

# Thermal Design and Rating of a Shell and Tube Heat Exchanger Using a Matlab® GUI

Luis Guillermo Obregon Quinones<sup>1\*</sup>, Luis Felipe Arrieta Viana<sup>2</sup> and Guillermo Eliecer Valencia Ochoa<sup>3</sup>

<sup>1</sup>Chemical Engineering Program, Research Group on Sustainable Chemical and Biochemical Processes, Universidad del Atlántico, Km 7 Antigua Vía a Puerto Colombia, Barranquilla, Colombia; luisobregon@mail.uniatlantico.edu.co

<sup>2</sup>Chemical Engineering Program, Research Group on Simulation and Process Control, Universidad del Atlántico, Km 7 Antigua Vía a Puerto Colombia, Barranquilla, Colombia; lfarrieta@outlook.com

<sup>3</sup>Mechanical Engineering Department, Research Group on Efficient Energy Management, Universidad del Atlántico, Km 7 Antigua Vía a Puerto Colombia, Barranquilla, Colombia; guillermoevalencia@mail.uniatlantico.edu.co

## Abstract

**Objectives:** To design and rate a Shell and Tube Heat Exchanger Using a Matlab® GUI and assess it with the evaluation guide ISO/IEC 9126-1 **Methods/Statistical analysis:** The general procedure is initiated by estimating the heat flow, the thermal properties and some dimensionless numbers in heat transfer based on the caloric temperature for the fluids. Finally, the films and overall heat transfer coefficients were used to estimate the heat transfer area, which is needed to calculate the approximate size of the equipment, and therefore its cost, been this goal a powerful tool for engineering education.

**Findings:** The student can see the effect of the dirt factor, the geometrical configuration, the thickness of the tubes, and the flow velocity inside or outside the tubes, etc., on the resistance of the total heat exchange between the fluids to later carry out laboratory experiences where they can compare the results and give a better explanation of the profiles obtained with the variable chosen to be studied. It can help engineering students to be more creative in finding different ways to increase the efficiency of heat exchangers or in the design of new ones. Using the program, it was determined the lowest obstruction factor to the heat transfer as a function of BWG number and external tube diameter, the correction factor of the log mean temperature difference and the Dittus and Boelter, and Sieder and Tate parameters. It was confirmed the importance of the software in the student learning process according to the software quality requirements and evaluation guide ISO/IEC 9126-1. **Application/Improvements:** The GUI let students to reach the heat transfer educational objectives and the program outcomes expected for new engineers improving the communication between design engineers and technicians in industry.

**Keywords:** Dittus and Boelter Parameters, Engineering Software Education, Graphical User Interface, Obstruction Factor, Shell and Tube Heat Exchanger

## 1. Introduction

The general industry of chemical processes around the world needs personnel highly capacitated in transport phenomena. People that possess that knowledge acquire the ability to find and solve different kind of unitary operation problems in many companies in an efficient manner. However, in order to have a complete understanding of this subject, it is necessary to understand their com-

ponents. One of them is the heat transfer phenomenon which is involved in power, chemical, and petrochemical plants, petroleum refineries, food industry, etc. This phenomenon has to be well understood when designing heat exchangers due to the need to take advantage of the maximum heat transmitted between two fluids.

With the goal of preparing professionals with the specific required training, some educative academies employ in their curriculum laboratory experiences where

\*Author for correspondence

the student can operate and analyze the behavior of heat exchangers, as well as to explain how close the theory to the reality is. Nevertheless, it takes too much time to carry out experiments to see the effect of all the factors involved in the design and operation of these equipments.

There is strong commercial software such as Aspen, ChemCAD, CcTherm, Pro/II, Simsci, etc., capable to simulate processes and equipments to get the highest efficiency<sup>1-9</sup>. These programs are really important for the broad industry because they are designed to choose the best process or equipment design through a complete research that involve a deep former knowledge of the user. The programs mentioned above are so extensive and robust that embraces a huge amount of different processes lacking for tutorials that help specific academy trainings. Even when most of these programs are user friendly, they are not designed for educational purposes.

