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REFRIGERATION TECHNOLOGY TRANSFER AT JPL/NASA

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ABSTRACT

The Jet Propulsion Laboratory (JPL) has long been involved with developing cryogenic refrigeration systems for the cooling of infrared sensors used by both the National Aeronautics and Space Administration (NASA) and the U.S. Defense Department. In 1989, JPL began spinning off this technology to provide commercial refrigeration and air conditioning. The areas of technology spin-off include the development of refrigerant mixtures to replace ozone-depleting Freon 12, the development of solid adsorption cooling systems for home air conditioning and railway car air conditioning, and the development of low-cost, lightweight liquid absorption air conditioning systems that can serve as gas-powered window air conditioning units or exhaust-heat-powered, automobile air conditioning systems.

I. Background

Starting in 1979, JPL has been involved in the development of cryogenic cooling systems for the cooling of infrared sensors used by both NASA and the U.S. Defense Department. In particular, JPL has been a leader in the development of solid sorption cryogenic refrigeration systems to provide cooling of infrared detectors for long life outer planet missions, as well as for earth-orbiting surveillance missions. Sorption compressors operate by sorbing a low pressure refrigerant onto solid powders, typically near room temperature, and exhausting the refrigerant at high pressures when the powder is heated an additional 100-200°C. When the high pressure refrigerant is pre-cooled and expanded, it provides net refrigeration. Thus, simple heating and cooling of the powders provide a basically solid-state cooling system with essentially no wear-related moving parts. The basic operation is shown in Figure 1, which has two sorbent beds heating (outgassing high pressure refrigerant) and two sorbent beds cooling (adsorbing low pressure refrigerant). Expansion of the pre-cooled refrigerant through an expansion valve, or orifice, provides cooling.

Since 1979, the Jet Propulsion Laboratory (JPL) has tested numerous hydrogen, oxygen, nitrogen, and krypton cryogenic sorption refrigeration systems[1,2] for cooling space-based infrared imaging systems. More recently, JPL has been developing a quick cooldown 10 K(-263°C) hydrogen sorption refrigeration system for the cooling of infrared sensors for the Strategic Defense Initiative Organization (SDIO) "Star Wars" missile tracking program. A proof-of-principle experiment was successfully conducted at JPL in 1991[3], and a JPL Space Shuttle experiment is planned for 1996.

II. Solid Sorption Refrigeration Spin-offs

For ground air conditioning applications, the simple sketch of Figure 1 has been found to be too inefficient to compete with alternate heat pump technologies. To conserve energy, a number of heat regeneration techniques have been attempted, whereby the waste heat from the sorbent bed is used to heat another sorbent bed. Shelton[4] and Tchernev[5] have devised a simple double-bed system, in which a hot sorbent bed that is being cooled will pass its heat to a coolant fluid which then passes through a heater (to make up for regeneration thermal losses) and then on to another sorbent bed. A number of alternate techniques using four, six, or more beds have also been proposed.[6,7]

Extensive studies have been performed at JPL, which show that a four bed approach is much more efficient that two beds, but that there is not a significant advantage in using more than four beds[8,9]. In particular, a patented four bed approach (Figure 2) will use a fluid (water or oil) to transfer hot and cold thermal waves[(10)]. In addition, it has been discovered that significant performance improvement can be attained if the coolest sorbent bed is cooled further at the end of each quarter cycle without regenerating the fluid through the other three sorbent beds. With this type of "bottoming", the JPL models have predicted a coefficient of performance (COP) of 1.0 for a 35°C day using ammonia adsorbed on activated carbon. The COP, using Freon-12 replacement fluid R134a, has been predicted to be about 0.8. These predicted efficiencies are higher than any other single stage heat-powered air conditioning systems presently on the market.

In order to confirm the analytical tools, a single compact sorbent bed was fabricated and tested in both heating and cooling modes. The sorbent bed (Figure 3) consisted of activated carbon with a binder that was molded into a finned aluminum tube extrusion (patent pending [(11)]). Pressurized water was selected as the heating and cooling means. A hollow ullage volume in the center of the water stream allowed enhanced fluid heat transfer coefficients. The transient thermal test results showed very good correlation to analytical predictions[(9)], although full system COP was not able to be measured with only one sorbent bed. Of the three refrigerants that were tested (R22, R134a, and ammonia), ammonia was almost three times superior to the others and yielded 1038 BTU/hr (304 watts) cooling for only a 0.51 Kg carbon bed.

This technology[10,11] has now been spun off and is being licensed by Aerojet General to provide 7.2 tons (25.3 kw) of air conditioning for a Los Angeles County subway car. For this application, the entire compressor heater power will be derived from the subway train's electro-resistive brake waste heat. The subway car sorption air conditioning installation is scheduled to occur in 1996. This same technology is also being evaluated by Aerojet to provide high-efficiency air conditioning systems for home and commercial applications.

