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Experimental and Evaluation of Wheel Liquid Desiccant Cooling System: A Preliminary Study

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ABSTRACT – *Human comfort is an important concern in accomplishing energy-efficient air conditioning systems. Temperature control is the most focused research in human comfort, but humidity control has played an important role to maintain indoor comfort too. That is why desiccant cooling could be one of the best solutions to replace conventional air conditioning systems. The proposed system in this paper is to establish a combination of well-known solid wheel cooling with liquid desiccant cooling. This paper will discuss extensively how we conduct the experiment so that we can achieve cooling for the intended space. Then we discuss the performance of the wheel in terms of humidity, air temperature, liquid temperature, and volume. The outcome of this paper could be the catalyst for a more complete build-up of wheel desiccant cooling systems in near future.*

KEYWORDS: Air-conditioning, desiccant cooling, relative humidity, air temperature

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1. INTRODUCTION

Blind cooling is important for space conditioning in automotive cabin cars, especially in warm climates and humid countries. Removal of moisture from the air represents a considerable portion of the air conditioning load. Conventionally, air conditioning systems must lower the air temperature below its dew point to accomplish dehumidification. This act will be resulting in a wet cooling coil surface that led to the growth of mold and bacteria which could lead to unwanted health issues and bad indoor air quality in conditioned spaces (Fekadu & Subudhi, 2018). Then, the air must be reheated to reach the desired comfort level. Nevertheless, this traditional process consumes extra energy and thus electricity demands would be increased. Along with the growth of cooling loads in the cabin wall, the peak electricity demand increases during the day. This causes problems concerning the energy supply as the demand for air conditioning is increasing each day. The inertia of energy plants leads to high consumption of fuel energy to ensure the provision of electricity (Cheng et al., 2019). This means that conventional air conditioning system has a serious issue in terms of inefficient removal of latent loads although they are very effective in removing sensible load within conditioned spaces.

These disadvantages of conventional air conditioning such as a vapor compression cycle can be resolved by a desiccant cooling system (Lee et al., 2021). Solar air conditioning is one of the highest technical levels whose advantages depend on how it adapts to a changing season. The greater the solar radiation is, the larger the refrigeration output the solar radiation can produce (Ali & Ratismith, 2021). Desiccant cooling systems offer a solution to meet the humidity and temperature requirements of buildings via decoupling latent and sensible loads. A desiccant cooling system is also considered a suitable option to replace conventional air conditioning where humidity control is the main concern (Charara et al., 2019). This humidity control can be done by using desiccants to humidify the air. Desiccant materials have strong absorption towards water vapor that is present in the air. The vapor pressure difference between the air and desiccant material was the driving force for this absorption of water vapor (Yao et al., 2016). There are three types of known desiccant cooling technologies which are solid, liquid, and hybrid desiccant cooling systems (Enteria & Mizutani, 2011).

The solid-based system uses solid desiccant materials that can hold off water vapor. There are several types of solid desiccant materials such as titanium silicates, silica gel, calcium chloride, molecular sieve, activated alumina, zeolite, lithium chloride, organic-based desiccants, composite desiccants, and compound (Mohammad et al., 2013b). The liquid desiccant cooling system uses the liquid desiccant in controlling air moisture content. The process of air moisture reduction is through the absorption process. For reduction of the air moisture content, the air is passed in the same way as in the air cooling done in the solid desiccant cooling system. There are several types of liquid desiccants such as tri-ethylene glycol, lithium chloride, calcium chloride, lithium bromide, a mixture of calcium chloride and lithium chloride, and so on (Mohammad et al., 2013a). A hybrid liquid desiccant air-conditioning system is a combination of the liquid desiccant dehumidification process in removing latent load and the cooling unit to meet the sensible cooling load. The main classification of the hybrid liquid desiccant cooling system is based on the cooling units used in the reduction of the dehumidified air temperature. By using a hybrid system, the dehumidifier can absorb enough moisture with the smaller size of the dehumidifier and lower the required regeneration temperature needed by the desiccant cooling system from 80ºC to 50ºC (Jain et al., 2011). The purpose of this paper is to study the performance of the wheel liquid desiccant cooling system that has been set up in the Faculty of Engineering, University of Nottingham.