Some researchers have designed other important software such as COMSOL Multiphysics, ANSYS Fluent, etc., where the user can see what happens internally in a heat exchanger, e.g. flow, temperature and pressure profiles<sup>10-12</sup>. The results obtained when using these programs are greatly exact and accurate; however, the level of understanding the physic involved in these programs are for graduate students because of the complexity of the numerical solutions used when solving the governing differential equations.

The lack of having an easy and practical educational tool that simulate process equipments create a restriction in undergraduate students to go beyond their training limits when designing or implementing trouble shooting in the industry or even more when creating new software. In addition, to complement the knowledge obtained theoretically and experimentally in the academy, it is necessary to implement in their curriculum user-friendly software<sup>13</sup> where the student would be able to understand and explain the phenomena happening in chosen equipment when different factors are changed.

The contribution of this paper is the development of new interactive software to design shell and tube heat exchangers. It let undergraduate students to manipulate different variables that let them to understand the phenomena happening internally inside the shell and tubes. The student can see the effect of the dirt factor, the geometrical configuration, the thickness of the tubes, and the flow velocity inside or outside the tubes, etc., on the resistance of the total heat exchange between the fluids to later carry out laboratory experiences where they can

compare the results and give a better explanation of the profiles obtained with the variable chosen to be studied. It can help engineering students to be more creative in finding different ways to increase the efficiency of heat exchangers or in the design of new ones. The software was developed under criteria-based assessment ISO/IEC 25010:2011 which consider the product quality and include usability, sustainability and maintainability. The assessment of these criteria was carried out under three case studies in undergraduate students of chemical engineering in the class of heat transfer at the Universidad del Atlantico, where 40 students highly prepared in computational coding worked with the software S&THEX-UA V1.0. The case studies selected were the determination of the lowest obstruction factor, the determination of the correction factor of the log means temperature difference, and the numerical determination of the Dittus and Boelter, and Sieder and Tate parameters. It was confirmed the importance of the software in the learning process because it was found a significant positive effect on the learning of the design of shell and tube heat exchangers supported by the software S&THEX-UA V1.0.

## 2. Algorithm Presentation

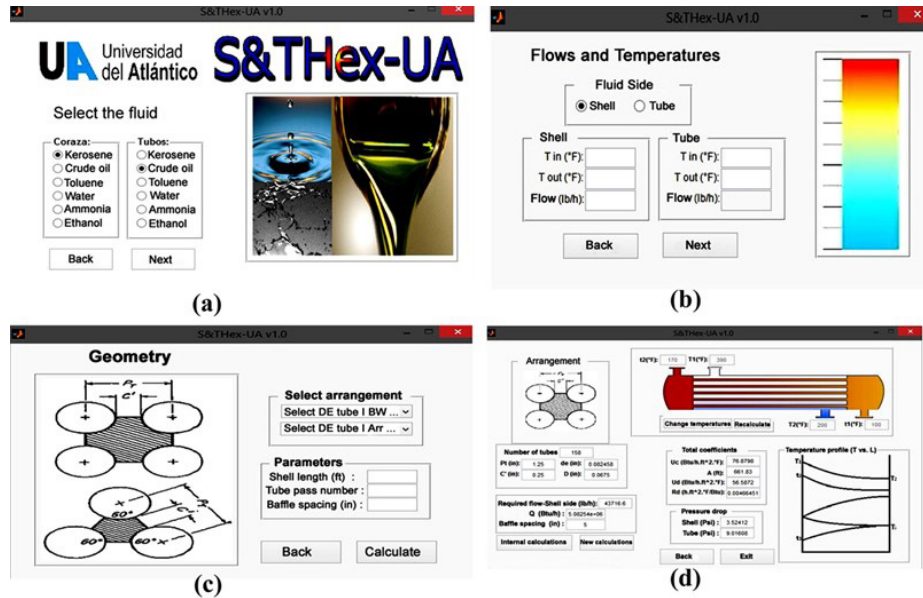
### 2.1 General Aim of the GUI Algorithm

The program S&THEX-UA V1.0, which is an innovative graphical user interface, can be used by undergraduate engineering students and engineers beginning their professional practice to solve real process problems.

