds no.	3554	1956
Bundle inlet	Reynolds no.	1463	2011
Bundle outlet	Reynolds no.	1489	1910
Fouling layer	(mm)		

Thermal Resistance

Shell	Tube	Fouling	Metal	**Over Des**
11.13	19.51	69.02	0.338	-0.98
Total fouling resistance				0.00593
Differential resistance				-8.41E-05

Shell Nozzles				**Liquid**
Inlet at channel end-No		**Inlet**	**Outlet**	**Outlet**
Number at each position		1	1	0
Diameter	(mm)	26.645	26.645	
Velocity	(m/s)	1.20	1.20	
Pressure drop	(kPa)	0.870	0.870	
Height under nozzle	(mm)	13.900	13.900	
Nozzle R-V-SQ	(kg/m-s2)	1434.89	1435.45	
Shell ent.	(kg/m-s2)	242.30	242.39	

		Inlet	**Outlet**
Tube Nozzle		RADIAL	RADIAL
Diameter	(mm)	26.645	26.645
Velocity	(m/s)	0.30	0.30
Pressure drop	(kPa)	0.050	0.032
Nozzle R-V-SQ	(kg/m-s2)	90.27	90.06

Annular Distributor		**Inlet**	**Outlet**
Length	(mm)		
Height	(mm)		
Slot area	(mm2)		

Diametral Clearances (mm)

Baffle-to-shell	Bundle-to-shell	Tube-to-baffle
3.1750	19.1335	0.7938

3.1Experimental Studies:

An experimental is designed and developed to carry out the proposed investigation on heat exchangers to determine overall heat transfer coefficient and shell side pressure drop respectively. The test setup is basically a shell and tube heat exchanger added with suitable calibrated instrumentation for measurement of flow rates, temperature and pressure drop.

The experimental setup is provided with hot 3 Electric Heaters of 2 KW capacity and two separate water supply connections with each having valves to regulate the flow rate of both shell side and tube side fluids.

The two similar heat exchangers-

1) With segmental baffles

2) With helical baffles

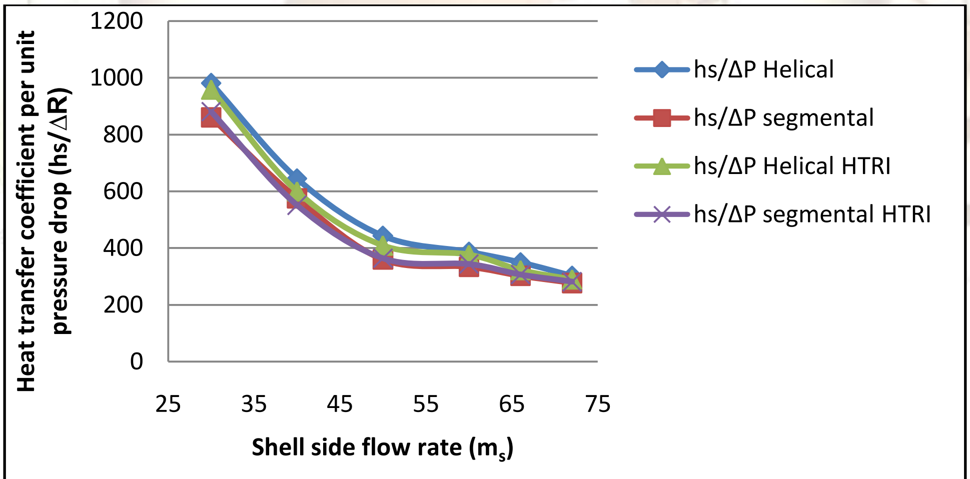
Were fabricated and used to study the effect of helical baffle on heat exchanger performance and shell side pressure drop. The observations under steady state condition were recorded by varying shell side flow rate for counter flow arrangements.

3.2Validation of Experimental & Numerical Results:

With the base of numerical analysis results carried out with HTRI software & the experimental results by experimentation on set up we have plot the graphs & charts. With help of these we have validated the result values as follows:

Table 3.1: Validation chart for hs/ΔP

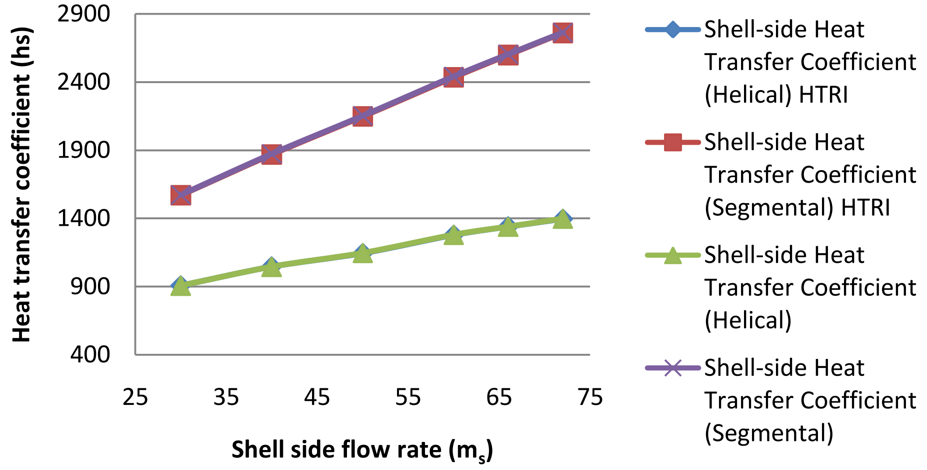
Shell-side flow rate	hs/ΔP Helical	hs/ΔP segmental	hs/ΔP Helical HTRI	hs/ΔP segmental HTRI
72	302.43	276.75	289.87	281.34
66	349.47	301.93	322.65	306.48
60	386.63	333.82	376.84	343.56
50	442.92	359.82	408.79	364.12
40	645.24	574.85	599.79	550.86
30	980.47	860.62	958.78	880.95



