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# CONTROLLING HUMIDITY IN AN INCUBATOR USING A MICROCONTROLLER-BASED ACTIVE HUMIDIFIER SYSTEM WITH AN ULTRASONIC NEBULIZER

**Dr. Mahendra Kumar Pathak** Guest Faculty, Department of Physics Maharaja Chhatrasal Bundelkhand University Chhatapur Madhya Pradesh

## ABSTRACT

The relative humidity inside the incubator was monitored and regulated. An ultrasonic nebulizer system served as an active humidifier to maintain the desired humidity levels within the incubator. To measure the humidity, an integrated circuit-based humidity sensor was utilized. Both the measurement and control functions were managed by a PIC microcontroller, whose high performance and speed offered system flexibility. This system is well-suited for use in the intensive care of newborns and premature infants. Additionally, because the humidifier produces aerosol in ambient conditions, it can achieve high relative humidity levels, making it suitable for therapeutic and diagnostic applications in medicine.

**Keywords:**
*Relative Humidity, Incubator, Ultrasonic Nebulizer, Active Humidifier, Integrated Circuit Humidity Sensor, PIC Microcontroller, System Flexibility, Newborn Intensive Care, Premature Infants*

## INTRODUCTION

An incubator is a specialized device that provides intensive care for newborns, particularly those who are premature or ill. It maintains a clean, sterile environment with stable temperature, appropriate relative humidity (RH), and oxygen levels, all critical for infant health [1–3]. Like other medical devices, incubators have limitations, requiring precise methods for humidity measurement and regulation. Electrical transducers such as resistive, capacitive, lithium chloride, electrolytic, and integrated circuit (IC)-type RH sensors are used for continuous monitoring. Among these, capacitive and IC-type sensors are preferred for their accuracy and favorable electrical properties [4–6].

Air humidification in incubators can be achieved through passive or active methods. Passive humidification relies on heating water to create moisture, but this method is unsuitable for incubators as it affects temperature control and struggles to maintain high RH levels at lower temperatures, especially between 23°C and 38°C [3,7]. It also introduces excess heat, making it impractical for confined environments [3].

In contrast, active humidification does not rely on heat, allowing high humidity levels to be achieved even at lower temperatures [8]. Ultrasonic nebulizers, which produce aerosols without adding heat, are ideal for humidifying incubators [3]. A nebulizer converts liquid into a fine mist and is commonly used in medical treatments [8–11].

This study developed a humidity measurement circuit using an IC-type sensor to monitor RH in the incubator, alongside a portable ultrasonic nebulizer for humidification. Both systems were controlled by a high-performance PIC microcontroller to enhance flexibility. The active humidification method ensured consistent high humidity levels without affecting temperature stability, which was also evaluated in the study.

## RESEARCH METHODOLOGY

### System Electronics

The system consists of four main components: the incubator chamber, RH measurement circuit, ultrasonic nebulizer, and microcontroller-based control circuit. The incubator walls are made of plexiglass, chosen for its low thermal conductivity, which minimizes external temperature fluctuations, and its transparency, making it suitable for phototherapy. Glass, being fragile, is unsuitable for this application [1].

Figure 1 shows the block diagram of the microcontroller-based humidity measurement and control system. The desired RH level is set using the UP button, with the value displayed on a three-digit screen. When the START button is pressed, the control unit compares the set RH with real-time readings from the humidity sensor inside the incubator. If the measured RH is lower than the set value, the ultrasonic nebulizer is activated via an opto-isolator. The nebulizer converts sterilized water into fine mist particles.

A 12V DC fan, also controlled by the microcontroller, circulates the mist evenly within the incubator, gradually increasing the RH. Once the desired RH is reached, the nebulizer and fan automatically shut off. If humidity exceeds the target, excess moisture escapes through small holes in the incubator walls, allowing natural humidity reduction even when access ports are closed.

## Patient Isolation and Safety Requirements

Patient isolation and safety are central to the incubator system's design. All electronic components, including the measurement system, humidifier, and driver circuits, meet IEC 60601-2-19 safety standards [12], while mechanical materials were selected to comply with safety regulations.

The programmable system's software was developed following IEC 60601-1-4 standards for Programmable Electrical Medical Systems [13], incorporating reliability features like the Watchdog Timer (WDT), Power-on Reset (POR), Power-up Timer (PWRT), Oscillator Start-up Timer (OST), and Brown-out Reset (BOR). The humidifier and RH measurement circuits were designed per IEC 60601-1-1 standards [14].

