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Application Study on Three-Bed Regenerative Thermal Oxidizers to Treat Volatile Organic Compounds

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Abstract. Organic solvents with different volatilities are widely used in various processes and generate air and water pollution problems. One of the popular treatment processes for volatile organic compounds (VOCs) is regenerative thermal oxidation for the high destruction and removal efficiency. In this paper, the authors presents a project case dealing with VOCs, the waste gas with triethylamine and N-butylamine is disposed by a three-bed RTO treatment process. Two novel strategies were used in this project compared with the conventional RTO systems. Firstly, heat storage materials are saddle-shaped honeycomb, which could reform the distribution of waste gas flow in the saddle area and improve the efficiency of heat exchange. Secondly, the control mode of quick-opening valve is exhaust temperature control method instead of the time interval. The operation data shows that more than 99% of destruction and removal efficiency of VOC is obtained with slightly-level natural gas consumption. This research could provide a practical basis for the design of a RTO system.

1. Introduction

Volatile organic compounds (VOCs), generated by automotive exhaust, chemical or petrochemical industries, are the most common pollutants. VOCs could react photo-chemically with NOx in air to form ozone, and destroy the atmosphere. Inadequate handling and disposal of these compounds have resulted in worldwide pollution of soil and groundwater by vapor sorption [1]. As a result, there is a growing demand in the abatement of VOCs. Numerous methods, such as water scrubbing, chemical scrubbing, fixed-bed activated carbon adsorption, activated carbon fiber adsorption, condensation, thermal oxidation, and catalytic thermal oxidation [2,3], have been used to destroy the VOCs and to reduce environmental pollution. Thermal oxidation has become an attractive choice of VOCs control. Particularly, regenerative thermal oxidizers (RTO) have been widely used for VOC control in industries with heat recovery up to 95% and without post-treatment [4-6]. RTO is more expensive than other systems, while the cost is usually offset by the lower fuel and maintenance requirements because of the unique heat storage and convection properties of the ceramic packing utilized. Furthermore, they are especially well suited for applications with high flows and dilute concentrations of organic vapors.

RTO are typically comprised of multiple heat storage beds that alternatively store and release heat to the air as the flow is periodically directed forward and backward through the interstitial volume. Through a sequence of cyclic operations, thermal regenerators of inert material (usually ceramic materials) recover heat from burnt gases and pre-heat the air to be processed, which maximizes the energy saving point of view [7]. External heat (typically from a burner) is only added at the point where the gases have been substantially pre-heated via contact with the beds.

RTOs were first introduced to the marketplace in the early 1970s by REECO (Research-Cottrell). Early units operated with 80 to 85% heat recovery efficiency [8]. California Finished Metals operates a RTO with a 840 Nm^3/min capacity and a thermal energy rate of 85%. To provide the necessary heat transfer area for contaminated oven gases to reach the preheated chamber at 260°C, and the clean gases depart the RTO and return to the oven at 340°C [9].Thermal efficiency of an RTO system is determined by the efficient use of combustion heat within the combustion chamber, the heat retention capacities of the regeneration chambers, and the proper switching of the ceramic beds between their function as heat-charge or discharge chambers [10]. RTO regenerators are usually made with inert materials organized to form either structured or random packed-bed regenerators. Structured regenerators are often in the form of monoliths with several regularly positioned channels. Random packed regenerator beds, on the other hand, are composed of randomly packed pebbles of a variety of shapes [11].

Based on the current research results, many parameters influence the performances of an RTO system: superficial gas velocity, bed height, cycle time, particle size and voidage. Thermal efficiency exhibits a slight reduction with respect to superficial gas velocity while pressure drops increase more sensibly [12]. An increase in bed height increases both pressure drop (linearly) and thermal efficiency (asymptotically). Increases in cycle duration produce less efficient processes. For relatively small mass flows, the decrease in efficiency is little and could be compensated by the savings on the costs related to periodic switches [13]. The greater the voidage of the bed, the lower the pressure drops throughout the entire plant. Moreover, thermal efficiency increases as the particle size decreases due to the greater surface area for heat exchange. The same effect is obtained in structured beds by decreasing the size of the channels. On the other hand, as the exchange surface area increases, pressure losses become more notable.

