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# Designing and Simulation of Heat Transfer in Tube Bundles with Triangular and Rectangular Heat Exchanger Arrangement

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## Abstract

In the current study, the heat transfer rate and pressure drop for the flow on the heat exchanger tube bundle with the two triangular and rectangular arrangements were computed experimentally using Grimson and Zukauskas equations and the ANSYS Fluent Software. Prior to running simulation in the ANSYS Fluent, the tubes bundle geometry was designed by the use of SOLIDWORKS Software, and then it was meshed by the ANSYS Software. The meshing was done 16 times for each arrangement. After the simulation, the results were compared to the experimental values obtained from Grimson and Zukauskas equations and their differences and reasons were discussed in the form of charts. It can be concluded from the experimental computations by Grimson and Zukauskas equations and comparing them with the results obtained from simulation of the intended models in the ANSYS Fluent Software (tables) that in the $S_L/D$ constant ratios (the ratio of distance between the two tubes to radius of one tube in the direction of flow), by the increase in $S_T/D$ (the ratio of the distance between the two tubes in the direction perpendicular to the flow), the heat transfer and pressure drop were significantly decreased. Finally, suggestions for the improvement of future works in this field have been provided.

**Keywords:** Heat exchanger, Triangular arrangement, Rectangular arrangement, Heat transfer.

## Introduction

The heat exchanger is a device that transfers heat energy to one or more fluids with different temperatures. This definition implies that there are at least two fluids in a heat exchanger between which the heat is transferred. The crossover heat exchangers are widely used in industrial applications such as the steam production in the boilers, or for air heating and cooling inside an air conditioner, or transferring heat from other gases. There is a type of exchangers in which a gas with a forced flow passes over the tubes while another fluid with a different temperature, which is used for heating and/or cooling, is flowing inside the tubes. In these heat exchangers, the flow of the fluid passing over the tubes, is named 'mixed flow', since it can move around freely during the heat exchange, while another fluid is flowing inside separate tube ducts during the heat exchange that cannot be mixed with itself, so it is called 'unmixed flow'. Whether the fluid inside the exchanger is flowing in the mixed or unmixed form, affects the total rate of heat transfer by the heat exchanger and the pressure drop in the passing flow.

There are studies conducted in this field. In 2008, Gholami and Ahmadi Kia investigated water spray effects on the natural cooling tower performance, numerically and analytically. The water is sprayed through the especial sprayers mounted between the radiators and shutters. The air passing through the small drops of water is cooled and is entered into the radiator, lowering the tower's output water temperature (Ahmadi Kia, and Gholami, 2008). In 2010, Jawadi et al. studied the improvement of power plan by the use of water drops injection into the condenser input air numerically and by the use of ANSYS Fluent Software (Javadi et al., 2010). Hurria and Elena in 2006, empirically investigated the heat transfer from a tube bundle in a crossover flow and compared their results with the Nusselt's theory equations. In 2004, George Faco and Oliveira computed the equations between heat transfer and the mass for designing small direct touch cooling tower (Facao and Oliveira, 2004). The obtained heat transfer and mass coefficients indicated that mass transfer is directly related to the air flow discharge and the heat transfer coefficients are related to the water spray discharge. Also, they discussed the air humidity effects.

In 2003, Ali Hasan and Kay Siren investigated the simple and finned tubes of evaporative exchangers (Hasan and Siren, 2003). In 1993, Hornata Walchik empirically studied the heat transfer increase from the air fin cooler with water sprayer (Walczyk, 1993). He considered a rooftop condenser with horizontal sprayer. His experimental results indicated that with the water spray, the heat transfer is increased by 125%. Nakayama et al. study`s results in 1988 revealed that when the water evaporates on the surface, it is the main mechanism of heat

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transfer increase (Nakayama, Kuwahara and Hirasawa, 1988). The pressure drop data showed that when there is a mixed air flow, compared to when the air is in a single-phase, in both cases the pressure difference is low, and it can be said that spray is not much effective on the pressure drop. In this regard, the current study aimed at investigating the effects of distance between the tubes on the heat transfer and pressure drop in flow passing over tubes bundle through the use of Grimson and Zukauskas equations and comparing them with results obtained from Computational Fluids Dynamic (CFD) in similar conditions.

