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M. R. Ally

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Sorption: Select Sorption Technology

M. R. Ally

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Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
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ABSTRACT

The purpose of this report is to select a sorption technology based on recent work completed on characterizing working pairs for both absorption and adsorption technologies based on Global Warming Potential (GWP) of less than 100 (relative to carbon dioxide, 100-year integration time horizon) and zero Ozone Depletion Potential (ODP). From a total of eighty-three potential working pairs (absorption technology), only 10 candidate working pairs were identified for absorption technology, and 8 potential working pairs for adsorption technology. After screening these ten potential candidates on the basis of sizes of the desorber, absorber/adsorber, evaporator, condenser, and rectifier (where applicable), the ORNL-Georgia Tech study concluded that best working pairs for absorption systems are NH_3-H_2O for the most compact system in terms of heat transfer equipment surface area, and NH_3-$LiNO_3$ (ammonia+Lithium Nitrate) and MeOH-[mmim][DMP] (methanol/1-methyl-3-methylimidazolium dimethylphosphate)) where efficiency is most important. MeOH-[mmim][DMP] was eliminated from further consideration because of its high cost. For comparative purposes, the costs of working fluids are, \$17.95/kg for NH_3; \$171.50/kg for $LiNO_3$; and \$\$3,530/kg for [mmim][DMP].

Based on a single-stage absorption and adsorption modeling using the Engineering Equation Solver (EES), the performance of both sorption systems was evaluated from known heat transfer correlations, and thermo-physical properties. Based on these results, the technology chosen is absorption technology for the reasons cited in **Section 4.**

1. METHODOLOGY

The methodology consists of two parts: (1) a thermodynamic performance with full characterization of thermodynamic properties (i.e. density, P-X-T and H-X-T behavior), and (2) a heat transfer analysis to capture performance based on thermo-physical properties such as viscosity, thermal conductivity, specific heat, and the heat transfer coefficients based on dimensionless parameters.

The operating conditions are based on Air-Conditioning, Heating, and Refrigeration Institute (AHRI)Standard 210/240-2008. In the analysis, the desorber temperature is varied to find a maximum in coefficient of performance (COP).

The working pair selection criteria are,

1. Fluid properties should allow for heat pump operation in ambient conditions between -40°C and 40°C.
2. Zero ODP and GWP below 100.
3. Health and safety considerations based on the Hazardous Material Identification System (HMIS) rating.
4. High COP for sorption cycle based on AHRI standards.
5. High rates of heat transfer in system components.

The cycle operating temperatures were as shown in ***Table 1***

Table 1 Cycle Operating Conditions

Absorber Temperature (T_a)		50°C
Condenser Temperature (T_c)		50°C
Evaporator Temperature (T_e)		-23°C
SHX Effectiveness (ε_{SHX})		0.95

For the model, the following assumptions were made.

- Desorber temperature is arbitrary (variable)
- Evaporator temperature based on -8°C air inlet (AHRI standard)
- Absorber/Condenser temperature for 45°C delivery
- Pure refrigerant in the condenser and evaporator
- Saturated states in all components
- Reversible pump
- 5°C closest approach temperature in all components providing heating (i.e. the condenser-rectifier and absorber)
- 10°C temperature non-equilibrium
- 15°C closest temperature is assumed between the evaporator and the ambient
- There is no inert mass in the adsorbent bed
- The adsorbed liquid is treated as a liquid for calculations of specific heat capacity
- The refrigerant flows from the condenser to the evaporator isenthalpically.

The focus of the modeling is to establish working pairs that (1) yield the highest coefficient of performance (COP) and (2) identify those that yield the smallest system that would ultimately translate to lower cost for the consumer.

2. RESULTS-ABSORPTION TECHNOLOGY

The maximum COP achieved with the 10 selected working pairs that matched the criteria indicated above, are shown in **Figure *1***.

