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# Development of a Microcontroller Based Automatic Storage Chamber for Orange Fruit (*Citrus Sinensis*)

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## ABSTRACT

Oranges are one of the commonest crops grown in Nigeria. It is rich in vitamin C and folic acid as well as a good source of fibre. About 30% to 50% of these oranges get spoilt after harvest due to lack of good storage facility. Hence, a high percentage gets spoilt before getting to the final consumers. The design of a microcontroller based automatic storage chamber for orange fruits will provide solution to this problem. The storage chamber consists of a cooling unit, power supply, microcontroller circuit, sensor and relay. The storage chamber was designed with specifications of the power rating of the compressor of 76 Watts and a volumetric dimension of 36cm x 45cm x 63cm. A PIC16F877A microcontroller was used in the design. A DHT11 sensor was interfaced with this microcontroller to monitor and control the temperature and humidity of the chamber. The compressor and relative humidity control circuit was designed to receive signals from the microcontroller in the range of 4oC to 7oC for temperature and humidity in the range of 85% to 95%. The microcontroller was programmed and coded in C computer language. The design of the storage chamber was achieved as well as the design of the microcontroller circuit. Simulations of the circuit were run on the Proteus 8 software. The result of the simulation gave a display of the temperature and humidity values on the LCD screen. The compressor was turned off when the temperature inside the chamber was below 7oC and the relative humidity below 95%. At this point the LCD screen displayed "temperature okay" to signify that it is at the desired value. The circuit was able to maintain the temperature and relative humidity in the chamber at these desired levels which would enhance the preservation of the orange fruit.

**Keywords**: Microcontroller, Orange fruits, relative humidity, temperature.

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## 1. INTRODUCTION

Orange fruit (*Citrus sinensis*) is a member of the citrus family along with mandarins (tangerines), lemons, limes, grapefruit, and kumquats [1]. Oranges are a component of the diet of many people globally because of their supply of vitamin C, which is essential in human nutrition. In Nigeria, about 930,000 tons of orange fruit are produced annually with producing states such as Benue, Nassarawa, Kogi, Ogun, Osun, Oyo, Ebonyi, Kaduna, Taraba, Ekiti, Imo, Kwara, Edo, and Delta [2]. About 30% - 50% of these oranges get spoilt on the way before getting to final consumers in the urban centers [2]. Hence, the need for proper storage technology after harvest is necessary to cater for this challenge. The common packaging in Nigeria includes packing in sack bags, jute bags, and locally made basket does not adequately tackle the problem associated with post-harvest losses. Appropriate storage technology can reduce wastage of a harvest surplus, allow storage for food shortages, and in some cases facilitate export to high-value market. Controlled atmosphere and low temperatures provides the maintenance of quality and shelf-life prolongation of fruit and vegetables.

As every tropical fruit, the orange (*citrus sinensis*) experiences chilling damages when stored at temperatures below $3^oC$ [3]. The storage of orange in control atmosphere of 90-95% humidity provides its life prolongation for about 3 to 12 weeks [4]. Therefore, freshly-plucked orange fruits should always be stored in a well-controlled chamber so as to meet the conditions necessary to guarantee the orange long term availability which is the temperature range of $4^oC$-$7^oC$ and 85%-95% relative humidity. Construction of this chamber is aimed at the improvement in quality and still-life period of oranges plucked after harvest, and also protect them against diseases and pest attacks during post -harvest. The design of the storage chamber makes use of a refrigerating system. In the course of this project, an electronic circuit that monitors the temperature and humidity inside the chamber using the DHT11 sensor, PIC16F877A microcontroller, relays, resistors, capacitors, diodes , transformer, 7805 voltage regulator, LCD display, BC547 Transistor.

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The compressor is controlled by a relay which is normally closed and becomes open when the temperature is optimum as monitored by the sensor with the value of temperature and humidity being displayed on an LCD screen at any given time. This process is continually repeated which makes it a closed loop process.

## 2. LITERATURE REVIEW

In recent times, various researches have been carried out to determine the optimum storage conditions of the fruit orange (*citrus sinensis*). Post-harvest treatments of these oranges are very important in extending orange life after they have been plucked from the tree.

