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A Review on Potential of Maisotsenko Cycle in Energy Saving Applications Using Evaporative Cooling

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***Abstract*—This paper reviews the underutilized applications that the Maisotsenko Cycle could have. The constraints set by the conventional vapor compression system are overcome by the use of Maisotsenko Cycle. Direct evaporative cooling is associated with the increased humidity though it gives a fair drop in temperature. On the other hand, humidity is controlled by the indirect evaporative cooling but the temperature drop is not sufficient. Both the systems are coupled in Maisotsenko cycle to form a new system. Opportunities for energy saving will be provided if this newly formed system is utilized properly. After reviewing the various literature in the field of evaporative cooling, scope of Maisotsenko cycle in energy saving applications is discussed. Tendency of conventional refrigerants to create pollution is vomited as the said system uses water as a cooling agent. For ensuring the better performance, use of different cooling pad materials is also suggested. Systems using Maisotsenko Cycle find a multi-climate application like dry and humid. Therefore a multi-climate country like India can be benefitted if the systems proposed in this paper can find certain practical applications.**

***Key Words*— Maisotsenko Cycle, Evaporative Cooling, Cooling pad material, Dew point cooling, Desiccants.**

I. Introduction

If India's energy and environmental scenario is concerned, there is a pressing need of energy conservation and environment preservation. The conventional evaporative cooling system (e.g. water cooler) is used for the cooling purposes in the dry and hot regions. This type of system gives the sufficient cooling, but the increased humidity of the air gives the feeling of discomfort. The other way to overcome the problem of increased humidity is use of indirect evaporative cooling system. This system though handles the humidity properly, but the cooling obtained with the said system is less. On the other hand, vapour compression refrigeration systems consume more electricity and some of the systems carry the potential to pollute the environment. Also cost of such systems is on the higher side. In this context, a new system which uses the advantageous aspect of both the evaporative cooling system and minimises the drawbacks has been put forward by Valeriy Maisotsenko. He developed a new thermodynamic cycle known as “Maisotsenko Cycle”. It is also called as the “M-cycle” which uses the simple cross flow heat exchanger and indirect evaporative coolers, but with a much different airflow [1].

In indirect evaporative air cooling, the exchanger does not allow the moisture to be added into product air stream. It is expected that air should reach the dew point temperature after its cooling without addition of moisture. But practically effectiveness of such coolers is approximately 54%. Thermodynamically an indirect evaporative air cooler passes the primary air (which will be the product air at outlet) on the dry side of the plate. The other side of plate is wet, which absorbs the heat from the dry side by evaporation of water. Thus, the dry side is cooled while wet side is added with latent heat of vaporization. This cycle allows any liquid or vapour to be cooled below the wet bulb and towards the dew point temperature for getting maximum cooling of incoming air. The cooling effect which is obtained by using the M-cycle finds the various applications. Some of them are direct while some are indirect. In a country like India, M-cycle may prove a very handy tool to conserve and save the energy. This paper reviews the various possible applications of M-cycle aiming at the energy conservation and environment preservation [2].

II. What is Maisotsenko Cycle…?

A simple concept of an evaporative cooling has been utilized by Maisotsenko Cycle (also called M-cycle). A wet channel and a dry channel are used to get the desired effect. Water is treated as cooling fluid. Water stream is sent through the wet channel where it gets evaporated giving out the cooling effect. But here owing to the evaporation, humidity is added into the air which is about to be introduced as a product air. Such air prohibits the attainment of the comfortable living condition as the increased humidity causes the feeling of dump and suffocation. In this process of M-cycle at wet channel, the energy in the air does not change. Warm dry air is changed to cool moist air. Heat in the air is used to evaporate water; no heat is added or removed making it an adiabatic process (Fan heat gain or pump energy is ignored in this evaluation.) This also assumes the water entering the system is to be evaporated at the wet bulb temperature of the entering air, and that there is no excess water. Therefore the water has a negligible effect on the adiabatic process. The enthalpy of the system does not change [2]

$h_{in} = h_{out}$

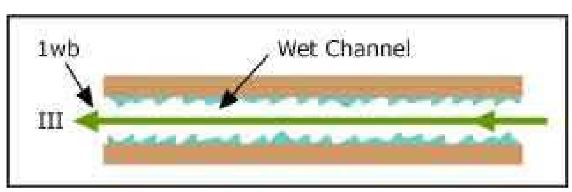

Fig 1: Cross section showing direct evaporative cooling

After getting processed in wet channel, thermodynamically indirect evaporative air cooler passes primary or product air over the dry side of a plate and secondary or working air over the opposite wet side of a plate. The wet side absorbs heat from the dry side by evaporating water and therefore cooling the dry side with the latent heat of vaporizing water into the air. The ideal and real conditions for indirect evaporative cooling are represented in Figure 2. The air with temperature t1 on the dry side of the plate travels in counter flow to the air on the wet side. Ideally the product air temperature on the dry side of the plate could reach the wet bulb temperature.

