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Theoretical and Experimental Analysis of Water Desalination System

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Abstract: ***The aim of this project is desalination of Brackish/sea water by humidification and dehumidification technique. The HDH water desalination system is analysed theoretically and experimentally. This HDH desalination system is the suitable technique for small-scale brackish/sea water desalination process. Based on the fact, air can absorb the vapor content by increasing its temperature. Here the system is analyzed with Open water Open air stream water heated process. The air is circulated by electric air blower for forced convection. As the air is forced from down of the evaporator, it is forced down process. The experimental setup is fabricated and the experiment is carried out to analyze the output parameters of the system with respect to various operating conditions. The system is water heated process with electrical water heater. The main components of the experimental setup include evaporator, condenser, centrifugal compressor, blower and electric water heater. In theoretical analysis, a mathematical model including mechanism of heat and mass transfer in the various components of the desalination system was developed. The theoretical analysis uses the mass balance and energy balance equations in each part of the system such as humidifier, dehumidifier, water heater and compressor.***

Keywords: Humidification, Dehumidification, Desalination.

I. INTRODUCTION

The fresh water shortage is the main problem for many countries. Because of the population rise and development of industrial& agricultural activities, the requirement of fresh water is increased. As the drinking water availability is decreasing day by day, the need for fresh water is increased due to non-purified and highly polluted water resources, many diseases are caused to human beings. Oceans constitute about 97.5% of the total amount, and the remaining 2.5% fresh water is present in the atmosphere, polar ice, and ground water. This means that only about 0.014% is directly available to human beings and other organisms. The earth's major water reservoir is ocean. Water scarcity is one of the major problems in several countries, to reduce those problems desalination of sea water is a best alternative. HDH desalination technique will play a vital role in solving this, since the only unlimited source of water is the ocean. HDH desalination process is the suitable technology for small-scale water desalination process. Several countries in the world uses desalination techniques for purifying the sea/brackish water in various methods.

A. Desalination Process

Desalination is a process of removal of salt content from the saline water. From the desalination process the highly concentrated saline water is reduced to low dissolved solid (TDS) salt water. Generally desalination refers to the removal of salts and minerals from the target water.

The several methods of desalination processes are shown in fig.1.

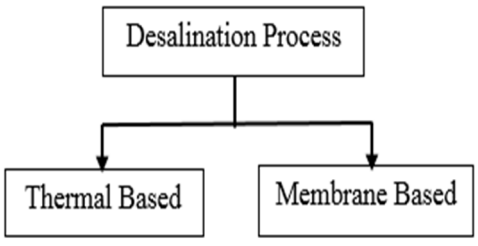

Fig.1. Desalination types

1) *Thermal Based Processes:* Thermal desalination process is based on the evaporation of water and condensation of vapor. Thermal based process is further classified into several types include: multi-stage flash distillation (MSF), multi-effect distillation (MED), and vapor compression distillation (VC). These processes require thermal and mechanical energy to evaporate the water. These processes can also able to implement by solar energy.

2) *Membrane Based Process:* The membrane process uses the special type of filter for the separation of the salt from the target water. The most common membrane process are reverse osmosis and electro dialysis. Based on the ability of membrane the dissolved particles are selectively separated from the water.

II. HDH DESALINATION SYSTEM

The Humidification Dehumidification (HDH) process is similar to the natural hydrological process where the sun heats the ocean, and then the water in the ocean evaporates to form clouds. Finally, the clouds are condensed and water is obtained as rainfall. The HDH process tends to repeat this natural hydrological cycle. The HDH process is based on the fact that air has an ability to absorb the water vapor. Air has an ability to carry water vapor by increasing the temperature. A HDH desalination process separates sea/brackish water into two streams: a fresh water containing a low concentration of dissolved salts and a concentrated brine water. In the HDH process, evaporation takes place by the mixing of hot water with dry air in the humidification chamber, and then passed to the dehumidification chamber, where a condenser is used to condense the vapor. The condensation occurs in dehumidifier (heat exchanger) in which salt water is preheated by latent heat recovery. The HDH process is classified based on the flow of air and water circulation. The types of HDH process is shown in fig.2.