It was designed with inputs such as a set of geometrical configuration and operating conditions i.e. the tube layout, flow rates, temperatures and a variety of liquid fluid. Then, it calculates the shell and tube side film, the overall heat transfer and the clean coefficients, the combined dirt factor and the total heat transfer area, using the physical properties of the different fluids as a function of the caloric temperature shown in Figure 1.

This software was registered in the D.N.D.A. Dirección Nacional de Derechos de Autor (National Leadership Copyright, in English), with register 13-45-25 at the 9 December 2014.

According to the academic web sites quality model<sup>14</sup> there are some important academic and pedagogical components of this software for educational and professional level that can be identified as follow:



**Figure 1.** Main View of the S&THex-UA v1.0 software. (a) Fluid Type Selection; (b) Operating conditions; (c) Geometrical configuration; (d) Results.

The software let undergraduate students to understand the thermal and hydraulic phenomena in shell and tube heat exchangers in order to reach the educational objectives heat transfer courses and the program outcomes expected for the new engineers.

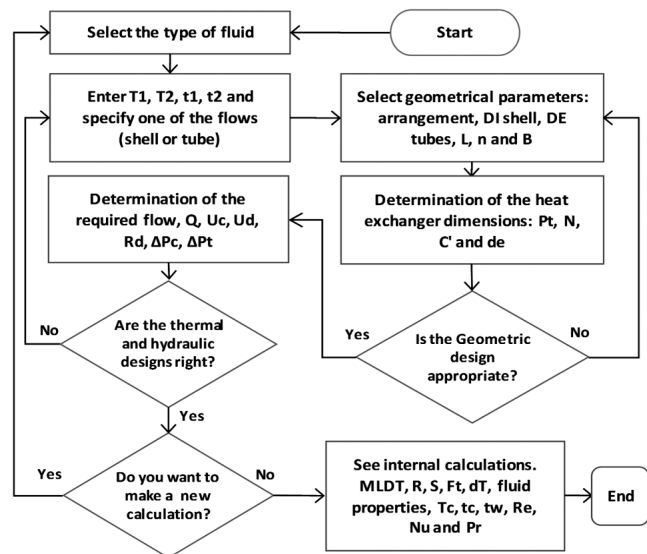
- For engineers in the industry, the software is a valuable instrument that can be used to improve the communication between the design engineers and the technician in engineering.
- When following a well-structured decision-making routine, the software involves a progressive learning process on heat transfer. The performance of a proposed heat exchanger using S&THex-UAv1.0 increases with the increase of the grade of learning of the user. The learning process has important implications for heat exchanger designers when determining the size of the equipment to be installed on any chemical plant, and for operators and maintenance personnel when estimating the clean coefficient respect to design coefficient values of the current heat exchanger.

## 2.2 Flowchart of the GUI

The S&THex-UA v.1 had been developed and tested with Matlab®7.0. It is expected to work with any modern version of Matlab/Simulink since R12. The system requirements depend heavily on the version of Matlab you are

using. S&THex-UA v.1 will run on any Microsoft 32-bit Windows PC on which Matlab/Simulink is installed. All the S&THex-UA file use less than 400 MB disk space.

The computational steps involved on the software are shown on Figure 2.



**Figure 2.** Flowchart of the S&THex-UA v1.0.

## 2.3 Relations Used in the Algorithm

All the fundamental equations involved in the software are organized as follows<sup>15</sup>:

The heat transfer is estimated by the energy balance in the heat exchanger as stated in Equation 1:

$$Q = UA\Delta T = WC(t_1 - t_2) \quad (1)$$

where the true temperature difference (see equation 2) is:

$$\Delta T = F_T \cdot LMTD \quad (2)$$

the logarithmic mean temperature differences (see equation 3) is:

$$LMTD = \frac{[(T_1 - t_2) - (T_2 - t_1)]}{\ln\left(\frac{(T_1 - t_2)}{(T_2 - t_1)}\right)} \quad (3)$$

the correction factor (see equation 4) is:

$$F_T = \frac{(\sqrt{R^2 + 1}) \ln\left(\frac{1 - S}{1 - RS}\right)}{(R - 1) \ln\left(\frac{2 - S(R + 1 - \sqrt{R^2 + 1})}{2 - S(R + 1 + \sqrt{R^2 + 1})}\right)} \quad (4)$$

