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Mechanical Engineering Department

THE CONTRIBUTION OF APPLYING ADSORPTION MATERIALS IN AIR DEHUMIDIFICATION UNDER IRAQI ENVIRONMENTAL CONDITIONS

A Thesis Submitted to the Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in mechanical Engineering

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بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

﴿ يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ ۚ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ ﴾

صدق الله العظيم

سورة المجادلة – الآية (11)

DEDICATION

To the lighthouse of knowledge, to our greatest and most honored Prophet Mohammed - May Peace and Grace from Allah Be Upon Him.

To the spring that never stops giving, and who weaves my happiness with strings from her merciful heart, ***to my mother***.

To him who strives to bestow comfort and welfare and never stints what he owns to push me in the success way and who taught me to promote life wisely and patiently, ***to my dearest my father***.

To the one supported me to complete this journeys, ***to my dear husband***.

To those whose love flows in my veins and my heart whom I always remember, to ***my brother and his wife and sisters***.

To those who taught me letters of gold and words of jewel of the utmost and sweetest sentences in the whole knowledge and who use their knowledge simply whose thoughts made a lighthouse guide us through the knowledge and success path, to my respected supervisors and teachers. To all the people who made this dream be real.

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2022

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Abstract

This study contributed to reducing the latent load on air conditioners by removing moisture, the aim of this study is to investigate the ability of adsorption materials, such as silica gel-Blue and sawdust, to be used as a dehumidifier for water vapor produced by human respiration, sweating, ironing clothes, etc.

The dehumidification system is designed in two parts, the first is responsible for absorbing moisture using adsorbent materials, and the second is exposed to sunlight to drying these adsorbents for reused.

The experiments were conducted in the summer months and for a period of four months. The results of these experiments showed that the relative humidity when using silica gel-Blue was 31%, 36%, 25% and 28% in May, June, July and August, respectively. While the relative humidity when using sawdust was 52% in May and June, while it was 47% in July and 39% in August. From conducting practical experiments that it needed 750 g of silica gel-Blue to remove the moisture generated by one person.

The amount of electrical energy consumed when using the dehumidifying system with and without the air conditioner was calculated and found to be 3.5 kWh and 5.1 kWh respectively.

The energy efficiency ratio of the air conditioner was calculated, and a noticeable improvement appeared when using the dehumidifying system with the air conditioner, where its value was 4.74, while when using the air conditioner alone was 3.25. It can be concluded that silica gel-Blue proved effective in removing moisture more efficiently than sawdust when it was used under the same experimental conditions.

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LATIN SYMBOLS

Symbols	*Description*	*Units*
A	Area of solid perpendicular to the direction of heat transfer	m^2
A_s	Cross sectional area	m^2
a	Thickness of air cavities	$W/m^2.°C$
Cp	Specific heat of for air.	kJ/kg. °C
$C1, C2, .., C_n$	Conductance factors	$W/m^2.°C$
CLF	Cooling load factor	……
CLTD	Cooling load temperature difference	°C
CLTDc	Corrected cooling load temperature-difference	°C
fi, fo	Indoor and outdoor air film coefficients respectively	$W/m^2.°C$
f	Attic factor	…….
h	Convection heat transfer coefficient	$W/m^2.°C$
h*g*	Specific enthalpy for water vapor	kJ/kg
h*f*	Specific enthalpy for water liquid	kJ/kg
h_{gf}	latent heat of evaporation	kJ/kg
k	Thermal conductivity of material	W/m.°C
K	Color correction factor	……..
LM	latitude and month correction factors	……..
$\dot{m}$	The mass flow rate.	kg / s
m_w	Mass of water vapor	kg
m_a	Mass of dry air	kg
m_n	Amount of water vapor	kg/s
p_{at}	Atmospheric pressure	pa
p_{ws}	Saturation pressure of water vapor of moist air	pa
$\dot{Q}_{cond}$	Heat transfer rate	W
$\dot{Q}_{emit}$	Heat transfer rate	W
$\dot{Q}_{conv}$	Convocation heat transfer	W
QL	Cooling load	W
q_l	Latent load	W
q_{sen}	Sensible load	W
R_t	Overall resistance of wall	m^2 .°C/w

