# An innovative interactive educational software on refrigeration systems to support virtual thermodynamic Class

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**Abstract-  Educational tools play a fundamental role in the teaching process as they allow for the speeding up of calculation processes and improve the processes of assimilation of concepts. The virtual laboratory proposed in this work focuses on promoting the training of mechanical engineering students in the area of thermal sciences since the mechanical engineer has to face problems with the operation, selection, and design of thermal machines and systems that work with different types of fluids and energy processes. This article presents the methodology and development of a computational tool developed in Matlab environment called RefriTerm that allows the energy analysis of refrigeration systems. Validation and verification tests were carried out to guarantee the accuracy of the results. It was found that the tool has a friendly environment easy to understand and use which allows to strengthen more deeply the topics related to the refrigeration systems and thus contribute to the teaching-learning processes.**

**Keywords – Educational tool, refrigeration, Matlab, software, learning**

## I. INTRODUCTION

Laboratory use in higher education institutions provides students with an environment in which they can understand practical processes and assimilate concepts. This allows students to link and assimilate in a practical way what they have learned within the classroom. However, the creation of these laboratory environments along with their maintenance requires an associated cost that must be injected.[1]. Therefore, the educational tools developed with the purpose of consolidation of the concepts related to thermodynamic processes, emerge as a way to complement the material given within the classrooms.[2]. Unlike the teaching methods of thermodynamics in the past, today we have the incorporation of computer tools that allow active participation of the students [3][4]. Some research has shown this to be the case, such as that carried out by Ahmet et al. [5] who implemented a t-test where they compared the performance of students interactively and virtually. The results revealed that students who made use of educational tools performed better in contrast to the use of common teaching methods.

Currently, there is software oriented towards the simulation of chemical processes and equipment such as ChemCAD, CCTherm, Pro / II, Simsci [6]–[10]. However, this software covers many topics, which are not entirely given in an undergraduate course, besides, these software are licensed. In another scenario, there is software such as COMSOL Multiphysics, ANSYS Fluent, OpenCalphad, that have been designed with a much more friendly environment for educational purposes[11], [12]. However, these tools still prove to be complex and time-consuming to manage

Also, optimizations, parametric studies, and numerical computer simulations have been carried out with various programs or computer software in which the effects that the parameters, components, or configurations of the heat exchangers have on the refrigeration systems are studied. For example, Kirinčić et al. [13] used the finite volume

method developed in Ansys, to model a heat exchanger, obtaining good agreement with experimental data, which allowed them to determine that this method is adequate to accurately predict the physical phenomena presented in the analyzed exchanger. Similarly, Nayak et al. [14] used the tool ANSYS to verify improvements in the performance and efficiency of heat exchangers, by using red brass as a material for the construction of tubes and shell. Taher et al. [15] analyzed the effect of the different spacing of the helical baffles in five heat exchangers using FLUENT® as a computational tool for simulation, resulting in that for the same mass flow the heat transfer decreases with increasing deflector gaps, similarly, the pressure gradient also decreases.

Other arrangements or modifications of the heat exchangers have been simulated with the use of different software and modeling languages having a good relationship with the experimental data, which facilitates the prediction of properties, events, and characteristics among others. Software is used such as HEXTRAN [16], HTRI [17] [18], SOLIDWORKS Flow Simulation [19], CFD [19]–[22], ANSYS FLUENT [23], GAMBIT [24], languages like Modelica [25], different methods, algorithms, schemes and even software working together to verify different behaviors within the system or to carry out it's total modeling  [26]–[28] obtaining excellent results that allow proposing new models or designs of heat exchangers and refrigeration systems. However, this requires detailed knowledge of the phenomena involved in the system, since they are not simple tools to operate that also support the learning process.

