EXPERIMENTAL INVESTIGATION OF IOT BASED THERMAL DRIVEN MULTIPLE EFFECT DISTILLATION SYSTEM (MED) FOR BRACKISH WATER TREATMENT

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ABSTRACT

In today's scenario, food security and economic prosperity are severely impacted by freshwater scarcity. It is a major need of humanity as it is the most vital resource on the planet. Our dependency will increase in the future so, it becomes necessary to take some measures to reduce water scarcity. Therefore, more attention is being paid to the thermal distillation process of wastewater or brackish water distillation to remove all kinds of micro-pollutants present in water. Distillation is a phase transition method that utilizes steam as a heat source to vaporize feed water. The concept of multiple effect distillation enhances the economic feasibility of the process by recycling the latent heat of vaporization. In this paper, we have the designing and fabrication of the vertical tube evaporator and model MED for estimating the total balance, energy balance, flow rate, etc, and by using the methods of El-Dessouky, Ettouney, and El-Hadik. We have also estimated the heat transfer area for the present MED unit. This developed model works well and can be used to work more number of effects.

KEYWORDS: *Desalination, Multiple Effect Distillation*

1. INTRODUCTION

Nowadays struggling for freshwater resources is one of the most difficult problems and this struggle keeps on increasing for decades due to the growing population [1]. The quality of water we are getting is also not much good. We have to install ROs and other purifying machines to get drinkable water. The anticipated shifts in future population demographics are projected to exacerbate the strain on existing water resources, both at a national level and on a global scale. [2].For ages, people are using desalting technologies for drinking water. Desalting means the eradication of dissolved salts and toxic chemicals from water [3]. The total distillate obtained from a unit per unit of energy consumed is a direct measure of the unit's efficiency and, indirectly, its economics.

This paper is arranged as follows: Part 2 and 3 gives the MED concept, materials needed for the unit, design, and fabrication of the unit. Part 4 is devoted to mathematical modelling and part 5 gives an overview of the heat transfer area. Part 6 gives out the result. The last section ends with conclusions.

2. MED CONCEPT

MED is one of the methods used to remove dissolved salts and toxic chemicals from water. It is a distillation method that can remove all concentrations and all types of impurities, operates on low specific energy and it is more efficient than other methods of desalination. MED is based on small-scale desalination system.

A small scale MED unit consists of a vertical tube evaporator, condenser, baby boiler, and pressurized feedwater preheater as the main components. The whole unit is insulated by glass wool (made of glass fiber). Here, a fire tube baby boiler is used to produce steam. The initial steam produced by the baby boiler is directed to the first VTE tube, where it undergoes condensation. The latent heat released during this process is then transferred to the feedwater, which is being evaporated on the outer surface of the shell. The steam generated in each stage is subsequently transferred to the following stage, where it boils the water contained within. Several feed configurations employed in the Multi-Effect Distillation (MED) system include Forward Feed (FF), Backward Feed, and Parallel Cross Feed (PCF).