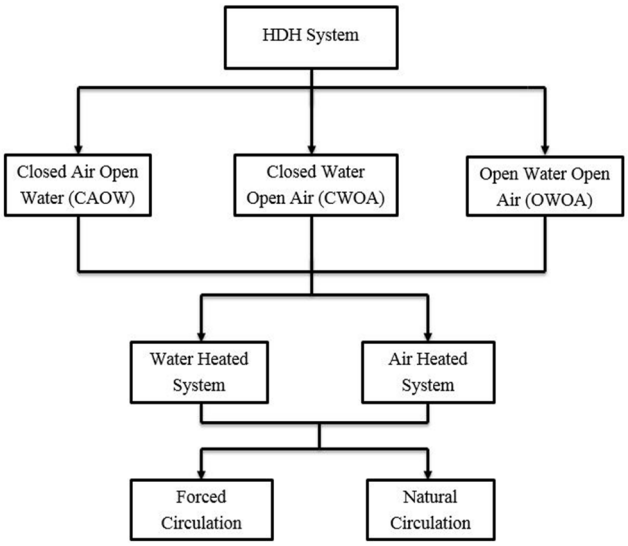

Fig.2 Types of HDH System

III. EXPERIMENTAL SETUP

The 2D diagram of the HDH system is shown in the fig.3.

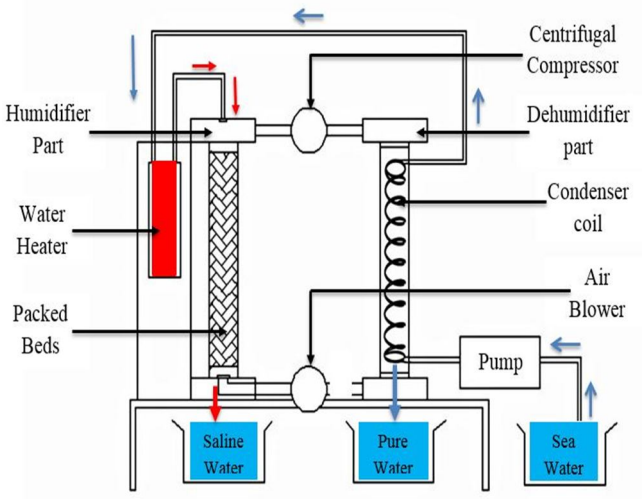

Fig.3. 2D Diagram of Fabricated model

A. Humidifier

As the air is humidified inside the evaporator, the evaporator is also called "humidifier". Water is sprayed at the top of the humidifier (evaporator) duct and flows downward through the packed beds by gravity with a continuous forced air stream flowing upward. The dimensions of the humidifier duct are 110 cm height, 16cm length, and 16cm width. A packing material is fixed inside the humidifier. The humidifier duct is made of galvanized iron sheet. The packing is supported such that it does not block the air flow and remains continuously wet. The packing material shown in figure.4. The inner surface of the humidifier duct is coated with zinc chrome primer in order to avoid corrosions in the material. A door type is provided in one side of duct to facilitate the changing of packing material easily.

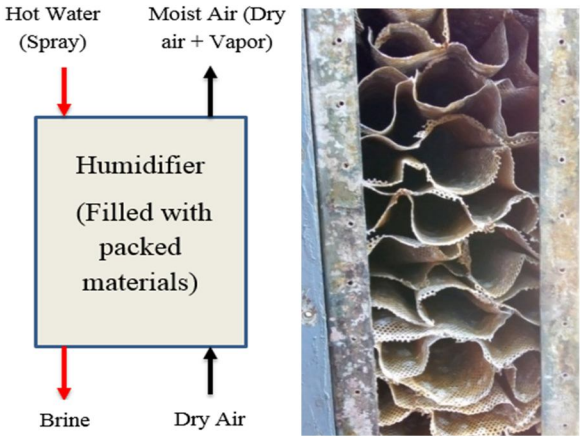

Fig.4. Humidifier and Packed Material

B. Dehumidifier

The condenser tower is called as dehumidifier. As the vapor gets dehumidified inside the condenser tower, the condenser is called dehumidifier. The working principle of the condenser is when the hot vapor flows over the cold water copper tube surface, the phase change takes place from vapor to liquid forms water droplets. The condensation tower occupies one compartment of the desalination unit. The condenser tower is made of galvanized iron sheet. The dimensions of the condensation tower are 110 cm height, 16 cm length, and 16cm width. A copper tube of 9m length and 0.9cm diameter formed as a coil is used as a condenser. The coil diameter is 14cm and the height of the condenser coil is 100cm. The inner surface of the dehumidifier duct is coated with zinc chrome primer to avoid corrosion inside the condenser surface. The cold water flows inside the coil and the vapor flows over the coil inside the condenser duct in a counter direction. The sea water is preheated by the condensation process of vapor and allowed to the water heater.

