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A Matlab-Based Program for the Design And Simulation of Wet Cooling Towers

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Computer based programs for education in chemical engineering has become an essential component to complete the program educational objectives and reach the student outcomes. There is a long list of chemical process simulators used as complement to traditional courses on process modeling, however, the field of chemical engineering cover a broad range of areas that make difficult the creation of a robust program that involve all the courses mainly the unit operations which is the heart of this discipline. The experience with these courses shows that there is still need for enhancement when trying to transfer the theoretic knowledge to computational trainings. In order to follow this line of transferring knowledge it is presented a registered application of a GUI in Matlab called CTw-UA v1.0 focused in humidification for the design of cooling towers, using the mass transfer fundamental equations for the design of cooling towers presented in highly relevant documents and popular academic books with some empirical information of different packings used in the industry. The operating conditions set by the user are the inlet and outlet temperatures of the liquid, the liquid flow, the dry and wet bulb temperatures of the inlet air, the type of packing and the relation (*L/Gmin*), and the outputs in the program are the number of decks of the packings, the efficiency of the tower, the air flow, the temperature profile of the air along the tower plotting the Mickley diagram, and the column dimensions, height and diameter. It was obtained the effect of the packing and inlet air conditions in the dimension of the tower, the variation of the height of the tower as a function of the outlet and inlet liquid temperatures for different packings and the variation of the efficiency and height of the tower as a function of the outlet liquid temperature. The software, which was accepted very well by a population of 90 students, was evaluated statistically in terms of clarity, precision and relevance with the application of a t test with a significance level of 5%.

1. Introduction

The chemical and process industry in general, generates large amounts of heat that must be dissipated so that it can be operated efficiently. The cooling towers make the control of the cooling process by controlled evaporation, reducing the amount of water consumed. The cooling is done by both sensible and latent heat. The aim in the tower is to increase the residence time and the contact area, which is achieved by increasing the height of the column and also interposing obstacles in order to facilitate the evaporative process. The instrumentation, design and simulation of water cooling devices has constituted during the development of unit operations, a frame of reference in the study, comprehension and application of the phenomenology of the mechanism of mass and energy transfer (Ocon Garcia and Tojo Barreiro 1972, Treybal 1980, Benitez 2016) .
The cooling equipments of simple systems such as the air and water vapor systems are a fundamental basis in preliminary studies of great industrial application. All this knowledge involves a very good training of the engineers involved in the design, operation and maintenance of the cooling towers. The laboratory units that contain the mass transfer phenomena are powerful tools that consolidate the knowledge developed in the classroom, and constitute a reference point in the learning chemical engineering processes. Learning to design and build a cooling tower involves many variables, making it necessary to complete the knowledge acquired theoretically and experimentally in the academy by including in the basic curriculum an easy to use

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computer program, where students can be able to understand and explain the phenomena that happen within the columns at different operating conditions of the system.

In recent years, new tools have been developed in the cooling tower model such as the developing of a mathematical model in ordinary differential equations using the concept of Artificial Neural Network (ANA) (Hosoz, Ertunc et al. 2007, Qi, Liu et al. 2016), functioning as a computational tool design that helps to evaluate the water temperature at the exit. Even though many studies has been done about modeling, numerical simulation and performance of cooling towers (Klimanek, Cedzich et al. 2015, Blain, Belaud et al. 2016, Qi, Liu et al. 2016, Li, Xia et al. 2017, Llano-Restrepo and Monsalve-Reyes 2017, Wang, Zhu et al. 2017) there are no information about software creation in this area are very limited so the engineers have a high limitation in the adequate training they can get.

The contribution of this article is the development of an interactive educational software named CTw-UA v1.0 to design cooling towers that determine the number of decks from the packings, the tower efficiency, the air flow needed, the dimensions of the tower and the temperature profile inside the tower using the Mickley diagram. Among the effects found it can be observed the effect of the type of packing and the air inlet conditions in the dimensions of the tower. In the statistical results for the development of the critical thinking in terms of clarity, precision and pertinence in undergraduate students of chemical engineering in the class of mass transfer, 90 students were chosen and divided in two groups randomly forming the control group and the experimental group which interacted and developed the case studies proposed with the help of the software. Data analysis was initiated for a sample of 45 data per group and subsequently, and by means of the *t*-test for independent samples it was confirmed the importance of the software in the learning process because it was found a significant effect on the learning of the design of cooling columns in engineering students supported by software CTw-UA v1.0.