On the other hand, there is work related to the development of educational applications-oriented to support the teaching processes in certain subjects at the engineering level. In this group, we find the work done by Diaz et al. [29] who developed a computer tool that allows the study of transient heat transfer. The authors performed a paired sample analysis by performing practical exercises with and without the aid of the tool. The results revealed that the implementation of the tool has a significant effect on the processes of assimilation of the concepts. Similar work was carried out by Zamora et al. [30] who developed an educational application in Matlab to determine the states in the electrical power system. The tool was developed to offer real scenarios in the simulation of this type of system in the electrical engineering courses. Also, Vicéns et al. [31] implemented Matlab to support the teaching processes of engineering students. Gupta et al. [32] developed a teaching-learning tool in Matlab environment to support the comprehension processes in the reading of psychrometric parameters. The results revealed that the use of this type of tool significantly increases the understanding of these processes with respect to conventional methods.

In this work, we present a computational tool developed in Matlab environment focused on the study of refrigeration systems, called RefriTerm. The tool was designed in an easy to use, practical and interactive way that allows strengthening the fundamental concepts of refrigeration systems in thermodynamics courses. Finally, this tool can carry out parametric studies in a fast and exact way of different configurations that have been proposed.

.II. Methodology

*2.1 Presentation of the software –*

Figure 1 shows the main window of the tool. In this first scenario, the student can choose which system he wants to study. By default, the software was programmed considering four types of refrigeration system configurations which are widely studied in thermodynamics courses. In addition, the fluid selected for this study is R134a. The software has the main interface as shown in Figure 1, show the main configuration such as Simple Refrigeration Cycle (SRC), Cascade Refrigeration Cycle (CRC), Multi-Stage Refrigeration Cycle (MSRC), and Absorption Refrigeration Cycle (ARC).

The interface shown in Figure 1 consists of an input and output data area, a tabular result display area at the bottom, and the graphical representation of the entire cycle on the right, in addition to buttons for calculating, deleting, and returning to the main window. The cycle in general allows to calculate the ideal steam compression cycle and the real cycle. The following cooling cycles are structured with a similar distribution of the interface by adding special fields according to the characteristics of each one, for example in the absorption cooling cycle the heat provided by the external source is needed or commonly a set of solar panels.
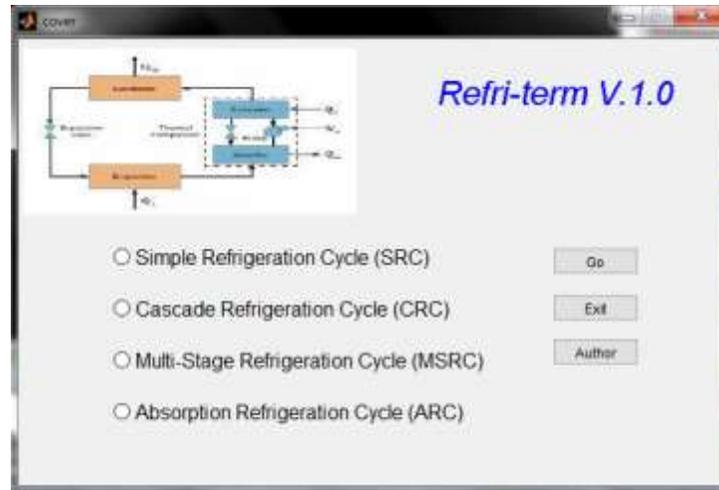
Figure 1.   Software Interface RefriTerm.

The software has two sections. The first is the panels where the student enters the system simulation input. Then, a second section, which corresponds to the system outputs. The software has the particularity of showing some thermodynamic and physical properties in the points of the system. This allows to see the changes of enthalpy and entropy through a process. In this way, the change in the value of an output parameter affects these properties, and the student will be able to analyze the behavior of the system.  Due to the ease of use, the tool can be used in extracurricular time allowing the student to navigate through it and perform case studies proposed by the teacher

Finally, the tool is a very valuable input for teachers, since it allows for the quick development of case studies, which allows for the identification of significant parameters that affect the performance of the system. Consequently, classes will be more dynamic and participatory, facilitating the processes of assimilation of the theoretical foundations in students.

