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STUDY OF A NEW GAS INLET STRUCTURE DESIGNED FOR XINJIANG OIL SHALE RETORT

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Abstract. *Uniformly distributed gas flow in the retorting zone suggests high thermal efficiency and high productivity for the oil shale retort using gaseous heat-carrier technology. In order to improve the gas flow distribution of Xinjiang oil shale retort, a double-deck gas inlet structure was designed and applied to it in this work. To test the efficiency of the new inlet structure, the gas flow distribution in the retorting zone was investigated through a three-dimensional cold model of the retort. Comparison of experimental results showed that the uniformity of gas flow distribution in the retorting zone increased over 8% and the sizes of "dead zone" decreased more than 10% when the retort was equipped with the double-deck gas inlet structure. This indicates that the application of the new gas inlet structure may significantly enhance the thermal efficiency of the pyrolysis process.*

Keywords: *Xinjiang oil shale retort, gas full circulation retorting technology, gas flow distribution, inlet structure, Jimsar oil shale.*

1. Introduction

Xinjiang oil shale retort is a new type of retorting device using gas full circulation retorting technology. Pan et al. have in more detail introduced the structure and working principle of the retort [1]. But it is also found that the gas flow distribution in the retorting zone of the retort is maldistribution, and the gas flow in the corners of the retorting zone is too weak to pyrolyze oil shale. It is well known that the uniformly distributed gas flow in the retorting

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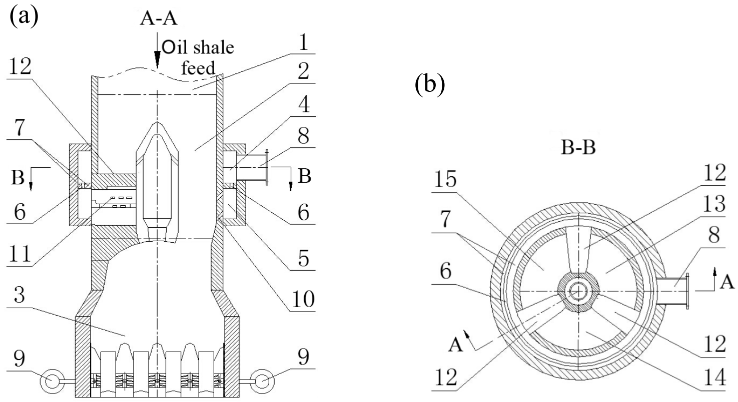
zone suggests high thermal efficiency, high products yield and high productivity for the retorts using gaseous heat-carrier technology; hence, the gas flow distribution in Xinjiang oil shale retort is necessary to be improved.

According to the fundamentals of fluid mechanics [2] and related studies [1, 3–6], the inlet structure which determines the flow patterns in the annular gas channel plays an important role in the flow distribution in the packed beds. Pan et al. [1] established that the feasible and effective way for improving the gas flow distribution in Xinjiang retort is to modify the gas inlet structure. Heggs et al. [5] investigated the gas flow distribution in the packed beds configured with an annular structure, and concluded that the U-type flow arrangement gives better flow distribution in the beds than the Z-type flow arrangement.

In this work, a new gas inlet structure is designed for Xinjiang oil shale retort to improve the gas flow distribution in the retorting zone. The inlet structure comprises a double-deck annular gas channel and a gas intake pipe, as shown in Figure 1. The upper annular channel and the lower annular



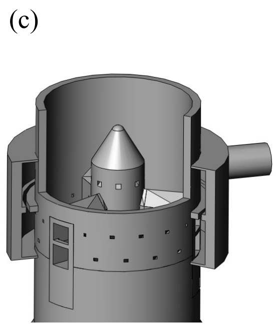


Fig. 1. The structure of Xinjiang oil shale retort equipped with the new gas inlet structure: (a) main view (A-A sectional drawing, the A-A section line is shown in (b)); (b) cross-sectional view of the retort; (c) the 3-D diagram of the retort. (1 – preheat zone; 2 – retorting zone; 3 – cooling zone; 4 – upper annular gas channel; 5 – lower annular channel; 6 – connection channel linking the upper annular channel and the lower annular channel; 7 – barrier structure; 8 – reheated recycled gas intake pipe; 9 – cold recycled gas intake pipe; 10 – orifices in the wall of the retorting zone; 11 – orifices in the support structures; 12 – support structure; 13 – part A; 14 – part B; 15 – part C).

