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Field Report

Application of Local Exhaust Ventilation System and Integrated Collectors for Control of Air Pollutants in Mining Company

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Abstact: Local exhaust ventilation (LEV) systems and integrated collectors were designed and implemented in a mining company in order to control emitted air pollutant from furnaces. The LEV was designed for capture and transition of air pollutants emitted from furnaces to the integrated collectors. The integrated collectors including four high efficiency Stairmand model cyclones for control of particulate matter, a venturi scrubber for control of the fine particles, SO_2 and a part of H_2S to follow them, and a packed scrubber for treatment of the residual H_2S and SO_2 were designed. Pollutants concentration were measured to determine system effectiveness. The results showed that the effectiveness of LEV for reducing workplace pollution is 91.83%, 96.32% and 83.67% for dust, SO_2 and H_2S, respectively. Average removal efficiency of particles by combination of cyclone and venturi scrubber was 98.72%. Average removal efficiency of SO_2 and H_2S were 95.85% and 47.13% for the venturi scrubber and 68.45% and 92.7% for the packed bed scrubber. The average removal efficiency of SO_2 and H_2S were increased to 99.1% and 95.95% by the combination of venturi and packed bed scrubbers. According to the results, integrated collectors are a good air pollution control option for industries with economic constraints and ancient technologies.

Key words: Air pollution, Integrated collectors, Cyclone, Scrubber, Venturi

Introduction

Air pollution is one of the most important agents that can affect human health as well as the environment, plants, and animals. Three million deaths from air pollution had been reported annually, making it one of the seven greatest hazards for the world[1].

Humans did not significantly affect the environment until relatively recent times. This is due to human population increasing for only a small part of recorded history, and the bulk of human-made produced air pollution is intimately related to industrialization[2].

With rapidly expanding industry, ever more urbanized lifestyles, and an increasing population, concern over the control of man-made air pollutants is now clearly a necessity[3].

Mining industries produce various pollutants that not only affect workers' health but also affect the health and welfare of nearby residents. One of these companies is located 7 km from Sarcheshme town in Kerman province in Iran. This company produces sodium sulfide by reverberatory furnaces. The sodium sulfate and powdered coal were mixed and reacted together to produce sodium sulfide in

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the furnace. Any cycle of this process longer than three hours increased the inside temperature of the furnace to 1,000° C. The ancient technology and application of fuel oil in the furnace produced and emitted high concentrations of various air pollutants, including airborne particles, sulfur dioxide (SO_2), and hydrogen sulfide (H_2S). These pollutants can be spread to nearby towns and cause many complaints, especially in warm seasons.

The human nose can detect the “rotten egg” odor of H_2S at a concentration of 0.4 parts per billion (ppb). The maximum allowable exposure for prolonged periods is 10 parts per million (ppm), the peak concentration for 10 minutes exposure is 50 ppm, and exposure to concentrations greater than 300 ppm for 30 min is fatal[4)].

Sulfur dioxide is a colorless gas that can be detected by taste and smell in the range of 1 to 3 mg/m^3. At a concentration of 10 mg/m^3, it has a pungent, unpleasant odor. The high solubility of this gas causes it to dissolve readily in water present in the atmosphere to form sulfurous acid (H_2SO_3). About 30% of the sulfur dioxide in the atmosphere is converted to sulfate aerosol (acid aerosol), which is removed through wet or dry deposition processes. Exposure to sulfur dioxide in the ambient air has been associated with reduced lung function, increased incidence of respiratory symptoms and diseases, irritation of the eyes, nose, and throat, and premature mortality. Health impacts appear to be linked especially to brief exposures to ambient concentrations above 1 mg/m^3 (acute exposures measured over 10 min)[5)].

