

# Training with virtual learning environments for industrial refrigeration systems.

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**Abstract.** This article describes an application for the training of engineering students and industrial refrigeration plants, based on virtual learning environments. The application developed in the Unity 3D engine allows the interaction and immersion user and environment; through the modeling of a cooling system by steam compression, the inclusion of disturbances using Matlab software that allows the manipulation of dependent variables to have a more realistic background in combination with the bilateral communication TCP / IP protocol. The exchange of information in real time between the two programs is essential because feedback between user and environment is needed, the user manipulates the system while updating its parameters according to the thermodynamic variables evaluated by Matlab. The application presents three training modalities, i) Pedagogical scene: conventional refrigeration module, ii) Industrial scene: real refrigeration installation, and iii) Failure mode; in order to relate the environments and integrate the user for that improve competencies and skills through the manipulation, supervision, and operation of processes. The result of this study is a virtual application based on the characteristics of virtual learning environments. Finally, the virtual application is validated with respect to a real one, disturbances influence the performance of the system is analyzed and the interaction with the environment is tested.

## 1. Introduction

Industrial refrigeration is a multidisciplinary process that encompasses science and engineering to meet the cooling needs of humanity, since it is globally expanded in many sectorial applications, such as refrigeration in electrical devices, food, among others. In addition, it has an economic impact on refrigeration technology throughout the world and will transcend in the future due to the growing demand for systems and applications [1]. The manufacture, characterization, and control of refrigeration equipment have evolved, each refrigeration cycle is autonomous, linked to working conditions, temperatures, loads and other relevant aspects such as the refrigerant used or the characteristics of the elements that compose it [2, 3]. In this way, the industrial refrigeration field demands methods or learning systems for the staff. The training plans are the main bases to adapt to the new person in his job; these cover short-term objectives and correctly prepare the next operator to acquire new knowledge, attitudes, skills and ensure that this reaches a new level of education, with the aim of obtaining an efficient labor development, [4] the business sector proposes basic models for training and prevention techniques and failures [5, 6], the lack of equipment for training and technologies is a limiting factor.

The implementation of Virtual Learning Environment (VLE), as a platform that provides interactivity, flexibility, scalability and standardization [7]; you have become a training method that

offers an environment where the user experiences an environment equal to reality, which can go through even better situations than a real situation in reference to cost and security, it is thus, that this technology, due to the experiences that it provides is used for military, medical and industrial training [8]. Virtual reality applied to industrial training helps the development of skills to field operators and engineering students in industrial safety issues providing useful and lasting information. The creation of environments allows the supervision, monitoring, and control of industrial processes [9, 10], therefore applying virtual technology directly to training curriculum in companies is fundamental. [11] However, in the area of industrial refrigeration systems focused on virtual reality have not been widely explored.

The modeling strategies of refrigeration systems propose dynamic models for heat exchangers (condenser and evaporator) [12], analyze these components that need to be evaluated for operation under various operating conditions, also study the static models for the compressor and the expansion valve. [13–15]. In the context of industrial refrigeration, EVA learning environments and modeling strategies, this article proposes the creation of a virtual learning environment in order to create an alternative for training, control and analysis of industrial refrigeration systems in combination with CAD software and mathematical Software in where the operation is observed when varying parameters of the refrigeration system; this allows the student or professional to have a degree of knowledge and ability to select correct techniques in the diagnosis of failures that may occur in the refrigeration team focused not only on immersion in the virtual environment but also on the interaction with the different components of the system.

In further research that complements this work will be aimed at energy efficiency that allows the proper operation of the compressor and heat exchangers, which work on the basis of capacity control and a higher coefficient of heat transfer respectively [16]. Optimizing a system from the electrical and thermodynamic point. Also, the use of artificial vision algorithms and integrate them with artificial intelligence (AI) allows determine in real time by means of artificial neural network with regressive propagation the heuristic self-tuning of the thermodynamic parameters ( $P$ ,  $T$ ,  $s$ ,  $h$ ), and to coordinate them with the virtual environment of the present research in refrigeration and air conditioning systems [17].