channel are connected through the narrow gap in the barrier structure. The gas flow distribution (gas velocity patterns) of the retort equipped with the new inlet structure was investigated through cold model experiments. The uniformity of gas flow and the sizes of "dead zone" in each part of the retort were calculated and compared with those of the retort equipped with the previous gas inlet structure.

2. Experimental

The experiments were performed in the cold model of Xinjiang oil shale retort made of transparent perspex and engineering plastics (scale 1:5). The structure of the model is shown in Figure 1. Soybean and corn mixture particles were fed to the model to simulate the complex vessels and voids of oil shale particles.

As done in literature [1], the gas velocity in the retort was measured through a thermal anemometer equipped with a customized control device system. To determine the effect of the new gas inlet structure on the gas flow distribution in the retort, the gas flow velocity at the same positions of the retorting zone was measured. The level distribution of the measuring points is shown in Figure 2a, and the radial distribution of measuring points (nine different mathematical degrees) at each level of the three parts of the retorting zone is shown in Figure 2b. The experiments were conducted with different gas flow rates for the purpose of comparison.

The uniformity of gas flow in each part of the retorting zone was calculated by the same method as in literature [1], using Equation (1):

$$Opt = \frac{W_{\text{mean}} - \frac{1}{n}\sum_{i=1}^{n}\left|W_i - W_{\text{mean}}\right|}{W_{\text{mean}}} \times 100\%, \tag{1}$$

where *Opt* is the uniformity of gas flow in each part of the retorting zone, %; W_{i} is the gas flow velocity at position i, m/s; W_{mean} is the average flow velocity, m/s; *n* is the number of measuring positions.

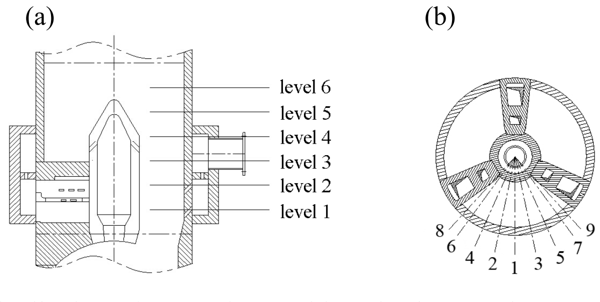


Fig. 2. The distribution of measuring positions in the retorting zone: (a) the level distribution; (b) the radial distribution.

The static pressures around the annular channel were measured. For the upper annular channel, the lower annular channel and the previous gas annular channel, four pressure taps were located spaced at 90° along the perimeter, as shown in Figure 3.

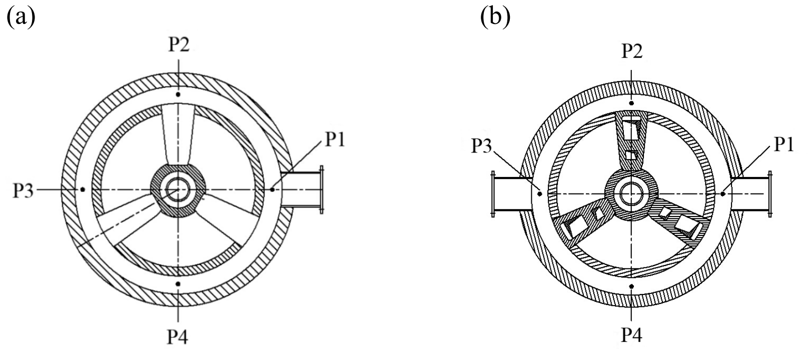


Fig. 3. Pressure taps arrangements along: (a) the double-deck gas annular channel; (b) the previous gas annular channel.

