2008-5435/12/42-26-31
INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE

IJOH 4: 26-31, 2012

ORIGINAL ARTICLE

The Role of Packing Media in a Scrubber Performance Removing Sulfuric Acid Mists

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Received January 8, 2012; Revised May 28, 2012; Accepted June 14, 2012

This paper is available on-line at *http://ijoh.tums.ac.ir*

ABSTRACT

The mass-transfer media plays a significant role on the performance of a packed tower. In this paper three counter-current single-stage packed towers at laboratory scale, randomly packed with two different sizes of two types of packing material were experimentally tested to study the role of the packing on the performance of them in the removal of sulfuric acid mists. Gas samples were extracted from specified points and quantified using US EPA method 8. All required steps were taken in order to comply with quality assurance procedures described in US EPA method 8. The results from 98 tests in four series including two types of packing materials each in two packing sizes revealed that 1.27 cm (0.5 inch) Raschig ring and Intalox saddle had higher removal efficiencies (94.0% and 92.3% respectively) than 2.54 cm Raschig ring and Intalox saddle (86.8 and 81.8% respectively). The statistical comparison of the average removal efficiencies showed that there was no significant difference (P_{value} = 0.344) between the average removal efficiency of the tower packed with 1.27 cm Intalox saddle and 1.27 cm Raschig ring. The highest removal efficiency of 98.2% was obtained at H_c/D_c ratio of 3 for 1.27 cm Raschig rings. The highest removal performance versus gas flow rate over packing volume (Q_{gas}/V_{pack}) ratio was obtained with average removal efficiency of 95.0% for 1.27 cm Raschig rings. It was concluded that 1.27 cm Raschig rings performed the best for removal of sulfuric acid mists from air stream using packed bed caustic scrubbers.

Keywords: *Scrubber, Packed tower, Sulfuric acid, Mist*

INTRODUCTION

A variety of wet scrubbers are widely used in mass transfer operations in cleaning up of flue gases. One of the more popular ones is the absorption tower randomly filled with packing materials [1, 2].

The mass-transfer or "packing" media plays an important role in a packed bed scrubber. Its influence on the system cost, efficiency and maintenance is significant. Some researchers claim that metal pall rings are the most efficient and economical packing materials, others argue that Intalox saddles are the best [3, 4]. More recent years have seen the introduction of structured packing materials which are touted by their manufacturers to have better characteristics [2, 5].

According to major manufacturers, their new packing materials increase capacity, resist fouling,

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Fig 1. Packed towers used in the study

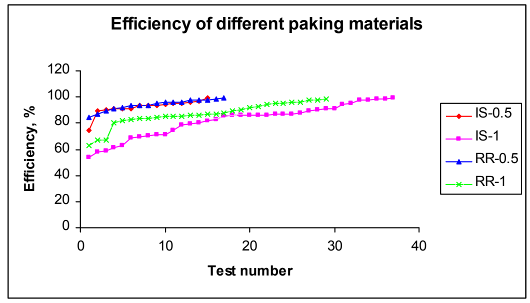


Fig 2. Efficiency of packed towers using different packing material

decrease column size and reduce pressure drop for capital and operating cost savings. In a well structured packing, the contact surface between gas and the scrubber liquid is maximized. This enables optimal efficiencies, and thus low operational costs.

However, various disadvantages have been reported with the random packing material [6]. Some of them have poor distributed air flow, poor wetting of packing, plugging and non uniform absorption. The regular (structured) packing offers the advantages of low pressure drop for the gas and greater possible fluid flow rates, usually at the expense of more costly installation than random packing [1, 2]. Usually large packing sizes are employed to reduce pressure drop. But the larger the size of a given packing is, the smaller the available surface area for contacting between the phases and the lower the contacting efficiency. These disadvantages may not be offset by the lower pressure drop. The higher the throughput and the lower cost resulting from the larger packing size [5].

