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Investigation on feasibility criterion as a measure for combined absorption heat pump and methanol steam reforming system performance

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1. Introduction

Methanol steam reforming (MSR) has attracted much attention as a method for hydrogen production, due to its endothermic nature which allows waste heat recovery. However, experimental MSR requires temperature of more than 473 K to enable a high conversion of methanol into hydrogen [1]. Therefore, in this research, a combined absorption heat pump (AHP) and MSR system was proposed, and evaluated in several conditions of MSR experiments and AHP parameters. A feasibility criterion as a measure of the combined system performance was also investigated.

2. Experiments of MSR

The experimental set-up of MSR consists of a reactor module, heating system, and gas analysis system [1]. The reactor chamber (11 x 69 x 3 mm) was filled with 1.5 gram $Cu/Zn/Al_2O_3$ MDC commercial catalyst, crushed into grains with diameter 500 µm - 1.18 mm. In the reactor chamber, methanol and water vapor will mix and react catalytically:

$$CH_3OH_{(g)}+H_2O_{(g)} \leftrightarrow CO_2+3H_2 \quad \Delta H^{\circ}_{298K} = 49.5\,\text{kJ/mol} \quad (1)$$

The operating condition of MSR experiment was performed at temperature range 160-225°C with variation of four different values of gas hourly space velocity (GHSV = 4000 h^{-1}, 2666 h^{-1}, 2000 h^{-1}, 1333 h^{-1}). GHSV is defined as the ratio between the gas flow into the reactor over the volume of catalyst:

$$\text{GHSV}[h^{-1}] = \frac{(CH_3OH + H_2O)_{IN}\ [m^3h^{-1}]}{\text{Volume of catalyst}\ [m^3]}. \quad (2)$$

Besides GHSV, two different values of steam to carbon (methanol) molar ratio (S/C=1 and 2) were also performed in this experiment.

The results of the methanol conversion in different operating conditions are shown in Fig. 1.

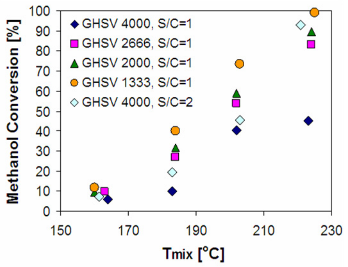

Fig.1. Experimental results of methanol conversion as a function of temperature in several GHSV and S/C conditions.

3. Calculation Method

The calculation step comprises of defining and calculation of AHP parameters, calculation of mixing temperature, interpolating the results of methanol conversion, and calculation of feasibility criterion.

The output temperature of AHP (T_A) can be calculated:

$$T_A = T_D (T_D / T_C)^n, \quad (3)$$

where T_D (373 K) is temperature of waste heat flowing through evaporator and generator of AHP, T_C (298 K) is the temperature of AHP condenser, and n is the step number of AHP [2]. Output temperature T_A can be adjusted by changing the step number. The work required for AHP ($\dot{W}_{AHP}$) to enhance the temperature of steam from temperature T_D to T_A is:

$$\dot{W}_{AHP} = \dot{n}_s c_{p,s} (T_A - T_D)^2 / T_A, \quad (4)$$

where $\dot{n}_s$ is the molar flow rate of steam, $c_{p,s}$ is the specific heat of steam (36.5 $Jmol^{-1}K^{-1}$).

After the steam achieved temperature of T_A, it is mixed with methanol, resulting in mixing temperature (T_{mix}):

$$\dot{n}_s c_{p,s} (T_A - T_{mix}) = \dot{n}_m c_{p,m} (T_{mix} - T_{CH_3OH}) \quad (5)$$

where $c_{p,m}$ is specific heat of methanol gas (61.4 $Jmol^{-1}K^{-1}$), $\dot{n}_m$ is the molar flow rate of methanol gas, T_{CH3OH} is temperature of methanol pre-heated with waste heat (373 K). The results of experimental MSR shown in Fig. 1 are curve-fitted with sigmoid function described by:

$$\eta_{MSR}(T_{mix}) = \frac{1}{1+\exp(-D(T_{mix} - x))}, \quad (6)$$

where D and x are coefficients to adjust the gradient and dislocation of the sigmoid function to fit the experimental data. Lastly, a feasibility criterion defined as:

$$\phi = \frac{\text{Energy gain by MSR}}{\text{Work required for AHP}} = \frac{\eta_{MSR}(T_{mix})\,\Delta H_{MSR}\,\dot{n}_m}{\dot{W}_{AHP}}, \quad (7)$$

is used to measure the performance of combined system.

4. Results and Discussions

The results of feasibility criterion as a function of AHP step number are shown in Fig. 2(a) and (b).

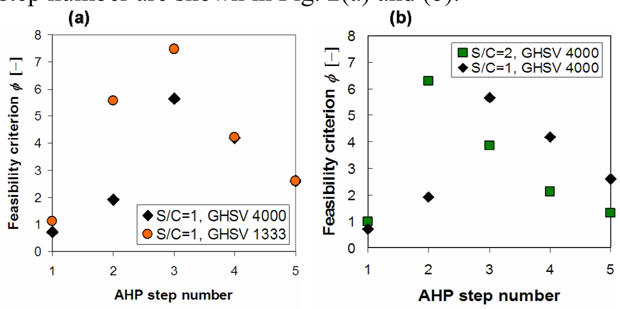

Fig.2. Feasibility criterion as a function of AHP step number. Results at (a) S/C=1, GHSV 4000 and 1333 h^{-1}, (b) S/C=1 and 2, GHSV 4000 h^{-1}.

The decrease of GHSV will increase feasibility criterion up to AHP step number 3, which corresponds to the increase of methanol conversion. Meanwhile, the increase of S/C results in shifting of feasibility criterion peak to AHP step number 2, which can be attributed to the much higher $\dot{W}_{AHP}$ required at higher AHP step number. The peak of feasibility criterion is due to the increase of methanol conversion caused by the increase of T_A (and consequently T_{mix}) at higher step number. However, when the step number is further increased, COP is decreased (which corresponds to drastic increase of $\dot{W}_{AHP}$) resulting in the decrease of feasibility criterion.

References

[1] W.Y. Wijaya, H. Watanabe, K. Okazaki, Proceedings of MISW (2009) 22, Tokyo, Japan.

[2] N. Inoue, K. Irie, Y. Fukusumi, Ebara Report 210-1 (2006) 12-19.

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