the effectiveness coefficient (see equation 5) is:

$$R = \frac{(T_1 - T_2)}{(t_2 - t_1)} = \frac{W_t C_t}{W_s C_s} \quad (5)$$

and the ratio of heat capacities (see equation 6) is:

$$S = \frac{(t_2 - t_1)}{(T_1 - t_1)} \quad (6)$$

The following equations are used to determine the caloric temperature of the hot and cold fluids. The ratio of the temperature differences between the cold and hot heat exchanger terminals, where the subscript 1 refers to the cold terminal and the subscript 2 to the hot terminal (see equation 7), is:

$$r = \frac{\Delta t_1}{\Delta t_2} \quad (7)$$

The overall heat transfer coefficient at the hot and cold terminals are evaluated in equation 8 and 9 as follow respectively,

$$U_1 = \left( \frac{h_{io} \cdot h_o}{h_{io} + h_o} \right)_1 \quad (8)$$

$$U_2 = \left( \frac{h_{io} \cdot h_o}{h_{io} + h_o} \right)_2 \quad (9)$$

The caloric constant (see equation 10) is:

$$K_C = \frac{U_2 - U_1}{U_1} \quad (10)$$

and the caloric fraction (see equation 11) is:

$$F_C = \frac{\frac{1}{K_C} + \frac{r}{r-1}}{1 + \frac{\ln(K_C + 1)}{\ln(r)}} - \frac{1}{K_C} \quad (11)$$

The caloric temperature of hot fluid (see equation 12) is:

$$T_C = T_2 + F_C (T_1 - T_2) \quad (12)$$

and for the cold fluid (see equation 13) is:

$$t_c = t_1 + F_C (t_2 - t_1) \quad (13)$$

The fluid cross-sectional area to the shell side (see equation 14) is:

$$a_s = \frac{DI \times C^B}{P_T \times 144} \quad (14)$$

The equivalent diameter for the shell (see equation 15) is:

$$d_e = \frac{4 \times \text{cross sectional area}}{\text{wetted perimeter}} \quad (15)$$

For square pith (equation 16) is:

$$d_e = \frac{4 \times \left( T_T^2 - \frac{\pi d_o^2}{4} \right)}{\pi d_o} \quad (16)$$

and for triangular pitch (see equation 17) is:

$$d_e = \frac{4 \times \left( \frac{1}{2} P_T \times 0.86 P_T - \frac{1}{2} \frac{\pi d_o^2}{4} \right)}{\frac{1}{2} \pi d_o} \quad (17)$$

The heat transfer convective coefficient is calculated using equation 18 as follow:

$$\frac{hD_e}{k} = a \left( \frac{D_e G_S}{\mu} \right)^b \left( \frac{c\mu}{k} \right)^c \left( \frac{\mu}{\mu_w} \right)^d \quad (18)$$

where  $a$ ,  $b$ ,  $c$  and  $d$  are parameters that depend on the flow regime and the side of the fluid.

The pressure drop in the shell (see equation 19) is:

$$\Delta P_S = \frac{f G_S^2 D_S (N + 1)}{2 g \rho D_e \phi_S} \quad (19)$$

The pressure drop in the tubes (see equation 20) is:

$$\Delta P_t = \frac{fG_t^2 Ln}{5.22 \times 10^{10} D_e s \phi_s} \quad (20)$$

and the return losses (see equation 21) is:

$$\Delta P_r = \frac{4nV^2}{2sg} \quad (21)$$

### 3. Result and Discussion

According to the software quality requirements and evaluation guide ISO/IEC 9126-1<sup>16</sup>, some factors were evaluated with the support of an academic panel on the area, such as the usability, sustainability and maintainability criteria as shown on Table 1.

