Strength Evaluation of a Preliminary Hot Gas Duct Design for the NHDD Program

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1. Introduction

Very High Temperature Gas Cooled Reactor (VHTR) has been selected as a high energy heat source for a nuclear hydrogen generation. The VHTR can produce hydrogen from heat and water by using a thermo-chemical process or from heat, water, and natural gas by steam reformer technology. The NHDD program being researched at KAERI is planning to produce hydrogen by using nuclear energy and a thermo-chemical process. Helium gas is the choice for the coolant of the NHDD program since it is an inert gas, with no affinity to a chemical or nuclear activity, therefore a radioactivity transport in the primary circuit of the NHDD program is minimal under a normal operation. Moreover, its gaseous nature avoids problems related to a phase change and water-metal reactions and therefore improves its safety. In this study, a strength evaluation for the HGD of the NHDD program has been undertaken based on the HTR-10 design concepts.

2. NHDD Program Concept

The schematic NHDD program is shown in Fig. 1. According to Fig. 1, two HGDs and an IHX are needed. One of the HGDs, which is called a primary HGD, is located between a reactor pressure vessel and the IHX. The other HGD, which is called a secondary HGD, is located between the IHX and SO_3 decomposer. The primary HGD which is a horizontal coaxial double-tube shown in Fig. 2 provides a passage for hot and cold helium gas. In this study, the preliminary design on the primary HGD of the NHDD program is carried out based on the HTR-10 design concepts [1] because of its successful operating experience and its simplicities as shown in Figs. 2-3. Passing through the NHDD reactor core, the hot helium gas is conveyed via the liner tube of the horizontal HGD to the IHX. After being cooled down, the cold helium gas is returned to the lower section of the reactor pressure vessel via a passage between the coaxial inner tube and the pressure vessel of the HGD.

3. Conceptual Design of the Primary HGD

The HGD is a unique component exclusively found in an HTR-module concept [2] where both the nuclear core and the power conversion unit are placed separately into two pressure vessels, which require a connecting duct between them. By passing through the nuclear core in the NHDD program, hot helium gas in the order of 950℃ is conveyed via the liner tube of the horizontal HGD (primary HGD) to the IHX as shown in Fig. 2. After being cooled down, the cold helium gas in the order of 490℃ is returned to the lower section of the reactor pressure vessel via a passage between the coaxial inner tube and the hot gas pressure tube as shown in Fig. 2. The helium gas pressure in the primary loop is assumed to be 7.0 MPa [3]. The reactor core is located inside the reactor pressure vessel, while the IHX and helium circulator are in an adjacent vessel, i.e. the IHX. Two vessels are assumed to be connected together by the HGD as shown in Fig. 2, one

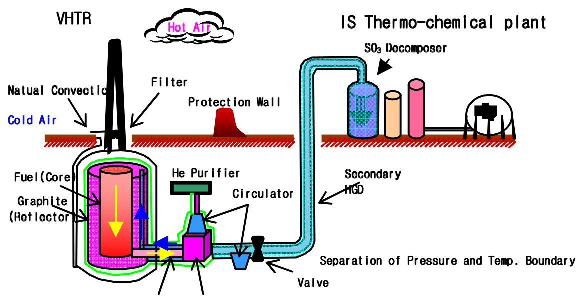

Fig. 1 NHDD Program

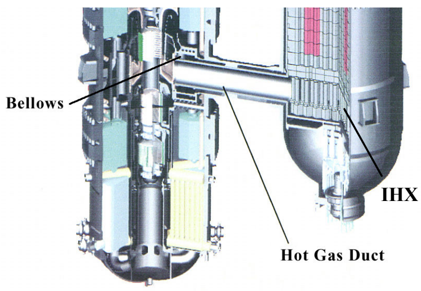

Fig. 2 Position of HGD

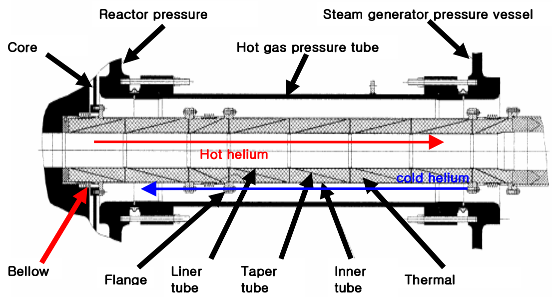

Fig. 3 Structure of the HGD

end is connected to the reactor pressure vessel by a flange; the other end is also connected to the IHX by a flange. The structure used to house the HGD of the NHDD program is similar to the structure housing of the HTR-10. This structure is composed of a liner tube, an inner tube, a hot gas pressure tube, thermal insulating fiber, and a separating taper tube. The inner tube acts as a supporting structure for the inner and taper tubes. Two sets of bellows are used in its design to compensate for a thermal expansion. The HGD is assumed to be divided into eight sections for an easier installation. Each section is assumed to be connected by a slide joint. The HGD has the following functions: 1) transporting the hot helium gas from the core to the IHX; 2) transporting the cold helium gas from the IHX to the core; 3) providing thermal compensations and avoiding large thermal stresses during various operating conditions.