According to [3] cooling reduces respiration, slows pathogen growth, reduces water loss and increases shelf-life and these orange fruits can be stored for up to 12 weeks under optimum storage conditions. Orange fruit begin to freeze in storage at -1°C. In Florida and Texas the temperature was considered to be between 0°C and 1°C with relative humidity of 85 to 90% while California and Arizona were considered to be between 3°C and 8°C with relative humidity of 90 to 95%. He also stated that controlled atmospheric conditions of 5 to 10% oxygen and 0 to 5% of carbon dioxide may aid in quality retention of orange fruits. However, he considered the addition of 5 to 10% of carbon monoxide which is dangerous to human health although it helps in improving decay control. The use of ethylene to de-green oranges was considered in his work which stimulates decay but ethylene use will not be used in the course of this project.

[5] Worked on a solar based temperature controlled fruit drying system which uses a microcontroller (PIC16F877), infrared light is used to internally heat the fruit to remove the water content within the fruit. Then air is blown inside the chamber to maintain the humidity below a specified level and exhaust the humid air out of the chamber. The microcontroller is used to control the functions of heating, blowing the air and giving time indication and maintain constant temperature throughout the chamber. Results after a day showed that this process had better performance than the conventional method and also temperature maintained were achievable based on user requirement. However, this is limited to only fruit drying method for storing fruits.

[6] Studied samples of orange and tomato fruits stored in the pot-in-pot evaporative cooler for 21 days during which tests carried out to quantify some nutritional parameters of moisture, ash, protein, lipid, vitamin C, carbohydrate and total sugar contents were assessed periodically. The study revealed that there were continuous decreases in the quality parameters, such as vitamin C content from 7.52 to 0.49% for orange, lipid content from 0.29 to 0.07% for orange, carbohydrate content from 12.23 to 9.53% for orange, protein content from 0.18 to 0.04% and total sugar content from 0.65 to 0.25%, while the value of moisture content increased to 85.32%, with increase in storage period.

[7] Researched on the effects of packaging and storage condition on the quality of orange fruit (*citrus sinensis*). Orange fruit (*citrus sinensis*) were harvested at green maturity stage and were divided into 60 fruits per packaging material (Sack bag, jute bag and basket) and stored at ambient conditions. Firmness and rot incidence were evaluated at 2 days interval for 17 days. At the end of the storage period, it was discovered that mass losses were 36.6, 39.6 and 20.8% in basket, jute bag and sack bag respectively. Rot incidence of 55% was observed in fruits packed in sack bag, 10% rot incidence occurred in fruits packed in jute bag while no rot incident was noticed in fruits packed in basket. This could be due to the large air space available for the exchange of air with the surrounding. The high number of rotten fruits in the sack bag could be as a result of condensation inside the packaging material due to poor or very low permeability of the package to airflow resulting to accumulation of heat. This method will not be considered because it fails to guarantee prolonged storage of up to six months.

[8] Investigated cartenoid losses in orange fruits. After storage under controlled conditions of oxygen, temperature and nitrogen, he discovered that oxygen was the main cause of degradation followed by temperature. The orange fruit preservation was optimal with little or no nitrogen involved as long as the temperature and oxygen conditions were met.

## 3. MATERIALS AND METHOD

The storage chamber for the orange monitors the temperature and relative humidity in the chamber. The system is made in such a way to keep accurate control and monitor both parameters such that there is a controlled atmosphere suitable for the storage of orange.
The design and construction of this project involved both the mechanical and electronic section.

### *3.1 Mechanical Section*

The mechanical section of this paper refers to the materials used for the refrigerating system. The refrigerating system consists basically of five components which are:

**Compressor:** The compressor is the heart of the system. The compressor does just what its name is. It compresses the low pressure refrigerant vapor from the evaporator and compresses it into a high pressure vapor. A 76 watts vane compressor is used for this purpose.

**Evaporator:** The plate type evaporator feeds the refrigerant in circulation; the evaporator is embedded in the plates of the refrigerator and hence makes cooling more efficient.