2. EXPERIMENTAL SETUP

Figure 1 illustrates the schematic diagram of the test rig that has been used to measure the performance of the plastic rotor wheel. Based on that test rig, humid air entered the ducting through the air inlet. At the same time, potassium formate solution (45 wt.%) at the top tank was released by the valve and flowed through the pipe before being sprayed evenly on top of the rotor wheel surface and channels. The rotor wheel was placed in a static position. In that position, humid air will be in contact with the solution to perform moisture removal from the humid air. As a result, the air that left the rotor wheel became dry air. Figure 2 shows the process flow for running the experiment.

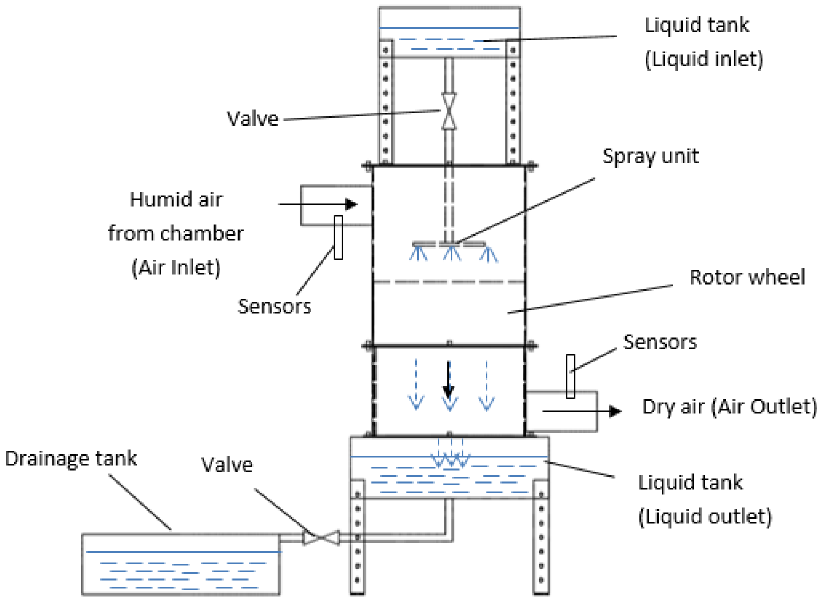

FIGURE 1: Schematic diagram of the test rig of the rotor wheel

Figure 3 shows the experimental setup for the test rig. We conducted the experiment using a controlled climate via an environmental chamber where we set the relative humidity at 60% and the temperature at 33ºC. Besides that, we used potassium formate (45 wt.%) as the working fluid. There are five types of speed that will be used, i.e., V_1 = 0.5 m/s, V_2 = 1.5 m/s, V_3 = 2.5 m/s, V_4 = 3.5 m/s, and V_5 = 4.5 m/s. The thermocouple was attached to the upper tank and lower tank to measure the temperature of the working fluid. Then the probes for relative humidity and temperature have been attached to the air inlet and outlet of the test rig. All the data was collected by the EK-H4 data acquisition system and then was stored as a Microsoft Excel Comma Separated Value file. The relative humidity difference and the temperature difference will be calculated to see the dehumidification and cooling process of the rig.

