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Effect of Choke Ring Position on Thermal and Fluid Flow in a SRU Thermal Reactor

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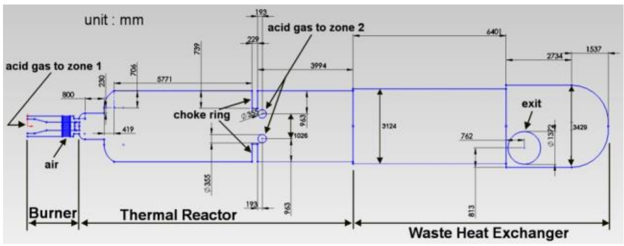
***Abstract*—The effect of choke ring position on the thermal and fluid flow in a SRU thermal reactor is investigated numerically. It is found that zone 1 is a higher temperature region while zone 2 is a lower temperature region. The average temperature and peak temperature in the SRU thermal reactor for a rich oxygen supply is higher than those of a normal oxygen supply. The temperature difference between zone 1 and zone 2 is smaller for a rich oxygen supply. The peak temperature for a smaller zone 1 is higher. The optimal location of the choke ring for the lowest peak temperature is 6m away from zone 1 corner. The highest sulfur concentration at exit occurs when zone 1 is the smallest.**

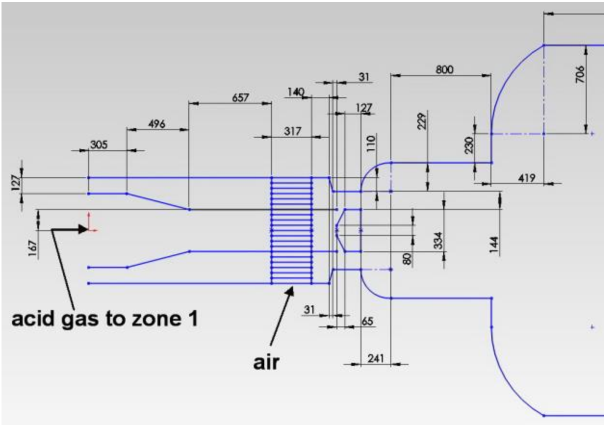
***Index Terms*—SRU thermal reactor, choke ring, sulfur recovery**

I. INTRODUCTION

Desulfurization is very important in petroleum refining process because oxysulfide arising from petroleum refining process is one of the major sources of air pollution. The most frequently used desulfurization process is the Claus process which converts the hydrogen sulfide in natural gas or crude oil into sulfur elements and thereby reduces the formation of oxysulfide. A sulfur recovery unit (SRU) thermal reactor is perhaps the most important equipment in a sulfur plant. It can convert the ammonia, hydrogen sulfide and hydrocarbons in the reactants into sulfur. Most of the sulfur elements are recovered from the SRU thermal reactor. The first section of a sulfur recovery unit based on Claus process is composed of a burner, a thermal reactor and a waste heat exchanger. Configuration and dimensions of the first section of a sulfur recovery unit for a typical petroleum refinery are shown in Fig. 1.



(a) overall view



(b) enlarged view for the burner section

Figure 1. Configuration and dimensions of the first section of a sulfur recovery unit for a typical petroleum refinery.

Manenti *et al*. [1] and [2] proposed a kinetic model with 2400 reactions and 140 species and implemented it in a proper reactor network to characterize the thermal reactor and the waste heat exchanger of sulfur recovery units. By doing so, reliable estimation of acid gas conversion, elemental sulfur recovery, and steam generation are achieved with the possibility to carry out an integrated process-energy optimization at the total plant scale. Selim *et al*. [3] examined quality of sulfur deposits collected from hydrogen sulfide combustion. Sulfur deposits from H_2S combustion under various conditions were captured and analyzed using X-ray powder diffraction and laser induced breakdown spectroscopy diagnostics. ZareNezhad and Hosseinpour [4] investigated different alternatives for increasing the reactor temperature of Claus SRUs by chemical equilibrium calculations. They found that the acid gas enrichment is a reliable technique for providing the required reactor temperature when a high flow of too lean acid gas is to be processed in a Claus unit. Monnery et al. [5] studied experimentally the reaction between H_2S and SO_2 at practical Claus thermal reactor temperatures between 850 and 1150^{o}C and residence times between 0.05 and 1.2 seconds. The new kinetic data were used to develop a new reaction rate expression.