The performance and efficiency of a packed tower scrubber is generally upon the following factors:

- The packing surface area over which gas/liquid transfer
- The even distribution of the scrubbing liquor throughout
- Gas velocity through the packed tower
- The liquid flow rate through the packed bed

The packing should provide a large surface area in a given volume, where the water wets its surface, and the gas contacts the water on the wetted surface. Small size packing may choke the bed in case of high dust and some type of contaminants loadings in the gas. Therefore large size packing may be applied in the upper bed and smaller size in the lower bed [7]. Smaller packing size provides a larger contact area, but it leads to a higher pressure drop as well. Higher risk of flooding is expected when small packing is used.

Higher packing depth increases the available contact area as well as the residence time available. More pressure drop is expected when the packing depth increases. Beyond a certain limit it is expensive to increase the packed bed height for additional gas cleaning [7].

The removal of sulfuric acid mists from the air stream has been a challenging task. Although the US EPA technical literature [8] recommended packed bed scrubbers for sulfuric acid mist removal from the air stream, but not many experimental investigations have been carried out to study the influences of different components of a packed bed tower on its' removal efficiency for sulfuric acid mists from the air stream.

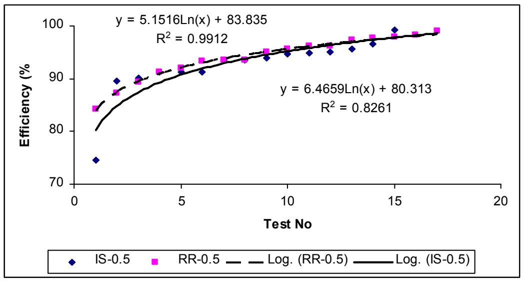
This paper describes the performance test results for 3 counter-flow single stage packed bed scrubbers constructed in laboratory-scale for sulfuric acid mist removal from air stream, using different packing materials.

MATERIAL AND METHODS

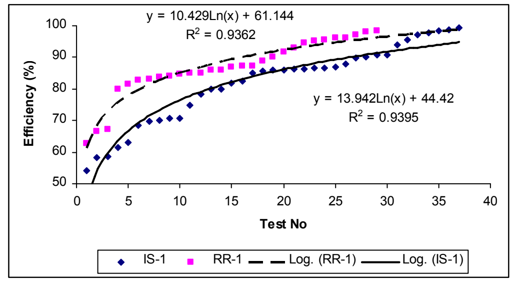
Packed tower scrubbers

Three counter-current single-stage packed tower scrubbers at laboratory scale were constructed from black iron painted with anti-corrosion paint. The diameter of the scrubbers was 10, 20 and 30 cm respectively. Two types of packing material including Raschig ring and Intalox saddle each in two different sizes of 1.27 cm and 2.54 cm were used. Three packing depths of 30.5, 45.7 and 61.0 cm (1, 1.5 & 2 feet) were employed respectively. The scrubbing beds were randomly packed. Each packed tower was comprised of a column shell, liquid distributor, packing material, and packing support. A photograph of the packed towers used in present study is shown in Fig. 1.

All required basic components as explained in reference nine [9], except mist eliminator were used in the constructed packed tower. When the void space over the bed is high and the gas velocity in the tower is lower than 18 m/s the application of demister is not recommended [10]. Mist eliminators are placed in the gas outlet to prevent any liquid droplet carry-over from bed to the outlet stack. The most common packing types



a: 1.27cm size



b: 2.54cm size

Fig 3. Efficiency of packed towers using different packing material

of ceramic Intallox saddles and Raschig rings which provide a large contact surface for scrubber solution and the contaminated air stream [11] were used.

Acid mist preparation

Injection of diluted acid was not practically successful to get a relatively high concentration of acid mist in the air. Therefore, high concentration acid was vaporized using electric heaters and the vapor was exhausted by a local hood to the packed tower. According to US EPA the sulfuric acid mist includes not only liquid mist but also sulfur trioxide (SO_3) and sulfuric acid vapor [9]. The number of heaters, their heating intensity, the volume of liquid acid in each container and the type of containers needed to be constant to produce an almost constant volume of acid mist during each test. With a constant volume of air exhausted by hood and a constant volume of generated acid mist, the concentration of acid mists remained almost constant at inlet ducts connected to the packed tower. Pretests were required prior to the main tests to get the size of each influencing parameter. Sulfuric acid mists in the input air ranged from 28.6-559.8 mg/m^3.