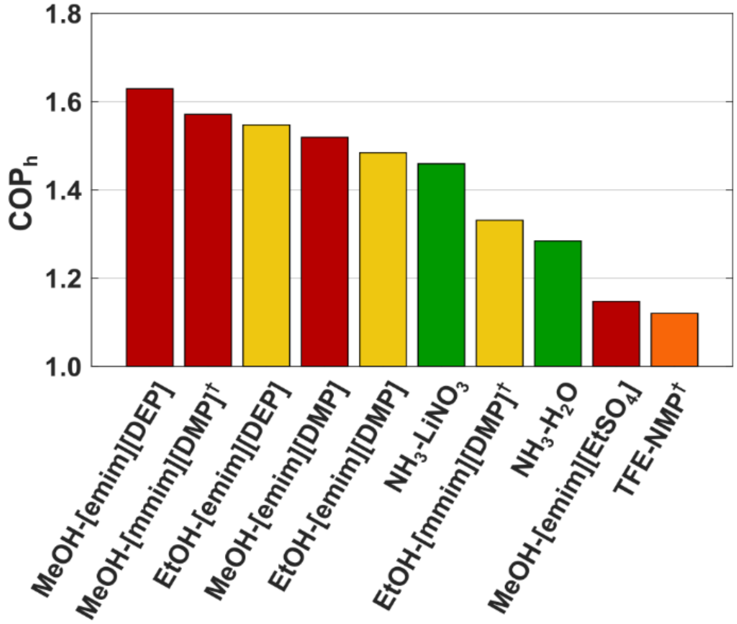
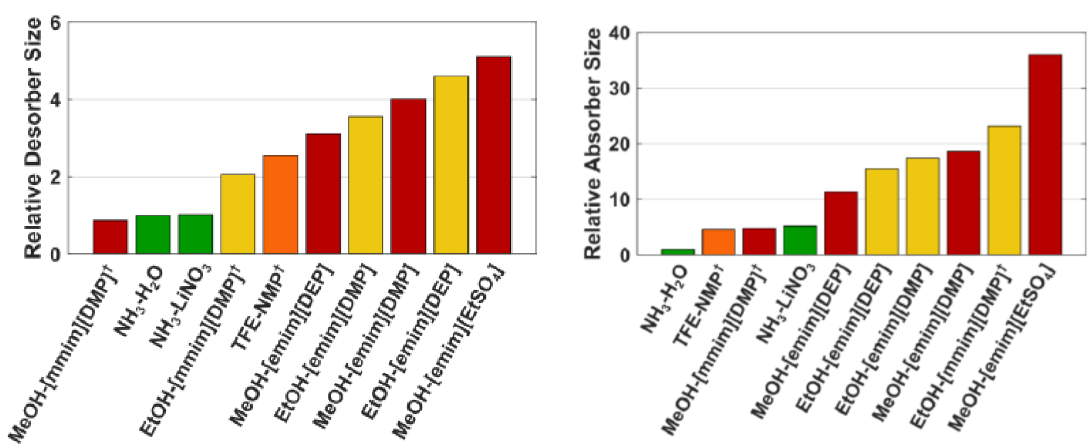


Figure 1 Maximum heating COP of selected working pairs (absorption)

The relative sizes of the equipment required for each of the 10 selected working pairs is shown in **Figure *2***.