The emitted dust from furnaces comprises sodium sulfate, coal, and soot. Sodium sulfate dust does not have significant health effects. Soot was formed from burning of fuel oil. The emitted soot from furnaces includes chemical complexes of various compounds, some of which are carcinogenic[6)]. Coal dust is an odorless dark brown to black dust, and causes pneumoconiosis, bronchitis, and emphysema in exposed workers. The current Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for the respirable fraction of coal dust (less than 5 percent crystalline silica) is 2.4 mg/m^3 time-weighted average (TWA) concentration. The American Conference of Governmental Industrial Hygienists (ACGIH) has assigned the respirable fraction of coal dust containing less than 5 percent crystalline silica a threshold limit value (TLV) of 2 mg/m^3 as a TWA for a normal 8-h workday and a 40-h work week[7)].

There are essentially only two general methods of air pollution control. These options are application of control technologies that clean air or remove pollutants, and prevention. As a general rule of thumb, prevention is more cost effective than application of so-called end-of-pipe treatment technologies. However, there are many situations where control technologies represent the only feasible methods to manage air pollution problems[5)]. The present process in this plant is the oldest production technology, and a change of technology is not possible for economic and other restrictions. Thus, it seemed necessary to design and implement local exhaust ventilation (LEV) for collection of air pollutants, and treatment with integrated collectors is the best alternative.

With respect to varieties of pollutants and high concentration of them, it was necessary to use a combination of air cleaning devices. These collectors must decrease air pollutants to environmental standard levels.

The aim of this study was design and implementation of proper LEV systems for reduction of workplace air pollutants concentration and integrated collectors in order to control emitted air pollutant from furnaces to protect workers’ and residential health.

Subjects and Methods

First, it is necessary to become familiar with the production process and determine the kind and concentration of air pollutants. Two furnaces were selected for pollution control; they have a stack from which pollutants can be emitted into the environment. The concentration of air pollutants has been measured at the workplace and in the stack. Due mainly to the furnace in interval it 2 to 3 meters, it worked so well in the distance measurements were performed. The measurements were repeated several times and in various cycles of furnace operations. The concentration of SO_2 and H_2S was determined via Kane-May Single Gas Analyzer (SGA94-SO_2) and Toxi RAE II Gas Analyzer, respectively. The reading of gas concentrations was carried out over one minute for any step. The isokinetic sampling method was selected to measure dust concentration in the stack based on British Standard (BS) 3405[8)].

In the second phase, LEV was designed to meet VS-55–03 and VS-55–04 standards set by the industrial ventilation committee of the ACGIH for capture and transmission of emitted pollutants[9)]. Because the pollution concentration fluctuates during each operating cycle of the furnace, the highest concentrations were used for design. Thus, four high efficiency cyclones were designed to collect dust exhausted from furnaces. The cyclones can effectively separate dust from air, especially coarse particles[3, 10]. The dust collected by cyclones was recirculated to furnaces. The diameter of cyclones was calculated from the ventilation flow rate and other geometrical dimensions were determined from the cyclone model[3]. The fractional and total collection efficiency of cyclones can be estimated with cut diameter (d_{pc}), which is defined as the size (diameter) of particles collected with 50% efficiency. A frequently used expression for cut diameter is

$$d_{pc} = \left[\frac{9\mu w}{2\pi N_e v_i \left(\rho_p - \rho_g\right)} \right]^{0.5} \tag{1}$$

Where:
μ: viscosity, lb/ft.s (Pa.s)
w: gas entry width, ft (m)
N_e: effective number of turns (5–10 for the common cyclone),
V_i: inlet gas velocity, ft/s (m/s)
ρ_p: particle density, lb/ft^3(kg/m^3)
ρ_g: gas density, lb/ft^3(kg/m^3)
Fractional efficiency (η_i) is expressed as

$$\eta_j = \frac{1}{1 + \left(\frac{d_{pc}}{d_{pj}}\right)^2} \tag{2}$$

Where d_p is the particle diameter (μm).
The overall efficiency of the cyclone (η) is a weighted average of the collection efficiencies for the various size ranges:

$$\eta = \frac{\Sigma \eta_j m_j}{M} \tag{3}$$

The exited fine particles from cyclones were removed by venturi scrubber, which has high collection efficiency for dust, even to submicron sizes[2, 3, 11].