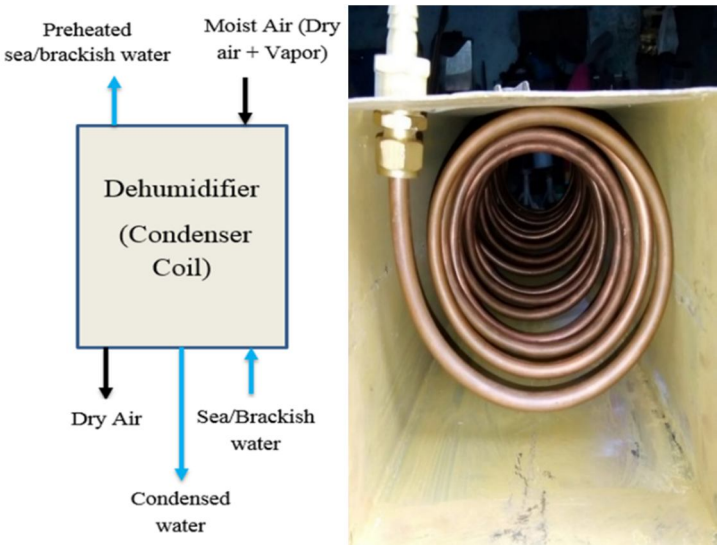

Fig.5.Dehumidifier and Condenser coil

C. Centrifugal Fan

An air blower is a mechanical device to force the air in a target direction. These fans increase the speed and volume of an air stream with the rotating impellers. The 15W air blower is used to flow the air from the bottom of the humidifier. Air blower sucks the atmospheric air and forced to the humidifier duct from the bottom to absorb the water vapour.

D. Water Heater

The electric water heater is used in this system. The water heater consists of thermostat, inlet and outlet pipe for water, relay, submerged electric resistance heating element. Thermostat regulates the temperature of water heater. The relay is used to cutoff the electric power, when the fixed temperature attained with the help of circuit breaker.

E. Storage Tanks

Storage tanks are the containers in which the water is stored. Three separate tanks used in this system are sea water tank, saline water tank and condensed water tank. The sea water tank is for the storage of the sea water from which the water is initially supplied. The saline water tank is placed at the bottom of the humidifier to collect the brine water from the evaporator. The condensed water tank is placed at the bottom of the dehumidifier to collect the water droplets formed by the phase change in the condenser.

IV. METHODOLOGY

The methodology of the process is represented in the fig.6.with the detailed flow of water and air/vapor.