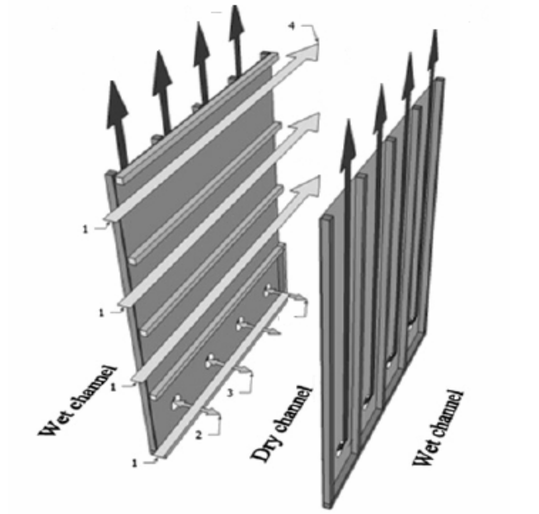

Fig 2: Wet and Dry Channels of M-Cycle Cross Flow Heat Exchanger

Theoretically, the working air on the wet side of the plate would increase in temperature from its incoming air wet bulb temperature to the incoming product air-dry bulb temperature and be saturated. Of course this would require a balancing of the product and working airflow rates with infinite amount of surface area and pure counter flow. Figure 2 shows the schematic of wet and dry channels [2].

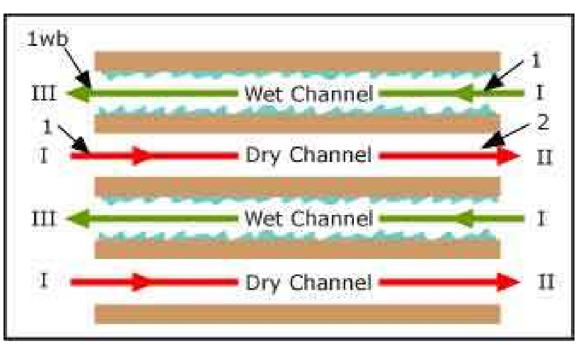

Fig 3: Cross section showing indirect evaporative cooling

III. Analysis of M-Cycle

For analyzing the M-cycle, some assumptions were made as follows:

1. Heat transfer and mass transfer processes take place in steady state conditions.
2. The model fabricated has an enclosure which is assumed to the system boundary.
3. Wet surface is completely saturated and the water vapor is uniformly distributed uniformly along the wet channel.
4. Temperature gradient of channel cross section is set to zero. Cross flow heat exchange process is assumed to be the best mode for heat transfer.
5. Temperature across the wall surface is uniform. The temperature difference between the wet and dry side is ignored.
6. Air is considered to be an incompressible fluid.
7. Principles of mass and energy conservation are employed for the analysis of the system [4].

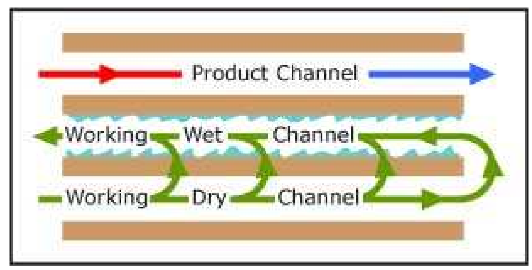

Fig 4: Working of M-cycle

The performance of M-cycle is elaborated using the concept "wet bulb effectiveness" (ϵ_{wb}). The wet bulb effectiveness is the ratio of temperature depression of the device to the wet bulb depression of the system where M-cycle is to utilized. It is given as:

$$\epsilon_{wb} = \frac{Ti - To}{Ti - Twb,i} \tag{1}$$

In above equation, T_i is the temperature of the inlet air, T_o the temperature of the outlet air whereas $T_{wb,i}$ is the wet bulb temperature of the inlet air. The value of the wet bulb effectiveness can be greater than unity. From this it can be said that using M-cycle air can be cooled below wet bulb temperature. While doing the same, very less (negligible) or no humidity is added to the air.