2. Material and Method

2.1. Presentation of the algorithm

Figure 1 is a screen capture of the main view of the CTw-UA v1.0, which shows the inputs given by the user. This software is a creative and original graphical user-friendly interface designed to solve real problems for chemical engineering students and engineers during their practical training. It is important in the industry for effective decision making about the size of the column being designed. Besides, the program can be used to make simulations and identify failures associated to an irregular functioning of the column. The software let students to have a better understanding about the momentum, heat and mass transfer inside a cooling tower.

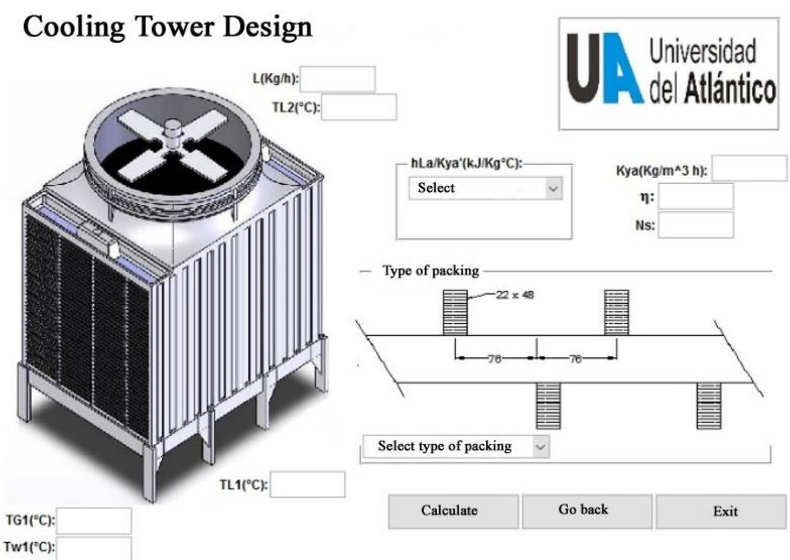

Figure 1. Main View of the CTw-UA v1.0 software.

2.2. Flowchart of the GUI

The requirements of CTw-UA v1.0 depend on the version of Matlab installed, although it does not require a previous installation. Figure 2 shows a flowchart of the program

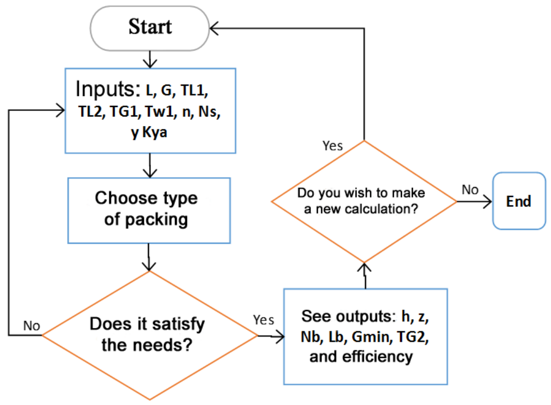

Figure 2. Flowchart of the CTw-UA v1.0

2.3. Main relations used in the algorithm

The fundamental equations of the software are organized as follow,
The enthalpy of the liquid is calculated from the global energy balance:

$$H_{y2} = H_{y1} + \frac{L*Cl}{G}(T_{L2} - T_{L1}) \quad (1)$$

The height of the tower is determined by the design equation:

$$Z = \frac{G_s}{K_y a M_B} \int_{Hy1}^{Hy2} \frac{dH_y}{(H_{yi} - H_y)} \quad (2)$$

And finally, the correlation for the packing is:

$$\frac{K_y aV}{L} = 0.07 + \mathrm{A(ND)}\left(\frac{L}{G}\right)^{-p} \quad (3)$$

3. Result and Discussion

It was designed a theoretical-practical guide to work with the software where it is explained all the experiences and the steps that the student must follow to use the software CTw-UA v1.0. The mentioned experiences are shown below and it was selected a population of 90 undergraduate students of chemical engineering to make a statistical analysis shown at the end of this section.