Air sampling and acid mist measurement

US EPA method No 8 was employed to measure the concentration of sulfuric acid mist at inlet and outlet ducts connected to the scrubber (Fig. 1). Gas samples were extracted from specified points located at the inlet and outlet ducts connected to the packed tower iso-kinetically. The sulfuric acid mist including sulfur trioxide and sulfur dioxide were stripped from the gas samples using 80% isopropanol. Subsequently, the sulfur dioxide was trapped in an absorbing solution of 3% hydrogen peroxide. Both fractions were analyzed separately by the barium perchorate-thorin indicator titration method [12-14].

A sampling rig similar to those explained in US EPA method 5 was employed. Construction details described in APTD-0581 were considered for sampling train [12]. SKC sampling pumps and standard laboratory equipments were applied. Four Greenburg-Smith design impingers as recommended by method 8 of US EPA were used for air sampling.

Metering system, a barometer and gas density determination equipment were all the same as those in method 8, section 2.1.8, 2.1.9, and 2.1.10 respectively. All sampling equipments were the same as those recommended by method 8 of US EPA.

Air flow and pressure loss measurement

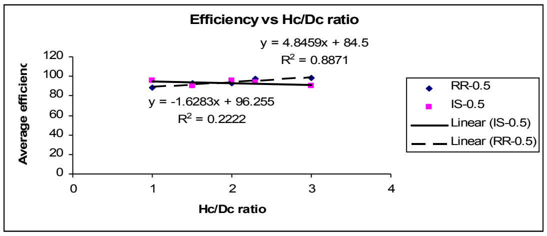
Air flow required for tests were produced by a variable flow rate fan model HVDLT-MK2, manufactured by UK air flow Co. A low pressure loss Venturi meter with accuracy of 95-99% was used to measure the flow rate. Calibrating tests were performed to choose the most precise air flow measuring device. A pitote tube with an accuracy of 98% was used to measure the pressure drop at packed tower in each test. Air flow rates were also double checked using pitote tube along with an inclined micro manometer.

Liquid flow and pH measurement

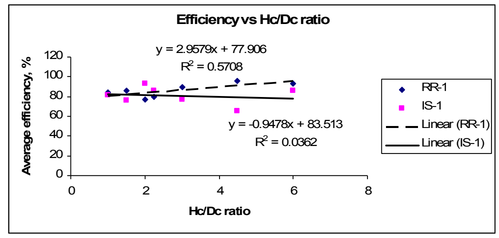
The scrubbing liquid was re-circulated through a pump and was set to desired rates using a valve. The liquid flow rate was measured 5 times during each

Table 1. The results of tests carried out with 1.27 & 2.54cm Indtalox saddle

Parameter	1.27 cm Indtalox saddle (n=15)			2.54 cm Indtalox saddle (n=37)		
	Max	μ±σ	Min	Max	μ±σ	Min
D_c, cm	30.0	21.3±6.4	10	30.0	22.7±8.4	10.0
H_c, cm	61.0	44.6±14.0	30.5	61.0	45.7±13.4	30.5
Q_g, cm^3/s	45000	25333.3±12724.9	10000	450000	30405.4±15607.1	10000
Q_l, cm^3/s	62.5	44.5±10.6	21.7	62.5	45.7±17.5	20.8
pH	5.5	3.1±1.2	1.9	3.8	2.7±1.1	1.3
C_{in}, mg/m^3	559.8	226.3±116.4	125.3	490.8	193.9±118.0	63.7
ΔP, pa	1932.4	554.4±541.4	264.5	881.9	247.8±249.9	58.7
E%	99.2	92.3±5.6	74.5	99.2	81.8±12.5	54.1

