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Investigation of a Wheel Liquid Desiccant Cooling System Performance via ANSYS CFX

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ABSTRACT

A liquid desiccant cooling system is an alternative air-conditioning system with significant energy-saving potential. This system is commonly used in the industrial sector, such as in dehumidifiers. The key component of the liquid desiccant cooling system is its dehumidification performance. Therefore, a study on a liquid desiccant dehumidifier has been conducted to predict its performance using computational fluid dynamics analysis. In these simulations, the effects of the temperature of the liquid desiccant and the velocity of air flow on the absorption process between the liquid desiccant and air were studied. The same applies to the velocity profile, which helps determine the airflow pattern within the dehumidifier. The model was constructed using ANSYS FLUENT and Autodesk Inventor. The model is the rotary desiccant wheel dehumidifier which was used to dehumidified the air:. ANSYS CFX was used for simulating the velocity profile to achieve the airflow pattern in the dehumidifier. The volume of fluid was selected as the multiphase method for the second simulation process. The temperature and mass fraction of water were monitored within the air during the counterflow simulation between the liquid desiccant and the air. The liquid desiccant chosen for this study was LiCl. The simulations were conducted at specific air velocities, and the behavior within the dehumidifier was observed. The analysis results revealed that the air entering the rotary desiccant wheel dehumidifier experienced a drop in velocity after passing through the desiccant wheel in the middle. Additionally, turbulence occurred after the air passed through the wheel and the dehumidifier's wall. Based on these findings, the design of an optimal dehumidifier and the selection of an appropriate air velocity for cooling can be carried out."

Keywords: Liquid desiccant; dehumidifier; rotary desiccant wheel dehumidifier; CFD; velocity profile; heat and mass transfer

INTRODUCTION

Communities spend 90% of its daily time indoors, thus increasing the use of energy in building operations to satisfy thermal comfort in the building (Lv et al. 2019). According to Somu et al. (2020), since 2019, the building sector has been the largest consumer of energy and contributes 40% to global energy consumption and greenhouse gas emissions in comparison with data in 2015, which amounted to 30%. Heating, ventilation and air conditioning systems account for half of a building's energy consumption.

In recent years, the demand for refrigeration has increased rapidly because of global warming. According to a study (International Energy Agency [IEA] 2018), refrigeration demand in 2100 will increase 40 times compared with the 2006 demand. The IEA also announced that the use of air conditioning systems for residential and commercial buildings has increased rapidly by three times from 1990 to 2018. The power capacity for cooling residential buildings in China and India will also increase remarkably to 22.5 and 13.5 TW, respectively, by 2050. About 10%–15% of the total energy used by buildings is used to provide the required humidity. This value is higher in buildings located in the tropics and subtropics (Guieysse et al. 2008). Another problem for air conditioning systems is the possibility of producing humid indoor air. Excessive humidity can cause many problems in buildings, such as the reproduction of fungi and viruses, corrosion in building materials, reduction of indoor air quality and discomfort for the occupants of these buildings (Guan et al. 2020). Thus, the demand for refrigeration has increased, aggravating the effects of global warming.

Instead of building additional air conditioning systems to meet the global demand, the ideal solution is to apply advanced air control technology to develop more advanced and efficient systems to reduce overall energy consumption. Dehumidifiers are one of the best technologies because it can help remove moisture from the air, thus cooling the air temperature and reducing the demand for coolant for air conditioning systems. Currently, common dehumidification methods in buildings include cooling condensation, solid desiccant and liquid desiccant dehumidification. Amongst these methods, the cooling condensation method is the most common and has been used in many practical buildings. However, this method wastes substantial energy due to supercooling, and it causes bacterial growth on the cooling coil due to the water concentration (Rafique et al. 2016). Therefore, to address sensible and latent heat loads, dehumidification systems with desiccants have been considered.

This system has two types of desiccants: solid and liquid. Solid desiccants, such as silica gel, zeolite, etc., can absorb water vapour directly. It can be installed as a rotating wheel type for operation. However, the drying regeneration temperature of a solid dryer in the drying process is high, which is approximately 90 °C–260 °C (Kim et al. 2016). The dehumidification of liquid desiccants is considered the new direction of development of dehumidification technology; it has a lower regeneration temperature of approximately 60 °C–90 °C and serves as an energy storage capacity.