Graph 3.1 hs/ΔR Vs m_s

Table 3.2: Validation chart for Shell-side Heat transfer coefficient

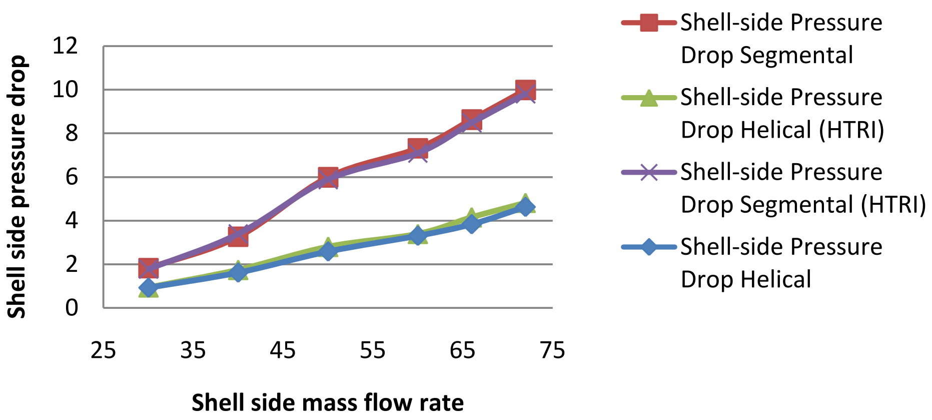
Shell-side flow rate	Shell-side Heat Transfer Coefficient (Helical)	Shell-side Heat Transfer Coefficient (Segmental)	Shell-side Heat Transfer Coefficient (Helical) HTRI	Shell-side Heat Transfer Coefficient (Segmental) HTRI
72	1398.46	2764.22	1396.61	2760.02
66	1340.23	2604.18	1338.38	2598.34
60	1279.77	2440.93	1277.88	2435.53
50	1146.29	2153.19	1145.44	2148.01
40	1044.65	1872.87	1045.16	1868.08
30	905.96	1572.55	907.01	1569.86



Graph 3.2 hs Vs m_s

Table 3.3: Validation chart for Shell-side Pressure Drop

Shell-side flow rate (lpm)	Shell-side Pressure Drop Helical (KPa)	Shell-side Pressure Drop Segmental (KPa)	Shell-side Pressure Drop Helical (HTRI) (KPa)	Shell-side Pressure Drop Segmental (HTRI) (KPa)
72	4.624	9.988	4.818	9.81
66	3.835	8.625	4.148	8.478
60	3.31	7.312	3.391	7.089
50	2.588	5.984	2.802	5.883
40	1.619	3.258	1.743	3.391
30	0.924	1.824	0.946	1.782



Graph 3.3. ΔR Vs m_s

4. Conclusion:

- From the Numerical & experimental results it is confirmed that the performance of tubular heat exchanger can be improved by helical baffles instead of conventional segmental baffles.
- Use of helical baffles in heat exchanger reduces shell side pressure drop, pumping cost, size, weight, fouling etc. as compare to segmental baffle for new installations. The helixchanger type heat exchangers can save capital cost as well as operating and maintenance cost and thus improves the reliability and availability of process plant in a cost effective way.
- For the helical baffle heat exchangers, the ratios of heat transfer coefficient to pressure drop are higher than those of a conventional segmental heat exchanger. This means that the heat exchangers with helical baffles will have a higher heat transfer coefficient when consuming the same pumping power.
- It can be concluded that proper baffle inclination angle will provide an optimal performance of heat exchangers

Nomenclature:

As cross flow area on shell side [m^2]
B baffle spacing [mm]
C_p specific heat, kJ/(kgK)
D_{is} inner diameter of shell [mm]
D_{os} outer diameter of shell [mm]
d_{it} inner diameter of tube [mm]
d_{ot} outer diameter of tube[mm]
j_i Colburn j-factor for an ideal tube bank
Gs mass velocity [kg/m^2s]
h_s shell side heat transfer coefficient [$W/(m^2k)$]
k_s shell side thermal conductivity
L length of tube [m]
N_b number of baffles
N_t number of heat exchange tubes
Pr Prandtl number
Q heat transfer rate [W]
Re_s Shell side Reynolds number
U Overall heat transfer coefficient [W/m^2 -K]
u_s shell side fluid velocity [m/s]
F_s, F_t fouling resistance [m^2K/W]
ΔP_s shell side total pressure drop [Pa]
ΔT_m logarithmic mean temp. diff. [°C]
m_t mass flow rate of hot fluid [Kg/s]
m_s mass flow rate of cold fluid [Kg/s]
t_{it} temperature of hot fluid at inlet [K]
t_{ot} temperature of hot fluid at exit [K]
t_{is} temperature of cold fluid at inlet [K]
t_{ot} temperature of cold fluid at exit [K]
φ baffle inclination angle [deg]
φ_s viscosity correction factor for shell-side fluids
μ viscosity [kg/m s]
ρ_t tube side fluid density [kg/m^3]
ρ_s shell side fluid density [kg/m^3]
CH continuous helical baffles
SG segmental baffles
s shell
t tube

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