Venturi collection efficiency was calculated from a more popular and widely used collection equation that is originally suggested by Johnstone[3]:

$$E = 1 - e^{-kR(\psi)^{0.5}} \tag{4}$$

Where
E: efficiency (fractional), Ψ: inertial impaction parameter (dimensionless), R: liquid-to-gas ratio (gal/1,000 acf or gpm/1,000 acfm), k: correlation coefficient, the value of which depends on the system geometry and operating conditions (typically 0.1–0.2 acf/gal).
The term Ψ is given by

$$\psi = \frac{C d_p^2 \rho_p v_t}{9 \mu_g d_o} \tag{5}$$

Where
d_p: particle diameter (ft), ρ_p: particle density (lb/ft^3), v_t: throat velocity (ft/s), μ_g: gas viscosity (lb/ft. s), d_0: mean droplet diameter (ft), C: Cunningham correction factor
This venturi has a rectangular adjustable throat whose area is varied by movable plate. This condition helps the designer and operator to adjust collection efficiency and pressure drop of venturi by changing gas velocity[12]. Velocities at such a constriction can range from 200 to 800 ft/s (from 61 to 244 m/s)[3]. Also, this scrubber can be reducing SO_2 effectively and H_2S somewhat by absorption.

The residual gaseous pollutants had been removed by packed scrubber. The technical characteristics of packed scrubber such as diameter and height of scrubber body, bed dimensions, the type and concentration of absorption liquid, liquid to gas ratio or L/G (l/m^3), and packing specifications were determined based on the pollution compound and concentrations, required collection efficiency, feeding gas flow rate, maintenance feasibility, capital, and operational cost[2].

After design, building, installation, and starting of systems, they were adjusted to venturi operational parameters (e.g., scrubbing liquid rate and throat gas velocity) and packed scrubber conditions (e.g., absorbing liquid concentration, pH, and feeding rate). The final stage of this project was to measure collector removal efficiency. Several measurements were carried out in the workplace to determine collection and local exhaust ventilation efficiency. Four stations including before cyclones, between cyclones and venturi, between venturi and packed scrubber, and the outlet stack (after packed scrubber) were selected for measurement of pollutant concentrations. The selected station locations had minimal turbulences based on ACGIH guidelines[9]. The dust concentration was determined based on isokinetic sampling method[8] and the gaseous concentrations were measured by direct reading devices. The measurements were repeated and averaged for 30-minute intervals during each cycle. The collection efficiency was calculated after measurement of pollutants concentrations at inlet and outlet of any collectors.

Results

The structure and layout of local exhaust ventilation systems and integrated collectors which comprises of two parallel cyclones for any furnace (sum of the four cyclones