3.1. Behavior of the operating lines with the relation *L/G* at different relative humidities

To create the relation, it was given the following conditions: inlet water flow 4000 Kg/h, (TL2) inlet water temperature 65°C, (TL1) outlet water temperature 35°C, environmental temperature 35°C, (Tw1) inlet air wet-bulb temperature 22°C. Then, different packing numbers and air wet-bulb temperatures are used to explain the cooling behavior obtained, as shown in figure 3. It can be seen that the relation L/G decreases when the air wet-bulb temperature increases maintaining constant the liquid and air temperatures. The lower the air wet-bulb temperature, the higher the amount of water to be cooled, although the capacity to evaporate increases causing a considerable loss of water. It happens because of the low relative humidity of the inlet air.

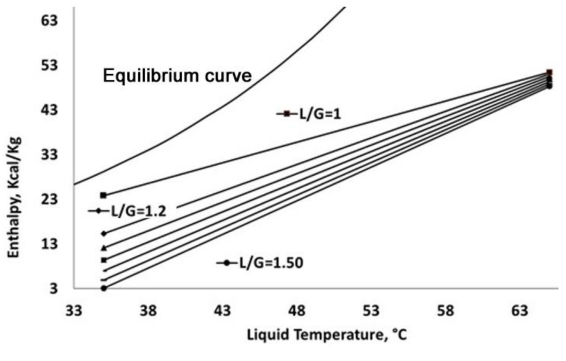

Figure 2. Operating lines at different humidity conditions

3.2. Effect of the type of packing in the height and area of the column at different air inlet wet-bulb temperatures

For this experience the following operating conditions were given, inlet water flow 5000 Kg/h, (TL2) inlet water temperature 60°C, (TL1) outlet water temperature 38°C, environmental temperature 35°C, mass transfer coefficient (Kya) de 2500 KJ/Kg°C for the cooling tower. The study was done for different types of packing and air wet-bulb temperatures as shown in figure 4.

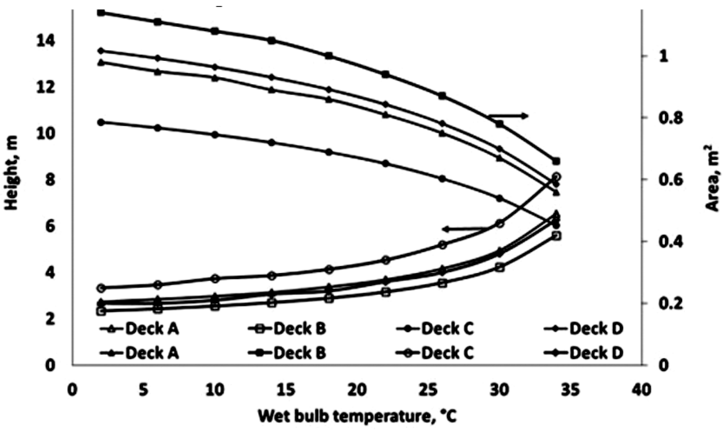

Figure 4. Effect of the wet-bulb temperature in the area and height of the cooling tower for different type of packing

With the help of the software CTw-UA v1.0, it can be seen an increase in the height and a decrease in the cross-sectional area of the tower when the air inlet wet-bulb temperature increases.
The results obtained help to choose the best type of packing because of the relation height-area which is the best criteria for the economy of the design.

3.3. Effect of the outlet water temperatures in the height of the tower

The following operating conditions were given for this experience: inlet water temperature (TL2) 70°C, inlet air dry-bulb temperature 35°C, inlet air wet-bulb temperature (Tw1) 20°Cenvironmental temperature 35°C, mass transfer coefficient (Kya) de 2500 KJ/Kg°C for the cooling tower, and it was chosen a factor of 3 for the minimum air flow needed. Figure 5 shows that an increase in the outlet water temperature cause a decrease in the height of the tower. It happens because of the decrease of the difference between the inlet and the outlet water temperature (TL2 – TL1). The selected packing has a great effect in the height of the tower. As can be seen in figure 5 the best type of packing is the deck A which produce the lowest height resulting in the lowest cost. It indicates that the geometry of the packing has the highest contact area causing the highest mass and heat transfer between the two fluids.