The simultaneous transfer of heat and mass occurs in a liquid desiccant cooling system (Wang et al. 2013). The transfer of mass of water vapour from the humid air to the liquid desiccant surface controls the latent load. It shows a simple liquid desiccant system containing a dehumidifier and a regenerator. Moisture from the inlet air is removed in the dehumidification or absorber unit, where the desiccant absorbs the water vapour from the process air. Mass transfer occurs due to the difference in vapour pressure. Heat is then released during condensation of water and heat exchange due to mixing. After dehumidification, air is introduced in the space or in an evaporative cooler to cool down further, whereas the diluted desiccant is pumped back to the regenerator. Before the diluted solution enters the regenerator, it initially passes through a liquid–liquid sensible heat exchanger and then a heating coil, where its temperature is raised. In the regenerator, the hot, diluted solution is exposed to regenerative air, and moisture is transferred from the weak solution to the air due to the difference in vapour pressure. This concentrated solution again passes through a liquid–liquid heat exchanger and a cooling coil before it enters the dehumidification unit. A liquid–liquid heat exchanger is used to preheat the weak solution and precool the strong solution.

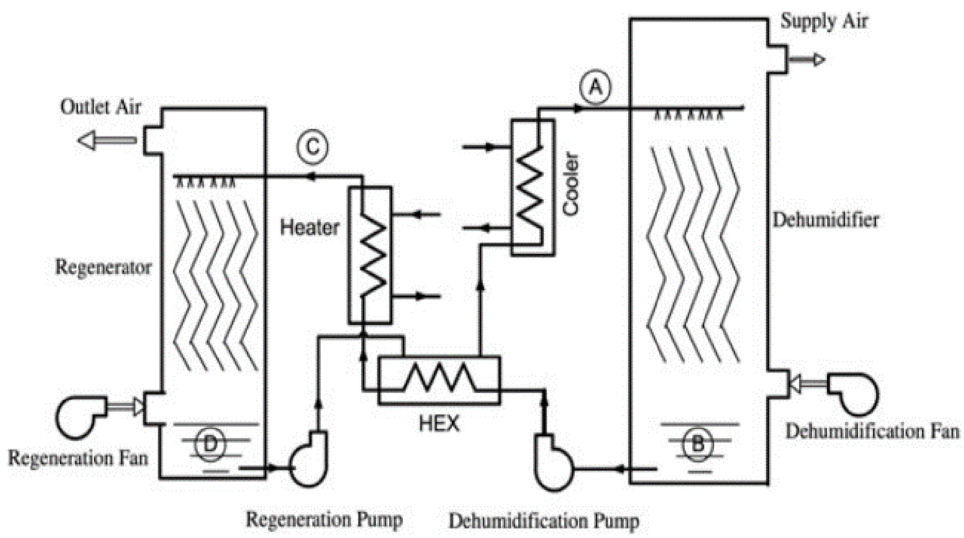

FIGURE 1. Liquid desiccant system

Figure 2 indicates the change of the vapour pressure of the desiccant solution during the dehumidification and regeneration processes. The desiccant solution enters the dehumidifier in State A, where it has a high concentration and lower vapour pressure than humid air. During dehumidification, the solution absorbs moisture and reaches state B with a lower concentration and a higher vapour pressure. Vapor pressure is altered further by heating the solution before it enters the regenerator in State C. At this stage, the vapour pressure of the solution is higher than that of the processed air, and it transfers the absorbed moisture to the air. Consequently, its vapour pressure is reduced, its concentration is increased, and it reaches state D. Afterwards, it is cooled to reduce its vapour pressure further (Wang et al. 2013).