The inner surface of a SRU thermal reactor is facilitated by refractory to protect its wall. The interior of a SRU thermal reactor is divided into two zones by a choke ring to increase residence time and enhance chemical reaction. An abrupt temperature rise or an

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excessively high temperature may lead to deterioration of the refractory. Therefore, the operating temperature range suggested by vendors for the operation of a SRU thermal reactor should be strictly followed. Because the operating temperature of a practical SRU thermal reactor can be as high as 1430°C and the hydrogen sulfide in the reactants is a highly acid gas, the refractory and heat exchanging tubes may be deteriorated and the sulfur recovery efficiency may be influenced. To resolve the abnormality of a SRU thermal reactor under high temperature operation, this paper is devoted to a numerical investigation of thermal and fluid flow in a SRU thermal reactor. The effect of choke ring position in a practical SRU thermal reactor is investigated. The purpose of this paper is to improve the performance and safety of a SRU thermal reactor under high temperature operation.

II. Numerical Methods and Physical Models

In this study, the FLUENT commercial code [6] is employed to simulate the reacting and fluid flow in a SRU thermal reactor. The SIMPLE algorithm by Patankar [7] is used to solve the governing equations. The discretizations of convection terms and diffusion terms are carried out by the power-law scheme and the central difference scheme, respectively. In respect of physical models, by considering the accuracy and stability of the models and by referring to the evaluation of other researchers, the standard *k-ε* Model [8], P-1 radiation model [9] and non-premixed combustion model with β–type probability density function [10] are adopted for turbulence, radiation and combustion simulations, respectively. The standard wall functions [11] are used to resolve the flow quantities (velocity, temperature, and turbulence quantities) at the near-wall regions. Detailed governing equations and convergence criterion were described in the author's previous study [12].

III. Results and Discussion

In this study, the numerical model of a practical SRU thermal reactor is constructed by unstructured grid. Five cell densities are tested to ensure a grid independent solution. They include 10,826 cells, 187,354 cells, 342,856 cells, 683,672 cells and 1,124,627 cells. Computational results show that the corner recirculation zone sizes of zone 1 and zone 2 as well as the cross-sectional average temperature profiles obtained by the last two meshes nearly coincide with deviation within 0.5%. Therefore, the mesh of 683,672 cells is adopted for subsequent discussion. Fig. 2 shows the numerical model of the SRU thermal reactor investigated. In Fig. 2, the heat exchanger section consists of 19 cooling tubes of diameter 0.5m, illustrated schematically in Fig. 3. The heat absorption rate of each heat exchanging tube is 40,000 W/m^2 and the other walls are adiabatic. No slip condition is applied on any of the solid walls. The exit of the heat exchanger section is connected to the subsequent equipment at 300K and 1 atm by a pipe of 1.372m in diameter and 11.5m in length.

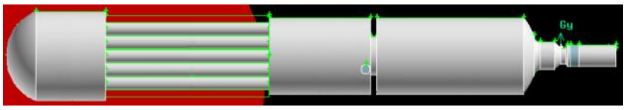


Figure 2. Numerical model of the SRU thermal reactor investigated.

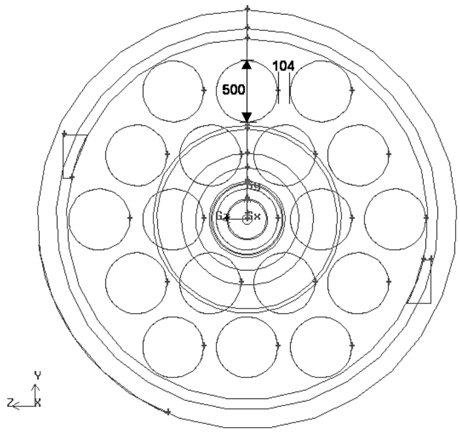


Figure 3. Illustration of the arrangement of heat exchanging tubes.

