DEVELOPMENT OF AIR CONDITIONER FOR FUTURE DEVELOPMENT WITH SALIENT FEATURES IN HEAT ADSORPTION SYSTEM

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ABSTRACT

The global demand for commercial and domestic refrigeration and air conditioning systems has dramatically increased; currently it takes around third of the total worldwide energy consumption. Mechanical vapour compression refrigeration systems use refrigerants with adverse environmental effects. Sorption refrigeration systems offer the potential for better alternative to the mechanical vapour compression systems, if their technology can be improved to overcome current limitations. Sorption refrigeration systems are driven using low grade energy, solar energy and waste heat, and can operate with environmentally friendly refrigerants and non corrosive materials. This chapter presents a comprehensive review for adsorption cooling systems, including adsorption principles, refrigerants used, range of adsorbent materials, working pairs, various bed designs, operating conditions, development techniques and their applications.

Emission and heat rejection from automobiles are largely responsible for urban environmental issues. Adsorption systems driven by engine waste heat exhibit huge potential to meet the demand for cabin thermal comfort while improving fuel economy. However, the mechanical vapour compression (MVC) systems are still the undisputed champions in automobile air conditioning. This paper provides a critical review on the development and progress of adsorption heat pumps specifically for automobile air conditioning. In doing so, some of the progress and development in land-based adsorption chillers (heat pump), which are not realistically relevant to automobile adsorption systems, are explicitly excluded. Matching the energy density, durability, and reliability of the MVC systems remain major hurdles. The importance of improving the energy density based on the overall system weight or volume, real-world tests under various driving modes and durability aspects are discussed.

1.0 INTRODUCTION

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature. One of the most important applications of refrigeration has been the preservation of perishable food products by storing them at low temperatures. Refrigeration systems are also used extensively for providing thermal comfort to human beings by means of air conditioning. Air Conditioning refers to the treatment of air so as to simultaneously control its temperature, moisture content, cleanliness, odour and circulation, as required by occupants, a process, or products in the space.

The subject of refrigeration and air conditioning has evolved out of human need for food and comfort, and its history dates back to centuries. The history of refrigeration is very interesting since every aspect of it, the availability of refrigerants, the prime movers and the developments in compressors and the methods of refrigeration all are a part of it. The French scientist Roger not has written an excellent book on the history of refrigeration throughout the world. Here we present only a brief history of the subject with special mention of the pioneers in the field and some important events.

Emission from the vast numbers of vehicles significantly contributes to the adverse urbanenvironmental issues. Subsequently, urban heat island effect and serious air pollution are becomingexistential threats to city dwellers. Approximately 55% of the world's population resides in urbanareas while this number is projected to be as high as 68% in 2050. As the urban population increases,the number of cars running in cities is expected to increase proportionally. This situation mightbecome worse if public transportation is poor or underdeveloped. Meanwhile, total vehicle productionincreased by 2.4%, while the production for 2017 was 95 million unit. According to the 2018report by the Japan Automobile Manufacturers Association (JAMA), Motor Industry of Japan 2018,the total number of passenger cars produced in 2017 was approximately 8.3 million which is a 5.8%increment.

The thermal efficiency of most internal combustion engines is well under 40% while most carsreject approximately 60–65% of the thermal energy from the combustion of fuel via the engine coolant and the exhaust. Japan's National Greenhouse Gas Emissions reported that ~7% of the CO2emission in 2016 came from transportation and automobiles. Thus, urban cities are subjected to the thermal energy rejection from vehicles, and the effective recovery of this rejection will immediately educe the rise in the ambient temperature. Due to the urban heat island effect, the usage of an onboardair conditioner to achieve cabin thermal comfort has increased. However, conventional mechanicalvapour compression (MVC) systems consume part of the engine power to operate the compressorand hence worsen fuel economy.

Figure depicts the breakdown of energy utilisation by a typicalautomobile. Approximately 65% of the thermal energy from the combustion of fuel is rejected throughthe exhaust, the engine coolant and the cabin heating during winter. This energy, for the cabin heating,can be considered as the useful effect in winter while in summer it can be considered as waste heat.Of the remaining 35% of thermal energy, friction losses and electricity generation account for 4% each.On average, the onboard air-conditioner consumes ~5% of the engine torque.