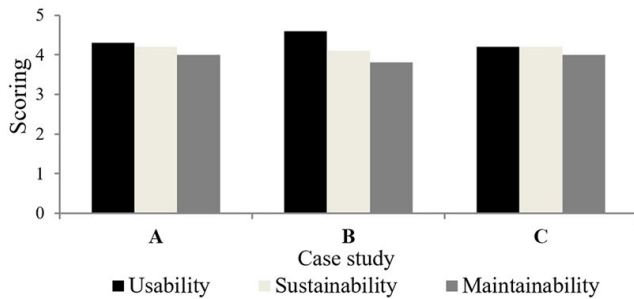


Figure 3. Scoring for the academic panel.

The assessment of the previous criterion was carried out fewer than three different case studies in the heat transfer course at Universidad del Atlantico, where 40 undergraduate engineering students highly prepared

Table 1. Software evaluation rubric

Criterion	Description	Out-standing (5,0 -4,5)	Good (4,5 - 3,5)	Satis-factory (3,5-3,0)	Unsatis-factory (1,0 - 0)
Usability	The software is perfect or near-perfect understood, very good comprehensive, appropriate, well-structured user guide and easy to learn how to use its commands.				
Sustainability	It is easy to see who owns the software, is easy to understand how the project is run and the development of the software managed and the software identity is clear and unique. The software requires few hardware capacity and reduces its own power consumption				
Maintainability	The sotware is easy to modify and contribute changes to developers, is usable on multiple platforms and interoperable with other required software.				

in computational coding were expected to work on the software S&THex-UA v1.0. The case studies were the determinations of the lowest obstruction factor, the determination of the correction factor of the log mean temperature difference, and the numerical determination of the Dittus and Boelter, and Sieder and Tate parameters. The average score obtained after the complete study is shown on Figure 3, where the usability was pondered in 4.4, the sustainability in 4.2 and the maintainability in 3.9.

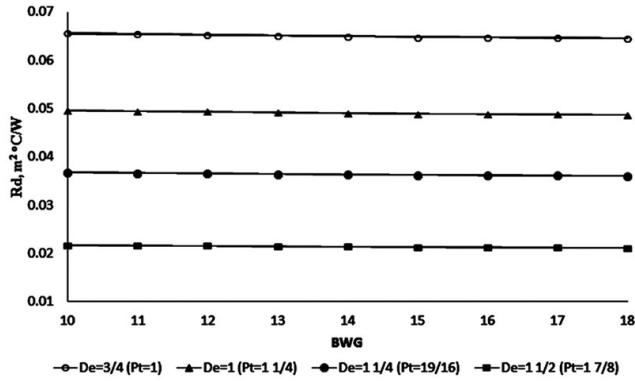
The results are a satisfactory evidence to ensure the quality of software as a powerful tool in the learning process on chemical engineering undergraduate students. The case studies developed for the students are explained as follow.

#### 3.1 Determination of the Lowest Obstruction Factor

A set of fixed values of operating conditions in the heat exchanger must be used to determine the obstruction factor to the heat transfer ( $Rd$ ) with the help of the software in Table 2. Then, different values of  $BGW$  and external diameter are used to obtain different values of  $Rd$  to give explanation of the behavior obtained using  $H_2O$  as shell fluid with a  $22727.27 \text{ kg/s}$  and  $C_2H_5OH$  as tube fluid Figure 4.

Table 2. Operating conditions for the shell and tube heat exchanger tested

$T_1(^{\circ}C)$	$T_2(^{\circ}C)$	$t_1(^{\circ}C)$	$t_2(^{\circ}C)$	D(m)	n	L(m)	B (in)
93.3	65.6	26.7	32.2	0.38	2	4.87	0.12