## **2. Problem Formulation**

At present, the training methods implemented are conventional and include very compact training boards, 2D simulation programs, and training guides, among others, which have limitations: they do not provide complete training, a limited number of users and lack interactivity. It is necessary to adapt these methods to the characteristics and requirements of the user and incorporate training resources based on learning principles. The advance of the new forms of training to the personnel for the operation of industrial equipment intends to replace the traditional teaching and to advance with new technological proposals in order to reduce costs and time. Besides to increase the level of knowledge with the implementation of virtual learning environments, to the being this an important tool that provides an easy adaptation and capacity of several users, as a result, the understanding of industrial processes. The activities that constitute the stages of the process are developed as shown in ‘figure 1’.

The first stage contains the Game Objects with properties of each element necessary for the application of virtual reality, where its manipulation in the environment is linked to the Controller Grab Object, to visualize the behavior of all 3D models.

The Input stage corresponds to the devices that allow immersion and interaction with the environment, the Gear VR gestural controller and the HTC VIVE virtual reality helmet.

The scripts stage develops bidirectional communication between Unity 3D, Matlab, and the input and output devices. With the mathematical model, the behavior of each 3D component of the environment. Variables of temperature, pressure, mass flow, etc are simulated which establishes the behavior of the system and allows its monitoring, these parameters vary according to the data that can be sent from both Matlab and Unity3D, that is, they can work as client-server and vice versa, Communication is generated through the TCP / IP protocol that allows to receive (port 55000) or send

data (port 55001) between the two platforms, for working in real time in the two programs obtaining control of the cooling system. In the process, the temperature or pressure input variables sent from a control panel of the Unity motor are directly linked to the mathematical modeling through the data processing and relations between operating variables, the received data are observed in the displays and gauges of the process.

The output stage covers the effects of sounds of the components of the industrial plant to give a real perception to the user, with a visual immersion in the environment and haptic response to the inputs and increase the level of user-environment interaction.

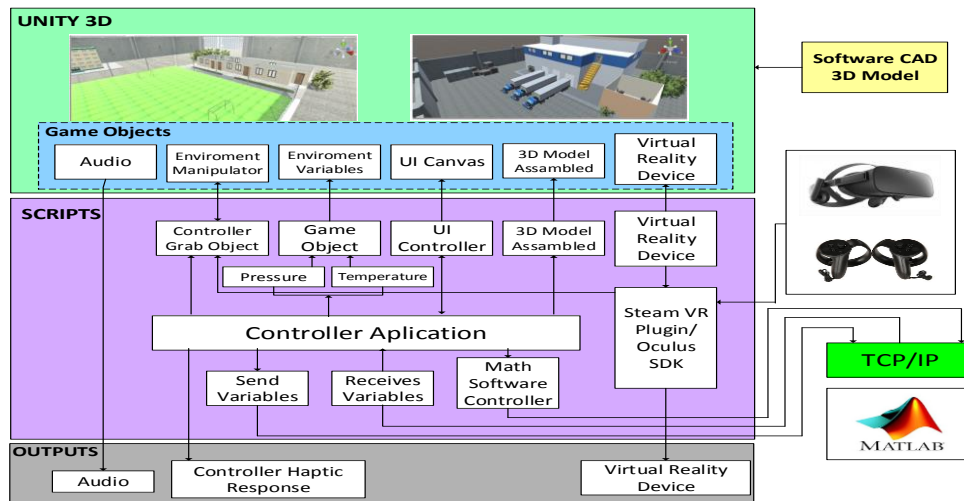


Figure 1. Stages of interrelationships of components.

### 3. Virtualization of the 3D Environment

#### 3.1. P&ID Description

To create a virtual application of the cooling system, the P & ID diagram shown in ‘figure 2’ is considered.

