A Study on the Effects of the Plant Configurations on the Nuclear Hydrogen Production Efficiency

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1. Introduction

For the proposed hydrogen economy to be viable, it is important to produce hydrogen with high efficiency. In this study, the effect of the plant configuration on the efficiency of nuclear hydrogen production is assessed .

2. Layouts, Methods and Results

For this study, the HyPEP-HC, a simple and fast-running program to assess the hydrogen production efficiency was written.[1] It is hard-coded to assess the efficiencies of the four different plant layouts and designed in modular fashion with some object-oriented programming. In all layouts, a VHTR (Very High Temperature Reactor) supplies the thermal power and its outlet is connected to an IHX (Intermediate Heat eXchanger). Four different cases of layouts have been assessed. The four cases have different combinations of the PCU (Power Conversion Unit), I-S (Iodine Sulphur) thermo-chemical unit, and the HTES(High Temperature Electrolysis System) and each layout was hard-coded into the code.

In all the assessments, the design characteristics of the PBR (Pebble Bed Reactor) and the PMR (Prismatic Reactor) were considered. Helium is assumed as the coolant for all units. The outlet temperature of VHTR was set at 950°C while inlet temperature was varied. The PCU is based on the Brayton cycle. For the heat and electricity demand of the I-S unit, the GA data for the operating temperature of 850 °C [2] have been used.

2.1. Configuration 1: Indirect layout, I-S, HTES and PCU in parallel connection

The configuration 1 consists of a VHTR, an IHX, a PCU, an I-S unit, a HTES and gas circulators. The screen-capture of the HyPEP-HC for this configuration is shown in Figure 1 and shows overall plant layout.

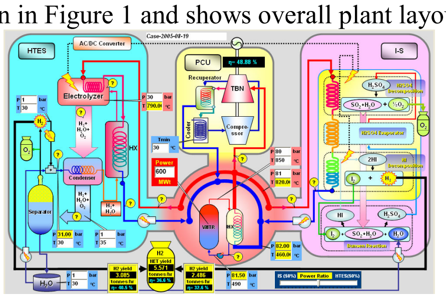

Figure 1 HyPEP-HC Model for Configuration 1

The VHTR, IHX and primary circulator are connected series. And the PCU, I-S and HTES are connected in parallel to the IHX. The helium in the I-S and the HTES are circulated by gas circulators. The PCU generates electricity to be used by the HTES, the I-S unit and the gas circulators. PCU generates just sufficient electricity for in-house usage. Figure 2 shows the results. The results show that for both I-S and HTES, the hydrogen production efficiency improve as the reactor inlet temperature is reduced.

The major contributing factor for the improvement is decreased power requirements of the gas circulators due to the lower temperature. The higher primary pressure also improves the efficiency for the similar reason. Compared with the PBR, the PMR has better efficiencies because the core pressure drop is smaller which leads to lower power requirements of the circulators. Using the currently available data, the expected hydrogen production efficiencies range from 21% ~47%. It should be noted that the results for the I-S unit is expected to be pessimistic because the current calculations used the data based on the outlet temperature of 850 °C.

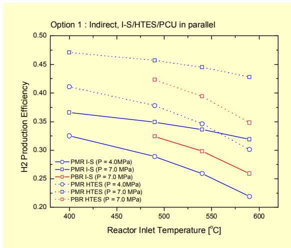

Figure 2. Results for Configuration 1

2.2. Configuration 2: Indirect layout, I-S only

The configuration 2 consists of a VHTR, an IHX, an I-S unit and gas circulators.

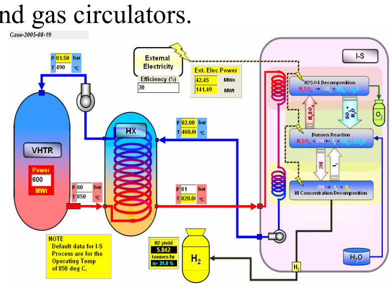

Figure 3. HyPEP-HC Model for Configuration 2

Figure 3 shows the screen-capture of the HyPEP-HC for this configuration. The VHTR is connected to IHX and the primary gas circulator. The I-S unit produces the hydrogen and the electricity needed by the circulator and the I-S unit. The efficiency electricity generation of the external source was assumed to be 30%.

