Analysis of Particulates and SO$_2$ Removal from Coal Combustion Emissions Using Cyclone and Wet Scrubber With Textile Wastewater Feed

Haryono Setiyo Huboyo*, Sudarno

Environmental Engineering Department, Faculty of Engineering, Universitas Diponegoro Jl. Prof. Soedarto, SH, Kampus UNDIP Tembalang, Semarang, Indonesia 50275

Abstract

Reuse of wastewater in the industry is mostly accomplished for watering plants. In a closed cycle, however, industrial wastewater can be returned through treatment to save water usage. This study aims to analyze textile wastewater's ability to be used as scrubbing liquid in the SO$_2$ gas and particulate removal from coal combustion using a packed wet scrubber. Usually, the textile industry uses boiler fueled by coal and discharging base/alkaline wastewater. The method is carried out experimentally using a prototype device using a combination of cyclone and scrubber, with a source of coal combustion gas emissions. We did experiments using textile wastewater four times and two times using clean water as a control. We monitor the SO$_2$, particulate emission in the gas stream, and pH, sulfate levels, and TSS levels in collected wastewater according to SNI. SO$_2$ gas and particulates from coal combustion will be absorbed by the scrubber's wastewater spray so that SO$_2$ will dissolve into sulfate, particulate matter into TSS. The study results using textile wastewater showed the removal efficiency of particulates on cyclone by 34-78%. The removal efficiency of SO$_2$ on wet scrubber was only 24.7%. There was an increase in TSS levels after passing through the scrubber by 46%. The rise in TSS and sulfate concentrations in the wastewater indicates the absorption of SO$_2$ and particulates into wastewater. Based on this result, we can use textile wastewater for controlling the emission of SO$_2$ and particulate from coal combustion by feeding it for the scrubber. However, the efficiency of this process is not optimal.

Keywords: air pollution; coal; control; emission; efficiency; industry

1. Introduction

Coal is widely used as a fuel for industrial processes such as boilers, “power plants,” and other uses. Industry in Indonesia uses coal. In addition to its relatively low price compared to other fossil fuels, Indonesia's coal reserves are quite large. Combustion coal emissions, for example, emitting a lot of hazardous trace metal elements (Nalbandian, 2012).

When the process consists of coal combustion, a significant amount of sulfur will be released, leading to air pollution and ultimately polluting water and soil. Emissions from uncontrolled coal-fired power plants indicate that sulfur oxide and PM, which enter the water, are twice as high as emissions from vehicles and factories every year. Moreover to SO$_2$, other SO$_x$, like sulfate (SO$_{2-}$), which contains fine particles, pollutes the air and water by traveling hundreds of miles from the power plant and producing sulfuric acid (H$_2$SO$_4$), a major constituent of acid rain. Dust was emitted annually to contribute to PM's formation and underlying risks to life expectancy (Munawer, 2018).

One effort to remove SO$_2$ and particulates is to use a wet scrubber. Pollutants that can be applied to wet scrubbers include organic vapors, vapors, gases (such as chronic acid, hydrogen sulfide, ammonia, chloride, fluoride, and SO$_3$), particulates, volatile organic compound, and hazardous air pollutants in the form of particulates (PMHAP). In general, wet scrubbers remove particulate through the impaction, inertia, and Brownian diffusion methods. Absorption is the process by which the dissolved component of a mixture of gases dissolves in a liquid (Richards, 2000).

On the contrary, clean water has become an environmental crisis where clean water availability is inversely proportional to community demand. Mirror to the scenario of world economic growth, global industrial consumption of water increased 1.8 times more, from 800 billion m$^3$ in 2009 to 1,500 billion m$^3$ in 2015. So far, the textile industry is the largest consumer of clean water.
water in the world with liquid waste, which contains various dangerous constituents if not appropriately handled (Buscio and Álvarez, 2019). Water consumption in the textile industry is 80-100 m³ for every ton of textile product produced, and liquid waste is discharged as much as 115-175 kg COD/ton of product, coupled with organic chemicals that are difficult to measure, color and salinity (Rosi et al., 2007).