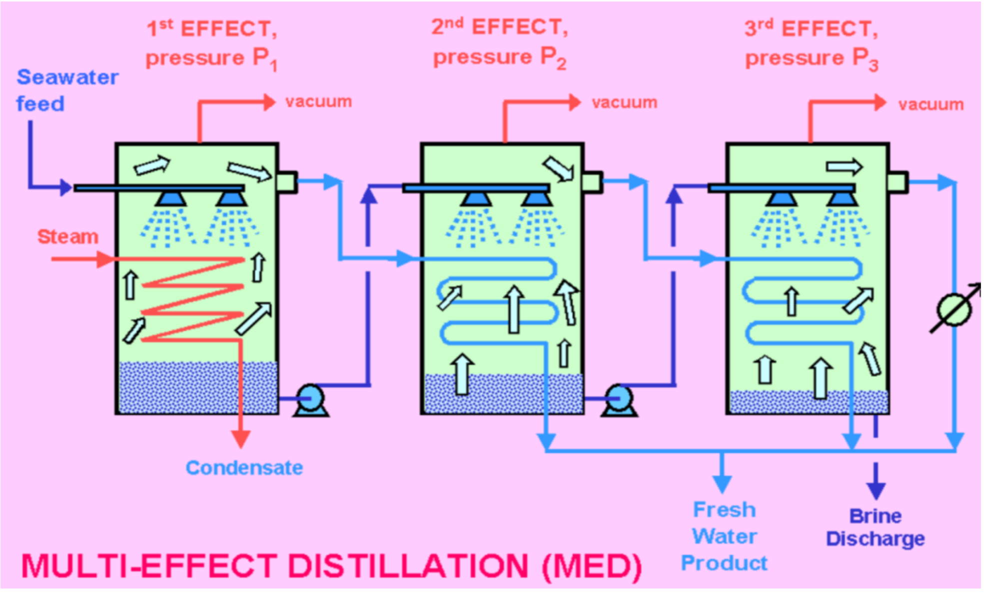

Figure 1. Schematic flow of MED unit

3. Materials and Methodology

Vertical tube evaporator, condenser, baby boiler, and the pressurized feedwater preheater as the main components.

3.1 MED Unit

The system we have in our institute is a thermal-driven multiple effect distillation unit. The MED system can be operated as n effects + condenser (n+C), where $1 \leq n \leq 6$. The present system we have works on 6+C configuration. The unit operates using diesel fuel or can be run by using LPG gas as fuel. The unit in the institute is presently working on LPG gas fuel. This MED unit is based on a mixed feed arrangement as it has parallel cross feed and forward feed for better thermal efficiency. Each VTE tube has a pressure and temperature IoT sensors to measure the pressure of steam and the temperature of both steam and brine.

Figure 2. MED Unit

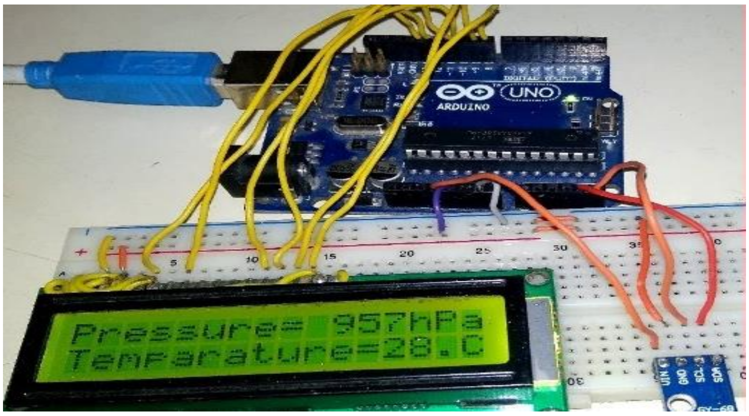

Figure 3. Pressure and Temperature reading

3.2 Vertical Tube Evaporator (VTE)

VTE serves as the central element responsible for facilitating the heat transfer within the system. The Multi-Effect Distillation (MED) unit comprises six VTEs, each consisting of four essential components: a steam chamber located at the top, a feed water chamber, an evaporator chamber, and a distillate chamber. The feed water is supplied through pipes via two inlet connections within the water chamber. In the initial VTE, the feed is received through parallel lines from both ports. In the second to sixth VTEs, one input is provided through a parallel feed line, while the other is introduced via forward feed through the inter-effect brine transfer. The water supply for the last VTE is only supplied from the forward water supply due to the low water supply requirements. An annular clearance arrangement was provided on each tube to evenly distribute the feed water to all tubes of the unit. The feed water drips through the resulting annular gap and along the tube in the center of the opening.

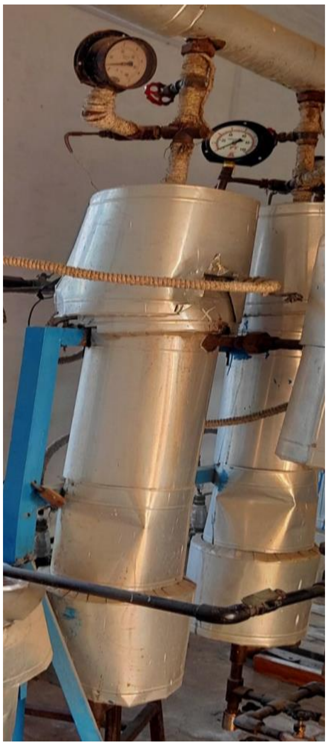

Figure 4. Vertical tube evaporator

3.3 Design of VTE

The number of tubes in the VTE is 7, the vertical tube length is 920 mm and the shell length is 750 mm. The outer diameter is 18mm and the inner diameter is 12mm respectively. The tubes are arranged equilaterally i.e, one tube is in the middle and the remaining six tubes have a pitch diameter of 64 mm. The ends of these tubes are securely fastened to Viton rubber "U" cross-section rings and can withstand temperatures in excess of 200°C. A stainless steel wire mesh insert is provided to increase turbulence in the tube. Each VTE is insulated with glass wool to minimize heat loss.

