Effect of temperature and pressure on the overall heat transfer coefficient in VHTR-based SI process heat exchangers

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1. Introduction

The sulfur-iodine (SI) cycle and Westinghouse sulfur hybrid cycle, combined with a very high temperature gas-cooled reactor (VHTR), are well-known as feasible technologies for hydrogen production [1]. The SI process consists of a Bunsen reactor; H_2SO_4, SO_3, and HIx decomposers; and a HI pre-heater. The overall heat transfer coefficient of the process heat exchanger (PHE) used in the SI process is a very important factor when sizing the PHE.

In this paper, a sensitivity analysis on the overall heat transfer coefficient has been carried out as a function of operation temperature and pressure.

2. Process Heat Exchangers and Used Equations

As shown in Fig. 1, the process gas in the tube side of shell-and-tube type equipment is heated by high-temperature helium in the shell side.

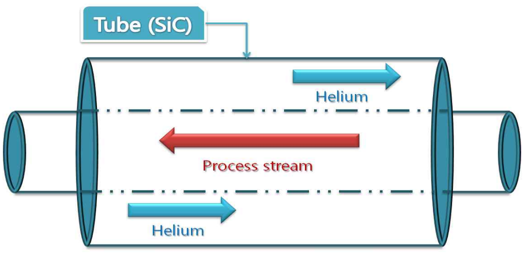

Fig. 1. PHE counter current flow model.

The target components in the VHTR-based SI process are a H_2SO_4 decomposer, SO_3 decomposer, and HI pre-heater.

Table I: Equipment Parameter

Device		H_2O	H_2SO_4	SO_3	SO_2	O_2
SO_3 Decomposer	Inlet mole flow rate (mol/s)	489.78	6.68	444.62	0	0
	Inlet temperature (K)	Process stream = 1023 , He = 1183				
	Outlet mole flow rate (mol/s)	503.35	2.16	163.57	285.62	142.81
	Outlet temperature (K)	Process stream = 1123 , He = 1085				
H_2SO_4 Decomposer	Inlet mole flow rate (mol/s)	228.06	277.41	173.90	0	0
	Inlet temperature (K)	Process stream = 740 , He = 1085				
	Outlet mole flow rate (mol/s)	498.78	6.68	444.62	0	0
	Outlet temperature (K)	Process stream = 1023 , He = 959.7				

Device		H_2O	I_2	HI	H_2
HI Pre-heater	nlet mole flow rate (mol/s)	1294.06	234.91	978	0
	Inlet temperature (K)	Process stream = 547.4 , He = 842.3			
	Outlet mole flow rate (mol/s)	1294.06	234.91	978	0
	Outlet temperature (K)	Process stream = 723 , He = 743			

The overall heat transfer coefficient can be expressed as follows [2].

$$\frac{1}{U}=\frac{1}{h_o}+\frac{1}{h_i(D_i/D_o)}+\frac{1}{h_w}+\frac{1}{h_s} \tag{1}$$

$$h_i=0.125\frac{\lambda_i}{D_i}\left(\frac{D_pG_i}{\mu_i}\right)^{0.75} \qquad 0.35<\frac{D_p}{D_i}<0.60 \tag{2}$$

$$h_i=0.813\frac{\lambda_i}{D_i}\exp(-6D_p/D_i)\left(\frac{D_pG_i}{\mu_i}\right)^{0.9} \qquad \frac{D_p}{D_i}<0.35 \tag{3}$$

$$h_0=\frac{0.273c_pG_o}{(c_p\mu_o/\lambda_o)^{2/3}(D_oG_o/\mu_o)^{0.365}} \tag{4}$$

$$h_w=\frac{2\lambda_t}{(D_o-D_i)} \tag{5}$$

U : overall heat transfer coefficient [W/(m2 . K)]
h_o : outside heat transfer coefficient [W/(m2 . K)]
h_i : inside heat transfer coefficient [W/(m2 . K)]
D_i : internal diameter of tube [m]
D_o: external diameter of tube [m]
D_p: diameter of packing material [m]
C : conversion factor(British units to MKS units,)
h_w: heat transfer across tube wall [W/(m2 . K)]
h_s : fouling heat transfer coefficient [W/(m2 . K)]
G_o : external superficial mass flow rate per unit area [kg/(s . m2)]
G_i : internal superficial mass flow rate per unit area [kg/(s . m2)]
λ_i : inside thermal conductivity [W/(m . K)]
λ_o : outside thermal conductivity [W/(m . K)]
λ_t : thermal conductivity of tube [W/(m . K)]
μ_i : internal viscosity of fluid [Pa . s]
μ_o : external viscosity of fluid [Pa . s]
c_p : heat capacity of fluid [kJ/(kg . K)]

3. Results and Discussion

Figs. 2, 3, and 4 show the temperature sensitivities of the overall heat transfer coefficient in the H_2SO_4 and SO_3 decomposers and HI pre-heater.