Water conservation is possible by the industry in addition to its high water consumption. For example, Hansen et al., 2016 reuse wastewater for cooling tower make-up water in the Petrochemical industry. The textile industry must consider water conservation for several reasons, the main one being the increasing need for clean water from various other sectors, such as the availability of clean water decreases (Shaikh, 2009). Through their research, de Aquim, Hansen, & Gutterres (2019) revealed the reuse of liquid waste. Liquid waste is one of the rational steps in preserving the environment, saving the cost of clean water consumption, and saving water treatment costs. Many advanced processes are needed for treating the textile wastewater for reuse due to the complexity of wastewater quality (Erdumlu et al., 2012; Yin et al., 2019). However, reused waste characteristics will determine the success of wastewater reuse in the industry (Feng, Wang, & Chen, 2006). Therefore, liquid textile waste tends to have a high pH and reasonable as a scrubbing liquid to remove acidic gaseous pollutants from coal combustion emissions.

This research objective is to analyze the potential reuse of the textile industry's alkaline wastewater to be utilized as water feeding for the scrubber process. We will analyze particulate and SO₂ removal efficiency by measuring flue gas parameters and in wastewater (from the scrubber process). Through this process, it is hoped that there will be added value in saving water use due to using wastewater instead of clean water. It is also expected that the scrubber process for acidic gases neutralizing by alkaline textile wastewater can be optimized.

2. Research Methods

The study was conducted with a laboratory-scale experimental method described in the schematic of the research device (Figure 1) or in the actual experimental prototype (Figure2) from A (furnace), C (cyclone), F (scrubber) sequentially as an air pollutant control instrument.

The prototype comprises of an integrated furnace with cyclone and packed column scrubber (loaded with marbles about one third). Coal combustion is performed in the furnace. Coal mass is equalized in each experiment to obtain homogeneous emissions. The scrubber flow system is countercurrent, where gas flows from below, while liquid flows from above. In this experiment, the dependent variables are combustion temperatures, emission concentration of SO₂ and particulate, concentration (in the liquid) of pH, sulfate, and TSS, while the independent variable is the L/G value. Coal mass for burning, scrubber bed height denotes for a static variable.

Then particulate and SO₂ samples are taken at three sampling points, namely, the inlet point (before cyclone), cyclone point (after the cyclone, before scrubber), and the outlet point (after scrubber). Due to
device constraints, the measurement at the scrubber outlet is only for SO₂ measurements. The SO₂ emission measurements are carried out with a portable gas analyzer (Bacharach PCA3). Particulate sampling was done iso-kinetically according to SNI 7117.17-2009.

Experiments were accomplished by varying the scrubbing liquid used, namely with textile wastewater and clean water. Experiments using liquid textile waste were done four times, and clean water experiments were conducted two times. The use of pure water as scrubber feeding is only for comparison with wastewater feeding. Textile liquid waste was kept for 12 hours to reduce TSS levels before being used as scrubbing liquid during the experiments. Then the wastewater was pumped into the wet scrubber using a pump at 5 LPM. The cyclone flow rate was set at 240 m³/hour. The L/G value was measured at the scrubber outlet, and the real gas stream rate is going through the scrubber. Scrubbing samples are taken before and after passing the wet scrubber. During the experiment, scrubbing liquid samples were measured for pH, sulfate levels, and TSS levels according to the methods in SNI 06-6989.20-2004 and SNI 06-6989.3-2004.

To get the removal efficiency, the following Formula 1.

\[
\eta = \frac{Q_0C_0 - Q_1C_1}{Q_0C_0} = 1 - \frac{Q_1C_1}{Q_0C_0}
\]  

(1)

where \(Q_0\) is inlet flowrate \((m^3/\text{seconds})\), \(Q_1\) is outlet flowrate \((m^3/\text{seconds})\), \(C_0\) is inlet concentration \((g/m^3)\) , \(C_1\) is outlet concentration \((g/m^3)\).

