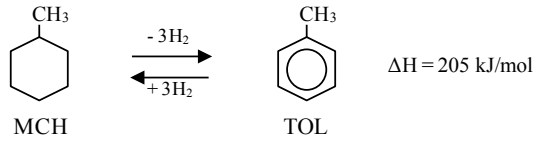
SPERA HYDROGEN *Process*

Introduction

SPERA HYDROGEN™ Process is a hydrogen storage and transportation technology for large-scale and long distance transportation, aimed at contributing to realize a low-carbon society. Chiyoda proposes a hydrogen supply chain concept using SPERA HYDROGEN™.

Hydrogen is fixed to toluene (TOL) and converted to methylcyclohexane (MCH), which is easy to store and transport under the ambient temperature and atmospheric pressure.

In this process, hydrogen is stored and transported in large-scale at low cost, since the cryogenic liquefaction or the compress for very high pressure are not required.



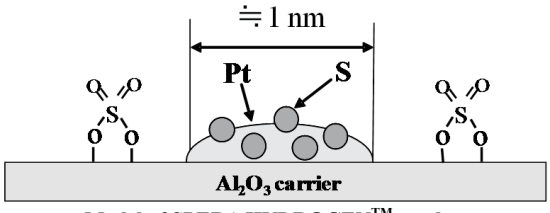
TOL/MCH reaction formula used for SPERA HYDROGEN™

Process Feature

Dehydrogenation Catalyst

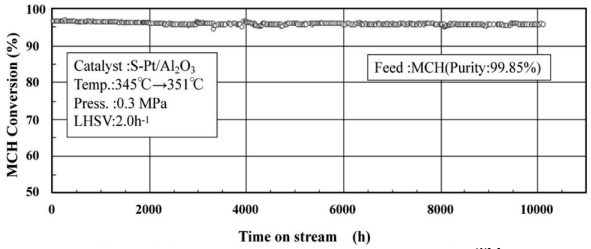
Since 1980's, the MCH dehydrogenation process couldn't have been commercialized due to severe catalytic deactivation. Chiyoda has developed a new dehydrogenation catalyst (SPERA HYDROGEN™ catalyst) based on nano-technology and a new process by scale-up engineering technology.

TOL hydrogenation process has been improved based on the conventional process, "SPERA HYDROGEN™ Process" has established by the new dehydrogenetion process and the hydrogenation process.



Model of SPERA HYDROGEN™ catalyst

SPERA HYDROGEN™ catalyst (S-Pt/Al_2O_3) consists of a uniform type with nano-size Pt clusters on alumina support. This well-dispersed Pt catalyst enables high reactivity and prevents catalytic deactivation by coking. Over a period exceeding 10,000 hours, the catalyst achieved over 95% MCH conversion, over 99% TOL yield and over 1,000 $Nm^3/h/m^3$-cat of hydrogen production at bench scale facility.