**Expansion valve:** This is placed before the evaporator and regulates how much refrigerant enters the evaporator.

**Condenser:** This is where the gas is changed to liquid form; hot vapor starts to flow through the tube. This vapor is later cooled to become a liquid refrigerant again

**Refrigerant:** The refrigerant is the working substance in the refrigerator in this R134a as it is environment friendly unlike Freon or R12 gases which deplete the ozone layer.

### *3.2 Design and Calculation of Chamber*

Orange to be stored = 10Kg

166g = 1 orange; Therefore for 10 Kg, $\frac{10{,}000}{166} = 60.24$ . Approximately 60 orange fruits.

With an average diameter of 7cm, the oranges are to be placed on three trays having 20 oranges on each tray. (i.e 5x4 on each tray).

Having 5 oranges at the length side, the length becomes $5 \times 7 = 35$. Using an approximation of 5% error the length becomes 35 + 1.75 = 36.75, which is approximately 37cm.

With a thickness of 4cm on both sides, 37 + 8 = 45cm.

Therefore, Length = 45cm, having 4 oranges with 7cm diameter, the breadth becomes 4 x 7 = 28cm.

Using an approximation of 5% error, the breadth 28 + 1.4 = 29.4 which is approximately 30cm.

Having a thickness of 3cm on both sides becomes: 30 + 6 = 36cm.

The area (L x B) then becomes: $Area = 45 \times 36$, Area = 1620cm$^2$. Since the height of the orange would also be 7cm, for 3 trays would be $7 \times 3 = 21cm$.

A 6cm stacking space is left between the orange and the tray is becomes: $6 \times 4 = 24cm$.

Thus, 21cm + 24cm = 45cm

Approximation error of 5 percent, 45 + 2.5 = 47.5cm approximately 48cm.

15cm for the electronic session is added and it becomes: 48 + 15 = 63cm.

#### *3.2.1 Heat Conduction (HC)*

Heat is conducted into the chamber through the walls of the chamber. The amount of heat flowing through these surfaces is a function of their thermal resistance (R-value), their area and temperature difference between one side and the other.
To determine the heat conduction:

$$HC = \frac{Area \times Temperature\ Difference}{R - value}$$

But room temperature is 25$^{o}$C,

Desired temperature is 5$^{o}$C, temperature difference = 25-5 = 20$^{o}$C = 68F

R-value = 0.55, Area =1.74 ft$^2$

$$HC = \frac{1.74 \times 68}{0.55} = 215.13\ Btu/hr = 63.04\ W$$

#### *3.2.2 Field Heat (FH)*

This is a source of heat is produced by the orange when brought into the chamber. Field heat is the product of the specific heat, SH, of the orange, the temperature difference, DT, between the field temperature and the storage temperature and the weight, W, of the orange.

$FH = SH \times DT \times W$ (www.angelfire.com)

Weight of orange is 10kg = 22.05lb, Specific heat, SH, is 0.9Btu/lb/F, Temperature difference, DT, is 68F

Therefore:
$FH = 0.9 \times 68 \times 22.05 = 1349.46Btu = 56.2275\ Btu/hr = 16.48$

#### *3.2.3 Heat of Respiration (HR)*

This is another source of heat. Horticultural crops are alive and give off heat as they respire. The amount of heat produced depends on the temperature, the crop and the conditions and the treatment the crop has received.

$HR = Weight \times HR_5{}^0$

$HR_5{}^0$ C = 0.0189 W/Kg (2006 ASHRAE Handbook-Refrigeration (SI))

$weight = 22.05lb = 10.00Kg$

$HR = 10 \times 0.018 = 0.189$

#### *3.2.4 Service Load (SL)*

$SL = 0.10 \times (HC + FH + HR)$

$SL = 0.10 \times (63.04 + 16.48 + 0.189) = 7.97\ W$

#### *3.2.5 Total Heat Load (THL)*

$THL = HC + FH + HR + SL$

$THL = 63.04 + 16.48 + 0.189 + 7.97 = 87.67\ W$

Recall that,1 HP = 745.699872 W
THL = 0.1176 HP
Therefore, the compressor power required for the chamber is 0.1 HP.