3. Result and Discussion

3.1. L/G ratio

To know the ratio of liquid to gas (L/G), we carefully measure the gas flow rate at the emission as well at the furnace outlet and compare it with the measurement of liquid flow rate at the scrubber inlet. Varying liquid flowrate is possible while varying gas flowrate is impossible due to the cyclone draft fan's static flow.

The outcome of the real L/G calculations is depicted in Table 1. The real L/G calculations results are bigger than the theoretical used L/G calculations for this research. Large L/G means having a high liquid flowrate and a tiny flow rate of gas.

Based on Table 1, the real L/G is obtained when measuring liquid and gas flow rate L/ G did not meet the EPA standards (2002) for acid gas that has around 2-20 gpm/1000 cfm. According to Richards (2000), the typical L/G ratio design for gas emission removal is higher than in particulates, which is 5-50 gallons/1000 ACF. Hence, the calculated real L/G in this research meets the typical design, according to Richards (2000).

3.2. Characteristics of Textile Wastewater

We tested the wastewater characteristics before it is being used. Based on Table 2, Textile wastewater has a high pH value as expected to remove acidic gases such as SO₂. It also had high COD, color, and TSS. These results are consistent with typical textile wastewater, namely high BOD, COD, SS, pH, and color (Yaseen and Scholz 2016). Other researchers have also identified high levels of metals (Sharma et al., 2007) and temperature (Dos Santos et al., 2007).

3.3. pH scrubbing liquid

Data for measuring the wastewater pH were shown in Figure 2. In tests 1 to 5, generally, the wastewater's pH decreased after being utilized as a scrubbing liquid. This shows that acidic SO₂ gas is able to lower the pH of wastewater that is alkaline even though it is not significant. In testing four and five, the pH of the wastewater has increased. Furthermore, in test 6, the pH showed somewhat stable.

| Parameter | Unit | Results | Standard by PERMENLH RI No.5/2014 |
|-----------|------|---------|----------------------------------|
| COD       | mg/L | 526.67  | 150                              |
| Color     | pt-co| 4844.3  |                                  |
| TSS       | mg/L | 1480    | 50                               |
| pH        | -    | 11.87   | 6.0-9.0                          |

Table 1. Ratio L/G during actual experiments

| Testing | Liquid Flow Rate (gpm) | Outlet Volumetric Flow Rate (cfm) | L / 1000 cfm |
|---------|------------------------|-----------------------------------|--------------|
| 1       | 1.321                  | 51.776                            | 25,511       |
| 2       | 1.321                  | 51.443                            | 25,676       |
| 3       | 1.321                  | 52.775                            | 25,028       |
| 4       | 1.321                  | 52.609                            | 25,107       |
| 5       | 1.321                  | 69.590                            | 18,981       |
| 6       | 1.321                  | 70.422                            | 18,756       |
| 7       | 1.321                  | 51.443                            | 25,676       |
| 8       | 1.321                  | 52.109                            | 25,348       |

doi: 10.14710/teknik.v41n3.33883 Copyright © 2020, TEKNIK, p-ISSN: 0852-1697, e-ISSN: 240-9919
The difference in pH values before and after the wet scrubber is most likely rooted by the effective contact of gaseous emission with scrubbed liquid. In this study, contact of gaseous emission with scrubbed liquid is a countercurrent method. However, the liquid spray was not so small enough to make intimate contact between the gaseous pollutant and scrubbed liquid.

Theoretically, it is hard to calculate the pH of the final alkaline scrubbing solution after having contact with SO$_2$ gas, considering impurities in both emissions and wastewater. However, based on the study by Sharma et al. (2010), which stated that the pH values of NaOH solution could reach as low as 4.75 after coming into contact for 75 min with SO$_2$ gas from coal burning in the power plant.