*2.2. Fundamental equations –*

 Figure 2 the diagram representing the simple refrigeration process is shown. Initially, the refrigerant starts from the 1 (Point 1) as superheated steam at the system's low pressure, then passes through the compressor where its pressure is increased through hydraulic work performed by the compressor. During this process, the refrigerant changes its enthalpy and entropy values. Subsequently, the compressed gas (Point 2) enters the condenser where it gives off heat through cooling water. The gas then exits the condenser (Point 3) at its saturation temperature and expands isenthalpic by decreasing its pressure to the evaporating pressure in the expansion valve. In the evaporator, the gas absorbs heat causing it to evaporate to the point 1.
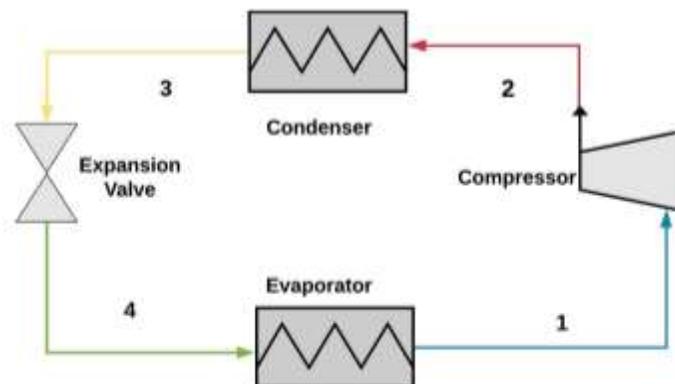


Figure 2.   Schematic diagram of the refrigeration cycle (SRC)

The system performance level shown in Figure 2, can be evaluated through the performance ratio (COP), which indicates the amount of heat removed from the system in the evaporator with respect to the amount of power supplied in the compressor, according to the equation (1) [33], [34].

$$COP = \frac{\dot{Q}_{in}}{\dot{W}_{in}},\qquad(1)$$

where $\dot{Q}_{in}$ is the amount of heat removed from the system, and $\dot{W}_{net}$ is the amount of power supplied to the system. Equation (1), can be rewritten in terms of hot and cold source temperature according to equation (2).

$$COP = \frac{T_L \Delta S}{(T_H - T_L)\Delta S} = \frac{T_L}{(T_H - T_L)} = \frac{1}{T_H/T_L - 1}.\qquad(2)$$

On the other hand, there are situations where the compression ratio is very high, efficiency is reduced and the compressor starts to deteriorate little by little. These ratios are very high when the evaporation temperature is very low compared to the condensation temperature. The solution to this problem is to compress the gas in several stages. The use of a heat exchanger to join two cycles (Step 1 and Step 2), decreases the gas discharge temperature and increases efficiency, as shown in Figure 3.
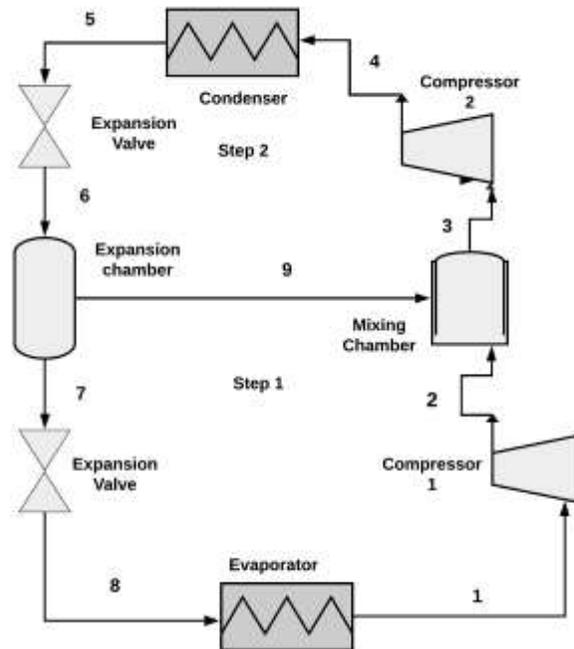


Figure 3.   Schematic diagram of the Multi-Stage Refrigeration  Cycle (MSRC

Therefore, the system performance coefficient can be rewritten according to equation (5).

