Energy Consumption Analysis and Comparison of HPC and HPS of HTR-10

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Abstract： In order to reduce the quantity of chemical impurities and the gaseous radionuclide fission products in the coolant helium, a helium purification system (HPS) should be designed for high temperature gas cooled reactor (HTGR) and gas fast reactor (GFR) et al. A HPS is mainly composed of a copper oxide bed, a molecular sieve bed and an active charcoal bed which work under high temperature, room temperature and low temperature, respectively. The energy consumptions of two typical HPS designs-helium pressure and chemistry control (HPC) and the HPS for HTR-10 are analyzed and compared.

Keywords: energy consumption; helium purification system; gas cooled reactor; FFT

1. Introduction

With the development of helium gas cooled reactor, like HTGR and GFR, researchers of different countries have extensively studied the helium purification technology [1]. There is a HPS designed for HTTR in Japan and another for HTR-10 in China, which both have been operating for years [2]. In France, CEA planned to build a pilot scale HPS-helium purification and pressure control system (HPC) to demonstrate the helium purification technology after the operation of a laboratory scale HPS-CIGNE, and the HPC is planned to be ready in use at the beginning of 2008 [3].

In a helium gas cooled reactor, to avoid the corrosion of high temperature materials in the reactor core and the helium-helium heat exchangers and decrease the radioactive pollution of components in power conversion unit (PCU), the HPS is designed to purify a bypass stream from the main helium coolant system to reduce the quantity of chemical impurities such as H2, CO, CO2, H2O, O2, N2, CH4 and the gaseous radionuclide fission products such as Kr, Xe, etc. These contaminants are mainly come from the new helium supply and residual air during first load and desorption from reactor components, air in-leakage, fission products migrated from the fuel elements, and moisture from steam generator leakage [4].

The fundamental principle of these HPS could be described into 3 parts, copper oxide beds, molecular sieve beds and active charcoal beds [1, 2, 3]. The copper oxide bed works under high temperature 250~350℃, to oxide the hard-adsorbed gases such as hydrogen and carbon

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monoxide into easy-adsorbed gases water vapor and carbon dioxide respectively. The molecular sieve bed works under room temperature to adsorb most of the water vapor and carbon dioxide in the helium stream, while the liquid nitrogen-cooled active charcoal bed adsorbs the other remained impurities at -160~-190℃.

Although with these three same beds, the detailed process designs for HPC and HPS in HTR-10 are different. From the point of energy consumption, these two typical designs of HPS are analyzed and compared.

2. Descriptions of HPC and HPS in HTR-10

Within the framework of R&D studies linked to the development of Generation Ⅳ nuclear reactors, CEA has started to build up some helium loops. To test the components, representative conditions have to be reached: temperature, pressure and chemical gaseous composition. To control the chemical composition at impurities low level contents, HPC is designed to purify and to adjust the composition of the helium contained in the loop. It represents 72kg/h of helium and only the gaseous contaminants are controlled. From the point of energy consumption, the purification system of HPC is schematically shown below in fig. 1. At the end of 2006, they had the first reception of components. And the facility will be available for its experimental program at mid 2007 [5].

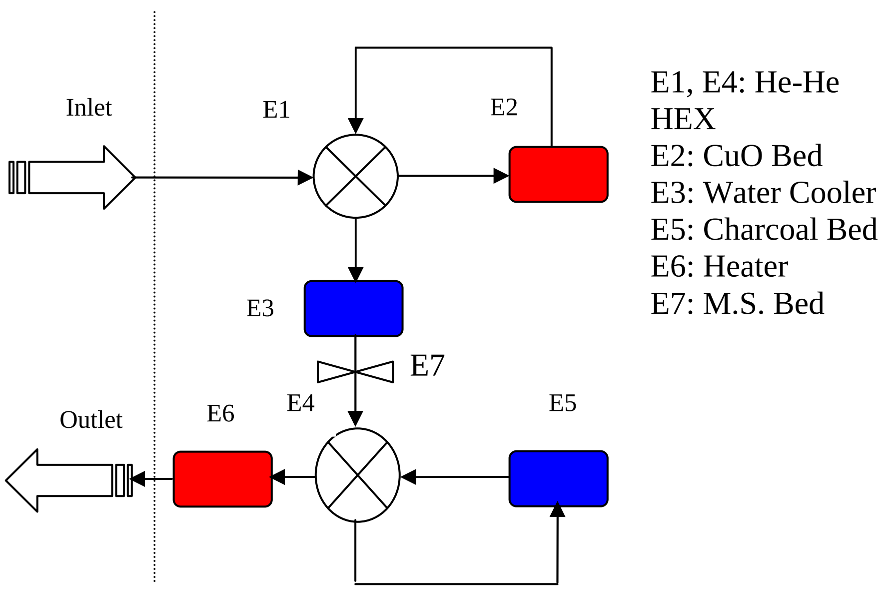

Figure 1 scheme of energy components of HPC

Components in red are heaters, coolers in blue and those white ones are adiabatic to environment. There are same rules in the following drawing.