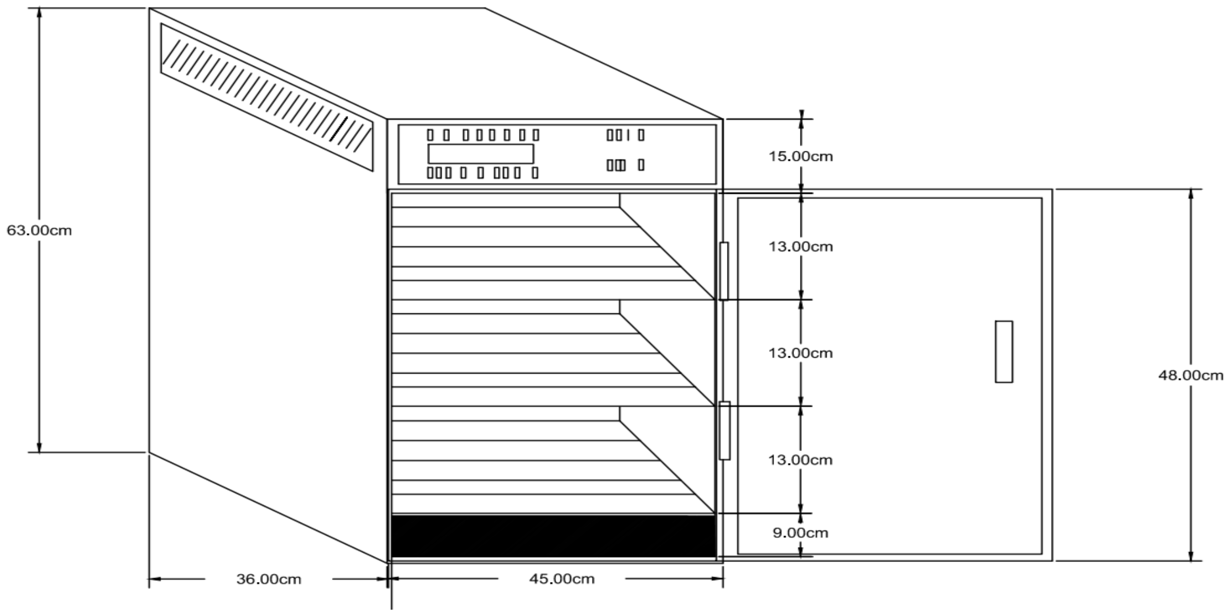


**Figure 1: Orange Chamber Design.**

***3.3 Electronic Section***

This section refers to the electronic materials and methods that were used in the course of this paper.

*3.3.1Microcontroller Section*

The microcontroller used for this work was the PIC16F877A due to its ease of programming. The peripheral Interface Controller 16F877A is a 40-pin, 8-bit microcontroller whose main architecture is the RISC (Reduced Instruction Set Computing) CPU. This PIC used for this paper has an input frequency of 20MHz as shown in Figure 2.

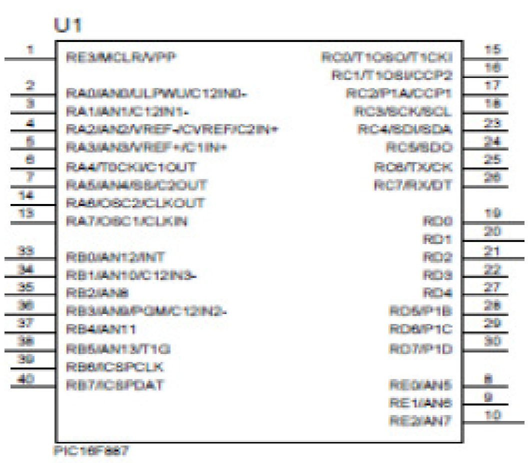


**Figure 2: Microcontroller unit.**

If frequency (f) is 20MHz, therefore time taken per cycle (T) is given as:

$T = \frac{1}{f}, \quad T = \frac{1}{20}, \qquad T = 0.05\mu sec$

For a PIC16F877A microcontroller, each instruction cycle takes four operating clock cycles. Therefore, for an input frequency of 20MHz, each instruction cycle will operate at: $0.05\mu \text{ sec} \times 4 = 0.2\mu \text{ sec}$

The PIC has two types of memory which are the program memory and the data memory. The microcontroller can be programmed using different programming languages. The microcontroller has 8 channel 10bit ADC with dedicate ADCON register for configures the functions of the analog input port pins (Mazidi). This in turn helps to compare the reference chamber temperature and display on LCD connected to PIC16F877A microcontroller.