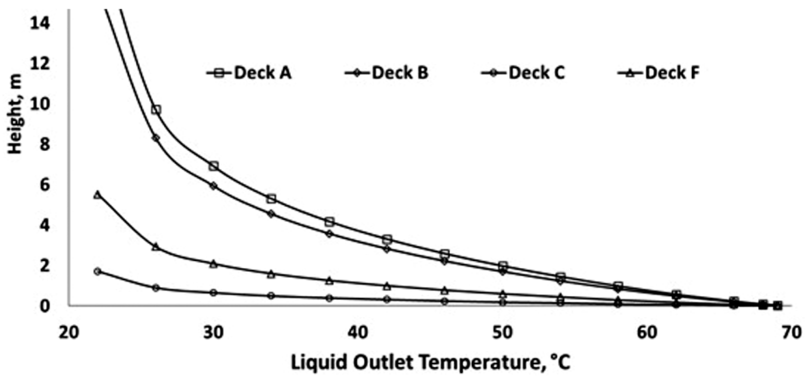

Figure 5. Effect of the outlet water temperature in the height of the tower.

3.4. Effect of the relation L/G on the outlet air temperature in the Mickley diagram.

When the flow of water is maintained constant and the air flow decreases, the relation L/G increases causing the slope of the red line less inclined making the outlet air temperature close to the inlet water temperature, see figure 6. It happens because there is less amount of air in contact with a high amount of the falling water obtaining easily an equilibrium in temperature in the top of the column.

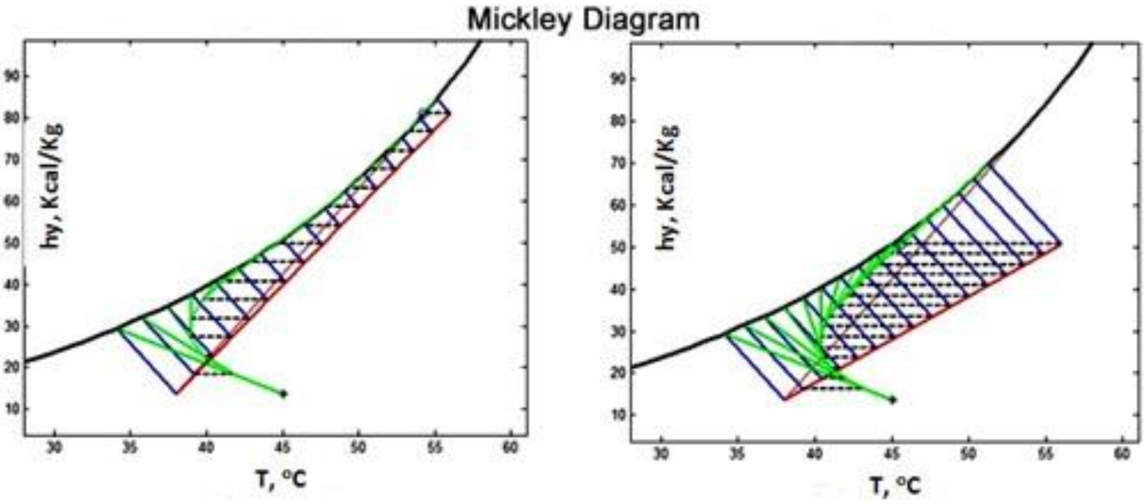

Figure 6. Behavior of the outlet air temperature as a function of L/G in the Mickley diagram

3.5. Statistical analysis in terms of clarity, precision and relevance

There were designed some surveys that were used to make a statistical analysis based on the grades given by the students according with the rubric conformed by the criteria and rating scale. The criteria used clarity, precision and relevance are part of the intellectual standards of quality to evaluate the critical thinking (Elder & Paul, 2007). The rating scale is composed of 4 ranges as shown in table 1 with a maximum of 5 and a minimum of 0.
A t-test with a significance level of 0.05 indicates that the working groups are equal in terms of clarity, precision and relevance which guarantee homogeneity in the population before the use of the software.
Then, an additional t-test were completed for the same terms of clarity, precision and relevance with the aim to evaluate statistically the difference in the average grade between the group of control and the experimental group which used the software CTw-UA v1.0. Table 2 shows the statistical results for the data obtained in both groups after the use of the software in the experimental group. It can be seen that all the *P*-values are lower than 0,05 indicating that there is a significant difference between the grades of both groups demonstrating that the software CTw-UA v1.0 has an important effect in the student learning process. This result shows the need to implement user friendly computational tools to guarantee a substantial learning and to improve the critical thinking of the students.

