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Efficiency Analysis of a Developed Industrial Refrigerator Using Liquid Desiccant Cooling as Mode of Operation

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ABSTRACT

This research study presents a comparative analysis of the evaporator temperatures in a liquid desiccant refrigerator and a conventional refrigerator. The aim of the study is to investigate the performance and efficiency of the liquid desiccant refrigeration technology and its potential benefits compared to conventional refrigeration systems. Evaporator temperature data was collected over a period of time for both systems, and the results were analyzed to gain insights into their cooling capabilities. Results shows that where the conventional refrigerator's evaporator temperature decreases by 9.2℃, the liquid dessicant evaporator temperature only decreased by 0.6℃. Hence, the liquid desiccant refrigerator demonstrated a slower cooling rate, maintaining higher initial evaporator temperatures, and exhibiting a more gradual temperature reduction with a coefficient of performance of 0.13. In contrast, the conventional refrigerator exhibited a faster cooling rate, achieving lower evaporator temperatures within a shorter time frame. Furthermore, the study underscores the importance of energy-efficient and sustainable cooling solutions in today's context of environmental concerns and energy conservation. Conclusively, although the conventional refrigerator achieves a higher cooling rate at a much faster pace, the liquid dessicant refrigerator with advantages such as improved moisture control, potentially higher energy efficiency and slower temperature reduction indicates a more balanced and controlled cooling process which could boost refrigeration processes if widely adopted.

1. INTRODUCTION

Leafy foods and fruits have the biggest losses across developing nations, representing 42% of the agricultural nation's losses and waste universally. An expected 93 million small-scale farmers and food supply pipelines are impacted by food losses in Nigeria [1-3]. Reducing food losses and waste adds to the acknowledgment of more extensive enhancements to agri-food frameworks towards accomplishing food security, further developing food quality, and following through on dietary results. An excessive number of African farmers do not get the income they merit since they have no chance of keeping their produce fresh [4-6].

The biggest economy and most populous country in Africa, Nigeria's development has basically revolved around oil income [7-9]. With huge territorial contrasts, poverty in Nigeria remains boundless, remaining at 39% below the public poverty line in 2016, or around 74 million individuals [10]. The majority of the country's poor live in the north, where the poverty rate is multiple times higher than in the south, and low network, market discontinuity, and struggle frustrate development [4, 11-13]. Portrayed by limited scope, and low efficiency, downpour took care of means of cultivating, farming remaining parts of the main wellspring of work for the populace and poor people, and records for 90% the country's livelihoods [14, 15]. As reported by Ogedengbe et al. [16], food losses in Nigeria account for a majority of shortages for farmers and households due to poor electricity. It is believed that devising a method for preservation of such food items for s longer period could be a major solution to this challenge.

The desiccant refrigerator is one in which the refrigerant is replaced with a desiccant in the process of cooling. This can be used to store bio-material industrially [17-19]. A desiccant refrigerator is a budget-friendly and highly efficient device for cooling, as a large percentage of energy used is regenerated, using renewable solar energy as well [20]. The solid desiccant refrigerator uses a desiccant as a dehumidifier to remove water from humid air, making use of the vapour pressure difference between the air and the desiccant to achieve cooling. Once the vapour pressure of the desiccant is the same as that of the air, the temperature may be reduced by injecting cold air [21]. The use of liquid desiccant assisted cooling to replace or enhance conventional cooling systems is gradually receiving more attention with researchers. As reported by Heidarinejad et al.

[22] who developed a desiccant-powered multi-stage evaporative cooling system, a better cooling performance could be achieved using desiccant systems; however, they also reported an increase in water consumption compared to some other conventional cooling types. Park et al. [23] developed a cooling system that uses a liquid desiccant to enhance the performance of the system. They reported a sharp drop of over 35% in the energy required thereby improving greatly the performance of the cooling system. Rafique et al. [24] who studied the recent trends in cooling systems with adapted liquid-desiccants reported that the technology could result in a huge revolution for energy conservation while providing needed comfort and preservation for mankind. As opined by Zhang et al. [25], the development of new cooling system models that can rapidly improve cooling performance while also achieving dehumidification is essential. This study therefore seeks to develop an industrial refrigeration system that employs a liquid desiccant system as a mode of operation.