*3.3.2 LCD Display*

The LCD display that was used is the LM041L (Figure 3)16x4 LCD display which makes use of a 5V power supply with operating temperature of 0°C-50°C and storage temperature of -20°C to 70°C. The data can either be sent in 4-bit 2-operations or 8-bit 1-operation so that it can interface to both 4 and 8 bit microprocessors.

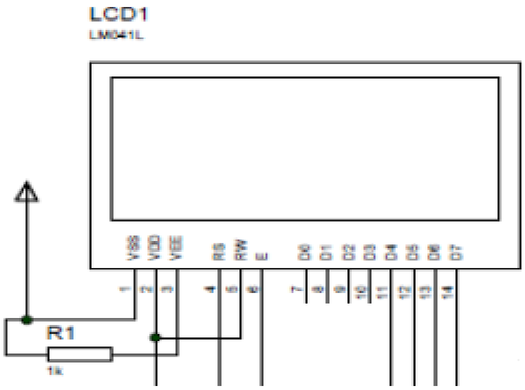


**Figure 3: LCD display.**

Where,
V = 5V, $R_1$ = 1K, $I = \frac{5}{1000} = 0.005\ A$, Therefore 5mA will be allowed to pass through the LCD. Note that the resistor is a pull up resistor.

*3.3.3 Reset switch*
For reset switch, Where:
V = 5V, $R_2$ = 10K

$$I = \frac{5}{10{,}000} = 0.0005\ A$$

Therefore a current of 0.5mA will be passing through pin 1 of the micro-controller. Note that the resistor is a pull up resistor for temperature sensor.

*3.3.4 Compressor Control*
The compressor control which comprises of a BC547 transistors (Figure 4) and a relay which operates on 12V and has a resistor connected to the base of the transistor. The relay which is on permanent off switches to the on state when it receives signal from the microcontroller that the temperature is above the desired range.

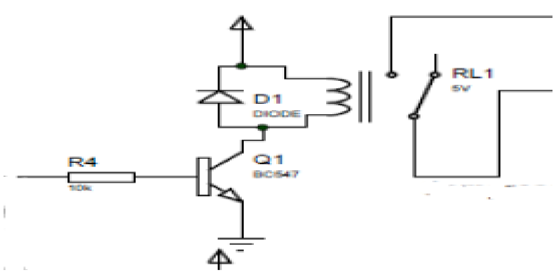


**Figure 4: Compressor Control.**

In this application the transistor is not being used as an amplifier but for switching, hence just a little amount of current is required for switching within the permissible range on the datasheet. At an ambient temperature of 25°C the transistor has a collector-emitter voltage of $5V_{CE}$ and a collector current of 2mA, a maximum current gain of $h_{fe}$= 800, when the transistor is on it draws a base current of 0.5mA and base emitter voltage $V_{BE}$ = 0.7V. The required resistor $R_4$ to limit the voltage of the transistor is given as:

$$R = \frac{V - V_{BE}}{i_B}$$

Where,

V = 5V, $V_{BE}$ = 0.7V, $I_B$ = 0.5mA

$$R = \frac{5 - 0.7}{0.0005} = 8{,}600\Omega$$

Approximating to the nearest standard resistor we have 10,000Ω

Therefore a resistor of 10,000Ω is required to limit the voltage of the transistor and allow it switch, $R_4$ = 10,000Ω.

*3.3.5 DHT11 Sensor*
Measurement and control of temperature and relative humidity finds applications in numerous areas. This sensing comprises of signal conditioning, ADC, calibration and communication interface built inside them. It includes a resistive-type humidity measurement component and an NTC temperature measurement component (Figure 6) and a high performance 8-bit microcontroller inside (Figure 5), and provides digital signal output.