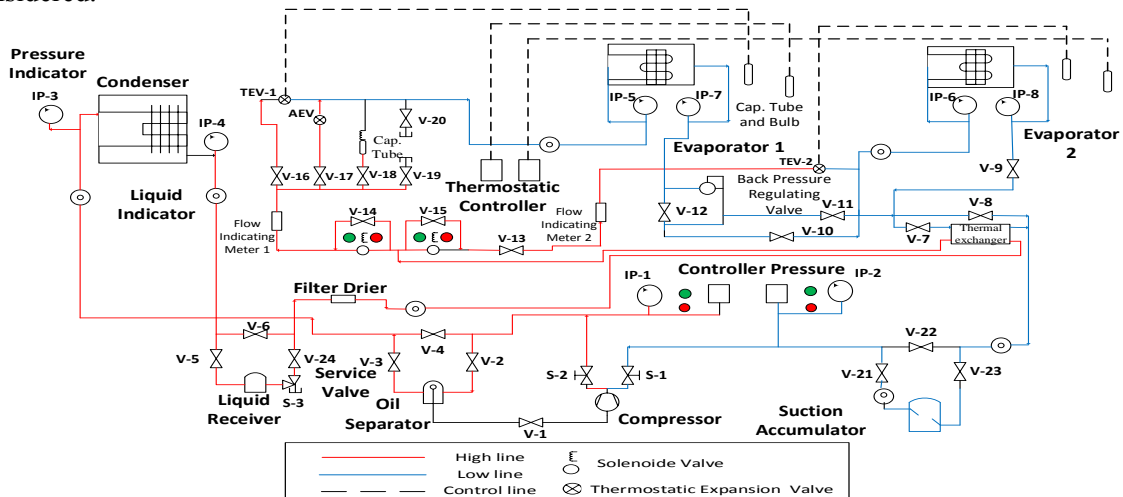


Figure 2. P&ID diagram of the refrigeration process.

It consists of the elements described below: The compressor is the central component that communicates two lines (high and low), the high-pressure line consists of valves that allow or not the passage of refrigerant to the condenser, without first having passed through the oil separator, at the outlet of the condenser there is a receiver of liquid intended to store excess refrigerant, then enters the filter drier necessary to remove moisture from the refrigerant, that flows towards the heat exchanger

here gains or produces heat, depending on the passage to the expansion valve or to the evaporator respectively, giving way to the conduction of the low-pressure line that consists of an evaporator and a suction accumulator to avoid the problem of refrigerant return in the compressor, for this reason, it is necessary to use sight peepholes, pressure and temperature gauges in the points of interest intended for the supervision of the same. These instruments will be in the virtual environment.

3.2. Parameters of the Cooling System

The parameters of the mathematical model for the evaporator are focused on analyzing the two zones that the refrigerant fluid crosses, the first made up of liquid-steam and the second only of steam; under the principles of conservation of energy, mass, and energy in the walls of the evaporator tube, it is possible to determine these phenomena according to the equations described by Navier-Stockes for fluids [18], these variations they are specified by means of the Leibniz rule, which provides the final equations for the areas under consideration; similarly it is analyzed for the areas of the condenser that have an additional liquid zone, see ‘figure 3’.

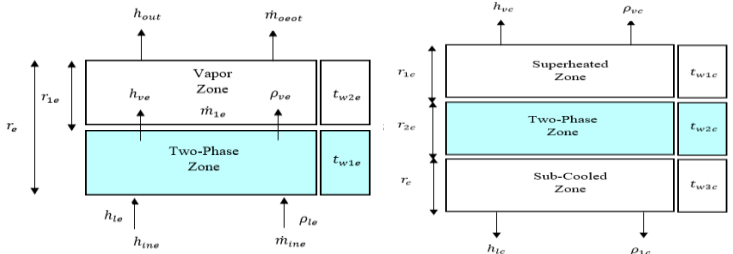


Figure 3. Areas of analysis a) Evaporator b) Condenser.

3.3. Description of the Multilayer System.

‘Figure 4’ presents a multilayer diagram that describes the different methodologies used in order that the user-environment experience is as close as possible to a real environment.

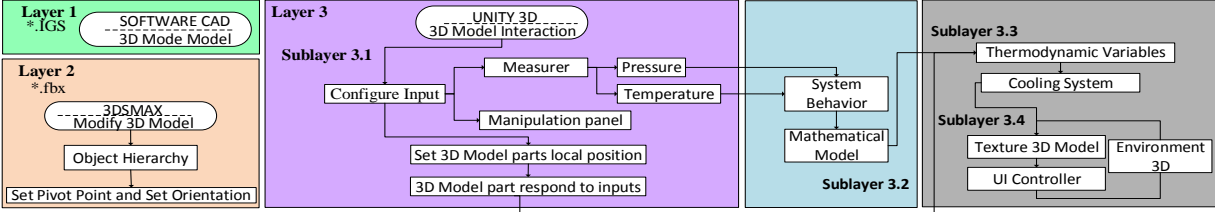


Figure 4. Multilayer diagram of the application creation process.