2. METHODOLOGY

2.1 Experimental procedure

The experimental procedure is as described in Figure 1. The experimentation commenced with a design of the entire system, this included the design calculations and sizing of specific components which was followed by a material selection process to ensure good fit of various materials used for different parts. The Fabrication of the various frames and parts quickly followed after which the testing of the performance of the developed cooling system was done. The whole process was concluded with a set of analyses from the results obtained.

2.2 Desiccator design

The design was done with solidworks and other CADs. The design layout of the components of the desiccant refrigerator is shown in Figure 2. To avoid failure, a number of factors have to be considered while selecting materials. This is to satisfy the need for the existence of the desiccant cooling refrigerators compared to vapour cooling refrigerators, which is primarily energy saving and cost-effectiveness.

Therefore, before the reservoir was constructed, materials were effectively evaluated to ensure affordable and efficient materials were used.

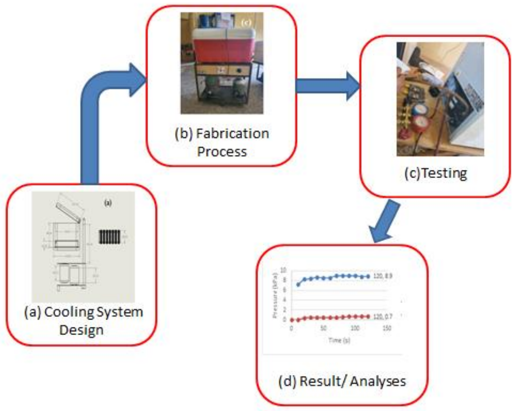

Figure 1. Experimental procedure

2.3 Material selection/component configuration

The liquid desiccant cooling system comprises of six major components namely; an air dehumidifier (which contains the desiccant), regenerator, heat exchangers, evaporator and condenser will be either built or purchased.

The materials selected for the experimental setup according to the design guidelines includes a filter dryer (used to remove impurities, such as moisture, acid, and dirt, from the refrigerant), a heat exchanger (used to transfer heat between two fluids or substances, commonly a refrigerant and the surrounding environment), and a charging valve (used to add or remove refrigerant from the system).

Also employed were a band heater (employed to replenish the liquid desiccant solution by removing the moisture that has been absorbed from the air), a throttle valve (employed to manage the flow rate of the liquid refrigerant through the system), a pressure reduction valve (PRV) (used to regulate the pressure of the liquid refrigerant entering into the evaporator of the refrigeration cycle), a refrigeration tube (employed to circulate the refrigerant through the different components of the refrigeration cycle and a thermostat (employed to regulate the temperature of the refrigeration cycle and maintain a consistent degree of cooling performance).

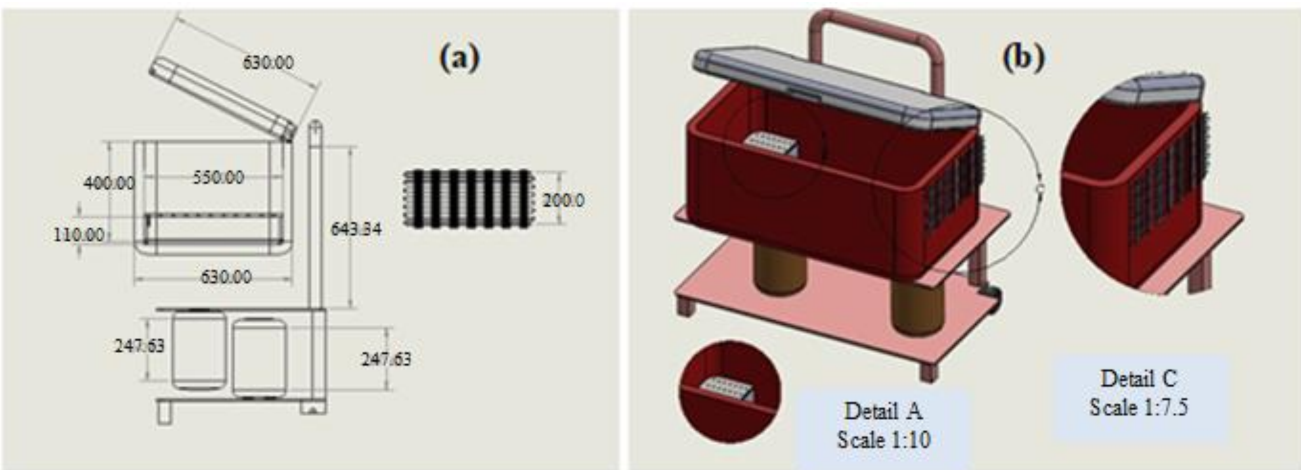

Figure 2. Liquid desiccant refrigerator developed (a) Design specification of a prototype; (b) Rendered prototype

An evaporator, a pump, an inverter and a regenerator where critical components used for this study as well. Figure 3 shows some of the major components used for the study.