Catalyst performance of SPERA HYDROGEN™ catalyst

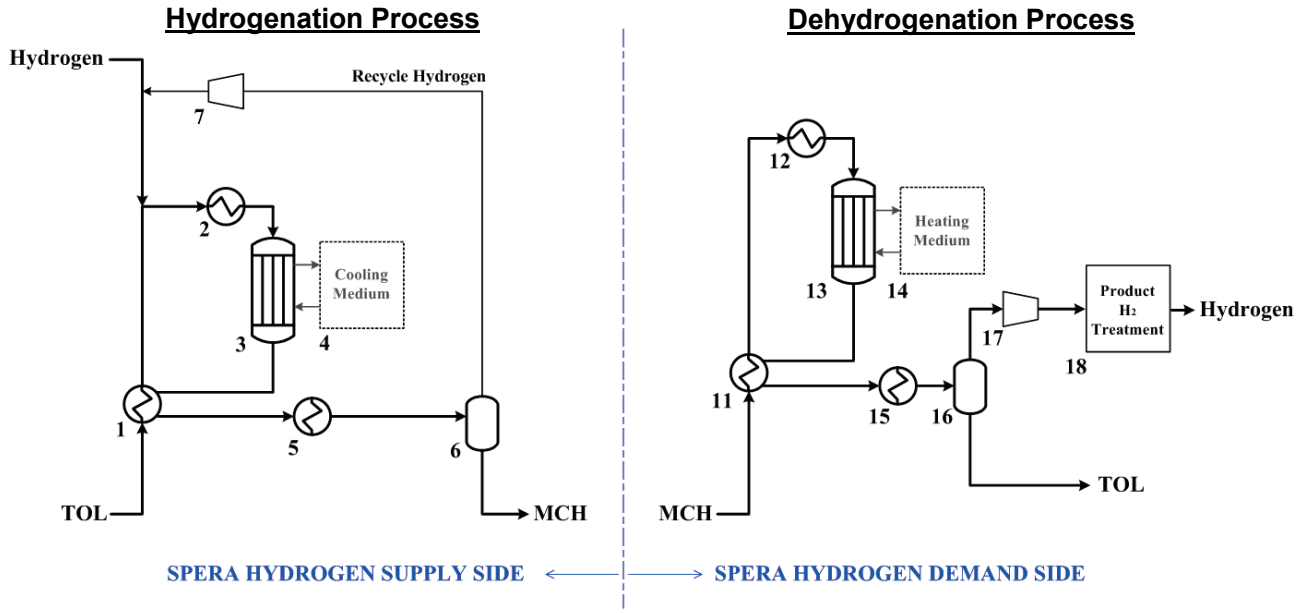
Process Performance

Chiyoda constructed the pilot plant at the capacity of 50Nm^3/h-H_2, and the demonstration operation of SPERA HYDROGEN™ process has been started from April 2013. The demonstration plant has hydrogenation and dehydrogenation units at the same site, the conversion between TOL and MCH is conducted repeatedly.

Although the plant capacity is only 50 Nm^3/h-H_2, the catalyst and reactor tubes have been the same as for the the commercial plant. SPERA HYDROGEN™ Process is able to be commerciallized easily at the any scale of the capasity by increasing the number of catalyst tubes. Following process performance was demonstrated.

Property	Value
Dehydrogenation Process	
MCH conversion	Over 95%
TOL yield	Over 99%
Hydrogen yield	Over 95%
Hydrogenation Process	
Overall TOL conversion	Over 99%
Hydrogen conversion	Over 99%
MCH yield	Over 99%
TOL and MCH	Recycled

Simplified Process Flow



Process Description

The remarkable feature of SPERA HYDROGEN™ Process is its simple process configuration. MCH and TOL react in the fixed bed tubular reactors in the vapor phase, and high product yield is achieved with a simple vapor and liquid separation drums.

The above diagrams are simplified process flows of the Hydrogenation and Dehydrogenation process for the SPERA HYDROGEN™ Process.

Hydrogenation Process: TOL feed is vaporized in the vaporizer (Eq.1) and mixed with hydrogen including recycle gas. The mixture feed is super-heated to the reaction temperature (Eq.2) and enters the top of the reactor (Eq.3), which is a fixed-bed tubular type reactor charged with hydrogenation catalyst. In the tubes, TOL reacts with hydrogen to produce MCH.

Hydrogenation is an exothermic reaction, the generated heat is removed by cooling water to control the reaction temperature, and the heat is recovered as steam which is utilized in the up-stream process as the clean heat without carbon emission. The effluent gas from the reactor is cooled and the condensed MCH is separated (Eq.6) from gas. The liquid product (MCH) is sent to storage Tanks.

Dehydrogenation Process: The MCH feed is vaporized in the Vaporizer (Eq.11), and super-heated in the charge heater (Eq.12) before entering the dehydrogenation reactor (Eq.13). The reactor is a fixed bed tubular type as same as hydrogenation. SPERA HYDROGEN™ catalyst is charged in the tubes. Since dehydrogenation is endothermic reaction, the heating source is required. The hot oil system is typically applied (Eq.14) to supply that reaction heat. However, that heat is not a loss, because the reaction heat is converted to the hydrogen energy through the reaction.

The effluent gas is cooled to separate hydrogen and condensed TOL (Eq.16). The separated hydrogen is compressed and treated to meet product hydrogen specifications. (Eq.18)

Main Equipment

1= TOL Vaporizer
2= Charge Heater
3= Hydrogenation Reactor
4= Cooling Medium
5= Product Cooler
6= MCH Separator
7= Recycle Gas Compressor
11= MCH Vaporizer
12= Charge Heater
13= Dehydrogenation Reactor
14= Heating Medium
15= Effluent Cooler
16= TOL Separator
17= H_2 Compressor
18= Product H_2 Treatment

Photo of SPERA HYDROGEN™ Demonstration Plant