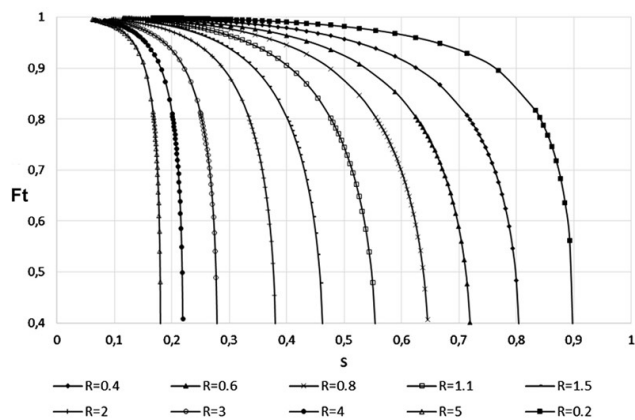


**Figure 4.** Obstruction factor (Rd) as a function of BWG number and external tube diameter.

It can be seen that the values of Rd decrease as the BWG and the tube external diameter increases. The behavior of the Rd as a function of BWG is due to the increase of the conductive thermal resistance of the system related to the increment of tube width. On the other hand, when the value of BWG is set constant and it is proceeded to increase the external diameter, the resistance to the heat transfer decreases. It happens because the heat transfer area increases considerably letting the heat to flow easily along the tube. The effect of the area is higher than the effect of the diameter.

### 3.2 Determination of the Correction Factor of the Log Mean Temperature Difference

In order to plot the correction factor of the log mean temperature difference ( $F_T$ ) as a function of the relative influence of the overall temperature difference on the tube flow temperature (S), for different heat capacity ratio (R), the next steps were followed:



**Figure 5.** Correction factor (Ft) for one-shell pass and 2, 4, 6, etc. (any multiple of 2), tube passes.

First the numerator value on equation 5 was keeping constant, while a set of inlet and outlet fluid temperatures through the tube data was generated for a constant and desired R value. The previous procedure could be applied as any time the user decided, as shown on Figure 5. It is important to consider the indetermination on the correction factor associated with the S value on equation.

The same sequence of steps can be used to plot the correction factor for two-shell passes and 4, 8, 12, etc. (any multiple of 4), tube passes.

### 3.3 Numerical Determination of the Dittus and Boelter, and Sieder and Tate Parameters

The mathematical models shave the following structure<sup>17,18</sup> as seen in equations 22 and 23

Dittus and Boelter:

$$Nu_u = a Re^b Pr^c \left( \frac{\mu}{\mu_w} \right)^d ; 0.7 < Pr < 160; Re > 2100 \quad (22)$$

Sieder and Tate:

$$Nu_u = a Re^b Pr^c \left( \frac{\mu}{\mu_w} \right)^d \left( \frac{D}{L} \right)^{\frac{1}{4}} ; Re \leq 2100 \quad (23)$$

For these models the fluid thermal properties were evaluated at the caloric temperature with the exception of  $\mu_w$ , which was evaluated at the wall temperature.

The following design conditions were set to calculate the parameters of both models, using a geometrical configuration: From 3/4 BWG 14 - Tube 3/4", triangle 1", Shell 15.25" in Table 3.

**Table 3.** Geometrical configuration for the shell and tube heat exchanger tested

D (m)	n	L (m)	B (m)	Shell Fluid	Tube Fluid
0.38735	8	4.8768	0.127	H <sub>2</sub> O	C <sub>2</sub> H <sub>5</sub> OH

To estimate the parameters of equations 22 and 23, different values of the flow inside the tubes, and the inlet and outlet temperatures of the shell and tubes were used with the purpose of obtaining a set of different values of Reynolds, Prandtl and Nusselt number as well as different values of the relation  $\mu/\mu_w$  as seen in Table 4 and 5.

The set of flow values were used in two ranges, one for turbulent flow in table 4 and the other for laminar flow in table 5 to evaluate the parameters of Dittus and Boelter, as well as Sieder and Tate respectively.