## Methodology

In the current study, the problem modeling was done using SOLIDWORKS Software. After the modeling, the modeled geometry was meshed by the use of ANSYS Software for thermal analysis of the problem in Fluent Software, and then, the rest of the simulations were done in Fluent Software. In all the used models, including the computational experiments in Fluent Software, the same air coefficient speed was considered, so that the comparison and effects of the parameters could be investigated. Therefore, the speed input conditions for the air inlet level were used in the whole model. The air input speed for each model was 6m/s and its temperature was 293.15 Kelvin. The fluid inside the tubes was hot water and its flow was in a way that increased the tubes outside surface temperature to 366.15 Kelvin. Thus, the boundary conditions of the wall have been defined with a fixed temperature. The heat transfer and pressure drop rate for the three rows of tube bundles with triangular and rectangular was determined. For making the results better, the results for different arrangements have been also computed.

Table 1: Heat transfer rate using Grimson experimental equation for the models with the rectangular arrangement

| $S_T/D$=3 (W) | $S_T/D$=2 (W) | $S_T/D$=1.5 (W) | $S_T/D$=1.25 (W) | $S_L/D$ |
|---|---|---|---|---|
| 0.6410 | 0.8451 | 1.2516 | 1.8433 | 1.25 |
| 0.6633 | 0.8382 | 1.2739 | 1.8315 | 1.5 |
| 0.8381 | 1.0113 | 1.2861 | 1.7795 | 2 |
| 0.8541 | 1.043 | 1.2961 | 1.6796 | 3 |

Table 2: Pressure drop rate using Zukauskas experimental equation for the models with the rectangular arrangement

| $S_T/D$=3 (Pa) | $S_T/D$=2 (Pa) | $S_T/D$=1.5 (Pa) | $S_T/D$=1.25 (Pa) | $S_L/D$ |
|---|---|---|---|---|
| 31.26 | 91.11 | 272.83 | 611.88 | 1.25 |
| 30.14 | 85.46 | 214.32 | 590.16 | 1.5 |
| 34.48 | 60.86 | 170.37 | 533.33 | 2 |
| 23.07 | 53.58 | 146.75 | 439.89 | 3 |

Table 3: Heat transfer rate using Grimson experimental equation for the models with the triangular arrangement

| $S_T/D$=3 (W) | $S_T/D$=2 (W) | $S_T/D$=1.5 (W) | $S_T/D$=1.25 (W) | $S_L/D$ |
|---|---|---|---|---|
| 1.023 | 1.1021 | 1.3185 | 1.8308 | 1.25 |
| 0.9806 | 1.1401 | 1.2950 | 1.7857 | 1.5 |
| 0.9181 | 0.9598 | 1.2392 | 1.6993 | 2 |
| 0.9063 | 0.9863 | 1.1874 | 1.5665 | 3 |

Table 4: Pressure drop rate using Zukauskas experimental equation for the models with the triangular arrangement

| $S_T/D$=3 (Pa) | $S_T/D$=2 (Pa) | $S_T/D$=1.5 (Pa) | $S_T/D$=1.25 (Pa) | $S_L/D$ |
|---|---|---|---|---|
| 52.69 | 102.79 | 232.18 | 798.76 | 1.25 |
| 50.46 | 100.35 | 243.79 | 836.89 | 1.5 |
| 49.11 | 101.82 | 255.4 | 874.83 | 2 |
| 46.88 | 107.69 | 278.62 | 950.45 | 3 |

In the findings chapter, the same results have been obtained for similar geometrical conditions by the use of Fluent Software, which were compared with the existing results.

