PROSPECTS OF HTGR PROCESS HEAT APPLICATION AND ROLE OF HTTR

S. SHIOZAWA, Y. MIYAMOTO
Department of Advanced Nuclear Heat Technology,
Japan Atomic Energy Research Institute,
Ibaraki-ken, Japan

Abstract

At Japan Atomic Energy Research Institute, an effort on development of process heat application with high temperature gas cooled reactor (HTGR) has been continued for providing a future clean alternative to the burning of fossil energy for the production of industrial process heat. The project is named "HTTR Heat Utilization Project", which includes a demonstration of hydrogen production using the first Japanese HTGR of High Temperature Engineering Test Reactor (HTTR). In the meantime, some countries like China, Indonesia, Russia and South Africa are trying to explore the HTGR process heat application for industrial use. One of the key issues for this application is economy. It has been recognized for long time and is still now that the HTGR heat application system is not economically competitive to the current fossil ones, because of the high cost of the HTGR itself. However, the recent movement on the HTGR development, as represented by South Africa Pebble Beds Modular Reactor (SA-PBMR) Project, has revealed that the HTGRs are well economically competitive in electricity production to fossil fuel energy supply under a certain condition. This suggests that the HTGR process heat application will be also possible to get economical in the near future. In the present paper, following a brief introduction describing the necessity of the HTGRs for the future process heat application, Japanese activities and prospect of the development on the process heat application with the HTGRs are described in relation with the HTTR Project. In conclusion, the process heat application system with HTGRs is thought technically and economically to be one of the most promising applications to solve the global environmental issues and energy shortage which may happen in the future. However, the commercialization for the hydrogen production system from water, which is the final goal of the HTGR process heat application, must await the technology development to be completed in 2030's at the earliest. The HTTR heat Utilization Development Project is hoped to contribute to the technology development, cooperating with other countries of interest.

1. Introduction

The ultimate potential offered HTGRs derives from their unique ability to provide heat at high temperatures (e.g. in the range from 500°C to 1000°C) for endothermic chemical processes. Heat from HTGRs can be used for production of synthesis gas and/or hydrogen and methanol by steam/methane reforming, production of hydrogen by high temperature electrolysis of steam and by thermochemical splitting of water, production of methanol by steam or hydrogasification of coal, and for processes which demand lower temperatures, such as petroleum refining, sea water desalination, district heating, and generation of steam for heavy oil recovery and tar sand mining. The application of such nuclear heat as above, referred herein as "process heat application", can make a significant contribution to resolve global environmental problems which result from burning fossil fuels.

This paper introduces the Japanese research and development activities on the process heat application as well as industries' prospect of the commercialization.

2. Research and development activities in Japan

(1) History

The history of the research and development activities on HTGRs dates from about 30 years back. At that time, the possibility of direct steel making was sought by utilizing the heat from HTGRs. Then, the VHTR (Very High Temperature Reactor) Project was initiated in 1969 at JAERI, Japan, including research and development (R&D) which covers all fields necessary for the reactor design and construction of the VHTR as well as process heat application systems. However, there was no urgent or strong commercial demands coming up afterwards, although the essential needs of the HTGRs were well understood for the future. Thus the Project was reviewed by the Government to shift it to more basic research for the future rather than immediate development for commercial use.

In accordance with this review, Atomic Energy Commission of Japan issued in 1987, the revision of Long term Program for Development and Utilization of Nuclear Energy, recommended that Japan should proceed with the development more advanced technologies for the future, in parallel with existing nuclear systems. The Long term Program emphasized that the HTGR is considered as one of the most promising nuclear reactors to improve the economy and to extend the application of nuclear energy. In conclusion, the construction of the High Temperature Engineering Test Reactor (HTTR) was decided to establish and upgrade HTGR technology basis as well as to be used as a tool for innovative basic research in the field of high temperature engineering. It should be noted that the HTTR is neither an experimental nor prototype rector for commercial HTGR, but a test rector for the future.

According to the revised Long term Program for Development and Utilization of Nuclear Energy, the construction of the HTTR was initiated in 1991 and is now in the stage of commissioning tests. The first criticality of the HTTR was attained in November 1998, followed by the rated power operation about one year later. The R&D on the process heat application has been also continued to couple the system to the HTTR.

