Journal of Engineering and Applied Sciences 14 (5): 1538-1548, 2019
ISSN: 1816-949X

New Correlation Equations for Finned Tube Heat Exchangers

Sajida Lafta Ghashim
Department of Mechanical Engineering, University of Baghdad, Baghdad, Iraq

Abstract: A new correlation equations were conducted on heat transfer parameters of air-side in circular finned-tube heat exchangers of staggered and in line arrangement. A Nusselt number and Euler number correlation are derived. The effects of fin height, fin spacing, fin pitch, tube outside diameter, fin diameter, transverse tube pitch, longitudinal tube pitch and number of rows are reflected in the correlations. The study covered the range of Reynolds number (8×10^3-5×10^4). Number of bundles used in this correlation 56 staggered and 33 in line. A numerical solution based on (DGA V1.00) and Excel programs were used to find constants of correlation equations. Also, Tecplot program is used to draw curves of results. Results show maximum deviation are in Nusselt number and Euler number correlations (6, 18% for staggered and 10, 11% for in line), respectively in addition, the effect of fin spacing or fin height on Nusselt number and Euler number in one bundle (S1 staggered and I1 in line) are investigated. Results showed that in staggered bundle arrangement S1, the Nu number increased and Eu number decreased when the fin spacing increased and fin height decreased. While the effect of decreased fin spacing and increased fin height led to in increased Nu number and Eu number at bundle I1 in line arrangement.

Key words: Circular finned tubes, staggered array, in line bundle arrangement, heat transfer coefficient, fin diameter, transverse tube pitch

INTRODUCTION

Finned tube one of most imported method to enhance heat transfer in heat exchanger. Literature survey reveals that correlation for a Nusselt and friction factor is derived for both in-line and staggered arrays tubes arranged in heat exchanger. Briggs and Young (1963) derived new correlation equation of Nusselt number. The scope of the research was to study effect three values of the fin thickness (0.457, 1.06 and 2.02) mm on heat transfer coefficient. The results showed, heat transfer coefficient decreased when value of fin thickness increased. Haaf (1988) explored a new pressure drop correlation for both in-line and staggered arrays. Mon (2003) investigated numerically pressure drop and heat transfer on finned circular tubes heat exchanger. The study cover the range of Reynolds number from 5000-70000. Continuity, momentum, energy and the (k-ε) turbulence model used in the numerical analysis. CFD code Fluent (ANSYS 15) and Gambit 2.2.30 are used to solve mathematical equations and its package based on finite volume method. The result for both in-line and staggered tubes are presented by temperature distribution between the fins, local Nusselt number along tube wall of bundle and temperature countor. Also, new Nusselt number and pressure drop correlation is obtained. Taler (2012) showed numerically the effect of extended surfaces in a cross-flow heat exchangers and new correlation equations obtained. Nonlinear regression method was used to find constant of correlation. Fajiang *et al*. (2012) studied experimentally heat transfer for flow spiral finned tube heat exchanger. The experiments were conducted with Re number 5×10^3~5.5×10^4 and using 13 spiral finned tube bundles heat exchangers. Diameter of base tube (d = 32 mm) range of fin pitch (0.22~0.5) fin height 0.22~0.5, transverse tube pitch 2~3.3125, longitudinal tube pitch 2~3.3125. Nusselt number and Euler number correlations were obtained. Also, the maximum deviation in heat transfer correlations and pressure drop correlations equal to (± 15, 15% in staggered while ±25 and ±30% for the in-line), respectively. Anoop *et al*. (2015) studied numerically and experimentally flow over finned tube in air heat exchanger. numerical simulations carried out by using CFD Code Fluent 6.3 for three dimensional and steady state. The flow was governed by the Navier-Stokes equations, continuity equation and the RNG (k-ε) material of tube and fin is alloy steel. The numerical study has been done with Reynolds number 2000<Re<50,000 for laminar and turbulent flow. Experimental study was conducted at 6 different Reynolds numbers between 1000 and 8000. experiments were conducted in the vertical wind tunnel. The dimension of length of the tube was 400 mm. Wais (2016) investigated numerically effect of 3 types of fin thickness on heat transfer in single row fin tube cross flow heat exchanger. ANSYS CFX program are used also, to perform model study three-dimensional flow and heat transfer parameters. The results show when increase fin thickness, the value of heat transfer decreased. The results compared with available correlations to check the numerical calculation.

In the present study, A Nusselt and Euler number correlation equations are derived. Effect of 7 variables in circular finned-tube heat exchangers are reflected in the correlations. Derivation of correlation equations based on dimensions of bundles of finned-tube heat exchangers of staggered and in line arrangement from the previous investigations by Mon (2003). Moreover, effect of fin spacing or fin height on Nusselt number and Euler number in one bundle for staggered and in line bundle arrangement are investigated. The study covered the range of Reynolds number (8×10^3-5×10^4).

MATERIALS AND METHODS

Mathematical modeling: There are seven variables as shown in Fig. 1 and 2 that affect on heat transfer coefficient and friction factor in circular finned-tube heat exchangers of staggered and in line arrangement. The variables:

- Fin height (h_f)
- Fin pitch (S_f)
- fin diameter (d_f)
- Fin Spacing (S)
- Tube outside diameter (d)
- Transverse tube pitch (S_t)
- Longitudinal tube pitch (S_L)
- Number of rows (Z)

Selection of data: Dimensions of bundles used for staggered and in-line arrangement as shown in Table 1 and 2, all dimensions are in mm. Depth of all bundles were considered with four rows except for the staggered bundle S6 and in-line I4 were performed with 2-6 rows and 3-5 rows, respectively. The equation for Nusselt number and Euler number are:

$$Nu = CRe^{a1}\left(\frac{S_f}{d}\right)^{a2}\left(\frac{S}{h_f}\right)^{a3}\left(\frac{d}{S_t}\right)^{a4}\left(\frac{d}{S_L}\right)^{a5}C_Z \quad (1)$$

$$Eu = CRe^{a1}\left(\frac{S_f}{d}\right)^{a2}\left(\frac{S}{h_f}\right)^{a3}\left(\frac{d}{S_t}\right)^{a4}\left(\frac{d}{S_L}\right)^{a5}Z^{a6} \quad (2)$$

where C, a1-a6 are the unknown constant which are to be determined from the data shown in Table 3 and 4. Several analyses where performed by using (DGA V1.00) and Excel program to find the constants of the Eq. 1 and 2. Also in Eq. 1 and 2 value of C_Z depends of number of row.