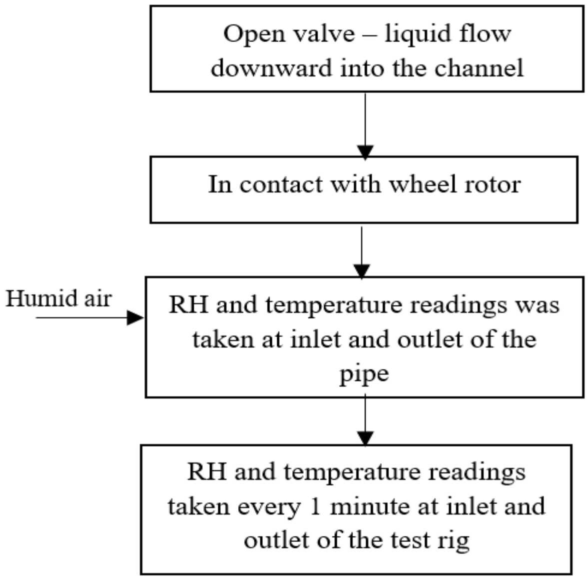

FIGURE 2: Process flow during the experiment

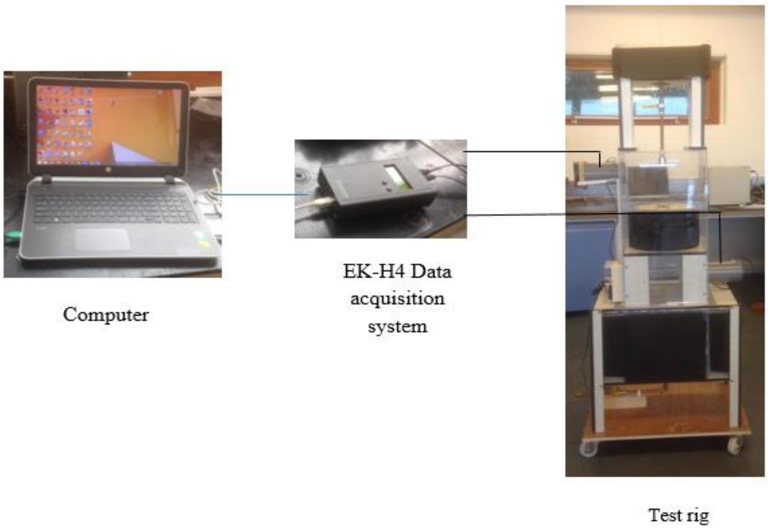

FIGURE 3: Test rig of the rotor wheel in the laboratory

3. RESULTS AND DISCUSSION

Now we are discussing the results of the wheel rotor that will be incorporated into the complete cooling system. As we can see in Figure 4, the dehumidification process happens because the humidity has been reduced from 60% to almost 51%. When we used air velocity V_1, mostly the relative humidity will fall around 54% to 55%. Then when can see that there is not much change when we set the air velocity to V_2 and V_3, where both humidity levels fall between 53% and 54%. After that, we increased the air velocity to V_4 and as a result, we get a relative humidity level in the range of 52% to 53%. Finally, for maximum speed V_5, the dehumidification process was achieved from 51% to 52%. In Figure 5, we can see the Relative Humidity Difference (RHD) according to air velocity. It seems clear that the higher the speed of air, the deeper dehumidification can be taken place. Table 1 shows the average value of relative humidity according to air velocity.

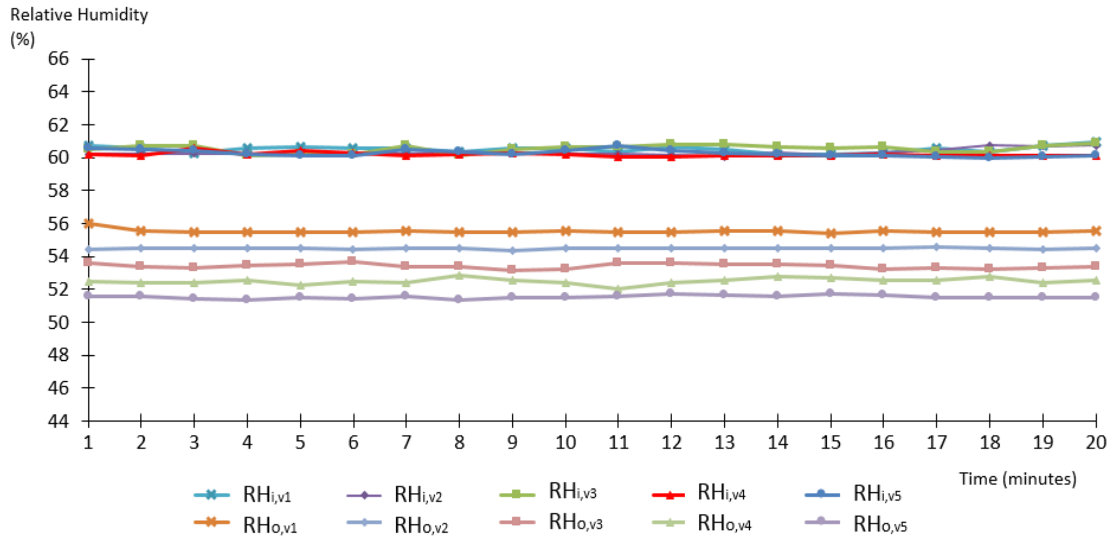

FIGURE 4: Relative humidity outlet versus time at variable speed when relative humidity inlet at 60%, and temperature at 33ºC using potassium formate