M-cycle can reach the temperature below wet bulb temperature which may sometime reach the dew point temperature. Its performance then may be judged by using the dew point effectiveness (ϵ_{dp}). It is expressed as

$$\epsilon_{dp} = \frac{Ti - To}{Ti - Tdp,i} \tag{2}$$

Where, T_{dp} is the dew point temperature of air.

If m_o is the mass flow rate of outlet air, and h_i and h_o are the respective enthalpies of air at inlet and outlet, the cooling effect for air obtained in M-cycle can be found by using the following equation

$$Q_{cool} = m_o (h_i - h_o) \tag{3}$$

If air is circulated using a fan or a blower, it requires some power to be driven (W_p), then for a cooling effect Q_{cool} obtained, coefficient of performance for Maisotsenko Cycle is calculated as

$$COP = Q_{cool} / W_p \quad (4)$$

Performance of the ordinary heat exchanger can be compared with M-cycle operated systems which will give the better results for the same energy input. On the other hand it can be said that M-cycle operated devices will consume the less amount of energy for producing the same results by ordinary heat exchangers.

IV. Overview of Applications of M-Cycle and Evaporative Cooling

Leland Gillan, a senior R&D engineer at Idalex, claims that the M-cycle could achieve efficiencies as high as 60% while simultaneously lowering emissions for humid air turbines. Gillan also claims that the M-cycle can be scaled to work with any size turbine, from micro to large, and that it would not suffer from the drops in efficiency that conventional gas turbines suffer at partial loads. Rather, he states, “the ability to add moisture using waste heat allows the Maisotsenko cycle to run at high efficiency at any load from 50% to 100%”. The M-Cycle claims that it can overcome the practical limitations of the “humid air turbine”. The main practical limitation of the Humid Air Turbine cycle is its humidification process. It uses a column saturator that ties evaporation to the boiling temperature of water at compressed air pressure. Raising humidity past this point would require a separate boiler—another piece of equipment whose cost, maintenance, and pressure and temperature losses are significant drawbacks.

According to researchers at Idalex, the M-cycle lacks those drawbacks because in it, humidity gains are limited only by the amount of waste heat available from the turbine’s exhaust gas [3].

The M-cycle also proposes the new system namely “Maisotsenko Combustion Turbine Cycle”. This system receives the hot, dry, compressed air and cools it toward its dew point temperature without adding humidity. This cool air extracts heat from the turbine’s exhaust gases, bringing them to a lower temperature at which even more heat can be extracted. The cooled air is split into two streams. The first stream cools itself by being passed in counter flow to the air being cooled and by adding moisture to it through an indirect evaporative heat and mass transfer process. The second stream is then passed in counter flow to the turbine exhaust gas stream while evaporating water into the air again in an indirect evaporative heat and mass exchanger. The two high humidity air streams are then recombined and sent to the combustor for heating before entering the turbine. By using the M-cycle, moisture in the compressed air stream is increased. This helps to increase the power and efficiency of the plant. Also M-cycle reduces the size of the heat transfer surface pressure losses, and capital cost by using a souped-up heat transfer process. Meanwhile, a Maisotsenko cycle air cooler can be used to increase compressor efficiency by supplying the compressor with cool air that has not had humidity added to it. This cooler air is easier to compress, which means less work for the compressor [3].

Numerical study of a M-cycle cross-flow heat exchanger for indirect evaporative cooling conducted by Changhong Zhan, et. al. concludes that the effectiveness of a cross-flow heat exchanger goes up by 16.7% if it is operated by using M-cycle for indirect evaporative cooler[4].

Cooling tower consumes high energy. Typical cooling tower utilizes the direct evaporative cooling mechanism. The temperature of water after cooling is reached up to the outside air wet bulb temperature. If M-cycle together with the indirect evaporative cooling is used for operating the cooling tower, “Gas Technology Institute” of USA claims that if the cooling towers are operated using the Maisotsenko Cycle, water can be cooled to the dew point temperature. The fan power can also be reduced so that the performance of the cooling tower can be enhanced considerably. This suggested design of cooling tower to be operated with the use of M-cycle has been patented in U.S.A. (Patent No. 6854278 and 6497107). M-cycle can be incorporated to design closed circuit and open circuit cooling tower. [5].