TABLE I. Boundary Conditions at the Acid Gas Inlet Holes and the Air Inlet Hole

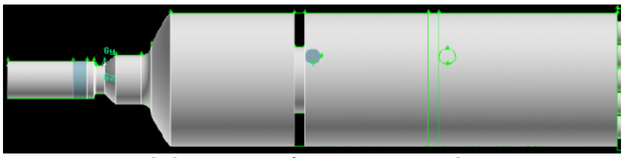
	Normal oxygen				Rich oxygen			
Mole fraction (%)	Acid gas to zone 1	Acid gas to zone 2	Air inlet		Acid gas to zone 1	Acid gas to zone 2	Air inlet	
O_2	0	0	19.87		0	0	23.85	
N_2	0	0	74.98		0	0	71.26	
H_2O	7.83	4.12	5.15		4.12	27.97	4.89	
CO_2	1.27	1.5	0		1.48	0	0	
H_2S	82.06	89.88	0		89.9	39.61	0	
CH_4	2.28	2.7	0		2.7	0	0	
C_2H_6	1.52	1.8	0		1.8	0	0	
NH_3	5.04	0	0		0	32.42	0	
Temperature (K)	319.92	316.15	403.15		313.15	316.15	397.15	
Pressure (N/m^2)	76920	75068	74382		75068	75068	89572	
Velocity (m/sec)	11.62	2.08	radial	tangential	11.46	1.88	radial	tangential
			12.4	34.1			10.8	29.8

In this study, two cases of oxygen supplies are investigated: a normal oxygen supply and a rich oxygen supply. A rich oxygen supply is designed to increase the sulfur recovery. Boundary conditions (including the species compositions, temperature, pressure and velocity) at the acid gas inlet holes of zone 1 and zone 2 as well as at the air inlet hole are listed in Table I. Turbulence kinetic energy is 10% of the inlet mean flow kinetic energy and turbulence dissipation rate is computed from (1).

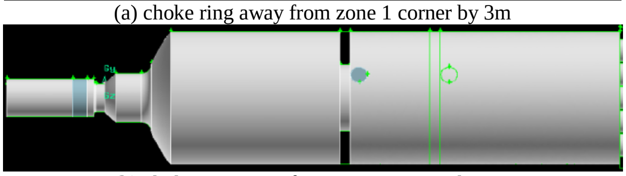
$$\varepsilon = C_{\mu}^{3/4}\frac{k^{3/2}}{l} \tag{1}$$

where l=0.07L, L is the hydraulic diameter, C_{μ}=0.09, k and ε are the turbulence kinetic energy and dissipation rate, respectively.

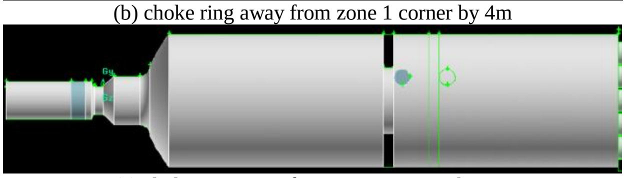
Five positions of the choke ring, away from zone 1 corner by 3m, 4m, 5m, 6m and 7m, respectively, are calculated to investigate the optimal position of a choke ring. Fig. 4 shows the numerical models of the SRU thermal reactor with choke ring at different locations



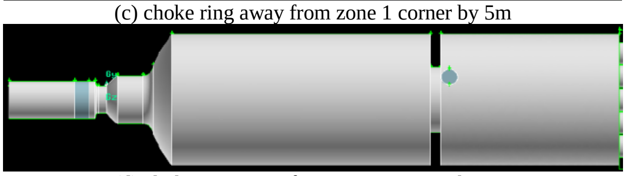
(a) choke ring away from zone 1 corner by 3m