3. Results and discussion

Figures 4 and 5 illustrate the radial distribution of the vertical velocity of gas flow measured at levels 1 and 6 of Xinjiang oil shale retort equipped with the double-deck gas inlet structure at a constant air flow rate, $Q = 285\ m^3/h$. The previous gas flow distribution in the retorting zone is described in literature [1]. It can be observed that although the vertical velocity of gas flow is still higher around the center line (line 1) of the three parts of the retort, the variation trend of gas velocity along the circle direction changes more slightly, and the gas velocity keeps nearly constant along the radial direction for the nine degrees in the retort equipped with the double-deck gas inlet structure. The velocity of the gas flow around the center line is obviously decreased, and the velocity of the gas flow around the support structures (the corners of each part), especially around lines 6 and 7, is considerably increased.

Table 1 shows the *Opts* of the three parts in the retorting zone measured at different levels and different air flow rates (the previous *Opts* are given in literature [1]). Figure 6 compares the total *Opts* of each level of the retorts equipped with different gas inlet structures. It can be observed that the *Opts* at different bed depths and air flow rates increased more than 8% when the retort was equipped with the double-deck gas inlet structure, which indicates that the gas flow uniformity in the whole retorting zone improved considerably. This can be easily seen from the gas velocity patterns too, as shown in Figures 4 and 5, and literature [1].