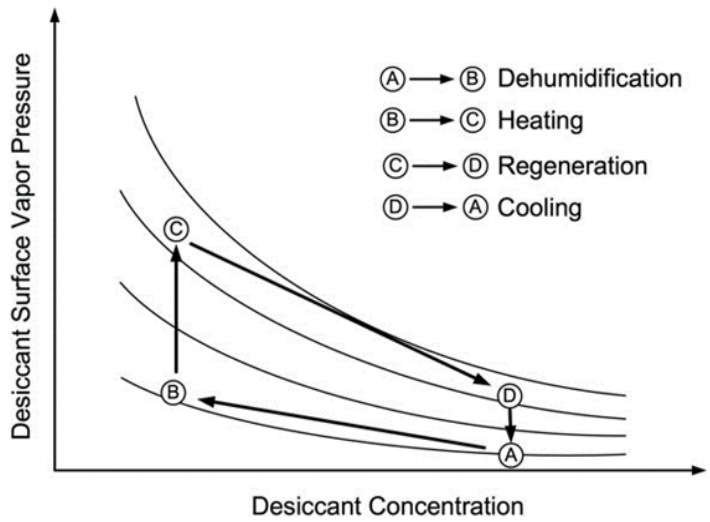

FIGURE 2. Change of the vapor pressure of desiccant in different stages

Liquid desiccant materials attract the water vapour towards itself, and these materials are used where air with a low dew point is needed. The strength of a liquid desiccant can be measured by its equilibrium vapour pressure, which increases exponentially with the temperature of the water or desiccant and increases as the desiccant absorbs water. A diluted liquid desiccant has a higher equilibrium vapour pressure than a concentrated liquid desiccant (Sahlot & Riffat 2016). According to Liu et al. (2011), two of the most used liquid desiccants are LiCl and LiBr. They concluded that LiCl removes moisture from air more effectively than LiBr because it has a lower vapour pressure. As mentioned above, the cooling demand had increased remarkably, thus causing several problems. The solution was to implement an advanced cooling system.

These papers collectively discuss the simulation of desiccant cooling systems using various software tools. Jani et al. (2020) provides an overview of using TRNSYS simulation software to evaluate the performance of desiccant cooling systems. Reddy et al. (2020) also use TRNSYS to study solar-aided liquid desiccant systems, which have been employed to reduce the dependency of air-conditioning systems on non-renewable sources of energy. Meanwhile, Sudhakar et al. (2019) have incorporated TRNSYS and MATLAB into co-software to simulate a solar desiccant cooling system and compare it with other commercially available software. Prajapati et al. (2022) use CFD software such as Fluent to study a solid desiccant cooling system that reduces power usage while simultaneously providing fresh and clean air. Overall, these papers demonstrate the use of simulation software to analyse and predict the performance of desiccant cooling systems, providing insights into their feasibility, efficiency, and potential for energy savings.

Therefore, the main objective of this paper is to study the velocity profile of a liquid desiccant dehumidifier which was constructed using ANSYS CFX software. ANSYS software can simulate situations accurately. The first dehumidifier is constructed as the model of rotary desiccant wheel dehumidifier, whereas the second model is the failing film dehumidifier. Both models are constructed in 2D. LiCl is selected as desiccant material for the simulation. The heat and mass transfer processes in the model determine the dehumidifier's performance.

METHODOLOGY

The flowchart of the research method and that of the simulation were developed to ensure that the analysis is always conducted smoothly and at the correct stage as shown in Figure 3. First of all, a literature review was conducted to observe the study's trends. Then, the models were constructed based on the proposed design using ANSYS Design and Autodesk Inventor. Subsequently, simulation parameters for ANSYS FLUENT and ANSYS CFX were set up in advance. Using this data, it was processed through the model and the software for data analysis. If the results are not sufficient, the parameters need to be re-evaluated. If the results are good, then an analysis and discussion will be conducted on velocity streamlines, total pressure contours, and kinetic turbulence energy contours. Finally, the project was concluded based on the findings.

