EVALUATION OF LIQUID DESICCANT COOLING SYSTEM ABSORBER FOR EVAPORATIVE COOLING

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Boyd Bayndend John

20th June 2022

DECLARATION

I hereby declare that this thesis, submitted to the University Malaysia Sabah as partial fulfillment of the requirement for the degree of Bachelor of Mechanical Engineering, has not been submitted to any other university for a degree. I also certify that the work described herein is entirely my own, except for quotations and summaries of sources that have been duly acknowledged.

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ABSTRACT

The liquid desiccant system is comprised of an absorber, a regenerator, a sensible heat exchanger, a solution heating coil, and a solution cooling coil. The high concentrated desiccant solution dehumidifies the process air as it enters the absorber. The desiccant solution becomes less concentrated as it leaves the absorber and is transferred to the regenerator to be heated to the regeneration temperature by the solution heating coil. Regenerating the liquid desiccant always requires a slightly high temperature to produce a high concentration desiccant solution for the absorption process. This project aimed to evaluate the liquid desiccant system air dehumidification by reducing the desiccant temperature before it enters the absorber. The operation was conducted using the liquid desiccant system without a plate-fin heat exchanger and the liquid desiccant system without a plate-fin heat exchanger, using weather dependence air temperatures and relative humidity, and different inlet air velocities.

ABSTRAK

Penilaian Penyerap Sistem Penyejukan Bahan Pengering Cecair untuk Penyejukan Penyejatan

Sistem bahan pengering cecair terdiri daripada penyerap, penjana semula, penukar haba yang waras, gegelung pemanas larutan dan gegelung penyejuk larutan. Larutan bahan pengering berkepekatan tinggi menyahlembapkan udara proses apabila ia memasuki penyerap. Larutan bahan pengering menjadi kurang pekat apabila ia meninggalkan penyerap dan dipindahkan ke penjana semula untuk dipanaskan kepada suhu penjanaan semula oleh gegelung pemanas larutan. Menjana semula bahan pengering cecair sentiasa memerlukan suhu yang tinggi sedikit untuk menghasilkan larutan bahan pengering berkepekatan tinggi untuk proses penyerapan. Projek ini bertujuan untuk menilai penyahlembapan udara sistem bahan pengering cecair dengan mengurangkan suhu bahan pengering sebelum ia memasuki penyerap. Operasi dijalankan menggunakan sistem pengering cecair dengan dan tanpa penyejuk luaran, menggunakan suhu udara masuk yang berbeza dan kelembapan relatif, dan halaju udara masuk yang berbeza. Keputusan eksperimen menunjukkan bahawa suhu bahan pengering pada salur masuk penyerap mempengaruhi penyahlembapan udara. Manakala, halaju udara masuk pada penyerap mempengaruhi penyahlembapan udara dengan ketara. Selain itu, didapati bahawa tanpa penyejuk luaran, penyahlembapan udara sistem mempunyai perbezaan 3% antara kelembapan relatif masuk dan kelembapan relatif keluar manakala dengan penyejuk luaran, perbezaannya ialah 5%. Pada masa yang sama, analisis menunjukkan bahawa dengan penyejuk luaran, suhu bahan pengering boleh menurun setinggi 5.2 darjah Celcius.

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LIST OF ABREVIATION

PFHE	Plate-Fin Heat Exchanger
LDACS	Liquid Desiccant Air Conditioning System
LDCS	Liquid Desiccant Cooling System
RH	Relative Humidity
T_{air}	Air Temperature
T_{sol}	Desiccant Temperature
In	inlet
Out	outlet

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CHAPTER 1

INTRODUCTION

1.1. Overview

It is essential to have air conditioning systems that use renewable energy. Solar-powered air-conditioning systems are the future, owing to their availability in a hot and humid climate and tremendous energy-saving potential. The liquid desiccant cooling systems are the optimal solution due to their disinfecting effect on the process air, high thermodynamic coefficient of performance, the convenience of liquid desiccant storage, and effective utilization of low-grade heat sources (Ghosh & Bhattacharya, 2021)

A liquid desiccant air conditioning system's main functionality is dehumidification which produces dry air by removing the moisture. However, the liquid desiccant loses its strength to attract moisture once it absorbs it. Any liquid desiccant system is high in energy consumption due to the cooling and heating of the liquid desiccant yet consumes lower energy than conventional vapor compression air conditioning. However, the dehumidification process can be separated from the cooling process to solve the energy demand. A hybrid liquid desiccant system is a great example. This system consists of three components, a cooling unit, absorber, and regenerator. However, due to the high level of air humidity, where the water content in the air is too high to evaporate, the system is far from efficient in high humidity conditions.