In China, HTR-10 reached its first full-power operation at 2002. A HPS is designed to reduce the quantity of chemical impurities in the primary coolant helium and to remove the gaseous radionuclide fission products. This actual purification train is designed for a helium flow rate of 10.5kg/h, corresponding with a 5% gas fraction of the helium inventory in primary circuit. It is anticipated that more than 2000h continuous purification operation will be reached between regeneration [1, 4]. The HPS is shown schematically in fig. 2 below.

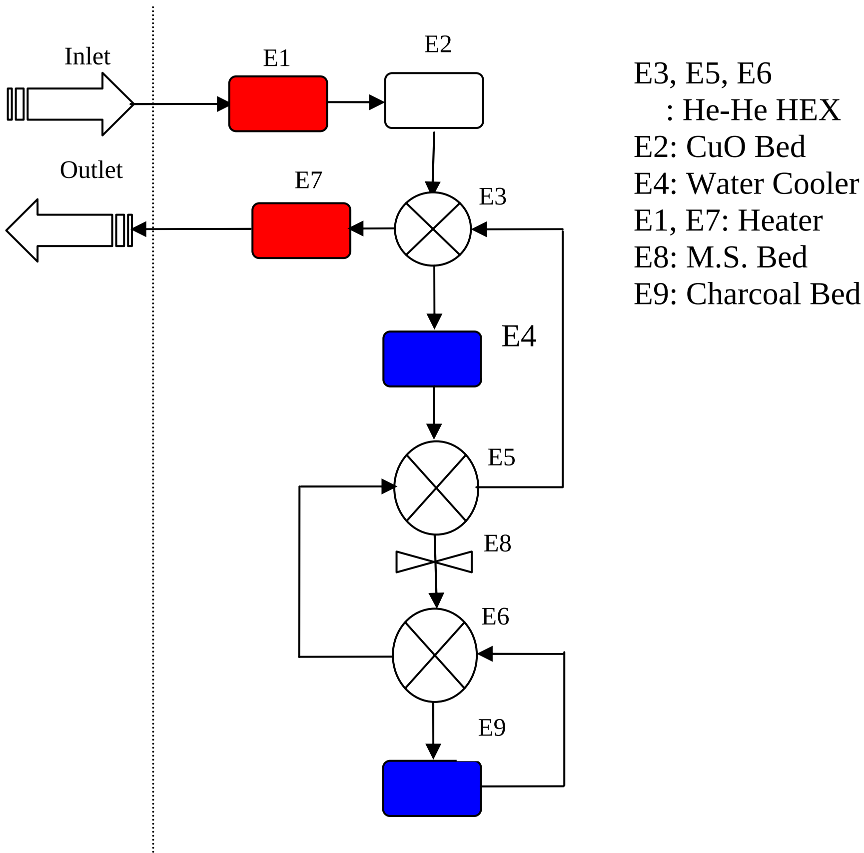

Figure 2 scheme of energy components of the HPS in HTR-10

3. Working conditions and assumptions

The working conditions of these two typical HPS are slightly different for the three adsorption beds, but quite different in temperatures at inlets and outlets, see table 1 below. The outlet temperature of HPC is considered not to be too high for a helium circulator, while HPS could have a higher outlet temperature due to its different helium circulator location.

Table 1 Working conditions of HPC and HPS in HTR-10

	T_{inlet}	T_{outlet}	T_{cuo}	$T_{M.S.}$	T_c	P	Q
HPC	100℃	50℃	350℃	20℃	-190℃	5MPa	72kg/h
HPS in HTR-10	250℃	185℃	250℃	20℃	-160℃	3MPa	10.5kg/h
This study	100℃	50℃	250℃	20℃	-180℃	5MPa	72kg/h

According to the established knowledge on copper oxide bed, when the operation temperature is over 200℃, there would be a perfect oxidation of hydrogen and carbon monoxide. With higher operation temperature, the capacity of hydrogen and carbon monoxide that could be transformed by the same weight copper oxide would increase [6]. To keep a balance of these two working conditions, the analysis was done under given conditions in table 1 above.