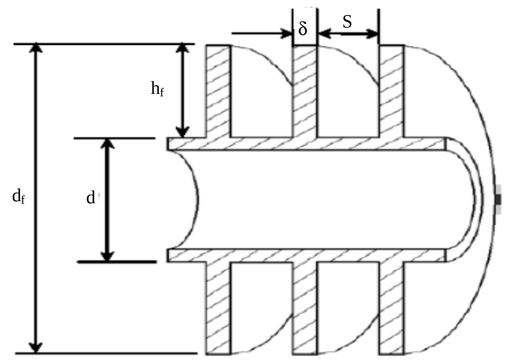

Fig. 1: Circular fin tube section

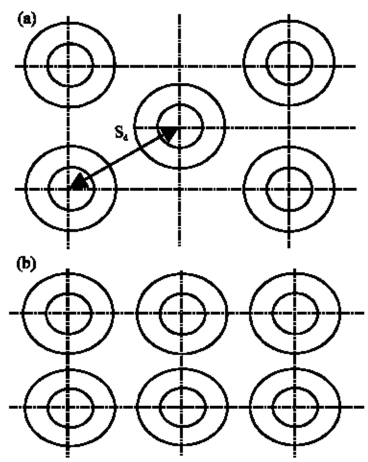

Fig. 2: Arrangements of tubes in bundles; a) Staggered and b) In line

Table 1: Dimensions of bundles for staggered arrangement (Mon, 2003)

Type	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
d	24	24	24	24	24	24	24	24	24	24	13.59	28	24	24
d_f	30	34	38	44	48	34	34	44	34	34	23.59	38	34	34
h_f	3	5	7	10	12	5	5	10	5	5	5	5	5	5
δ	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.6	0.5	0.5	0.5	0.5
S	2	2	2	2	2	1.6	4	0.7	2	2	2	2	2	2
S_f	2.5	2.5	2.5	2.5	2.5	2.1	4.5	1.2	2.3	2.6	2.5	2.5	2.5	2.5
St	36	40.8	45.6	52.8	57.6	40.8	40.8	52.8	40.8	40.8	28.30	45.6	48.4	64.8
S_L	31.17	35.33	39.49	45.73	49.88	35.33	35.33	45.73	35.33	35.33	24.52	39.49	41.92	56.12
Z	4	4	4	4	4	2-6	4	4	4	4	4	4	4	4

Table 2: Dimensions of bundles for in line arrangement (Mon, 2003)

Type	I1	I2	I3	I4	I5	I6	I7	I8	I9
d	24	24	24	24	24	13.59	24	24	24
d_f	34	38	44	34	34	23.59	34	34	34
h_f	5	7	10	5	5	5	5	5	5
δ	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
S	2	2	2	1.6	4	2	2	2	2
S_f	2.5	2.5	2.5	2.1	4.5	2.5	2.5	2.5	2.5
S_t	40.8	45.6	52.8	40.8	40.8	28.31	47.6	40.8	40.8
S_L	40.8	45.6	52.8	40.8	40.8	28.30	47.6	47.6	47.8
Z	4	4	4	3-5	4	4	4	4	4

Table 3: Dimensions of 56 types of staggered arrangement finned tubes in Nu equation

Type	Z	Re	S_f/d	S/h_f	d/S_t	d/S_L	C_Z
S6	2	8600	0.087500	0.320000	0.588235	0.679310	0.8656483
S6	2	17000	0.087500	0.320000	0.588235	0.679310	0.8656483
S6	2	43000	0.087500	0.320000	0.588235	0.679310	0.8656483
S6	3	8600	0.087500	0.320000	0.588235	0.679310	0.9131156
S6	3	17000	0.087500	0.320000	0.588235	0.679310	0.9131156
S6	3	43000	0.087500	0.320000	0.588235	0.679310	0.9131156
S4	4	5000	0.104167	0.200000	0.454545	0.524820	0.9464678
S13	4	5000	0.104167	0.400000	0.495867	0.572518	0.9464678
S14	4	5000	0.104167	0.400000	0.37037	0.427656	0.9464678
S1	4	8600	0.104167	0.666667	0.666666	0.769798	0.9464678
S2	4	8600	0.104167	0.400000	0.588235	0.679310	0.9464678
S3	4	8600	0.104167	0.285714	0.526316	0.607749	0.9464678
S4	4	8600	0.104167	0.200000	0.454545	0.524820	0.9464678
S5	4	8600	0.104167	0.166667	0.416666	0.481040	0.9464678
S6	4	8600	0.087500	0.320000	0.588235	0.679310	0.9464678
S7	4	8600	0.187500	0.800000	0.588235	0.679310	0.9464678
S8	4	8600	0.027270	0.070000	0.454500	0.524810	0.9464678
S9	4	8600	0.095833	0.400000	0.588235	0.679310	0.9464678
S10	4	8600	0.108333	0.400000	0.588235	0.679310	0.9464678
S11	4	8600	0.183959	0.400000	0.480076	0.554241	0.9464678
S12	4	8600	0.089286	0.400000	0.614036	0.709040	0.9464678
S13	4	8600	0.104162	0.400000	0.495867	0.572541	0.9464678
S1	4	17000	0.104162	0.666667	0.666660	0.769798	0.9464678
S2	4	17000	0.104162	0.400000	0.588235	0.679310	0.9464678
S3	4	17000	0.104162	0.285714	0.526316	0.607902	0.9464678
S4	4	17000	0.104162	0.200000	0.454545	0.524820	0.9464678
S5	4	17000	0.104162	0.166667	0.416666	0.481155	0.9464678
S6	4	17000	0.087500	0.320000	0.588235	0.679310	0.9464678
S7	4	17000	0.187500	0.800000	0.588235	0.679310	0.9464678
S8	4	17000	0.027270	0.070000	0.454500	0.524810	0.9464678
S9	4	17000	0.095833	0.400000	0.588235	0.679310	0.9464678
S10	4	17000	0.108333	0.400000	0.588235	0.679310	0.9464678
S11	4	17000	0.183959	0.400000	0.480076	0.554241	0.9464678
S12	4	17000	0.089286	0.400000	0.615168	0.709040	0.9464678
S13	4	17000	0.104167	0.400000	0.495867	0.572519	0.9464678
S14	4	17000	0.104167	0.400000	0.370370	0.428578	0.9464678
S1	4	43000	0.104167	0.666666	0.666600	0.769324	0.9464678
S2	4	43000	0.104167	0.400000	0.588235	0.679310	0.9464678
S3	4	43000	0.104167	0.285714	0.526316	0.607902	0.9464678
S4	4	43000	0.104167	0.200000	0.454545	0.524820	0.9464678
S5	4	43000	0.104167	0.166667	0.416660	0.481148	0.9464678
S6	4	43000	0.087500	0.320000	0.588235	0.679310	0.9464678
S7	4	43000	0.187500	0.800000	0.588235	0.679310	0.9464678
S8	4	43000	0.027270	0.070000	0.454500	0.524810	0.9464678
S9	4	43000	0.095833	0.400000	0.588235	0.679310	0.9464678
S10	4	43000	0.108333	0.400000	0.588235	0.679310	0.9464678
S11	4	43000	0.183959	0.400000	0.480076	0.554241	0.9464678
S12	4	43000	0.089286	0.400000	0.615168	0.709040	0.9464678
S13	4	43000	0.104167	0.400000	0.495866	0.572519	0.9464678
S14	4	43000	0.104167	0.400000	0.370370	0.428578	0.9464678
S1	4	70000	0.104167	0.666667	0.666666	0.769324	0.9464678
S3	4	70000	0.104167	0.285714	0.526316	0.607902	0.9464678
S7	4	70000	0.187500	0.800000	0.588235	0.679310	0.9464678
S6	5	8600	0.087500	0.320000	0.588235	0.679310	0.9687050