Figure 4 shows the results. As in the results of the configuration 1, the power requirements of the gas circulators have major effect on the overall hydrogen production efficiency. Thus, the efficiency increases as inlet temperature decreases, and as primary pressure increases. The overall hydrogen production efficiency ranges between 20% ~ 35%.

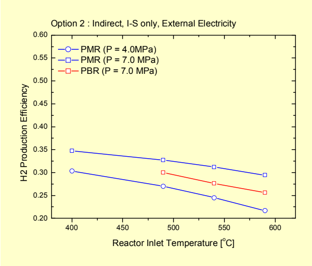

Figure 4. Results for Configuration 2

2.3. Configuration 3: Indirect layout with PCU in series with VHTR, I-S only

The configuration 3 consists of a VHTR, an IHX, a PCU, an I-S unit and a gas circulator for I-S.

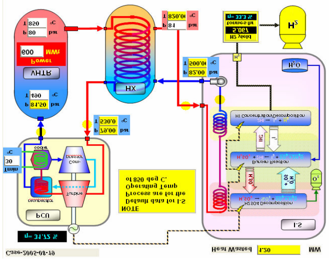

Figure 5. HyPEP-HC Model for Configuration 3

The helium for the prima ry is circulated by the PCU. Figure 5 shows the screen-capture of the HyPEP-HC for this configuration.

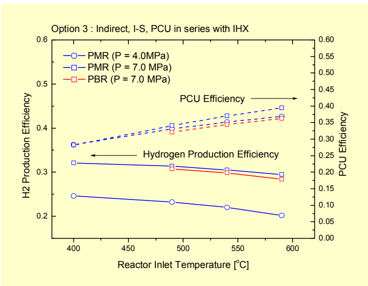

Figure 6. Results for Configuration 3

This configuration differs with the Configuration 2 in having a PCU to supply all the electricity needs of the plant. The PCU is connected downstream of the IHX as the hot temperature is needed for the I-S.

The results are shown in Figure 6. As expected, the PCU efficiency for the electricity generation increases as the inlet temperature increases thus improving the circulator thermal power requirement. However this increase is not sufficient and the overall hydrogen production efficiency decreases as inlet temperature is raised. The overall hydrogen production efficiency ranges between 20% ~ 32%.

2.4. Configuration 4: Indirect layout with PCU in series with VHTR, HTES only

The configuration 4 consists of a VHTR, an IHX, a PCU, a HTES unit and a gas circulator for HTES. Figure 7 shows the screen-capture of the HyPEP-HC for this configuration. This configuration differs with the Configuration 3 in having a HTES in stead of an I-S unit. The PCU is connected downstream of the IHX as the hot temperature is needed for the HTES.

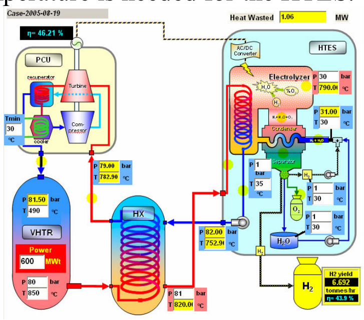

Figure 7. HyPEP-HC Model for Configuration 4

The results are shown in Figure 8. As before, the PCU efficiency for the electricity generation increases as the inlet temperature generally increases but the increase is less marked because the IHX takes little energy compared with the I-S case. However this increase is not sufficient and the overall hydrogen production efficiency decreases as inlet temperature is raised. The overall hydrogen production efficiency ranges between 30% ~ 45%.

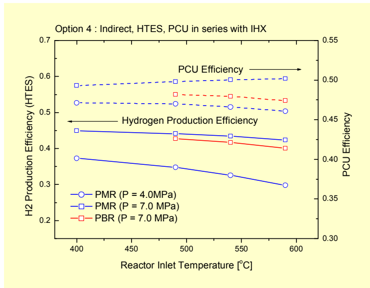

Figure 8. Results for Configuration 4

3. Conclusions

From layout study, it was found that the circulator power has a strong effect on the overall efficiency. It is therefore important to design a layout that minimizes the circulator power requirements.

REFERENCES

[1] Y. J. Lee et al., "Preliminary Study on the NHDD Plant Configuration, a VHTR coupled to Hydrogen Production Systems", Proceedings of ICAPP'05, May 2005.

[2] L. C. Brown et al., "High Efficiency Generation of Hydrogen Fuels using Nuclear Power", pp. 3-6 ~ 3-25, GA-A24285, General Atomics, 2003.