$$COP = \frac{\dot{Q}_{in}}{\dot{W}_{Step\ 1} + \dot{W}_{Step\ 2}},\qquad(3)$$

of the equation (3), $\dot{Q}_{in}$ is the heat absorbed in the evaporator, $\dot{W}_{Step\ 1}$ and $\dot{W}_{Step\ 2}$ are the powers supplied on compressors one and two respectively. By observing that the heat given off by the Step A is equal to the one transferred to the Step B, the energy conservation equation for the heat exchanger as a function of mass flows can be expressed as (4).

$$\dot{m}_A(h_2 - h_3) = \dot{m}_B(h_5 - h_8),\qquad(4)$$

of the equation (4), mass flows can be directly related to the variation of enthalpy between stages according to the equation (5).

$$\frac{\dot{m}_A}{\dot{m}_B} = \frac{(h_5 - h_8)}{(h_2 - h_3)}. \tag{5}$$

Compressors are devices that increase the pressure of the fluid by raising its temperature. In this process, it can be considered adiabatic, and changes in kinetic and potential energy are not taken into account, see Figure 4.
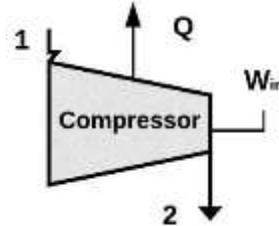
Figure 4.    Energy balance of the compressor

Figure 4 shows an input current to the control volume, and a power supplied The efficiency of the compressor is defined as the amount of hydraulic work performed in relation to the amount of energy supplied, according to equation (6).

$$\eta = \frac{\dot{m}(h_2 - h_1)}{\dot{W}_{in}} \tag{6}$$

On the other hand, Figure 3 shows the schematic diagram of the condenser. By applying an energy balance to the control volume, the amount of heat yielded can be obtained according to the equation (7)
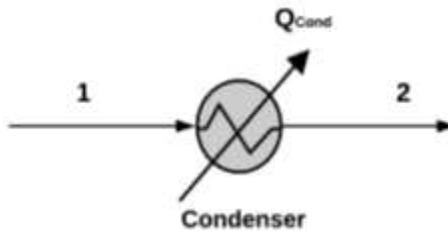
Figure 5.    Condenser energy balance

in the condenser the working fluid gives off heat to the cooling substance (water or air) until it reaches its saturation state, the process is carried out in an isobaric way.

$$\dot{m}h_1 = \dot{Q}_{Cond} + \dot{m}h_2 \tag{7}$$

where $\dot{m}$ is mass flow of the coolant. Similarly, Figure 6 shows the energy balance applied to the evaporator, which can be expressed as the equation (8)
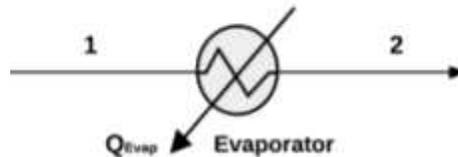
Figure 6.    Evaporator energy balance

In the evaporator, the working fluid absorbs heat from the cooling medium, causing a temperature rise. The phase change of the substance occurs at a constant temperature and constant pressure.

$$\dot{m}h_1 + \dot{Q}_{Evap} = \dot{m}h_2 \tag{8}$$

## III. RESULTS AND DISCUSSION

In this section, validation tests of the tool are performed. This is achieved through a comparison between the results obtained from calculations made by undergraduate students of Mechanical Engineering based on textbooks, and those obtained by the tool. The analyses are performed for each of the proposed configurations

*3.1. Validation of the software RefriTerm –*

To corroborate the computational tool developed, a comparative analysis was made between the results obtained when performing problems manually and comparing the data obtained with the data thrown by RefriTerm. Table 1 shows the comparison of data for exercise 11-15 in the book of thermodynamics Cengel.