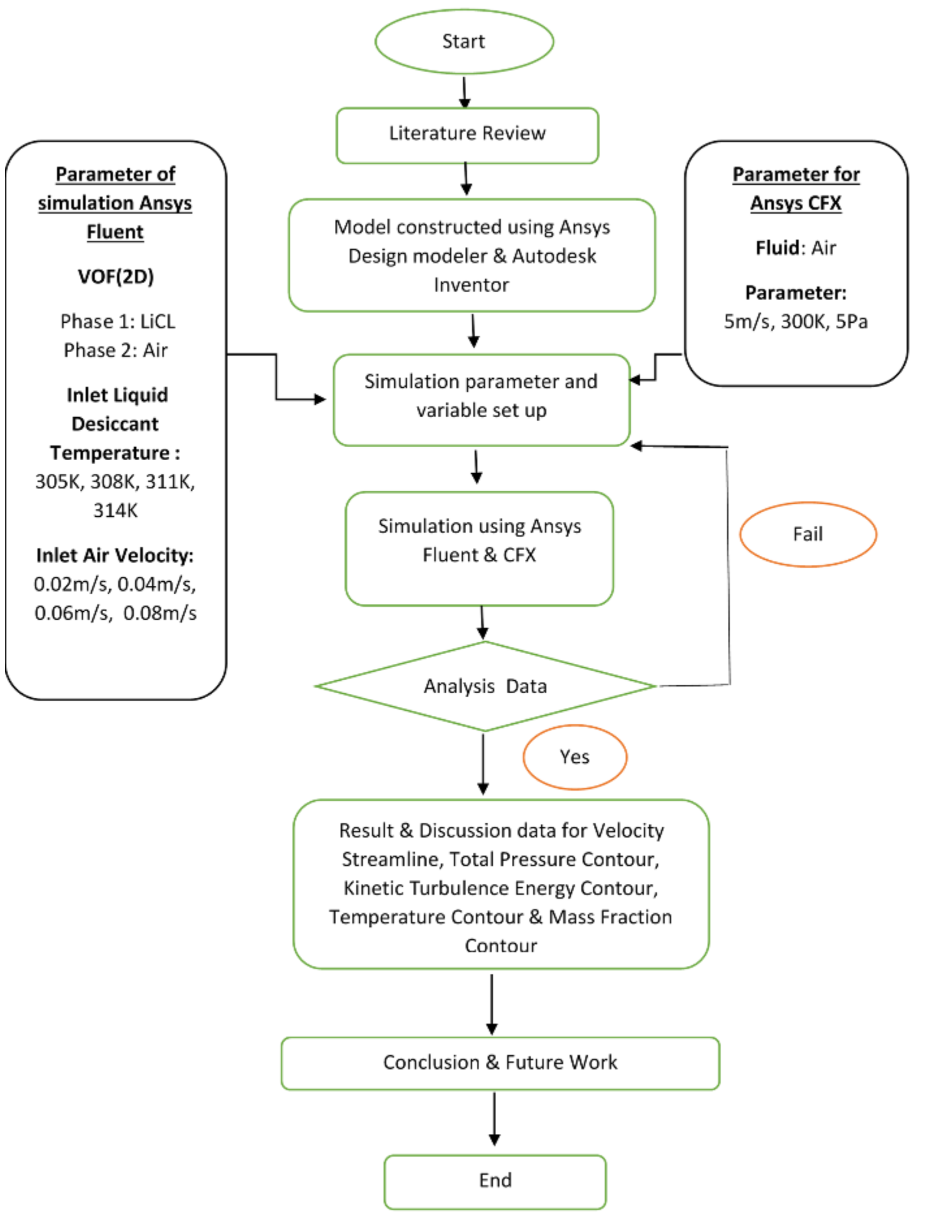

FIGURE 3. Flowchart of simulation process

MODEL GEOMETRY

Before entering the simulation stage for the result, a model geometry must be built. The first model was constructed as the model of a rotary desiccant wheel dehumidifier using Autodesk Inventor, as shown in Figure 4. The model was in 2D. The diagram shows the presence of two holes on either side of the wall, one of which is the air inlet, and the other is the outlet. The rectangle in the enclosed dehumidifier represents the rotary desiccant wheel, which carries the regenerated liquid desiccant for the absorption process with the warm and humid air. The model was constructed in a 500 mm x 500 mm size, where the wheel in the middle has a size of 420 mm diameter x 150 mm. The inlet and outlet air pipes were 200 mm diameter x 100 mm.