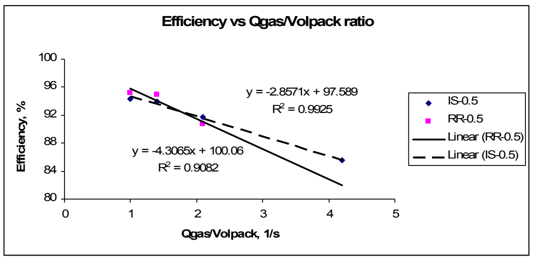


a: 1.27cm size

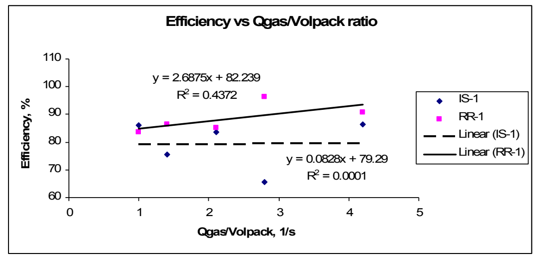


b: 2.54cm size

Fig 4. Average efficiency versus H_c/D_c ratio for different packing materials



a: 1.27cm size



b: 2.54cm size

Fig 5. Average efficiency versus packing volume

sampling period using a flow meter. The pH of scrubbing liquid was being regulated using sodium hydroxide. Scrubbing liquid pH was measured 5 times during each sampling period. The pH meter was calibrated prior to each sampling test. Other parameters including, air and water temperature, barometric pressure and etc were also measured during each sampling period as described in method 8 of US EPA.

RESULTS

A total number of 98 tests in four series including two types of packing materials each in two packing sizes were carried out. Sulfuric acid mists in the input air ranged from 28.6-559.8 mg/m^3. Fig. 2 shows the overall performance of the packed towers using different types of packing material. The smaller sizes of packing have the higher efficiency. This is true for both types of packing.

The removal efficiencies of both packings with the same size are compared in Fig. 3-a & b.

The results from 15 tests carried out with 1.27 cm Intalox saddle packing showed that maximum, average ±standard deviation and minimum values of efficiency were 99.2, 92.3±5.6 and 74.5% respectively. Table 1 shows more details of other parameters during these tests.

Maximum, average±standard deviation and minimum efficiencies of 37 tests conducted with 2.54 cm Intalox saddle were 99.2, 81.8±12.5 and 54.1% respectively. The values of other parameters during these tests are shown in Table 1.

Seventeen tests were carried out with 1.27 cm Raschig rings whose results are shown in Table 2. The results showed that the maximum, average ±standard deviation and minimum values of efficiency were 99.1, 94.0±4.1 and 84.2% respectively. According to Table 2, maximum, average ±standard deviation and minimum efficiency of 29 tests carried out with 2.54 cm Raschig rings were 98.4, 86.8±9.1 and 62.7% respectively.

Figure 4 illustrates the average removal efficiency at different packing depth to bed diameter ratio (column height to column diameter or H_c/D_c). The results showed that for 1.27 cm (0.5 inch) Intalox saddles, the highest removal efficiency of 95.6% was obtained at H_c/D_c ratio of 1. The lowest removal efficiency of 90.2% was obtained at H_c/D_c ratio of 3. Similar tests showed that in the case of 1.27 cm Raschig rings, the highest average efficiency of 98.2% was obtained at H_c/D_c ratio of 3, while the lowest removal efficiency of 88.4% was obtained at H_c/D_c ratio of 1.

The variations of removal efficiency versus gas flow rate to packing volume (Q_{gas}/V_{pack}) ratio are shown in Fig. 5. The results revealed that for 1.27 cm Intalox saddles, the highest removal efficiency of 94.3% was obtained at Q_{gas}/V_{pack} ratio of 1s^{-1}. As this ratio increased, the removal efficiency decreased until the lowest efficiency of 85.5% obtained at 4.2 s^{-1} Q_{gas}/V_{pack} ratio (Fig. 5-a). For 1.27 cm Raschig rings, the highest efficiency of 95.0% was obtained at Q_{gas}/V_{pack} ratio of 1s^{-1}, while the lowest efficiency was 90.7%. Figure 5-a illustrates that the variation of efficiency versus Q_{gas}/V_{pack} ratio for both packing materials had similar linear trends.

