Use of Plc as ICTS for Humidity Control in the Refrigeration Area of an Agricultural Industry of the Mexicali Valley, México

Roberto Carlos Valdés Hernández, Juan Gabriel López Hernández, Adelaida Figueroa Villanueva, José Luis Arcos Vega

Abstract: ***This work shows the need to apply information and communication technologies (ICTs) with a Programming Logic Controller (PLC) to control humidity by remote monitoring in the refrigeration process of an agricultural industry located in the Mexicali Valley of northwestern Mexico, where large amounts of orange are grown in this region of the country. This industry there were automated electronic devices (AEDs) for humidity control in the refrigeration area to prevent the deterioration of this agricultural product, only that the AEDs installed inside the evaluated company, did not operate properly due to the presence of outdoor atmospheric pollution (hydrogen sulfide (H_2S)) and oxide sulfur (SO_2)), and extreme climates in summer and winter (variations of temperature and relative humidity (RH))in this area of the country, that had an negative effect in indoors environments, and damaged their electrical connections. The principal climatic variables are the temperature and relative humidity (RH). The humidity in the refrigerated room for the orange keep its nutritional and physiological conditions, had to be between 45% and 55%. As AED, did not function properly, the climate inside the agricultural industry was not controlled, causing low and high humidity levels. With indexes below 30% humidity in the refrigerated room, oranges dehydrated and began to wilt, in addition to losing weight that was considered as unfit products for marketing. And at levels greater than 60% humidity, in this agricultural product microorganisms formed and caused rot, considered as a defective product and in both cases causing economic losses. The PLC was used with a wireless system and installed in an isolated room that only specialized personnel could enter if necessary. This was done in this way, to avoid deterioration of their electrical connections and that they did not operate as the AEDs and had adequate humidity control, to constantly maintain adequate humidity in the refrigerated room and avoid the generation of defective products. The research was made out from 2018 to 2019.***

Keywords: TICs, PLC, DEA, agricultural industry and humidity control

I. INTRODUCTION

Orange is a citrus highly cultivated in large quantities in the northwestern region of the Mexican Republic, which is a border zone bordering the states of Sonora, Mexico and California in the United States, which is illustrated in figure 1. In this region are around 70 agricultural industries as small and big companies (Valdes, Lopez, Figueroa and Amaro, 2020). This agricultural product as well as other fruit and vegetables, are cultivated, transported and packed with very rigorous quality levels to be able to take full advantage of the quantity of these, avoiding they damage very easily, and the agricultural industries of this zone of Mexico and all places of the world make very juice profits (Vardges, Magdana, Christopher and Aleksan (2020); James D. Lisa B. 2003). The orange in this region of the country is packed and shipped for consumption in this region and other areas of the Mexican Republic, in addition to its export to the United States, especially to the states of Arizona and California with strict control measures for quality. Both California and Arizona are regions of that country, which cultivate enormous quantities of orange, only that their populations generate great consumption and, as they are not sufficient to its population, they must resort to exporting from the Mexicali Valley with the rigorous regulations in quality control in the agricultural industry located in this region where the research was conducted. For this reason, was neccesary taked the strict quality control measures to avoid deterioration rapidly and with it possible fines for any damage to health and loss of customers. The Mexicali Valley belongs to the city of Mexicali and borders the state of Sonora in Mexico and the state of California in the United States as shown in figure 1, and in this zone of Mexico is located around 75 agricultural industries (INDEX-BC, 2019).