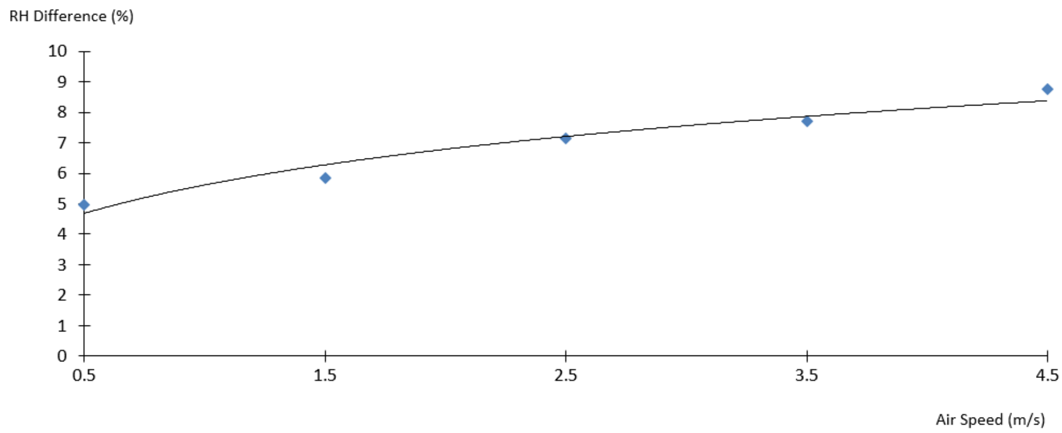

FIGURE 5: Relative humidity difference or dehumidification versus air speed

TABLE 1: Average value of relative humidity according to air speed

RH (%)	Air velocity (m/s)				
	0.5	1.5	2.5	3.5	4.5
RH in	60.51	60.32	60.55	60.19	60.28
RH out	55.53	54.48	53.41	52.49	51.52
Differences (Δ)	4.98	5.84	7.14	7.69	8.75

For temperature change, as shown in Figure 6, it was also observed that the air temperature at the outlet has decreased compared to the air temperature at the inlet which is 33ºC. When air velocity was set at V_1, the temperature decreased to 31.65ºC. After we increased the air velocity to V_2, we can see the air temperature was further reduced to 31.17ºC. Then for air velocity at V_3, the air temperature reached around 30.64ºC. After that, the air temperature was further reduced to 29.93ºC when using air velocity at V_4. At maximum air velocity V_5, it was observed that the air temperatures at the outlet are at 28.76ºC. Then, Figure 7 shows the temperature difference (TD) according to air velocity. From the observation, we could see that temperature can be reduced significantly if we increased the air velocity. Table 2 shows the average value of temperature according to air velocity.