Depending on the cabinsize, the capacity of the installed air conditioner varies. Following Lambert and Jones, Table 1lists theinfluence of operating the air conditioner on the performance of different types of vehicles, i.e., mini,small, and standard as per the classification under the Road Vehicles Act of Japan [3,6]. It is noted thatthe mechanical air conditioner used up a significant portion of the power production, especially duringidling. Hence, the implementation of cabin air-conditioning systems that utilise or recover waste heatfrom the engine will provide a two-pronged benefit: (i) improved fuel economy and (ii) reduced heatrejection at a lower temperature.

2.0 LITERATURE REVIEW

Antonellis, D.S ,Joppolo, C.M., Molinaroli, L.(2010) An environmental control system utilizing solar energy would generally be more cost active if it were used to provide both heating and cooling requirements in the building it serves. Various solar powered heating systems have been tested extensively, but solar powered air-conditioners have received little more than short-term demonstration attention. This paper reviews past efforts in the field of solar powered air-conditioning systems with the absorption pair of lithium bromide and water. A number of attempts have been made by researchers to improve the performance of the solar applied air-conditioning (chiller) subsystems. It is seen that the generator inlet temperature of the chiller is the most important parameter in the design and fabrication of a solar powered air-conditioning system. While collector choice, system design and arrangement are other impacting factors for the system operation.

Anyanwu, E.E. (2003) Solar absorption air-conditioning has the advantage of both the supply of the sunshine and the need for refrigeration reach maximum levels in the same season. Although solar powered air-conditioning systems are readily available in commercial sizes, existing solar cooling systems are not competitive with conventional electricity-driven or gas-®red air-conditioning systems because of their high ®rst cost. Several technical problems associated with the design and development of absorption chillers based on continuous cycles have been successively resolved, and new trends gradually developed towards the redesign of the chiller generator for operation at temperatures lower than 1008C.

Arora, J.S., (2004) Of the two main technologies of solar cooling systems discussed in this paper, the emphasis is placed on the cooling technology rather than on the thermal technology, which places an important factor in increasing the COP of the refrigeration systems. It is shown that although the single effect system with refrigerant storage has the advantage of accumulating refrigerant during the hours of high solar insolation, the double effect convertible system has a higher overall COP. And the two-stage system has the advantage of lowering the generator temperature, which improves the system performance and the use of conventional ¯at-plate collectors to achieve high COP. There are many other achievements carried out by researchers, nevertheless, further improvements should be made to the solar powered air-conditioning systems in order to compete with the conventional air-conditioning systems.

Assoa, Y. B., Menezo, C., Fraisse, G., Yezou, R., &Brau, J. (2007) The objective of this thesis is to search for an efficient way of utilizing solar energy in air conditioning applications. The current solar Air Conditioners (A/C)s suffer from low Coefficient of Performance (COP) and performance degradation in hot and humid climates. By investigating the possible ways of utilizing solar energy in air conditioning applications, the bottlenecks in these approaches were identified. That resulted in proposing a novel system whose subsystem synergy led to a COP higher than unity. The proposed system was found to maintain indoor comfort at a higher COP compared to the most common solar A/Cs, especially under very hot and humid climate conditions.

Beery, K.E. and Ladisch, M.R. (2001) The novelty of the proposed A/C is to use a concentrating photovoltaic/thermal collector, which outputs thermal and electrical energy simultaneously, to drive a hybrid A/C. The performance of the hybrid A/C, which consists of a desiccant wheel, an enthalpy wheel, and a vapor compression cycle (VCC), was investigated experimentally. This work also explored the use of a new type of desiccant material, which can be regenerated with a low temperature heat source. The experimental results showed that the hybrid A/C is more effective than the standalone VCC in maintaining the indoor conditions within the comfort zone. Using the experimental data, the COP of the hybrid A/C driven by a hybrid solar collector was found to be at least double that of the current solar A/Cs. The innovative integration of its subsystems allows each subsystem to do what it can do best. That leads to lower energy consumption which helps reduce the peak electrical loads on electric utilities and reduces the consumer operating cost since less energy is purchased during the on peak periods and less solar collector area is needed.