## Findings

*SOLIDWORKS Modelling:*

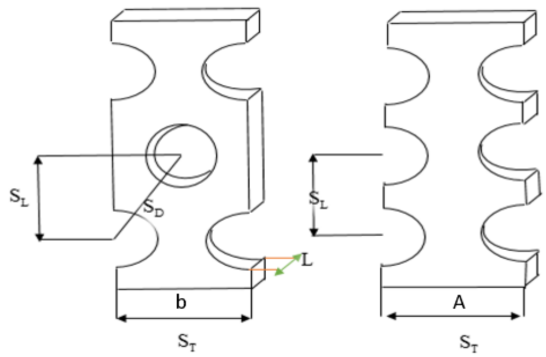


**Figure 1:** Schematic of different arrangements of the tubes, a) rectangular, b) triangular

It should be noted that the tubes diameter (D) and the transverse thickness (L) in both of the arrangements were 16.4 and 2 mm, respectively. Also, in the computations used in the experimental equations, the airspeed has been considered to be 6 m/s, which was equal to the speed considered for the Fluent Software, so that the comparison and effects of the parameters can be investigated by the experimental analysis.

*Modelling the Tube Bundle with Rectangular Arrangement in SOLIDWORKS Software:*

Due to the existence of asymmetry in the shape of the tubes bundle, only half of the whole shape has been modeled in SOLIDWORKS Software. The value of $S_L$ and $S_T$ has been 20.5 mm, which was equal for both of the arrangements.

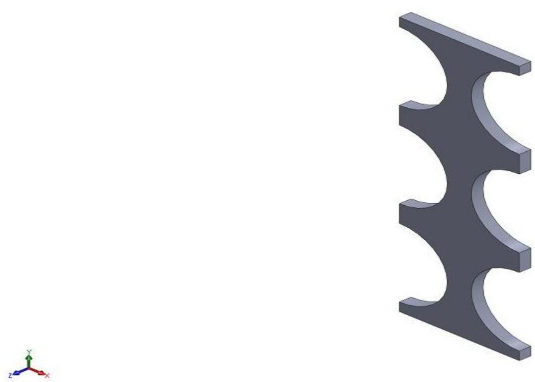

**Figure 2:** Schematic of rectangular arrangement of tubes bundle in SOLIDWORKS

*Modelling the Tubes Bundle with Triangular Arrangement in SOLIDWORKS Software:*

The value of $S_L$ and $S_T$ has been 20.5 mm, which was equal for both of the arrangements.

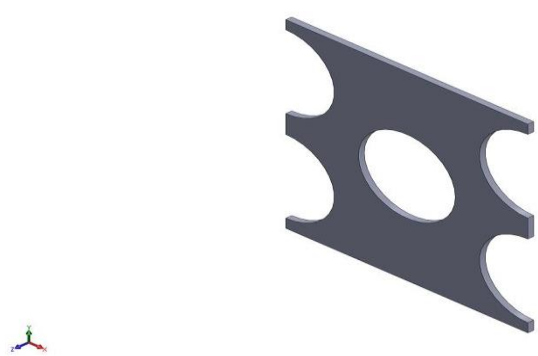

**Figure 3:** Schematic of triangular arrangement of tubes bundle in SOLIDWORKS

*Meshing in ANSYS Software:*

The meshing was done 16 times for each arrangement. Table (5) shows the number of meshing in ANSYS Software for the three rows of tubes with a rectangular arrangement.

Table 5: The number of meshes used in heat exchanger with three rows of tubes bundle with rectangular arrangement

| $S_T/D=3$ | $S_T/D=2$ | $S_T/D=1.5$ | $S_T/D=1.25$ | $S_L/D$ |
|---|---|---|---|---|
| 280430 | 166430 | 109760 | 81100 | 1/25 |
| 318440 | 190460 | 128120 | 98310 | 1/5 |
| 389440 | 237720 | 162200 | 127630 | 2 |
| 533300 | 340630 | 241310 | 190880 | 3 |

Table 6: The number of meshes used in heat exchanger with three rows of tubes bundle with triangular arrangement

| $S_T/D=3$ | $S_T/D=2$ | $S_T/D=1.5$ | $S_T/D=1.25$ | $S_L/D$ |
|---|---|---|---|---|
| 276950 | 165500 | 108710 | 80810 | 1.25 |
| 314960 | 188340 | 127480 | 96380 | 1.5 |
| 390910 | 242090 | 165430 | 128440 | 2 |
| 542280 | 339510 | 240230 | 190890 | 3 |