3.3.1. LAYER 1 (CAD Design). The creation of the virtual environment is based on the design of a 3D model made in CAD software. For the virtual application, mechanical parts of the compressor, evaporator, condenser, valve, filters, control panels, etc. are designed, as shown in ‘figure 5a’; for a refrigeration module and ‘figure 5b’ a real industrial refrigeration installation. The environment created has a high level of detail and realism in order to meet the objective of training. The final design is a file with extension IGS.

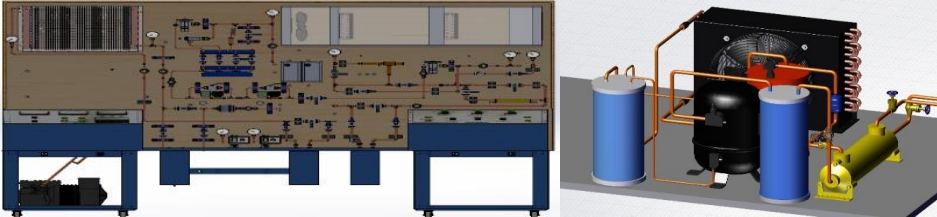
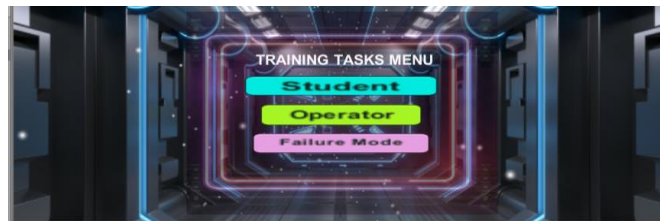


Figure 5. Refrigeration assemble system in the CAD software: (a) refrigeration module, (b) industrial refrigeration installation.

3.3.2. *LAYER 2 (Modeling Software)*. The design developed in the CAD software does not have formats compatible with the virtual tool, due to this, the 3D model is imported and it is perfected when incorporated in the 3DS Max software that; it allows to modify, establish the hierarchies of each element, and determine reference points (Pivot) useful for orientation and location. This is incorporated into Unity 3D with the model in file with extension Fbx.

3.3.3. *LAYER 3 (Game Engine)*. In this layer, the 3D models of the refrigeration system are manipulated with the virtual tool. The scenario has three areas of training as shown in 'figure 6'. These perform the same principle of operation. Below are the sublayers.



**Figure 6.** Training Task Menu developed in Unity 3D.

The sublayer 3.1 represents interaction with the components of the cooling system, by means of a control panel, which allows the user to enter values of temperature or pressure. Buttons are used that have their own programming scripts for the virtual interface whose function will be reflected in a display. It also develops the possibility of manipulating the mobile elements of the system with own events of Unity3D these are, On Trigger Enter, On Trigger Stay, On Trigger Exit; which detect the moment that objects in the environment are going to be manipulated and activate functions in response to necessary collision events, living the complete experience in the virtual environment using input devices such as HTC VIVE and Gear VR. It should be noted that the refrigerant to be used attributes unique thermodynamic properties that make each system different and provides a high degree of realism to the virtual application. In addition, in the future, the system allows for creating behavior monitoring by varying the type of refrigerant.

Sublayer 3.2 'figure 7', illustrates the implementation of mathematical modeling performed in the toolbox Simulink of Matlab, it presents a dynamic model for heat exchangers (condenser and evaporator), on the other hand, a static model for the compressor and the expansion valve; that predicts the mass flow and enthalpy of refrigerant R404a, a physical model is developed based on energy, mass balances and amount of movement capable of predicting the behavior of the system.

The mathematical model uses manipulable input parameters such as mass flow, evaporator and condenser pressures or temperatures, disturbances such as overheating in the evaporator, subcooling in the condenser, overheating in the suction gas line and cooling in the pressure gas line.