3.0 METHODOLOGY

One of the improvements that would make the absorption machine more suitable for solar operation is refrigerant storage. Basically, the idea is to provide, in association with the condenser, a storage volume where the refrigerant can be accumulated during the hours of high solar insolation. Then, this stored liquid refrigerant can be expanded at other times to meet the required loads. Storage is also needed in the absorber to accommodate not only the refrigerant but also sufficient absorbent to keep the concentration within allowable limits. The advantages of refrigerant storage over other methods include: the energy storage per unit volume is high as the latent heat of evaporation, which is larger, compared to available sensible heat changes, is involved; . losses are low as the storage occurs at or near room temperature; . further advantages arise when the storage is applied to the lithium bromide± water cycle; . water has one of the highest enthalpies of evaporation among known liquids; . the storage pressure is low so that the strength of the storage vessel is not critical.

Fig. shows the schematic of the single-effect cooling system. The refrigeration circuit includes the usual generator, condenser, evaporator and absorber together with a sensible heat exchanger, a mechanical pump and pressure reducing valves or equivalent. A refrigerant store is associated with the condenser while an absorber store is associated with the absorber. Heat rejection is accomplished by a cooling tower from which water is circulated through the absorber, condenser store and condenser in series. Other water circuits could be used: indeed there may be some advantages to be gained in using parallel operation, notably the cooler water available for the condenser and the possibility of shutting flow to the condenser altogether when there is no generation.

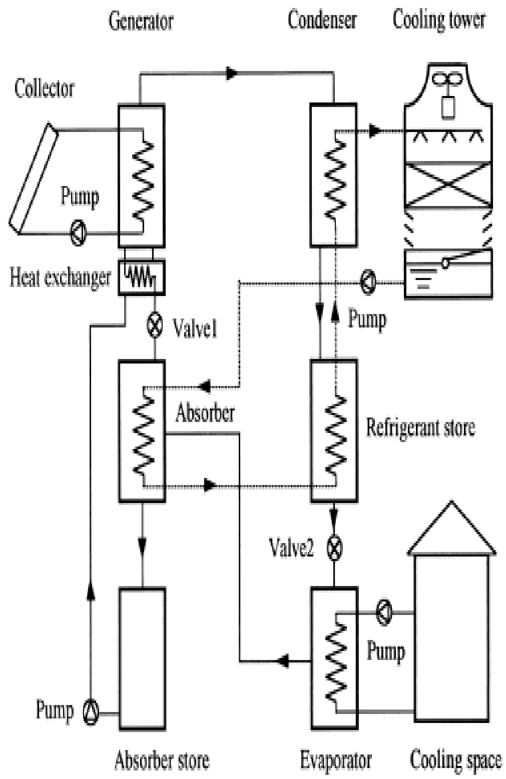


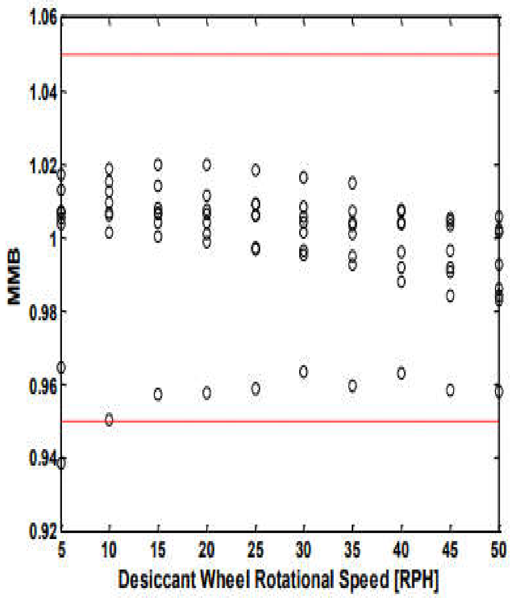
Figure Flow chart of the solar cooling system with refrigerant storage

Room air is circulated through the evaporator, and is maintained at a constant temperature, within the limits of the room thermostat and air-conditioner, by operating an on±o valve in the refrigerant line before the evaporator. A solar powered air-conditioning system of this type was modeled based on the above conception and geographical data in Brisbane, Australia. They have reported that the generation of refrigerant ceases several hours before sunset although a significant amount of energy is still being collected. The stoppage occurs because of the high boiling point of the solution that has become highly concentrated with so many refrigerants in the store. During the night as the refrigerant flows from the store to the absorber, the evaporator cooling rate continually decreases as the solution concentration decreases and causes a higher pressure and temperature in the evaporator. Fortunately, the building load has also decreased.