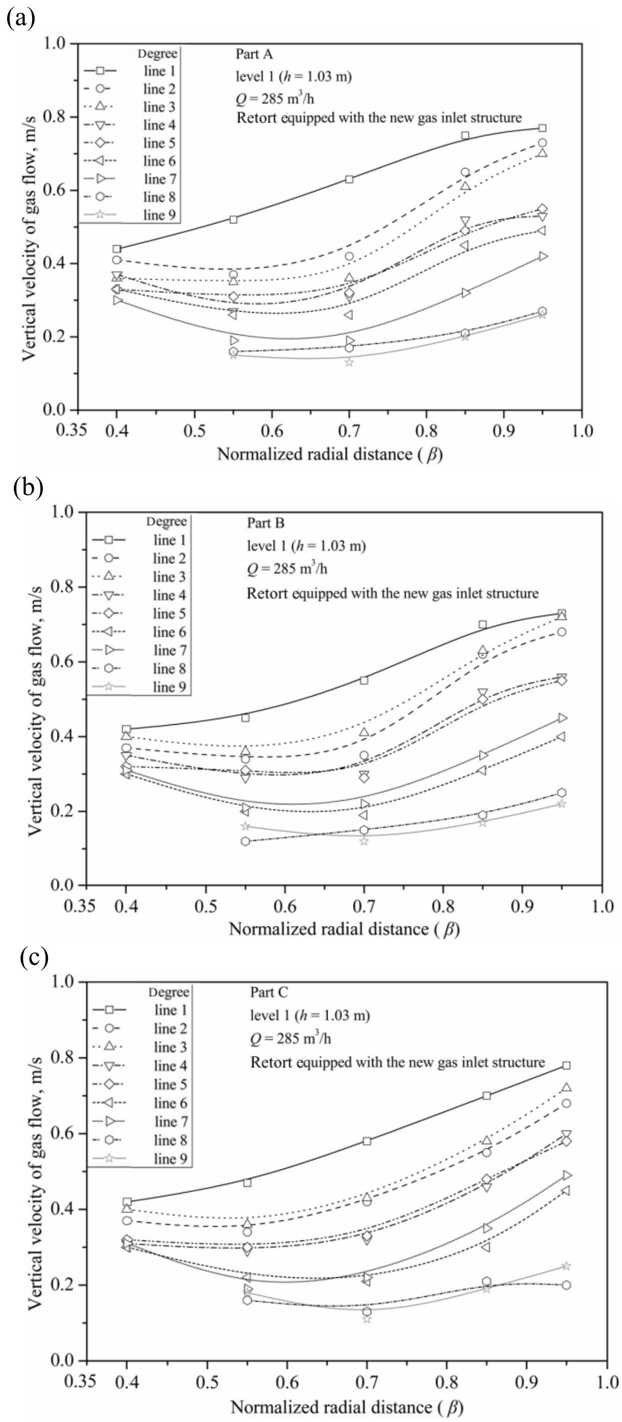


Fig. 4. The radial distribution of vertical gas flow velocity in: (a) part A, (b) part B, (c) part C of the retort equipped with the new gas inlet structure at level 1 at a constant air flow rate, $Q = 285\ m^3/h$.

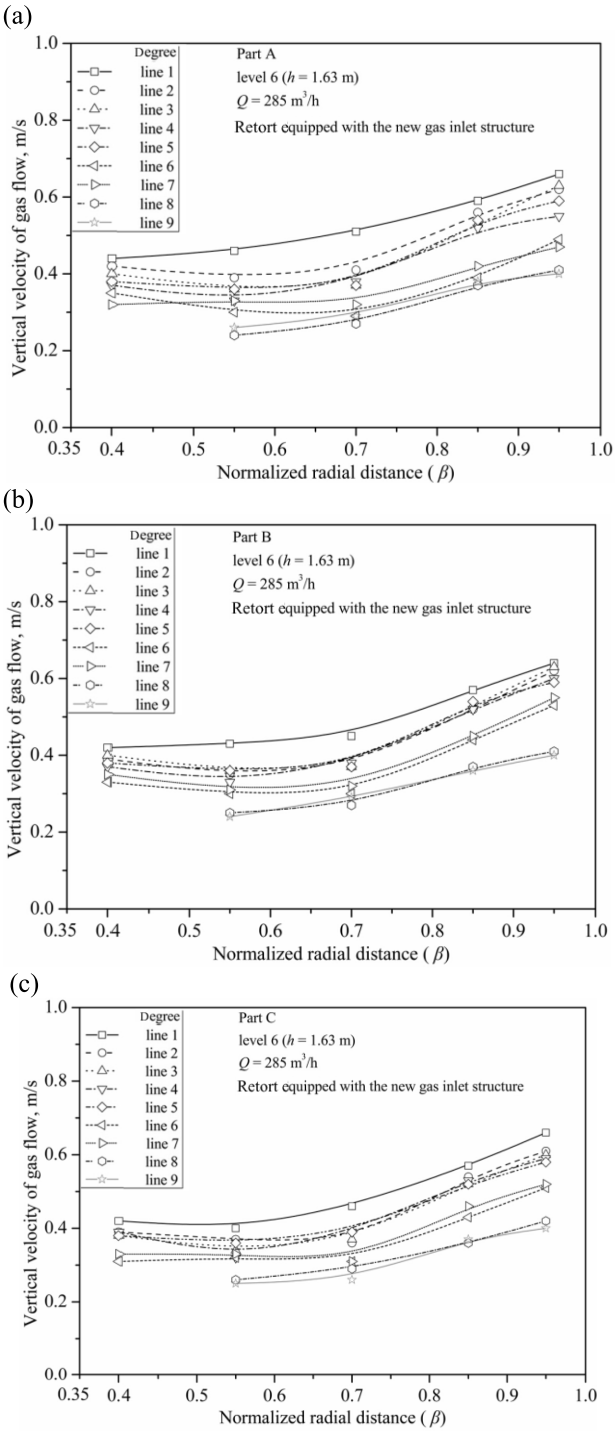


Fig. 5. The radial distribution of vertical gas flow velocity in: (a) part A, (b) part B, (c) part C of the retort equipped with the new gas inlet structure at level 6 at a constant air flow rate, $Q = 285$ m^3/h.

