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PRODUCTION OF SOLAR HYBRID FUELS OF DME, METHANOL AND H_2 IN AUSTRALIA AND SHIPPING TO JAPAN

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ABSTRACT

Solar hybrid fuel production from natural gas using concentrated solar thermal energy in Australia was studied, assuming that 54.6MW/(one unit of solar farm) of the concentrated solar thermal energy is used for the endothermic process of stream reforming (solar steam reforming; SSR) with total solar energy conversion efficiency of 45.5% (120MW of heliostat field; one unit of solar farm). With 23 units of the solar farm, natural gas of 2516t/d can be reformed by the SSR. To ship the product fuel to Japan by existing tankers, the syn-gas (CO + $3H_2$) produced by the SSR is separated into one mole of H_2 (375t/d) and the mixed gas of one mole of CO and two moles of H_2 which is converted to one mole of methanol (6000t/d) to be shipped by existing tankers. The one mole of H_2 will be used in Australia as the H_2 fuel with 25% solar share (CO_2 reduction). To improve cost barrier between oil and the methanol produced by SSR, the CO_2 zero emission process of the combined process of SSR and AT (auto-thermal process) is proposed as the one whose methanol cost can be competitive with oil, when carbon tax is introduced. By shipping the methanol produced by the CO_2 zero emission process of the combined process of SSR-AT (economically feasible), we can reduce CO_2 emission by co-firing coal and methanol at coal-firing power stations in Japan. In this system, an excess H_2 fuel with solar energy is produced, and can be used in Australia.

INTRODUCTION

The endothermic reactions of methane steam reforming and coal gasification can absorb concentrated solar thermal energy. With this process, the fossil fuel of natural gas and coal can be up-graded to the syn-gases, which bear 20-25% of the solar energy (solar hybrid fuel). This means that we can produce 100% fuel energy using 20-25% of the solar energy, and that we can reduce the solar facility cost by four to five times to produce 100% fuel energy. Thus the solar hybrid fuel production system (solar steam reforming; SSR, solar coal gasification; SCG) is expected to be commercialized when operated at the sun-belt [1-4]. Also this solar hybrid fuel production system (SSR or SCG) can be combined with the several processes such as auto thermal process (AT-process), two step water splitting process, and solar thermal power generation system etc. for more economically and technically feasible operation.

In the SSR process, the concentrated solar thermal energy is supplied to the endothermic process of the steam reforming, and the theoretical content of the syn-gas is CO+$3H_2$ (H_2/CO = 3). In the AT-process or partial oxidation process (POX process), the thermal energy needed for the endothermic process of the natural gas reforming is supplied by combustion of natural gas in the reactor, therefore the molar ratio of H_2/ CO of the syn-gas becomes lower compared with that produced by the SSR. Thus, the lowering in the H_2 content comes from excluding the solar thermal energy supplied in the SSR process, and the solar share in the syn-gas becomes zero in the AT- and POX-process. On the other hand, the production cost of the syn-gas will be minimized in the POX or AT-process because of excluding the higher construction cost of the solar facility. And, when the carbon tax is introduced, the production of the H_2 fuel with solar energy (solar hybrid fuel production) seems to have an advantage. These considerations suggest that there is an optimum combination among the systems which will provide the most feasible to produce solar hybrid fuel in relation to the reduction of the production cost and the CO_2 emission.

This paper describes the study on the combined systems among the SSR and AT systems to find out the most economically feasible system for production of solar hybrid fuels (methanol and hydrogen), which can minimize the CO_2 emission. Also, the production of methanol (or DME) will be considered from the view point of shipping from the sun-belt in Australia to Japan in the liquid fuel which can be transported by the existing tankers.

NOMENCLATURE

DME	dimethyl ether
AT	Auto thermal
SSR	Solar steam reforming

H_2 PRODUCTION BY THE SOLAR STEAM REFORMING USING CONCENTRATED SOLAR THERMAL ENERGY

In the steam reforming system, one mole of CO and three moles of H_2 are produced by the reaction of the methane steam reforming (solar steam reforming; SSR), as given by

$$CH_4 + H_2O = CO + 3H_2 \quad +206.16 \text{ kJ/mol} \qquad (1).$$

The CO is converted to H_2 by shift reaction of

$$CO + H_2O = CO_2 + H_2 \quad -41.2 \text{ kJ/mol} \qquad (2).$$

Totally the H_2 production from one mole of CH_4 is given by

$$CH_4 + 2H_2O = CO_2 + 4H_2 \text{ (total reaction)} \qquad (3).$$

When the concentrated solar thermal energy is used for the endothermic process of eq. 1, four moles of H_2 can be theoretically produced. This means that, compared with the conventional process, where the heat for the endothermic process is supplied by burning natural gas, 23% larger amount of H_2 fuel (solar hybrid fuel) can be produced by introducing the solar energy. Also, here, we have to consider the conversion of the syn-gas to methanol or DME(dimethyl ether), when the product fuel is transported to Japan by the existing tanker.