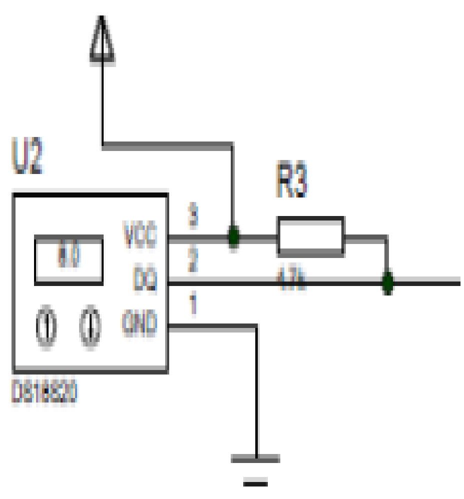


**Figure 5: DHT11 Unit.**

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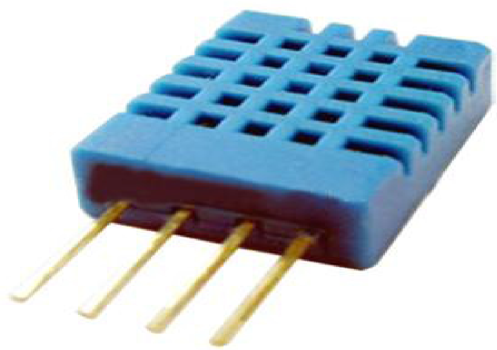

**Figure 5: DHT11 sensor.**

Where,
V = 5V, R3 = 4.7K

$$I = \frac{5}{4.7} = 0.00106\ A$$

Therefore a current of 1mA will be allowed to pass through pin 10 of the microcontroller.

## 4. RESULTS AND DISCUSSION

The circuit was designed using program software Isis Proteus 8, this application was used to simulate the microcontroller's programming. Only the temperature circuit could be simulated the figures below shows the results of the temperature circuit when simulated.