3.4. Combustion Temperature

The combustion temperature somewhat influences the SO$_2$ emission concentration. Meanwhile, the scrubber outlet temperature indicates the contact of the liquid scrubber with gas emissions. Therefore, temperature measurements were conducted at the inlet or the furnace and the outlet or wet scrubber. The results of combustion and wet scrubber outlet temperature can be seen in Figure 3. There was a drastic temperature drop at the furnace outlet with the scrubber outlet. The temperature drop occurs along with the flow from the furnace to the scrubber. However, the largest decrease is predicted to occur between the scrubber inlet and outlet. Theoretically, the higher the gas temperature, the lower the absorption rate, and vice versa. The lower the gas temperature, the higher the absorption rate will be. High-temperature gas can also cause the solution to decrease because it evaporates. If the outlet of the gas flow temperature increase, it is an indication of a change in operation. It could be originated by increasing outlet process temperature, increasing the gas flow rate, or decreasing the liquid flow rate (EPA, 2005). With different gases, according to Abdurrakhman et al., 2018, the decreasing temperature in scrubbers will increase the absorption rate of H$_2$S gas almost linearly. Thus, in this study, dropping the temperature significantly due to intimate contact between scrubbed liquid (wastewater) with gaseous emission from a furnace.

3.5. Analysis of Removal for Particulates on Cyclone

By installing cyclone, the performance of particulate removal in a reactor is supposed to be better. Therefore, cyclone removal efficiency needs to be identified to study its relation to the efficiency of particulate removal in wet scrubbers. The particulate removal efficiency of the cyclone is summarized in Figure 4.

In this research, a conventional cyclone is used theoretically to remove particles with sizes greater than 5 μm. Finer particles are difficult to separate through a centrifugal mechanism because centrifugal force will push the finer particle to move outside the cyclone. (Huang et al., 2018; Kim et al., 1990). Therefore, the cyclone's removal efficiency in this experiment removes coarse particulate matter from the flue gas, thus producing flue gas that still carries fine particulates. Figure 4 shows the fluctuating particulate removal efficiency in cyclones.

Experiment 1 - 4 depicts the cyclone eliminates particulate with varying efficiency. Experiments using wastewater as a scrubbing liquid (experiments 1 - 4) particulate removal efficiency ranged from 34 % to 78%. The highest efficiency occurred in experiment four, and the lowest particulate removal efficiency occurred in experiment one. The difference in removal efficiency was caused by mass loading entering the cyclone due to fluctuating combustion results at the furnace. In test number 6, there was an error in the combustion process, thus not shown in this graph.

Table 3 shows the amount of gas emission entering the cyclone with the cyclone's efficiency in each experiment. Experiment 4, which has the highest efficiency, also has the highest mass loading among other experiments. While in experiment 1, which had the lowest efficiency among experiments with wastewater, it had a loading mass of 1.4 m$^3$/minute. This is comparable to what was revealed by Huang et al. (2018) that a rising in loading mass will increase cyclone removal efficiency for the velocity of inlet gas less than 15 m/sec.

![Figure 2. Liquid Scrubbing pH Before-After Scrubber](image1)

![Figure 3. Scrubber Temperature Measurement Results](image2)
Besides loading mass, other parameters affecting cyclone removal efficiency are inlet velocity (Ray et al., 1998). According to Byatt-Smith et al. (1996), the velocity of the flue gas has to be high enough to push the particle out of the path until the flue gas exits the outlet. In general, if the inlet velocity increases, so efficiency will also increase. Through their experiment, Wei, Sun, and Yang (2019) explained that the low velocity of inlet gas would cause low kinetic energy. The centrifugal force acts on relatively low particles so that it is hard to be released from its path. Suppose the inlet gas's velocity is relatively high; the radial displacement (i.e., the displacement of particles from the radial path) will be higher than the downward-directed gas velocity. In a study trial with clean water, low efficiency was obtained in experiment 5 (Table 3). The cyclone’s low efficiency might be originated by improper placement of the particle measuring device after the cyclone.