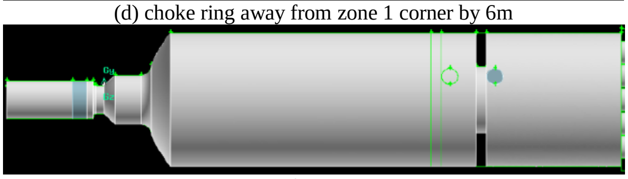
(b) choke ring away from zone 1 corner by 4m



(c) choke ring away from zone 1 corner by 5m



(d) choke ring away from zone 1 corner by 6m



(e) choke ring away from zone 1 corner by 7m

Figure 4. Numerical models of the SRU thermal reactor with choke ring at different locations.

For a normal oxygen supply, Fig. 5 shows the comparison of cross-sectional average temperature for the SRU thermal reactor with choke ring at different locations. It is observed that zone 1 is a higher temperature region while zone 2 is a lower temperature region. Temperature decreases abruptly across the choke ring because of conversion of thermal energy into kinetic energy across the choke ring due to flow acceleration. Similar results can be observed in Fig. 6 which shows the temperature profile for the SRU thermal reactor with choke ring at different locations. It is seen that a larger zone 1 leads to a larger higher temperature region. In a practical SRU thermal reactor, the refractory may be ruptured due to an excessively high temperature, for example, near the zone 1 corner. The peak temperature in the SRU thermal reactor is listed in Table II and labeled in Fig. 6. It can be seen that, although a smaller zone 1 leads to a smaller higher temperature region, the peak temperature is not necessarily lower. On the contrarily, for a smaller zone 1, the peak temperature may be higher due to the compression effect of a smaller region. There exists an optimal location of the choke ring for the peak temperature to be lowest. It is seen that the reactor with choke ring away from zone 1 corner by 6m has the lowest peak temperature. From Table II it is also observed that the highest sulfur concentration at exit occurs when the choke ring is located at 3m away from the zone 1 corner, i.e. when zone 1 is the smallest.

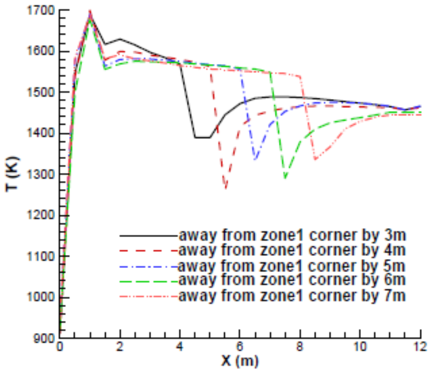
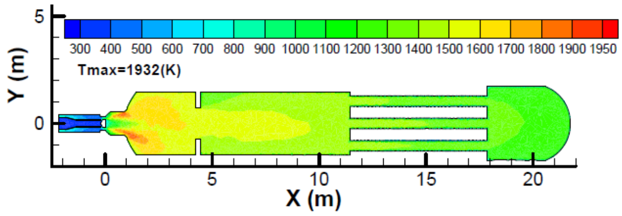
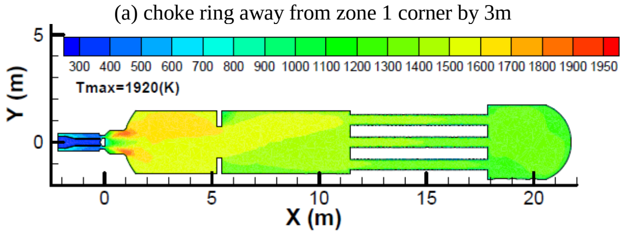


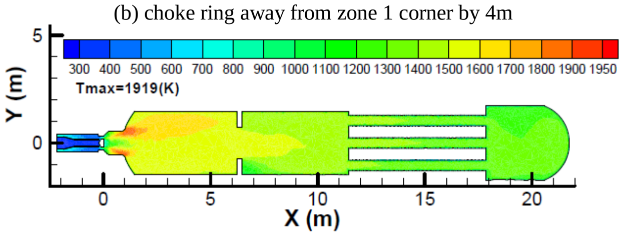
Figure 5. Comparison of cross-sectional average temperature for the SRU thermal reactor with choke ring at different locations (normal oxygen supply).