Figure 5. Arrangement of tubes

Figure 6. Inside of VTE tube

4. MATHEMATICAL MODEL

- Total Balance in the effect is

  $M_{fi} = M_{di} + M_{bi}$

- Energy Balance in effect is

  $M_{d\ i-1}\ \lambda_{i-1} = M_{Di}\ \lambda_i = UA*LMTD$

- Salt Balance in effect is

  $X_{fi}\ M_{fi} = X_{bi}\ M_{bi}$

where M is mass flow rate, U denotes overall heat transfer coefficient in kW/m^{2}K, X denotes salinity in ppm, i refers to effect number and f, b, d denotes feed, brine, and distillate, respectively.

5. HEAT TRANSFER AREA

Equation used for calculating Heat Transfer Area

$M_d\ \lambda = UA\Delta T$

Where M_d is the distillate flow rate, λ is the latent heat of vaporization and ΔT is the temperature difference [K].

6. Results and Description

Table 1. Effect-wise steam temperature (T) for different input steam pressure in 6+C unit

PS_1 (kgf/cm^2)	TS_1 (°C)	TS_2 (°C)	TS_3 (°C)	TS_4 (°C)	TS_5 (°C)
1.5	103	102	101	97	81
2.0	103	100	101	104	97
2.2	105	101	99	116	104
2.5	107	103	94	106	98
2.8	105	101	100	102	97
3.0	110	109	111	103	97
3.2	116	109	111	103	97

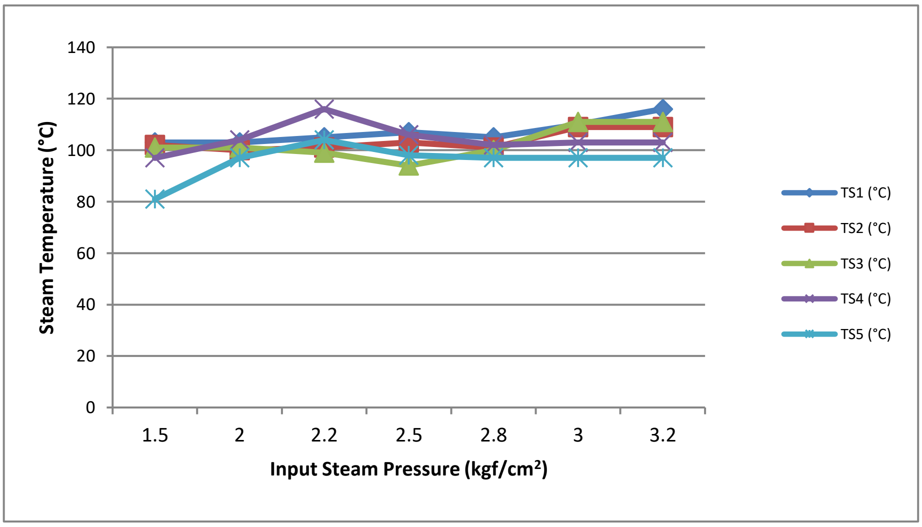

Figure 7. Effect-wise steam temperature variation for different input steam pressure in 6+C unit

As we can understand from table 1, the unit runs on seven different input steam pressure. When steam is applied to the first effect, heat transfer occurs with water on the shell side, producing fresh steam at relatively low pressure. The magnitude of the fresh steam is measured based on pressure, while the distillate from the second effect serves as an indicator. This process is reiterated, resulting in a gradual decrease in temperature with each subsequent effect. However, it is noteworthy that at a pressure of 2.2 bar, the temperature decrease is observed until the third effect, after which it begins to rise. This observation highlights the non-uniform nature of the temperature distribution.