Table 3: Continue

Type	Z	Re	S_f/d	S/h_f	d/S_t	d/S_L	C_Z
S6	5	17000	0.087500	0.320000	0.588235	0.679310	0.9687050
S6	5	43000	0.087500	0.320000	0.588235	0.679310	0.9687050
S6	6	8600	0.087500	0.320000	0.588235	0.679310	0.9825061
S6	6	17000	0.087500	0.320000	0.588235	0.679310	0.9825061
S6	6	43000	0.087500	0.320000	0.588235	0.679310	0.9825061
S6	2	8600	0.087500	0.320000	0.588235	0.679310	0.8656483
S6	2	17000	0.087500	0.320000	0.588235	0.679310	0.8656483
S6	2	43000	0.087500	0.320000	0.588235	0.679310	0.8656483
S6	3	8600	0.087500	0.320000	0.588235	0.679310	0.9131156
S6	3	17000	0.087500	0.320000	0.588235	0.679310	0.9131156

Table 4: Dimensions of 33 types of inline arrangement finned tubes in Nu equation

Type	Z	Re	S_f/d	S/h_f	d/S_t	d/S_L	C_Z
I4	3	86000	0.0875	0.320	0.5880	0.5880	1.1
I4	3	17000	0.0875	0.320	0.5880	0.5880	1.1
I4	3	43000	0.0875	0.320	0.5880	0.5880	1.1
I1	4	86000	0.1040	0.500	0.5880	0.5880	1
I2	4	86000	0.1040	0.357	0.5260	0.5260	1
I3	4	86000	0.1040	0.250	0.4545	0.4545	1
I4	4	86000	0.0875	0.320	0.5880	0.5880	1
I5	4	86000	0.1870	0.800	0.5880	0.5880	1
I6	4	86000	0.1830	0.400	0.4800	0.4800	1
I7	4	86000	0.0890	0.400	0.6140	0.6140	1
I8	4	86000	0.1040	0.400	0.5040	0.5040	1
I9	4	86000	0.1040	0.400	0.5880	0.5040	1
I1	4	17000	0.1040	0.500	0.5880	0.5880	1
I2	4	17000	0.1040	0.357	0.5260	0.5260	1
I3	4	17000	0.1040	0.250	0.4545	0.4545	1
I4	4	17000	0.0875	0.320	0.5880	0.5880	1
I5	4	17000	0.1870	0.800	0.5880	0.5880	1
I6	4	17000	0.1830	0.400	0.4800	0.4800	1
I7	4	17000	0.0890	0.400	0.6140	0.6140	1
I8	4	17000	0.1040	0.400	0.5040	0.5040	1
I9	4	17000	0.1040	0.500	0.5880	0.5880	1
I1	4	43000	0.1040	0.500	0.5880	0.5880	1
I2	4	43000	0.1040	0.357	0.5260	0.5260	1
I3	4	43000	0.1040	0.250	0.4545	0.4545	1
I4	4	43000	0.0875	0.320	0.5880	0.5880	1
I5	4	43000	0.1870	0.800	0.5880	0.5880	1
I6	4	43000	0.1830	0.400	0.4800	0.4800	1
I7	4	43000	0.0890	0.400	0.6140	0.6140	1
I8	4	43000	0.1040	0.400	0.5040	0.5040	1
I9	4	43000	0.1040	0.500	0.5880	0.5880	1
I4	5	86000	0.0875	0.320	0.5880	0.5880	1
I4	5	17000	0.0875	0.320	0.5880	0.5880	1
I4	5	43000	0.0875	0.320	0.5880	0.5880	1

For staggered arrangement:

$$C_Z = 0.71476+0.097819\ Z-0.012509\ Z^2+0.0068758\ Z^3-0.00013396\ Z^4 \quad (3)$$

For in line arrangement:

$$C_Z = 2-0.45\ Z+0.05Z^2 \quad (4)$$

The resulting correlation of Nusselt number and Euler number for suitable range of Reynolds number (8×10^3-5×10^4) with $Z \geq 2$ has the following form:

Staggered array:

$$Nu = 0.296Re^{0.555}\left(\frac{S_f}{d}\right)^{-0.06}\left(\frac{S}{h_f}\right)^{0.01}\left(\frac{d}{S_t}\right)^{-2.61}\left(\frac{d}{S_L}\right)^{2.94}C_Z \quad (5)$$

$$Eu = 37.480Re^{-0.23}\left(\frac{S_f}{d}\right)^{-0.06}\left(\frac{S}{h_f}\right)^{-0.28}\left(\frac{d}{S_t}\right)^{16}\left(\frac{d}{S_L}\right)^{-15.4}Z^{0.87} \quad (6)$$

In line array:

$$Nu = 0.2127Re^{0.661}\left(\frac{S_f}{d}\right)^{0.39}\left(\frac{S}{h_f}\right)^{-0.031}\left(\frac{d}{S_t}\right)^{0.87}\left(\frac{d}{S_L}\right)^{-0.61}C_Z \quad (7)$$

$$Eu = 3.889Re^{-0.16}\left(\frac{S_f}{d}\right)^{0.24}\left(\frac{S}{h_f}\right)^{-0.48}\left(\frac{d}{S_t}\right)^{2.2}\left(\frac{d}{S_L}\right)^{-1.1}Z^{0.56} \quad (8)$$

Correlations from literature review

Heat transfer correlations

Mon (2003): For staggered:

$$Nu = 0.284Re^{0.6}Pr^{0.333}\left(\frac{A}{A_t}\right)^{-0.15}F^{-0.075}\left(\frac{S_t}{S_d}\right)^{1.06} \quad (9)$$

For in line:

$$Eu = 0.356Re^{0.6}Pr^{0.333}\left(\frac{A}{A_t}\right)^{-0.15}F^{-0.173}\left(\frac{S_t}{S_L}\right)^{-0.475} \quad (10)$$

Briggs and Young (1963): The correlation can be applied for staggered tube arrangement, for Reynolds number range: 1.1×103 ≤ Re ≤ 1.8×104, 13.49 mm ≤ d ≤ 40.89 mm, 4.3 mm ≤ h_f ≤ 16.58 mm, 1.82 mm ≤ S ≤ 2.76 mm , 0.33 mm ≤ δ ≤ 2.02 mm, 27.43 mm ≤ S_t ≤ 110 mm, 23.76 mm ≤ S_L ≤ 96.13 mm, Z ≥ 4:

$$Nu = 0.134Re^{0.681}Pr^{0.333}\left(\frac{S}{h_f}\right)^{0.2}\left(\frac{S}{\delta}\right)^{0.1134} \quad (11)$$

