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The study of operating an air conditioning system using Maisotsenko-Cycle

Mohammad S.Khan*, Sami Tahan*, Mohamad Toufic El-Achkar* and Saleh Abou Jamus*

Abu Dhabi University, Abu Dhabi, United Arab Emirates

*E-mail: 1047548@students.adu.ac.ae

Abstract: The project aims to design and build an air conditioning system that runs on the Maisotsenko cycle. The system is required to condition and cool down ambient air for a small residential space with the reduction in the use of electricity and eliminating the use of commercial refrigerants. This project can operate at its optimum performance in remote areas like oil diggers and other projects that run in the desert or any site that would not have a very high relative humidity level. The Maisotsenko cycle is known as the thermodynamic concept that captures energy from the air by using the psychometric renewable energy available in the latent heat in water evaporating in air. The heat and mass exchanger design was based on choosing a material that would be water resistant and breathable, which was found to be layers of cardboard placed on top of each other and thus creating channels for air to pass through. Aiming for this design eliminates any high power electrical equipment such as compressors, condensers and evaporators that would be used in an AC system with the exception of a 600 W blower and a 10 W fan, thus making it a more environmentally friendly project. Moreover, the project is limited by the ambient temperature and humidity, as the model operates at an optimum when the relative humidity is lower.

1. Introduction

Air conditioners have become a necessity in any household to artificially create and maintain an indoor environment by ventilation, cooling and heating to meet criteria that ASHRAE standards state are within the comfortable ranges. With today's world being focused on preserving energy and making use of wasted energy within a system, renewable energy is considered to be an integral part of any project. Recent studies and researches by Professor Maisotsenko have found an effective and environmentally friendly cycle named as the M-Cycle, which has been used in applications in recent years such as cooling towers, combustion devices and air conditioner [1].

This project aims to design an air conditioning system that uses the M-Cycle in order to cool down and dehumidify ambient air to acceptable standards, with the minimal amount of energy consumption and being environmentally friendly [1-2].

1.1. Impact of the project on the environment

With newer standards looking to completely eliminate all refrigerants including HFCs, this project is independent and is no need of a refrigerant thus eliminating this issue.

As a result, this will reduce the demand for electricity significantly, thus reducing the energy consumed and the amounts of air pollutants and power plants pollution. It can be achieved in terms of



using less energy for electrical components that are used in typical AC systems, heat rejection and the use of unwanted refrigerants [3].

The materials used in the project are all recyclable which gives the advantage for the project when it wears out to be recycled and reused again in the same application or another rather than piling up on the landfills.

1.2. Maisotsenko Cycle and Refrigeration Cycle

Table 1 [4] shows the differences between using an air conditioning system that uses the typical refrigeration cycle against an air conditioning system that operates on a Maisotsenko cycle.

Table 1. Refrigeration cycle and M-Cycle.

Cycles	Advantages	Disadvantages
Refrigeration Cycle	• The refrigerant used is cheap, available and easily. • It is a reversible cycle, in order to turn it to heating. • Low maintenance cost. • Low pressure drops.	• Danger of frosting at the valves • The quantity of refrigerant used per ton of refrigeration is high
Maisotsenko Cycle	• Environmentally friendly cycle with minimal heat rejection.	• Works at lower efficiency when the humidity is higher. • The system cannot be used to cool down a larger residential area.

1.3. Project Objectives

This project aims to reach the following objectives:

- Designing an AC system with low power consumption compared to a vapor compression cycle.
- Designing an AC system with low heat rejection. Designing an AC system which is environmentally friendly.
- Designing an AC system that can meet the standards to provide comfortable conditions in the space.
- Decreasing the maintenance cost as compared to a typical AC system.
- Using the knowledge gained over the past four years and the courses taken during the undergraduate mechanical engineering curriculum [5].

1.4. Outcomes and deliverables

Throughout performing this project, the design process and prototype made, give an expectation of the outcomes that are required for this project:

- Reaching the maximum relative humidity 90-95% for the primary air flow after exiting the heat and mass exchanger.
- Having a comparison between the simulation and prototype results, and attaining the lowest possible percentage error.
- Achieving a temperature drop from the primary air flow inlet to the primary air flow outlet.

2. Literature Review

2.1. Basics of M-cycle

Energy cycles productivity is measured through their efficiency. Dating back to 2003, combined power cycles on average show efficiency of 50%. However, with the introduction and use of the Maisotsenko cycle has increased the efficiency by a further 10%. The cycle operates through 4 main steps where the water and working air enter the heat and mass exchanger [5].