Table 1. Software validation results

| | Enthalpy [ kJ/kg] | | |
|---|---|---|---|
| **State** | **GUI** | **Manual** | **Error (%)** |
| 1 | 236.970 | 236.97 | 0.0000 |
| 2 | 278.973 | 278.93 | 0.0154 |
| 3 | 101.595 | 101.61 | 0.0147 |

Figure 7 shows the results produced by the tool in the validation process.
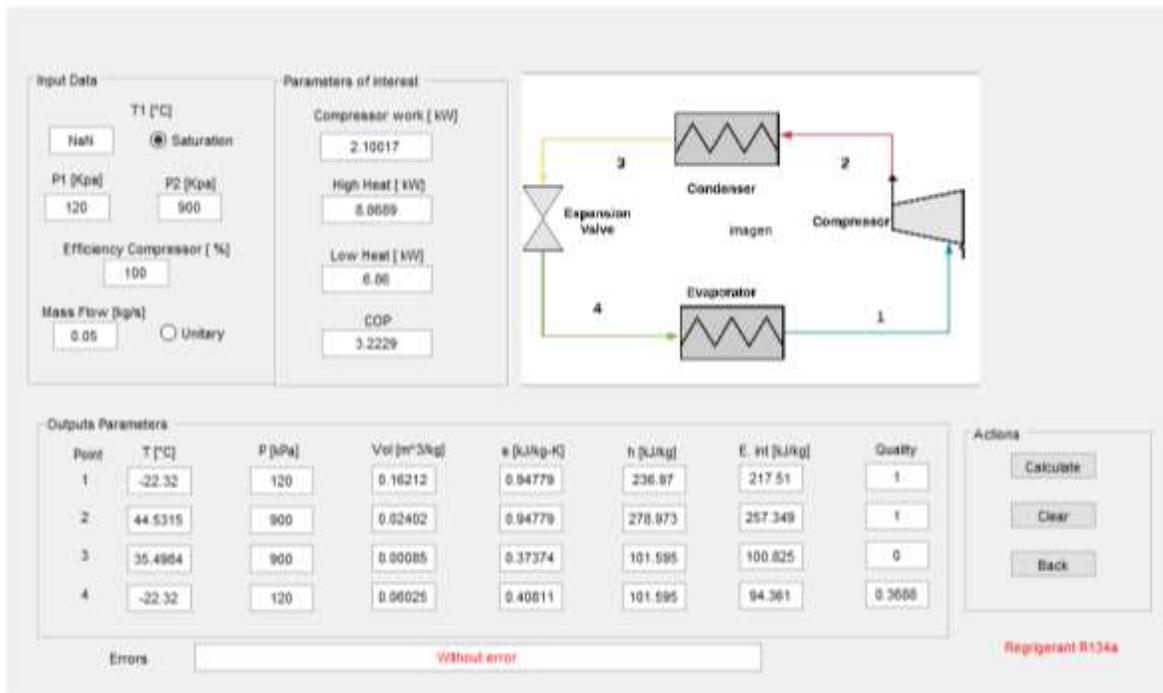


Figure 7.   Case one simulation results, software RefriTerm

### 3.2 Compressor case study

To verify the effectiveness of the software the same type of simple process was performed but with different data to observe the variation of the error with different combinations of data, Table 2 shows the validation results.

Table 2. Second tool validation case

| | Enthalpy [ kJ/kg] | | |
|---|---|---|---|
| **State** | **GUI** | **Manual** | **Error (%)** |
| 1 | 244.46 | 244.46 | 0.0000 |