Schmidt (1963): The correlation used for Reynolds number range: $1\times10^3 \le Re \le 4\times10^4$, 5 ≤ A/At ≤ 12, Z ≥ 3. For staggered: C = 0.45, For in line: C = 0.3:

$$Nu = CRe^{0.625}Pr^{0.333}\left(\frac{A}{A_t}\right)^{-0.375} \quad (12)$$

VDI-GVC (1997): The correlation can be applied for staggered and inline tube arrangement for: $1\times10^3 \le Re \le 1\times10^5$, 5 ≤ A/At ≤ 30, Z ≥ 4. For staggered: C = 0.38, for in line: C = 0.22:

$$Nu = CRe^{0.6}Pr^{0.333}\left(\frac{A}{A_t}\right)^{-0.15} \quad (13)$$

Pressure drop correlations

Mon (2003): For staggered:

$$Eu = 0.75Re^{-0.24}F^{-0.49}\left(\frac{S_t}{S_d}\right)^{0.64}Z \quad (14)$$

For in line:

$$Eu = 0.536Re^{-0.23}\left(\frac{A}{A_t}\right)^{0.068}F^{-0.49}\left(\frac{S_t}{S_d}\right)^{-2.18}Z \quad (15)$$

Haaf (1988): The correlation can be applied for Reynolds number range: $2\times10^2<Re<1\times10^4$, Z ≥4, for staggered: C = 4.25, for in line: C = 2.5:

$$Eu = CRe^{-0.25}\left(\frac{S_L}{d}\right)^{0.4}Z \quad (16)$$

Robinson and Briggs (1966): The correlation can be applied for Reynolds number range: $2\times10^2<Re<1\times10^4$, for staggered: C = 4.25 for in line: C = 2.5:

$$Eu = 18.93Re^{-0.316}\left(\frac{S_L}{d}\right)^{-0.92}\left(\frac{S_t}{S_d}\right)^{0.515}Z \quad (17)$$

RESULTS AND DISCUSSION

The aim of the research is to attain new correlations. The Nusselt number and Euler number data are correlated for number of row from Eq. 2-6 and Eq. 3-5 for staggered and in line tube banks, respectively. In this new correlations take the effect of seven geometric of heat exchanger in the correlations.

Figure 3 show the Nusselt and Euler number results are plotted versus the Re number for all bundles staggered arrangement. The Nu number increase with increases Re number at different types of bundles .The results illustrated decreases fin height, fin diameter, transverse tube pitch and longitudinal tube pitch causes increase Nusselt number. It was noticed, also that increase fin spacing causes increase Nusselt number. But Euler number affected by same geometric mentioned previously reverse effect.

Figure 4 show the Nu and Eu number results are plotted versus the Re number for all bundles in line arrangement. It was concluded from the results that Nu number increase with increases Re number at different types of bundles and slightly different between the bundles. Moerever, decrease fin height, transverse tube pitch and longitudinal tube pitch causes increase Nusselt number and decrease Euler number.

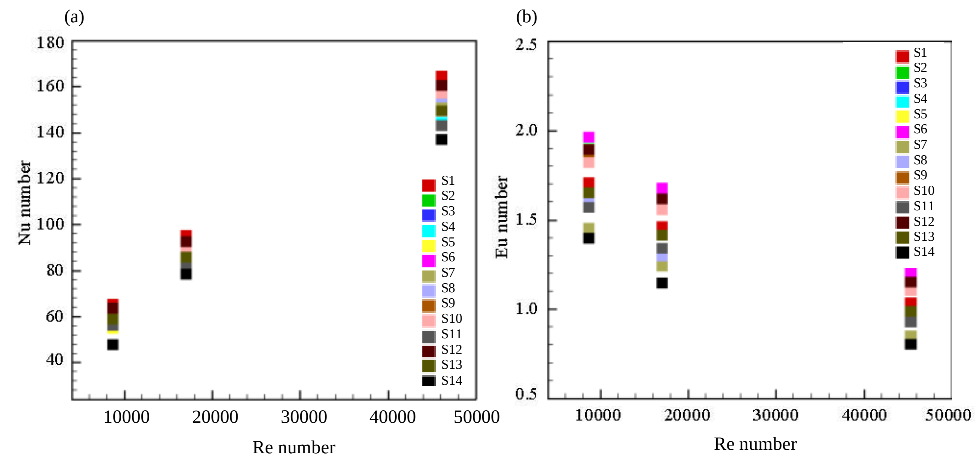

Fig. 3: Nu and Eu number variation with Re number for different staggered bundle arrangement; a) Nu number and b) Eu number

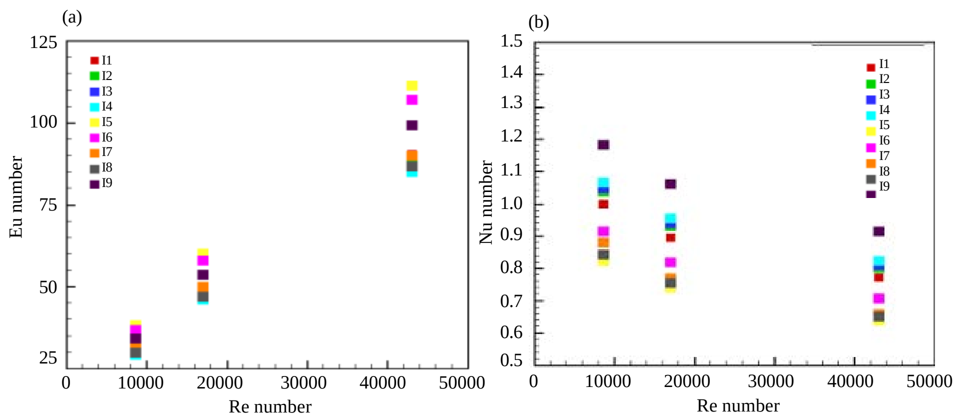

Fig. 4: Nu and Eu number variation with Re number for different inline bundle arrangement; a) Nu number and b) Eu number

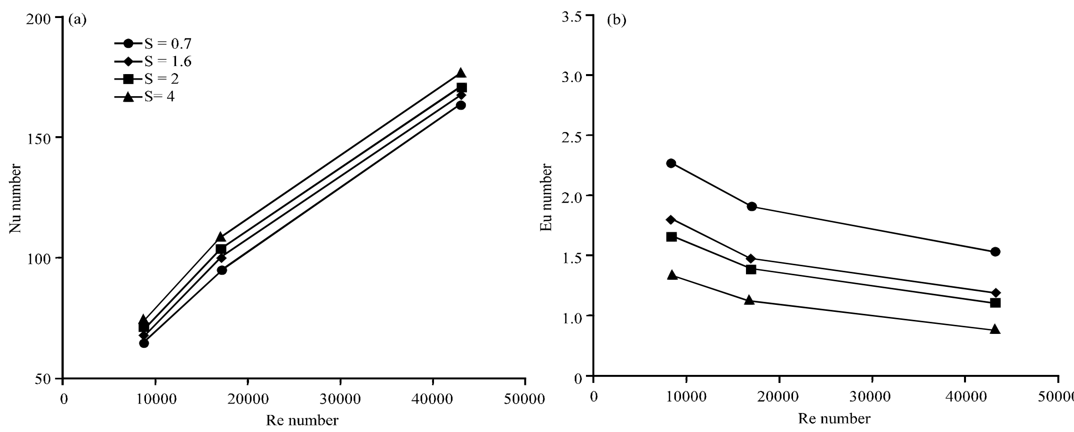

Fig. 5: Nu and Eu number variation with Re number for S1 bundle staggered arrangement at different fin spacing; a) Nu number and b) Eu number