Table 1. Rubric for the collection of data of the instrument used in the measurements

Rubric to evaluate answers to open-ended questions										
	Theoretical-practical guide	Student:			Group					
	Excellent	Good	Regular	Deficient	Pretest			Postest		
Criteria	[4.5 - 5.0]	[3.8 - 4.4]	[3.0 - 3.7]	[2.9 - 0]	C1	C2	C3	C1	C2	C3
Clarity	The answer given by the student is understandable or intelligible. It expresses very clearly what it means. Express what is understood in his own words. You can give examples. Expectations are met 100%.	Expectations are met 80%	Expectations are met 50%	Expectations are met 20%						
Precision	The response given by the student is specific, presenting details that give their understanding of the subject. Expectations are met 100%.	Expectations are met 80%	Expectations are met 50%	Expectations are met 20%						
Relevance	The answer given by the student considers the aspects that are closely related to the question asked. Expectations are met 100%.	Expectations are met 80%	Expectations are met 50%	Expectations are met 20%						

Table 2. Statistical results after the use of the software.

Dependent variables	N	CONTROL GROUP				EXPERIMENTAL GROUP				Valor P	Tcrit	T
		M	SD	MIN	MAX	M	SD	MIN	MAX			
Clarity	45	3,05	0,29	2,41	3,42	4,15	0,25	3,80	4,50	0,0000	2.05	-12.25
Precision	45	3,01	0,17	2,71	3,52	4,02	0,21	3,55	4,32	0,0000	2.05	-8.34
Relevance	45	2,99	0,25	2,50	3,35	3,95	0,30	3,48	4,55	0,0000	2.05	-9.03

Note: M=Mean, SD= Standard Deviation, Tcrit.= T critical value

4. Conclusions

The computational tool CTw-UA v1.0 was introduced successfully in a chemical engineering class where the students evaluated their capacity to make an analysis of the design of a cooling tower

The software help the user go beyond a simple experiment because of the use of multiple simulations in a packed cooling tower with different geometrical configurations and operating conditions

Four experiences were made with the help of the software studying the relation of the operating lines at different relative humidities, the effect of the packing in the height and area of the column at different air inlet wet-bulb temperatures, the effect of the outlet water temperatures in the height of the tower, and the effect of the relation L/G on the outlet air temperature in the Mickley diagram.

It was selected a population of 90 undergraduate students of chemical engineering to make a statistical analysis. Two groups of 45 students were used, the control group and the experimental group, and with the use of the t-test they result equal in terms of clarity, precision and relevance guaranteeing homogeneity in the population before the use of the software.

The statistical analysis indicates that there is a significant difference between the grades of both groups demonstrating that the software CTw-UA v1.0 has an important effect in the student learning process. It means that it is necessary to implement a user-friendly software to assure an important learning and to improve the critical thinking of the students.

References

Benitez, J. (2016). Principles and Modern Applications of Mass Transfer Operations, Wiley.

Blain, N., et al. (2016). "Development and validation of a CFD model for numerical simulation of a large natural draft wet cooling tower." Applied Thermal Engineering 105: 953-960.

Hosoz, M., et al. (2007). "Performance prediction of a cooling tower using artificial neural network." Energy Conversion and Management 48(4): 1349-1359.

Klimanek, A., et al. (2015). "3D CFD modeling of natural draft wet-cooling tower with flue gas injection." Applied Thermal Engineering 91: 824-833.

Li, X., et al. (2017). "Performance enhancement for the natural draft dry cooling tower under crosswind condition by optimizing the water distribution." International Journal of Heat and Mass Transfer 107: 271-280.

Llano-Restrepo, M. and R. Monsalve-Reyes (2017). "Modeling and simulation of counterflow wet-cooling towers and the accurate calculation and correlation of mass transfer coefficients for thermal performance prediction." International Journal of Refrigeration 74: 47-72.

Ocon Garcia, J. and G. Tojo Barreiro (1972). Problemas de Ingeniería Química, Operaciones Básicas, Editorial Aguilar.

Qi, X., et al. (2016). "Performance prediction of a shower cooling tower using wavelet neural network." Applied Thermal Engineering 108: 475-485.

Treybal, R. E. (1980). Mass-Transfer Operations, McGraw-Hill Book Company.

Wang, Q., et al. (2017). "Numerical simulation of heat transfer process in solar enhanced natural draft dry cooling tower with radiation model." Applied Thermal Engineering 114: 977-983.