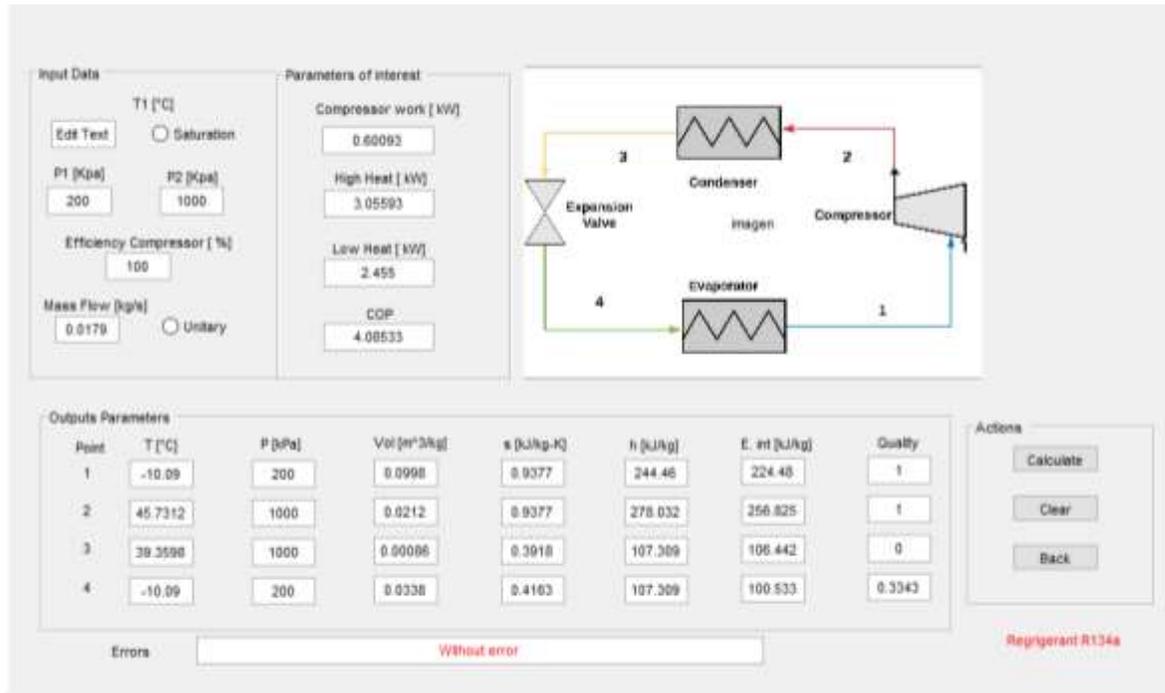| | | | |
|---|---|---|---|
| 2 | 278.032 | 277.98 | 0.0187 |
| 3 | 107.309 | 107.32 | 0.0102 |



Figure 8.    Case two simulation results, software RefriTerm

In both cases, errors of less than 2 hundredths of a unit were obtained for the enthalpies, which indicates that it is a safe tool in the calculation of thermodynamic properties of substances and therefore the calculation of the system parameters will be consistent.

*3.3 Multi-stage error testing*
By adding multiple stages to the calculation made by the program, you expose yourself to an increased error in final stages, because any deviation will increase exponentially from one stage to another.

Table 3. Comparison of the results of the two-stage refrigeration cycle

| Enthalpy [ kJ/kg] | | | |
|---|---|---|---|
| **State** | **GUI** | **Manual** | **Error (%)** |
| 1 | 234.44 | 234.44 | 0.0000 |
| 2 | 271.405 | 271.40 | 0.0018 |
| 3 | 269.13 | 262.40 | 2.5647 |
| 4 | 287.292 | 287.28 | 0.0041 |
| 5 | 127.2 | 127.22 | 0.0157 |
| 6 | 81.4958 | 81.51 | 0.0174 |