The liquid desiccant system combined with an evaporative cooling system is one of the best alternatives for humidity control. It involves removing the water molecules from the air using liquid desiccant; such substance has the capacity of higher moisture storage. The liquid desiccant regains its characteristic of holding water during the availability of a heat source. The liquid desiccant can filter microorganisms such as bacteria and viruses. The liquid desiccant air-conditioning system's performance depends on the absorber (or dehumidifier) and regenerator. This component exchanges heat and mass transfer simultaneously since air and the desiccant solution exchange heat and moisture (Gurubalan & Simonson, 2021). The regenerator will produce a robust desiccant solution by increasing the solution temperature between 60 to 70°C; the liquid desiccant then was transferred to the absorber, where it will absorb water vapor or water molecules from humid air producing dry air. Finally, the dry air will be delivered to the evaporator to be cooled.

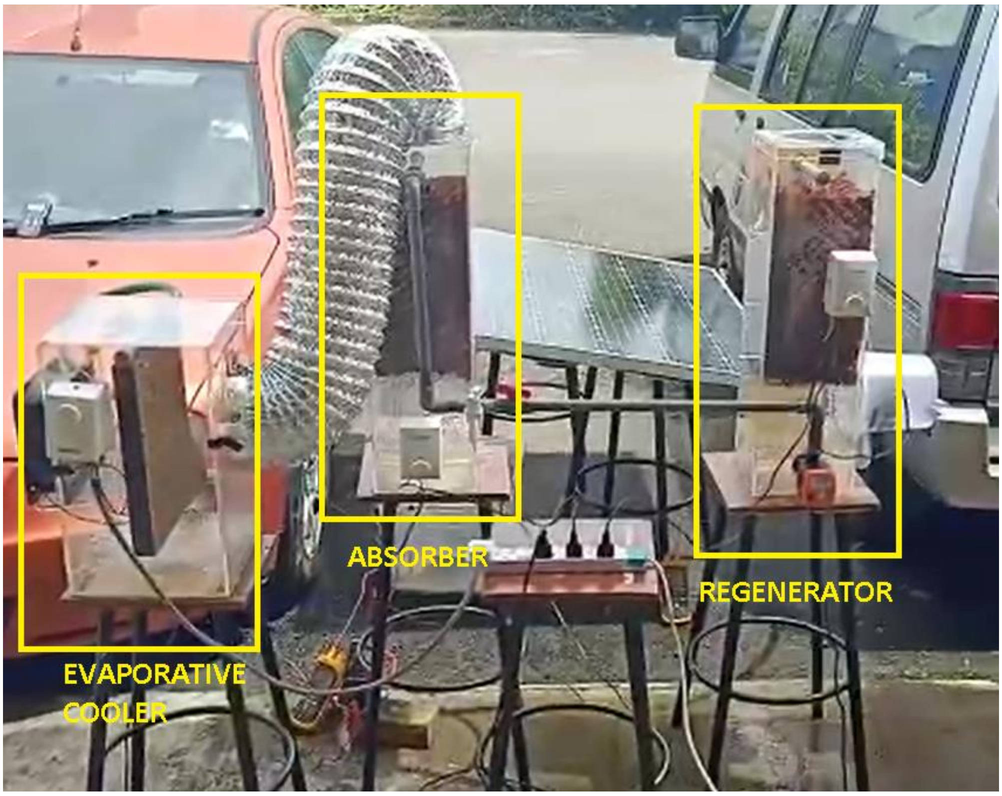


Figure 1.1: Existing Liquid Desiccant Air Conditioning System.

This project uses a liquid desiccant system developed by a master student MK1911017T Zulkarnain bin Hassan under the supervision of Dr. Mohd Suffian bin Misaran @ Misran and Nancy Julius Siambun. Mr. Zulkarnain's liquid desiccant system consists of the absorber, regenerator, evaporative cooler, and solar collector. Under the same author's supervisor, Dr. Mohd Suffian bin Misaran @

Misran, this paper will focus on assisting Mr. Zulkarnain's research of liquid desiccant air conditioning systems, mainly in absorber performance.