In Fig. 5 and 6 discussed the effect of fin height and fin spacing on Nu number and Eu number in staggered bundle arrangement S1 at constant (fin thickness = 0.5, tube outside diameter = 24, fin diameter = 30, transverse

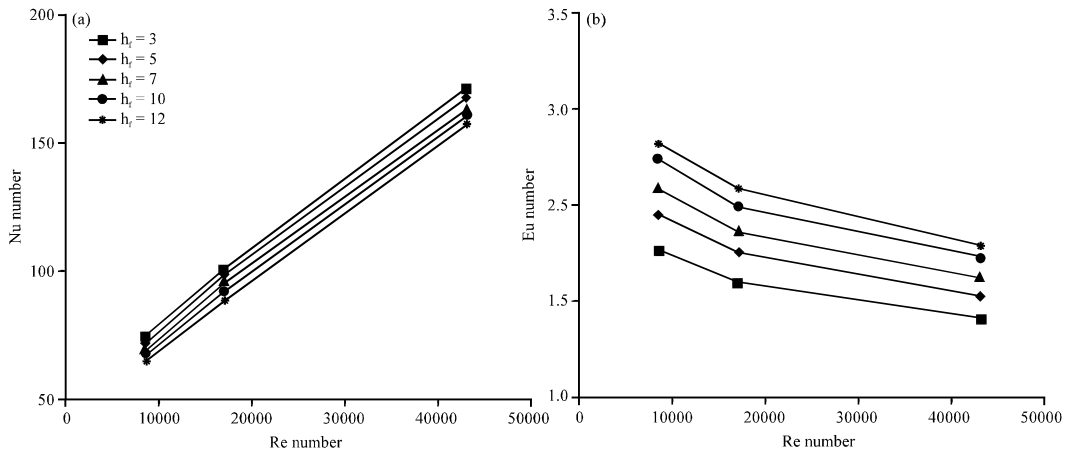

Fig. 6: Nu number variation with Re number for S1 bundle staggered arrangement at different fin height; a) Nu number and b) Eu number

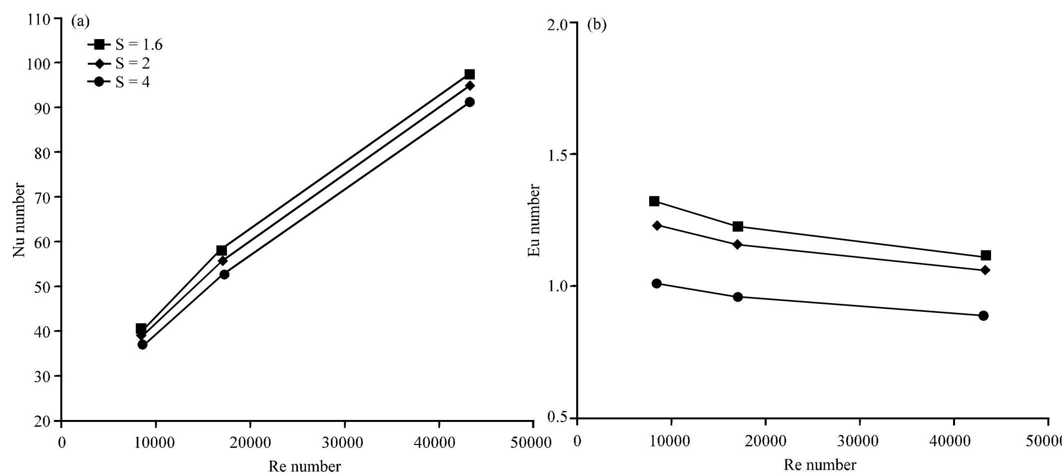

Fig. 7: Nu and Eu number variation with Re number for I1 bundle in line arrangement at different fin spacing; a) Nu number and b) Eu number

tube pitch = longitudinal tube pitch = and number of rows = 4). The results illustrated Nu number increased and Eu number decreased when the fin spacing increases from 0.7-4 and fin height decreased from 12-3.

Figure 7 and 8 show the Nu number and Eu number results are plotted versus the Re number for I1 bundle in line arrangement at constant (fin thickness = 0.5, tube outside diameter = 24, fin diameter = 34, transverse tube pitch = 40.8, longitudinal tube pitch = 40.8 and number of rows = 4). The results showed that the effect of decreased fin spacing and increased fin height led to in increased Nu number. Also, similar behavior was noticed for Eu number. From Fig. 9 and 10, it is evident that the proposed correlations are in good agreement with the equations of Mon (2003).

Comparison with other correlations: To check the result of new correlations, its comparison with the correlations from the literature are shown in Table 5-8, for staggered and in line arrangements tubes. Also, deviation of present correlation was calculated by using the formula:

$$\text{Deviation} = \frac{Nu_{Eq.}-Nu_{Fluent}}{Nu_{Eq.}}*100\% \quad (18)$$

The maximum deviation of Nusselt number and Euler number correlation are shown in Table 9-12 (6, 18% for staggered and 10, 11% for in line), respectively.

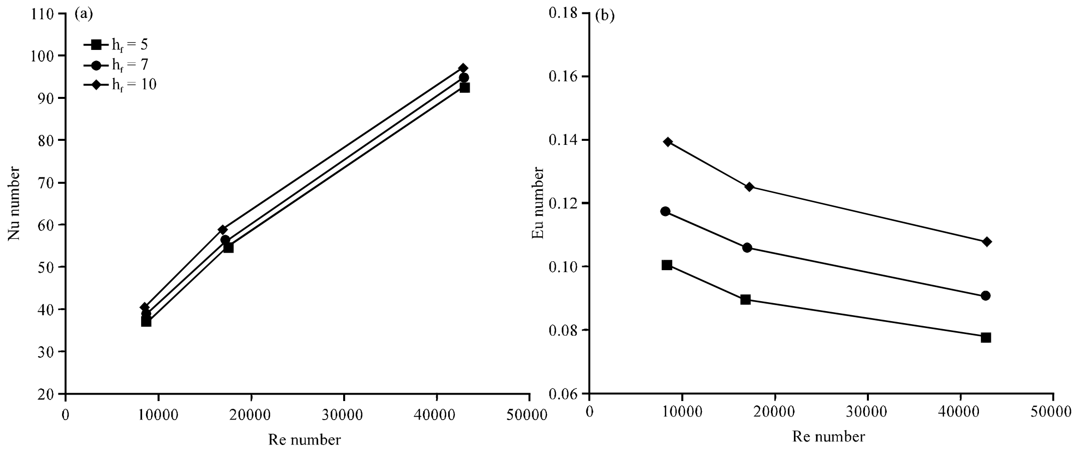

Fig. 8: Nu and Eu number variation with Re number for I1 bundle in line arrangement at different fin height; a) Nu number and b) Eu number