This paper considers the disposal of a kind of exhaust gas generated during calcinations in a catalyst processing, the project is located in Zibo, China, and the main components of the waste gas are triethylamine and N-butylamine. Chemical absorption method was used in the past, however the absorption liquid will be saturated soon and the VOCs degradation was poor and unstable. As a result, the surrounding residents were unsatisfied with the plant for the unsavory smell. Now a three-bed RTO is used to dispose the exhaust gases, the equipment photograph of three-bed RTO is shown in Figure 1. The present study focuses on the characteristics and operations of this RTO system.

2. Design and operation

The working principle of the three-bed RTO is shown in Figure 2. The arrangement comprises a horizontal combustion chamber connecting three vertical heat-exchange canisters loaded with refractory material, such as ceramic intalox saddle or honeycomb monolith blocks.

A burner installed in the middle of the combustion chamber provides heat for the oxidized startup or a lower concentration of organic exhaust gas. Fast-actuating valves reverse flow direction every 1-3 min. The bed that collects heat during the previous cycle returns it to the process gas entering the oxidizer.

The three-bed RTO has the following functional mode: the waste gas, mixture of organic vapor and air, penetrates into the lower part of a bed, where it is warmed on contact with hot ceramic packing which has been heated by the combustion gases of the previous cycle. At the exit of the bed, the

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warmer waste gas enters the combustion chamber. The burner using natural gas (CH_4) as the auxiliary fuel maintains the temperature of the combustion chamber.

Figure 1. Photographs of three-bed RTO

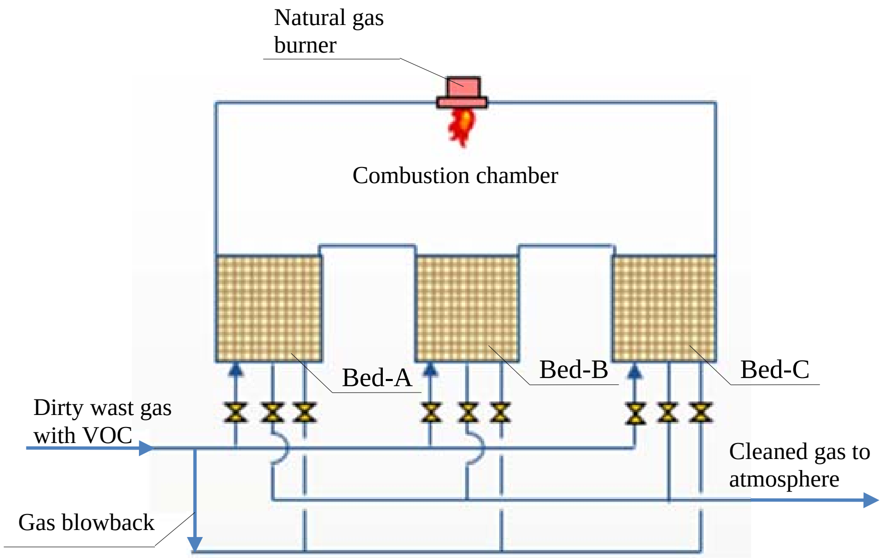

Figure 2. Schematic of three-bed regenerative thermal oxidizer (RTO)

The waste gas is ignited and oxidized in this chamber change into COx, NOx and H_2O. The combustion gas then passes through Bed 1, where it is cooled through contact with the packing. The stored energy would then be used to preheat the incoming waste gases during the next cycle. While this cycle is running, the unused Bed 2 is purged with hot clean gases, which could purge any organic vapors or carbons in the bed remained from the previous cycle.