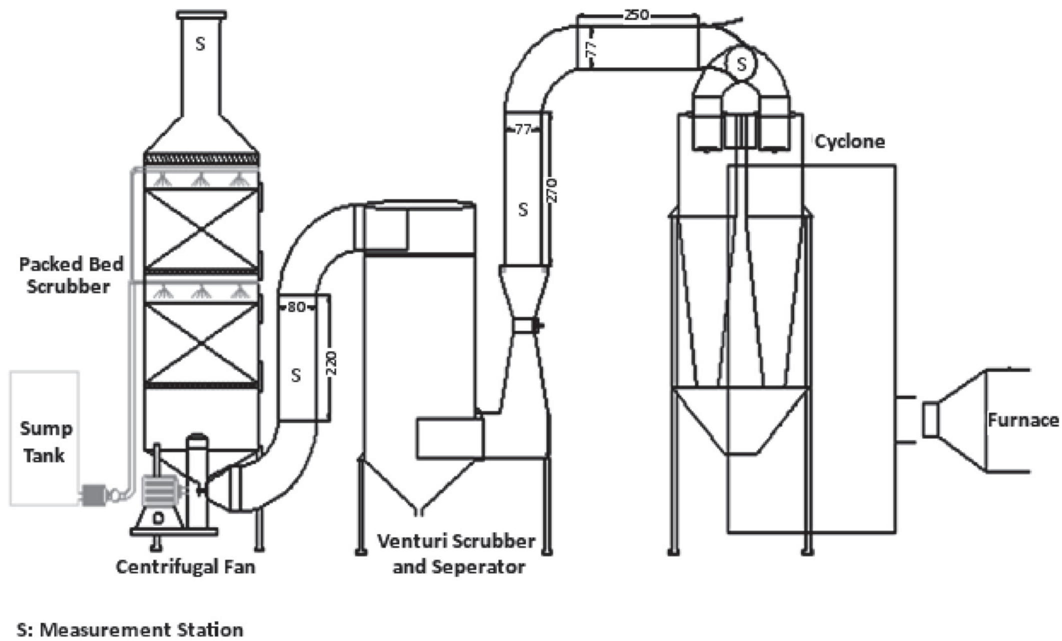

Fig. 1. Structure and layout of ventilation system and integrated collectors.

Table 1. Comparison of LEV efficiency for control of air pollutants

Pollutants	No- LEV (n=21)		With-LEV (n=21)		Efficiency (%)
	Arithmetic Mean	Standard deviation	Arithmetic Mean	Standard deviation	
Dust (mg/m^3)	117.2	7.44	9.57	8.87	91.83
SO_2 (ppm)	32.92	2.1	1.21	0.8	96.32
H_2S (ppm)	22.48	1.5	3.67	0.954	83.67

Table 2. Geometrical dimensions of cyclones

Dimensions	D_c	h	z	H	B	a	b	D_e	S
Size (m)	1.2	1.8	3	4.8	0.45	0.6	0.24	0.6	0.6

for two furnaces), a venturi scrubber-equipped cyclonic mist eliminator and a packed bed scrubbers is shown in Fig. 1.

The maximum needed suction airflow rate was estimated about 15300 m^3/h (9,000 cubic feet per minute) for each furnace and total of 30,600 m^3/h based on ACGIH ventilation standard of VS-55–03 and VS-55–04 [9] and furnace capacity. The duct size was estimated for minimum duct velocity of about 17.8 m/s (3,500 feet per minute).

The effectiveness of LEV for reducing workplace pollution is presented in Table 1. As seen from the results, LEV had a significant role in capturing and collecting emitted air pollutants from furnaces. The highest and lowest LEV efficiency relates to SO_2 and H_2S, respectively.

Two high efficiency Stairmand model cyclones were designed for each of two branches. The cyclones had the same dimensions. The cylindrical body diameter (D_c) of cyclone has calculated about 1.2 m for 7,650 m^3/hr entrance flow rate. The other dimensions of cyclones such as cylindrical body height (h), total height (H), conical height (z), solid outlet diameter (B), gas entry height (a) and width (b), vortex finder diameter (D_e), and distance from top (s) have a certain relation with D_c [2, 3, 13]. The values of these dimensions are shown in Table 2. The pressure loss of these cyclones was determined to be 725 pa (2.9 in.w.g).

The venturi scrubber is designed based on 61 m/s (200 ft/s) as minimum air velocity at the throat. The maximum throat diameter was calculated about 45 cm for this velocity. The movable plate can change throat diameter and air velocity. The air velocity of the throat can be increased to

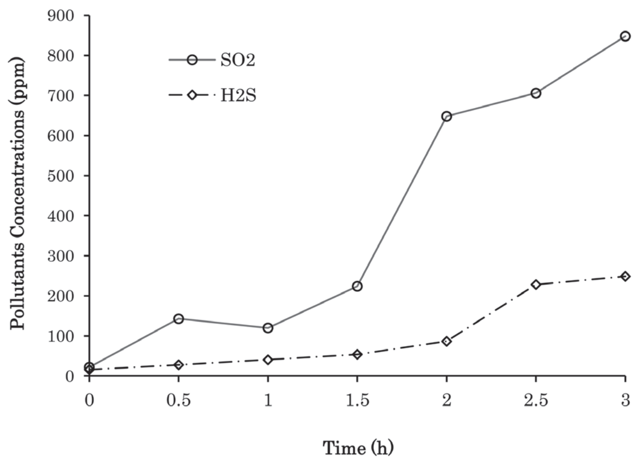

Fig. 2. Changes of gaseous concentration during of an operation cycle.