3.6. SO$_2$ Removal Efficiency

The measurement results of SO$_2$ gas emission concentrations using scrubbing liquid wastewater are highlighted in Table 4, while the measurement results of SO$_2$ gas emission concentrations using clean water scrubbing liquid are explained in Table 5. Likewise, the emission load for particulates, emission load for SO$_2$ gas is also fluctuating. The experiment’s efficiency by scrubbing textile waste is lower than using clean water, possibly because the contact of SO$_2$ gas and clean water occurs more intensively. The presence of TSS in textile wastewater makes water spray not optimal.

Based on previous research using artificial waste (Huboyo et al., 2019), on average, the removal efficiency of SO$_2$ gas reached 36.5%. Also, compared with the same device but no cyclone installed, the removal efficiency of SO$_2$ is around 31-78% (Huboyo et al., 2000). So this research outcome showed smaller than using artificial wastewater and no cyclone installed. As shown in Figure 6, clean water is three times better at removing SO$_2$ gas. The unstable gas emission input loading during the measurement causes the efficiency results to fluctuate significantly. Of course, this efficiency figure is below the expectations of the scrubber performance. Improvements to the wastewater spray system are indispensable to improve scrubber performance.

### Table 3. Mass Loading, Inlet Velocity and Cyclone Efficiency

| Feeding          | Trial | Inlet | Mass  | Cyclone |
|------------------|-------|-------|-------|---------|
| Textile          | 1     | 3.7   | 1.43  | 34      |
| wastewater       | 2     | 3.7   | 1.31  | 34      |
| Clean            | 3     | 5.2   | 2.62  | 69      |
| water            | 4     | 5.2   | 2.65  | 78      |
| water            | 5     | 5.7   | 1.65  | 7       |
| water            | 6     | 5.6   | 1.64  | *       |

* error results

### Table 4. SO$_2$ Removal Efficiency With Wastewater Liquid Scrubbing

| Experiment Number | SO$_2$ Concentration (mg/m$^3$) | Volumetric Flow Rate (m$^3$/sec) | Emission Load (mg/sec) | Efficiency (%) | Average Efficiency (%) |
|-------------------|----------------------------------|----------------------------------|------------------------|----------------|------------------------|
|                   | inlet | outlet | inlet | outlet | inlet | outlet | inlet | outlet | inlet | outlet | inlet | outlet |                      |                      |
| 1                 | 49.13 | 58.30  | 0.0291 | 0.0243 | 1.43  | 1.42   | 0.90  |        |       |       |       |        |                      |                      |
| 2                 | 36.03 | 31.44  | 0.0293 | 0.0248 | 1.06  | 0.78   | 26.06 |        |       |       |       |        |                      |                      |
| 3                 | 14.41 | 11.14  | 0.0409 | 0.0328 | 0.59  | 0.37   | 38.00 |        |       |       |       |        |                      |                      |
| 4                 | 14.41 | 11.79  | 0.0411 | 0.0332 | 0.59  | 0.39   | 33.83 |        |       |       |       |        |                      |                      |

**Figure 4.** Graph of Particulate Removal Efficiency on Cyclone

**Table 5.** SO$_2$ Removal Efficiency With Clean Liquid Scrubbing

| Experiment Number | SO$_2$ Concentration (mg/m$^3$) | Volumetric Flow Rate (m$^3$/sec) | Emission Load (mg/sec) | Efficiency (%) | Average Efficiency (%) |
|-------------------|----------------------------------|----------------------------------|------------------------|----------------|------------------------|
|                   | inlet | outlet | inlet | outlet | inlet | outlet | inlet | outlet | inlet | outlet | inlet | outlet |                      |                      |
| 5                 | 27.08 | 20.09  | 0.0450 | 0.0243 | 1.22  | 0.49   | 59.99 |        |       |       |       |        |                      |                      |
| 6                 | 40.18 | 27.95  | 0.0442 | 0.0246 | 1.77  | 0.69   | 61.26 |        |       |       |       |        |                      |                      |

DOI: 10.14710/teknik.v41n3.33883 Copyright © 2020, TEKNIK, p-ISSN: 0852-1697, e-ISSN: 240-9919
3.7. SO\textsubscript{4} and TSS Concentration in Wastewater

