Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Conceptual Design on the Main Components for NHDD Program

[a] Keenam Song,[a] J-Y Kim, K-H Lee, Y-W Kim
a Korea Atomic Energy Research Institute, P.O.BOX 105 Yusong, Taejon, KOREA

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 iodine-sulfur (I-S) process or from heat, water, and natural gas by applying steam reformer technology. New concepts based on a VHTR have been of interest for an energy source with a thermo-chemical process for a hydrogen production. The NHDD (Nuclear Hydrogen Development and Demonstration) program being developed at KAERI also uses the same concepts to produce heat at temperatures in the order of 950℃. Helium is the choice for a coolant since it is an inert gas, with no affinity for a chemical or nuclear activity therefore a radioactivity transport in the primary circuit is minimal under a normal operation. Moreover the gaseous nature avoids problems related to a phase change and water-metal reactions and therefore improves its safety. It also allows for the use of the Brayton cycle, the improving the thermal efficiency and economics. Brayton cycle designs can be indirect, with an intermediate heat exchanger (IHX) provided as an interface between primary and secondary circuits. For nuclear hydrogen applications, an IHX is required to transfer heat from high temperature high-pressure primary helium to an intermediate heat transfer fluid. In the NHDD program, helium is considered as the intermediate fluid. A baseline candidate of a thermo-chemical process for the NHDD program is the Sulfur Iodine (S-I) Cycle. This cycle consists of three chemical reactions to dissociate water, which needs only water and heat to be added to the cycle. Key components of the NHDD program are an IHX and a hot gas duct (HGD). In this study, a strength evaluation of the HGD for the NHDD program has been carried out based on the HTR-10 design concepts. And, also a conceptual design of the IHX for the NHDD program has been carried out.

2. NHDD Program Concept

The schematic NHDD program is shown in Fig. 1. According to Fig. 1, two HGDs and an IHX are needed in the NHDD program. 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 SO3 decomposer. The primary HGD which is a horizontal coaxial double-tube provides a passage for hot and cold helium gas. In this study, the conceptual design of the primary HGD in the NHDD program is based on the HTR-10 design concepts[1] because of its successful operating experience and its simplicities as shown in Fig. 2. Passing through the NHDD reactor core, hot helium gas is conveyed via the liner tube of the horizontal hot gas duct 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 hot gas duct.