Table 2. Effect-wise brine temperature (TB) for different input steam pressure in 6+C unit

PS_1 (kgf/cm^2)	TB_1 (°C)	TB_2 (°C)	TB_3 (°C)	TB_4 (°C)	TB_5 (°C)	TB_6 (°C)
1.5	78	66	72	65	62	46
2.0	88	81	78	64	60	43
2.2	95	77	76	88	61	52
2.5	99	93	78	97	63	56
2.8	101	94	82	99	64	58
3.0	102	103	102	75	73	62
3.2	92	109	103	91	70	65

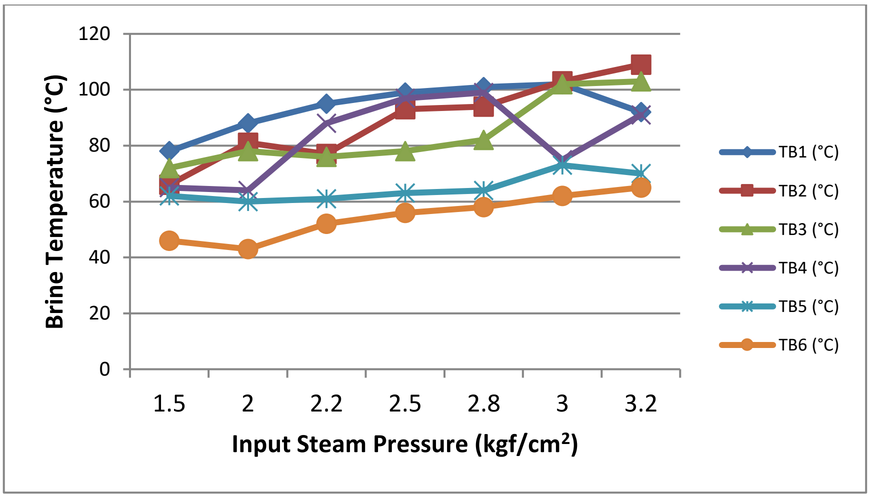

Figure 8. Effect-wise brine temperature variation for different input steam pressure in 6+C unit

In the above table, we are looking at the readings of the brine temperature at each effect in the unit, the brine temperature is highest in the first effect and it decreases with each upcoming effect and the lowest brine temperature is observed in the last effect. But according to the table, the readings are non-uniform.

Table 3. Effect-wise steam pressure (PS) for different input steam pressure in 6+C unit

PS_1 (kg/cm²)	PS_2 (kg/cm²)	PS_3 (kg/cm²)	PS_4 (kg/cm²)	PS_5 (kg/cm²)	PS_6 (kg/cm²)	PS_C (kg/cm²)
1.4	1.0	0.9	0.2	0.18	0.35	0.12
2.0	1.1	0.8	0.4	0.2	0.15	0.1
2.4	2.0	1.5	1.0	0.8	0.52	0.28
3.0	2.3	1.8	1.2	0.78	0.5	0.32

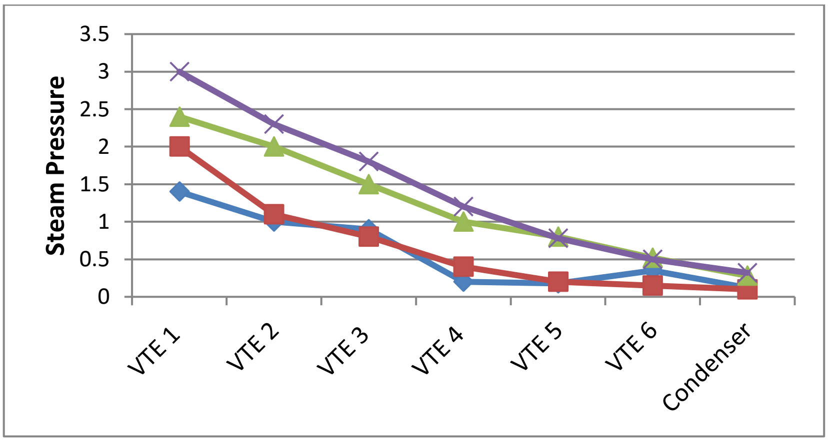

Figure 9. Effect-wise steam pressure (PS) variation for different input steam pressure in 6+C unit

The pressure pattern of the steam exhibits a peak value in the initial effect and a corresponding minimum value in the final effect. As the steam advances to subsequent effects, the pressure gradually decreases, resulting in a reduction in the quantity of distillate generated with each successive effect.

7. Conclusions

The production of distillate keeps on increasing with an increasing number of effects in the system. A further increase in no. of effects is possible with this existing system of MED but, there will be higher energy consumption and it depends on the capacity of the boiler we using. We might need to modify the boiler for operating an increased number of effects.

1) When steam progress to next effect, input steam pressure decreases.
2) On increasing the input steam pressure, the brine temperature first increases (or decreases) and then decreases (or increases).
3) On increasing the input steam pressure, the effect wise steam temperature is non-uniform.