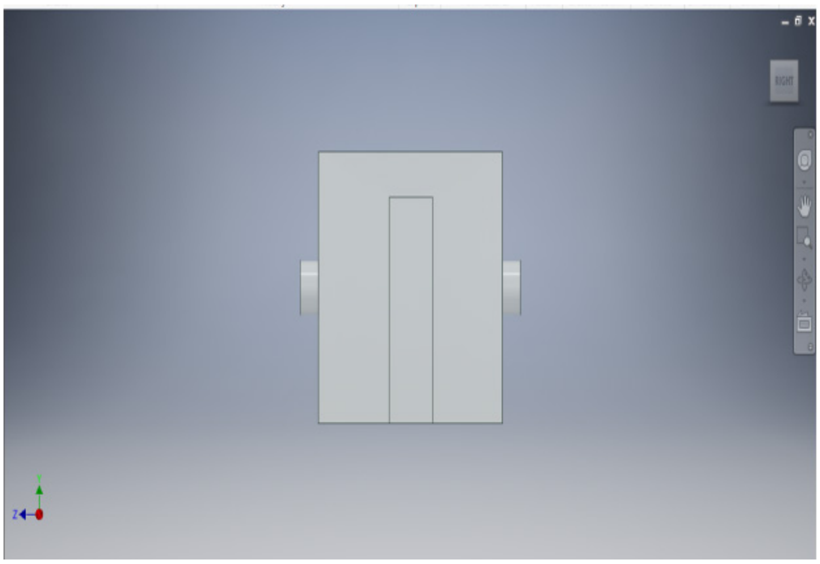

FIGURE 4. Rotary desiccant wheel dehumidifier

SIMULATION SETUP

The simulation displays the streamline velocity of the air flow in the dehumidifier, which enters from the left air inlet, passes through the middle rotary desiccant wheel and leaves on the right side of the outlet. These variables were considered to ensure smooth operation and accurate results. Table 1 indicates the parameter setup for the simulation of a rotary desiccant wheel dehumidifier using ANSYS CFX software.

TABLE 1. Parameter setup for the model

Fluid	Inlet Air Velocity	Inlet Air Temperature	Outlet Relative Pressure
Air	5 m/s	300 K	5 Pa

This research is conducted to determine the performance of a liquid desiccant dehumidifier on the basis of the heat and mass transfer process in the model. This simulation needs a few boundary conditions to obtain successful and reliable results, as shown in Table 2.

TABLE 2. Boundary conditions

Parameter	Information
Model	VOF
Gravity of y-axis	-9.81 m^2/s^2
Type of Solver	Pressure-Based
Solving Method	SIMPLE
Pressure Scheme	PRESTO!
Momentum	First Order Upwind
Volume Fraction	Geo-reconstruct

According to the literature of Koronaki et al. (2013), LiCl has the best dehumidifier efficiency in comparison with other inorganic desiccants, such as LiBr. Hence, LiCl was chosen as desiccant for dehumidification in this work. The basic state of LiCl solution was set, as shown in Table 3. The properties must be inserted manually to create the LiCl solution because the database of ANSYS Fluent does not include it. Humid air is available in the Fluent database.

TABLE 3. Property input of LiCl

Density (kg/m^3)	Viscosity (kg/m)	Surface Tension	Specific Heat Capacity
1180	0.00359	0.0859	2933

In addition, the two phases must be setup to ensure phase interaction between the liquid desiccant solution and the humid air in the multiphase model simulation.

TABLE 4. Phase setup for the simulation

Phase	Material
Phase 1	LiCl
Phase 2	Mixture Template (air + (water vapor

After all the boundary conditions have been setup, the parameters of operation for the second model must also be completed to achieve the results. Tables 5 and 6 indicate the parameters of operation for the heat and mass transfer of the liquid desiccant with moist air in the simulation. Four sets of different inlet temperatures were set up for the desiccant to observe the heat transfer between the liquid desiccant and the air in the model. The inlet air velocity and temperature were 300 K and 0.02 m/s, respectively.

TABLE 5. Parameter operation for the model

Inlet Solution Temperature	Inlet Solution Velocity
305K	0.05 m/s
308K	0.05 m/s
311K	0.05 m/s
314K	0.05 m/s

Next, another four sets of different inlet air velocity values were set up to complete the listed objectives. The inlet desiccant temperature and velocity were constant for every case, i.e. 300 K and 0.05 m/s, respectively.