An experimental study on the performance of two stage system of nocturnal and indirect evaporative cooling carried in Teheran has shown that indirect evaporative cooling is capable of producing the comfort conditions. And if such systems are coupled with some models of hybrid systems, then the effectiveness of the cooling increases considerably. Such systems may be considered as the renewable source of energy. These energy efficient, eco-friendly cooling systems can be utilized as replacements for the conventional mechanical refrigeration systems which use vapor compression consuming high energy [8].

In some regions of Iran, evaporative cooling systems cannot provide comfort condition during hot season. For cities where comfort condition cannot be obtained using these systems, IEC units can be utilized in recovery cycle (secondary flow from indoor air) or regeneration cycle (secondary flow is a fraction of IEC outlet air) to achieve lower temperatures. In addition, IEC system can be used as a pre-cooling unit before mechanical cooling systems in climates with higher wet bulb temperature forming a hybrid evaporative/mechanical cooling system. In this case, the energy consumed by IEC stage is much less than the energy saved from reducing the load on refrigeration system. As a result, the overall energy consumption of the system will reduce. Another saving could result from the reduction in size of the refrigeration equipment required. IEC system may also reduce the total operational time of refrigeration equipment during a year [9].

B. Riangvilaikul and S. Kumar carried the experiments to investigate the effect of an indirect evaporative cooling in which they used the concept of dew point cooling. The working principle of their study resemble with that of Maisotsenko cycle. Dew point evaporative cooling is utilized to deliver the good performance of a heat exchange mechanism in various operating conditions. The dew point cooling can alone be deployed to attain the comfort condition for living

V. Why Maisotsenko Cycle…?

A fresh air is the only available healthy air as it is not contaminated with certain hazardous impurities. Refrigerated air conditioning works by recycling the same air over and over and progressively reduces its temperature. The space which is to be air-conditioned requires being a sealed system for recirculation. The air becomes stale and it can be carried from one place to another. The Maisotsenko Cycle air conditioning constantly delivers fresh, cool air into the room. There is no recycling or recirculation of stale. Also, there is no need to shut the windows and doors or to restrict people movements to trap air. It can be suitable for indoor and outdoor lifestyle. And because it does not add or remove the moisture, Maisotsenko Cycle air conditioning can deliver a chilly cold, in some cases achieving temperatures colder than the theoretical enthalpy limit for a given ambient humidity.

The Maisotsenko Cycle does not use a compressor. It uses fan-driven evaporation to remove heat energy, transferring the temperature drop via a patented Heat and Mass Exchange (HMX) unit to the room air. The room air is never in contact with the evaporation process or with water, so (unlike with evaporative air conditioning) its natural moisture content is not changed. Without a compressor, Maisotsenko uses up to 80% less electricity to run. It's cost effective for householders to run all day, gradually cooling the entire thermal mass of their home, creating a more stable, comfortable temperature that requires less cooling energy to maintain. This is the home air conditioning that even pensioners can afford to run.

One of the applications of evaporative cooling has been observed in Malaysian building. Its exergy analysis concludes that evaporative cooling is the feasible technology which can reduce the mechanical cooling. Also it can cut off the energy requirement for air conditioning applications simultaneously reducing the emissions which are hazardous for global environment [7].

The M-cycle may become a popular choice for cooling applications. As it is based on the evaporative cooling, it has following four reasons for which it prominently claims that it is worth implementing. The reasons are as follows:

Reason 1: Energy efficient

The first reason indirect-direct evaporative cooling should be considered is because research shows it can be more energy efficient, for instance, than standard packaged air-conditioning. Many power companies — and this include SRP, Pacific Gas & Electric (PG&E), Pacific Power, Southern California Edison, and PNM — are offering incentives to businesses that implement this effective method of cooling.

Reason 2: CFC-free cooling

A second significant benefit is that these systems are free from environmentally damaging products. The indirect-direct method produces desirable temperatures by taking advantage of the cooling properties of water. Because these systems rely on water, they leave a significantly smaller carbon footprint and therefore offer a sustainable method of cooling. Pictured is an indirect-direct evaporative cooling system. This particular system, from United Metal Products, is providing cooling to a large grocery distribution centre in Phoenix, Ariz.