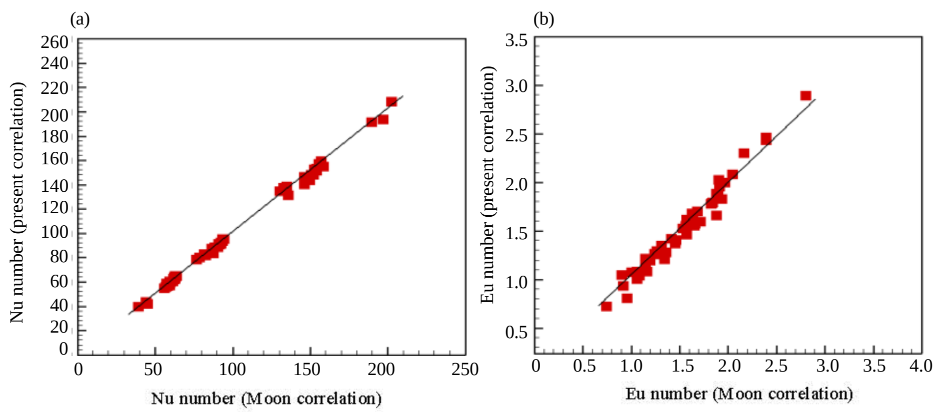

Fig. 9: Comparison of Nu and Eu number numerical values for staggered finned tube heat exchangers with correlated by Eq 5 and 6; a) Nu number and b) Eu number

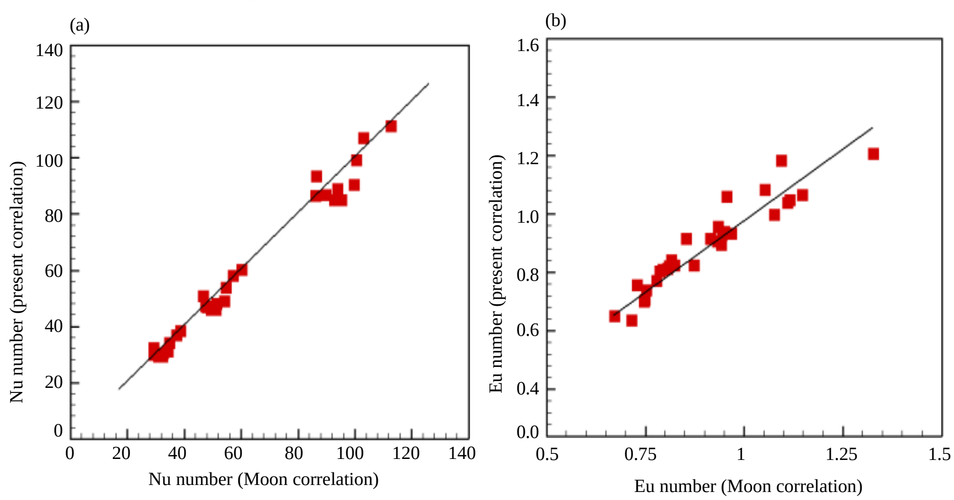

Fig. 10: Comparison of Nu and Eu number numerical values for in line finned tube heat exchangers with correlated by Eq. 7 and 8; a) Nu number and b) Eu number

Table 5: Comparison Nu number correlation with correlations from literature for various number of row at staggered bundle arrangement

Type	Z	Re number	Nu Eq. present study	Nu fluent (Mon, 2003)	Nu equatin (Mon, 2003)	Nu equation (Briggs and Young, 1963)	Nu equatin (Schmidt, 1963)	Nu equatin (VDI-GVC,1997)
S6	3	8600	60.620	61.02	54.370	51.490	50.29	55.500
S6	3	17000	88.480	90.14	81.800	81.900	76.99	83.540
S6	3	43000	148.090	150.46	142.810	154.090	137.51	145.790
S4	4	5000	42.043	44.82	36.300	33.230	29.13	36.900
S13	4	5000	43.560	44.18	38.750	38.170	38.56	41.280
S14	4	5000	39.570	39.24	37.280	38.170	38.56	41.280
S1	4	8600	65.250	62.81	58.600	61.160	64.21	61.210
S2	4	8600	62.310	61.90	55.290	55.220	54.12	57.160
S3	4	8600	59.850	59.60	52.910	51.630	47.56	54.280
S4	4	8600	56.800	57.69	50.260	48.070	40.88	51.090
S5	4	8600	55.080	55.96	48.880	46.350	37.62	49.420
S6	4	8600	62.830	62.43	54.370	51.490	50.29	55.500
S7	4	8600	60.570	59.43	57.99	68.628	66.92	62.230
S8	4	8600	47.330	46.610	44.98	49.890	52.78	53.980
S9	4	8600	62.630	61.85	55.52	58.520	54.51	57.320
S10	4	8600	62.173	62.04	55.18	54.090	53.93	57.080
S11	4	8600	56.270	56.76	53.17	55.220	51.89	56.200
S12	4	8600	63.770	62.31	55.79	55.220	54.57	57.350
S13	4	8600	58.870	57.40	53.65	55.220	54.12	57.160
S1	4	17000	95.250	93.30	88.20	97.290	98.31	92.120
S2	4	17000	90.960	91.01	83.22	87.840	82.861	86.037
S3	4	17000	87.430	86.57	79.63	82.120	72.81	81.700
S4	4	17000	82.920	81.65	75.64	76.470	62.59	76.900
S5	4	17000	80.460	78.53	73.57	116.850	57.60	74.390
S6	4	17000	91.710	92.27	81.84	81.900	76.99	83.540
S7	4	17000	88.420	88.20	87.28	109.150	102.46	93.660
S8	4	17000	81.240	80.24	83.234	94.530	96.34	98.230
S9	4	17000	91.420	90.85	83.57	93.081	83.46	86.280
S10	4	17000	90.750	91.21	83.05	86.040	82.56	85.910
S11	4	17000	82.140	82.64	80.03	87.840	79.44	84.600
S12	4	17000	92.640	92.24	83.98	87.840	83.56	86.320
S13	4	17000	85.920	86.53	80.76	87.840	82.86	86.030
S14	4	17000	78.550	76.56	77.70	87.840	82.86	86.030
S1	4	43000	159.180	156.65	153.92	183.030	175.59	160.760
S2	4	43000	152.240	153.33	145.23	165.250	147.99	150.140
S3	4	43000	146.330	146.17	138.97	154.500	130.05	142.570
S4	4	43000	138.780	134.76	132.01	143.860	111.79	134.200
S5	4	43000	134.670	130.23	128.38	138.710	102.88	129.810
S6	4	43000	153.500	153.95	142.81	154.090	137.51	145.790
S7	4	43000	147.990	151.77	152.31	205.350	183.00	163.450
S8	4	43000	133.430	131.12	139.87	142.230	143.87	147.110
S9	4	43000	153.010	152.43	145.84	175.110	149.07	150.570
S10	4	43000	151.890	153.89	144.93	161.870	147.46	149.920
S11	4	43000	137.470	132.65	139.66	165.250	141.89	147.630
S12	4	43000	155.060	158.16	146.55	165.250	149.24	150.640
S13	4	43000	143.810	149.60	140.93	165.250	147.99	150.140
S14	4	43000	131.470	135.80	135.60	165.250	147.99	150.140
S1	4	70000	208.560	202.38	206.19	206.190	255.06	238.100
S2	4	70000	191.780	189.36	186.16	215.300	176.36	191
S3	4	70000	193.950	196.69	204.04	286.170	248.16	218.960
S6	5	8600	64.311	63.18	54.37	51.490	50.29	55.500
S6	5	17000	93.872	93.39	81.84	81.900	76.99	83.540
S6	5	43000	157.110	155.43	142.81	154.000	137.51	145.790
S6	6	8600	65.220	63.6	54.37	51.490	50.28	55.500
S6	6	17000	95.200	94.13	81.84	81.900	76.99	83.540
S6	6	43000	159.350	156.79	142.81	154.090	137.51	145.700