1.2. Problem Statement

In today's modern society, conventional air conditioning places a significant energy load on the electrical grid. As people's living standards rise exponentially, the demand for air conditioning systems that provide thermal comfort to humans has increased globally. While vapor-compression-based air conditioning systems are widely installed to provide comfort conditions inside a building, they are associated with a significant issue of air pollution. According to (Ghosh & Bhattacharya, 2021), buildings absorb around 32% of the earth's primary energy and generate approximately 34% of direct greenhouse gas emissions; additionally, a total of 30% to 50% of energy was spent by the air-conditioning system.

Liquid desiccant cooling systems have become attractive compared to conventional air conditioning due to many advantages, such as effective utilization of low-grade heat sources and less environmental damage. The current liquid desiccant system has no temperature control of the desiccant solution before entering the absorber.

Regenerating the liquid desiccant always requires a slightly high temperature to produce a robust desiccant solution for absorption. (Guo et al., 2017a) studies describe the high temperature of desiccant solution from the regenerator into the absorber as a significant cause that led to poor dehumidification due to the carryover of heat during the absorption process. Because of this, (Lim & Jeong, 2018c) studies explain that to make sure the absorber is as efficient as possible, it is essential to reduce the temperature of the robust desiccant solution.

1.3. Research Objectives

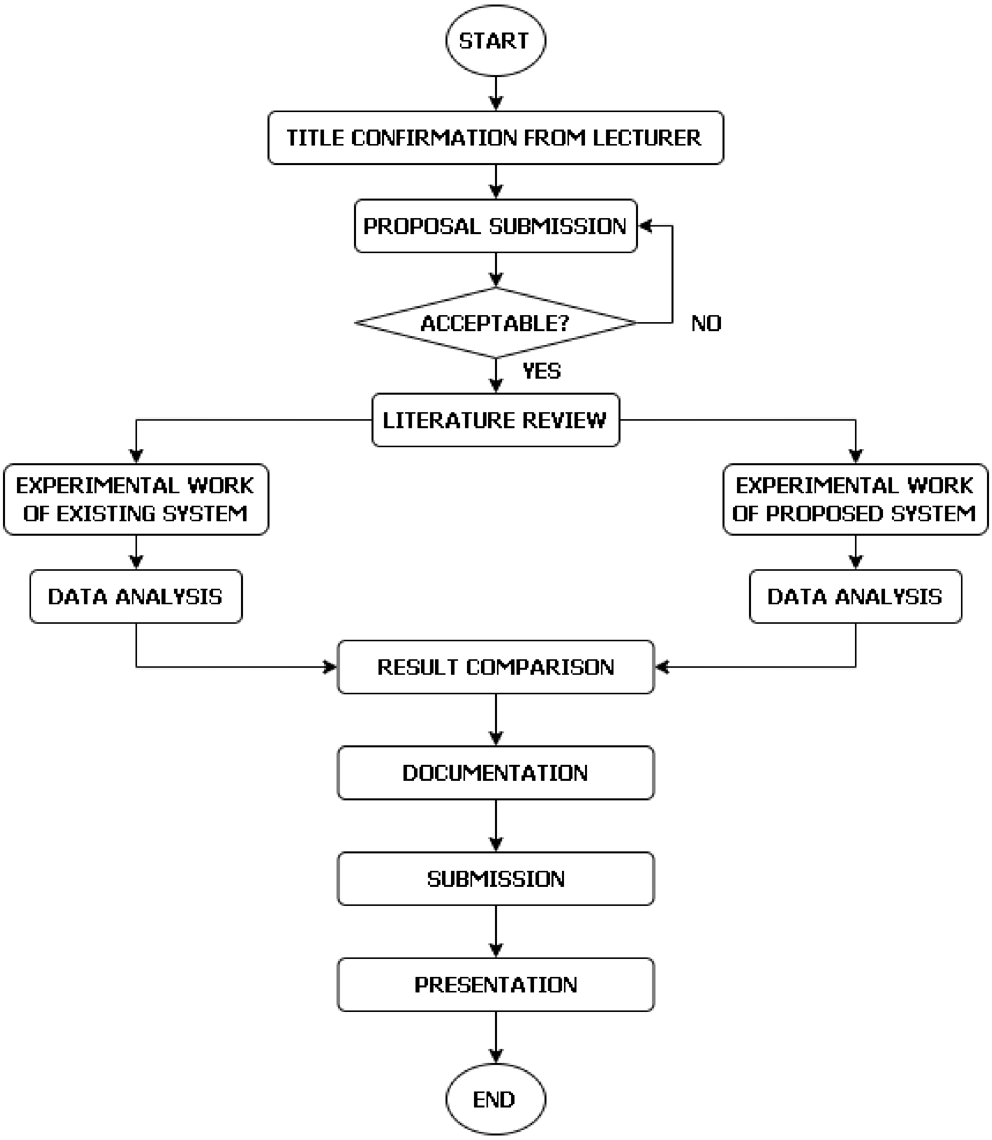
This project investigates the absorber performance using a plate-and-fin heat exchanger that acts as the external desiccant solution cooler in a liquid desiccant cooling system. The sub-objectives that complement the main objective is to measure the air relative humidity and the liquid desiccant temperature difference between the liquid desiccant system without a plate-fin heat exchanger and the liquid desiccant system with a plate-fin heat exchanger.