Figure 1 shows the flow chart of the production of methanol (one mole) and hydrogen (one mole) using the concentrated solar energy in the sun-belt [5]. For evaluation of material and energy balance in Figs. 1-4, it is assumed that the thermal energy in the endothermic process is theoretically supplied from the concentrated solar thermal heat and combustion heat of natural gas. The syn-gas (one mole of CO and three of H_2) can be produced by the SSR. Also, it is assumed that 54.6MW/(one unit of solar farm) of the concentrated solar thermal energy is used for the endothermic process with the total solar energy conversion efficiency of 45.5% (120MW of heliostat field for one unit of solar farm. In Fig. 1, with 23 units of the solar farm, natural gas of 2516t/d can be reformed by the SSR. To ship the product fuel to Japan by existing tankers, the syn-gas ($CO + 3H_2$) produced by the SSR is separated into one mole of H_2 (375t/d) and the mixed gas of one mole of CO and two moles of H_2 which is converted to one mole of methanol (6000t/d) to be shipped by existing tankers. The methanol can be transported to Japan by the existing tankers from the sun-belt. The H_2 gas (375t/d; corresponding to the one mole of H_2 with 25% solar share) (solar hybrid H_2) separated by the PSA can be used in Australia by transporting through the natural-gas pipeline in Australia. This will contribute to reduction of the CO_2 emission in Australia. Thus, we can obtain two kinds of products of the H_2 (one mole) and the methanol (one mole methanol = two moles of H_2 at the H_2-refueling site in Japan). In the system of Fig.1, natural gas fuel is upgraded to the mixed fuel of the H_2 and methanol by solar energy.

The economical evaluation for the solar hybrid H_2 production system in Fig. 1 showed that the investment cost for the solar concentrating system to supply the endothermic energy for the methane steam reforming will be compensated with the benefit from the production of H_2 along with methanol for the system of Fig.1. And, the cost of the methanol produced in Fig.1 can be competitive with the LNG cost (competitive with DME cost produced by POX), when carbon tax is introduced. However, there is the cost barrier between oil and the methanol produced by SSR.

Figure 2 shows the solar hybrid H_2 productions system, which makes the solar hybrid fuels production more economically feasible. This system is the combined-process of the SSR and AT process (SSR-AT combined-process). In the day time (6h), the steam reforming according to eq. 1 using solar concentrated heat (SSR) can be operated. In the night (18h), the AT process is applied. The ratio of the operation time in day and night time is 1 : 3. With this process, the production cost of the solar hybrid fuels of H_2 and methanol can be

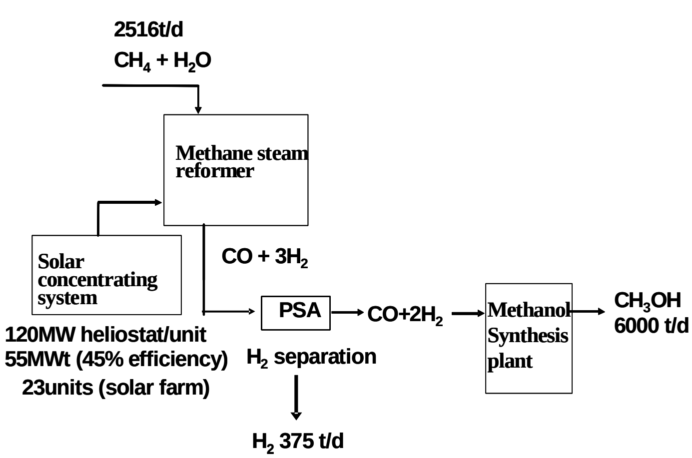

Fig. 1 H_2 and Methanol production by steam reforming with solar concentrating system at sun-belt.

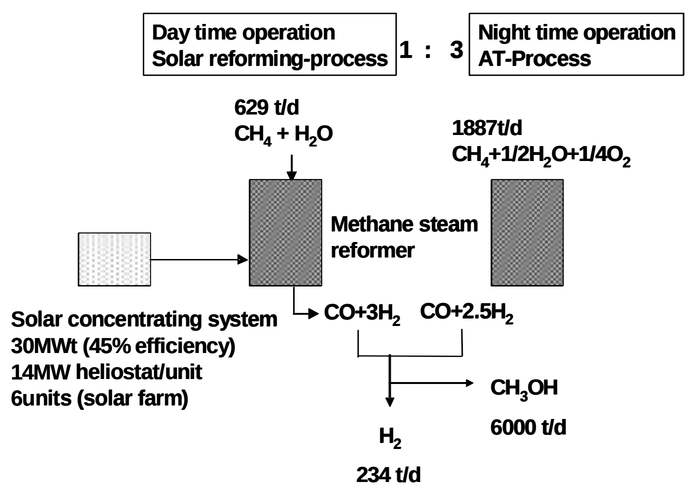

Fig. 2 Combined-process of Solar Steam Reforming and AT-process(SSR-AT combined-process).

cost of the solar facility (solar farm number of 23 is reduced to 6). The economical evaluation showed that the cost barrier reduced further by 1/4, compared with the system of Fig. 1, mainly because of excluding the higher construction between oil and the methanol produced by SSR can be improved by the combined process of SSR and AT process, when carbon tax is introduced.