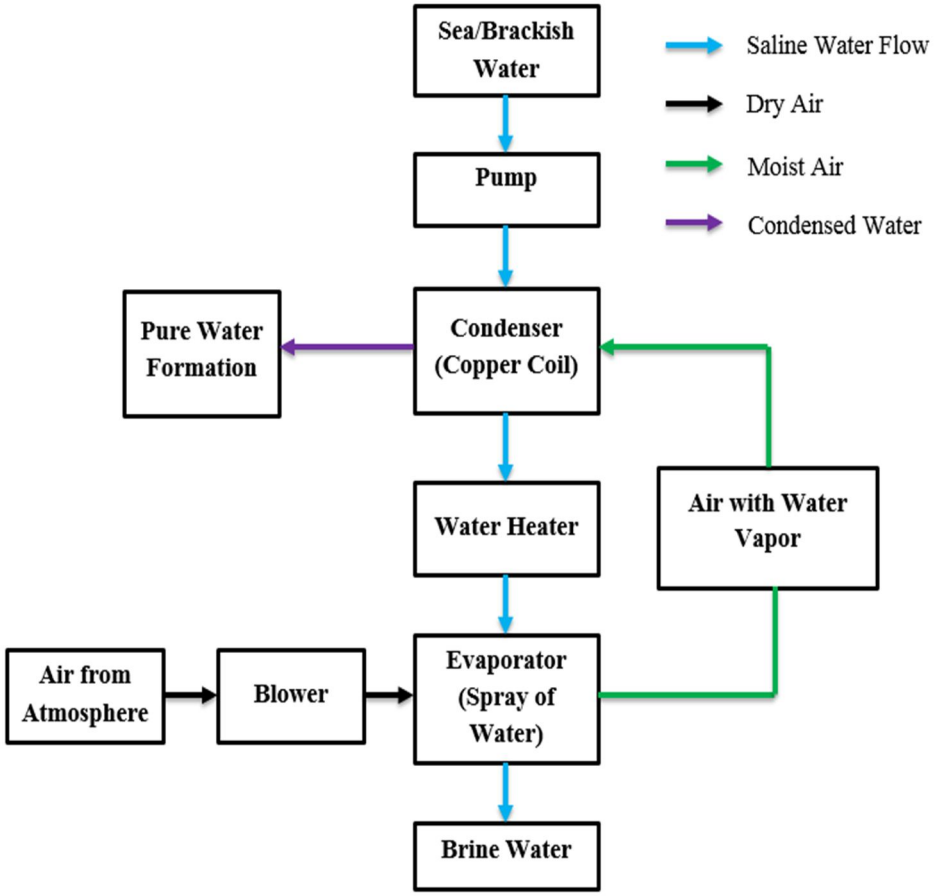

Fig.6. Methodology

V. EXPERIMENTAL RESULT

The experimental setup is fabricated and studied. The experiment is carried out with the operating conditions like water temperature at humidifier inlet and the vapor temperature at dehumidifier inlet. From the experimental analysis at the humidifier inlet water temperature is 750C, the productivity of fresh water production is about 2.13Kg/hr.

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VI. THEORETICAL ANALYSIS

The theoretical part analyze the parts of the HDH system like humidifier, dehumidifier and water heater with mass balance and energy balance equations.

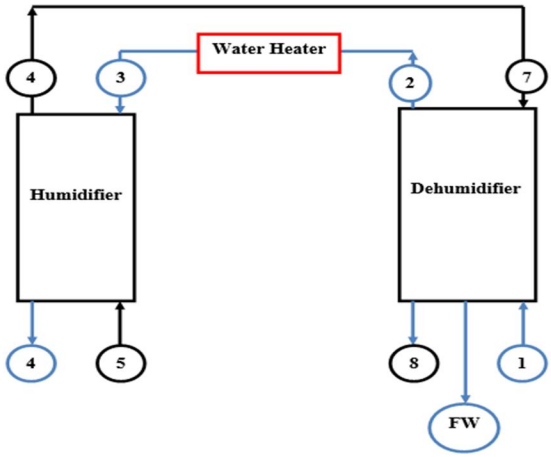

Fig.7. Theoretical representation

1) Sea/Brackish water (Condenser coil inlet)
2) Preheated water (Condenser coil outlet)
3) Hot Water (Heater Outlet)
4) Brine Water (Humidifier Exit)
5) Dry Air (Humidifier Inlet)
6) Moist Air (Dry air + Water vapor)
7) Moist air
8) Dry air (Dehumidifier exit)

FW- Fresh water

A. Humidifier

Mass balance: $m_3 + m_{a5}w_5 = m_6w_6 + m_4$

Energy balance: $h_3 + w_5h_{a5} = h_{a6}w_6 + h_4$

Here, $h_{a6} = h_{a5} + wh_{w6}$

$= c_pt_5 + w[h_{fg} + c_pt_6]$

$h_{a6} = 1.005\,t_5 + w[2503 + 1.88t_6]$

B. Dehumidifier

Mass balance: $m_1 + w_7m_{a7} = m_2 + w_8m_{a8} + m_{pw}$

Here, $m_1 = m_2$, $m_{a7} = m_{a8}$

Energy balance: $h_{w1} + w_7h_{a7} = h_{w2} + w_8h_{a8} + h_{pw}$

Here, $h_w = c_pt_w$

Moist air =dry air +water vapor

$h_{a7} = h_{a5} + w_7h_{w7}$

$= c_{pa}t_{a5} + w_7[h_{fg} + c_{pw}t_7]$

$h_{a7} = 1.005t_{a5} + w_7[2503 + 1.88t_{pw}]$

Finally,

The mass flow rate of fresh water,

$$m_{pw} = m_a[w_7 - w_8]$$

m_a - Mass flow rate of air

m_w - Mass flow rate of water
h_a - Enthalpy of air
h_w - Enthalpy of water
w - Specific humidity
t - Temperature
p_v - Partial pressure of vapor
p_a - Partial pressure of dry air

From the above equations the theoretical results of humidifier and dehumidifier are determined and plotted as graph below.