SOURCE CODE

```
#include <Wire.h>
#include <Adafruit_BMP280.h>
#include <WiFi.h>
#include <Adafruit_MQTT.h>
#include <Adafruit_MQTT_Client.h>

// Wi-Fi credentials
const char* ssid = "YOUR_WIFI_SSID";
const char* password = "YOUR_WIFI_PASSWORD";

// Adafruit IO credentials
#define AIO_SERVER      "io.adafruit.com"
#define AIO_SERVERPORT  1883
#define AIO_USERNAME    "YOUR_AIO_USERNAME"
#define AIO_KEY         "YOUR_AIO_KEY"

// Sensor objects
Adafruit_BMP280 bmp;

// Pin assignments
const int temperaturePin = A0;

// Sensor readings
float temperature;
float pressure;

// MQTT client
WiFiClient client;
Adafruit_MQTT_Client mqtt(&client, AIO_SERVER, AIO_SERVERPORT, AIO_USERNAME,
AIO_KEY);

// MQTT topics
Adafruit_MQTT_Publish temperatureFeed = Adafruit_MQTT_Publish(&mqtt, AIO_USERNAME
"/feeds/temperature");
Adafruit_MQTT_Publish pressureFeed = Adafruit_MQTT_Publish(&mqtt, AIO_USERNAME
"/feeds/pressure");

void setup() {
  Serial.begin(9600);

  // Connect to Wi-Fi
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(1000);
```

```
    Serial.println("Connecting to WiFi...");
  }
  Serial.println("Connected to Wi-Fi!");

  // Initialize sensor
  if (!bmp.begin(0x76)) {
    Serial.println("Could not find a valid BMP280 sensor, check wiring!");
    while (1);
  }

  // Connect to Adafruit IO MQTT broker
  mqtt.connect();
  Serial.println("Connected to Adafruit IO MQTT broker!");
}

void loop() {
  // Read temperature
  int rawValue = analogRead(temperaturePin);
  temperature = (rawValue / 1023.0) * 5.0; // Convert to voltage
  temperature = (temperature - 0.5) * 100.0; // Convert to Celsius

  // Read pressure
  pressure = bmp.readPressure() / 100.0; // Convert to hPa

  // Publish data to Adafruit IO MQTT broker
  if (mqtt.connected()) {
    char tempString[8];
    char pressureString[8];
    dtostrf(temperature, 6, 2, tempString); // Convert float to string with 2 decimal places
    dtostrf(pressure, 6, 2, pressureString); // Convert float to string with 2 decimal places

    temperatureFeed.publish(tempString); // Publish temperature
    pressureFeed.publish(pressureString); // Publish pressure
  }

  mqtt.processPackets(10000); // Process MQTT packets every 10 seconds

  delay(5000); // Wait for 5 seconds
}
```

REFERENCES

[1] A. E. Ercin and A. Y. Hoekstra, "Water footprint scenarios for 2050: A global analysis," *Environ Int*, vol. 64, pp. 71–82, 2014, doi: 10.1016/j.envint.2013.11.019.

[2] J. Schewe *et al.*, "Multimodel assessment of water scarcity under climate change," *Proc Natl Acad Sci U S A*, vol. 111, no. 9, pp. 3245–3250, Mar. 2014, doi: 10.1073/pnas.1222460110.

[3] O. K. Buros, "The ABCs of Desalting."

[4] H. T. El-Dessouky, H. M. Ettouney, and F. Mandani, "Performance of parallel feed multiple e€ect evaporation system for seawater desalination." [Online]. Available: www.elsevier.com/locate/apthermeng

[5] "Fundamentals of Salt Water Desalination."

[6] M. A. Darwish and H. K. Abdulrahim, "Feed water arrangements in a multi-effect desalting system," *Desalination*, vol. 228, no. 1–3, pp. 30–54, Aug. 2008, doi: 10.1016/j.desal.2007.05.039.

[7] O. M. A. Al-Hotmani, M. A. A. Al-Obaidi, Y. M. John, R. Patel, and I. M. Mujtaba, "Scope and limitations of the mathematical models developed for the forward feed multi-effect distillation process-a review," *Processes*, vol. 8, no. 9. MDPI AG, Sep. 01, 2020. doi: 10.3390/PR8091174.

[8] M. A. Darwish, F. Al-Juwayhel, and H. K. Abdulraheim, “Multi-effect boiling systems from an energy viewpoint,” *Desalination*, vol. 194, no. 1–3, pp. 22–39, Jun. 2006, doi: 10.1016/j.desal.2005.08.029.

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