R_a	Dry air gas constant	J/ (kg_{da}·K)
SC	Shading coefficient	……
SHG	Solar heat gain	W/m^2
T_o	Average outdoor temperature	°C
T_R	Room temperature	°C
Ts	Surface temperature	°C
T_∞	Fluid temperature	°C
t	Dry-bulb temperature	°C
td	Dew-point temperature	℃
tw	Wet-bulb temperature	℃
U	Overall heat transfer coefficient	W/m^2 .℃
v	Fluid velocity	m/s
$\dot{V}$	Average air infiltration.	m^3/s
w	Humidity ratio	kg/kg dry air
w_s	Humidity ratio of the saturated moist air	kg/kg dry air
W_{in}	Input work	Watt
xa, xb, x1, x2, .., xn	Wall layers thicknesses	m
X_w	Mole of water vapor in a moist air	mole
X_{ws}	Mole of water vapor in a saturated moist air	mole

Greek Symbols

Symbol	Description	Unit
ΔT	Temperature difference	°C
Δx	Thickness of solid	m
ΔW	The change for humidity ratio between indoor and outdoor air	kg/kg dry air
Δh	the change between indoor and outdoor air enthalpy	kJ /kg
φ	Relative humidity	%
σ	Stefan-Boltzmann constant ($5.67.10^{-8}$)	$W/m^2.K^4$
ρ	Air density	kg/m^3

LIST of ABBREVIATIONS

Abbreviations	Explanation
A/C	Air-conditioner
ASHRAE	American society of heating refrigerating and air conditioning engineers
CFC	chlorine carbon fluorescence
COP	Coefficient of performance
COSQC	Central organization for standardization and quality control
DS	Dehumidification system
EC	Evaporative cooling
EER	Energy efficiency ratio
EH	Evaporative humidifier
GSHP	Ground source heat pump
HAP	Hourly analysis program
HVAC	Heating ventilating and air conditioning
IQD	Iraqi dinar
PVC	Polyvinyl chloride
PV	Photovoltaic
RH	Relative humidity
T	Temperature
USB	Universal serial bus

Chapter One

INTRODUCTION

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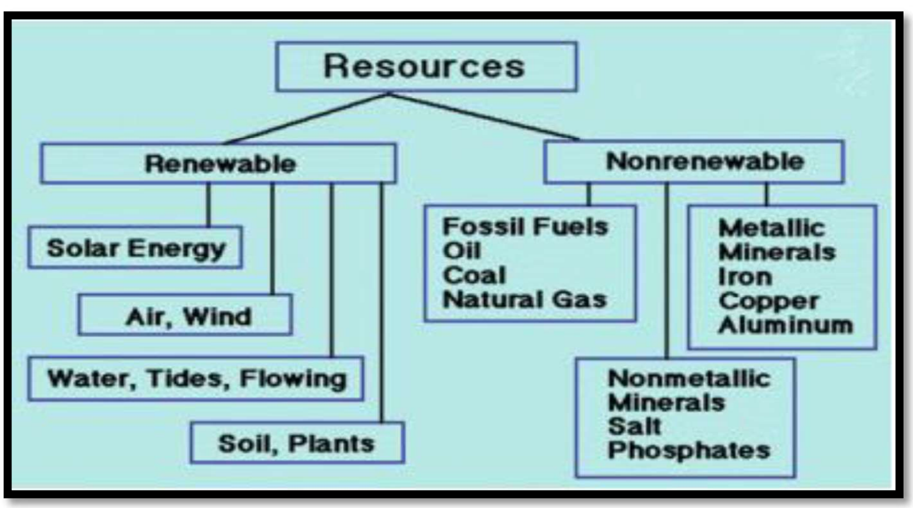
Introduction

1.1 Introduction

In the recent years, due to growth in the robust global economy, there was an increase in the demand for energy internationally. Several nations, including the United States, China, and India, collectively account for over (70%) of global energy demand. Applications for cooling and heating use the majority of this energy (Kusch-Brandt 2019).

Nonrenewable energy sources have been and continue to be the primary source of energy for many years (T and Rus 2012), implying that renewables account for less than (10%) of global energy consumption. Figure (1.1) depicts a comparison of renewable and non-renewable energy sources (Kazem et al.2013).