Sublayer 3.3. The physical signal ports provide the thermodynamic variables; these variables are visualized in the measurement equipment installed at each point of the system and the user interacts with the application by actuating the elements that make up the cooling system, in addition to manipulating the control panel.

Sublayer 3.4. This stage, centers on the development of the scenario in the virtual application, providing textures, color, and details through a user interface (UI). On the other hand, for greater immersion of the user in, an environment is developed according to the task to be executed, compatible with the mobility and movement of the user.

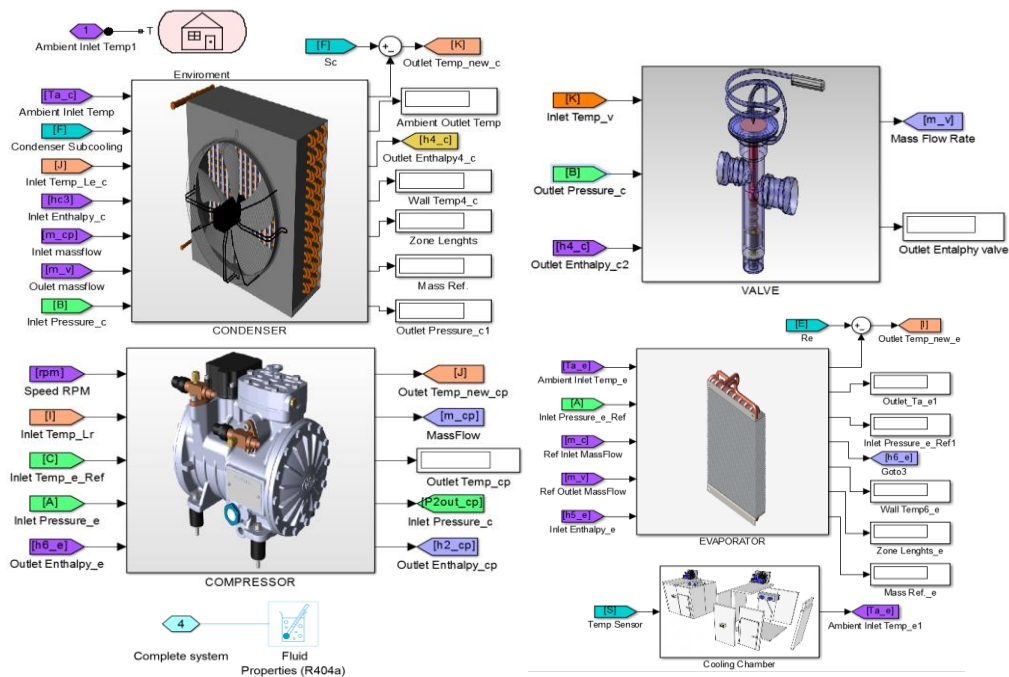


Figure 7. Mathematical modeling of the refrigeration system in Matlab-Simulink.

#### 4. Physical- Virtual Validation

As a function of the training, it is necessary to perform tests for the analysis of each point of interest in the system. To carry out the tests, a physical training module is used, configured for an industrial indicated in 'figure 8'; that it provides thermodynamic data based on ISO 5151 and ANSI / ASHRAE 16 standards.. In Table 1, the measured values of the physical cooling module are established.