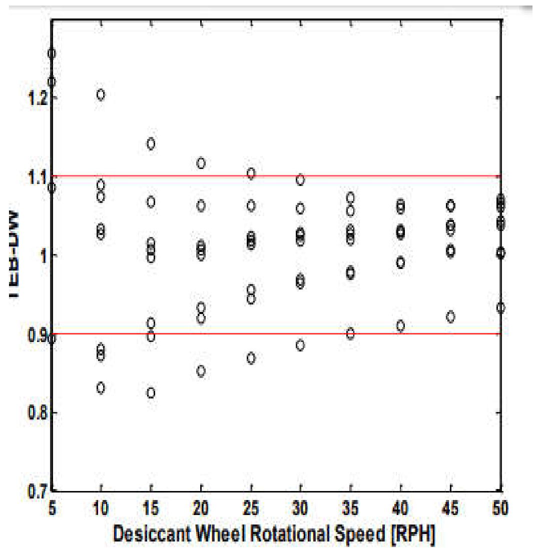
4.0 RESULTS

Prior to analyzing the results, the moisture mass balance ratio and the total energy balance are checked to make sure that they are within the acceptable range. Figure 48 show the MMB for all the tests. The MMB values are maintained within 5% except for a few outliers. Figure show the TEB for all the tests. It has to be mentioned that there is no standard requirements for the range of acceptable TEB values. However, various precautions were taken in order to maintain the TEB values within 10%. The value of TEB deviates out of the range due to the decrease of the enthalpy difference at lower rotational speeds.

The small enthalpy difference for both air steams, the process and the regeneration air streams, makes the ratio sensitive to small changes in either stream. This indicates that it is harder to maintain the ratio at lower rotational speed given that different energy losses to the environment are expected from the two air streams.