The water that acts as the working fluid is fractioned off into wet channels in the heat and mass exchanger. The heat is then transferred to the air by evaporation and is rejected. This results in the product fluid exiting with low relative humidity [6].

2.2. Applying M-Cycle to Air Conditioning systems

With air conditioning being a huge necessity for any industry or residential building, a lower energy consumption and more environmentally friendly approach is needed to be taken as electricity plays a huge role in air conditioning for the use of compressors and so forth [6].

The use of indirect evaporative cooling which refers to the Maisotsenko cycle approach can eliminate the fact of increasing the humidity when lowering the air temperature whilst also avoiding any potential health problems due to contaminated droplets that enter into the cooled space [6-7].

2.3. Heat and Mass Exchanger

The main component that allows the Maisotsenko cycle to run with such efficiency is the heat and mass exchanger (HMX). This type of exchanger is formed through several sheets of material known as rigid pad. This material is water resistant and breathable. Several evenly spread pathways made throughout the dry air flow are made, which gradually divert air from the dry channels to the wet channels with an even velocity distribution [7].

Whilst articles and journals have reviewed and focused on heat and mass exchangers, they do not go into the design and set up of the heat and mass exchanger but rather explain how they operate and what it can achieve when being used. This can give a general idea of what a heat and mass exchanger is and how the components of the heat and mass exchanger come together to carry out its objective.

This project aims to further understand and design a heat and mass exchanger by implementing parameters needed to operate it so that it can be practically made in order to use for a Maisotsenko cycle for an air conditioning system. The choice of this material came from experimental work yet the best results were found after trying the cardboard which roughly shows an efficiency of 75-95% [8].

2.4. Mathematical Modelling

2.4.1 for the air stream in the dry channel (secondary air)

Mass balance equation

$$\dot{m}_w = \dot{m}_d + \dot{m}_{w.v} = \dot{m}_d + \dot{m}_d(w) = \dot{m}_d(1 + w) \quad (1)$$

$$\dot{m}_d = \dot{m}_D \quad (2)$$

$$w_{in} = w_{out} \quad (3)$$

Energy balance equation

The energy conservation balance considering only sensible heat transfer on the plate surface is given as:

@ Inlet:

$$h_1 = T_{in} + (w_1 * 2501.3) + (1.86 * T_{in}) \quad (4)$$

@ Outlet:

$$h_2 = T_{out} + (w_2 * 2501.3) + (1.86 * T_{out}) \quad (5)$$

Q Lost:

$$Q_{lost} = \dot{m}_D \Delta h = \dot{m}_D (h_2 - h_1) \quad (6)$$

2.4.2 for the air stream in the wet channel (primary air)

Mass Balance Equation

The mass conservation balance for the water vapor inside the wet channel:

@ Bottom channel

$$\dot{m}_w = X\dot{m}_w + (1 - X)\dot{m}_w \quad (7)$$

@ Upper channel:

$$m(1 - nX) + Xm = m(1 - X(n - 1)) \quad (8)$$

where:

X : Represents the fragment of the air that travels through the material to the upper channel.

n : Represents the number of needed sections in one channel

Energy balance equation

@ Inlet:

$$t_1 = t_{in} \quad \text{and} \quad w_1 = w_{in} \quad (9)$$

$$h_1 = 0.24T_1 + (w_1) * (1061.2 + 0.444T_1) + (1.86 * T_{in}) \quad [9] \quad (10)$$

where:

$$h_x = h_1 \quad (11)$$

@ Outlet:

$$m_w(1 - nX)(h_1) + (m_wX)(h_1) + m_vh_w = m_w(1 - X(n - 1))h_2 \quad (12)$$

2.4.3 Heat Exchanger

$$Q = \frac{T_1 - T_2}{\Sigma R} \quad (13)$$

3. Prototype

Several iterations and designs are made until the final design in terms of material and the geometry of the model itself. Building the prototype consists of building a heat and mass exchanger with a material that fits the specifications of being breathable and water resistant. This heat and mass exchanger is placed within a box made of a thermally insulating material and therefore having minimal heat rejection. A heat exchanger is placed on the top of the box to allow heat exchange between the primary and secondary air streams. The aim of this process is to lower the dry bulb temperature.

3.1. Material Selection

The material selection process mainly requires finding a material fitting the specifications of being breathable and water resistant in order to fulfill the requirements needed for an indirect evaporative cooling process. Materials such as polypropylene and fiber mesh were tested.

In the last iteration, the decision was reached to use a heat and mass exchanger made out of a material named rigid pad which had properties that matched the specifications that were set. Several layers were placed on top of each other with curvatures creating numerous channels for the primary air to pass through them. The channels are made in several opposing directions and hence giving a greater area for the air to disperse in.