**Table 4.** Numerical data to calculate the Dittus and Boelter parameters

Tube flow (Kg/h)	$T_1$ (°C)	$t_1$ (°C)	$t_2$ (°C)	$T_2$ (°C)	$Nu$	$Re$ (tube)	$Pr$ (tube)	$\mu/\mu_w$
22727.3	93.3	26.7	32.2	65.6	539.19250	85341.0	9.49432	1.628027
20454.5	93.3	26.7	32.2	65.6	496.22518	76806.6	9.49435	1.642600
18181.8	93.3	26.7	32.2	65.6	452.23806	68272.2	9.49439	1.659201
15909.1	93.3	26.7	32.2	65.6	407.07455	59737.9	9.49442	1.678457
13636.4	93.3	26.7	32.2	65.6	360.52458	51203.6	9.49447	1.701239
11363.6	93.3	26.7	32.2	65.6	312.29914	42669.4	9.49453	1.728943
9090.9	93.3	26.7	32.2	65.6	261.97615	34135.2	9.49460	1.764020
22727.3	65.6	4.4	15.6	43.3	394.63348	45420.1	15.88440	1.890107
20454.5	65.6	4.4	15.6	43.3	363.20097	40877.4	15.88460	1.907693
18181.8	65.6	4.4	15.6	43.3	331.01765	36334.7	15.88490	1.927587
15909.1	65.6	4.4	15.6	43.3	297.96747	31792.1	15.88520	1.950448
13636.4	65.6	4.4	15.6	43.3	263.89778	27249.7	15.88560	1.977231
11363.6	65.6	4.4	15.6	43.3	228.59377	22707.3	15.88600	2.009424
9090.9	65.6	4.4	15.6	43.3	191.74767	18165.1	15.88650	2.049589
22727.3	37.8	1.7	10.0	15.6	346.28632	39461.6	17.78410	1.268372
20454.5	37.8	1.7	10.0	15.6	318.46951	35515.2	17.78420	1.273389
18181.8	37.8	1.7	10.0	15.6	290.01052	31568.8	17.78430	1.279057
15909.1	37.8	1.7	10.0	15.6	260.81072	27622.4	17.78440	1.285557
13636.4	37.8	1.7	10.0	15.6	230.74095	23676.1	17.78460	1.293162
11363.6	37.8	1.7	10.0	15.6	199.61985	19729.8	17.78480	1.302284
9090.9	37.8	1.7	10.0	15.6	167.18607	15783.6	17.78500	1.313643

**Table 5.** Numerical data to calculate the Sieder and Tate parameters

Tube flow (Kg/h)	$T_1$ (°C)	$t_1$ (°C)	$t_2$ (°C)	$T_2$ (°C)	$Nu$	$Re$ (tube)	$Pr$ (tube)	$\mu/\mu_w$
545.5	93.3	26.7	32.2	65.6	13.277300	2035.270	9.54403	3.040325
454.5	93.3	26.7	32.2	65.6	12.515105	1707.600	9.49075	3.067801
363.6	93.3	26.7	32.2	65.6	11.592185	1366.070	9.49078	3.019477
272.7	93.3	26.7	32.2	65.6	10.501414	1024.550	9.49083	2.956972
181.8	93.3	26.7	32.2	65.6	9.134969	683.027	9.49089	2.868671
90.9	93.3	26.7	32.2	65.6	7.195938	341.508	9.49101	2.718196
22.7	93.3	26.7	32.2	65.6	4.461490	85.375	9.49123	2.425774
545.5	65.6	4.4	15.6	43.3	12.764655	1092.830	15.85230	3.013846
454.5	65.6	4.4	15.6	43.3	11.995315	910.675	15.85250	2.984113
363.6	65.6	4.4	15.6	43.3	11.116093	728.526	15.85270	2.947277
272.7	65.6	4.4	15.6	43.3	10.076349	546.380	15.85300	2.899122
181.8	65.6	4.4	15.6	43.3	8.772834	364.240	15.85350	2.830082
90.9	65.6	4.4	15.6	43.3	6.920708	182.108	15.85430	2.709658
22.7	65.6	4.4	15.6	43.3	4.302296	45.521	15.85610	2.464732
545.5	37.8	1.7	10.0	15.6	11.542500	948.412	17.76400	1.569420

454.5	37.8	1.7	10.0	15.6	10.853748	790.334	17.76420	1.561019
363.6	37.8	1.7	10.0	15.6	10.066281	632.258	17.76440	1.550607
272.7	37.8	1.7	10.0	15.6	9.134575	474.185	17.76470	1.537041
181.8	37.8	1.7	10.0	15.6	7.965571	316.115	17.76500	1.517624
90.9	37.8	1.7	10.0	15.6	6.302395	158.050	17.76570	1.483888
22.7	37.8	1.7	10.0	15.6	3.944161	39.509	17.76720	1.415661

The next step is to write the equation 22 in logarithmic scale, see equation 24:

$$\ln(N_u) = \ln(a) + b \ln(\text{Re}) + c \ln(\text{Pr}) + d \ln\left(\frac{\mu}{\mu_w}\right) \quad (24)$$