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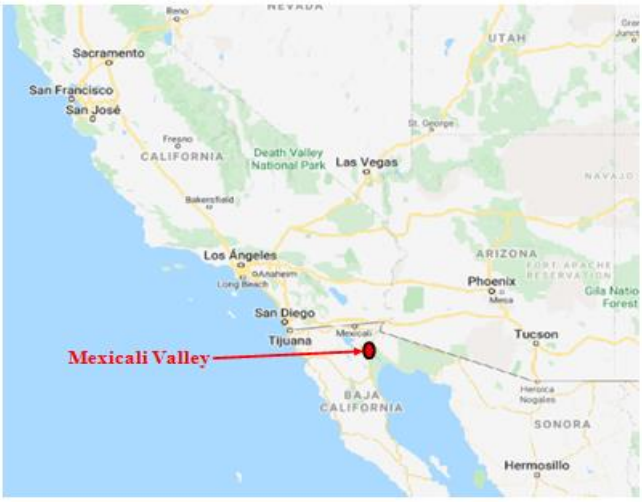
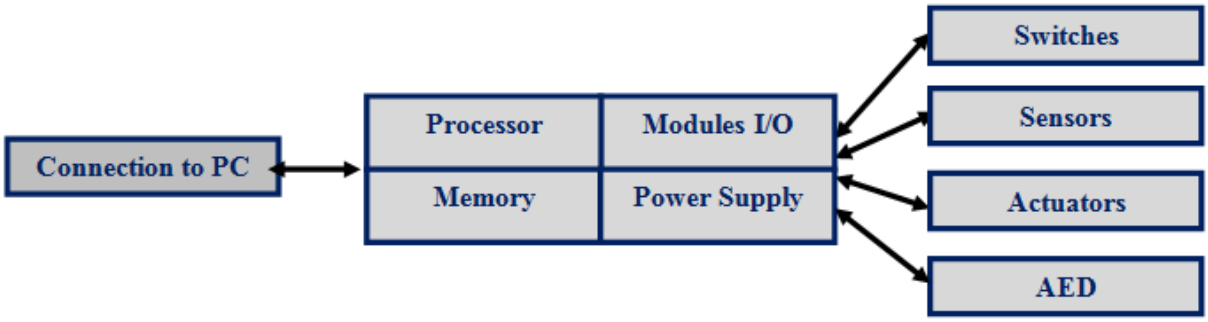


Fig1. Geolocation of the Mexicali Valley where are a big areas of orange crops
Source: Google map: https://www.google.com.mx/maps/@34.1807872,-106.3199099,6z

The PLC as a tool for ICT

The PLC that is considered a ICTs, is a widely used microcomputer in the industry for the control of electronic devices and mechanical actuators, which control industrial operations in manufacturing areas (Birgit, Susanne, Juliane, Thomas, Sebastian, Jens (2016)). These teams are easy to program in a basic training with ladder diagram algorithms and can run according to the type of activity, because it contains timers that can be programmed with highly regulated time periods, either slowly or quickly. The components that are related with a PLC are showed in figure 2, where in the left segment are the peripherals as the connection of a computer (laptop or desk computer), followed with the internal sections of PLC (processor, modules I/O, memory and power supply) and finally the external components (sensors, actuators, AED, switchers and other actuator elements).



The algorithm of the software with the ladder diagram in the PLC, illustrates the operations by steps according of the activation and desactivation of the active and passive electronic components as correlated with the timmers to determine the times of operation (Guttel, Weber and Fay. (2008)). The PLC is considered a very important tool of the TICs because it is a small system, with a lower cost than laptop and desktop computers and easy to transport to be used in different field activities (Vogel-Heuser, Fay, Schafer and Tichy (2015)). The AED was coupled to the PLC, operating to detect the variations of the sensors used in the room refrigeration, and controlled the actuators from the PLC to adjust fastly these variations and maintain the climatic conditions to conserve the nutritional and physiological properties.

Use of AED for air pollution control

The AED used were fabricated with active and passive components that are interconnected with each other to develop a specific function according to each electronic circuit, being considered as an automated electronic device, when performing operations in certain periods of time or according to detection of some specific characteristic (Tzyh, (2020)). The AED had to maintain adequate humidity in the refrigeration room, which is the penultimate stage before shipment, and prevent the orange from deteriorating. However with the presence of air pollutants derived of sulphur such as H_2S and SO_2 coming from outside the company and penetrating the interiors of the industry through holes and slits in the ceilings and walls of the industry where the Investigation, the AED did not operate properly and there was no climate control (López, Acosta, Romero, Toledo, Garduño, Márquez, Hinojosa (2013)). These pollutants caused a deterioration in the electrical connections of the AED, and that is why sometimes they operated and in others they did not, causing the adequate humidity in the refrigeration room for this agricultural product not to be maintained, which is why it was damaged, being considered a defective product and generating economic losses.