3.2. Prototype Setup

The heat and mass exchanger used is of certain dimensions $0.45 \times 0.08 \times 0.13$ in meters, a distance of 0.05m is left between the heat and mass exchanger and the acrylic glass box, in order to have the remaining air flow pass over it and collect the air that has been cooled down and humidified. With a fiber mesh material attached at the bottom of the heat and mass exchanger in order to hold any excess water that would otherwise drip onto the bottom of the acrylic housing.

With the heat and mass exchanger being setup as explained, the rest of the prototype design can be completed. The assembly will show that within the acrylic glass box, a plastic tube will be placed on top of the heat and mass exchanger where it will be fed with water and will act as a sprinkler.

The second part of the prototype consists of a simple heat exchanger, where the primary air flow that has passed through the heat and mass exchanger will exchange heat with a secondary air flow that is simply ambient air which would be passed in a pipe above it, as they would be separated by an aluminum sheet. This setup is displayed in figure 1.

4. Results and Discussion

4.1. Simulation Results

After running the C++ code and EES program, the results obtained for the temperatures in graph as shown in figure 2. Where at 15% humidity level the temperature has dropped from 27.0°C to 15.2°C. Whilst under high humidity levels such as 80% the drop decreases to about a difference of 1.9°C. The results show what was expected and that is that the optimum performance for this design is when the humidity is at the minimal and the ambient temperature is at a maximum, this showed a temperature drop of 18.2°C.

These results have proved that using the water as the working fluid have affected the temperature drop that may not be similar to that of using typical refrigerants such as R134-a but are still within what is considered to be satisfying results. Moreover, the advantage to using the water over a refrigerant is the ease of availability and being more environmentally friendly.

Figure 2 shows 4 different curves for the simulation results at different humidity levels. This proves the analysis made before running the simulation that under higher humidity levels the temperature drop will decrease and not reach comfortable levels. This is due to the fact that the primary air inlet has a higher relative humidity when entering into the heat and mass exchanger and thus has a less of a capacity to absorb moisture and cool down.

Figure 3 and figure 4 shows the simulation result with different flow rate and cross section area respectively. As shown in figure 3 the drop in temperature increases when the flow rate increased because as the flow rate increase there will be more air molecules which can evaporate more water causes the air to be colder.

Where figure 4 shows that as the cross section increases the drop in temperature increases too because the heat transfer in function of the surface area which means as the cross section area increases there will be more heat transfer causes the air to be colder.

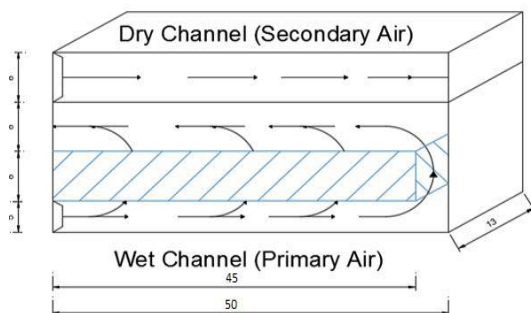


Figure 1. Prototype setup.

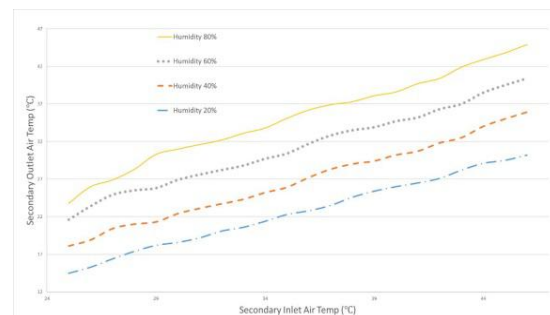


Figure 2. Simulation Results with different relevant humidity.

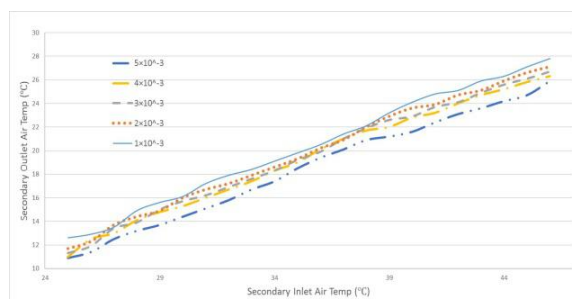


Figure 3. Simulation result with different flow rate.