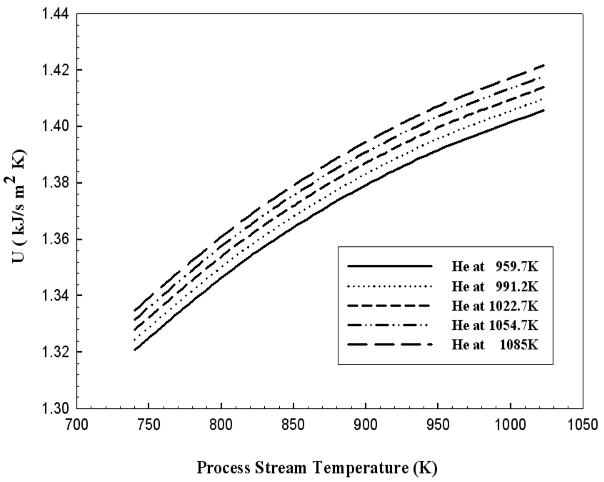

Fig. 2. Overall heat transfer coefficient as a function of helium temperature in a H_2SO_4 decomposer.

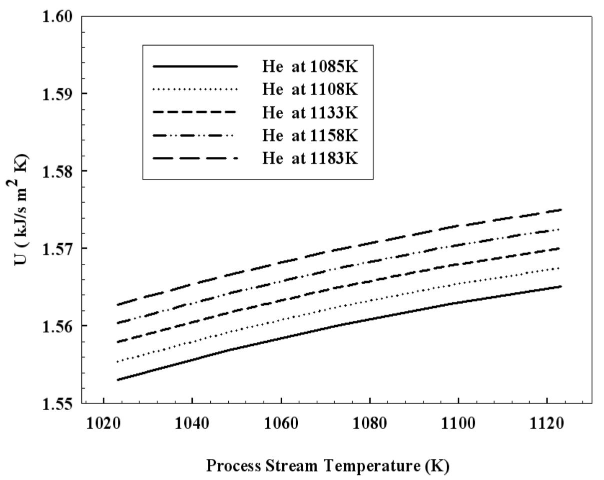

Fig. 3. Overall heat transfer coefficient as a function of helium temperature in a SO_3 decomposer.

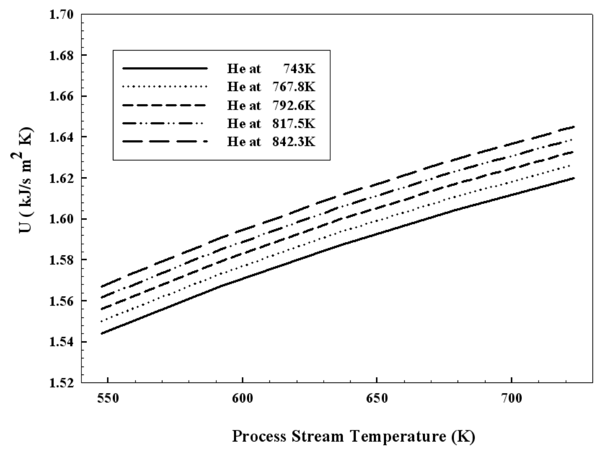

Fig. 4. Overall heat transfer coefficient as a function of helium temperature in a HI pre-heater.

Figs. 5 and 6 show the pressure sensitivities of the overall heat transfer coefficient and internal heat transfer coefficient in the SO_3 decomposer, respectively; The H_2SO_4 decomposer and HI pre-heater have the same trend as the SO_3 decomposer.

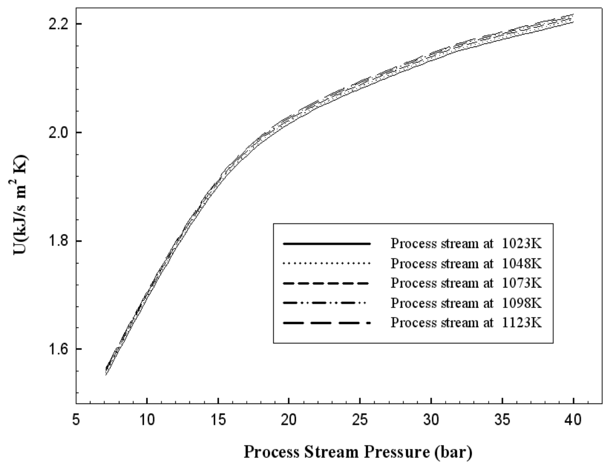

Fig. 5. Overall heat transfer coefficient as a function of process stream pressure in a SO_3 decomposer.

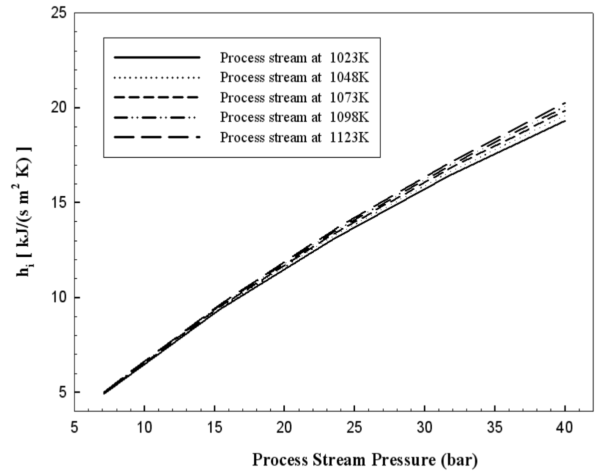

Fig. 6. Internal heat transfer coefficient as a function of process stream pressure in a SO_3 decomposer.

4. Summary

The effects of operation temperature and pressure on the overall heat transfer coefficient have been analyzed. The overall heat transfer coefficient is increased with an increase in the operation temperature and pressure in the process heat exchangers installed inside the H_2SO_4 and SO_3 decomposers and the HI pre-heater.

Acknowledgments

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