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COST ANALYSIS OF SHELL AND TUBE HEAT EXCHANGERS WITH CONCENTRIC HELICAL TUBE COILS

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Abstract: *The paper deals with the manufacturing costs of shell and tube heat exchangers with concentric helical tube coils. The most common correlations for calculating prices of shell and tube heat exchangers found in open literature were tested using the market data for a comparison and they have shown significant deviations. A new correlation for estimating prices of heat exchangers with concentric helical tubes (when the shell is made of carbon steel and the helical tube of copper) was determined in the following form:*

$$C_{in} = 614 \cdot S_{hts}^{0.627}$$

Key words: *heat exchanger, correlation, manufacturing costs, helical tube*

1 INTRODUCTION

Heat exchangers with helical tubes are often encountered in chemical and petrochemical industries, HVAC systems, thermal, environmental and many other engineering applications. They can be used as heaters, coolers, condensers and evaporators, and their design is largely restricted to non-fouling fluids [1,2]. In comparison with straight-tube heat exchangers, heat transfer rate of helically coiled heat exchangers is significantly greater because of the secondary flow pattern in planes normal to the main flow [3,4]. Basically, helical coil heat exchangers are a compact shell and tube apparatuses, consisting of several layers of coiled tubes within a closed shell. There is a number of types of these apparatuses and in the present study heat exchangers with concentric helical tubes (HECHT) are to be investigated. Tube bundle of HECHT consist of a number of tubes wound helically around a central supporting tube and placed in a cylindrical shell. Rows of tubes can be wound in the same direction (Fig. 1) or in the opposite directions (Fig. 2).

Between the tube coils the wire inserts are placed in order to prevent the collision of tubes [1,5,6]. Despite the decades of application of the heat exchangers with helical tube coils in the industry, the problems related to their economic costs have not been fully explored.

Taking this into consideration, the primary objective of this paper was to determine the manufacturing costs of shell and tube heat exchangers with concentric helical tubes. These costs in general case include the costs of materials for apparatus, energy, labor, and other costs.

2 CALCULATION PRICE OF HEAT EXCHANGERS

Only several correlations for estimating the cost of shell and tube heat exchangers can be found in literature. They are based on knowledge of the design of the apparatus, the operating pressure, the heat transfer surface, the material the apparatus is made of, etc. The most often cited correlations are listed in Table 1, where they are not given in its original form, but are adjusted
in order for the price to be expressed in an appropriate manner (in this case EUR2014 month September).

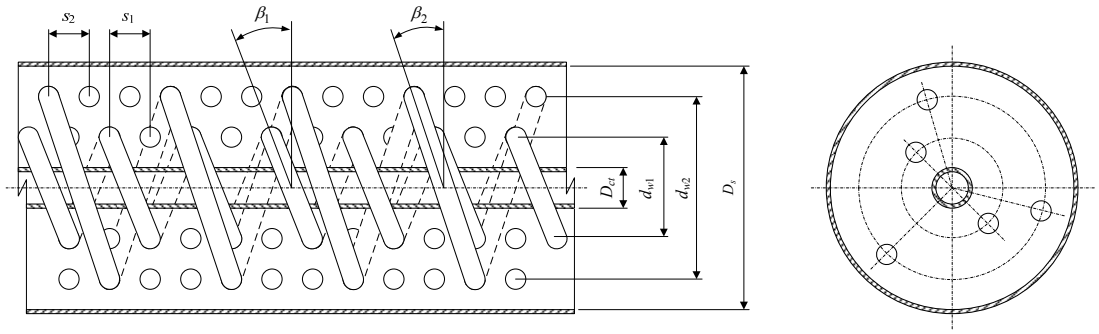

Figure 1 HECHT with tubes wound in the same direction.