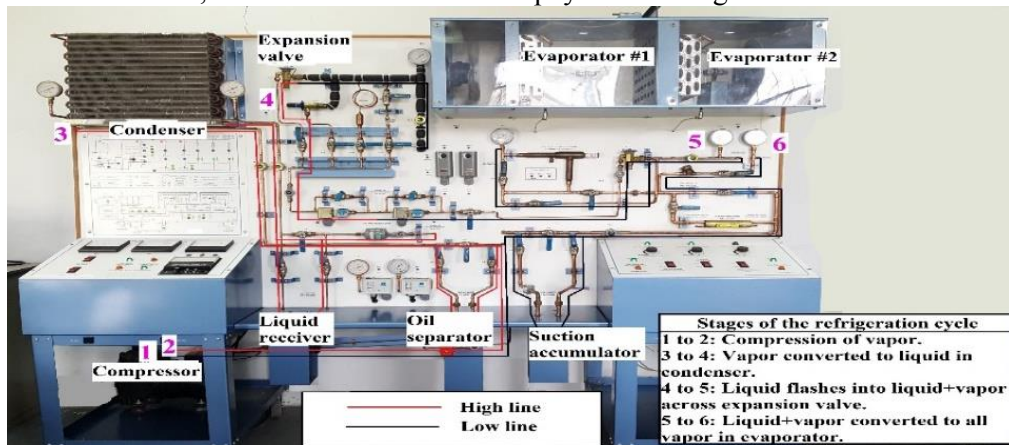
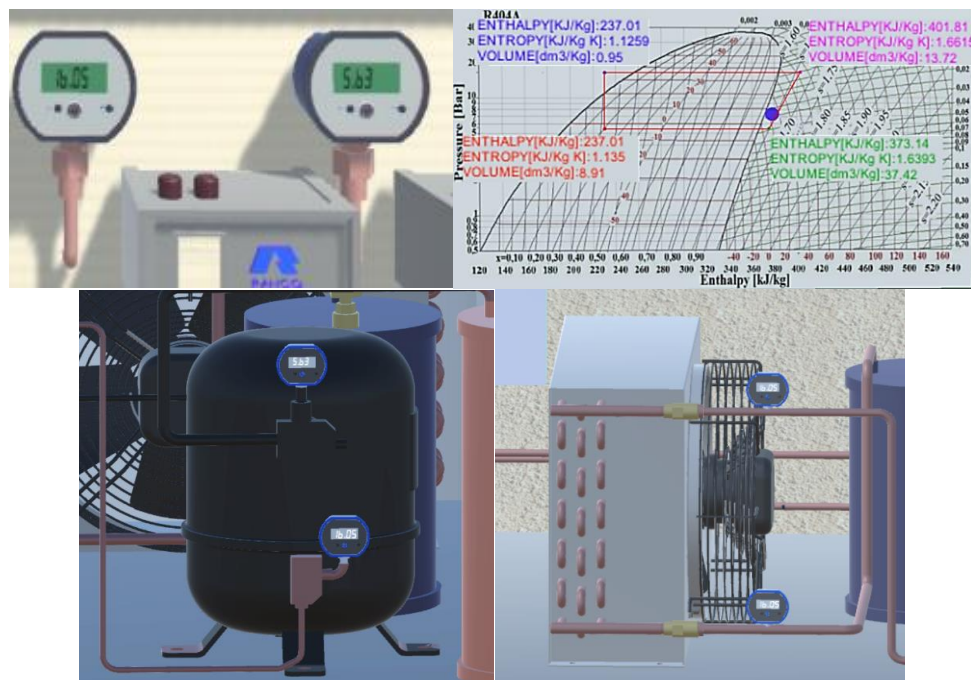


Figure 8. Physical training module for refrigeration.  
Table 1. Values measured in physical cooling module.

Point	Pressure (P) (bar)	Temperature (T) (°C)	Specific volume (v) (dm <sup>3</sup> /kg)	Enthalpy (h) (kJ/kg)	Entropy (s) (kJ/kgK)	Steam quality (x) --
1	5,63	7	36,97	373,53	1,6401	
2	16,05	52,39	13,33	400,88	1,6570	
3	16,05	52,39	13,33	400,88	1,6570	
4	16,05	25,64	0,96	237,22	1,1273	
5	5,63	-2,52	9,09	237,22	1,1372	0,241
6	5,63	7	36,97	373,53	1,6401	

The working conditions are the pressure of 5.63 bars on the low line, 16.05 bars on the high line, temperature  $-2^{\circ}\text{C}$  and  $35^{\circ}\text{C}$ ; the temperature calculations are  $9^{\circ}\text{C}$  of subcooling in the condenser and  $9^{\circ}\text{C}$  of superheating in the evaporator.

The mathematical model of the system provides the values of enthalpy, entropy, temperature, pressures, and volume in the considered points, for the virtual application ‘figure 9’.