The system is powered by a mains-fed DC/DC converter with 6 kV DC isolation, preventing direct electrical contact between the patient and RH sensor. The nebulizer, designed modularly, delivers water particles into the incubator via a 1-meter plastic pipe, ensuring electrical insulation in line with IEC 60601 safety requirements.

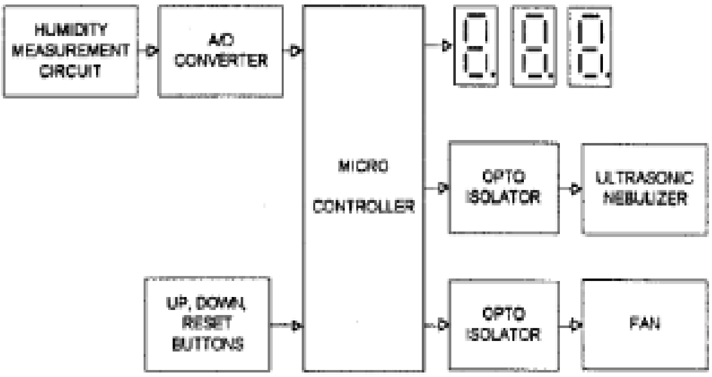

**Figure 1: Microcontroller-based humidity y measurement and control system**

## Relative Humidity Measurement System

The incubator's relative humidity (RH) is measured using a Monolithic IC-type humidity sensor (HIH3605A, Honeywell). Changes in humidity alter the sensor's capacitance, which is converted into voltage signals by internal circuits. The sensor outputs a linear voltage from 0.8 V (0% RH) to 3.9 V (100% RH), maintaining linearity within ±0.5% RH. It has a fast 15-second response time in slow-moving air at 25°C, low drift over time, and ±2% RH accuracy across the full RH range in non-condensing air at 25°C [6].

The nebulizer releases fine water particles into the incubator, which are warmed to form water vapor. While condensation can affect sensor accuracy, prolonged exposure to RH above 90% causes only a reversible 3% RH shift, meaning readings may be slightly higher than actual humidity.

## Sensor Operating Conditions and Circuit Design

The sensor functions between –40°C and 85°C, with accuracy slightly affected by temperature: +0.007% RH/°C at 0% RH and –0.22% RH/°C at 100% RH. It is sensitive to electrostatic discharge (ESD) but protected by internal diodes handling up to 16 kV. Additional protection includes fast static diodes on input/output pins and aluminum housing with one open end to shield from ESD and bright light like sunlight or phototherapy [6].

Figure 2 shows the IC-type humidity measurement circuit. An AC/DC converter powers the system, with a stable 2.5 V reference supply (drift ~50 ppm/°C) ensuring accurate readings. A buffer circuit with an op-amp maintains high input and low output impedance. A zero and span circuit adjusts the sensor's voltage output from 0.8 V (0% RH) and 3.9 V (100% RH) to a 0–4 V range, matching 0–100% RH in the incubator.

**Ultrasonic Nebulizer**

Figures 3 and 4 illustrate the block diagram and circuit details of the ultrasonic nebulizer, respectively. The nebulizer primarily consists of a power oscillator circuit, with the ultrasonic crystal serving as its core component. This crystal facilitates oscillation under all conditions, generating water particles through ultrasonic vibrations. Operating at a frequency of 1.73 MHz, the ultrasonic crystal vibrates within a reservoir of sterilized water, producing water particles ranging from 0.5 to 6 µm, with an average size of 3 µm. The 1.73 MHz frequency is sufficient to achieve the desired particle size; higher frequencies yield smaller particles. Additionally, the density of the water droplets is influenced by the power supplied to the crystal higher power levels result in denser droplet formation. The nebulizer requires 40 VA (Volt-Ampere) of power for optimal operation.