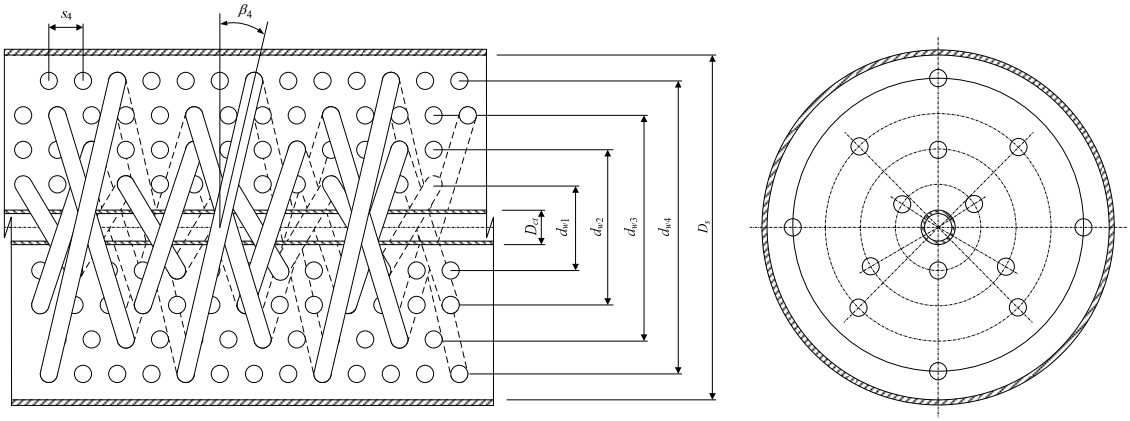

Figure 2 HECHT with tubes wound in the opposite direction.

Table 1 Correlations for estimation price of shell and tube heat exchangers by various authors

No.	Material (Shell-Tube)	Temp. (°C)	Pressure (bar)	S_{hts} range (m^2)	Correlation	Ref.	Eq.
1	Carbon steel- Carbon steel	-	-	-	$C_{in} = 6325 + 326 \cdot S_{hts}^{0.80}$	[8]	(2)
2	Carbon steel -Stainless steel	-	-	-	$C_{in} = 7695 + 370 \cdot S_{hts}^{0.85}$	[8]	(3)
3	Stainless steel - Stainless steel	-	-	-	$C_{in} = 9035 + 293 \cdot S_{hts}^{0.91}$	[8]	(4)
4	Carbon steel -Titanium	-	-	-	$C_{in} = 12649 + 623 \cdot S_{hts}^{0.92}$	[8]	(5)
5	Titanium - Titanium	-	-	-	$C_{in} = 15811 + 632 \cdot S_{hts}^{0.93}$	[8]	(6)
6	-	-	-	$0.5 \div 0.27$	$C_{in} = 970 \cdot S_{hts}^{0.432}$	[9]	(7)
7	Carbon steel - Carbon steel	-	$20 \div 30$	$10 \div 600$	$C_{in} = 1499 \cdot S_{hts}^{0.64}$	[10]	(8)
8	Carbon steel - Brass	-	$20 \div 30$	$10 \div 600$	$C_{in} = 1368 \cdot S_{hts}^{0.71}$	[10]	(9)
9	Carbon steel - Stainless steel	-	$20 \div 30$	$10 \div 600$	$C_{in} = 1394 \cdot S_{hts}^{0.86}$	[10]	(10)
10	Stainless steel -Stainless steel	-	$20 \div 30$	$10 \div 600$	$C_{in} = 2006 \cdot S_{hts}^{0.82}$	[10]	(11)
11	Carbon steel - Carbon steel	≤ 350	≤ 10.5	$9 \div 6500$	$C_{in} = 9096 + 120 \cdot S_{hts}$	[11]	(12)
12	Stainless steel - Titanium	-	-	-	$C_{in} = 32956 + 4011 \cdot S_{hts}^{0.81}$	[12]	(13)
13	Carbon steel - Carbon steel	≤ 300	≤ 50	-	$C_{in} = 3406 \cdot S_{hts}^{0.68}$	[13]	(14)
14	Carbon steel - Aluminium	≤ 300	≤ 50	-	$C_{in} = 4428 \cdot S_{hts}^{0.68}$	[13]	(15)
15	Carbon steel -Monel	≤ 300	≤ 50	-	$C_{in} = 7115 \cdot S_{hts}^{0.68}$	[13]	(16)
16	Carbon steel – Stainless steel	≤ 300	≤ 50	-	$C_{in} = 5791 \cdot S_{hts}^{0.68}$	[13]	(17)
17	Stainless steel - Stainless steel	≤ 300	≤ 50	-	$C_{in} = 9878 \cdot S_{hts}^{0.68}$	[13]	(18)