Table 6: Comparison Eu number correlation with correlations from literature for various number of row at staggered bundle arrangement

Type	Z	Re	Eu equation present study	Eu Fluent (Mon, 2003)	Eu equation (Mon, 2003)	Eu equation (Robinson and Briggs, 1965)	Eu equation (Haaf, 1988)
S6	3	8600	1.53	1.53	1.49	1.98	1.54
S6	3	17000	1.30	1.32	1.27	1.59	1.30
S6	3	43000	1.05	1.00	1.01	1.191	1.03
S4	4	5000	2.16	2.30	2.33	2.47	2.61
S13	4	5000	1.87	1.66	1.72	2.67	2.52
S14	4	5000	1.57	1.62	1.33	2.043	2.83
S1	4	8600	1.71	1.6	1.72	2.96	1.96
S2	4	8600	1.82	1.79	1.83	2.64	2.06

Table 6: Continue

Type	Z	Re	Eu equation present study	Eu Fluent (Mon, 2003)	Eu equation (Mon, 2003)	Eu equation (Robinson and Briggs, 1965)	Eu equation (Haaf, 1988)
S3	4	8600	1.88	1.88	1.93	2.38	2.15
S4	4	8600	1.90	1.96	2.05	2.08	2.28
S5	4	8600	1.90	2.02	2.12	1.92	2.36
S6	4	8600	1.96	2.00	1.99	2.64	2.06
S7	4	8600	1.45	1.37	1.44	2.64	2.06
S8	4	8600	4.00	3.91	4.12	4.81	4.61
S9	4	8600	1.83	1.79	1.85	2.64	2.06
S10	4	8600	1.82	1.78	1.83	2.64	2.06
S11	4	8600	1.57	1.46	1.59	2.19	2.23
S12	4	8600	1.89	1.87	1.90	2.75	2.02
S13	4	8600	1.65	1.57	1.51	2.25	2.20
S1	4	17000	1.46	1.41	1.46	2.39	1.65
S2	4	17000	1.56	1.557	1.56	2.13	1.73
S3	4	17000	1.60	1.60	1.64	1.92	1.81
S4	4	17000	1.63	1.62	1.74	1.67	1.92
S5	4	17000	1.62	1.68	1.80	1.54	1.99
S6	4	17000	1.68	1.70	1.69	2.13	1.73
S7	4	17000	1.24	1.26	1.22	2.13	1.73
S8	4	17000	2.98	2.88	3.00	3.23	3.41
S9	4	17000	1.57	1.55	1.57	2.13	1.73
S10	4	17000	1.55	1.55	1.55	2.13	1.73
S11	4	17000	1.34	1.21	1.35	1.76	1.88
S12	4	17000	1.62	1.62	1.62	2.21	1.70
S13	4	17000	1.41	1.42	1.28	1.81	1.86
S14	4	17000	1.14	1.21	0.99	1.38	2.09
S1	4	43000	1.19	1.19	1.16	1.78	1.31
S2	4	43000	1.26	1.25	1.24	1.59	1.37
S3	4	43000	1.29	1.26	1.31	1.43	1.44
S4	4	43000	1.31	1.27	1.39	1.25	1.52
S5	4	43000	1.31	1.28	1.44	1.15	1.58
S6	4	43000	1.35	1.27	1.35	1.59	1.37
S7	4	43000	1.00	1.07	0.97	1.59	1.37
S8	4	43000	1.80	1.85	1.81	1.98	2.00
S9	4	43000	1.26	1.29	1.26	1.59	1.37
S10	4	43000	1.25	1.29	1.24	1.59	1.37
S11	4	43000	1.08	1.03	1.082	1.316	1.49
S12	4	43000	1.30	1.35	1.29	1.65	1.35
S13	4	43000	1.14	1.16	1.02	1.35	1.47
S14	4	43000	0.95	0.81	0.79	1.03	1.65
S1	4	70000	1.05	1.08	1.04	1.53	1.16
S2	4	70000	1.16	1.08	1.16	1.22	1.27
S3	4	70000	0.89	1.04	0.87	1.36	1.21
S6	5	8600	2.38	2.44	2.49	3.30	2.57
S6	5	17000	2.041	2.088	2.11	2.66	2.17
S6	5	43000	1.64	1.553	1.69	1.98	1.72
S6	6	8600	2.79	2.89	2.99	3.96	3.09
S6	6	17000	2.39	2.46	2.54	3.19	2.60
S6	6	43000	1.93	1.82	2.03	2.38	2.06

Table 7: Comparison Nu number correlation with correlations from literature for various number of row at in line bundle arrangement

Type	Z	Re	Eu equation present study	Eu Fluent (Mon, 2003)	Eu equation (Mon, 2003)	Eu equation (Robinson and Briggs, 1965)	Eu equation (VDI-GVC, 1997)
I	3	8600	32.29	29.3	27.86	33.5200	32.23
I4	3	17000	50.67	46.59	41.93	51.3200	48.36
I4	3	43000	93.58	86.52	73.16	91.6500	84.38
I1	4	8600	31.21	34.40	29.54	36.0810	33.09
I2	4	8600	30.64	32.61	27.56	31.7000	31.42
I3	4	8600	29.82	30.75	25.39	27.2500	29.58
I4	4	8600	29.36	32.234	27.86	33.5300	32.13
I5	4	8600	38.41	38.81	35.04	44.6100	36.02
I6	4	8600	36.95	37.39	30.55	34.5910	32.53
I7	4	8600	33.41	32.63	33.00	35.1239	36.23
I8	4	8600	29.98	29.31	31.45	36.0700	33.08
I9	4	8600	34.28	34.88	31.78	36.0800	33.09
I1	4	17000	48.97	54.09	44.45	55.2300	49.80
I2	4	17000	48.07	51.26	41.48	48.5400	47.29
I3	4	17000	46.79	48.07	38.22	41.7200	44.52
I4	4	17000	46.06	51.25	41.93	51.32	48.36

Table 7: Continue

Type	Z	Re	Eu equation present study	Eu Fluent (Mon, 2003)	Eu equation (Mon, 2003)	Eu equation (Robinson and Briggs, 1965)	Eu equation (VDI-GVC, 1997)
I5	4	17000	60.27	60.34	52.74	68.28	54.20
I6	4	17000	57.98	57.12	45.98	52.95	48.96
I7	4	17000	57.91	51.81	49.87	54.12	56.12
I8	4	17000	47.04	47.46	47.33	55.22	49.79
I9	4	17000	53.79	54.60	47.83	55.23	49.80
I1	4	43000	90.43	99.67	77.57	98.63	86.91
I2	4	43000	88.77	93.97	72.37	86.68	82.52
I3	4	43000	86.40	86.27	66.69	74.51	77.67
I4	4	43000	85.07	95.18	73.17	91.66	84.39
I5	4	43000	111.31	112.67	92.03	121.95	94.59
I6	4	43000	107.08	103.11	80.24	94.56	85.44
I7	4	43000	97.12	96.10	98.00	99.99	100.12
I8	4	43000	86.88	89.71	82.59	98.62	86.88
I9	4	43000	99.35	100.48	83.46	98.63	86.90
I4	5	8600	29.36	31.04	27.87	33.53	32.14
I4	5	17000	46.06	49.38	41.941	51.33	48.37
I4	5	43000	85.07	92.79	73.18	91.66	84.39