Table 1. The *Opts* of the three parts of the retort equipped with the double-deck gas inlet structure at different levels and different air flow rates, %

Gas flow rate, m^3/h	Level	Part A	Part B	Part C
Q = 285	1	63.93	63.23	63.30
	2	64.2	64.53	64.49
	3	65.8	65.86	65.61
	4	69.63	69.91	69.89
	5	72.67	72.97	72.65
	6	77.40	77.80	77.02
Q = 320	1	66.14	65.59	65.98
	2	66.47	66.86	66.84
	3	67.56	67.72	67.84
	4	71.31	72.01	71.49
	5	74.16	74.49	74.27
	6	78.65	78.61	78.43
Q = 360	1	67.69	67.28	67.39
	2	68.10	68.31	67.99
	3	69.43	69.47	69.34
	4	72.58	73.01	72.68
	5	75.47	75.63	75.56
	6	78.82	78.99	78.78

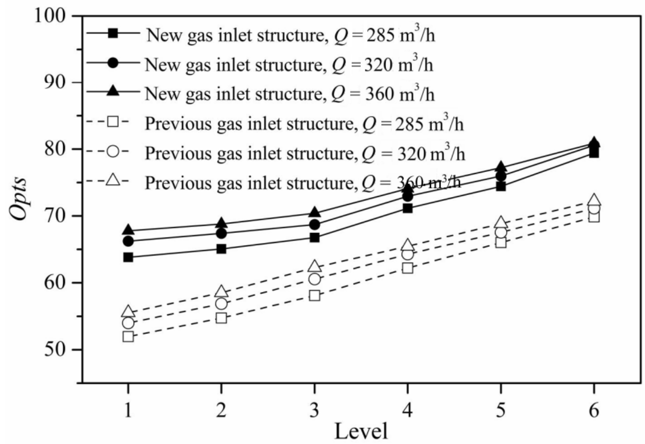


Fig. 6. Comparison of the total *Opts* of each level of the retorts equipped with different gas inlet structures.

For the retort equipped with the previous gas inlet structure, the vertical velocity of gas flow in part B was weaker than that in parts A and C, while the flow distribution in part A was similar to that in part C as these parts are similar in structure. When the retort was equipped with the double-deck gas inlet structure, the gas flow distribution in all the three parts was similar and improved, which means that the thermal efficiency in the whole retort was more uniform and the service life of the retort could be extended.

In literature [1], an area where the vertical velocity of gas flow is less than 0.2 m/s is called “dead zone” because the flow intensity is so weak that oil shale in such a region cannot be completely pyrolyzed. The sizes of “dead zone” at different depths for various air flow rates for the retort equipped with the new gas inlet structure are estimated and compared (Table 2). As the gas flow uniformity in the retorting zone was improved, the size of “dead zone” at each level of the retort decreased more than 10%, which indicates that more oil shale particles could be completely pyrolyzed during the pyrolysis process, especially the particles in the corners of each part.

Table 2. Comparison of the sizes of “dead zone” at different levels of the retorts equipped with different gas inlet structures at various air flow rates, %

Gas flow rate, m^3/h	Level	Size of “dead zone”, %	
		Retort equipped with the double-deck gas inlet structure	Retort equipped with the previous gas inlet structure
Q = 285	1	17.05	27.13
	2	14.73	25.23
	3	11.63	21.7
	4	5.43	18.19
	5	2.33	15.41
	6	0	13.18
Q = 320	1	14.73	25.21
	2	12.40	23.38
	3	7.75	19.24
	4	3.68	18.01
	5	1.55	14.13
	6	0	12.31
Q = 360	1	11.63	23.53
	2	10.85	21.83
	3	6.68	18.63
	4	2.33	16.53
	5	0	13.21
	6	0	11.1