1.4. Scope of Works

The scope of works for this project is as follow:

i. Conduct literature review of existing past research related to liquid desiccant cooling system from multiple sources including journals, book, and articles.
ii. Study and understand the working principle of the liquid desiccant cooling system.
iii. Study the requirements on designing the liquid desiccant cooling system.
iv. Setup the previous studied liquid desiccant cooling system, execute experimental work and carry out performance analysis of the absorber.
v. Setup the proposed modified liquid desiccant cooling system, execute experimental work and carry out performance analysis of the absorber.
vi. Compare the performance analysis of the absorber.
vii. Carry out documentation of the project progress and data.

1.5. Research Methodology



1.6. Literature Review

The fundamentals of liquid desiccant cooling systems will be studied in this section based on previous research conducted by various researchers. The primary focus is on the absorber configuration and the temperature and relative humidity difference between the absorber inlet and outlet. It provides a detailed strategy for carrying out the experimental study. A *literature review* is a structure and strategy used to find solutions to problems related to a research project.

1.7. Experimental Work and Data Analysis

The experiment will be conducted for two different liquid desiccant system. To determine which liquid desiccant system is better, the system will be evaluated in terms of temperature and relative humidity difference across absorber inlet and outlet.

1.8. Result Comparison

Upon both system evaluation complete, the result obtained will be compared and visualize in the form of table, graph, or timing chart.

1.9. Documentation

This project's documentation is thesis writing. It consists of identifying the problem, configuring it, and testing it until the desired result is obtained. All the methods used in this project have been included. There are also figures, graphs, tables, and diagrams. The final section of the project documentation provides a summary of what has been accomplished on this project and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1. Background Studies

The idea of changing the air properties from moist to dry emerged in the 20th century 1955, when an open-cycle air-conditioning system was developed using trimethylene glycol as the solution to dehumidify the processed air. Since then, many researchers have been interested in air conditioning and have developed various ways and approaches to refine the system (Tu et al., 2009).

A desiccant is a substance or chemical that absorbs or attracts moisture from the air, resulting in desiccation in its immediate proximity. This chemical attracts and removes moisture from air or gas, keeping things dry and thereby preventing corrosion (Pellett et al., 2018).