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Another factor that caused humidity variations in the refrigeration room and caused a negative effect on the nutritional and physiological conditions, was the extreme climatic factor of the exerior that caused the RH and temperature indices not to remain within 45% to 55% (Topuz, Topakci, Canakci, Akinci, Ozdemir (2005)**),** the extreme climatic variations of the company and therefore the presence of defective products and economic losses (López, Valdez., Schorr, Tiznado and Soto (2010)). For the control of atmospheric pollution, three AED were used in conjunction with the sensor that represents each evaluated parameter and they are explained below:

1. H_2S sensor. The erred sensor was used to detect the concentration indexes of this aggressive contaminant that deteriorated the electrical connections of the AED, being mentioned in the previous topic and linked to the AED, to activate the active and passive electronic components that will be explained in the following topical. This pollutant was the one that had the greatest effect on the damage to the electrical connections of the AED, both in the summer and in the winter.
2. SO_2 sensor. The sensor that detected concentration levels of this pollutant that damaged the electrical connections of the AED was used, generating a greater effect in the winter season, due to its chemical composition. This sensor was mentioned in the previous topic and, like the previous sensor, it was coupled to an AED for SO_2 detection.
3. Temperature and humidity sensor. This sensor has the joint function of evaluating both the temperature levels in degrees centigrade and the relative humidity variable in percentage, in conjunction with an AED.

In each types of sensor were used an indicator as a ligth bulb to indicate when they were functioned and in the sequence of time of periods.

Operation of DEA as a detection and control system

The use of AEDs in industrial processes is highly relevant because it supports the rapid and effective detection of characteristics to verify their optimal functionality for customers (Duygu, Shimeng and Wong (2013). In addition, it can detect defects that are solved within companies and thus avoid manufacturing defective products that damage the prestige of the company or customer demands for late delivery of manufactured products or failures in their functionality (Ionescu (2010); Marcantonioc, Lorenzo, Loredana,, Marco,and Massimo (2013)). The DEA block diagram used in this research is shown below in figure 3:

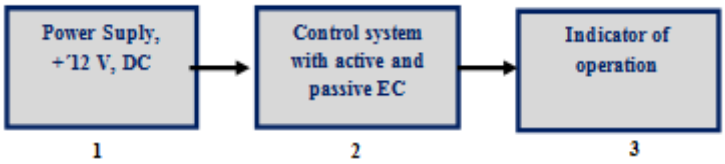

Fig. 3. Block diagram of the control system.
EC. Electronic components

The figure 3 shows the AED operates as a first stage with a 12-volt direct current source that supplies the voltage for the operation of the sensors of presence of particles in parts per million (ppm) of H_2S, and SO_2, and variations of temperature (ºC) and RH (%). These sensors generates the electrical pulses to be coupled to the AED and then to the PLC. The AED function consists in three steps principally, the generation of the electrical signal of the power supply of 12-volt of direct current (DC), then the second step is activated a sensor and with this was activated the control system of 12-volt of DC to active 2N2222 transistor as a NPN type to active a relay, which convert the direct current in alternative current (AC) of 12-volt to 120-volt. The2N2222 transistor generates an electrical interruption and supply of the current depending on the action of each sensor. In turn, the transistor is connected to a resistance of 1000 ohms of ¼ watt that regulates the current at the base of the transistor to prevent it from receiving a higher value than indicated and burning, stopping operation. And as a third step as a system, indicates that it is a 60-watt spotlight to determine when the sensors were working, representing the detection of any functionality or defect characteristic of the manufactured product (Kalpakjian (2014).

AED linked to a PLC

In this investigation, the process of connecting the AED as the hardware phase, with the computer system with specialized as the software (Burali (2012)), consisted of six stages, which are shown in Figure 4 and their phases are explained in detail:

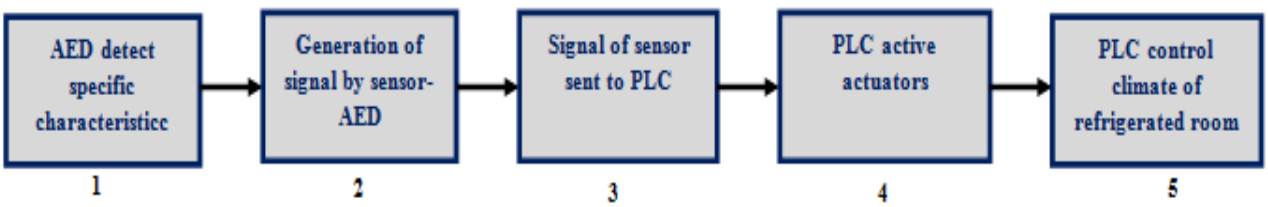

Fig. 4. Block diagram of hardware coupling with software for information analysis