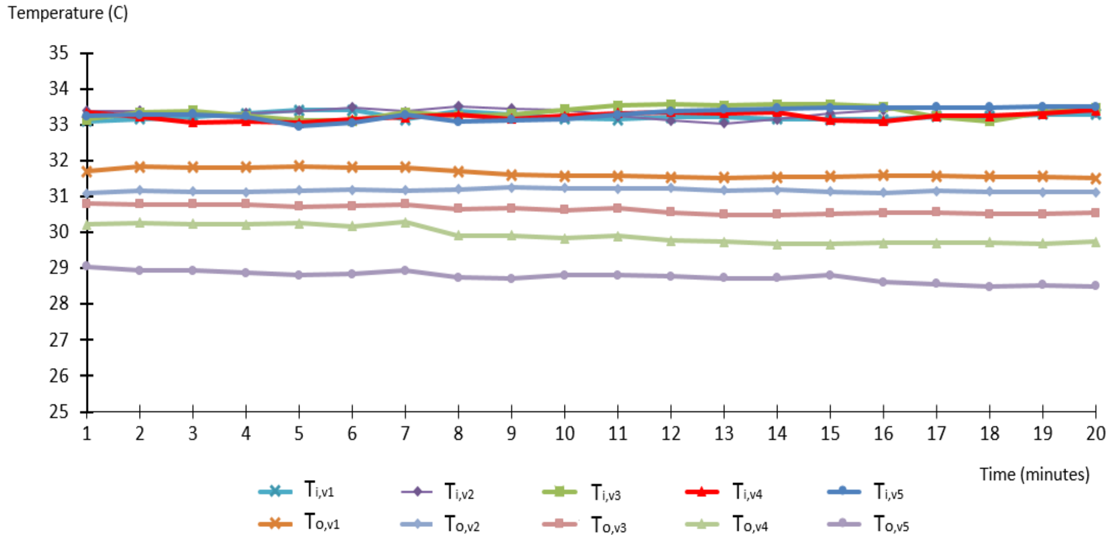

FIGURE 6: Air temperature outlet and inlet versus time at variable speed when relative humidity inlet at 60%, and temperature at 33ºC using potassium formate

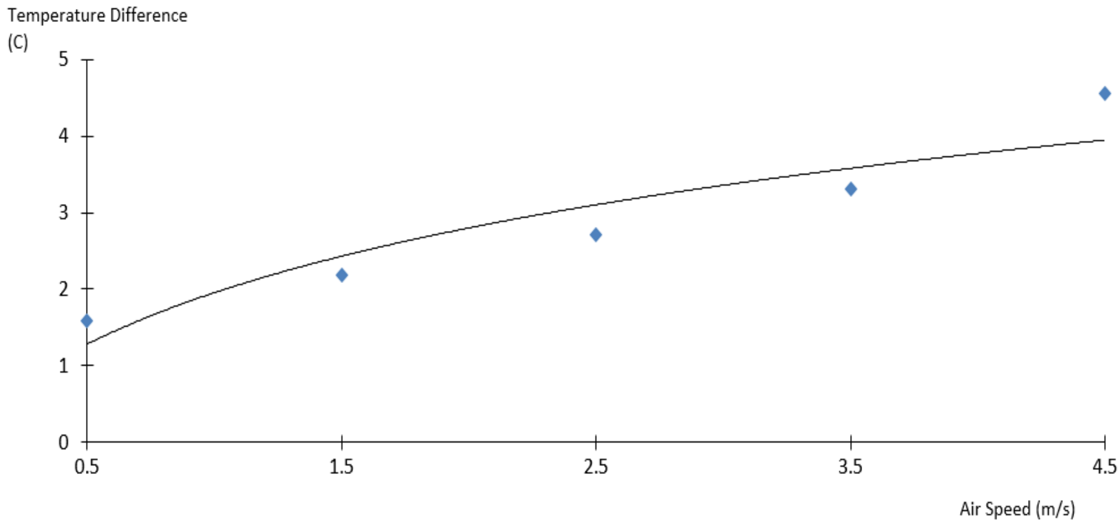

FIGURE 7: Air temperature differences versus air speed

TABLE 2: Average value of temperature according to air speed

Temperatures (ºC)	Air velocity (m/s)				
	0.5	1.5	2.5	3.5	4.5
T in	33.24	33.35	33.35	33.23	33.31
T out	31.65	31.17	30.64	29.93	28.76
Differences (Δ)	1.58	2.19	2.72	3.30	4.55

Besides that, we can also see that there is a temperature rise in potassium formate when we use varied air velocities as shown in Figure 8. The initial temperature T_o of potassium formate in the upper tank is stable at around 21ºC. When we set up the air velocity to V_1, we can see the temperature rise to around 22.43ºC. Then, when the air velocity rose to V_2, the potassium formate temperature also raised to around 22.86ºC. After that, we can see the temperature of potassium formate change increased again to 23.70ºC after we change to air velocity V_3. Afterward, we increased the air velocity again to V_4 and the liquid's temperature also rose to 24.86ºC. Finally, for air velocity V_5, we can see that the temperature is the highest at around 25.85ºC. Figure 9 shows the temperature difference (TD) for potassium formate at various air velocities. Based on the graph, the potassium formate can absorb higher heat with an increasing air velocity in the test rig. Table 3 displayed the details of the average value of potassium formate temperatures according to air velocity.