Table 8: Comparison Eu number correlation with correlations from literature for various number of row at in line bundle arrangement

Type	Z	Re	Eu equation present study	Eu Fluent (Mon, 2003)	Eu equation (Mon, 2003)	Eu equation (Haaf, 1988)
I4	3	8600	0.91	0.93	1.021	0.96
I4	3	17000	0.81	0.80	0.87	0.81
I4	3	43000	0.70	0.74	0.70	0.64
I1	4	8600	0.99	1.07	1.26	1.28
I2	4	8600	1.03	1.11	1.34	1.34
I3	4	8600	1.04	1.11	1.44	1.42
I4	4	8600	1.06	1.14	1.36	1.28
I5	4	8600	0.82	0.82	1.02	1.28
I6	4	8600	0.91	0.91	1.15	1.39
I7	4	8600	1.21	1.24	1.25	1.27
I8	4	8600	0.84	0.81	1.11	1.36
I9	4	8600	1.18	1.09	1.67	1.36
I1	4	17000	0.89	0.94	1.08	1.08
I2	4	17000	0.93	0.94	1.14	1.13
I3	4	17000	0.94	0.94	1.23	1.20
I4	4	17000	0.95	0.93	1.16	1.08
I5	4	17000	0.73	0.75	0.87	1.08
I6	4	17000	0.82	0.80	0.98	1.17
I7	4	17000	0.51	0.49	0.61	0.70
I8	4	17000	0.75	0.72	0.957	1.15
I9	4	17000	1.06	0.95	1.42	1.15
I1	4	43000	0.77	0.77	0.87	0.85
I2	4	43000	0.80	0.78	0.92	0.89
I3	4	43000	0.81	0.79	0.99	0.951
I4	4	43000	0.82	0.87	0.94	0.85
I5	4	43000	0.63	0.71	0.71	0.85
I6	4	43000	0.70	0.74	0.79	0.93
I7	4	43000	0.14	0.14	0.14	0.22
I8	4	43000	0.65	0.67	0.77	0.91
I9	4	43000	0.914	0.85	1.15	0.913
I4	5	8600	1.20	1.32	1.70	1.60
I4	5	17000	1.08	1.05	1.45	1.35
I4	5	43000	0.933	0.96	1.17	1.073

Table 9: Maximum deviation of Nu number and Eu number correlations, staggered arrangement Nu correlation

Variables	Eq. Present study (%)	Eq. Mon (2003) (%)	Eq. Briggs and Young (1963) (%)	Eq. Schmidt (1963) (%)	Eq. VDI-GVC(1997) (%)
Maximum deviation	6	19	48	35	17

Table 10: Staggered arrangement Eu correlation

Variables	Eq. Present study (%)	Eq. Mon (2003) (%)	Eq. Robinson and Briggs (1965) (%)	Eq. Haaf (1988) (%)
Maximum deviation	18	19	92	75

Table 11: In line arrangement Nu correlation

Variables	Eq. Present study (%)	Eq. Mon (2003) (%)	Eq. Schmidt (1963) (%)	Eq.VDI-GVC (1997) (%)
Maximum deviation	10	22	23	14

Table 12: In line arrangement Eu correlation

Variables	Eq. Present study (%)	Eq. Moon (2003) (%)	Eq. Haaf (1988) (%)
Maximum deviation	11	53	67

CONCLUSION

A new correlation has been developed to predict the heat transfer for both staggered and in-line arrangements in finned tubes heat exchanger. For both staggered and in-line arrangements, the Nu number increased with increased Re number at all bundles. But Eu number has an adverse effect. The change in value of Nusselt number or Euler number was very small between the bundles for staggered and in line arrangement. In staggered bundle arrangement S1 when increased fin spacing and decreased fin height provides increased of Nu number and decreased Eu number. Decreased fin spacing and increased fin height causes increased both Nu number and Eu number for I1 bundle in line arrangement. Maximum deviation in Nusselt number and Euler number correlations (6, 18% for staggered and 10, 11% for in line), respectively.

NOMENCLATURE

Symbol/Description

d = Tube diameter (mm)

d_f = Fin diameter (mm)

Eu = Euler number

h_f = Fin height (mm)

k = Thermal conductivity (W/(m.°K))

Pr = Prandtl number
P = Pressure (N/m^2)
Re = Reynolds number
S_t = Transverse tube pitch (mm)
S_L = Longitudinal tube pitch (mm)
S = Fin spacing (mm)
S_f = Fin pitch (mm)
Nu = Nusselt number
Z = Number of row
δ = Fin thickness (mm)

REFERENCES

Anoop, B., C. Balaji and K. Velusamy, 2015. A characteristic correlation for heat transfer over serrated finned tubes. Anal. Nucl. Energy, 85: 1052-1065.

Briggs, D.E. and E.H. Young, 1963. Convection heat transfer and pressure drop of air flowing across triangular pitch banks of finned tubes. Chem. Eng. Prog. Symp. Ser., 59: 1-10.

FaJiang, H., C. WeiWu and Y. Ping, 2012. Experimental investigation of heat transfer and flowing resistance for air flow cross over spiral finned tube heat exchanger. Energy Procedia, 17: 741-749.

Haaf, S., 1988. [Heat Transfer in Air Coolers]. In: Handbook of Refrigeration, Plank, R., (Ed.). Springer, Berlin, Germany, ISBN:9783540154778, pp: 435-491 (In German).

Mon, M.S., 2003. Numerical investigation of air-side heat transfer and pressure drop in circular finned-tube heat exchangers. Ph.D Thesis, Freiberg University of Mining and Technology, Freiberg, Germany.

Robinson, K.K. and D.E. Briggs, 1966. Pressure drop of air flowing across triangular pitch banks of finned tubes. Chem. Eng. Prog. Symp. Ser., 64: 177-184.

Schmidt, E., 1963. [The heat transfer to finned tubes and the calculation of tubular heat exchangers (In German)]. Kaltetechnik, 15: 370-378.

Taler, D., 2012. Experimental determination of correlations for mean heat transfer coefficients in plate fin and tube heat exchangers. Arch. Thermodyn., 33: 1-24.

VDI-GVC, 1997. [VDI Heat Atlas: Calculation Sheets for Heat Transfer]. 8th Edn., Springer, Berlin, Germany, ISBN:9783540629009, Pages: 1414 (In German).

Wais, P., 2016. Correlation and numerical study of heat transfer for single row cross-flow heat exchangers with different fin thickness. Procedia Eng., 157: 177-184.