Ordinary regenerators are made by inert material of two geometric types: ceramic bricks with longitudinal square holes having a 3mm x 3mm cross flow area (these are usually referred to as structured beds), or randomly arranged pebbles, with average diameter usually larger than 1 cm (random packing beds). Considering the operation cost and the effect of heat exchange, this project selects the structured packing beds, and the ceramic is saddle-shaped shown in Figure 3.

The saddle-shaped ceramic bricks are arranged regularly shown as Figure 4. When the waste gas passes through one brick from the one end, the gas flow is collected into a larger cavity, in which the waste gas could be integrated again and then passes through the next brick, and the uniform heat absorption-heat release process is facilitated.

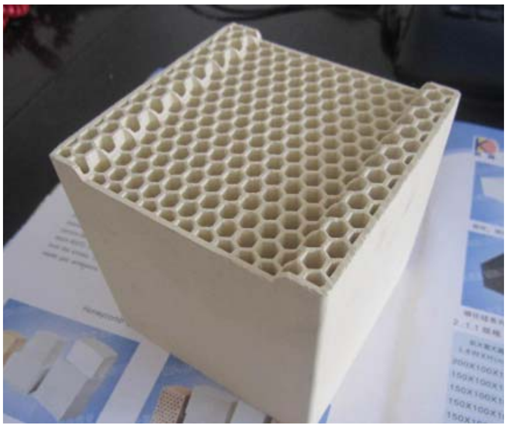

Figure 3. Ceramic honeycomb regenerator

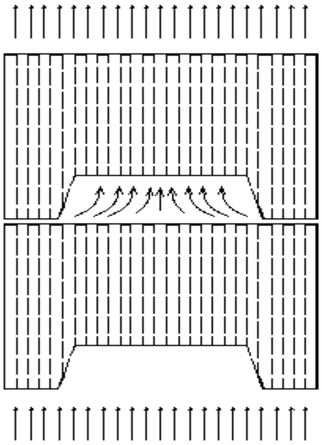

Figure 4. Streamline of waste gas pass through ceramic honeycomb

Table 1 lists the design parameters of the present RTO system.

Table 1. RTO design parameters

Number	Name	Unit	value
1	Waste gas intake quantity	m^3/h	5000
2	Waste gas concentration	mg/Nm^3	1000
3	Heat loss	%	0.5
4	Incineration flue gas temperature	°C	800
5	Natural gas consumption	m^3/h	8
6	Flue gas residence time	S	1
7	Combustion chamber volume	m^3	5.5
8	Flue gas outtake quantity	m^3/h	5000
9	Flue gas outtake temperature	°C	120

3. Results and discussion

3.1. Heat storage properties of ceramic Bed

Commonly, the control of the opening and the closing of fast-actuating valves is determined by time interval, the valves reverse flow direction in the system every 1-3 min empirically.

In present work, the opening and closing of the valve is switched every 90 seconds. The exhaust temperatures of the three-bed were tested shown in Figure 5. As can be seen from it, the temperature of exhausting end moment of Bed A and Bed B are about 120°C and 115°C respectively, which coincides with the design values well. However, the temperature of exhaust gas of Bed C is about 150°C, which deviate the expected value about 30°C, and the heat loss is very serious. The temperature monitoring results shows there are some defects of Bed C. As well known that readjusting the ceramic material is a very difficult and time-consuming work, so it is necessary to adjust the exhaust control method to solve this problem. As a result, flue gas outtake is changed to temperature-control method.