18	Carbon steel - Carbon steel	-	-	$9 \div 90$	$C_{in} = 2095 \cdot S_{hts}^{0.551}$	[14]	(19)
19	Admiralty	-	-	$9 \div 90$	$C_{in} = 1522 \cdot S_{hts}^{0.679}$	[14]	(20)
20	Copper–brass	-	-	$9 \div 90$	$C_{in} = 1844 \cdot S_{hts}^{0.679}$	[14]	(21)
21	Carbon steel- Copper	$0 \div 200$	$2 \div 30$	$2.5 \div 38$	$C_{in} = 749 + 332 \cdot S_{hts}$	[15]	(22)

Table 2 Year built of apparatus

No.	S_{hts}, m^2	Year built	Cost of apparatus in year built	Cost of apparatus (EUR$_{2014}$)
1	0.5	2013	500	525
2	1	2014	600	614
3	1.5	2011	850	823
4	2	2012	1100	1083
5	2.5	2009	1190	1381
6	3	2010	1275	1221
7	4	2011	1360	1316
8	5	2012	1550	1526
9	6	2013	1650	1731
10	7	2012	1750	1723
11	8	2010	1880	1800
12	9	2012	2180	2146
13	10	2011	2150	2080
14	12	2010	2520	2413
15	15	2013	2850	2989
16	18	2011	3420	3308
17	20	2011	3800	3676
18	22	2010	4180	4002
19	25	2010	4750	4548
20	30	2012	5700	5610
21	35	2010	6650	6367
22	40	2012	7600	7480
23	44	2013	8250	8652
24	47	2013	9030	9470

Prices of apparatuses have to be corrected also from the year in which they were manufactured (Table 2) in the year for which the analysis is done. The simplest method, which is used to correct the price, takes into account the increasing costs due to market trends and the cost is given by next equation:

$$C_A/I_A = C_B/I_B \qquad (1)$$

where

- C_A, EUR, price of apparatus at the moment A,
- C_B, EUR, price of apparatus at the moment B,
- I_A, index of price at the moment A,
- I_B, index of price at the moment B [5,7].

3 ANALYSIS OF MANUFACTURING COSTS OF HEAT EXCHANGERS WITH CONCENTRIC HELICAL TUBE COILS

For the heat exchangers with a concentric helical tube coils, the correlation for the assessment of investment costs is not encountered in the literature. Therefore, the goal of this analysis was to determine deviations that appear during the use of the existing correlations.

Deviation in prices calculated using the correlation 2 $\div$ 22 and the actual price of apparatuses (data obtained from the manufacturers on territory Bosnia and Hercegovina, Serbia and Croatia) is expressed using statistical indicators: correlation ratio (CR) and the root-mean square deviation (RMSD), which are also shown in Table 3.

The analysis proved from these correlations show significant deviations and that they cannot be successfully used to describe the manufacturing costs for the mentioned type of shell and tube heat exchangers (a heat exchanger with concentric helical tube coils, where the apparatus shell is made of carbon steel and the heat exchanger's tubes are made of copper).