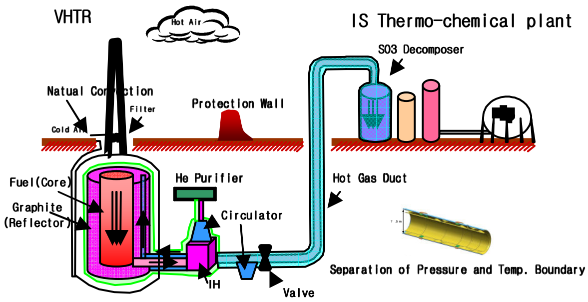

Fig. 1 NHDD Program

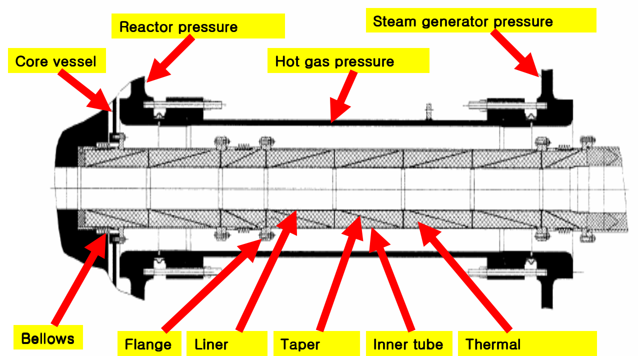

Fig. 2 Structure of the HGD

The IHX transfers the high temperature heat coming from the VHTR to the I-S process. The secondary HGD which is located between the IHX and SO3 decomposer designed with the same structure as the primary HGD. Passing through the IHX, hot helium gas is conveyed via the liner tube of the horizontal hot gas duct to the SO3 decomposer. After being cooled down, the cold helium gas is returned to the IHX via a passage between the coaxial inner tube and pressure vessel of the HGD. Even if many kinds of IHX concepts are prevailing, such as a compact heat exchanger of the plate-fin or printed-circuit type and tubular type heat exchanger[2], the type of the IHX for the NHDD has not been determined as yet but several studies for selecting a proper type have been conducted[3,4]. Design of the IHX needs a large amount of studies and experiments with regards to the heat transfer performance, secondary coolant and material selection, and its structural integrity etc. Due to the inherent high temperature operation of the IHX, a design approach by experiments has encountered many restrictions.

3. HGD Conceptual Design

The HGD is a unique component exclusively found in an HTR-module concept where both the nuclear core and the power conversion unit are paced into two pressure vessels, which need a connecting duct. Passing through the HTR-module 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. After being cooled down, the cold helium gas in the order of 400-590℃ is returned to the lower section of the reactor pressure vessel via a passage between the coaxial inner tube and pressure vessel of the hot gas duct. The helium gas pressure in the primary loop is supposed to be 3.0 MPa. 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 supposed to be connected together by the primary HGD, one end is connected to the reactor pressure vessel by a flange; the other end is connected to the IHX by a flange also. The structure used to house the primary HGD of the NHDD program is similar to the structure housing the HTR module. This structure is composed of an inner tube, outer tube, insulation layer and corundum bricks, etc. The outer tube acts as the supporting structure for the inner tube and insulation layer. Both ends of the outer tube are welded to corrugated pipes to absorb the thermal expansion. The primary HGD is supposed to be divided into five sections for an easier installation. Each section is supposed to be connected by a slide joint. Corundum bricks are supposed to be used as insulating material between the two inner tubes and they are supposed to be fixed to the outer tube.

Structure design and strength evaluation of the primary HGD of the NHDD program have been carried out based on the HTR-10 design methodology[1] with considering some assumptions in the NHDD program[5].

4. IHX Conceptual Design

The indirect-cycle VHTR is one of the leading contenders for the next generation nuclear reactor, as it allows for a common heat source to be used for a hydrogen production while minimizing the complexity and risk associated with the nuclear part of the cycle. In the NHDD program, the IHX will need to have both a high effectiveness and low pressure drop. The indirect-cycle gas cooled reactor of the NHDD program produces heat at temperatures in the order of 950℃. This heat can be used for a hydrogen production, via an S-I process.

The IHX must be a highly reliable boundary between the primary and the secondary coolants, compact, and thermally efficient. Printed circuit heat exchangers or plate-fin type compact heat exchangers are favored because of their size and high efficiency. Shell and tube heat exchangers can be a backup option. As the heat exchange system must operate under very high-temperature conditions, an alternative solution for minimizing the operational stresses could be integrate within a secondary pressure boundary.

5. 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. For the indirect gas cooled reactors, an intermediate heat exchanger and a hot gas duct are considered to be the key components. Strength evaluation results[5] on the HGD for the NHDD program showed that the preliminary geometric dimensions would be acceptable for the design requirements. So, the preliminary geometric data is supposed to be the basic design data of the HGD for the NHDD program

Acknowledgements

This project has been carried out under the nuclear R & D program by MOST (Ministry Of Science and Technology in Republic of Korea).

REFERENCES

[1] Huang Z. Y. et al., 2002, NED, 218, 137-145.
[2] Tochen P. et al., 2004, 2nd Int. Topical Meeting on the High Temp. Reactor Technology, # Paper E09, Beijing, China.
[3] Tak N. I. and Lee W. J., 2006, Trans. Of Korean Nuclear Society Spring Meeting, Chuncheon, Korea.
[4] Kim M. H. et al., 2006, Trans. Of Korean Nuclear Society Spring Meeting, Chuncheon, Korea.
[5] Kim J. Y., 2006, NHDD-KA06-ME-005 Rev.00, Nov. 28.