*Rectangular Arrangement Simulation:*

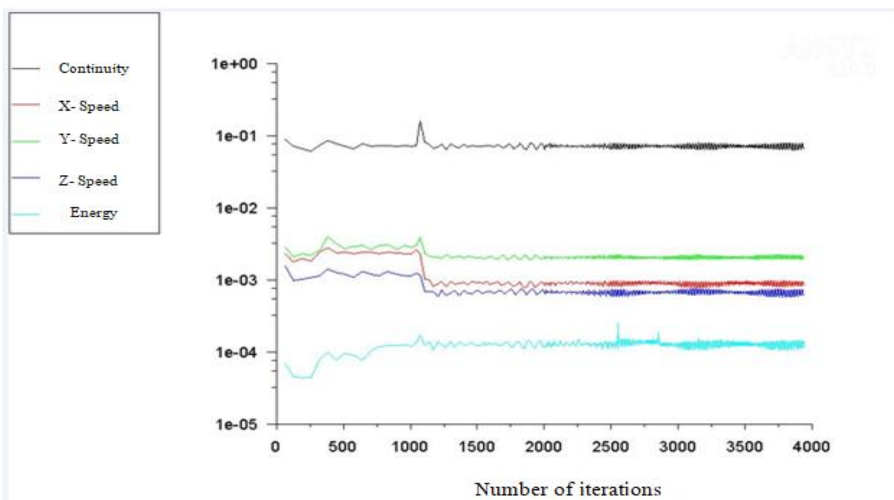


**Figure 4:** The relationship between the number of iterations and the equations convergence in rectangular arrangement

As it is seen in figure (4), the higher the number of iterations got, the more the equations convergence was. However, higher number of iterations required more time and higher hardware power. In the followings, in order to decrease the work volume, only the results of simulations with the $S_T/D=1.25$ and $S_T/D=1.5$ per $S_L/D=1.25$, have been shown for both rectangular and triangular arrangements.

Table 7: Pressure drop obtained from Fluent Software for the models with the rectangular arrangement

| $S_T/D=3$ (Pa) | $S_T/D=2$ (Pa) | $S_T/D=1.5$ (Pa) | $S_T/D=1.25$ (Pa) | $S_L/D$ |
|---|---|---|---|---|
| 26/5 | 46/75 | 119 | 318/28 | 1/25 |
| 27/25 | 48/45 | 125/75 | 326/5 | 1/5 |
| 28/25 | 49/25 | 133/75 | 343/5 | 2 |
| 28/75 | 49/75 | 143 | 371/75 | 3 |

Table 8: Heat transfer rate obtained from Fluent Software for the models with the rectangular arrangement

| $S_T/D$=3 (W) | $S_T/D$=2 (W) | $S_T/D$=1.5 (W) | $S_T/D$=1.25 (W) | $S_L/D$ |
|---|---|---|---|---|
| 0/7134 | 0/7734 | 0/8981 | 1/0345 | 1/25 |
| 0/745 | 0/7945 | 0/9547 | 1/0934 | 1/5 |
| 0/8042 | 0/8725 | 1/0287 | 1/1460 | 2 |
| 0/8341 | 0/9841 | 1/540 | 1/1830 | 3 |