III. Liquid Absorption Spin-offs

Liquid absorption systems perform very similarly in principle to solid sorption systems, except that the liquid moves through the unit. A typical liquid absorption system is shown in Figure 4. Low pressure ammonia is absorbed into water in the absorber part of the unit. It is then pumped to a high pressure and passes through a heat exchanger into a hot gas generator section. The ammonia desorbs at high pressure from the water, and most of the water vapor is distilled out of the ammonia in the rectifier. The depleted liquid solution then passes back to the absorber where it is cooled and ready to absorb low pressure ammonia.

Liquid absorption systems have both some advantages and disadvantages compared to solid sorption systems. For ammonia systems, water will absorb about three times as much ammonia by weight as the best carbon adsorbent. Although heat transfer is easier for liquid systems, the mass transfer of refrigerant back into liquid solution is more difficult. A very large cooled surface area is typically required to enhance liquid/gas absorption, and this surface area is usually very sensitive to motion and/or gravity.

Recently, the Southern California Gas Company has funded JPL to develop a high performance liquid absorption system that can be compact enough to fit into a typical window unit air conditioning unit for cooling multi-unit dwellings. JPL has now fabricated a bench-model, proof-of-principle liquid absorption unit that may be compact enough for window air conditioning units.

The actual design is still proprietary, but the unit promises to be low cost, lightweight, reasonably efficient, and motion insensitive. Preliminary tests will be performed in March 1995 using a water/ammonia combination in the apparatus. Subsequent funding by Ford Automotive will have allowed testing of R134a in the same apparatus by the time of this publication. The intent is to develop air conditioning units for cars that can be powered by automotive exhaust waste heat.

Although all testing is to be performed in a stainless steel apparatus, actual commercial fabrication of ammonia units would consist of mild steel with appropriate corrosion inhibitors. R134a units could be fabricated from inexpensive aluminum alloys.

IV. Refrigerant Mixtures

JPL has also been actively involved in developing refrigerant mixtures for cooling applications. It has been known for some time that refrigerant mixtures can provide cooling from room temperature down to as low as about 65K in a single expansion stage. A British patent was issued in 1973 to a group of Russians[12] who mixed neon, nitrogen, and various hydrocarbons to attain cooling as low as 65K, and produced an order of magnitude cooling improvement over the use of nitrogen alone.

With funding from the U.S. Defense Department, JPL developed a computer code[13] that accurately predicted the Russian performance numbers as well as numerous other measured gas mixture performances.

In 1989, NASA drew upon JPL's fluid mixture experience, and funded JPL to develop a refrigerant mixture replacement for ozone-depleting Freon refrigerant 12 (R12). Starting with a list of approximately sixty refrigerants with similar boiling pints, JPL produced a family of six fluid near-azeotropic (constant boiling point) mixtures that have saturation pressures similar to R12 (Table 1). The mixtures, however, are about fifty to one hundred times less damaging to the Earth's ozone layer[14].

Furthermore, the mixtures are of low toxicity, are non-flammable, and are likely to have an improved coefficient of performance and better compatibility with oil than Refrigerant 134a, the present leading replacement for Refrigerant 12. Although the newly discovered JPL blends are likely to cost more than the recently patented Dupont ternary blend[15], they are at least four times less ozone-damaging than the Dupont blend, and they are at least twice as azeotropic.

V. Summary and Conclusions

Based on JPL's long-established role as an innovator in space-based cryogenic refrigeration technology, JPL has successfully spun off three potentially rewarding areas in commercial refrigeration. In the area of solid adsorption refrigeration, Aerojet Corporation has licensed JPL/Caltech technology and is building a 7.2 ton (25.3 kW) air conditioner for a Los Angeles County subway train. The air conditioner will be powered by the waste heat from the train's electro-resistive breaking system. Aerojet is also developing the technology for home and industrial air conditioning.

In the area of liquid absorption air conditioning systems, JPL is developing a compact, low cost, water/ammonia cooler for gas-fired window units for the Southern California Gas Company. The ammonia loop would be located entirely outside of the room to be cooled and would be coupled by a water cooling loop to the interior portion of the unit. A similar unit using R134a, instead of ammonia, is to be tested for Ford Automotive. This unit would be eventually powered by automotive exhaust waste heat.

In the area of mixed fluids, a family of six, near-azeotropic mixture substitutes has been found for ozone-depleting Freon 12. The mixtures have low toxicity, are non-flammable, and are about fifty to one hundred times less ozone-depleting than Freon 12. They may be particularly useful in replacement applications where Refrigerant 134a, and its problematic lubricants, cannot be used.

