# Appendix C

# CHEMICAL HEAT PUMP SYSTEMS

## C.1. 2-PROPANOL - ACETONE SYSTEM

A key process is the dehydrogenation catalysis of 2-propanol under mild reaction conditions converting low-quality heat into chemical energy and recovering high-temperature heat or hydrogen gas at the energy demand site.

$$(CH_3)_2CHOH \longleftrightarrow (CH_3)_2CO + H_2 - 55 \text{ kJ/mol}$$

The 2-propanol / acetone / hydrogen chemical heat pump is operated in three steps:

1. 2-propanol dehydrogenation
   is an endothermal reaction at low temperatures (≈ 80 °C) assisted by a catalyst.
2. Acetone hydrogenation
   is the reverse exothermal reaction at higher temperatures (150 - 200 °C).
3. Separation
   of the 2-propanol from acetone and hydrogen by condensation in a fractional distillation column at ambient temperatures.

High thermal efficiencies can be achieved with properly designed catalysts. A pilot plant for this chemical heat pump system was constructed in Oarai, Japan, and successfully tested in 1994. A pilot plant driven by solar energy was realized at the Florida Solar Energy Center demonstrating an average yield of 180 ml/h of hydrogen (over several days).

## C.2. CYCLOHEXANE - BENZENE SYSTEM

The reaction couple consists of cyclohexane dehydrogenation at 200 °C under normal atmospheric pressure and benzene hydrogenation at 350 °C.

$$C_6H_{12} \longleftrightarrow C_6H_6 + 3\ H_2 - 206 \text{ kJ/mol}$$

This system can be realized in a tube wall type reactor.

The use of a membrane reactor with a hydrogen-permeable palladium alloy membrane inside a catalyst-packed bed allowed a shifting of the chemical equilibrium to efficiently drive the dehydrogenation process at lower temperatures, e.g., waste heat. It thus serves as a chemical heat pump system.

## C.3. HYDRIDE SYSTEM

A closed-loop heat pump system based on hydrides, a **metal hydride super heat pump (MHSHP)** system, has been investigated at JAERI with the purpose not only to amplify nuclear waste heat, but also to mass store hydrogen for transportation purposes. The L reactor contains an MHX alloy where hydrogen is stored. A medium-temperature heat source liberates the hydrogen. After transfer to the H reactor, the hydrogen is absorbed in the Ca alloy and upon reaction liberates high-temperature heat which can be decoupled from the system by a helium heat exchanger. Candidate MHX materials are currently subject to further research. In a test facility, heat conversion from 500 to 900 °C was achieved. The MHSHP system is considered to be connected to the UT-3 hydrogen production cycle.

## C.4. SPONGE IRON

The use of sponge iron resulting from the direct iron ore reduction as a hydrogen storage system has been found to be practicable although with the penalties of a heavy weight, its solid state as a fuel, and not too high an amount of energy to be stored. Applications might be seen in heavy transportation systems, e.g., fuel cell powered locomotives.