*Simulation of Triangular Arrangement:*

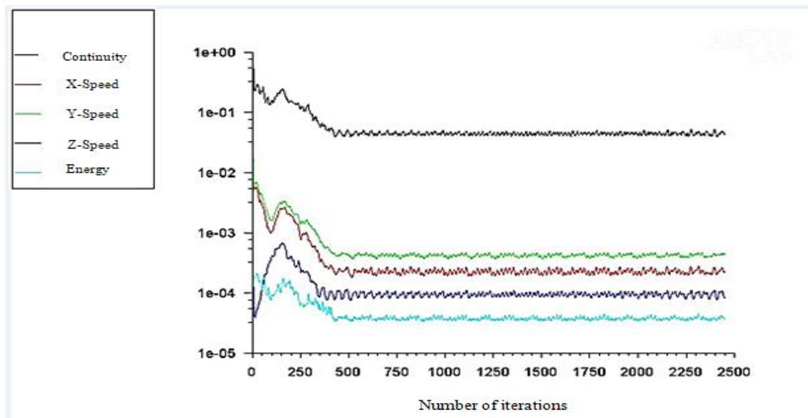


**Figure 5:** The relationship between the number of iterations and the equations convergence in triangular arrangement

As it is seen in figure (5), the higher the number of iterations got, the more the equations convergence was. Table (9) shows the pressure change rate for other models with the triangular arrangement, and table (10) shows the heat transfer for other models with the triangular arrangement.

Table 9: Pressure drop obtained from Fluent Software for the models with the triangular arrangement

| $S_T/D$=3 (Pa) | $S_T/D$=2 (Pa) | $S_T/D$=1.5 (Pa) | $S_T/D$=1.25 (Pa) | $S_L/D$ |
|---|---|---|---|---|
| 65/25 | 74/5 | 130 | 323/75 | 1/25 |
| 57/5 | 67/5 | 131/75 | 337/75 | 1/5 |
| 49/25 | 68/25 | 133/75 | 340/5 | 2 |
| 48/75 | 78/75 | 145 | 362/75 | 3 |

Table 10: Pressure drop obtained from Fluent Software for the models with the rectangular arrangement

| $S_T/D$=3 (W) | $S_T/D$=2 (W) | $S_T/D$=1.5 (W) | $S_T/D$=1.25 (W) | $S_L/D$ |
|---|---|---|---|---|
| 0/9963 | 0/0239 | 1/1035 | 1/2978 | 1/25 |
| 0/9813 | 1/0144 | 1/0955 | 1/2105 | 1/5 |
| 0/9434 | 0/9953 | 1/1186 | 1/1895 | 2 |
| 0/9419 | 1/0111 | 1/1374 | 1/1988 | 3 |

*Comparison between the Results Obtained from Experimental Computations and the Results Obtained from the Simulation:*

It can be concluded from the experimental computations by Grimson and Zukauskas and comparing them to the results obtained from simulation of the intended models in Fluent Software (tables) that in the $S_L/D$ coefficient ratios (the ratio of the distance between two tubes to diameter of one, in direction of the flow), by the increase in $S_T/D$ ratio (the ratio of the distance between two tubes in the direction perpendicular to the flow), the heat transfer and pressure drop was significantly decreased.

Since in the experimental computations, the gas output temperature after heat transfer was unknown, the log mean temperature equation couldn`t be used. Thus, as it is seen from the results, with $S_L/D$ ratio being fixed, and the increase in $S_T/D$ ratio, the values obtained from the two methods got close, due to the increase in cooling gas flow passing surface, and consequent closeness of the mean temperature of gas passing flew to its numerical value in the exchanger inlet.

*The Comparison of Heat Transfer and Pressure Drop in Rectangular and Triangular Arrangements:*

In the rectangular arrangement of tubes, with the $S_T/D$ ratio being fixed in 1.25 and the increase in $S_L/D$ ratio in the results obtained from Grimson equation, the heat transfer rate was decreased while the results obtained from Fluent Software turned out to be the opposite. In other fixed ratios of $S_T/D$, with the increase in $S_L/D$, both methods showed the same results, i.e. the increase in heat transfer rate.

In the triangular arrangement of the tubes, with the $S_T/D$ ratio being fixed in 1.25 and 1.5, with the increase in $S_L/D$ ratio, the heat transfer was decreased in the results obtained from Grimson equation, while it was the opposite for results obtained from Fluent Software. In other fixed ratios of $S_T/D$, with the increase in $S_L/D$, both methods showed the same results, i.e. the increase in heat transfer rate.

In the rectangular arrangement of the tubes, with the $S_T/D$ ration being fixed at 1.25, and the increase in $S_L/D$ ratio, in the results obtained from Zukauskas equation, the pressure drop rate was decreased, while it turned out to be the opposite in results obtained from Fluent Software, i.e. with the increase in $S_L/D$ ratio, and fixed values of $S_T/D$, the pressure drop was increased.