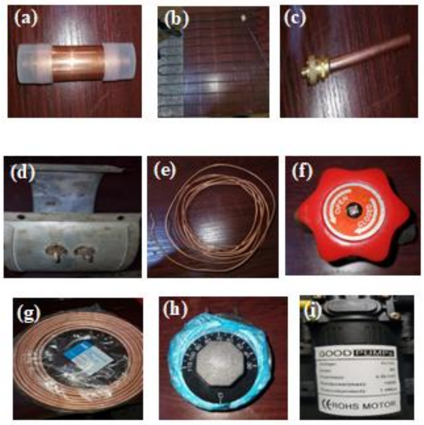

Figure 3. Materials used for experimentation (a) filter dryer; (b) heat exchanger; (c) charging valve; (d) band heater; (e) throttle valve; (f) pressure reducing valve; (g) refrigeration tube; (h) thermostat; (i) pump

2.4 Fabrication process

The prototype needed a base for support and platform for which the materials were fabricated on. A 0.701mm iron plate was selected. Having a load carrying capacity of 5.479kg/m^2, it is able to efficiently carry all materials used as shown in the system development setup. It was joined by welding the plates and angle bars with types attached to the base. The frame is as shown in Figure 4(a).

The connectors for the tubes for transport of the liquid round the system were welded to the tanks serving as the absorber using oxy-acetylene welding to ensure there were no leaks during operation. The precaution was necessary since pressure drop due to leaks in the system would lead to pressure drop at critical point which will lead to reduced efficiency of the system.

The generator was developed by using a 4.5kW heating band wrapped around the tank. This is for adequate heat dissipation in the generator reservoir.

The heater was connected to an AC converter to convert from 230v AC voltage to a 12v DC as it is a 12v heating band.

The condenser was connected with generator which was fixed to the base plate of the frame using a refrigeration tube and a throttle valve fixed midway of the flow medium to increase the pressure of the heated water vapour flowing through the medium to the heat exchanger serving as the condenser which converts the water vapour to liquid. With a filter dryer to remove impurities in the process fluid valve stationed at the inlet of the condenser, the steam can be converted to low very low pressure liquid which can be cooled in the condenser.

Refrigeration tube was welded to the outlet of the condenser to take the low pressure water to the evaporator which absorbs the heat in the evaporator compartment. This water low pressure water is transported back to the absorber via the refrigeration tube which was welded to the outlet of the evaporator and the inlet of the absorber.

The low pressure water brought back to the absorber for the LiBr-water solution once more is to be transported to the generator. To efficiently transport this solution a refrigeration tube was welded to the outlet of the absorber and the inlet of the generator reservoir. However, a pump is needed to move the water from the absorber to the generator. Midway of the connection was cut and was welded to the connectors of the pumps with the outlet of the absorber welded to the inlet of the pump and outlet of the pump to the inlet of the generator.

Temperature control is important in the generator to ensure the system reduces power consumption at times when optimum temperature is reached. A thermostat was connected to the generator to turn it off automatically at those times. The component set-up and finished system is shown in Figures 4(b) and (c) respectively.

To power the system, the pump and the heater was connected to circuit breakers and connected to a 13A plug.

Figure 4. (a) Fabricated frame; (b) Filter dryer, condenser, AC converter and thermostat setup; (c) System developed

2.5 Experimental set-up

The generator temperature and absorber temperature were tested using a pair of thermocouples to measure at exact times the temperature readings at both the generator and absorber. The reading of the evaporator was taken by a thermometer with probes placed on the evaporator coil. A pressure gauge was connected at the inlet of condenser just after throttle valve at which pressure of refrigerant is maximum and the outlet of the evaporator where the pressure is minimum when working to compare the vapour difference of both.

Control values for the test were obtained from values of a conventional refrigerator running on a cyclopentane refrigerant by connecting the thermometer to the evaporator compartment to obtain values for the evaporator temperature (°C). This was used to compare the cooling responses of both refrigerators. The experimental set-up is as shown in Figure 5.