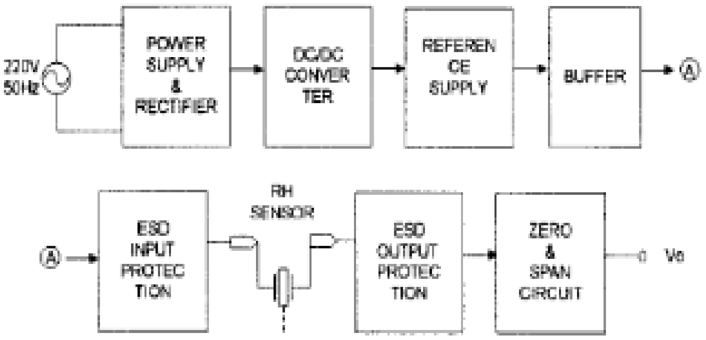

**Figure 2: Humidity measurement circuit**

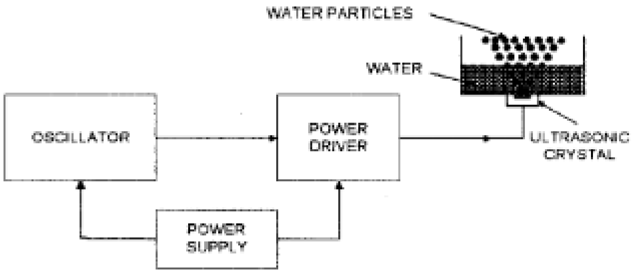

**Figure 3: Ultrasonic nebulizer**

The particle sizes produced are sufficient to humidify the incubator chamber. If needed, the density of these particles can be adjusted using a P3 potentiometer, which increases the forward bias of the power transistor, thereby raising particle density. A DC fan mixes the water droplets with air, and evaporation occurs when these droplets enter warm air circulated by a heater. Without the heater, airflow from the fan could cool the baby. Both the fan and heater help regulate the incubator's temperature. Since water droplets are heavier than air, proper circulation is necessary, requiring two fans: one to move particles from the nebulizer through a plastic pipe and another to circulate heated air within the chamber [6].

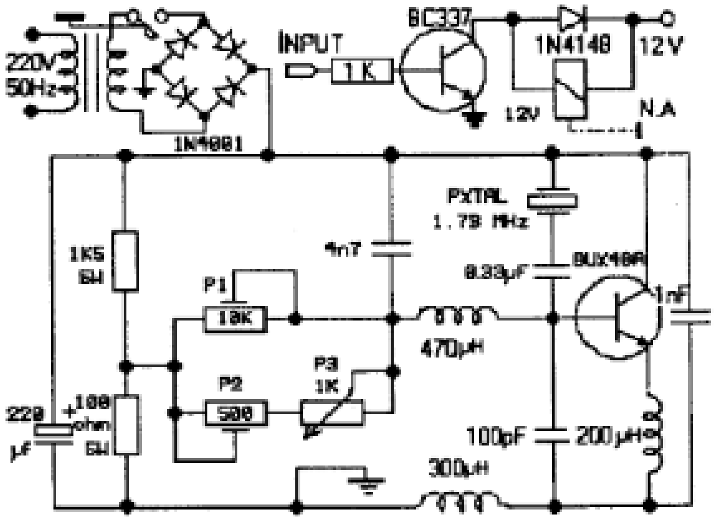

**Figure 4: Circuit of the ultrasonic nebulizer**

### Microcontroller-Based Control Unit

The system is controlled by a PIC 16C74A microcontroller, selected for its RISC architecture, which ensures faster performance and simplified programming with just 35 instructions. Built-in timers like WDT, POR, PWRT, OST, and BOR enhance reliability. The Watchdog Timer (WDT) resets the device during software timeouts, preventing malfunctions. The Power-On Reset (POR) activates when Vdd rises between 1.2–1.7 V, while the Power-Up Timer (PWRT) adds a 72 ms delay for voltage stabilization. The Oscillator Start-Up Timer (OST) provides a 1024-cycle delay to stabilize the crystal oscillator, and the Brown-Out Reset (BOR) resets the chip if Vdd drops below 4.0 V [15].

The PIC reads RH data via an A/D converter, compares it with the set RH, and controls the nebulizer and DC fan accordingly. A three-digit display shows the incubator's RH. The PIC 16C74A includes 192 bytes of RAM, 4 KB of EEPROM, 33 I/O pins, an 8-bit ADC with eight channels, three timers, two CCP modules, and 12 interrupt sources. The hardware and software for this application use 213 bytes of memory, with peripheral circuits integrated as shown in Figure 5 [15].

### Power Supply and Control Mechanism

The power supply energizes the microcontroller and circuits, while a 4 MHz crystal oscillator provides the timer's clock signal. The control unit has three buttons: RESET restarts the system, UP sets the desired RH, and START initiates measurement and control. The desired RH is shown on a three-digit display when UP is pressed, and the current RH appears once START begins the humidification process. To decrease the RH set point, the UP button cycles to the maximum before resetting to zero for adjustment.