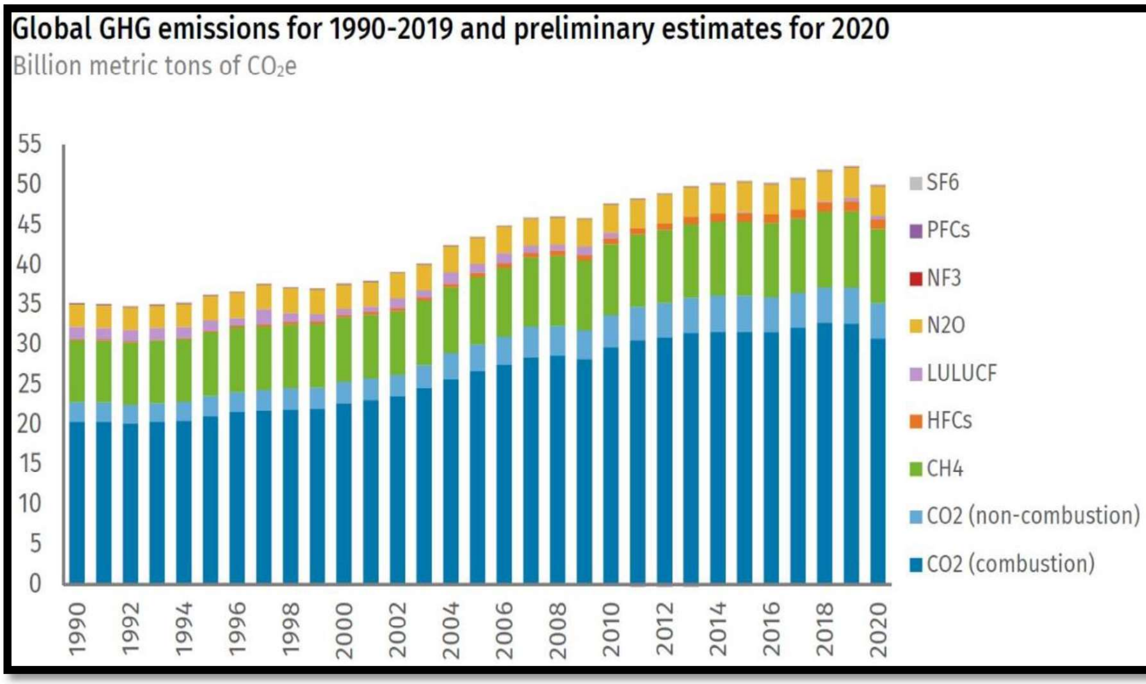


Figure(1.1) Comparing renewable and nonrenewable energy sources (Kazem et al. 2013).

Additionally, as a result of the increased use of fossil fuels, annual carbon dioxide emissions connected to energy rose by (1.7%) (Schmidt et al. 2017). There is problem with the depletion of primary energy sources, CO_2 emissions to the environment are steadily increasing. Increased emissions result in a host of climatic difficulties, such as a rise in global temperature (Chaichan and Kazem 2018).

Based on our preliminary estimates for 2020, global emissions including emissions of all six Kyoto gases, inclusive of land-use and forests and international bunkers dropped from 52.4 gigatons of CO_2 in 2019 to 50.1 gigatons in 2020.

This marks a 4.4% decline from 2019 levels, by far the largest drop in recorded history. The reduction in emissions in 2020 due to the COVID-19 pandemic and global recession was 10 times greater than the impact on emissions from the 2008 global financial crisis. Since the beginning of the twenty-first century, greenhouse gas emissions have gradually climbed the total annual global emissions of fossil CO_2 are broken down by sectors in Figure (1.2). Over (40%) of all energy-related carbon dioxide, emissions are attributabled to the usage of energy for cooling and heating (Paardekooper et al. 2018). More than any other custom construction application, the need for thermal energy for cooling has increased quickly (Fernández et al. 2016). Therefore, using low-temperature heat sources to create a cooling effect for an air conditioning application might help offset environmental wrongs including ozone depletion, global warming, and rising energy costs. In order to address and lower the issues of global warming, carbon dioxide emissions, and energy consumption, particularly for HVAC applications, absorption and adsorption systems, which use low-temperature heat sources, are promising technologies to solve these problems (Chen et al. 2015) and (Wang et al. 2017).



Figure(1. 2) Total global annual emissions of fossil CO_2 in metric tons of CO_2/year by sector(Anon 2021).

The first benefit of an adsorption system is use especially waste heat represents solar, hot exhaust gas, and geothermal to generate cooling effects without potentially harmful environmental influences the second advantage of an adsorption system is important for numerous applications, including the delivery of drinking water, thermal batteries, and dehumidification. The third benefit of this system is that it simply has a few valves and no other moving parts, which lowers maintenance expenses. The majority of adsorption systems also have other advantages including simplicity of use, low noise and vibration, no crystallization, environmentally friendly operating refrigerant, and a long lifespan (Demir et al. 2008).