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The figure 4 shows the interrelation of AED with the PLC, operating in five steps, which are explained now:
Step 1. Illustrates the detection a specific characteristic as presence ofH_2S or SO_2 pollutants or variations of temperature and RH and convert to electrical signal as digital signal.
Step 2. Represents generation of digital signal of sensor coupled with the AED.
Step 3. Sent the digital signal to the PLC to active the algorithms
Step 4. Show the activation of actuators by the PLC.
Step 5. Represents the control with PLC of climatic conditions in the refrigeration room area.

Algorithms used in PLC

The PLC is programmed with algorithms based on a ladder diagram that simulates the operations of passive or active elements, where it is expressed as a ladder with a follow-up from the beginning of the related operations and some do not develop until some stage each section on the ladder is activated and operations continue to be elaborated until the end of the instructions and work for the PLC, with digital logic functions (Fatur (2012, Vogel, Legat, Folmerand Rosch (2014)). The figure 5 shows two instructions as enter input variables and the ouput as the response to the actions of the two inputs completing the full process of the ladder diagram (LD) in a PLC with graphics where are elaborated and a LD. An example of a ladder diagram is presented below:

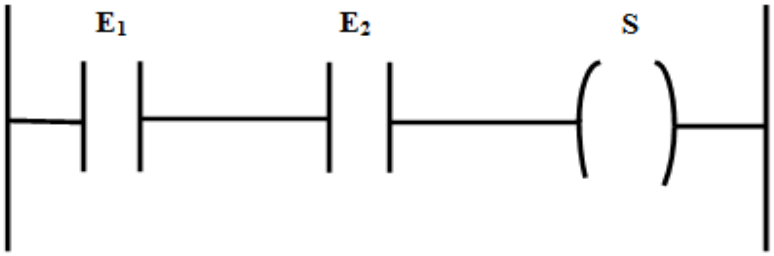

Figure 5: Ladder diagram of an operation with three variables: E1 is the first input variable, E2 is a second variable, and S is the output as a response to the operation of E1 and E2

In the Mexicali Valley there are factors that generate negative erect in materials of any kind, including the textures of fruits and vegetables that are easily deteriorated when the parameters of air pollution, especially those derived from sulfides whose presence at levels sometimes In this region of the Mexican Republic they exceed air quality standards (López, Acosta, Romero, Toledo, Garduño, Márquez, Hinojosa (2013)). This occurs, both in outdoors and indoors where 4. Mhey are more aggressive, and especially those derived from sulfur, essentially H_2S, which come from the Cerro Prieto Geothermal plant, located around 15 km (Kms) from the evaluated industry and through the flow wind (direction and wind speed) is transported to it. Another source of air pollutant emission is SO_2 emitted from the large number of automobiles, where around 25,000 vehicles are calculated in an area of 50 square kilometers (Km^2), being around 1 car for every 2 Km^2 (López, Valdez., Schorr, Tiznado and Soto (2010)). This is of great concern to government authorities that in recent years the flow of automobiles from the United States has increased as vehicles scrapped and purchased in Mexico at a low cost. In addition to air pollutants, extreme indices of climatic variables, mainly temperature and RH, are contemplated, as previously mentioned about the levels of these climate parameters that in extreme conditions, a rapid deterioration of materials is generated, and especially of the texture and nutritional and physiological conditions. The Air Quality Standards (AQI) was proposed by the Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAT-Mexico) and the Environmental Protection Agency (EPA-USA) (López, Arreola, Martínez, Mendieta, García, Pérez and Rocha (2012).