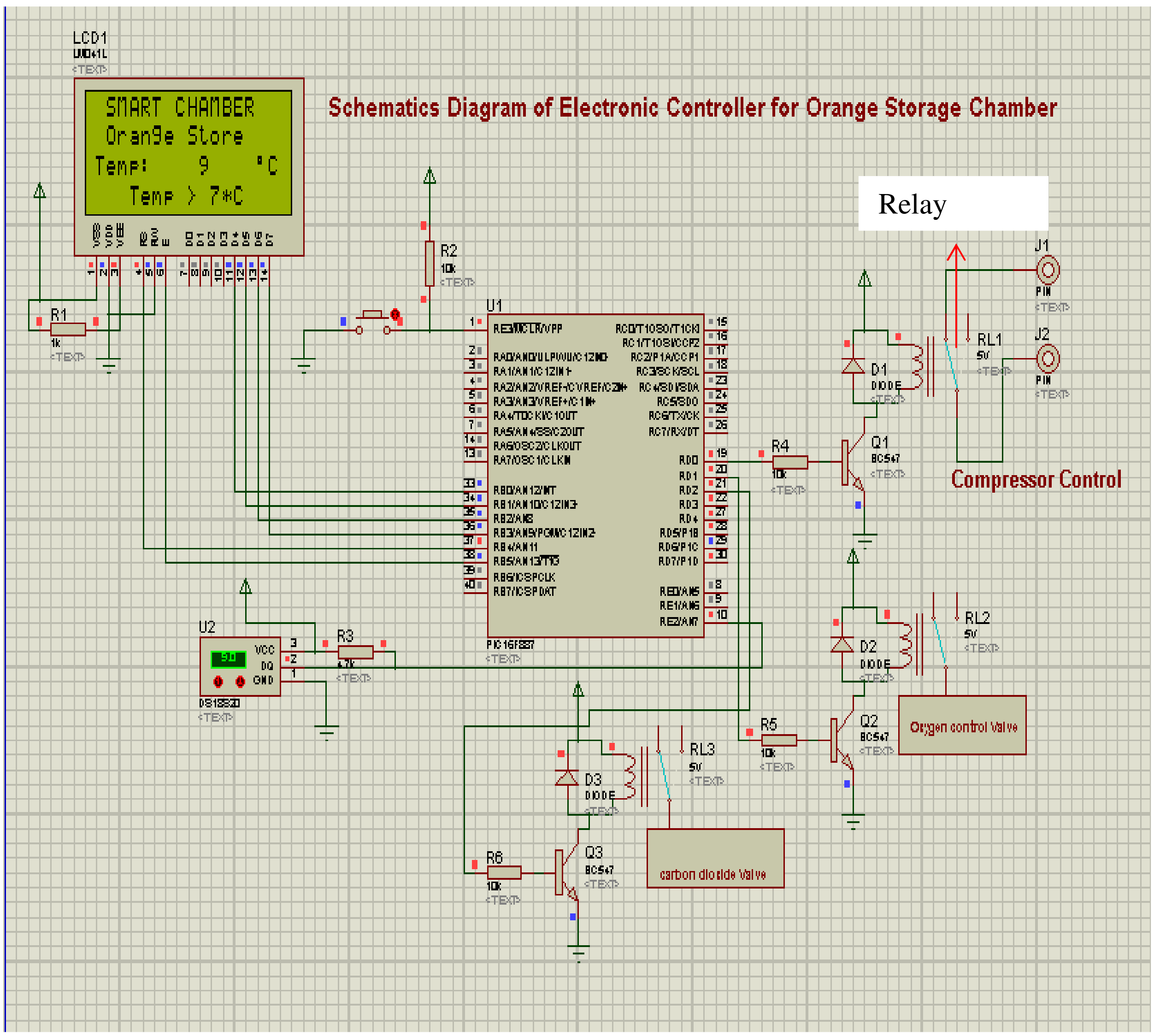


**Figure 7: Designed circuit during simulation with relay closed.**

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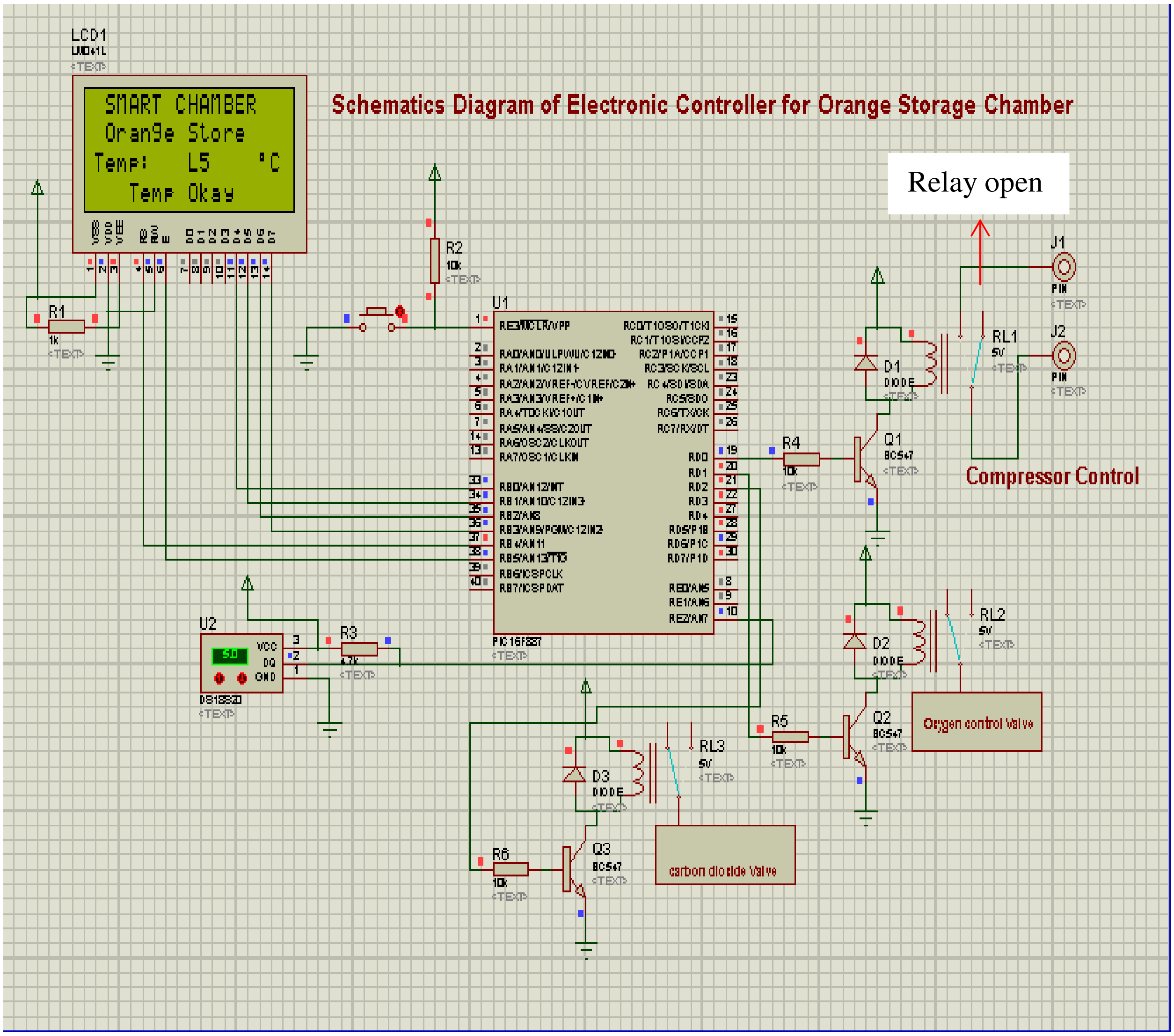