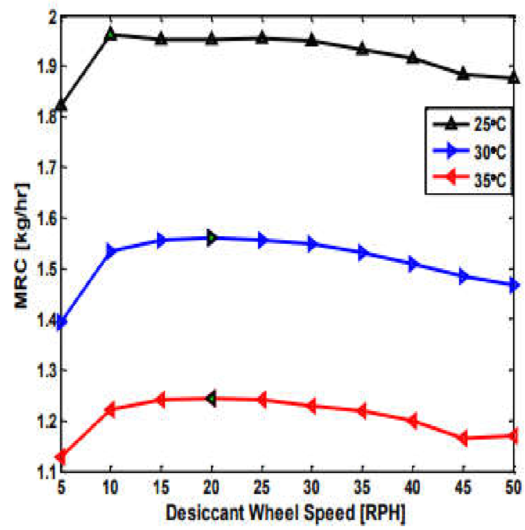


Graph Moisture Mass Balances of all the tests

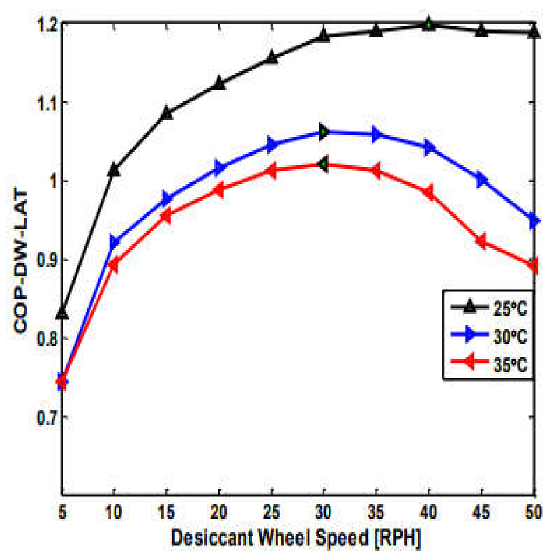


Graph Total Energy Balances of all the tests

The effect of the ambient air temperature on the DWC MRC and COPLat were investigated. The MRC, and the COPLat, increase with decreasing ambient temperature. For the same humidity ratio, the lower the dry-bulb temperature is, the higher the relative humidity (RH). This indicates that the desiccant material water vapor content will be higher as shown by the isotherm line, which makes the MRC value higher. For the same regeneration temperature, the COPLat would follow the same trend. Equation indicates that the shape of the COPLat lines should be similar to that of the MRC. However, it has to be remembered that the regeneration temperature is kept constant and not the regeneration heat. In order to maintain a constant regeneration temperature, different regeneration heat is required based on the DW process air stream outlet conditions and the EW's effectiveness.

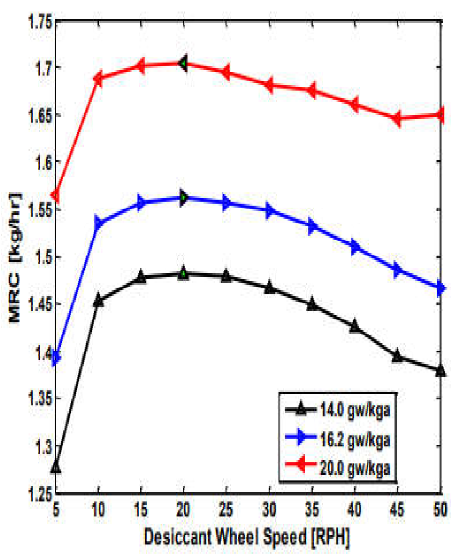


Graph Effect of process air temperature on MRC



Graph Effect of process air temperature on COPLat

Another important variable to investigate is the humidity ratio of the DW process inlet. It was found that the higher the humidity ratio is, the higher the MRC, and COPLat, values are. That is because at the same temperature, the higher the humidity ratio is, the higher the water vapor pressure. High water vapor pressure difference between the moist air and the desiccant surface increases the adsorption process. However, the condition of the moist air at the DW's process outlet is not necessarily drier. When the process air inlet is more humid, the humidity difference across the DW is higher as shown in Figure which makes the MRC value higher. However, the process air outlet is more humid as shown in Figure.



Graph Effect of process air humidity ratio on MRC

Effect of process air humidity ratio on DW's process outlet humidity ratio Investigating the effect of increasing the ventilation mass flow rate was possible due to utilizing variable speed fans. Figure shows that as the mass flow rate across the DW is increased, the MRC value increases. In order to maintain the same regeneration temperature, more heat is required for the higher mass flow rate. Therefore, the COPLat for the higher mass flow rate reduces

5.0 CONCLUSION

Demand for cabin thermal comfort and the availability of waste heat from internal combustionengines set favorable conditions for adsorption systems. However, the implementation of adsorptionsystems in automobiles can be considered to be in its infancy since almost no car is utilizing such asystem in practice. Improvements in the energy density and real-world test results are essential forfurther progress and the realisation of widespread usage of adsorption systems in vehicles.

Thereremain several unknowns or challenges such as meeting tight safety aspect, performance stability,durability level, and economic feasibility. Developments in adsorption chiller industry are oftenreported or depicted as relevant progress in automobile air conditioning. Adopting the performanceindicators normally used in landed or immobile adsorption heat pump industry such as specificcooling energy (SCE) or specific cooling power (SCP) are unhelpful or even might disguise as actualprogress because these parameters are based on the dry mass of the adsorbent. The compactness andlight weight of the adsorption systems as a whole package is crucial for better fuel economy.

Hence,improved and concise performance parameters should be employed instead. Adsorption systemsfor automobile air conditioning are in a separate league and demand special yet specific and focusedresearch. The emergence and pervasive acceptance of electric vehicles chop away the waste heatavailability and might further setback the adaptation of adsorption systems. Nevertheless, due tothe current limitations, such as readiness of the grid and charging stations, IC engine-driven vehiclesmight still be running on the roads for the foreseeable future. Thus, expedited development andprogress, along with regulatory support such as green incentives, are essential for the realisation ofadsorption systems for automobile air conditioning.

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