In the triangular arrangement of the tubes, with the $S_T/D$ ratio being fixed at 1.25 and 1.5, and the increase in $S_L/D$ ratio, the results obtained from both the Zukauskas and the Fluent Software showed an increase in the pressure drop and in the $S_T/D$ ratio fixed at 2, with the increase in $S_L/D$, both methods had initially a decrease and then an increase in the pressure drop. Finally, in the $S_T/D$ ratio fixed at 3, with the increase in $S_L/D$, the results obtained from both methods showed a decrease in pressure drop. In the followings, some charts are drawn for a better understanding of what was mentioned.

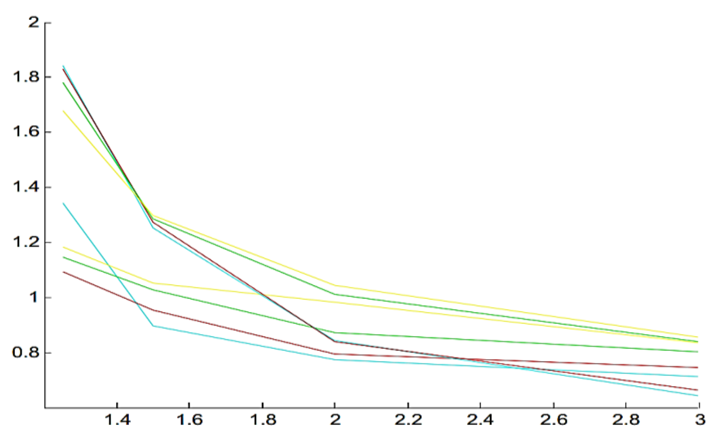


**Figure 6:** The comparison in heat transfer between the experimental equations and the Fluent Software for the rectangular arrangement

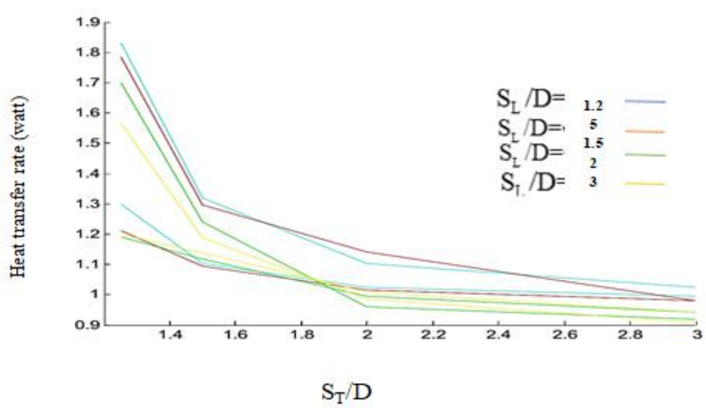


**Figure 6:** The comparison in heat transfer between the experimental equations and the Fluent Software for the triangular arrangement

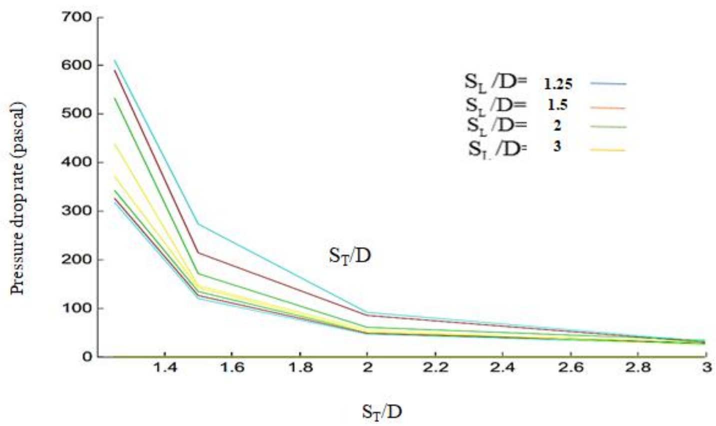


**Figure 6:** The comparison in pressure drop between the experimental equations and the Fluent Software for the rectangular arrangement