In case of 2.54 cm Intalox saddles, as the Q_{gas}/V_{pack} ratio increases from 1s^{-1} to 4.2s^{-1}, the average removal efficiency is almost constant with highest value of 86.1% and the lowest value of 86.5% (Fig. 5-b). For

Table 2. The results of tests carried out with 1.27 & 2.54 cm Rashig rings

Parameter	1.27 cm Rashig rings (n=17)			2.54 cm Rashig rings (n=29)		
	Max	μ±σ	Min	Mmax	μ±σ	Min
D_c, cm	30.0	24.7±5.1	20.0	30.0	19.7±7.8	10.0
H_c, cm	61.0	45.7±13.2	30.5	61.0	45.7±12.9	30.5
Q_g, cm^3/s	45000	31762.7±12862.4	20000	45000	23793.3±13993.3	10000
Q_l, cm^3/s	62.5	51.5±10.7	41.7	62.5	40.9±16.2	20.8
pH	6.4	3.4±1.4	1.9	6.6	3.6±1.5	1.8
C_{in}, mg/m^3	285.8	139.5±50.7	81.4	437.9	174.2±109.9	54.2
ΔP, pa	1058.2	623.4±278.0	293.9	1126.8	468.1±415.9	117.6
E%	99.1	94.0±4.1	84.2	98.4	86.8±9.1	62.7

2.54cm Raschig rings, as the Q_{gas}/V_{pack} ratio increases from 1 to $4.2s^{-1}$, the average removal efficiency increases from 83.5% to 90.7% (Fig. 5-b).

DISCUSSIONS

The preparation of sulfuric acid mist in air stream was a challenging task since the attempts of injecting diluted sulfuric acid into air stream to get high concentrations of acid mist in the air failed. The boiling of sulfuric acid in an open cup under a local exhaust hood was a novel method to get high concentrations of sulfuric acid mists in air stream experienced in present study. The result complies with US EPA literature that defines sulfuric acid mist including not only liquid mist but also sulfur trioxide and sulfuric acid vapor [9].

Using peroxide-free isopropanol is a vital step to comply quality assurance procedures when US EPA method 8 is applied. Four commercial brands of isopopanol were tested to achieve this.

The sulfuric acid removal efficiency of Ceilcote Air Pollution Control Company's packing towers packed with Tellerette packing material in 91.4 cm packing depth is 85-90% [15]. The comparison of the results from present study with those from Ceilcotte Co showed that the removal efficiency of sulfuric acid using packed towers with 1.27 cm Italox saddle and Raschig rings are higher than Tellerette packing. The removal efficiency of 2.54 Raschig ring is in the range of Ceilcote Co for Tellerette but the removal efficiency of 2.54 cm Intalox saddle is lower than those announced by Ceilcotte Co.

The purpose of using packing is to provide large surface area of scrubbing liquid which allows sufficient gas residence time for contact. It promotes turbulent mixing between gas and liquid phases. The results from present study also showed that smaller packing materials provide larger surface area of scrubbing liquid which led to higher removal efficiency (Tables 1 & 2).

With smaller packing size, the effective cross sectional area of tower decreases leading to higher gas velocity. Higher turbulent gas velocities increase the tower performance. For a scrubber which has a smaller cross sectional area, there is a higher potential for liquid to be held at packing void spaces. This situation increases scrubber pressure drop and decreases the mixing between the liquid and gas. Besides, variation of the liquid and gas flow rates is one of the reasons that the gaseous pollutants lack the required residence time to be absorbed by the liquid. Consequently, gas velocity across the scrubber influences the retention time of the dirty gas which can affect the scrubber efficiency. Flooding occurs when packing void spaces is totally filled by the liquid. Flooding results in a layer of liquid at the top of packing and this forbids the liquid from flowing down through the packed bed. This significantly affects the absorption process and should be avoided.