**Figure 9.** Data in the virtual system: (a) Compressor pressures (Module), (b) Mollier diagram (thermodynamic variables), (c) compressor pressures, (d) evaporator pressures.

In Table 2, it shows the data displayed in the indicators within the virtual environment

**Table 2.** Values of the virtual application.

	Pressure (P)	Temperature (T)	Specific volume (v)	Enthalpy (h)	Entropy (s)	Steam quality (x)
Point	(bar)	( $^{\circ}\text{C}$ )	( $\text{dm}^3/\text{kg}$ )	( $\text{kJ}/\text{kg}$ )	( $\text{kJ}/\text{kgK}$ )	--
1	5,63	7	37,42	373,14	1,6393	
2	16,05	52,39	13,72	401,81	1,6615	
3	16,05	52,39	13,72	401,81	1,6615	
4	16,05	25,64	0,95	237,01	1,1259	
5	5,63	-2,52	8,91	237,07	1,1350	0,242
6	5,63	7	37,42	373,14	1,6393	

#### 4.1. Physical – Virtual Analogy.

A cooling system can be analyzed using the Mollier (P-h pressure-enthalpy) curves characteristic of the working fluid, which describe the behavior of the cooling circuit; for the physical and virtual system, the Mollier curves are determined for refrigerant R404a ‘figure 10’, with the parameters obtained from Table 1 and Table 2. The coefficient of performance (COP) of the physical system is 4.98 with an efficiency of 20.06% and that of the application is 4.74, with an efficiency of 21.05%. The analogy of the environment (physical and virtual) is based on the enthalpies, the cooling coefficient (COP) and the steam quality. The error of enthalpy in the compression step 1-2 is 0.165%, for the condensation step 3-4 is 0.155% and in the evaporation step 5-6 is 0.08%; the efficiencies

demonstrate the similarity that exists with an error of 3.59%, finally the quality of steam in point 5 results in 0.41% error.

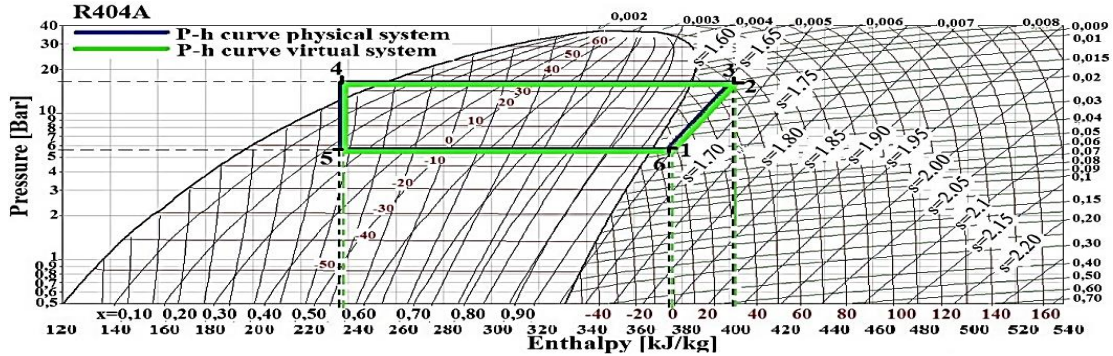


Figure 10. P-h curves for the physical vs virtual training system.

4.2. Disturbances.

The degree of subcooling reduces the amount of condensed liquid, when using the same basic conditions of superheat, evaporation and condensation temperature of Table 2, the increase in the degree of subcooling of 15 ° C reduces in volume flow, consequently, improves the COP to 5.31 with an efficiency of 19%, besides influencing the sizing of pipes.

5. Analysis and discussion of the results

The application allows different forms of student training, operator and failure mode. Student mode, ‘figure 11a’, the user interacts with the environment with actions that are carried out through a maneuver protocol, at the same time supervising the operation. Operator mode, ‘figure 11b’, In addition to the interaction and supervision, the user acquires a visual training can observe a refrigeration plant with the actual location of the components.