Evaluation of nutritional and physiological conditions of the orange

These aspects in an orange must be constantly evaluated both in the cultivation, transport and packaging processes; and especially in the areas of the Mexicali Valley, where agricultural activities are carried out, in agricultural industries and in the commercialization areas in markets, supermarkets or street markets where the sale and purchase of vegetables, fruits and vegetables is carried out. In this region of the Mexican Republic, very strict measures of quality of agricultural and health products must be considered, to avoid any health risk situation (Topuz, Topakci, Canakci, Akinci, Ozdemir (2005)**).** The nutritional conditions are considered the flavor, the nutritional value analyzing the nutrients that the orange provides to the human being for health aspects and its nutritional development (such as vitamin C, which is of great support to avoid respiratory infections), as well as the aroma that characterizes this fruit. The physiological conditions include the texture, color and hardness, mainly (Barakat, Yehia and Sayed (2012)). These factors are modified when the exposure of the orange to extreme climates (either in summer or winter) or to certain air pollutants, such as those mentioned in this study, is generated, sometimes observing the rapid deterioration of nutritional and physiological conditions, and not having the proper care these agricultural products can mix in the packaging processes and deteriorate other oranges that are in good condition with contact. This happens because both in the process of cultivation, transport or packaging, the oranges are losing water and with it they sometimes do not achieve their adequate formation and with it the rapid rot.

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Processes in agricultural industry

In the agricultural industry, there are various stages of the operations processes in the so-called agricultural product packers, where all characteristics of the stages are evaluated from the beginning to the end, to apply when continuous improvement is required. At each stage there are characteristics that can be repeated in later phases, and even when it is not contemplated that products are manufactured in this type of company, it is considered that the steps of an agricultural industry (Shamseldin, Mohamed, Kabeil (2010)), have manufacturing areas due to the various operations that are made and is showed in figure 6.

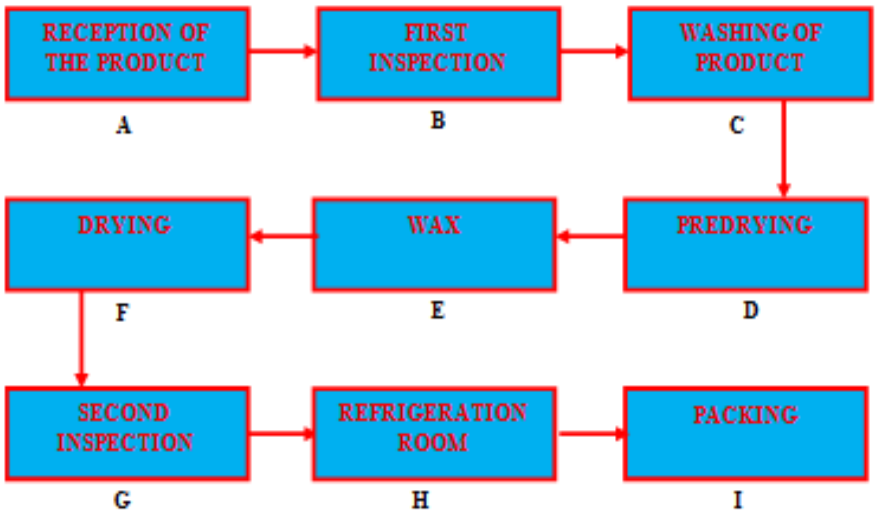

Fig 6. Stages of the process of receiving and packing the orange in the agricultural industry

The nine steps of the operation process of the figure 6 is explained below that are used in the evaluated industry:

Step A. The activity of receipt of the product is prepared, which in the case of this investigation is the orange in large boxes of 50 kilograms, requiring three people in the evaluated industry.

Step B. A first inspection of the aforementioned agricultural product is carried out on five tables with one person at each inspection table, being around 10 kilograms per table.

Step C. It is carried out with a high pressure hose system controlled by an electronic equipment between three people in three lines of linear process flow, to eliminate microorganisms or small particles attached to the orange in the cultivation or transport process. .

Step D. It is made with an electronic system that controls a team that creates an air flow to generate the drying of the orange, so that particles do not adhere to this agricultural product.

Step E. It is carried out with light brushing equipment, to avoid damaging the texture of the orange, to give it a shine that improves the appearance of this agricultural product to generate attractive sales.

Step F. It is carried out to generate a drying with a stronger function so that the waxing of the previous stage, and the orange remains as an attractive product for its commercialization.

Step G. It is elaborated with the second inspection for a stricter quality control, detecting oranges with deteriorated nutritional and physiological conditions in order to avoid damaging other oranges.

Step H. It is the place where the research was concentrated with the control system with PLC and it is where the oranges are concentrated before being packed and sent for commercialization. At this stage, the climate control factors inside the refrigerated areas must be taken care of.

Step I. It is the last stage in the evaluated company, which concentrates on organizing the oranges in separate boxes with brown paper selected for its toughness, softness and aesthetics.