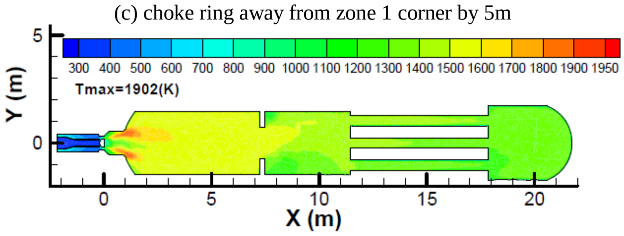
(a) choke ring away from zone 1 corner by 3m



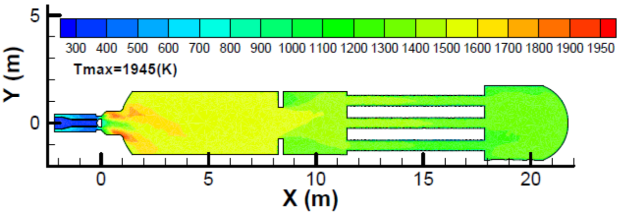
(b) choke ring away from zone 1 corner by 4m



(c) choke ring away from zone 1 corner by 5m



(d) choke ring away from zone 1 corner by 6m



(e) choke ring away from zone 1 corner by 7m

Figure 6. Temperature profile for the SRU thermal reactor with choke ring at different locations (normal oxygen supply).

TABLE II. PEAK TEMPERATURE IN THE SRU THERMAL REACTOR AND THE SULFUR CONCENTRATION AT EXIT FOR A NORMAL OXYGEN SUPPLY

Separation between zone 1 corner and choke ring (m)	Peak temperature (K)	Sulfur concentration at exit (mole fraction)
3	1932	0.0793
4	1920	0.0788
5	1919	0.0790
6	1902	0.0791
7	1945	0.0791

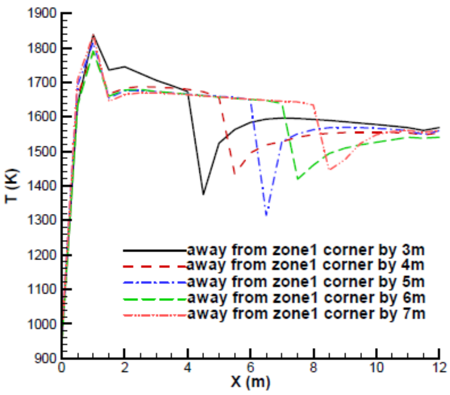
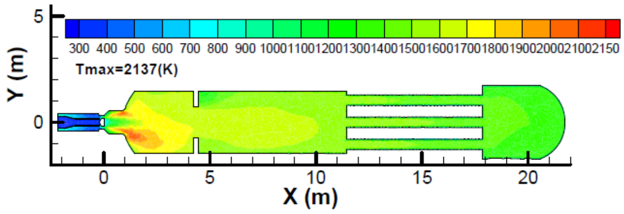
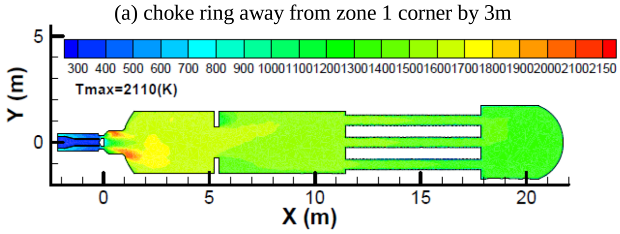


Figure 7. Comparison of cross-sectional average temperature for the SRU thermal reactor with choke ring at different locations (rich oxygen supply).