ACKNOWLEDGMENTS

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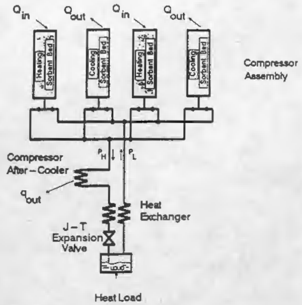

Figure 1. Basic Sorption Refrigeration Concept

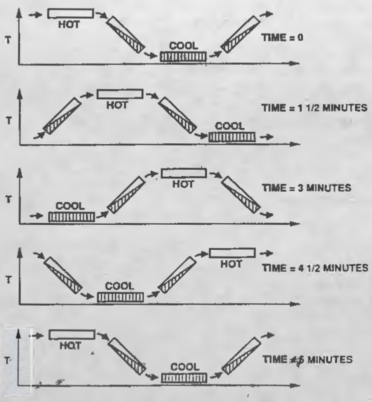

Figure 2. Sorption Compressor Regenerative Thermal "Wave"

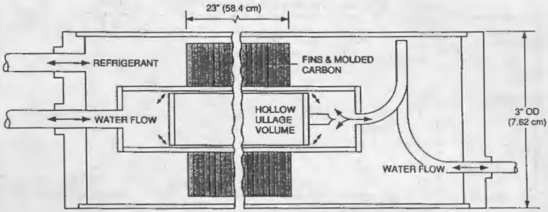

Figure 3. Sorption Compressor Assembly Cross-Section

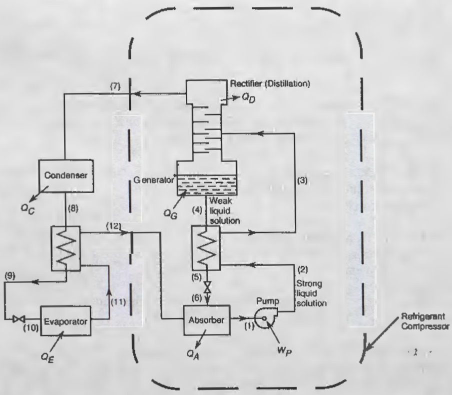

Figure 4. Common Liquid Absorption Refrigeration System

Table 1. JPL Near-Azeotropic Mixture Replacements for R12

Mixture	Component A*	Component B*	Component C*	Component D*
1	0.8<R134a<1.0	R124<0.5		
2		R142b<0.5		
3		R124<0.5	R142b<0.5	
4		R152a<0.5	R124<0.5	
5		R152a<0.5	R142b<0.5	
6		R124<0.5	R142b<0.5	R152a<0.5

*0.0<(B+C+D)<0.5
All fractions are given as mole fractions.

References.

1. **Jones, J.A. and Golben, P.M.**, "Design, Life Testing and Future Designs of Cryogenic Hydride Refrigeration Systems," *Cryogenics*, 25 212 (1985).

2. **Jones, J.A.**, "Sorption Cryogenic Refrigeration -- Status and Figure," *Adv Cryog Eng* (1988).

3. **Bard, S., Rodriguez, J., Wu, J., and Wade L.**, "10 K Sorption Cooler Development," *Proceedings of the Seventh International Cryocooler Conference*, Santa Fe, New Mexico (November 17-19, 1992).

4. **Shelton, S.V., Wepfer, W.J., and Miles, D.J.**, "Square Wave Analysis of the Solid-Vapor Adsorption Heat Pump," *Heat Recover Systems & CHP*, No. 3, pp. 233-247, Great Britain (1989).

5. **Tchernev, D. and Emerson, D.**, "Closed Cycle Zeolite Regenerative Heat Pump," 2nd International Workshop on Research Activities of Advanced Heat Pumps, Graz Austria (September 1988).

6. **Miller, E.B.**, "The Development of Silica Gel Refrigeration," *Refrigerating Engineering*, Vol. 17, No. 4, pp. 103-108 (1929).

7. **Wade, L., Alvarez, J., Reyba, E., and Sywulka, P.**, "Development of a High Performance Sorption Refrigerator," paper presented at Space Cryogenics Workshop, California Institute of Technology, Pasadena, California (August 1989).

8. **Jones, J.A. and Vassilis Christophilos**, "High Efficiency Regenerative Adsorbent Heat Pump," ASHRAE Winter Annual Meeting, Chicago, Illinois (January 1993).

9. **Jones, J.A.**, "Sorption Refrigeration Research at JPL/NASA," Solid Sorption Refrigeration Conference, International Institute of Refrigeration, Paris, France (November 18-20, 1992).

10. **Jones, J.A.**, "Regenerative Adsorption heat Pump," U.S. Patent #5,046,319, Jet Propulsion Laboratory/California Institute of Technology, Pasadena, California.

11. **Jones, J.A. and Yavrouian, A.**, "Activated Carbon Sorbent with Integral Heat Transfer Device," U.S. Patent Pending (1992).

12. **Vladimir Nikolaevich Alfeev et al**, "Refrigerant for a Cryogenic Throttling Unit", British Patent #1,336,892, November 14, 1973.

13. **Jones, J.A.**, "Development of a Cryogenic Mixed Fluid Cooling Computer Code - JTMIX", AIAA 26th Thermophysics Conference, Honolulu, Hawaii, June 24-26, 1991.

14. **Jones, J.A.**, "Near Azeotropic Mixture Substitute for Dichlorodifluoromethane", JPL Patent Application JPL 9001, 1990.

15. **Bivens, Donald J. and Connon, Helen A.**, "Haloncarbon Blends for Refrigerant Use", U.S. Patent 4,810,403, March 7, 1989, E.I. Dupont deDemours & Co.