The A/D converter converts RH sensor data to 8-bit digital values via the RA0 port of the PIC (Figure 6). The microcontroller compares set and measured RH values, activating the ultrasonic nebulizer and fan when needed. Both devices operate through an opto-isolator circuit (Figure 7), and potentiometer P3 adjusts water particle density for stable RH.

Fresh air circulation prevents condensation, but at 100% RH and 34°C with closed ports, water may drip onto the baby or mattress. Double-walled incubators, with two plexiglass layers separated by 1–2 cm of air, reduce condensation more effectively than constant fan operation [3].

## RESULTS AND DISCUSSIONS

The humidity level in the incubator is crucial for the baby's survival, simulating the mother's environment. To ensure this, a system has been developed and tested through various experiments. Since temperature is a key control parameter in the incubator, the effects of humidification on temperature were examined. Babies' skin may dry out due to health issues or water loss, necessitating higher humidity levels. The developed system was tested to humidify the incubator air in the range of 22.2–90% RH at 22.8°C.

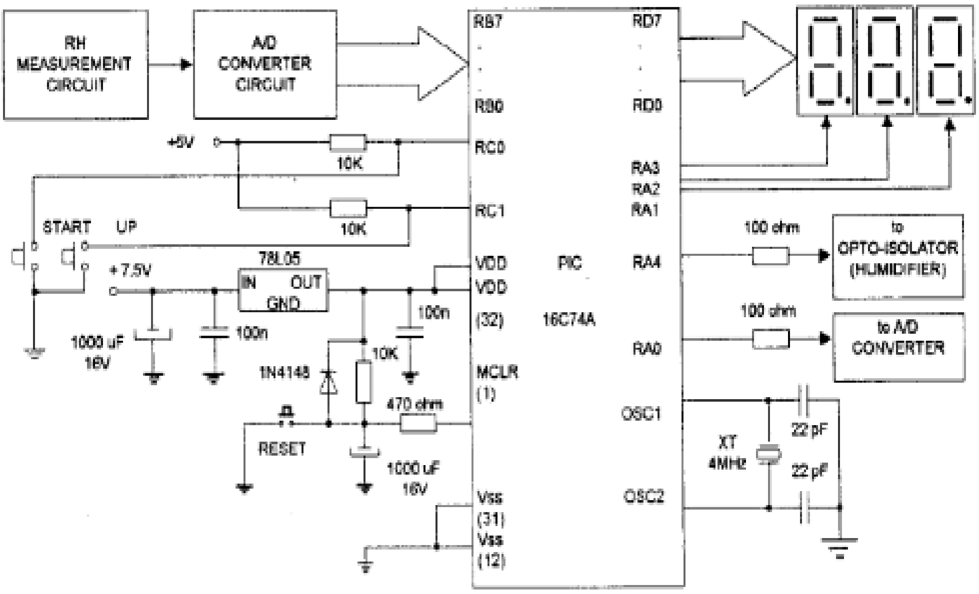

**Figure 5: Micro controller-based control unit**

To assess stability, tests were conducted at low, medium, and high humidity levels. A second RH meter (LUTRON, HT-3004) was used for comparison. This digital RH meter, with a range of 10–95% RH and a resolution of 0.1% RH, provided accurate readings of ±4% at 23°C. Additionally, temperature measurements were taken using three devices: two digital thermometers with a range of 0–60°C and a resolution of 0.1°C, and a mercury thermometer for high accuracy. The average of these readings was used to determine the incubator's temperature. The RH results from the developed system were compared with those of the external RH meter, and the temperature was recorded as the average of all three thermometers used [15].