2.2. Liquid Desiccant System.

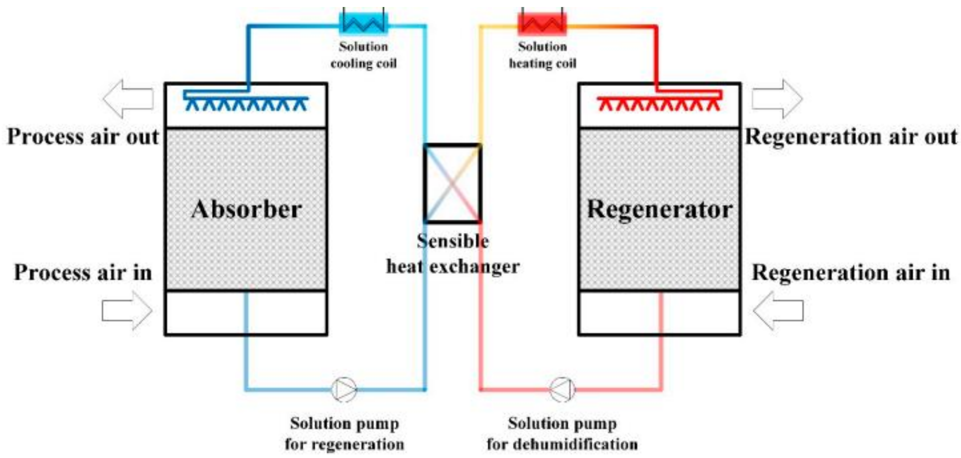


Figure 2.0: Liquid Desiccant Air Conditioning System
(Source: Shin et al., 2018)

A liquid desiccant unit comprises an absorber, a regenerator, a sensible heat exchanger, a solution heating coil, and a solution cooling coil, as shown in Figure 1.1. The high concentration desiccant solution dehumidifies the process air as it enters the absorber. Because this dehumidification process is exothermic, the solution cooling coil should cool the desiccant solution before it enters the absorber. The diluted desiccant solution leaving the absorber should be transferred to the regenerator after being heated to the regeneration temperature by the solution heating coil.

Moisture transfer to and from the desiccant solution is driven by the vapor pressure difference between the desiccant solution and the air passing through the solution in the absorber or regenerator. The driving force of moisture transfer to and from the desiccant solution is the vapor pressure difference between the desiccant solution and the air passing through the solution in the absorber or regenerator (Sahlot & Riffat, n.d.).

In general, for the regeneration process, the weak desiccant solution entering the regenerator should be heated to 45-to-80-degree Celsius, whereas the robust solution entering the absorber should be cooled to 15-to-30-degree Celsius (Rafique et al., 2016). The sensible heat exchanger preheats and precools the solutions that leave the absorber and regenerator to reduce the energy consumed in solution cooling and heating. The solutions that exit the sensible heat exchanger are heated and cooled in the heating and cooling coils, and a gas boiler and a chiller are typically used to treat the required solution heating and cooling loads in the coils.

Desiccant dehumidification is a possible alternative to traditional air conditioning systems for humidity control. It is the process of extracting water vapor from the air using a hygroscopic desiccant substance (Gurubalan et al., 2019).

Desiccants are divided into two categories based on their material type: liquid and solid.

According to (Gurubalan et al., 2019; Rafique et al., 2016; Sahlot & Riffat, n.d.) Liquid desiccants are preferred over solid desiccants because of their benefits, such as lower pressure drop on the airside, lower regeneration temperature, higher energy storage, higher moisture holding capacity, and more flexibility in utilizing the heat source for regeneration, can be regenerated. In contrast, the heat source is available and stored for later use, can filter microbial contamination (bacteria, viruses, and molds), and is appropriate for combined cool and heat systems.

2.3. Principle of Desiccant Cooling

Desiccant absorbs moisture from air or gas through one of two processes: physical adsorption or chemical reaction, resulting in a reduction in humidity. Silica gel is an example of a physical adsorbent, whereas calcium oxide is an example of a chemical reagent (Y. Chen, 2017).

Furthermore, a substantial differential in vapor pressure exists between the incoming air and the desiccant solution, resulting in a greater driving force for the desiccant to collect moisture from the humid air (X. Chen et al., 2018a).