COMBINATION OF SSR-TA PROCESS WITH SOLAR THERMAL POWER GENERATION SYSTEM, AND WITH TWO STEP-WATER SPLITTING PROCESS

In the process of Fig.2, the O_2 gas should be generated. When the O_2 gas is obtained by cryogenic separation using compressor and its power is supplied by combustion of fossil fuels, the CO_2 will be emitted. However, when the power for the compressor is supplied by the solar thermal power, the CO_2 emission can be theoretically reduced to zero. And, theoretically the methanol can be produced in the condition of CO_2 zero emission. Therefore, we can reduce the CO_2 emission at coal-firing power stations by co-firing coal and methanol in Japan, when the methanol is shipped to Japan.

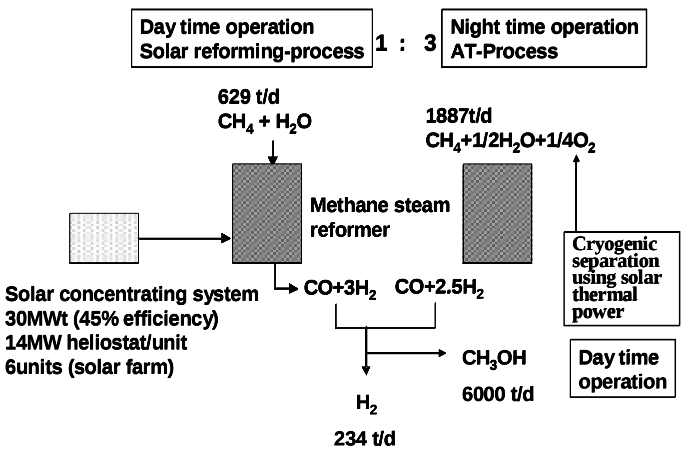

Fig.3 CO_2 zero emission process of SSR-AT combined-process.

Also, as given by Fig.4, the O_2 gas can be obtained by the two-step water splitting process (TWS process) using concentrated solar thermal energy [2,7,8]. In this combined system of SSR, AT, and TWS (SSR-AT-TWS combined-process), the H_2 fuel productivity increases to 328t/d (Fig.4). The economical evaluation indicated that the cost barrier between oil and the methanol produced by SSR is not so largely improved by SSR-AT-TWS combined-process in the condition that carbon tax is introduced. However, this system has much higher CO_2 reduction factor than the SSR-AT with the cryogenic separation system for O_2 generation. Thus, the SSR-AT-TWS combined-process seems to be expected for the technology to be used to reduce CO_2 emission as the mid-term technology.

When compared with the PV-electrolysis system to generate O_2 by water splitting, the TWS process has the advantage that the electrolysis step can be omitted. In this sense, the TWS process will be more practically applicable for the water splitting process using solar energy.

Thus, the CO_2 zero emission process of SSR-AT combined process would be the most effective process for reducing the CO_2 emission and can be operated more economically for the production of methanol and DME, which can be shipped to Japan in the form of the liquid fuel (solar hybrid fuels of methanol and DME).

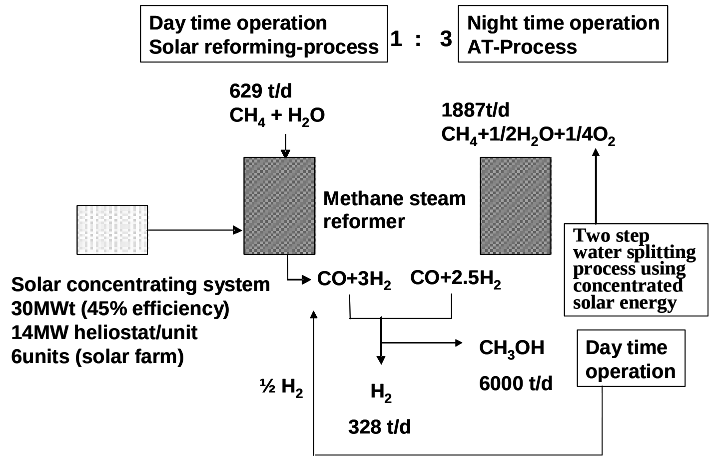

Fig. 4 SSR-AT-TWS combined-process.

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