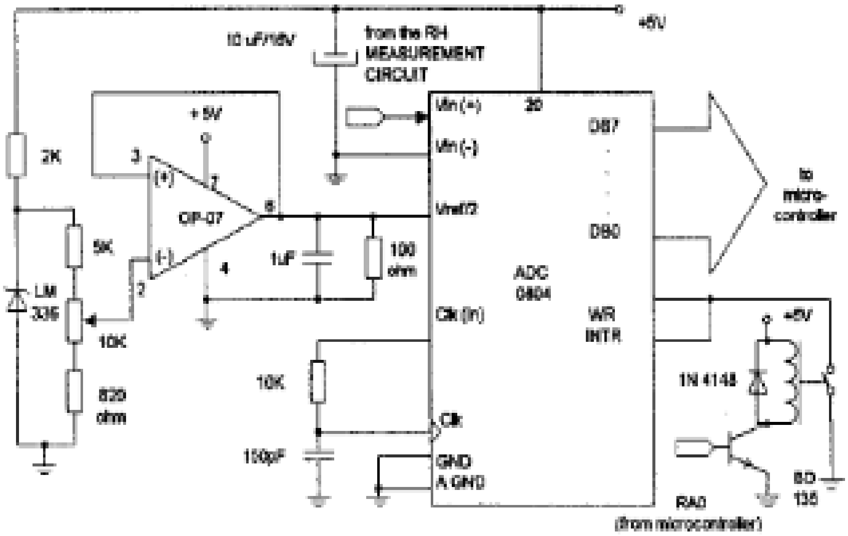

**Figure 6: A/D converter circuit.**

The first test evaluated the performance of the developed humidification system. The incubator's humidity was gradually increased using the UP button, starting from 22.2% RH at 22.8°C. Measurements were taken every 2 minutes, totaling 125 readings. Results, plotted in a graph (Figure 8), showed the system could easily reach up to 90% RH. The temperature remained stable throughout, as no heater was used for humidification. Minor temperature differences were observed due to varying sensor response times, but overall, the temperature stayed constant at 22.8°C during the test [15].

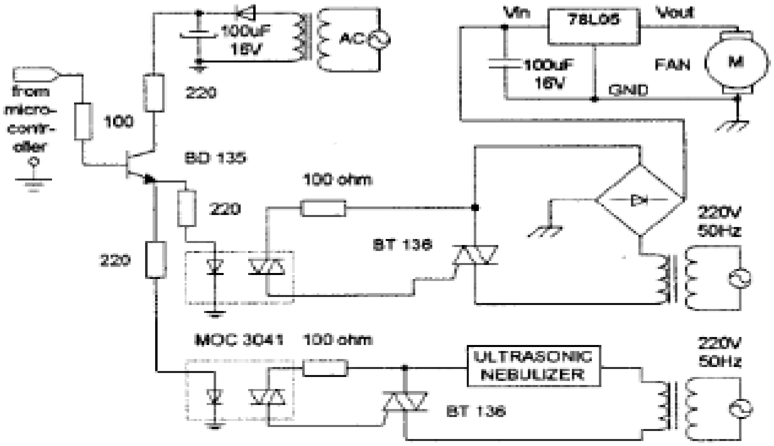

**Figure 7: Opto -isolator circuit.**

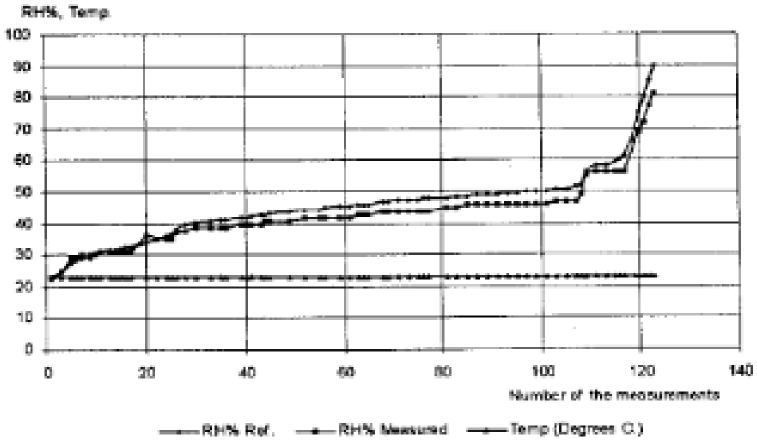

**Figure 8: Performance test results of the developed system**

The second test focused on low humidity, setting the incubator to 30% RH using the UP button. Starting at 23% RH and 19.4°C, the results showed slight differences due to sensor response times, but temperature remained stable between 19.4–20.1°C (Figure 9).