C. Fresh water production with respect to Humidifier inlet temperature

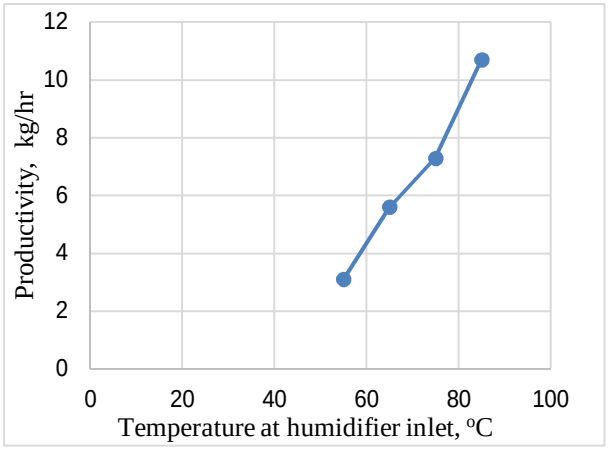

Fig.8. Productivity at hot water temperature (2Kg/min)

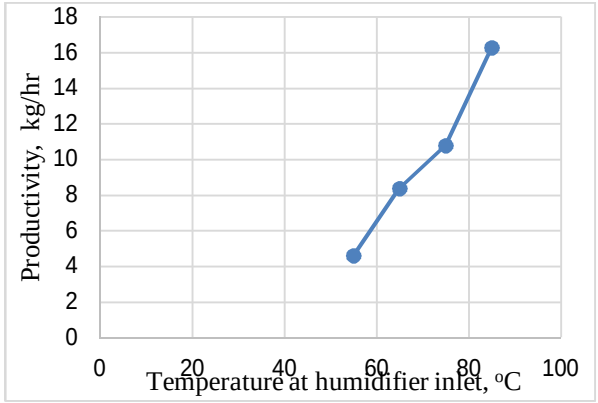

Fig.9. Productivity at hot water temperature (3Kg/min)

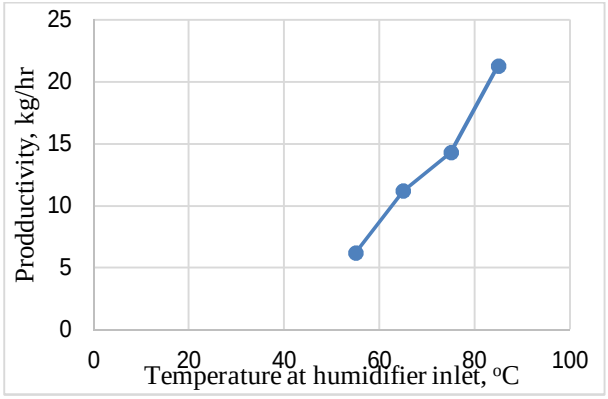

Fig.10. Productivity at hot water temperature (4Kg/min)

D. Fresh Water Production With Respect to Mass Flow Rate Of Air

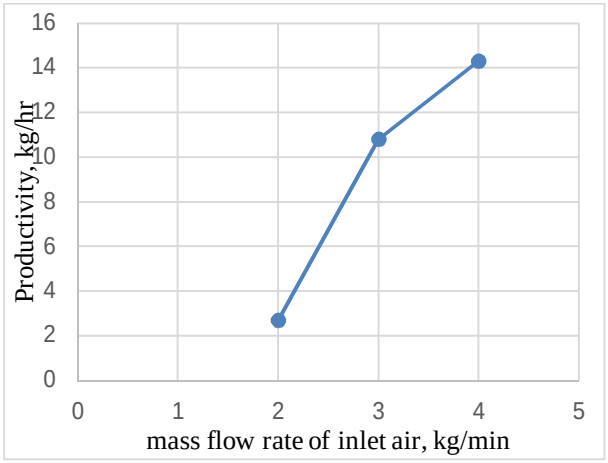

Fig.11. Productivity at air flow rate

VII. RESULT AND DISCUSSION

From the obtained results it is noted that an increase in humidifier inlet temperature of water improves the productivity of fresh water. The increase in pressure and decrease in velocity of moist air at condenser will improves the condensation efficiency.