Ishikawa diagram for climate control in refrigeration room

The Ishikawa diagram is an important tool as the improvement continuous (Alftan, Kaipia, Loikkanen and Spens (2015)) was utilized to evaluate the six parameters that are presented more frequently in any type of operations in any type of industry and in this case was analyzed each step of the process explained in the last section. The Ishikawa diagram is showed in figure 7.

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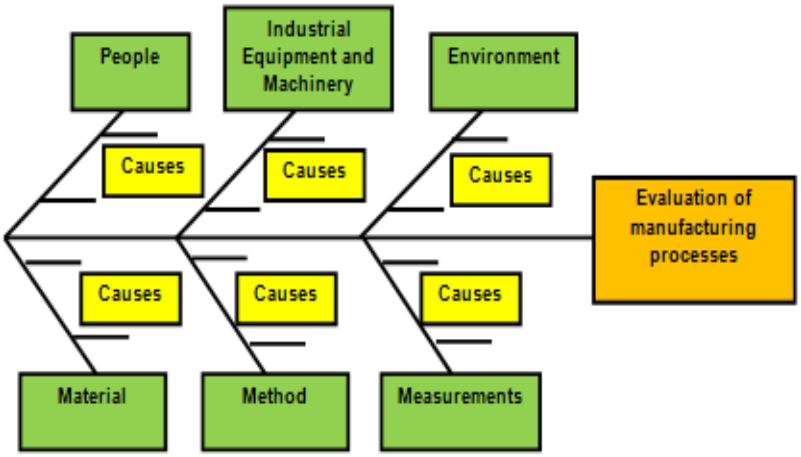

Fig 7.Steps of the process of receiving and packing of orange in the agricultural industry

The Ishikawa diagram was used with six factors involved in each operation made in the company, being the analysis of:

1. People. Were the workers that make the activities, evaluating the time and movements in each operation.
2. Environment. Was the employment relationship of management and supervision personnel with workers who carry out activities at each stage of the evaluated agricultural industry.
3. Industrial equipment and machinery. Were the analysis of equipments of activities in washing, drying, waxing equipment and the refrigeration room.
4. Material. Were the gloves, glasses and necessary tools, and also the necessary materials to make the operations.
5. Method. Was the way of made the operations, standing or sitting, types and times of movements for carry out the activities.
6. Measurement. Was prepared the appropriate measurements and compare them with quality standards established by specialized institutions or organizations.

II. METHODOLOGIES

Method and materials

The use of a PLC instead of the AEDs in the manufacturing processes of the evaluated agricultural industry provided the necessary support for the solution of problematic situations in industrial processes, where there are various scientific studies that refer to the application of PLCs in the industry. The study was made in two phases, the first consisting of determining the causes of what caused certain oranges to deteriorate throughout the packaging process, evaluating each step with the aim of analyzing the causes and consequences using continuous improvement tools. The second phase was developed to establish the type of system that would replace the AED, without presenting any deterioration situation in its electrical connections, having the PLC in a quarter of nine square meters (m2), being isolated and having trained personnel to elaborate the specialized algorithms that will elaborate the control process. The two phases mentioned are explained in greater detail below:

Phase 1 of the investigation. It was made with meticulous analysis, observing each operation and movement of each worker to determine if the activities were not rigorous or repetitive, causing discomfort to the personnel working in the evaluated stages, from the time the orange was received from a growing area until your packaging to be directed towards their marketing. To this phase the tool used was the Ishikawa diagram explained above.

Phase 2 of the investigation. Based on the analyzes of the previous stage, we proceeded to evaluate control systems and how to keep it in good condition so that it would generate climate control adequately in the refrigeration room and preserve in good condition the nutritional and physiological characteristics of the orange. After evaluating the options of using an electronic system with greater operating capacity, and selecting the PLC, algorithms were developed to analyze the control process of climate control operations in the refrigeration room. This isolated microcomputer generated the electrical signals with the instructions of the developed algorithms, controlling the three sensors mentioned above and evaluating their operability for periods of time using the PLC timers.