TABLE 6. Parameter operation for the model

Inlet Air Velocity	Initial Mass Fraction
0.02 m/s	0.1
0.04 m/s	0.1
0.06 m/s	0.1
0.08 m/s	0.1

Through this simulation, this study can prove that the performance of a liquid desiccant dehumidifier is affected by the inlet desiccant temperature and the inlet air velocity based on the heat and mass transfer processes that occur in the model.

RESULT AND DISCUSSION

SIMULATION RESULTS

On the basis of the set parameters, this simulation was performed using ANSYS CFX. The velocity streamline contour, total pressure contour and turbulence kinetic energy contour were obtained from the simulation. During result generation, the graph of momentum and mass could be observed to determine whether it meets the convergence or not, thus helping monitor and ensure that the test is valid and running properly. The graph of momentum and mass over the accumulated time step of simulations generated during the solution process in this study is illustrated in Figure 5. Meanwhile, Figure 6 shows the turbulence generated against the accumulated time step.

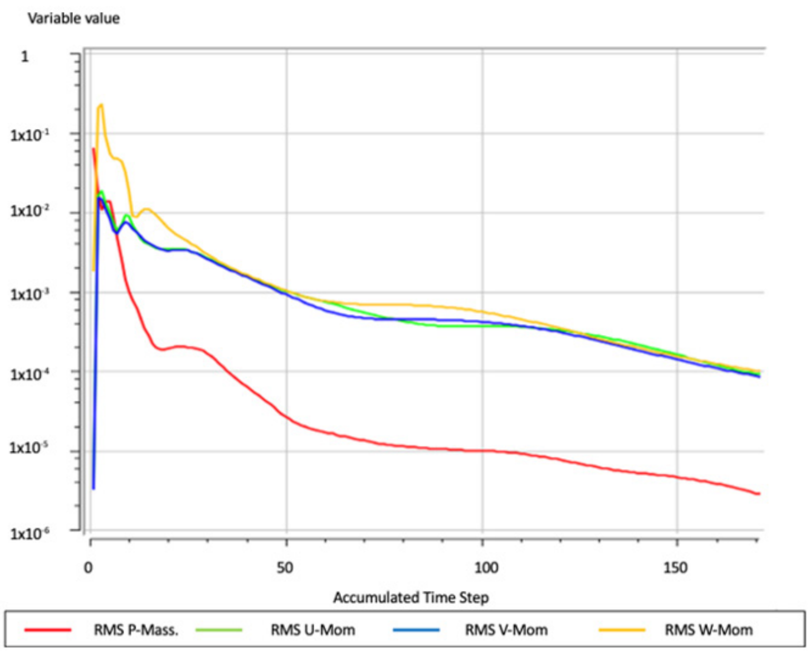

FIGURE 5. Graph of mass and momentum generated

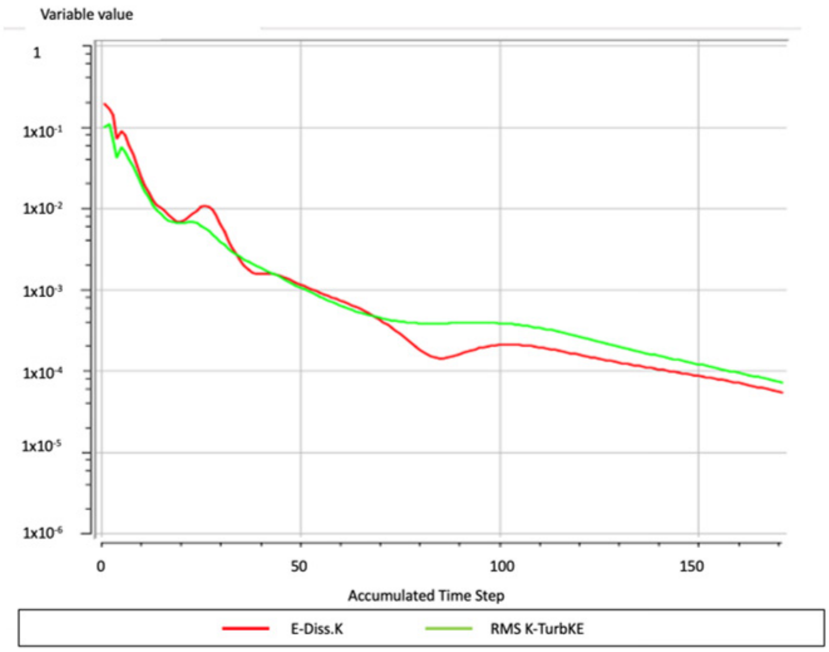

FIGURE 6. Graph of turbulence generated