To determine SO\textsubscript{2} absorption in wastewater, sulfate (SO\textsubscript{4}) testing is performed. Sulfate testing refers to SNI 06-6989.2004 about the sulfate test method. The results of sulfate testing in wastewater are shown in Figure 7. Figure 7 shows the addition of sulfate levels of wastewater at the inlet or before use on wet scrubbers and outlets or after the wet scrubber. The addition of the sulfate content showed that the absorption of SO\textsubscript{2} in the wastewater. In the 5th test (not shown), sulfate levels decreased because there was no effective absorption of SO\textsubscript{2}. A decrease in sulfate levels may be possible because fly ash attached to marbles can become absorbent and reduce levels of SO\textsubscript{2}. According to Lee (1990), coal fly ash can act as an absorbent in SO\textsubscript{2} removal. SO\textsubscript{2} is absorbed in sulfite and sulfate form.

Figure 8 shows TSS testing results in trials with variations in liquid waste as a wet scrubber feed. Generally, the results indicated are TSS levels have increased from before to after being used as feed liquid. This increase demonstrates that the liquid feed in the wet scrubber can remove particulates from the flue gas, so the TSS levels after being used are higher than before except for the second experiment. The TSS level went up by 46% after the liquid gets through the scrubber (beyond experiment 2).

As showed in Figure 9, the increase of TSS concentrations during the experiment with clean water feeding showed a drastic increase with an average of 225%. Research trial with clean water, much particulate matter in flue gas is absorbed in the scrubber.

The efficiency for pollutant removal with wastewater is much lower than that of clean water. For sustainable waste treatment, industrial wastewater reuse as scrubber feed water needs to be continuously studied to achieve the desired efficiency. It is hoped that the industry will use water resources efficiently. Ultimately, water sources could be allocated for basic human needs.

4. Conclusion

The study results demonstrated that the efficiency of removing particulate matter through scrubbing wastewater feeding was on average 24.7% lower than that of clean water, which reached 60%. The increase in TSS and sulfate concentrations in the wastewater indicates the absorption of SO\textsubscript{2} and particulates into wastewater. Research shows the probability of using industrial wastewater to reduce water use for scrubber feeding as a feeding scrubber. Fluctuations in the mass loading rate of combustion will also produce fluctuations in combustion emissions.

Figure 6. SO\textsubscript{2} Concentration and Removal Efficiency

Figure 7. Sulfate Test Results in Wastewater

Figure 8. TSS Content of Scrubbing Liquid

Figure 9. The concentration of TSS of Clean Water Scrubbing Liquid
Acknowledgment

This study was supported by the Directorate General of Research and DevelopmentReinforcement, Ministry of Research, Technology and Higher Education, Republic of Indonesia (Grant Number.: 101-176/UN7.P4.3/PP/2019).

References

Abdurrahman, A., Kurniawan, D., Adhim, M.M.(2018). The Effect of Temperature Variation on Water Scrubber System to Optimize Biogas Purification. E3S Web of Conferences 42:01006

Buscio, V., López-Grimau, V., Álvarez, M. D., & Gutiérrez-Bouzán, C. (2019). Reducing the environmental impact of textile industry by reusing residual salts and water: ECUVal system. Chemical Engineering Journal, 373(March), 161–170.

Byatt-Smith, J., Day, R., Harlen, O., Howison, S. D., Lister, J., Smith, S. L., & Stone, R. (1996). Minimum Particle Size for Cyclone Dust Separator. 1–6.

de Aquim, P. M., Hansen, É., & Gutterres, M. (2019). Water reuse: An alternative to minimize the environmental impact on the leather industry. Journal of Environmental Management, 230, 456–463.

Dos Santos, A.B., Cervantes, F.J., van Lier, J.B. (2007) Review paper on current technologies for decolourisation of textile wastewaters: perspectives for anaerobic biotechnology. Bioresource Technology, 98, 2369–2385

Environmental Protection Agency. (2005). Appendix b can illustrations. https://www.epa.gov/sites/production/files/2016-05/documents/draftcamppb.pdf, accessed at November 2nd, 2020.