The DhT11C Arduino PIC sensor was used to monitor the temperature and humidity of a specific environment such as the refrigeration area of the evaluated industry, at a cost of 800 Mexican pesos. All sensors operate at 24 volts, which uses the direct current voltage input of the used Siemens S7-1200. The PLC Siemens S7-1200 with 12 V and 100 mA model 6ED1052-1MD00-0BA3 was used in this investigation, with a cost lower than 5000 Mexican pesos and with various control functions. The used PLC was connected with PnP type electronic sensors indicating that signals with positive output were obtained, which is very ideal for coupling with Siemens PLCs, because they capture positive signals. To monitor the sulfhidric acid (H_2S) that comes from the Geothermal Power Plant that generates electricity for the city and Mexicali Valley, in addition to the population of San Luis Río Colorado, Sonora and some cities in the southern United States of California. For this study was necessary use the H2S MQ-136 sensor at a cost of 800 Mexican pesos. The sulfur dioxide (SO_2) levels were determined with the 15x15 SO_2 Sensor 20 ppm P Package models 110-601, at a cost of 500 Mexican pesos.

SO_2 comes from the immense vehicular traffic of the Mexicali Valley, where around 80% of the population of the Mexicali Valley owns a car and in a family of parents and two children you can have up to four vehicles that generate this aggressive pollutant (López, Arreola, Martínez, Mendieta, García, Pérez and Rocha (2012)).

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The control system with the PLC sent the signal directly to the ADE that contain the sensors for detecting the aforementioned air pollutants, as well as the climate parameters mentioned above. The AED were checked each week and was a cost of 100 Mexican pesos and was very easy to fabricate, having a lot of these in a store room.

III. RESULTS

The presence of certain oranges in the industry evaluated without knowing what was happening before carrying out the investigation, where these agricultural products caused damage to other oranges and decreased quality, which caused a preoccupation in the areas of personnel management and supervision, as well as workers, specialized in manufacturing processes and continuous improvement. Knowing that the deterioration of the electrical connections of the AEDs caused an inadequate operation in these electronic devices, and did not generate adequate control of the climate in the refrigeration room, the solution was obtained immediately, being the application of the PLC to control of environmental conditions. The detection of the refrigeration room stage was based on analysis with one of the main tools for continuous improvement such as the Ishikawa Diagram, making it known where the main problem was originated.

Programming Algorithm for climate control in refrigerated room

A relevant aspect was that there are previous scientific studies where the PLCs have carried out sensor control operations to increase the productivity and quality of manufactured products, but in this research the control of a suitable climate environment for the preservation of the orange and avoid its rapid deterioration. The algorithms elaborated in the PLC for the climate control were generated according to the way in which the sensors should be activated for the detection of both polluting particles and climate variations, so nine stages were elaborated as shown in the figure 8 with the activations with the internal switches of the PLC and the control of the periods of time required for an optimal operation of the complete system (Sensor-AED-PLC). A representation of a screen in computer of a simulation of the operation process and control by the PLC in the refrigeration room is illustrated in figure 9, where is observed the elements that participates and a conveyor with the oranges with times controlled.