It's assumed that for both systems, all the helium-helium heat exchangers (he-he HEX) are adiabatic to environment and have an initial recuperating efficiency (α) of 95%, without any pressure drops; the working temperatures for all these three beds are fixed during the operation period; the constant-pressure specific heat is constant at a value of 5.19kJ/(kg. K); to make an equal comparison of two processes, the mass flow rate is set according to that of HPC, 72kg/h.

Finite-time thermodynamics method is adopted in solving these two models [7]. Within the long operation period of the reactor, the α of the he-he HEX could decrease, so the analysis was done considering α decreasing down to 50%, which means the he-he HEX works with a quite bad performance.

4. Results and comparisons

From the view of energy conservation, the energy consumptions of these two designs are calculated with finite-time method. The total energy consumption is defined as the algebraic sum of all the coolers and heaters in the system. The energy consumptions of each energy components in the systems are shown in fig. 3 and fig. 4 for HPC and HPS in HTR-10, respectively. It can be seen from fig.3 that, all of the four energy components in HPC, would have lower energy consumptions with higher α, so as the total energy consumption of the system. It's an inversely-proportional relationship between the energy consumptions of each component and α. Under its designed working condition, HPC could have quite small energy need for both copper oxide bed heater (red line+ symbol) and the liquid nitrogen cooler (blue line+ symbol).

For HPS, the copper oxide bed heater has constant energy consumption with various α because of fixed temperatures at both inlet and copper oxide bed without any HEX between.

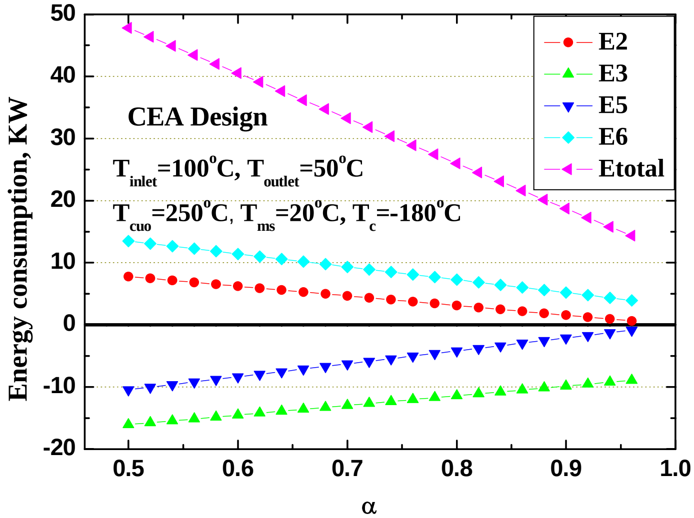

Figure 3 Energy consumption of HPC

With an increasing α, HPS would have a smaller liquid-nitrogen cooler and a bigger water cooler at the outlet due to higher temperature at the outlet of E3 HEX cold-side with steady temperature at inlet of hot-side from copper oxide bed.

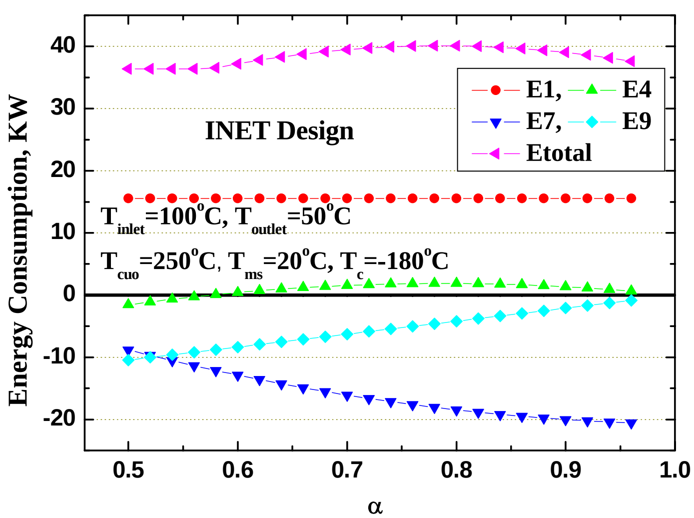

Figure 4 Energy consumption of HPS in HTR-10

5. Conclusion

Energy consumptions of HPC and HPS of HTR-10, have been analyzed and calculated as an adiabatic process by finite time thermodynamics (FTT), considering the heat resistance losses in the HE-HE Heat Exchangers (HEX), and free of pressure drop and gas leakage, under a typical working conditions of HPS with different efficiencies of HEX.

The results show that:

1. It's an inversely-proportional relationship between the energy consumptions of each component and α in HPC;
2. The total energy consumption in HPS of HTR-10 is not sensitive to α, even when α is as low as 50%;
3. Less energy consumption of HPC, compared to HTR-10 design, is based on high α;

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