The statistical analysis revealed that when the scrubbing tower is packed with 1.27 cm Intalox saddle, its average removal efficiency (92.3%) is significantly higher (P_{value} = 0.003) than that when it is packed with 2.54 cm Italox saddle (81.8%). The results show that as the Raschig ring size increases from 1.27 cm to 2.54 cm, the removal efficiency decreases significantly (P_{value} = 0.004) from 94.0% to 86.8%.

The comparison of the average removal efficiency with 1.27cm Intalox saddle and Raschig rings showed that there was no significant difference (P_{value} = 0.344) between the average removal efficiency of the tower packed with 1.27 cm Intalox saddle and 1.27 cm Raschig ring packing material. There was also no significant difference (P_{value} = 0.08) between the average efficiency of the scrubber when it is packed with 2.54 cm Intalox saddle and the same size Raschig rings. The results show that 1.27 cm Raschig rings has the highest removal efficiency (94.0%). The smaller size of packing had the higher efficiency that was consistent with other works [10].

The linear trend of average removal efficiencies at different H_c/D_c ratios for 1.27 cm Intalox saddles and Raschig rings show that in the case of Intalox saddles, as the H_c/D_c ratio increases, the average sulfuric acid mists removal efficiency decreases, while for 1.27 cm Raschig rings, by increasing H_c/D_c ratio, the average removal efficiency increases (Fig. 4).

For 2.54 cm (1 inch) Intalox saddles, the highest removal efficiency of 92.8% was obtained at H_c/D_c ratio of 2 while the minimum removal efficiency of 65.6% was obtained at H_c/D_c ratio of 4.5 (Fig. 4). In case of 2.54 cm Raschig rings, the highest efficiency of 96.3% was obtained at H_c/D_c ratio of 4.5 while, the lowest removal efficiency of 77.4% was obtained at H_c/D_c ratio of 2.

For 2.54 cm (1 inch) Intalox saddles, as the H_c/D_c ratio increases, the average removal efficiency decreases as well (Fig. 4). While, for 2.54cm Raschig rings as the H_c/D_c ratio increases, the average removal efficiency increases (Fig. 4). The comparison of the results in Fig. 4-a & b shows that, the linear trends of efficiency variations for both packing materials at different sizes are similar. For Intalox saddles, as the H_c/D_c ratio increases the removal efficiency decreases but for Raschig rings, as the H_c/D_c ratio increases, the average removal efficiency increases.

The Tukey statistical analysis of the results showed that the H_c/D_c ratio had a significant influence on the average removal efficiency of the packed tower when it was packed with different sizes of either Raschig ring or Intalox saddle.

Higher H_c/D_c ratio represents higher air velocity and more turbulent flow in the pack tower which may decrease the residence time. The residence time is not expected to have a significant influence on the performance of a caustic packed tower but the turbulent air flow in packed tower is expected to promote its performance. Therefore, as the ratio of H_c/D_c increases, higher efficiencies are expected in a caustic packed tower. This is true in the case of Rashig rings of both sizes but it is not true in the case of Intalox saddles. The shape of packing could lead to such a controversial result. More studies required to find out the reason.

The present study showed that as the packing depth increased the scrubber performance promoted which complies with other studies [15, 16]. As the packing depth was increased, additional packing promoted absorption rate since it created more gas liquid contacting surface.

The removal efficiency of scrubbers obtained for different packing material in the present study well agrees with those claimed by Ceilcote Air Pollution Co [15].

Our results revealed that the effect of type of packing on caustic packed bed scrubber performance for the separation of sulfuric acid was negligible in comparison with other parameters. Numerical examples simulated by [17] showed the same results for the separation of VOC by the packed bed towers.

CONCLUSIONS

1. Smaller packing leads to higher removal efficiency of sulfuric acid mist from air.
2. Higher H_c/D_c leads to a different performance in a tower packed with Intalox saddles and Rashig rings.
3. As the packing depth increases the scrubber performance promotes.

ACKNOWLEDGEMENT

This project was founded by Shahid Beheshti University of Medical Sciences (registered No. P/25/11/277 date 11 April 2010). The authors wish to greatly appreciate them for their effort. The authors declare that there is no conflict of interest.

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