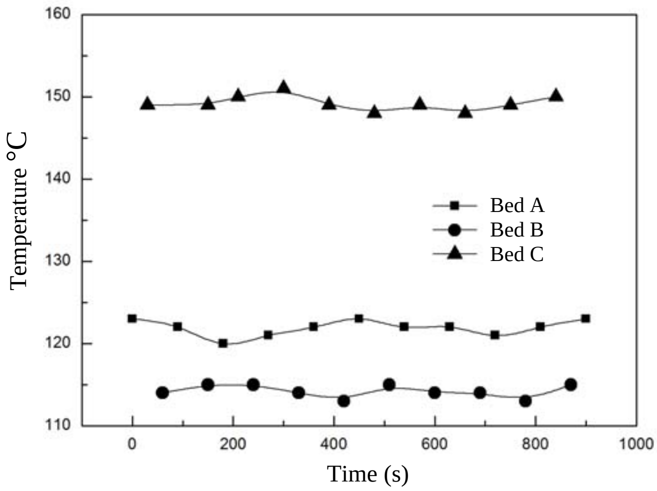

Figure 5. Temperature varies with time of three-bed RTO

3.2. Exhausting temperature-control method

To reduce exhaust heat loss, the control procedure is optimized, and the exhaust temperature control method is used in this project, that is, when the exhaust temperature is higher than 120°C, which indicating the regenerative cycle has completed, and the exhaust valve is closed. Figure 6 shows the continuously exhausting time of the three-bed at each exhausting cycle. As can be seen from it, the exhausting time of Bed A and Bed B could continue to exhaust for about 90 seconds in each cycle, which agree with design value. While Bed C's is only 50 seconds, indicating that the heat storage capacity of Bed C is far less than the design value. There will be a great deal of heat without recovered if according to the design value for 90 seconds.

3.3. RTO performance test

Figure 7 shows the waste gas temperature profile during a complete cycle from entering to leaving RTO. It can be seen from this figure that the gas temperature increases linearly during the gas passing through the regenerator Bed, and the temperature increases to about 500°C. After entering the combustion chamber, the gas temperature rises rapidly to 850°C. The temperature is maintained for a period of time in chamber, then the gas exits RTO through another regenerator Bed, and the regenerator recovers the heat of the high-temperature flue gas for heating the waste gas to be disposed in the next cycle.

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3.4. Destruction and removal efficiency

The local environmental protection departments paid a great attention to the present project closely. A third party organization was invited to measure the emission of gas when the RTO was put into use. The test result shows that the exhaust concentration of VOCs is about 30 ppm (part per million) while.