Reason 3: Water savings

The indirect-direct systems use a significantly less amount of water to provide cooling. This may not seem like the case at first glance. However, when the additional electricity needed for standard packaged air conditioning systems is considered, an indirect-direct system can use approximately 50 per cent less water. This is because power companies primarily rely on large cooling towers and reservoir water to produce electricity.

Reason 4: Competitive initial cost

An indirect-direct evaporative cooling system has a very competitive initial cost. This means that the savings that an indirect-direct system provides — by cutting the operation cost (sometimes in half) and decreasing maintenance costs — leads to real long-term savings at no additional initial cost.[13]

Thus, evaporative cooling proves to be a fairly useful tool in refrigeration and air conditioning. It has several advantages and fewer disadvantages, which make it suitable for being utilized in many cooling applications.

These various factors make the Maisotsenko Cycle a very useful and effective tool to be utilized as a cooling system or cooling enhancement device along with some of the equipments which are used in practice. Less power, no pollution, fresh air all time, low cost, etc. are the advantages of the M-cycle which need to be considered as far as today’s severe scenario of energy and pollution is concerned.

VI. Maisotsenko Cycle and India

India is the country which is a diverse in all respect. Climate, culture, availability of natural resources, population density, energy consumption, etc. are the factors available with different proportions across the Indian terrain. Kashmir is cold and dry. Kerala and Tamil Nadu are hot and humid. Rajasthan is characterized by a very hot and dry climate. In order to maintain the comfort living conditions, we require an air conditioning system. Up till now, we have been using the conventional vapor compression refrigeration system. The problems associated with the same have already been discussed earlier in this paper.

India’s energy demands are expected to be more than double by 2030, and there is a pressing need to develop ways to conserve energy for future generations. Thus energy consumption can be reduced drastically by using energy efficient appliances. In India, the Union ministry of power's research pointed out that about 20-25% of the total electricity utilized in government buildings in India is wasted due to unproductive design, resulting in an annual energy related financial loss of about Rs 1.5 billion. Conventional heating ventilation and air conditioning systems (HVAC) consume approximately 50% of the building energy. This type of air conditioning is therefore neither eco- friendly nor sustainable. Selection of proper air conditioning system for buildings can not only help the country save electrical energy but also reduce greenhouse emissions.

In the summer months of April, May and June, the evaporative cooling has a great potential for indoor cooling in Delhi's climate which is hot and reasonably dry. In the literature, there are a few studies which deal with the simulation of evaporative cooled building in Delhi. Kant examined the possibility of space conditioning of a multi-storeyed office building in Delhi using evaporative cooling in summer months of April, May and June. The effect of number of air change per hour (ACH) and fresh air bypass factor (BPF) was studied by simulation. Kant computed diurnal hourly values of temperature and humidity in a room having a direct evaporative cooler. They compared their simulation data with and without the roof exposed to the solar radiation during the summer months of Delhi. They observed that the room conditions were affected much more with the changes of ACH as compared to the roof exposure. [11]

The principle of Maisotsenko Cycle which can be utilized in variety of energy saving applications in India is that it maintains the humidity level of an incoming air. So this specialty of M-cycle gives us a way to introduce this technology in certain applications which are associated with the problem of higher humidity. Raised humidity during the progress of a particular application finds to be troublesome in case of life of a product, efficiency of the product, considerable savings in electricity, etc.

V. Maisotsenko Cycle for Energy Saving Applications

As discussed earlier, M-cycle has a huge potential to save energy in various ways. In some applications, it contributes directly. Coolerado Cooler is the best available example. The Coolerado Cooler evaporates water in a secondary (or working) airstream, which is discharged in multiple stages. No water or humidity is added to the primary (or product) airstream in the process. This approach takes advantage of the thermodynamic properties of air, and it applies both direct and indirect cooling technologies in an innovative cooling system that is drier than direct evaporative cooling and cooler than indirect cooling. The technology also uses much less energy than conventional vapor compression air-conditioning systems and therefore can be a cost- and energy-saving technology for many Federal facilities in the United States. As the M-cycle has successfully demonstrated its potential in U.S.A., the parallel system has a fair scope of being developed in India as well.

Performance tests have shown that the efficiency of the Coolerado Cooler is 1.5 to 4 times higher than that of conventional vapor compression cooling systems, while it provides the same amount of cooling. It is suitable for climates having low to average humidity, as is the case in much of the western half of the United States. This technology can also be used to precool air in conventional heating, ventilating, and air-conditioning systems in more humid climates because it can lower incoming air temperatures without adding moisture [12].