Figure 5. Testing control values for conventional vapour refrigerator

3. RESULT AND DISCUSSION

Table 1 shows the condenser pressure and evaporator pressure of a liquid desiccant refrigerator over a specific time period. Several trends and patterns can be observed by analyzing the data. The condenser pressure starts at 0.0kPa and gradually increases over time. However, between time 0 and time 10 minutes, the condenser pressure rises significantly from 0.0kPa to 7.2kPa. After this initial spike, the condenser pressure continues to increase but at a slower rate. It reaches its highest value of 9.0kPa at time 70kPa and remains relatively constant at that level for the remaining duration.

In contrast, the evaporator pressure starts at 0.0kPa and shows a gradual increase over time. It remains constant at 0.0 until time 20, after which it starts to rise. From time 20minutes to time 40minutes, the evaporator pressure increases from 0.4kPa to 0.5kPa. After time 40, the evaporator pressure stabilizes at 0.5kPa and remains constant for the rest of the recorded data.

Based on these observations, it is inferred that the liquid desiccant refrigerator is operating under a certain load or heat input, as indicated by the increasing condenser pressure. The stability in the evaporator pressure suggests that the pressure in the evaporator, where the refrigerant or desiccant absorbs heat, has reached a balanced state.

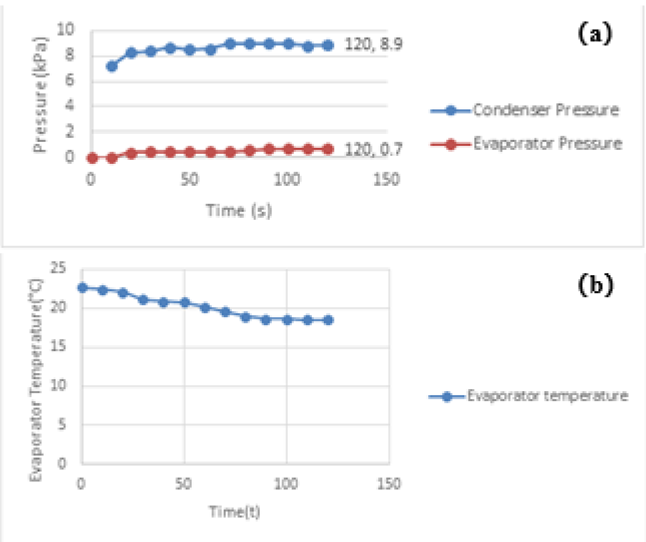

Figure 6. (a) Evaporator-condenser pressure (kPa) against time (t); (b) evaporator temperature (°C) against time (t)

Furthermore, the fact that the condenser pressure consistently remains higher than the evaporator pressure throughout the observed time period indicates the expected direction of heat flow from the evaporator to the condenser in a refrigeration cycle.

Figure 6 represents the time and evaporator temperature of a system over a specific time period. By analyzing the data, we can observe the changes in the evaporator temperature over time. Here are some key observations and analysis based on the given data:

The evaporator temperature starts at 22.7°C and gradually decreases over time. From time 0 to time 20minutes, the temperature decreases slightly from 22.7°C to 22.1°C. However, from time 30 onwards, the temperature begins to decrease at a faster rate. It reaches its lowest value of 18.5°C at time 110 minutes and remains relatively constant at that level for the remaining duration.

Based on these observations, it can be inferred that the decreasing evaporator temperature indicates that the system is effectively absorbing heat from its surroundings. As time progresses, the temperature decreases, suggesting that the system is removing thermal energy from the evaporator.

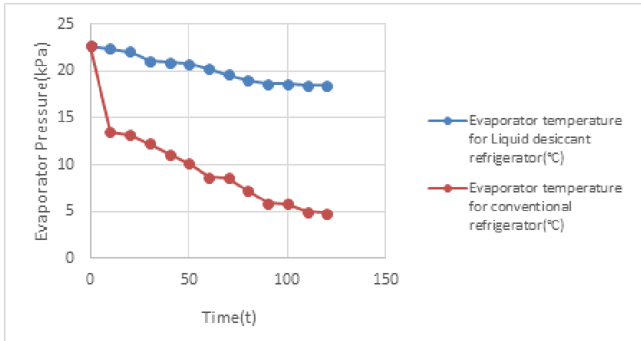

Figure 7. Evaporator temperature for both liquid desiccant and conventional refrigerator against time (t)

Figure 7 presents the evaporator temperatures of a liquid desiccant refrigerator and a conventional refrigerator over time. Analyzing the data reveals distinct differences between the two systems.