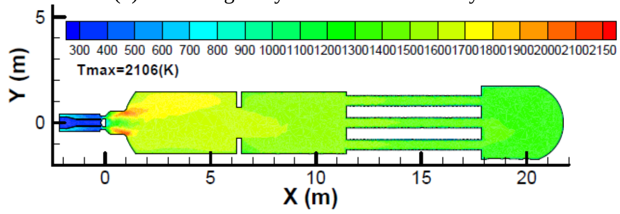
For a rich oxygen supply, Fig. 7 shows the comparison of cross-sectional average temperature for the SRU thermal reactor with choke ring at different locations. Similar to a normal oxygen supply, zone 1 is a higher temperature region while zone 2 is a lower temperature region. However, the average temperature for a rich oxygen supply is higher than that of a normal oxygen supply. In addition, the temperature difference between zone 1 and zone 2 is smaller for a rich oxygen supply because of the more complete chemical reaction. Further, it is seen from Fig. 8 that, similar to the normal oxygen supply, a larger zone 1 leads to a larger higher temperature region. The peak temperature in the SRU thermal reactor for a rich oxygen supply which is listed in Table III and labeled in Fig. 8 is higher than that of a normal oxygen supply. It can also be seen that, similar to the normal oxygen supply, although a smaller zone 1 leads to a smaller higher temperature region, the peak temperature is not necessarily lower. On the contrarily, for a smaller zone 1, the peak temperature may be higher due to the compression effect of a smaller region. The optimal location of choke ring for the peak temperature to be lowest is 6m away from zone 1 corner, which is the same as that for a normal oxygen supply. From Table III it is also observed that the highest sulfur concentration at the exit occurs when the choke ring is located at 3m away from the zone 1 corner, i.e. when zone 1 is the smallest, which is also the same as that for a normal oxygen supply.



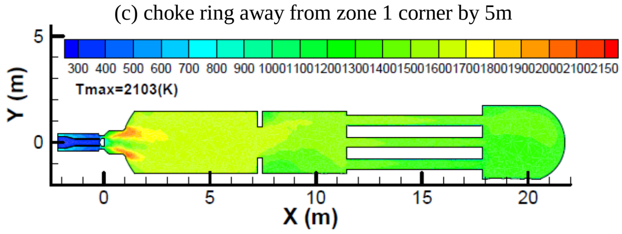
(a) choke ring away from zone 1 corner by 3m



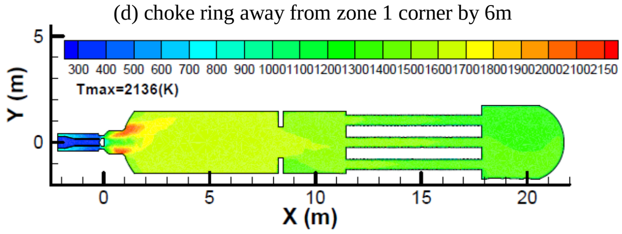
(b) choke ring away from zone 1 corner by 4m



(c) choke ring away from zone 1 corner by 5m



(d) choke ring away from zone 1 corner by 6m



(e) choke ring away from zone 1 corner by 7m

Figure 8. Temperature profile for the SRU thermal reactor with choke ring at different locations (rich oxygen supply).

TABLE III. PEAK TEMPERATURE IN THE SRU THERMAL REACTOR AND THE SULFUR CONCENTRATION AT EXIT FOR A RICH OXYGEN SUPPLY

Separation between zone 1 corner and choke ring (m)	Peak temperature (K)	Sulfur concentration at exit (mole fraction)
3m	2137	0.0919
4m	2110	0.0907
5m	2106	0.0907
6m	2103	0.0902
7m	2136	0.0916

IV. CONCLUSION

In this paper, the effect of choke ring position on the thermal and fluid flow in a SRU thermal reactor is investigated numerically. It is found that zone 1 is a higher temperature region while zone 2 is a lower temperature region. The average temperature and peak temperature in the SRU thermal reactor for a rich oxygen supply is higher than those of a normal oxygen supply. The temperature difference between zone 1 and zone 2 is smaller for a rich oxygen supply. The peak temperature for a smaller zone 1 is higher. The optimal location of the choke ring for the lowest peak temperature is 6m away from zone 1 corner. Finally, the highest sulfur concentration at exit occurs when zone 1 is the smallest.

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