Temperature and humidity play a major role in these situations, side effects on occupants, equipment, building materials, and other items susceptible to temperature and humidity variations are reduced when these variables are set at a suitable level. Moreover, poor interior temperature conditions, for example, have a detrimental impact on people's productivity and efficiency, and they cause materials and equipment to deteriorate at a faster pace or even malfunction. As a result, the HVAC system's primary purpose is to meet the requirements for climate comfort while avoiding undesirable impacts (Lstiburek et al. 2015).

Another vital issue associated with latent load that shows up during summer in hot countries the significant rise in internal humidity resulting from the breathing of the occupants of the space, which provides an uncomfortable environment. Heating, ventilation, and air conditioning HVAC systems, as well as humidifiers, can help to mitigate the problem. Complex HVACs, on the other hand, which maintain both temperature and humidity, are costly and energy intensive. As a result, this study looks into ways to use adsorption material to minimize the load of dehumidification on the air conditioner by adsorbing moisture no electricity consumption and then drying it using solar energy.

1.2 Adsorption material overview

Adsorption materials are widely used in deployments to remove humidity from space. Where environmentally friendly, adsorption-cooling systems can be powered by low-grade heat sources like solar energy or waste heat. The absence of moving parts, and lack of crystallization or corrosion are all advantages of adsorption refrigeration systems .Add to that the performance of an adsorption chiller is unaffected by changes in the temperature of the heat source, making them suitable for solar applications (Younes et al. 2017).

Adsorbents having a hydrodynamic radius of 0.25 mm to 5 mm are commonly utilized as spherical pellets, rods, moldings, or monoliths. They must be abrasion resistant, thermally stable, and have small pore diameters, which results in a larger exposed surface area and hence a higher adsorption capacity. The adsorbents must also have a specific pore structure that allows gaseous vapors to move quickly (Prithiviraj et al. 2019). The majority of industrial adsorbents were dividing into three categories (Li et al. 2020):

1- Hydrophilic adsorbents have a strong affinity for polar compounds as if water Silica gel, zeolites, and porous or active alumina are examples.
2- Non-polar adsorbents, often known as "hydrophobic" adsorbents, have a higher affinity for oils and gases than for water; activated carbons, polymer adsorbents, and silica lite are examples of these materials.
3- Polymer-based chemicals depending on the functional groups in the polymer matrix, they can be polar or non-polar.

Adsorption is a physically occurring process in which molecules of one substance cling to the surface of another, leaving a thin coating of the adsorbate on the adsorbent surface (Cevallos 2012) .This varies from absorption, which occurs when a liquid or solid (the absorbent) dissolves or permeates a fluid (the absorbate) (Ben-Mansour et al. 2016). Adsorption can occur as a result of a physical process known as physical adsorption, or physisorption, which was product by Van der Waals forces, or a chemical process known as chemical adsorption, or chemisorption, which is caused by van der Waals forces. Due to electrostatic attraction and Van der Waals interactions between adsorbate molecules and the atoms that make up the adsorbent surface, the state adsorbate molecules are held in the pores of the adsorbent. Either desiccant is a form of sorbent with a high affinity for water, and they have been widely employed in air processing applications for dehumidification and drying (Davidson et al. 2014).

1.3 Renewable energies in Iraq

Iraq does not have a difficulty developing new energy resources because it is one of the world's richest oil countries (Abass Ahmed and Pavlyuchenko 2019). Many raw resources are available in Iraq from a variety of geographical locations. The majority of them have a wide geologic range, allowing for some site selection freedom. Many raw materials are still not being optimally used. However, due to an increase in demand, Iraq is experiencing a rising shortage in meeting its electrical energy demands. Because of their restricted production capacities and numerous problems due to their age, electrical power producing facilities fail to meet it.

In recent days, most of the focus nation has centered on renewable energy, notably solar energy (United Nations Environment Programme. 2007). Studies on the utilization of solar energy in Iraq began in 1973; many studies had been carried out in order to arrive at equations that may be used to depict the density of solar energy in Baghdad and other places.

Most of the theoretical and practical research in this field at the time was concentrated on solar water heaters and solar refrigerators. The building of theoretical models, such as the mathematical and numerical representation of solar water heaters, was the starting point for studies and theoretical study. In this context, Iraqi investigations revealed a high level of concordance between actual and theoretical results. Subsequent research has focused on identifying acceptable ways to improve the efficiency of solar power generation by introducing variables and meteorological elements.

Iraqi researchers investigated the possibility of producing hydrogen for energy purposes using high-concentration solar radiation, as this gas is regarded an energy transporter and burns cleanly. Several successful experiments have been conducted using the industrial salt gradient pond for energy storage in a variety of applications, including heating agricultural greenhouses and boosting the productivity of solar distillates bound to the solar pond (Chaichan and Kazem 2018). In addition to solar radiation data is one of the most basic requirements for the most cost-effective utilization of solar energy applications.