183 m/s (600 ft/s). The liquid feeding rate was estimated at 950 l/min. The scrubbing liquid was water to which, after pre-setup test, a weak alkali was added to increase of SO_2 and H_2S removal efficiency. The minimum pressure loss of venturi was estimated at 7,000Pa (28 in.w.g) for 61 m/s throat gas velocity. Average removal efficiency of particles by venturi scrubber was 78.47% for throat gas velocity of 61 m/s. This collector had high removal efficiency for SO_2, from 86.36% to 98.58% with average of 95.85%. The H_2S removal efficiency in venturi has varied from 22.22% to 60.7% with average 47.13%.

The packed bed scrubber design was determined by considering the highest concentration of H_2S and SO_2. The body diameter and height of this scrubber were calculated at 3.25 m and 4.2 m, respectively. The total height of the bed is estimated at 2.85 m with raschig ring packing. The selected absorber was composed of caustic and sodium hypochlorite. Total pressure loss of this scrubber was estimated at 2032Pa.

The packed bed scrubber is the last collector mainly designed for H_2S treatment. The H_2S removal efficiency by packed scrubber ranged from 90.2 to 95.98%. The combination of NaOH and NaOcl as alkali has been solved in water and it was used for H_2S absorption. The pH of feeding solution adjusted about 11–13. In addition to H_2S, the residual SO_2 from venturi treated efficiently. Average SO_2 removal efficiency by this scrubber was 68.45%. The dust loading of introduced air stream to packed scrubber can obstruct packing pores [2, 3], but since the cyclones and venturi had removed a major load of emitted dust, especially with diameter higher than of 1μm, this problem was resolved.

For suction of pollutants and to recompense pressure loss throughout the systems, a centrifugal fan with radial blade has been designed. This fan has an actual flow rate of 30,600 m^3/h with total static pressure about 10,500 Pa. The selected electric motor for this fan has 184 kilowatt (kW).

The pollutant concentrations changed during each furnace operating cycle, as mentioned earlier. In the first measurement station (before-cyclones) of ventilation systems, the dust concentration changed from 11,012 mg/m^3 during the 20–30 min initially to 572 mg/m^3 during the last hour of operating cycles. The fluctuations of SO_2 and H_2S concentration in the first station are given in Fig. 2. Concentrations of SO_2 and H_2S vary from 22 and 16.2 ppm at the starting of furnaces to 848 and 248.8 ppm at end of the operating cycle, respectively.

The concentration of gases did not change in the second station (between cyclones and venturi). The measurement of dust concentration in this station shows that the cyclones have good efficiency for collection of particles. For a peak concentration of dust, efficiency of cyclones reached 94.02%, so the dust concentration was reduced from 11,012 mg/m^3 to 658.3 mg/m^3. The venturi scrubber was an effective collector for removal of all pollutants, with collection efficiency for highest introduced concentration of dust of 78.86%. Also, the concentration of SO_2 was reduced significantly in venture. However the H_2S removal efficiency was even lower. The major removal of H_2S belongs to the packed scrubber, with collection efficiency ranged from 90.2% to 95.98% for various concentrations with average of 92.7%. Also, the residual SO_2 was absorbed as high. Figs. 3 and 4 present removal efficiency of scrubbers for absorption of SO_2 and H_2S.

Discussion

Local exhaust ventilation is an effective tool for engineering control of emitted pollutants from reverberatory furnaces and warm sources [14, 15]. Because the charged materials were about 2.5–3 ton into furnaces per any production cycle, the maximum exhausted air flowrate were estimated about 15,300 m^3/h for each furnace and a total 30,600 m^3/hr for two furnaces adapted from VS-55–03 and VS-55–04 [9]. Exhaust hoods are located at the end of furnaces to protect against exited pollutants. Hood opening dimensions and distance from outlet of furnace were selected so that it can be collected for all pollutants. Due to high temperature of exhaust air from furnaces, hoods made from sheet steel A 516 Gr70 that has high thermal