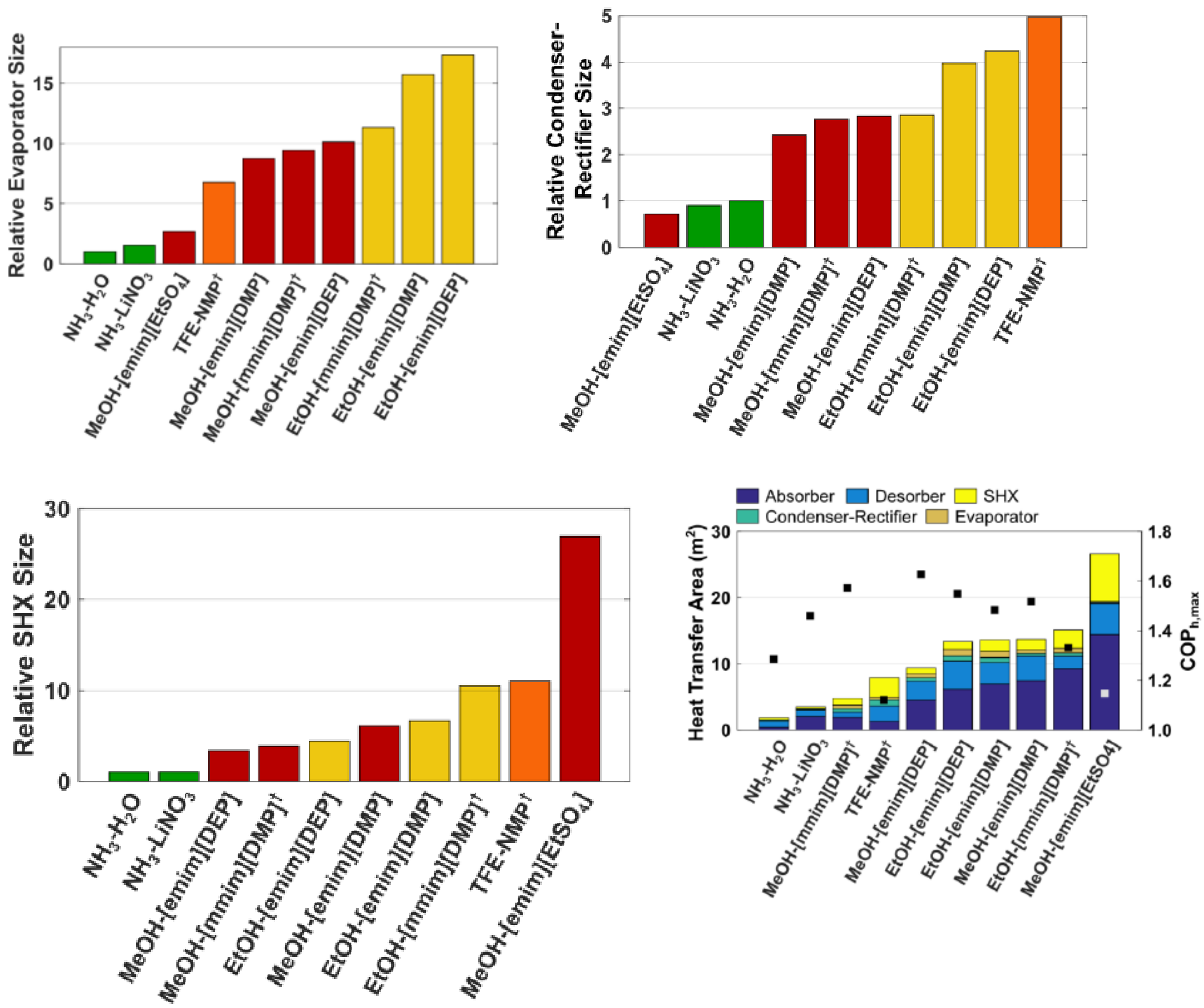


Figure 2 Relative sizes of equipment for each of the 10 selected working pairs

Refrigerants that operate above atmospheric pressure, such as ammonia, can use compact heat exchanger geometries such as micro-channels. Because these geometries allow forced flow, the convective heat transfer coefficients are expected to be higher, which will result in less required heat transfer area. In addition, microchannel geometries have a significantly higher surface area-to-volume ratio than falling film geometries, resulting in a system with a smaller footprint for the same heat transfer area.