As expected for enthalpy three (h3) We obtained an error higher than 2.5% due to the chain deviation of this cycle, but in general, the error between stages remained at hundredths of an error for the other stages.
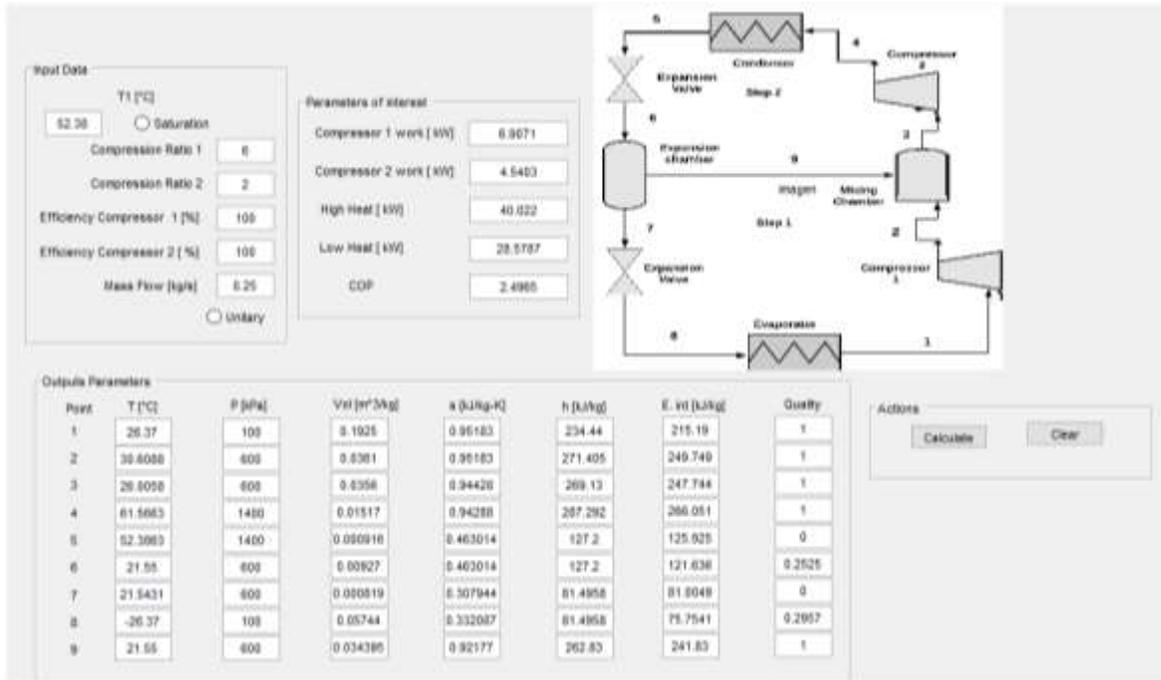
**Figure 1**. Simulation result of case three RefriTerm software.

With the proposed software we calculated the heat removed, the heat delivered to the environment, the work done by the compressors, the mass flow of some cycles, and the COP, obtaining an error range of [0, 0.44] % in all the applications that the program counts.

Besides, a client-server environment was designed for the SICVI-567 platform, taking into account aspects such as friendliness and ease of interaction so that the student has a learning environment, in addition to creating the third virtual course in the SICVI-567 platform, as well as the two existing subjects that are university courses and citizen culture.

There was a great acceptance by the students towards the virtual laboratory as a complementary tool. The LVs are tools that promise a great contribution to the development of the subjects and in the significant learning of the students, besides saving of money for the institutions that do not have the facilities nor the budget to adapt and to maintain expensive equipment. In the course of thermodynamics, laboratory practices are not carried out because it is not contemplated in the content of the program, the students suggest that this virtual tool be gradually included and taken as part of the subject. Also, there was an increase in the capacity of solving problems and a better understanding of the concepts in the sample of the students who carried out and shared the practical guide of the laboratory.

## IV.CONCLUSION

In this work, an educational tool was developed that allows the analysis of the energy performance of cooling systems considering different configurations, called "RefriTerm". The program was developed in Matlab environment which allowed to solve the different fundamental equations of mass and energy balances of each one of the components involved in the studied configurations. Besides, the software was subjected to verification and validation tests through typical textbook exercises to guarantee a good simulation

The results obtained showed that the tool can be used suitably since it fits to exercises found in most thermodynamics textbooks related to the analysis of cooling systems. As far as pedagogical aspects are concerned, RefriTerm is accurate and produces quickly which facilitates the process of assimilation of concepts related to the subject. Also, it allows the student to identify different simulation parameters that allow them to generate case studies and thus identify those variables that have a significant impact on the system.

Finally, the teacher can use this tool to increase the speed of calculation and provide more flexibility and objectivity when performing analysis. Besides, the tool can be used from any computer which allows the accessibility of the student at any time for its study and thus be able to deepen the topics given in classes given by the teacher.

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