2.4. Working Principle of Liquid Desiccant Cooling System

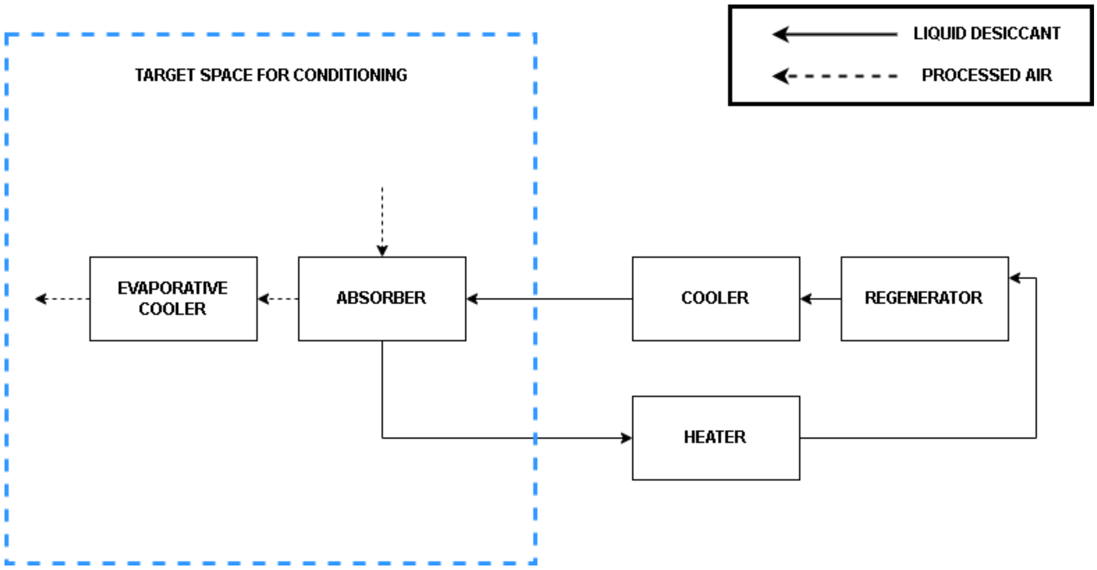


Figure 2.1: Basic Component of Liquid Desiccant Cooling System.
(Source: Shin et al., 2018)

The fundamental component that makes up a liquid desiccant cooling system are direct evaporative cooler, absorber, regenerator, heater, and cooler, as shown in Figure 2.1. However, many types of configurations utilize the liquid desiccant in search of better performances (Shin et al., 2018a).

According to author Narayanan (Narayanan, 2017), a liquid desiccant air-conditioning system uses a liquid desiccant substance to remove moisture and latent and perceptible temperatures from process air. Concentrated and cooled liquid desiccant flows into the absorber through a porous media in the basic design. Return air rises through the porous material, sending moisture and heat to the liquid desiccant in the opposite direction. The liquid desiccant flows into the regenerator after being diluted by the water absorbed from the air at the bottom of the porous media.

In addition, Narayanan then explains that the regenerator heats the weak liquid desiccant solution, which is sprayed on another porous surface, using a heat source such as gas or oil-fired, waste heat, or solar heat. To regenerate a concentrated liquid desiccant, the heated solution transfers the absorbed moisture to a counter-flowing airstream. The cooled liquid desiccant solution returns to the absorber to complete the cycle after the regenerator's return feed passes through a cooling tower or chiller. Several designs include a counterblow heat exchanger between the absorber and the regenerator to reduce the amount of external heating and cooling required.

2.5. Absorber Cooling Mechanism

Decreasing the desiccant temperature before it flows into the absorber is very important regarding dehumidification performance (Narayanan, 2017). Most researchers in the fields of liquid desiccant cooling systems use built-in or external cooling devices to reduce the desiccant temperature. For example, Kabel's (Kabeel et al., 2018) liquid desiccant cooling system has a solution-solution heat exchanger installed, as shown in Figure 2.2.

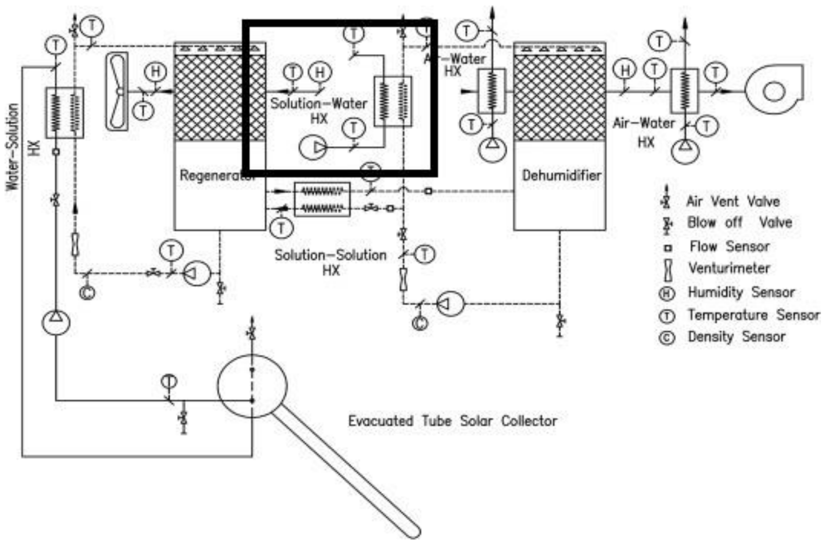


Figure 2.2: Solution-Solution Heat Exchanger.
(Source: Kabeel et al., 2018)