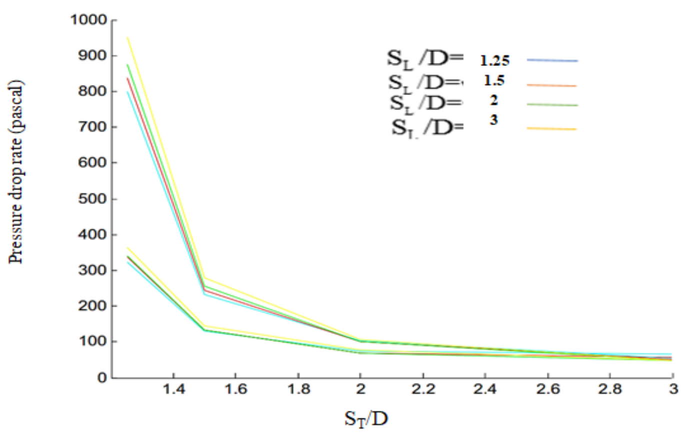


**Figure 6:** The comparison in pressure drop between the experimental equations and the Fluent Software for the triangular arrangement

## Conclusion

1- In the rectangular arrangement of the tubes, with $S_T$/D ratio being fixed, Zukauskas equation recommended the increase in $S_L$/D ratio for the decrease in pressure drop, while the Fluent Software showed the decrease in $S_L$/D ratio for the reduction in pressure drop. Also, the experimental equations, for higher heat transfer rates with the assumption of $S_T$/D being fixed, recommended a decrease in $S_L$/D in values closer to 1, while the Fluent Software recommended an increase in $S_L$/D for higher heat transfer rates.

2- In the triangular arrangement of the tubes, the results obtained from Zukauskas and Fluent Software had good accordance in terms of pressure drop, as in both methods, with $S_T$/D ratio being fixed at 1.25 and 1.5, and the increase in $S_L$/D ratio, the pressure drop was decreased. Also, with $S_T$/D ratio being fixed at 2, both methods initially showed a decrease and then an increase in pressure drop. Finally, with $S_T$/D ratio being fixed at 3, both of the methods showed a decrease in pressure drop with the increase in $S_L$/D ratio. However, for heat transfer rate, in Grimson equation results, with $S_T$/D ratio being fixed at 1.525 and 1.5, the increase in $S_L$/D ratio has been shown for the increase in the heat transfer rate. For other fixed values of $S_T$/D, both of the methods showed a decrease in $S_L$/D for increasing the heat transfer rate.

3- In both rectangular and triangular arrangements of the tubes, the results obtained from experimental computations and the Fluent Software indicated that with $S_L$/D ratio being fixed, and with the increase in $S_T$/D, the pressure drop and heat transfer rates were significantly decreased, and the ratio of this decrease for each fixed $S_L$/D ratio was an approximately fixed and specified value. As a result, it is seen that the highest effects on the heat transfer and pressure drop belonged to the changes in distance between the tubes in the direction perpendicular to the gas flow passing over the tubes, in both the Grimson and Zukauskas equations and the Fluent Software, while the changes in distance between the tubes in the direction of gas flow passing in the tubes had fewer effects on the heat transfer and pressure drop in the passing gas.

4- The results obtained from Grimson equation showed that in values of $S_T$/D ratio close to 1 (1.25), with the increase in $S_L$/D ratio, the heat transfer ratio in heat exchanger was higher for the rectangular arrangement as compared to the triangular arrangement, while for other situations, in similar conditions, the heat transfer in triangular arrangement was higher than rectangular arrangement. The results obtained from the Fluent Software revealed that in the similar conditions for a heat exchanger with crossover flow, the heat transfer in triangular arrangement of the tubes was higher than the rectangular arrangement. Also, it is seen in the computations by Zukauskas and Fluent Software that in the similar conditions for a heat exchanger with crossover flow, the pressure drop in the triangular arrangement of the tubes was higher than the pressure drop in rectangular arrangement.

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