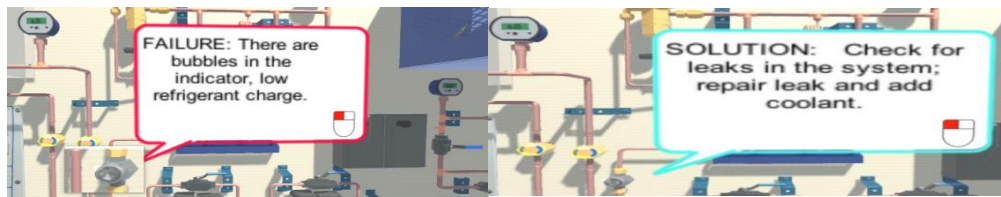


Figure 11. Training modes: (a) Scene students, (b) Scene operator.

Failure mode. Localization of problems in the system, it simulates the effects caused by a malfunction due to bad maneuver in some element of the diagram of ‘figure 2’, the user identifies faults and recommended solutions through warning windows, are described below:

- 1.Existing leaks due to loss of constant load of refrigerant charge, see ‘figure 12’.





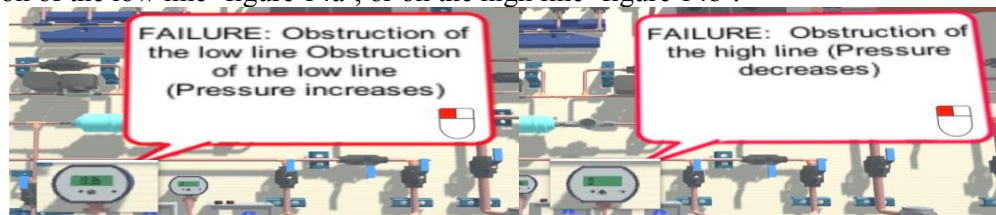
**Figure 12.** Physical training module for refrigeration.

2. Electrical failure due to lack of power to the compressor winding (Detection of visual failure-Light), see 'figure 13'.



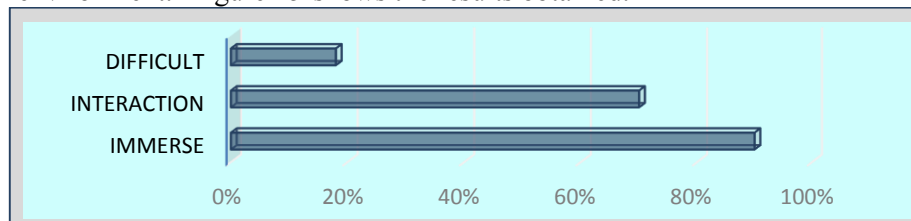
**Figure 13.** Warning indicator (yellow light).

3. Obstruction of the low line 'figure 14a', or on the high line 'figure 14b'.



**Figure 14.** Failures in the system lines: (a) low line failure, (b) high line failure.

Finally, to determine the efficiency of the application, a test is proposed to the technical participants in this area; each one of them received an induction on the operation of the training methods, with the objective of carrying out a protocol of activities to operate the industrial refrigeration environment. 'Figure 15' shows the results obtained.



**Figure 15.** Training system evaluation results.

The results obtained indicate that the virtual application contributes to visual and practical learning, as well as the development of the professional's skills in this area since it allows to identify and interact with all the components of the system.

## 6. Conclusion

This article proposes a virtual learning environment (VLE) for the purposes of pedagogical and industrial training in Refrigeration System, based on the analysis of the parameters determined by the physical training module; there is a relative error of 3.59% between the application virtual with respect to the working conditions used and the performance determined in Mollier curves. An application with a high level of reliability is achieved. The impact it produces on users makes the application more effective training than conventional training. The platform allows a level of scalability, such that the trainee, as the instructor, can connect simultaneously in the virtual environment with the possibility of

evaluating, that is, it has the ability to be multi-user. With the creation of interactive tasks in the virtual application, the user can monitor the behavior of the system, as well as instructing on possible faults that may arise, forms students and professionals with useful knowledge and decision-making capacity. The set of functionalities allow the e-learning system to have an easy adaptation, thus achieving a flexible environment. One of the functions is the entry of the temperatures of cooling and overheating in the virtual environment, which allows studying the improvement of the cooling coefficient keeping the basic data of the cooling system, as well as reducing the energy consumption and the size of the pipes in order to reduce costs and time.

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