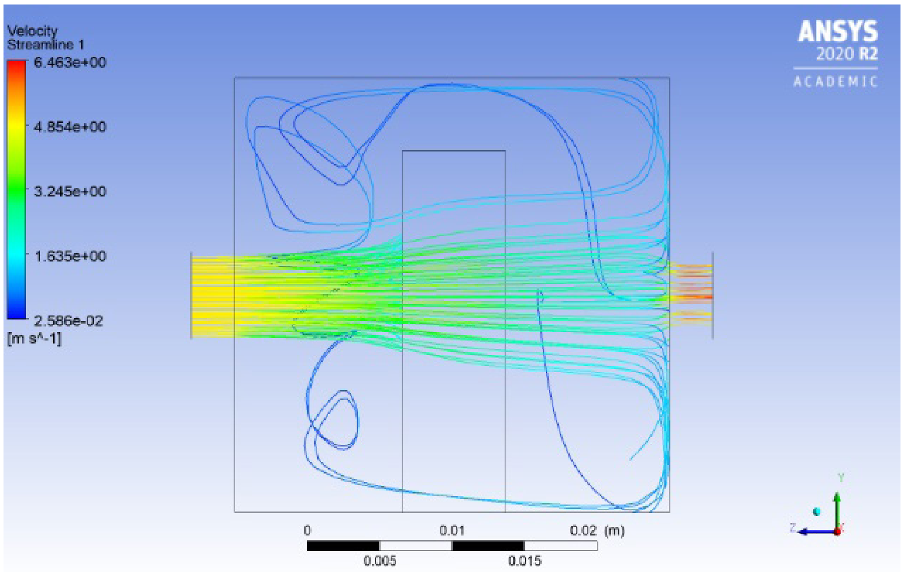

FIGURE 7. Velocity streamline for rotary desiccant wheel dehumidifier

The following is the contour result obtained from the simulation using ANSYS CFX for the model. Figure 7 indicates the velocity streamline for the simulation of the first model. Velocity streamlines allow us to observe the air velocity inside the dehumidifier. As shown in the figure, the air velocity enters the dehumidifier at a moderate speed of 5 m/s, which is indicated by the yellow airflow on the left side of the model. The air velocity then experiences a drop to 3.25 m/s when passing through the desiccant wheel in the middle of the model due to the pressure drop when the air passes through the desiccant wheel.

Figure 8, which shows the total pressure contour obtained from the simulation, has proven that the total pressure has dropped by 5 Pa at the location of the desiccant wheel in the dehumidifier. The air velocity rose again to 6.46 m/s when air left the dehumidifier on the right side of the model. This increase is due to the relative pressure applied to the outlet of the dehumidifier. Hence, the desiccant wheel affects the velocity of airflow in the dehumidifier, which reduces the velocity and affects the performance of the dehumidifier.