When the retort is equipped with the double-deck gas inlet structure (see Fig. 1), the reheated recycled gas no longer flows into the retorting zone directly via the orifices after flowing into the annular channel as before, i.e. in the retort equipped with the previous gas inlet structure. Instead, it flows around the upper annular channel firstly and becomes more uniform due to the existence of the barrier structure, and then flows into the lower annular channel uniformly through the narrow gap connecting the two layers. The static pressures around the double-deck annular channel and the previous annular channel are given in Table 3. The results show that the static pressures around the lower annular channel are almost constant while the pressures around the upper and previous annular channels suggest more maldistribution. Hence, the reheated recycled gas could flow into the retorting zone uniformly at any azimuth of the retort while the sizes and location of the orifices were calibrated to the optimal condition, and then the gas flow distribution in the retorting zone was improved.

Table 3. The static pressure along the gas annular channel, Pa

Gas flow rate, m^3/h	Pressure taps	Retort equipped with the double-deck gas inlet structure		Retort equipped with the previous gas inlet structure
		upper annular channel	lower annular channel	
Q = 285	P1	508	340	346
	P2	516	341	361
	P3	516	341	346
	P4	516	341	361
Q = 320	P1	570	369	388
	P2	579	370	406
	P3	579	370	388
	P4	579	370	406
Q = 360	P1	643	414	437
	P2	652	415	456
	P3	652	415	437
	P4	652	415	456

From the point of view of hydrodynamics, the smaller the ratio of the cross section area of flow output (the narrow gap linking the upper and lower annular channels) to the total area of the annular cross section, the larger the resistance of the upper annular channel, then the more uniform of the flow distribution in the bed (retort). In other words, better uniformity of flow distribution in the retort is achieved at the cost of the larger resistance of the pipe and the annular channel (see Table 3). One of the purposes of this study is to get the maximal uniformity of flow distribution in the retorting zone at the cost of minimal pressure in the upper annular channel and the pipe.

As discussed above, the increase of gas flow uniformity in the retorting zone could increase the thermal efficiency and productivity of retorts using gaseous heat-carrier technology. Hence, it can be concluded that the application of the new gas inlet structure may significantly enhance the thermal efficiency of the pyrolysis process. Several researchers have modified the gas inlet structure to improve the flow distribution and thermal efficiency in the packed bed. For example, Dai et al. [3] studied the flow distribution in hot blast stoves and designed an inlet structure with diversion bricks to solve the problem of an uneven distribution of airflow temperature. The design has been applied to the stoves at Liuzhou Iron & Steel Co., Ltd. and has offered good economic benefit in practical production. Heggs et al. [5] investigated the effect of flow arrangements in the annular structure on the flow distribution in the packed bed, and established that the reverse U-type flow arrangement gives better flow distribution in the packed bed.

In addition, the new gas intake structure has only one reheated recycled gas intake pipe. The reduction of the number of intake pipes could save about 0.06 million dollars of investment cost for each retort and reduce the difficulty of operation and management.

4. Conclusions

In this work, a double-deck gas inlet structure was designed for Xinjiang oil shale retort to improve the gas flow distribution in the retorting zone. The results show that the better uniformity of flow distribution in the retorting zone is achieved at the cost of the larger resistance of the upper annular channel and the pipe. As the uniformity of gas flow distribution in the retort increases over 8% and the size of "dead zone" decreases more than 10% when the retort is equipped with the double-deck gas inlet structure, the thermal efficiency of the pyrolysis process may increase significantly.

Nomenclature

h	–	height of the level from bottom to top, m;
n	–	number of measuring positions;
Opt	–	uniformity of gas flow in each part of the retorting zone;
P	–	pressure, Pa;
Q	–	gas flow rate, m^3/h;
r	–	radial distance, m;
R	–	bosh radius of the retorting zone, m;
W_i	–	vertical velocity of gas flow at position i, m/s;
W_{mean}	–	average flow velocity, m/s.
Greek		
β	–	normalized radial distance, r/R.

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