For the liquid desiccant refrigerator, the evaporator temperature starts at 22.7°C and gradually decreases over time. From time 0 to time 20, the temperature decreases by approximately 0.6°C, reaching 22.1°C. The decline becomes more pronounced from time 30 onwards, with a notable decrease of approximately 3.6°C by time 110. The evaporator temperature then stabilizes at 18.5°C for the remaining duration. This gradual decline in temperature suggests that the liquid desiccant refrigerator operates with a slower cooling rate and a more gradual temperature reduction.

Table 1. Measured values of evaporator temperature and Evaporator of conventional refrigerator

Time(t)	Evap. Temp. (°C)	Gen. Temp. (°C)	AbsorbTemp. (°C)	Cond. Press. (kPa)	Evap Press. (kPa)	Enthalpy (h_1)	Enthalpy (h_2)
0	22.7	23.1	28.3	0.0	0.0	0.0	0.0
10	22.4	63.2	32.3	7.2	0.0	25.2	0.0
20	22.1	93.2	35.7	8.3	0.4	62.9	2486.6
30	21.1	98.1	37.6	8.4	0.5	115.1	2486.6
40	20.9	98.5	38.1	8.7	0.5	115.1	2473.2
50	20.8	98.1	37.6	8.5	0.5	115.1	2473.2
60	20.2	98.2	38.0	8.6	0.5	115.1	2473.2
70	19.6	98.3	39.2	9.0	0.5	115.1	2450.2
80	19.0	98.7	40.6	9.0	0.6	115.1	2430.7
90	18.6	98.7	40.1	9.0	0.7	115.1	2430.7
100	18.6	98.8	40.9	9.0	0.7	115.1	2430.7
110	18.5	98.8	40.8	8.8	0.7	115.1	2430.7
120	18.5	98.8	40.9	8.9	0.7	115.1	2430.7

In contrast, the conventional refrigerator exhibits a different pattern. The evaporator temperature also starts at 22.7℃ but decreases at a significantly faster rate compared to the liquid desiccant refrigerator. From time 0 to time 20, the temperature decreases by approximately 9.2℃, reaching 13.5℃. The temperature continues to gradually decrease and reaches 4.8℃ by time 120. This faster cooling rate and larger temperature drop indicate a more efficient and rapid cooling process in the conventional refrigerator.

The disparities in evaporator temperature between the two systems can be attributed to their different operating principles and efficiency levels. The liquid desiccant refrigerator likely utilizes a desiccant material to absorb moisture and enhance the cooling process, resulting in a slower temperature reduction. Conversely, the conventional refrigerator follows traditional refrigeration cycles, allowing for faster cooling rates.

6. CONCLUSIONS

In conclusion, the analysis of the evaporator temperatures for a liquid desiccant refrigerator and a conventional refrigerator provides valuable insights into their respective cooling performances. The liquid desiccant refrigerator exhibits a slower cooling rate and a more gradual decrease in evaporator temperature compared to the conventional refrigerator. This suggests that the liquid desiccant refrigerator operates with a different mechanism, likely utilizing desiccant materials to enhance the cooling process.

The findings from this research highlight the potential benefits of the liquid desiccant refrigeration technology, such as improved moisture control and potentially higher energy efficiency. The slower temperature reduction observed in the liquid desiccant refrigerator indicates a more balanced and controlled cooling process, which may be advantageous for certain applications where precise temperature regulation and humidity control are crucial.

On the other hand, the conventional refrigerator demonstrates a faster cooling rate and achieves lower evaporator temperatures. This aligns with the well-established principles of traditional refrigeration systems that are widely used in various settings. The conventional refrigerator's efficiency in rapidly achieving lower temperatures may be advantageous in scenarios where quick cooling is required.

Overall, this research sheds light on the different characteristics and performance of liquid desiccant refrigerators compared to conventional refrigerators. The findings provide valuable insights for further exploring and optimizing liquid desiccant refrigeration technology, potentially opening up new possibilities for energy-efficient cooling and humidity control applications.

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