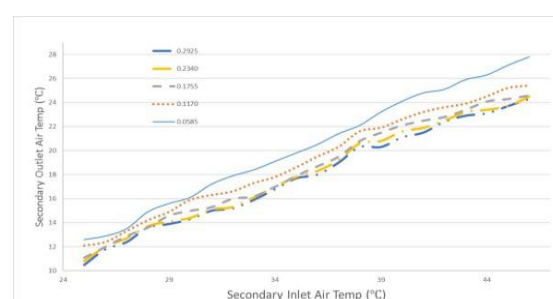


Figure 4. Simulation results with different cross section area.

4.2. Prototype Results

Figure 5 the difference noticed is caused by a major factor other than how many loops the air went through in the heat and mass exchanger which is the humidity level of the primary air. The more humid the air is, the less cool air provided from the secondary air stream. The rises and falls are caused by the difference in the humidity levels of the air provided, where at the low humidity it is noticed that the secondary air is cooler.

After the results had been obtained, figure 6 shows the experimental results with those found through the simulation. The graph shows similar results with the maximum difference around 1°C at the 25°C. Percentage error was calculated for the entire values and showed an average of 5.1%. The difference found between the simulation and prototype results are due to the reasons that the primary inlet air flowing into the heat and mass exchanger had not completely passed through it and some of it had leaked from either side of the housing as fixing the heat and mass exchanger was not completely secured.

Another reason that could've shown this error is that the housing used for the model does not have perfect insulation and will have heat escaping. With the values being obtained from the simulation and experiments, the coefficient of performance can be found to be according to these calculations as:

$$\frac{\text{Cooling load}}{W_{in}} = \frac{6307.2 \text{ W}}{600 \text{ W}} = 10.512$$

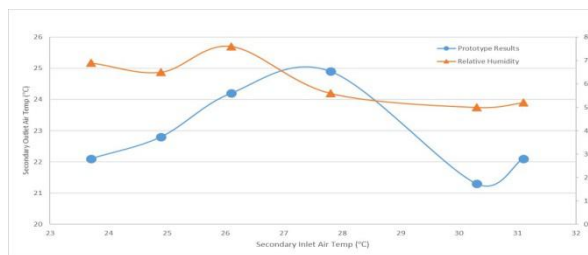


Figure 5. Prototype results.

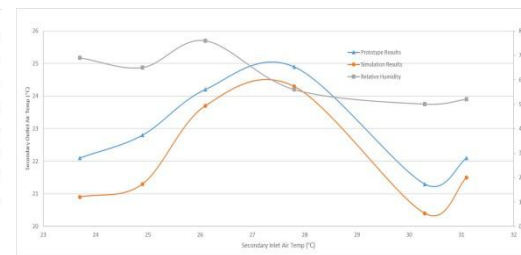


Figure 6. Prototype vs simulation.

5. Future Developments

Due to some of the restrictions that were faced throughout this project such as the budget and timing limitations, not all ideas and objectives could be completed for the project. Therefore, some of the future developments that can be included for the project are as follows:

As the design currently runs on a minimal electrical energy, it is possible to run the system on completely green energy and be independent of electricity. This can be done by powering the blower and fan with solar panels.

The current model designed can only output a certain temperature as according to the tabulated results, which gives a limitation to the output temperature and cannot be set by the user as desired. This can be improved by having the consumer choose the desired temperature within the available values. This can be done by means of controlling the mass flow rate of the primary air flow. The setup for this development is done by adding an electronic damper at the tip of the blower.

As the humidity was one of the limitations of the system which would limit the temperature drop that would occur for the secondary air, integrated liquid desiccant can be utilized. This cycle can be placed before the primary air inlet in order to decrease the humidity of the outside air, considering humidity levels are relatively high in the Middle East region. As the humidity drops this allows for a more efficient cycle.

6. Conclusion

The main objective of this project was to design an air conditioning system that would have a minimal electrical energy consumption and for it to be environmentally friendly. This would mean designing a

system that would be independent of the common electrical components in a typical air conditioning unit including a compressor, evaporator and condenser.

Such a design relieves the user of much of the maintenance issues due to lack of electrical components. Moreover, the absence of a compressor would eliminate the use of a refrigerant and thus making the system more environmentally friendly.

To conclude, running the prototype and displaying the results showed that the main objective of using a green and lower power consumption air conditioning design operated on a Maisotsenko cycle was achieved by reaching a cooling load of 2.0 TR under optimum conditions. However, due to the system being a function of relative humidity which is an uncontrollable variable under simulation results but only reached 1.87 TR due to the weather conditions under the prototype run. Achieving this was in terms of, increasing the humidity and dropping the temperature of the primary air stream, in order to heat exchange with the secondary air stream.

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