Table 3 Statistical parameters of literature correlations

No.	Correlation/EUR	*CR*	*RMSD*	Eq.
1	$C_{in} = 6325 + 326 \cdot S_{hts}^{0.80}$	0	438.76	(2)
2	$C_{in} = 7695 + 370 \cdot S_{hts}^{0.85}$	0	551.75	(3)
3	$C_{in} = 9035 + 293 \cdot S_{hts}^{0.91}$	0	641.66	(4)
4	$C_{in} = 12649 + 623 \cdot S_{hts}^{0.92}$	0	979.37	(5)
5	$C_{in} = 15811 + 632 \cdot S_{hts}^{0.93}$	0	1214.7	(6)
6	$C_{in} = 970 \cdot S_{hts}^{0.432}$	0.8284	29.02	(7)
7	$C_{in} = 1499 \cdot S_{hts}^{0.64}$	0	159.53	(8)
8	$C_{in} = 1368 \cdot S_{hts}^{0.71}$	0	177.64	(9)
9	$C_{in} = 1394 \cdot S_{hts}^{0.86}$	0	310.93	(10)
10	$C_{in} = 2006 \cdot S_{hts}^{0.82}$	0	431.06	(11)
11	$C_{in} = 9096 + 120 \cdot S_{hts}$	0	616.41	(12)
12	$C_{in} = 32956 + 4011 \cdot S_{hts}^{0.81}$	0	3088.83	(13)
13	$C_{in} = 3406 \cdot S_{hts}^{0.68}$	0	541.19	(14)
14	$C_{in} = 4428 \cdot S_{hts}^{0.68}$	0	733.03	(15)
15	$C_{in} = 7115 \cdot S_{hts}^{0.68}$	0	1237.52	(16)
16	$C_{in} = 5791 \cdot S_{hts}^{0.68}$	0	988.93	(17)
17	$C_{in} = 9878 \cdot S_{hts}^{0.68}$	0	1756.32	(18)
18	$C_{in} = 2095 \cdot S_{hts}^{0.551}$	0	201.48	(19)
19	$C_{in} = 1522 \cdot S_{hts}^{0.679}$	0	187.23	(20)
20	$C_{in} = 1844 \cdot S_{hts}^{0.679}$	0	247.38	(21)
21	$C_{in} = 749 + 332 \cdot S_{hts}$	0	79.17	(22)

Therefore, on the basis of the data given in Table 2 (for 2014 year price), a new correlation was found in form (Figure 3):

$$C_{in} = 614 \cdot S_{hts}^{0.627} \quad (2)$$

for range 0.5 m^2<S_{hts}<47 m^2, 4<p<25 bar, 10<T<180 ºC.

Its statistical parameters are CR=0.9497 and RMSD=15.94%. In the above equations (2 ÷ 22) the value of heat transfer surface (S_{hts}) was expressed taking into account the outside surface of helical tube coils.

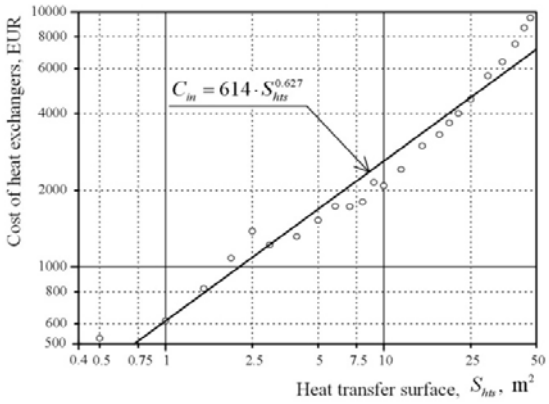

Figure 3 Manufacturing costs for apparatus versus to heat transfer surface

The new correlation for determining the price of shell and tube heat exchangers with concentric helical tube coils (when the shell is made of carbon steel and the tube is made of copper) has the following form

$$C_{in} = 614 \cdot S_{hts}^{0.627} \quad (3)$$

for range 2.50<S_{hts}<38 m^2, 4<p<25 bar, and 10<T<180 ºC. Statistical parameters of this equation are, CR=0.9497 and RMSD = 15.94.

4 CONCLUSION

The paper presents the main types and manufacturing costs for shell and tube heat exchangers with concentric helical tube coils. The cost analysis was conducted using the actual price (data obtained from the manufacturer) of apparatus with helical tube coils on territory Bosnia and Hercegovina, Serbia and Croatia.

After examining the correlations currently found in the existing body of literature on investment costs of shell and tube heat exchangers, it was concluded that a new correlation needs to be found.

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Nomenclature

C_A, EUR price of apparatus at the moment A,
C_B, EUR price of apparatus at the moment B,
C_{in}, EUR, investment cost of heat exchanger (price of manufactured apparatus),
D_{ct}, mm, diameter of, carrier tube,
D_s, mm, internal diameter of heat exchanger,
d_{w1}, mm diameter of helical tube 1,
d_{w2}, mm diameter of helical tube 2,
I_A, index of price at the moment A,
I_B, index of price at the moment B,
p, bar, operating pressure of heat exchanger,
s_1, mm, pitch of helical tube coils 1,
s_2, mm, pitch of helical tube coils 2,
S_{hts}, m^2, heat transfer surface.

Greek letters

β_1 , angle of helical tube coils for diameter d_{w1},
β_2 , angle of helical tube coils for diameter d_{w2},