Today, photovoltaic cells have shy uses and little power in processing electricity for individual residues, pumping water for agricultural purposes, and using it for telecommunication systems in areas that are difficult to access the power grid (Chaichan and Kazem 2018). The use of solar energy has flourished in Iraq as a result of the long summer season and the abundance of solar radiation. Iraq was note for its strong sun for lengthy periods; according to weather statistics. In Baghdad, the solar radiation intensity per hour is 416 W/m^2 in January and in June, it is 833 W/m^2 irradiance (Chaichan and Kazem 2018).

Solar radiation data is one of the most basic requirements for the most cost-effective utilization of solar energy applications. One of the important difficulties for determining the benefits of solar energy in Iraq, according to Iraqi academics, is measuring and recording solar energy data in all Iraqi areas (Ibrahim et al. 1983). The latest mathematical correlations linking temperature, many of these studies applied humidity, and solar radiation period. These research and observations revealed a high level of precision in providing solar radiation data for each region of Iraq.

Today, the ministry of higher education and scientific research, the ministry of electricity, and the ministry of science and technology all fund solar research. Many research projects are being carried out by Iraqi government university groups, including the compilation of solar radiation data, a project to provide solar-powered telecommunications stations in remote areas, and a feasibility study for the use of Photovoltaic (PV) systems to pump water from wells to cultivate remote areas (Landis 1997).

1.4 Case study of weather in Iraq

Iraq's climatic characteristics vary according to the four seasons, each of which has a different length; summer and winter are the two primary seasons, while spring and fall are the two shorter seasons. the weather conditions present an extra problem for Iraq which is marked by low relative humidity during this season, and Iraq's dry summer season is scorching, therefore electricity demand is seasonal, with a peak in the summer months due to rising temperatures in most sections of the nation (Kazem and Chaichan 2012). During the summer, peak electricity demand is predicted to be roughly 50% higher than average consumption, widening the gap between network electrical supply (which works at maximum capacity) and demand (Al-Kayiem and Mohammad 2019). In Iraq, temperatures begin to rise gradually from April until they reach their maximum values in July, then return and decrease at the end of August. (The values of temperature and solar radiation for the months of practical experiments in Diyala for the year 2022 are in Appendix A).

1.5 Significance of research

To avoid the collapse of the environmental and social systems in many countries throughout the world, all political, economic, and technical components must pay close attention to environmental degradation, climate change, and increasing demand for energy (Bernhardsson 2005). Accomplishing this aim has been base on designing a dehumidification system that operates with low electric power (fans power only) to get rid of the excess moisture generated by the occupants of the space and provide a comfortable environment for them. Because the humidity in the buildings increases can lead to the formation of mold and dust mites, which can lead to health problems like asthma and allergies, as well as respiratory discomfort (Choi et al. 2014).

1.6 Aim and objectives

1. The aim of this study is to study the effectiveness of using adsorbents in removing moisture from a specific space.
2. Comparing the experimental results when using silica gel and sawdust to remove moisture and discussing those results.
3. Study the using of renewable energy (solar energy) and its effectiveness in the process of removing moisture from the adsorbent materials.
4. This research is reducing the consumption of electrical energy, given that the system used does not need significant electrical energy to operate.
5. Study the effectiveness of using silica gel-Blue and sawdust in dehumidification process as cheap materials and abundantly available by conducting several experiments in the summer by designing a system prepared for this purpose and calculate the amount how much silica gel-Blue it was need to remove moisture generated by one person.

1.7 Thesis outlines

- The first chapter is an introduction to the conventional energy used in cooling and heating, the global crises that affected it, and the use of solar energy as one of the inexpensive alternatives to renewable in the drying of Silica-gel Blue from moisture.
- The second chapter provides a brief explanation of some literary studies and their findings on the use of silica gel - Blue and sawdust in dehumidification and the use of solar energy and the most important applications and contributions.

- The third chapter deals with the theory and governing equations that used in this thesis and the important laws, equations, formulas reducing the use of fossil fuel.
- The fourth chapter shows the methodology in research of where the location of the site and the materials used in the dehumidification and the design of the system, and the method of getting results.
- The fifth chapter provides addition to the discussion of the results, displays the details of the outcomes as charts, tables, and graphs of the data.
- The sixth chapter concludes this work and makes some recommendations for future work.