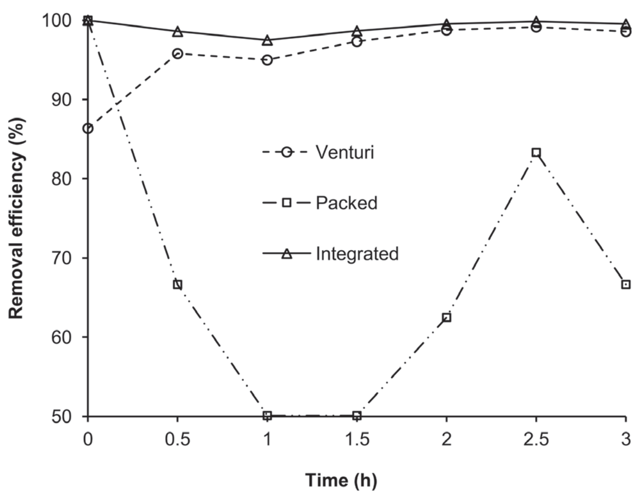

Fig. 3. Collection efficiency of scrubbers for SO_2.

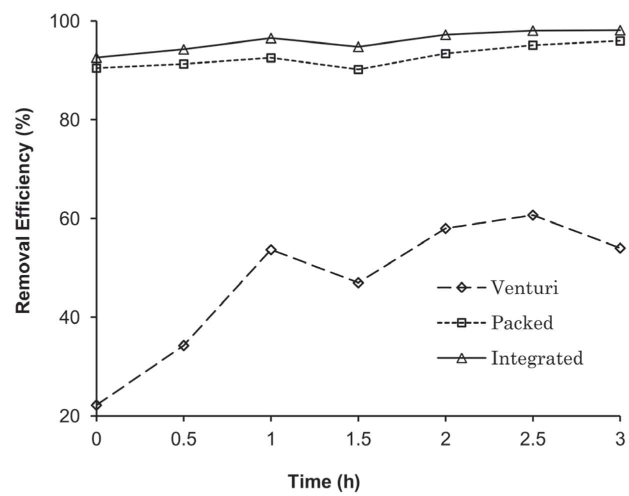

Fig. 4. Collection efficiency of scrubbers for H_2S.

resistance. This layout and structure of hood helps to provide of maximum efficiency for collection of fugitive pollutants because of the minimum need for draft force. This ventilation system had a significant effect on air pollutant concentrations at the workplace.

As shown in Table 1, the efficiency of LEV for reduction of air pollutants had been from 83.67% to 96.32% for various pollutants. The residual concentration for all pollutants had been lower than occupational exposure limits (OEL), so the concentration of dust at the workplace was reduced to 9.57 mg/m^3, which is lower than national OEL and ACGIH TLV of 10 mg/m^3[3, 16, 17], and OSHA and NIOSH exposure limits of 15 mg/m^3[3, 18]. Also, concentrations of SO_2 and H_2S were reduced below the OEL. The national occupational exposure limit for H_2S is 10 ppm and the limit for SO_2 is 2 ppm[16]. In the various studies, LEV has a different efficiency for air pollution reduction, so the Bahrami study on the stone crushing plants showed that the LEV efficiency for reduction of dust concentrations had attain as high as 99%[19], while in the Kulmala study show that the efficiency of LEV increase to maximum 60%[15]. The main causes for this variation are the different kinds and concentrations of pollutants and specification of LEV.

The integrated collectors are a good approach for operation with varied or high concentration of pollutants[10, 20]. The studied operation has various pollutants with different natures, so several collectors are needed to achieve emission standards. The high efficiency cyclones were selected as pre-dust collectors. These cyclones have good efficiency for dust removal from the air stream so their collection efficiency increased to 94.02% for the highest introduced concentration. Several studies showed that the cyclone is a good pre-collector when dust concentration is high[10, 21, 22]. The relatively high collection efficiency of cyclones is due to a higher percent of particles with diameter larger than 5 µm. These cyclones have high collection efficiency for large particles[2, 3]. The results of a study carried out in stone crushing showed that the removal efficiency of cyclones ranged from 81% to 97% by concentration variation[10].