Now, the parameters are determined by the use of a multiple linear regression which has the following structure, see equation 25:

$$y = a + bX_1 + cX_2 + dX_3 \quad (25)$$

Where,

$$y = \ln(Nu) \quad (26)$$

$$X_1 = \ln(\text{Re}) \quad (27)$$

$$X_2 = \ln(\text{Pr}) \quad (28)$$

and

$$X_3 = \ln\left(\frac{\mu}{\mu_w}\right) \quad (29)$$

Software such as Matlab and excel have special functions user friendly to apply multiple linear regressions. The same procedure is used to calculate the parameters of equation 23.

Tables 4 and 5, show that the Prandtl number and  $\mu$  are not constant for each run because the fluid properties are evaluated at the calorific temperature which has a dependence on the flow. The variation of the  $Pr$  number and the fluid properties are almost negligible that one can consider as variables only  $Nu$  and  $Re$ . However, if this consideration is used the calculated values of the parameters will not be the same obtained by Dittus and Boelter, and by Sieder and Tate. The parameters  $a$ ,  $b$ ,  $c$  and  $d$  are extremely sensitive to small changes in the values of  $Pr$  and  $\mu$ . This is something that a undergrad student can test by making constant the mentioned variable and applying a linear regression. With the use of table 3, the multiple linear regressions estimate the Dittus and Boelter parameters as follow:  $a=0.027$ ,  $b=0.8$ ,  $c=0.333$  and  $d=0.14$ .

Using table 4 the results obtained for the Sieder and Tate parameters are:  $a=1.8$ ,  $b=0.333$ ,  $c=0.333$  and  $d=0.14$ .

## 4. Conclusions

A mathematical tool for process, chemical and mechanical engineering for the design of shell and tube heat exchangers "S&THex-UA v1.0" has been presented with the application of three examples where the student can see its capacity by making a simple analysis of heat exchanger designs. The program make use of the calorific temperature for the hot and cold fluid with a given set of geometrical configuration and operating conditions such as the tube layout, flow rates, temperatures and kind of liquid fluid to make all the calculations helping the students to go through the design by obtaining the shell and tube side film coefficients, the overall heat transfer coefficient, the clean coefficient, the combined dirt factor and the total heat transfer area which give to the user an idea of the approximate size of the heat exchanger.

The program was designed so that the student can get a set of experimental data of a shell and tube heat exchanger and use them as an input to later compare the efficiency of that heat exchanger with a different one run with different geometrical configurations. This helps students to go beyond a simple experiment and analyze different heat exchangers at the same time.

The lowest obstruction factor as a function of BWG number and external tube diameter was obtained so that the student can see the effect of different factor on the resistance to the total rate of heat transfer. This can help students to think in the application of experimental designs to see not only the effect of different factors but also in the interaction of all of them.

It was plotted the correction factor of the log mean temperature difference ( $F_r$ ) as a function of the relative influence of the overall temperature difference on the tube flow temperature ( $S$ ), for different heat capacity ratio ( $R$ ). The making of this plot by the students help them to understand the profiles obtained and find explanation of



the different phenomena found for a cross-flow in multi-pass shell and-tube heat exchangers.

It was determined Dittus and Boelter, and Sieder and Tate parameters. With the help of the software students can see how sensitive these parameters are to small changes in temperature and flow. In fact, by comprehending how these parameters are calculated, the students can propose new models of the Nusselt number with the use of some statistical software.

The use of the Graphical User Interface (GUI) will increase the efficiency of a heat transfer class since it makes students to get a better comprehension of what happen inside a shell and tube heat exchanger by correlating all the different variables found on them.

The scoring results obtained with the 40 students ensure the quality of software as a powerful tool in the learning process of chemical engineering undergraduate students according to the software quality requirements and evaluation guide ISO/IEC 9126-1

## 5. Acknowledgment

The authors are grateful for the financial support from the Universidad del Atlántico with the sponsored project “*Design of computational tools to support the learning of unit operations in engineering students*” in the Internal Call for Research Projects named *Investigative equity* (Equidad investigativa)

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