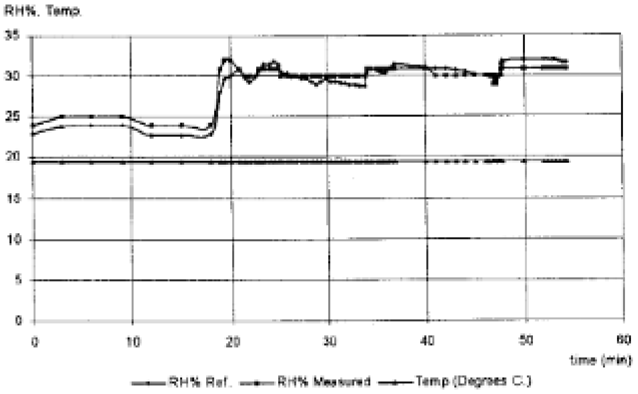

**Figure 9: Low humidity level test of the developed system**

The third test targeted a mid-level humidity of 50% RH. Initially, the incubator measured 29% RH and 18.8°C. After starting the humidification process, the RH quickly rose to 50% within 11 minutes, slightly overshooting to 53.3% due to a 15-second sensor lag. The temperature remained unaffected (Figure 10).

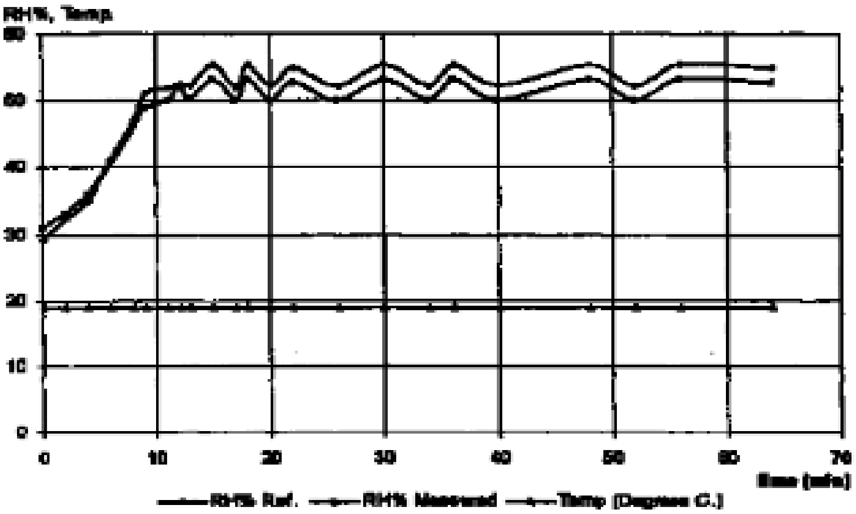

**Figure 10: Middle humidity level test of the developed system**

The final test aimed for 70% RH at a temperature range of 18.9–19.1°C. Despite the challenging conditions, the system reached the desired humidity within 22 minutes (Figure 11). While the system wasn't tested at typical incubator temperatures (~36°C) or with a baby inside, it demonstrated the capacity to maintain RH levels in dynamic environments. This is due to the active humidification method, which operates independently of temperature.

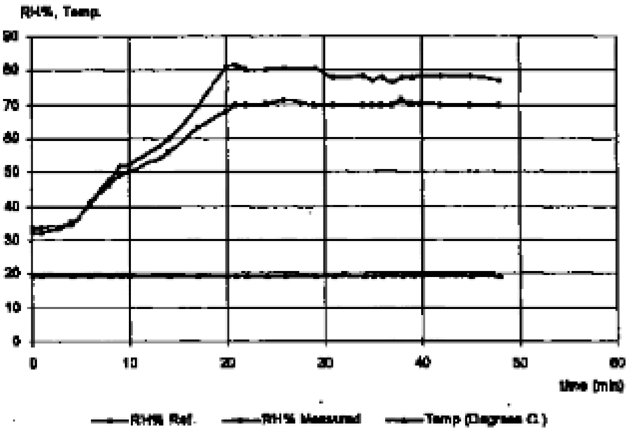

**Figure 11: High humidity level test of the developed system**

## CONCLUSION

In this study, a humidity measurement and control system was developed to regulate the humidity level within the incubator environment. The system utilizes an active humidifier, which efficiently maintains high humidity levels even in varying ambient conditions. Additionally, temperature is one of the control parameters that remains unaffected by the humidification process. The humidity measurement circuit incorporates an IC-type humidity sensor, known for its superior linearity, higher accuracy, and faster response time compared to other humidity sensors. This ensures that the RH within the incubator is maintained with minimal fluctuations around the target control values. Furthermore, the use of a high-performance, high-speed PIC microcontroller enhances the efficiency of both measurement and control processes, providing improved overall system performance.

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