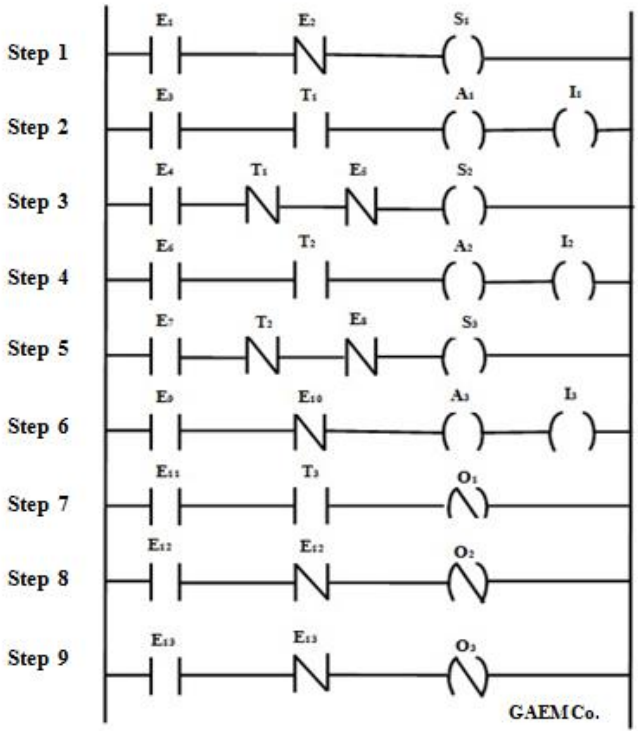

Fig 8. Ladder diagram of the climate control algorithm

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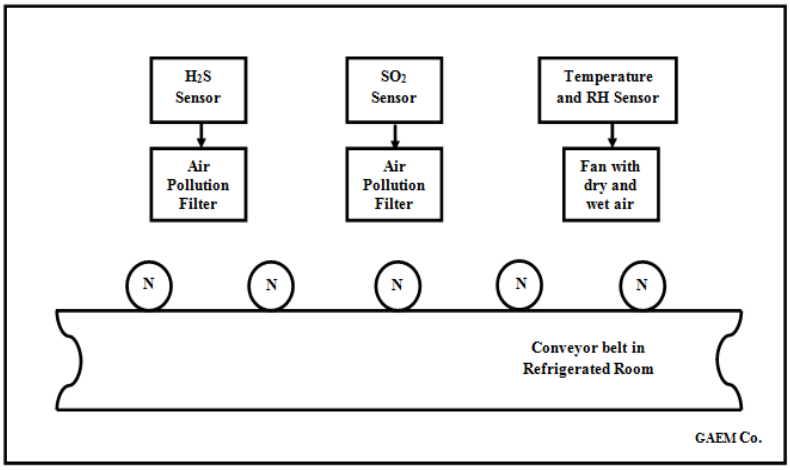

Fig 9. Computer screen of the refrigerated room process

Analysis of AED operation

An evaluation of the operation of the AED was carried out to determine the rates at which it operated with the maximum level close to 80% and the minimum close to 10%, as shown in Figure 10, with the colors of yellow and orange in its maximum levels and colors sky blue and blue green with the minimums. Productivity indices ranged from 0% to 90% and quality indices from 0% to 80%, considering that there were some stages with complex processes and thus it was not possible to obtain 100%.

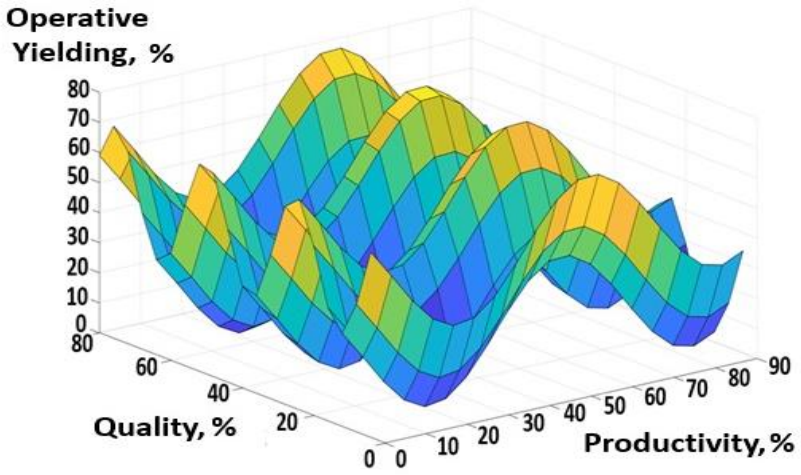

Fig 10. Correlation analysis of operability of AED and productivity and quality (July, 2018)

IV. CONCLUSIONS

The use of ICTs in small and medium-sized companies located in the city and the Mexicali Valley is relevant to include other factors such as the AED copled with a PLC, as well as functional characteristics of industrial equipment and machinery, labor and distribution of flows of processes. Furthermore, air pollution parameters were considered and some negative effects of this type of aspects were observed**.** Detection of contaminating particles and climate control in the cooling room with the PLC that generated better reliability than the AEDs that were damaged and stopped operating was of great importance, because the PLC in the isolated room with the Adequate communication connections, operated in optimal conditions to have the climate of the area evaluated and preserve the nutritional and physiological characteristics of the orange in a good state. The ICTs are a relevant technology that is very useful in the automation of industrial processes, as observed in this research. It could be determined that this type of technology is of great interest in the generation of smart industries with sophisticated and low-cost AEDs, such as the one used in this study, a docking system with the computer and a specialized database. Manufacturing processes were found to improve productivity and quality rates with automated electronic systems controlled by ICTs.

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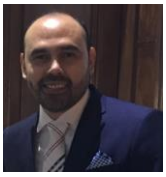

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