(2) Current status

In Japan, the basic study on HTGR process heat application had been made for longer than 20 years mainly at JAERI, Japan. The current R&D activities have successively followed the past basic studies in larger engineering scale tests within a framework of the HTTR Heat Utilization Project, including international cooperation. Some IAEA Member States are cooperating in the design and evaluation of potential HTTR heat utilization systems within a frame of the IAEA Coordinate Research Programme (CRP). Countries participating in this CRP include China, Israel, Germany, Russia, Indonesia, Japan and the USA. In the CRP, the processes being assessed are selected by the CRP participants according to their national interest depending on status of technology, economic potential, environmental considerations, and other factors. The following are being examined:

(1) Steam reforming of methane for production of hydrogen and methanol
(2) Thermochemical water splitting for hydrogen production (IS Process)
(3) High temperature electrolysis of steam for hydrogen production
(4) Gas turbine for electricity generation
(5) CO_2 reforming of methane for production of hydrogen and methanol
(6) Combined coal liquefaction and steam generation

Among them, the steam reforming of methane was selected as the first candidate to be demonstrated at the HTTR for production of hydrogen (and methanol). In the next to the steam reforming system, the system of either the gas turbine or the thermochemical water splitting (IS process) is the highest priority candidates for the HTTR test.

(i) Steam reforming system [1–6]

The steam reforming system was selected as the first candidate of the HTTR heat utilization demonstration test, because its technology is proven in the non-nuclear application with fossil energy sources so that an early coupling to the HTTR is possible. Also, the technology obtained through the development of the HTTR steam reforming system would be applicable to other possible process heat application systems such as CO_2 reforming and thermochemical hydrogen production systems of e.g. IS process.

For this purpose, an extensive effort has been continued in the system design and R&D for improving the efficiency of the hydrogen productivity. An out-of-pile mock up test is prepared at present in prior to the coupling. The first HTTR demonstration will be hopefully shown in 2004 or a little later. The details are available in the separate papers shown in the references.

(ii) IS Process [1–4, 7–10]

In the steam reforming hydrogen production system mentioned above, methane is used as a feed gas together with water to produce hydrogen, thus the emission of CO_2 is unavoidable. It is generally understood that the final goal of the hydrogen production system using HTGRs is to produce it from water without emission of CO_2. For this purpose, the thermochemical IS process was studied in a small scale laboratory experiment. In the experiment, a closed-cycle continuous operation in a steady state for 48 hours was successfully achieved at JAERI. Then the development activity will be shifted to more engineering system development using a larger scale facility at a hydrogen production rate of std. 50 litters an hour. The coupling to the HTTR will be possible at earliest in 2010. The details are available in the separate papers shown in the references.

3. Industries prospect for commercialization

In parallel to the HTTR activities, Japanese nuclear industries' group is trying to explore the development of the HTGRs. In their tentative survey, it was recognized that the HTGRs with gas turbine may be possible to be economically competitive to the current LWRs, as is planned to be built in South Africa. Then, they will recommend that the HTGRs shall be commercialized in Japan first for electricity generation with gas turbine system, hopefully in 2010's. In response to this recommendation, some feasibility studies or design works will be initiated soon among them in cooperation with JAERI.

With respect to the process heat application by HTGRs, it is concluded that its application will be promising in the future from not only the global environmental point of view, but also the conservation of fossil fuels resources. In this regard, the hydrogen production from water, not from fossil fuel, is recognized as the ultimate goal of the HTGR process heat application. Under this understanding, the development study on the thermochemical water splitting for hydrogen production like the "IS Process" is evaluated to be the highest priority. On the other hand, it was found that no direct or urgent demand for the nuclear process heat application exists at present in Japan. Furthermore, technologies are assessed to be not matured or well developed in the thermochemical water splitting system, still now. It is therefore directed that the current development study underway at JAERI be continued with focus on technical development of materials to be used at chemical reaction equipment and on improvement of efficiency and economy. The first pilot plant in Japan for the process heat application with the HTGR is foreseen in 2030's at the earliest.

It is also pointed out that the potential needs for the process heat application exist in some overseas countries like China, Indonesia, the Russian Federation and South Africa. The commercialization will be coming up earlier in these countries than in Japan. Therefore, some industries are looking to their countries, trying feasibility studies.

4. Economic aspect

One of the biggest problems is absolutely economy for the commercial process heat application systems. It is said that the economy of the total system is made worse by capital cost for HTGRs which supply heat to the heat application system via intermediate heat exchanger, because it is presumed that the cost fraction of heat application system downstream intermediate heat exchanger and hot duct is relatively small in comparison with HTGRs themselves. According to a private communication, a German simple estimation suggests the fraction is less than one-third, maybe one-fifth. The operation and maintenance cost will be relatively small in comparison with the current fossil fuel systems. Thus, the economy improvement of the reactor is inevitable for the success of the commercial plant.