VIII. CONCLUSION

When the system is provided with solar collector for water heating, it will be the most effective process of sea/brackish water desalination. HDH system is operated with simple fact that the air has an ability to absorb the water vapor and able to condense when the temperature reduces. The HDH desalination will be the potential method for sea/brackish water purification when the demand is decentralized.

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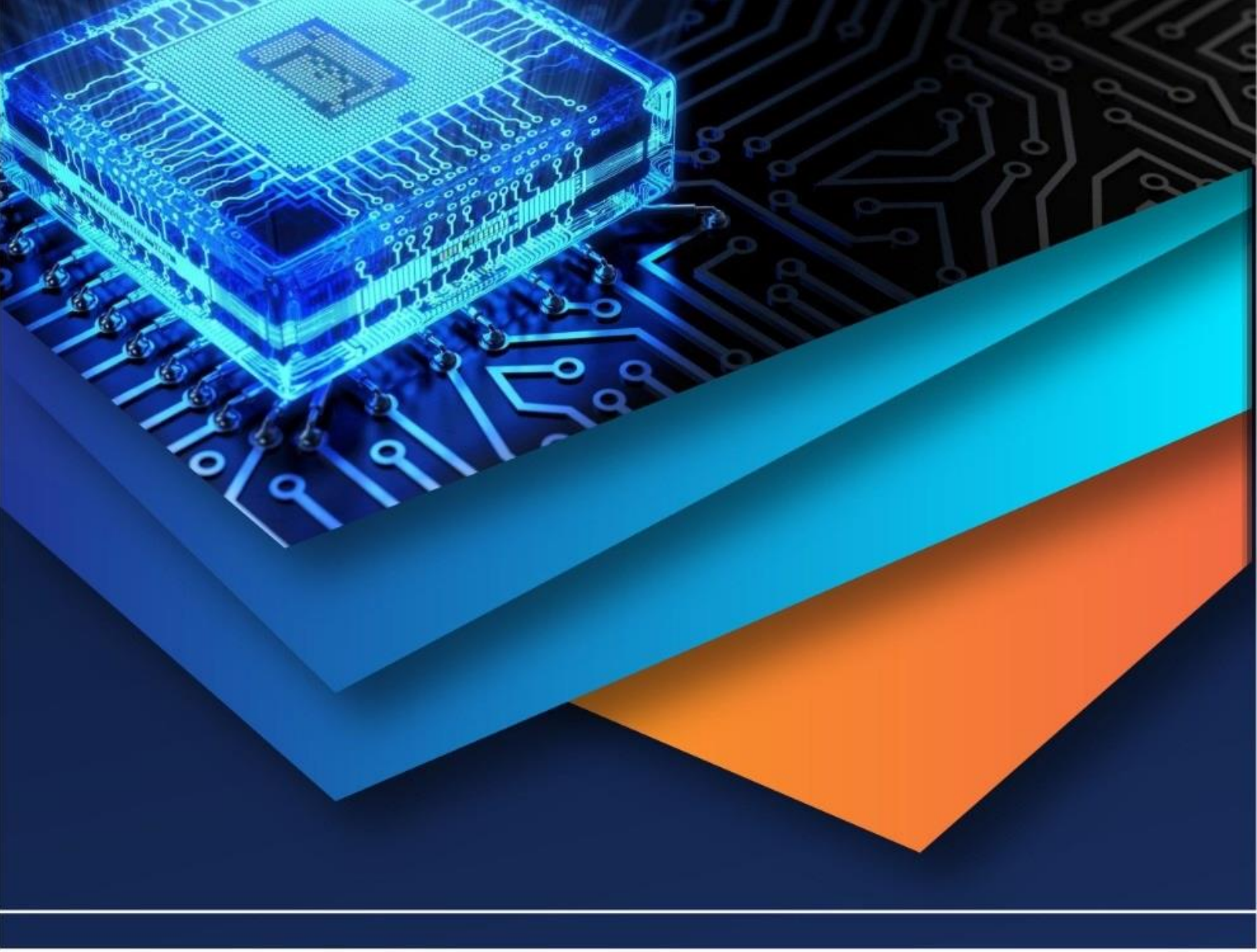

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