Erdumlu, N., Ozipek, B., Yilmaz, G., Topatan, Z. (2012). Reuse of Effluent Water Obtained In Different Textile Finishing Processes. Autex Research Journal, 12(1), 23 - 28

Feng, X., Wang, N., & Chen, E. (2006). Water system integration in a catalyst plant. Chemical Engineering Research and Design, 84(8A), 645–651.

Hansen, E., Rodrigues, M.A.S., de Aquim, P.M. (2016). Wastewater reuse in a cascade based system of a petrochemical industry for the replacement of losses in cooling towers. Journal of Environmental Management, 181, 157-162

Huang, A. N., Ito, K., Fukasawa, T., Fukui, K., & Kuo, H. P. (2018). Effects of particle mass loading on the hydrodynamics and separation efficiency of a cyclone separator. Journal of the Taiwan Institute of Chemical Engineers, 90, 61–67.

Huboyo, H.S., Sudarno (2019). The use of artificial wastewater for water feeding of scrubber for treating coal burning emission. IOP Conf. Ser.: Earth Environ. Sci. 361 012019

Huboyo, H.S., Sudarno, Prassanty LN (2020). Wet Scrubber for Coal Combustion with The Use of Textile Wastewater Feeding. IOP Conf. Series: Earth and Environmental Science. 506 (2020) 012012

Richards, J.R (2000). Control of gaseous emissions: student manual. ICES Ltd. The Multimedia Group, Raleigh North Carolina, USA.

Kim, J. C., & Lee, K. W. (1990). Experimental study of particle collection by small cyclones. Aerosol Science and Technology, 12(4), 1003–1015.

Munawer, M. E. (2018). Human health and environmental impacts of coal combustion and post-combustion wastes. Journal of Sustainable Mining, 17(2), 87–96.

Ray, M. B., Luning, P. E., Hoffmann, A. C., Plomp, A., & Beuemer, M. I. L. (1998). Improving the removal efficiency of industrial-scale cyclones for particles smaller than five micrometre. International Journal of Mineral Processing, 53(1–2), 39–47.

Rosi, O.L, Casarci, M, Mattioli, D, Florio L.D. (2007). Best available technique for water reuse in textile SMEs (Battle Life Project) Desalination 206(1-3), 614-619.

Shaikh, M. A. (2009). Water conservation in textile industry. Pakistan Textile Journal, 58(11), 48–51.

Sharma, K.P., Sharma, S., Sharma S, Singh, P.K., Kumar, S., Grover, R., Sharma PK. (2007) A comparative study on characterization of textile wastewaters (untreated and treated) toxicity by chemical and biological tests. Chemosphere 69, 48–54.

Sharma, R., Acharya, S., Sharma A.K.(2010). Effect of absorption of sulphur dioxide in sodium hydroxide solution to protect environment : a case study at shree power, Beawar, Rajasthan. International Journal of Chemical Science 8(2), 1021-1032

Nalbandian, H. (2012). Trace element emissions from coal. In International Energy Agency Clean Coal Centre. ISBN 978-92-9029-523-5.

Wei, Q., Sun, G., & Yang, J. (2019). A model for prediction of maximum-efficiency inlet velocity in a gas-solid cyclone separator. Chemical Engineering Science, 204, 287–297.

Yaseen, D.A., Scholz, M. (2016) Shallow pond systems planted with Lemna minor treating azo dyes. Ecological Engineering. 94:295–305

Yin, H., Qiu, P., Qian, Y., Kong, Z., Zheng, X., Tang, Z., Guo, H. (2019). Textile Wastewater Treatment for Water Reuse: A Case Study. Processes 7(34), 2 - 21

doi: 10.14710/teknik.v41n3.33883 Copyright © 2020, TEKNIK, p-ISSN: 0852-1697, c-ISSN: 240-9919