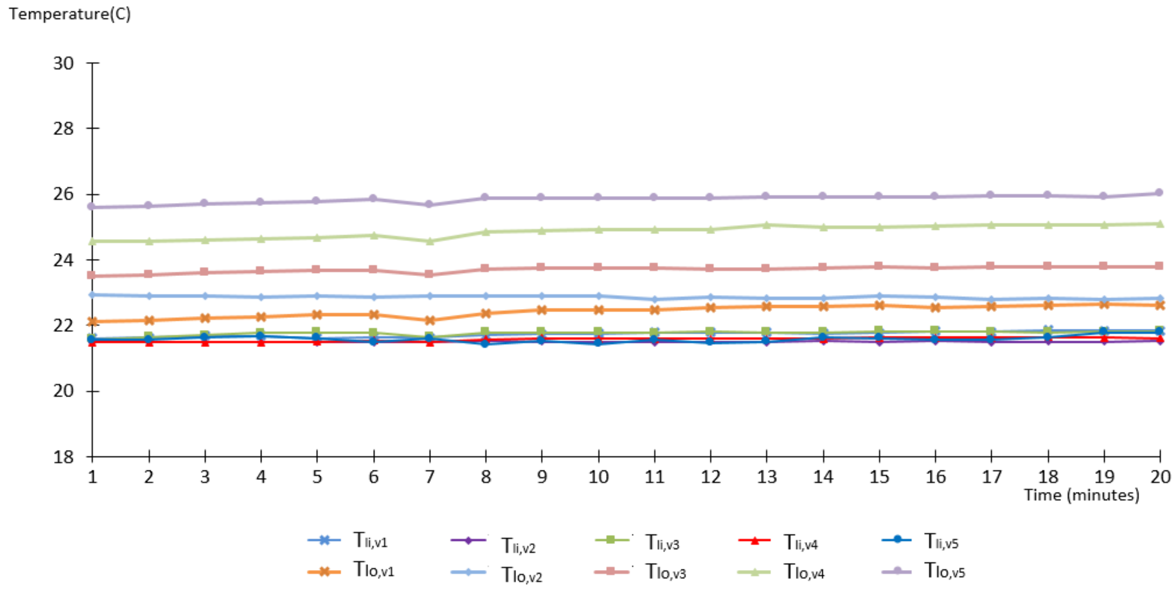

FIGURE 8: Initial temperature T_o and final temperature T_f of potassium formate versus time when relative humidity inlet at 60% and temperature at 33ºC

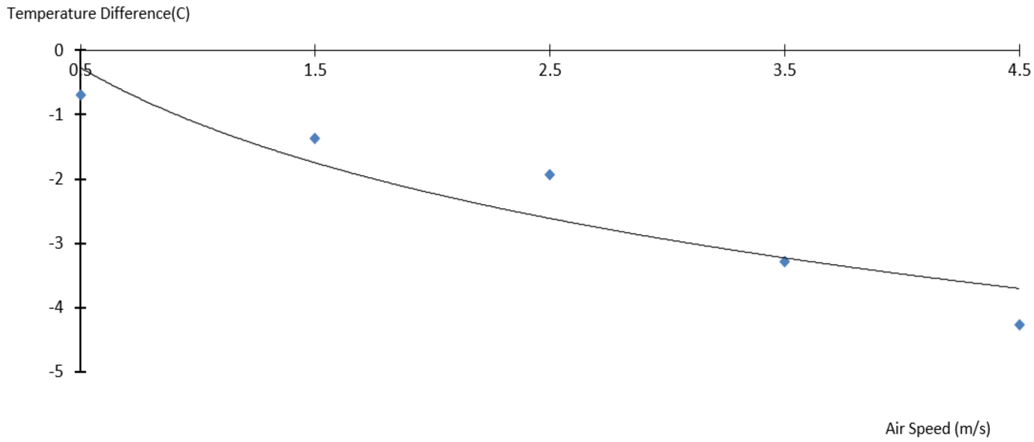

FIGURE 9: Temperature differences of potassium formate versus air speed

TABLE 3: Average value of potassium formate temperatures according to air speed

PF temperatures (ºC)	Air speed (m/s)				
	0.5	1.5	2.5	3.5	4.5
T in	21.73	21.49	21.76	21.57	21.57
T out	22.43	22.86	23.70	24.86	25.85
Differences (Δ)	-0.69	-1.37	-1.94	-3.29	-4.27