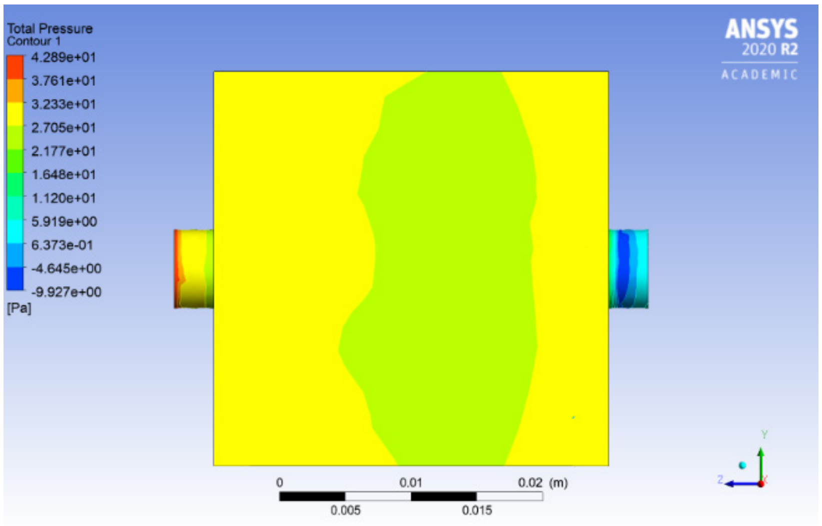

FIGURE 8. Total pressure contour for rotary desiccant wheel dehumidifier

The velocity streamlines from the simulation also allow us to observe the airflow pattern in the dehumidifier. As shown in Figure 7, several turbulence flows occurred in the model. This finding can be supported by the turbulent kinetic energy contour shown in Figure 9. The turbulence kinetic energy at the middle of the dehumidifier, where the wheel is located, is around 0.3184 m^2/s^2, which is higher than the surrounding internal pressure. The energy at the wall on the right side is also higher at approximately 0.2435 m^2/s^2. Turbulence kinetic energy is the energy content of eddies in turbulent flows. The larger the size of the dehumidifier, the higher the energy content of eddies. High-energy regions are those where a large amount of turbulent energy is extracted from mean flow. In short, turbulence flow had occurred at the rotary wheel and the wall of the dehumidifier.

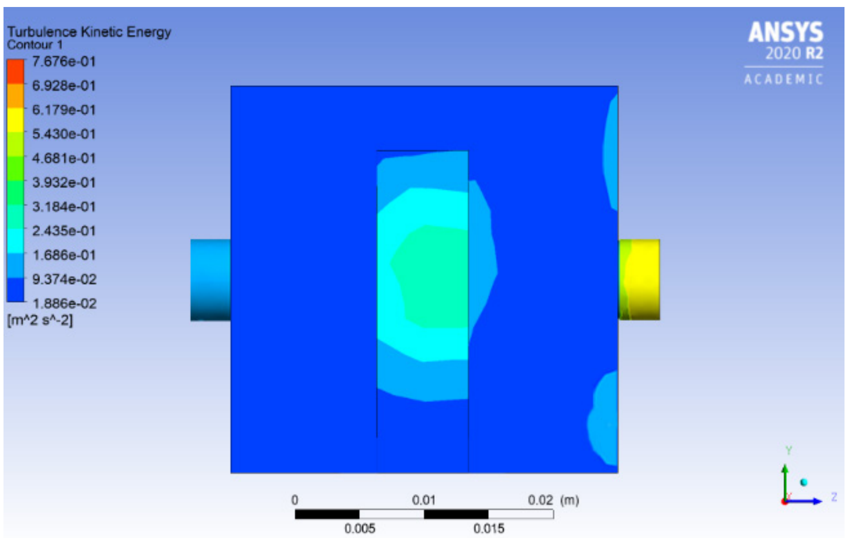

FIGURE 9. Turbulence kinetic energy contour for the rotary desiccant wheel dehumidifier

CONCLUSION

Models of dehumidifiers were extensively investigated in this study. The performance of the latest cooling system, especially the liquid desiccant dehumidifier, was evaluated on the basis of heat and mass transfer and the airflow profile. The model, which is the rotary desiccant wheel dehumidifier, was constructed using Autodesk Inventor. The simulation was conducted using ANSYS CFX to determine the velocity profile of the dehumidifier. The simulation results revealed some of the important points:

1. that turbulent flow occurs in the rotary desiccant wheel dehumidifier. High-turbulence kinetic energy in the dehumidifier means that turbulence flow appears at that location.
2. In addition, the air velocity in the dehumidifier was reduced due to the pressure drop during airflow passage through the rotating wheel for the absorption process in the liquid dehumidifier.
3. The results show that when there is higher air input into the dehumidifier, the distribution of the air stream becomes more scattered and unstable.

Nevertheless, it remained in the controlled state, and lower velocity of air must be used. For future research, it is recommended to do in-depth simulation such as temperature and humidity ratio in the system.

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DECLARATION OF COMPETING INTEREST

None

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