In respect to a national emission limit of 250 mg/m^3 for residential far-field and 150 mg/m^3 for near-field[23], a dust collection efficiency of 97.73 to 98.64% was needed. The venturi scrubber has provided this efficiency but particle removal efficiency increases with increasing pressure drop because of increased turbulence due to high gas velocity in the throat. This high removal efficiency requires high energy consumptions. The collection efficiency has a direct relation with pressure loss at venturi scrubbers[3, 12]. In addition to energy saving, application of cyclones helps to reduce suspended solids concentration in used scrubber liquid, as it reduces wastewater treatment time and costs. Also, dust feeding into packed scrubber could obstruct packing and cause related problems[3, 12, 13].

Venturies are the most commonly used scrubbers for particle collection and are capable of achieving the highest particle collection efficiency of any wet scrubbing system. Venturi scrubbers can be used for removing gaseous pollutants; however, they are not used when removal of gaseous pollutants is the only concern. This collector has moderate collection efficiency for soluble gases[2, 3, 12]. Application of cyclones as pre-collector causes a maximum needed dust collection efficiency of venturi reduce to 77.21% (from 658.3 mg/m^3 which is the maximum dust exiting concentration from cyclones to 150 mg/m^3 for near-field standard). This efficiency can easily be provided by venturi.

Absorption of SO_2 by venturi is very good as showed in the Fig 3. A good solubility of SO_2 in water and relative low gas throat velocity were the main factors for this efficiency. Lower gas velocity in venturi throat causes the corresponding residence time to be increased[3, 12]. The SO_2 removal efficiency was related to gas concentration and gas velocity. A study carried out by Bowden *et al.* showed that removal efficiency of venturi was 20–30% for introduced SO_2 concentration of 5–10 ppm[24], while the average SO_2 concentration in our study has been 400–500 ppm. The study of Noujoumi showed that the venturi scrubber had removal efficiency of 23–98%[25]. Adding alkali to water to adjusting scrubbing liquid at pH of 8 can increase SO_2 removal efficiency[26]. SO_2 absorption into venturi can be helpful to H_2S removal in packed bed scrubber because the alkali scrubbing liquid consume most of it.

Variation of H_2S removal efficiency by venturi relates to introduced H_2S concentration and presence of other pollutants in passed stream. This result is similar to the Bowden study[24] that the efficiency had been 20–30%. Maree *et al.* showed that using Fe (III) solution as absorption liquid in venturi can achieve H_2S removal efficiency about 30–75%[27]. Generally, the venturi has a low to moderate removal efficiency for H_2S that mainly relates to its low solubility.

The effectiveness of the packed scrubber for removal of H_2S has been proven by several studies[28–32]. The alkali mixtures of NaOH and NaOcl as absorption liquid has good efficiency for H_2S removal in a packed scrubber[4]. The best H_2S removal efficiency by pH of 11–13 was reported by Jian G. Lua *et al.*[30] and Brettschneider *et al.*[31].

This research concluded that a combination of cyclones with scrubbers can treat various pollutants with allowable efficiency. Average removal efficiency of particles by the cyclone and venturi scrubber was 94.02% and 78.47%, respectively, while 98.72% of particles were removed by a combination of them. This combination reduced the maximum emitted concentration of dust from 11,012 mg/m^3 to 139.1 mg/m^3(after venturi), SO_2 reduced from 848 ppm to 4 ppm, and H_2S reduced from 248.8 ppm to 4.6 ppm into the stack. The average removal efficiency of SO_2 and H_2S were increased to 99.1% and 95.95% by the combination of venturi and packed bed scrubbers. The exited concentration for all three studied pollutants in worst emission condition was reduced below environmental standards. The results of this project showed that integrated collectors for this process with special technical, economic, and environmental conditions can be a desirable option, and the recovery and reuse of collected dust is a good approach for compensation of the capital and operational costs.

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