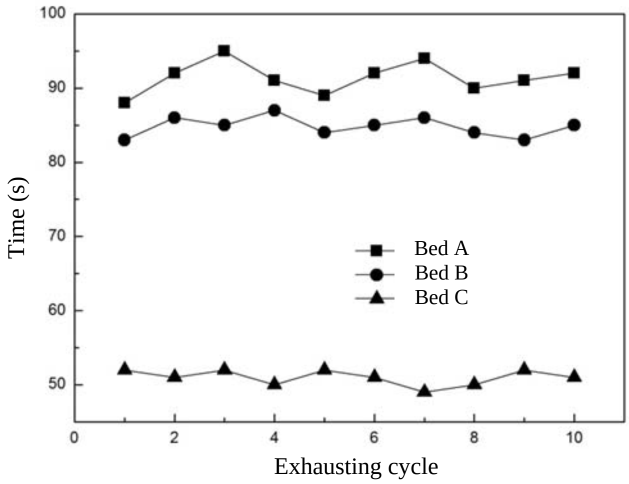

Figure 6. Continuously exhausting time of three-bed

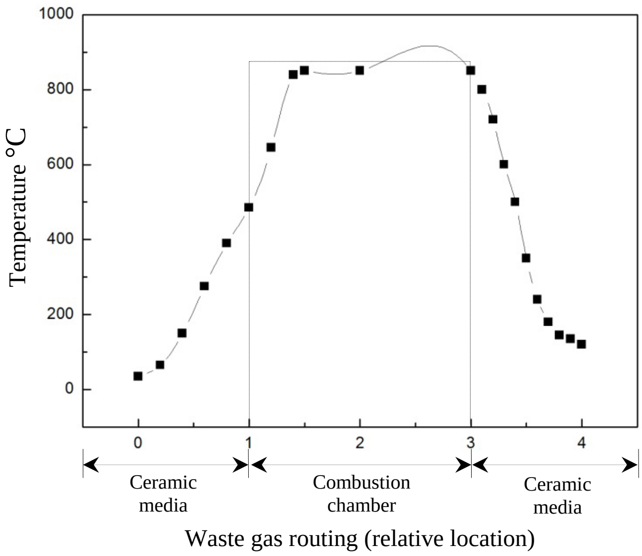

Figure 7. Temperature profile of waste gas in RTO

The primitive concentration is 2000 ppm. The destruction and removal efficiency is up to 99.5%, and the consumption of natural gas is only 4.5m^3/h. The operation and the test result all indicate that the RTO have an excellent performance on dealing with VOCs.

4. Conclusion

In this study, a three-bed RTO was designed to dispose calcined waste gas with triethylamine and N-butylamine. The project has been running for six months, the running results show that the saddle-shaped honeycomb ceramic bed has a good efficiency of heat recovery. The exhausting temperature-control method is a better option to determine the opening and closing of the quick-opening valve with minimal exhaust heat loss. The operation data shows more than 99% of destruction and removal efficiency of VOCs is obtained with slightly-level natural gas consumption. Based on these results, the

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RTO makes an excellent result in both technically and economically feasible, and the RTO is capable of destroying waste VOCs with adequate efficiency. The authors recommend that saddle-shaped honeycomb ceramic bed and exhausting temperature-control method as the priority program for the design of a new RTO system in treatment of VOCs.

Acknowledgments
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References

[1] T.G. Poulsen, P. Moldrup, T. Yamaguchi, J.W. Massmann, J.A. Hansen, VOC Vapor sorption in soil: soil type dependent model and implications for vapor extraction, J. Env. Eng. 124 (1998) 145-150.
[2] K.B. Schnelle Jr., C.A. Brown, Air pollution control technology handbook, CRC Press, New York, 2002.
[3] U.S. Environmental Protection Agency, Handbook-control technologies for hazardous air pollutants, EPA-625-6-91-014, Research Triangle Park, NC, 1991.
[4] M. Bannai, A. Houkabe, M. Furukawa, T. Kashiwagi, A. Akisawa, T. Yoshida, H. Yamada, Development of efficiency-enhanced cogeneration system utilizing high-temperature exhaust-gas from a regenerative thermal oxidizer for waste volatile-organic-compound gases, Appl. Energy, 83 (2006) 929-942.
[5] A. Vij, A primer on damper technologies for regenerative thermal oxidizers understanding the multiple functions that valves serve in common RTO systems, Met. Finish. 104 (2006) 17–22.
[6] M. Amelio, P. Morrone, Numerical evaluation of the energetic performances of structured and random packed beds in regenerative thermal oxidizers, Appl. Therm. Eng. 27 (2007) 762–770.
[7] Masashi, K., Toshiaki, H., 1998. The scientific and technology of combustion highly preheated air. 27th Symposium (International) on Combustion, 27 (1998): 3135-3146.
[8] Church, F. L. Deodorant for a container firm: Regenerative oxidation. Modern Metals, 9 (1989) 76–80.
[9] Nester, J. L., and Uphues, R. Regenerative thermal oxidizer upgrades allow coil coater to increase production and maintain regulatory compliance. Met. Finish. 95 (1997) 46–48.
[10] D.A. Lewandowski, Design of thermal oxidation systems for volatile organic compounds, Wiley-Interscience publication, Wisconsin, 2000.
[11] Afandizadeh S, Foumeny EA. Design of packed bed reactors: guides to catalyst shape, size, and loading selection. Applied Thermal Engineering, 21 (2001) 669–682.
[12] Pitts DM. Regenerative thermal oxidizers structured packing improves performance. Chemical Engineering, 1 (1999) 113–119.
[13] Lewandowski DA, Nutcher PB, Walder PJ. Advantages of twin bed regenerative thermal oxidation technology for VOC emission reduction. Air and Waste Management Conference on Emerging Solutions to VOC and Toxics Control , Clearwater, FL, 1996.