The HGD is a Safety Class 3 and Seismic Class 1 component. It consists of flanges, bellows, a liner tube, an inner tube, a separating taper tube and thermal-insulating fiber. Design parameters of the HGD are listed in Table 2. For the used thermal-insulating fiber in this study the maximum packing pressure is assumed as 0.03MPa.

The HGD has to operate at high temperature and medium pressure conditions for a long time. Its performance for a thermal insulation between the hot and cold helium flow, its ability to resist temperature cycles and pressure cycles and to sustain a total structural integrity at high temperature and medium pressure conditions will play an important role for the long-term safe operation of the NHDD program. The preliminary geometric dimensions for the HGD of the NHDD program have been selected by considering the thermal power of the NHDD program. Structure design and strength evaluation for the HGD of the NHDD program have been undertaken based on the HTR-10 design methodology in case that the following assumptions for the NHDD program are considered; 1) Distance between the axes of the reactor pressure vessel and the IHX is 8855 mm (the length of the primary HGD made of Mod. 9Cr-1Mo, the radius of the reactor and the radius of IHX made of 316 SS are assumed to be 3200 mm, 3330 mm, 2325 mm, respectively.); 2) The thermal expansion coefficient of 316SS is 1.02 x10^{-5} K^{-1}; 3) The temperature rise of the components of the primary loop boundary under accident conditions is 250 ℃; 4) The temperature rise of the inner tube made of Mod. 9Cr-1Mo under accident conditions is 400 ℃; 5) The thermal coefficient and length of the material of the pressure vessel end of the inner tube are 6.9 x10^{-6} K^{-1}, and 900 mm, respectively; 6) The material of the thermal-insulation fiber is AL_2O_3; 7) The flow rate of the helium is 83.73 kg/s; 8) For the used thermal-insulating fiber, the maximum packing pressure is 0.03 MPa and the pressure difference is under 0.2 MPa; 9) The materials of the liner and the taper tube are the same as those of HTR-10. Strength evaluation results for the HGD are listed in Table 3 [4].

Table 1 NHDD Design Configuration

	Design Options
Power [MW_{th}]	200
Fuel Type	Prismatic or Pebble
Pressure Boundary [MPa]	7.0
Inlet/Outlet Temperature [℃]	490/950

Table 2 Design Parameters for the HGD

Tube	ID (mm)	Thickness (mm)	Design Temp. [℃]	Length
Inner T.	d_1=1090	δ_1=10	T_1=550	
Liner T.	d_2= 836	δ_2=7	T_2=950	l_2= 612
Taper T.		δ_3=3		l_3= 600

Table 3 Strength Evaluation Results

Item	Design Options	Results
Thermal compensation of bellows Strength evaluation of the liner tube [MPa] Strength evaluation of the inner tube [MPa] - Mean shear stress (τ_4) [MPa]	3 [mm/ripple] $\sigma_1 < S_3(=9.33)$, $\sigma_1^{acc} < 1.5\ S_3\ (=14.0)$ $\sigma_4\ (S_2=110.0)$, $\sigma_4^{acc} < 1.5\ S_2\ (=165.0)$ $\tau_4 < 1.33$ x $0.6\ S_2\ (=88)$	Need 1 or 2 ripples $\sigma_1 = 1.8$, $\sigma_1^{acc} = 11.9$ $\sigma_4 = 1.6$, $\sigma_4^{acc} = 10.9$ $\tau_4 = 17.9$
Taper tube (small dia.end) - Max. nominal stress (S_1) [MPa] - Mean shear stress (t_1) [MPa]	$S_1^{max} <$ 1.5 S_3 (=14.0) $t_1 <$ 1.33 x 0.6 S_3 (= 7.4)	S_1^{max} =0.42 t_1 =0.29
Taper tube (large dia. end) - Max. nominal stress (S_2) [MPa] - Mean shear stress (t_2) [MPa]	$S_1^{max} <$ 1.5 S_3 (=14.0) $t_1 <$ 1.33 x 0.6 S_3 (= 7.4)	S_2^{max} =0.41 t_2 =0.19

4. Conclusion

The indirect cycle gas cooled reactors that produce heat at temperatures in the order of 950℃ are being considered in the NHDD program at KAERI. Preliminary strength evaluation results for the HGD of the NHDD program showed that the preliminary decision on the geometric dimensions would be acceptable for the design requirements. So, the preliminary geometric data will be used for the basic design data for the HGD of the NHDD program.

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