2.1.1 Conclusion on Absorption technology

Based on the analysis applied to the set on AHRI operating conditions and the assumptions and criteria stated above, the best working pair is NH_3-H_2O because of its impacts on system compactness (e.g., physical size & weight). MeOH-[mmin][DMP] is attractive for maximizing system COP with modest increase in system size vs. NH_3-H_2O. The NH_3-$LiNO_3$ pair is also a candidate for the highest COP provided it does not encounter temperatures where crystallization occurs.

3. RESULTS-ADSORPTION TECHNOLOGY

The Georgia Tech study investigated the variation in COP and in Specific Heating Effect (SHE) of three categories of adsorbents: Activated Carbon (AC), Metal Oxide Formation (MOF), and Composite. On average, MOF adsorbent showed the largest variability in COP, while AC+NH3 was the best compromise between high COP, high SH (see **Figure *3***

The variation in heating COP and SHE are mainly related to the peculiarities of the adsorption bed and the adsorption process, depending on the type of adsorbent.

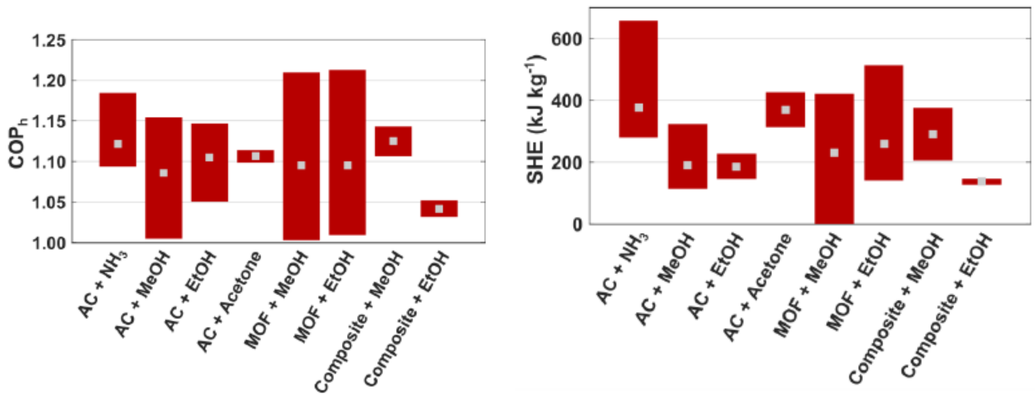


Figure 3 Variation in COP (left) and in SHE (right) for the three categories of adsorbents

From **Figure *3*** it may be concluded that AC+NH_3 represents the best choice in terms of both COP and SHE.

In heating mode, Activated Carbons (ACs) + NH_3 demonstrate the highest SHE as a category, with seven of the top ten working pairs coming from this category. There are two major reasons for this. First, ammonia has the highest heat of vaporization of the working pairs considered for heating; thus it can deliver more energy at the condenser and during the adsorption step than other working pairs. Second, the adsorbed refrigerant remaining at the end of the desorption step is fairly high. This results in more sensible energy that can be delivered during the adsorption step.

The relative performance of ammonia and a specific activated carbon (AX-21) relative to 10 working pairs is shown in **Figure 4** where it is clear that AX-21+NH_3 is the preferred choice.