In India, M-cycle can be used to alter certain available systems where it finds an indirect application. In a conventional vapor compression based Air Conditioning system, condenser exchanges heat to liquefy the vapor refrigerant. For that, a fan stays in operation for causing the air flow at faster rate. The objective of doing the same is to increase the heat transfer rate. It can also be increased if the temperature of air is lowered down so that heat exchange rate increases. This results in higher efficiency, less compressor work, more evaporation, more cooling effect. Its ultimate effect is reduced energy consumption. In order to achieve the less temperature air at condenser, M-cycle heat exchanger can be incorporated between the fan and the condenser so that air flowing over condenser coils will be cooler with same inlet and outlet humidity.

Another application that an M-cycle can have is its direct use in an indirect evaporative air conditioning. This system consists of series of alternate wet and dry channels. In wet channel, cooling is achieved and this cooling effect is then transferred to the dry channel. Through the dry channel, product air flows from where it receives this cooling effect with no addition in humidity. Depending upon the temperature drop required and volume to be air conditioned, the size and number of wet and dry channels are decided.

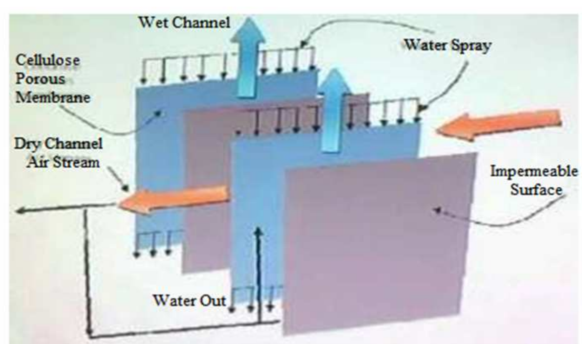

Fig 5: Cellulose porous stack heat exchanger configuration of a DPEC

In M-cycle heat exchanger, cooling pads are found in wet channels adjacent to dry channels. Any heat exchanger application of Maisotsenko Cycle can be evaluated by using the different cooling pad material. Depending upon the availability, life, cost, ease of access a cooling pad material selection can be carried out. The different cooling pad materials are wood wool, cotton wool, honey comb cooling pads, cooling mattresses, coconut coir, Khus pad, etc.

If M-cycle is to be used in a humid and hot region for cooling purpose, humidity might be the factor of concern. In such a case, product air of the particular terrain (expected to be too humid to be called comfort) can be treated with desiccants. A comprehensive ventilation approach requires not only air exchange but also in many cases indoor humidity control. High humidity levels decrease occupant comfort and increase the like hood of problems, such as mild growth. Occupants presently use air-conditioning systems or dehumidifiers in order to reduce the indoor moisture levels. These systems use large amounts of electricity, are expensive to operate and are useful only a couple of months a year in some regions in Canada. An energy-efficient home may need little cooling during periods of mild temperature, but humid months may result in insufficient dehumidification and higher than desired indoor humidity. One technology that can help improve the dehumidification performance and eventually reduce the electricity consumption for residential air-conditioning is the use of a solid desiccant wheel with indirect-evaporative cooling [13].

Desiccant cooling is a simple technology which can be joined to other technologies like Maisotsenko Cycle in humid regions to improve their efficiency. Evaporative and radiant ceiling cooling for instance, are not effective in climates where the wet-bulb temperature is high. Desiccant cooling can supplement them advantageously by extending their climatic applicability's scope. Its potential contribution in improving indoor air quality, costs and energy savings, as well as environmental protection makes it attractive [14].

As the Maisotsenko Cycle finds its applications in turbines, heat exchangers, coolers, etc. in U.S.A., it can be adopted in India for various applications. If we can work out on saving fewer percentage of energy for the same output or if we can deliver the higher output for the same energy input, this can extend a very helping hand towards India's ill scenario of energy.

VI. Conclusion

This paper after reviewing the literature of many authors across the globe regarding the Maisotsenko Cycle, evaporative cooling, desiccant cooling, cooling pads concludes that M-cycle cools down the product air without any rise in humidity. This principle of M-cycle can find a very vital role in many applications of cooling. It may be directly or indirectly. This includes air conditioning, water cooler, some turbines, heat exchangers, etc.

Acknowledgment

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