**Figure 8: Designed circuit during simulation with relay open.**

Figure 7 shows the circuit sensing a temperature of 9°C and the relay is closed meaning that the compressor is in operation and cooling continues.
In Figure 8 the temperature is at 5°C which is an okay temperature that is required, the relay becomes open meaning that at this point the compressor is off and the compressor does not cool further.

*4.1 Tests after Construction*

After the construction was complete, the circuit was tested for the temperature and humidity. Since there was no chamber available, ice cold pure water was placed on the sensor to decrease the temperature to a certain value.

The temperature and humidity readings were displayed on the LCD screen as shown in Figure 9 and Figure 10.

**Figure 9: Temperature reading displayed on LCD screen.**


**Figure 10: Humidity reading displayed on LCD.**

*4.2 Discussion*

The simulation in Figure 8 shows the operation of the relay when the temperature is above the desired level and the relay is on meaning that the compressor is in operation. The simulation in Figure 9 shows the relay open when the temperature is within the desired range meaning that the compressor is off at this time. When the temperature begins to rise again and exceeds the required level the compressor comes on again. The constructed circuit was tested using a refrigerator, the temperature dropped to 15 degrees Celsius and at this point the relay was on which means that a compressor connected to it would be on. The humidity and temperature value were displayed on the LCD as shown in Figure 8 and Figure 9. The temperature and relative humidity have a mathematical relationship which is shown below,

$$Td = T - \frac{(100 - RH)}{5} \quad [9]$$

Where,
Td = dew point temperature in degree Celsius
T =observed temperature in degrees Celsius
RH= Relative humidity in percent

With this equation, the dew point, temperature or relative humidity can be calculated if the other parameters are known.

## 5. CONCLUSION

At the end of this work, the aim of this paper which is to design a storage chamber based on a microcontroller to control and monitor the temperature and humidity inside the chamber for optimum storage of orange was achieved. Other results that were obtained in the course of this work were the implementation of the design on a printed circuit board and incorporation of a digital display for the temperature and humidity. The optimum conditions for operation are within the temperature range of $4^{o}$C and $7^{0}$C, 85% and 95% for relative humidity.

The electronic design consists of a power supply which receives 220V of electricity and steps it down to 12V and 5V to power the relays and PIC16F877A microcontroller respectively. The PIC16F877A microcontroller was selected based on its ease of programming. A DHT11 sensor was interfaced with this microcontroller to monitor and control the temperature and humidity, send the signal to the microcontroller to take action on the relay based on the pre-set instructions using C language. When the electronic circuit was switched on, it displayed the current temperature and humidity on the LCD screen. As the temperature dropped to $7^{o}$C and below the relay turned off the compressor so as to prevent further cooling. At this point the LCD screen displayed temperature okay to signify that it was at desired value. The circuit was able to maintain the temperature and relative humidity at these desired levels which would enhance the preservation of the orange fruit.

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