It is obvious that the HTGR safety is achieved by a core with low power density. In comparison to the current LWRs, the power density is less than one-tenth in the HTGRs. Such low power density yields the inherent safety aspect, whereas it requires more capital due to the scale demerit. For example, the size of the pressure vessel of the HTTR with 30 MW thermal output is as large as that of medium size of LWR with 500 MW electrical output. The HTGRs are apparently disadvantageous in economy in comparison with the current LWRs.

On the other hand, the inherent safety aspect in the HTGRs could make it possible that no or quite limited engineering safeguards of reactor grade quality are needed. The only safety elements in the entire system are the fuel element and graphite core components which can be checked in running operation, while the safety of LWRs with high power density is ensured by extensive, active and passive safeguards and the reactor grade quality of the components and materials. Sophistication and expensive reactor grade quality is particularly required for all components of LWRs, but, in the case of HTGRs, ultimately only for the fuel element and graphite core components. Thus, the HTGRs would provide a new, qualitatively different safety, resulting in decreasing the cost. This saftey aspect can also make the heat application system designed in a general industrial safety grade, not nuclear grade, resulting in the significant cost reduction of the system. JAERI is now under developing a new safety philosophy applicable to the future commercial heat application systems, including countermeasures against possible fire or explosion by combustion gasses like methane and hydrogen.

It is also true that the economy of the process heat application system with the HTGRs depends on the productivity efficiency and availability of the system. At JAERI the study for improving the efficiency is taken by developing e.g. in the case of thermochemical IS process, innovative membrane technologies such as high temperature hydrogen separation membranes made of ceramics.. As for availability, the HTTR demonstration test will give the answer. In conclusion, it can be said that the economy improvement of the reactor can solve the problem of the overall economy of the nuclear process heat application systems. The planned commercial development of the gas-turbine HTGRs can be, therefore, regarded as a primary step for the future process heat application system development.

5. CONCLUDING REMARKS

Under an understanding that HTGRs can play an important role to expand the nuclear heat application to chemical industries against the current environmental issue of the CO_2, JAERI proceeds with the development of the nuclear process heat application systems coupling to the HTTR. Global eyes are kept by not only nuclear persons of interest but also the public upon the development of the HTTR heat utilization system, since its successful achievement may enhance the possibility to solve the environmental issue of CO_2 emission as well as a possible energy crisis which might happen in the future.

Finally it should be emphasized that an overall support and understanding from the overseas countries of concern are needed and wished for the success of the Project. The Project is highly expected to contribute so much to promoting international cooperation on the development of HTGRs and its process heat application.

REFERENCES

[1] Present Status of HTGR Research and Development, JAERI (1998).

[2] Y. Miyamoto et al.; Present Status of Nuclear Heat Utilization Systems Development for a High Temperature Gas Cooled Reactor in JAERI, Proc. Int. Conf. Future Nucl. Systems Global'97, 1, 538–543 (1997).

[3] Y. Inagaki et al.; Development Program on Hydrogen Production in HTTR, IAEA TCM on Conservation and Application of High Temperature Gas Cooled Reactor (HTGR) Technology, Beijing, China, 5–6 November 1998.

[4] M.Ogawa et al.; Development Program on HTTR Heat Application Systems at JAERI, IAEA TCM on Prospect of Non Electrical Applications of Nuclear Energy, Beijing, China, 20–23 April 1999.

[5] K. Hada et al. ; Development Program on Hydrogen Production in HTTR, Proc. 3rd JAERI Symposium on HTGR Technologies, (1996).

[6] Y. Inagaki et.al. ; Out-of-Pile Demonstration Test Program of HTTR Hydrogen Production System by Steam Reforming of Natural Gas, Proc. 5th Int. Conf. on Nucl.

[7] K. Onuki et al.; Thermochemical water-splitting for hydrogen production, Proceedings of 8th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics, Vol.3, Kyoto, Sep.30–Oct. 4, 1997, pp.1803–1808.

[8] H. Nakajima et al.; A study on a closed-cycle hydrogen production by thermochemical water-splitting process, Proceedings of 7th International Conference on Nuclear Engineering, Tokyo, Apr.19–23, 1999. (in press).

[9] G-J. Hwang et al.; Hydrogen separation in H_2-H_2O-HI gaseous mixture using silica membrane prepared by chemical vapor deposition, Journal of Membrane Science (in press).

[10] M. Futakawa et al.; Corrosion test of compositionally graded Fe-Si alloy in boiling sulfuric acid, Corrosion Engineering, 46, 811–819(1997).