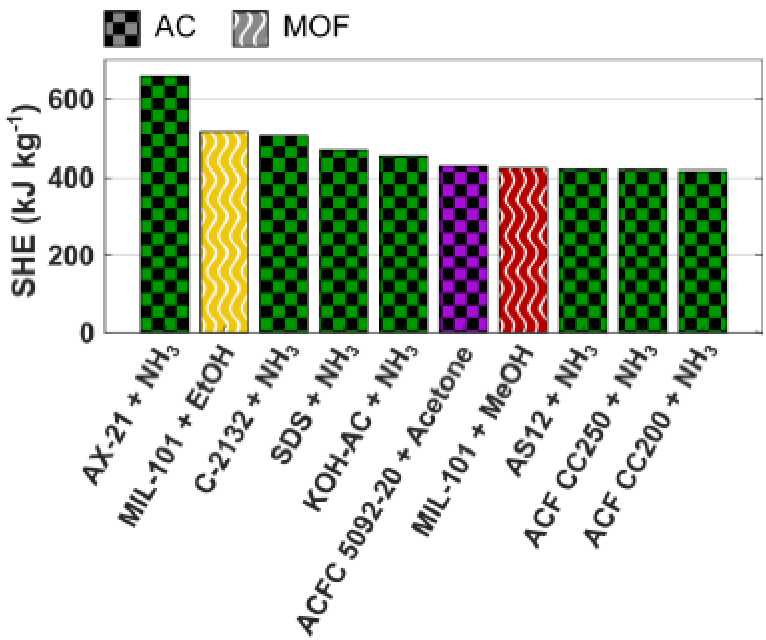


Figure 4 SHE of the 10 selected adsorption pairs

Combining the results of

Figure 3 and **Figure 4**the specific heating power (SHP) is shown in **Figure *5***

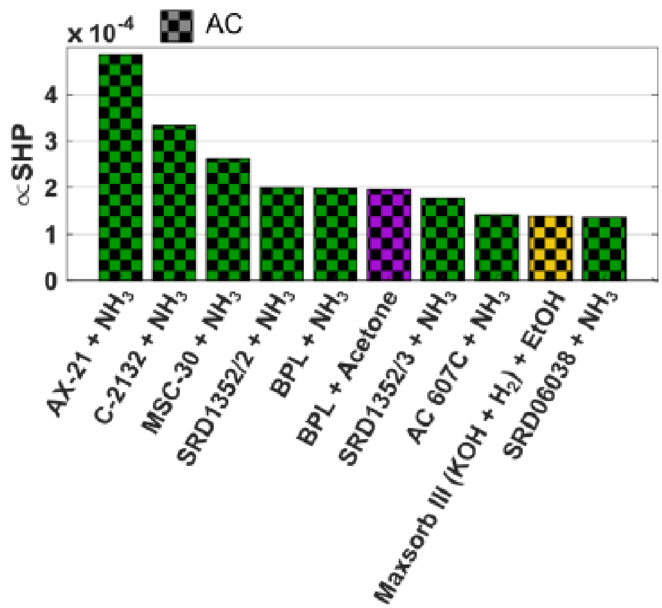


Figure 5 The specific heating power (SHP) of the 10 selected adsorption working pairs

3.1 CONCLUSION ON ADSORPTION TECHNOLOGY

Of the 81 adsorption working pairs analyzed, only two seemed feasible for heating applications. Heat transfer and inter- and intra-particle mass transfer are limiting factors in adsorption technology. The two best working pairs for the adsorption system seems to be (AX-21+NH_3)[1] and ethanol+MIL-101[2]

4. SELECTION OF SORPTION TECHNOLOGY

- In both, absorption as well as adsorption systems, the workings pairs that performed the best in terms of COP has ammonia as the refrigerant.
- The two highest scoring absorption working pairs, NH_3-H_2O and NH_3-$LiNO_3$ have significantly higher COPs that the top two adsorption working pairs, AX-21+NH_3 and ethanol-MIL-101
- Adsorption technology has disadvantages of interparticle and intra particle mass and heat transfer that influences the overall cycle efficiency adversely.
- Adsorption technology is a batch process where heating is done in tandem. Absorption is a continuous process.
- Based only on a thermodynamic model the highest COP for adsorption technology is 1.21. This is unlikely to meet the 20% reduction in system cost compared to the baseline gas-fired technology for residential applications.
- The COPs of adsorption systems appear to be consistently lower than that of absorption systems
- Absorption technology appears to be preferential relative to adsorption technology for residential applications.

[1] AX-21 is a coal-based activated carbon

[2] MIL is a chromium terephthalate-based mesoscopic metal−organic framework (MOF)