Figure 10 shows the volume of potassium formate according to increasing air velocity. It's interesting to see that volume of potassium formate increased when we raised the incoming air velocity. This is because of the increasing amount of water content that was absorbed by the desiccant liquid during performing dehumidification. Meanwhile, Table 4 shows the details of potassium formate and water content after under variable air velocity variation.

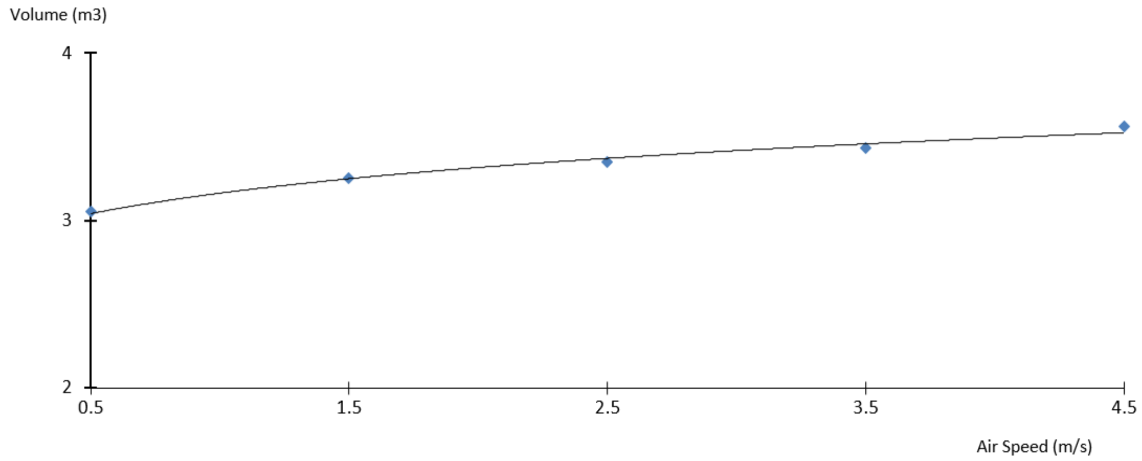

FIGURE 10: Volume of potassium formate versus air speed

TABLE 4: Liquid and water content at the liquid inlet and liquid outlet after several speed variation

PF volume	Air speed (m/s)				
	0.5	1.5	2.5	3.5	4.5
Volume in (Liter)	3	3	3	3	3
Volume out (Liter)	3.025	3.03	3.037	3.041	3.048

Based on these results, we can say that the air velocity can affect the dehumidification capability substantially. The higher the air velocity, the deeper dehumidification takes place. If more air comes into the system, it means more air penetrates the dehumidification wheel and interacts with the desiccant solution, and the vapor pressure difference will lead to the absorption of moisture from the air to the liquid desiccant. Moreover, potassium formate has a kind of sensible cooling that manages to reduce the temperature of the air, but only if the liquid's temperature is lower than in the air. The more air pumped into the system, the more air surface that can be cooled by the potassium formate in the dehumidification wheel. The increased liquid desiccant temperature in the lower tank is associated with heat transfer from the air in the chamber to the liquid desiccant. If the temperature of the air is higher than the liquid desiccant, the liquid desiccant will act as a heat absorption medium and thus reducing the air temperature. If more hot and humid air was injected into the system, more heat can be withdrawn, and the liquid becomes hotter than before.

4. CONCLUSION

Based on the results obtained, the rotor wheel can be used to dehumidify and at the same time to cool the incoming hot air into the system. This will be the stepping stone to complete the whole system that which portable, light in weight, and able to perform dehumidification without much carry-over from the desiccant solution. This could be a good guideline to perform a preliminary test prior to a complete package of the system.

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