Other than Kabeel, Lim and Jeong (Lim & Jeong, 2018a) take a different approach by using the thermoelectric module for heating and cooling the desiccant and a sensible heat exchanger to pre-heat and pre-cool as shown in Figure 2.3. However, Lim and Jeong conclude that the method is unsuitable for the cooling process as the heating side of the thermoelectric module is more dominant, reducing the cooling capacity of its opposite side.

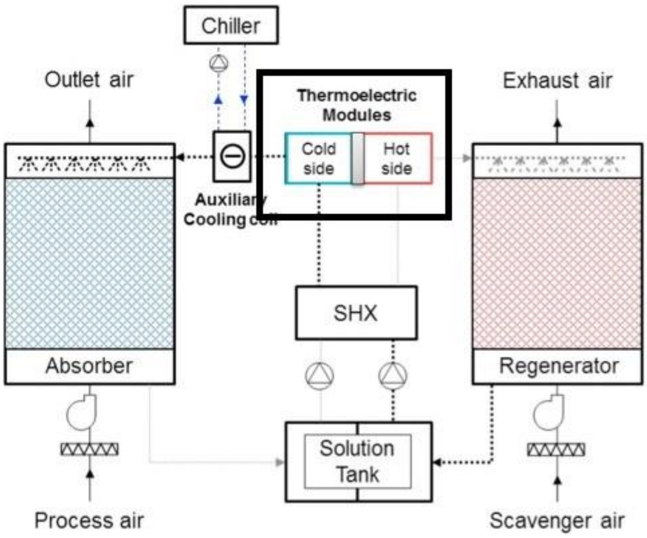


Figure 2.3: Thermoelectric Modules.
(Source: Lim & Jeong, 2018)

Different researchers, such as Dong (Dong et al., 2017b), use internally cooled absorbers where the desiccant exchange sensible heat against cooling water, as shown in Figure 2.4.

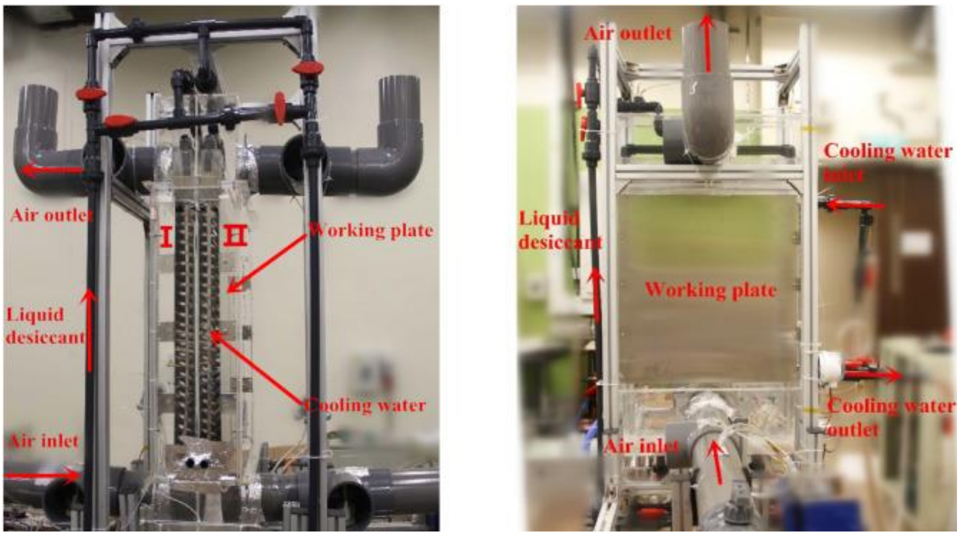


Figure 2.4: Internally Cooled Absorber.
(Source: Dong et al., 2017a)