

Development of Air Pollutants Treatment System for Industrial Processes using Petroleum Coke

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ABSTRACT

Considering the SO₃ treatment method that is currently not regulated in Korea and the ultrafine particles (PM_{2.5}) treatment method that is recently becoming an issue, this study investigated the components of the most effective process in relation to the process sequence change and reactive materials' concentration change by organizing bench-scale experimental equipments in order of Furnace - SCR - Dry ESP - Wet Scrubber - Wet ESP - SO₃ Remover. It was found out that the SO₃ remover placed before the wet scrubber increased treatment efficiency by 7 times and the fine particle treatment efficiency as well when compared to the initial process. Based on this, we want to construct an economic system for efficiently removing SO₃ and fine particle in the real industrial fields.

Keywords: SO₃ Treatment, Air Pollutants, Petroleum Coke, Bench-Scale

1. INTRODUCTION

For companies with equipment that uses heat, cost reduction for the fuel greatly influences the company when it comes to its competitiveness. As the world oil price continuously rises and fluctuates, more companies are alternatively using petroleum coke, which is cheap solid fuel, as one of the ways to reduce costs and increase competitiveness. Recently, the use of petroleum coke is increasing in China as well as in Korea. Its primary advantage is its low price; however, it also causes the need for efficient treatment of its high content of fine particles and sulphur. It contains 0.3 to 8% of sulphur in its raw materials, which causes high concentration of SO_x during combustion. SO_x generated through combustion is converted to a certain amount of SO₃ through an SCR equipment or to SO₃ and H₂SO₄ through cooling during later processes, and then it increases corrosion and fouling of machines and components in the downstream of the boiler while reducing the efficiency of the boiler and the heat consumption rate of the entire power plant. In addition, there are disadvantages in using petroleum coke such as pollution of air heater and SCR catalyst resulting from reactions of SO₃ and ammonia, competition between SO₃ and mercury in the absorption area of carbon particles, consequent decrease in efficiency of mercury emission treatment and generation of blue lead (Robert E. Moser, Power 2006. 10). Especially in Korea, civil complaints about blue lead are frequently reported, which necessitates the companies to devise urgent measures to address heavily consumed times and costs for civil services. This study was conducted to find an adequate treatment technology for SO₃ and ultrafine particles which are generated during the fuel combustion of petroleum coke. We aimed to find a technology applicable to actual use by firstly investigating emission characteristics of air pollutants through field researches, literature study and actual experiments, and by designing and making a treatment device for a complex process based on the researches in cooperation with Korea Testing Laboratory (KTL).

2. METHODS

In this study, following the construction of a bench scale equipment in the first year, a pilot scale equipment was constructed as seen in Figure 1 in order to measure the appearance of air pollutants that are emitted while combusting petroleum coke. The scale was designed to 10CMM based on the amount of exhaust gas. Light oil was used as fuel for the first heating and after a certain level of temperature was reached, only petroleum coke was combusted to identify the appearance of exhaust gas.

2.1. Construction of Pilot Scale Equipment

In this study, following the construction of a bench scale equipment in the first year, a pilot scale equipment was constructed as seen in Figure 1 in order to measure the appearance of air pollutants that are emitted while combusting petroleum coke. The scale was designed to 10CMM based on the amount of exhaust gas. Light oil was used as fuel for the first heating and after a certain level of temperature was reached, only petroleum coke was combusted to identify the appearance of exhaust gas. The equipment in Figure 2 was made by downscaling the real process used in the current industrial sites to fit 10CMM. The experiment was conducted to



Figure 1 Pilot Equipment

determine the characteristics of concentration of acid gas and

fine particle per each process and to change the process sequence aiming to investigate the efficiency of the overall process. In case of Wet ESP, we tried to find whether the precipitation efficiency is improved by applying the method that we designed.

2.2. Measurement Item and Analytical Method

Measurement items for petroleum coke combustion was NOx (NO, NO2), SOx (SO2, SO3), TSP, PM10, PM2.5, flow rate, etc. The equipments used for measurement are as follows: a portable flue gas analyzer (Optima 7) for measuring acid gas; Lancom 200 for SO3; an isokinetic sampling device (KNJ Stack sampler) for generated dusts; and a portable flowmeter (AMI310, KOMO Instrument) for flow rate.

3. RESULT

Before conducting the process test, we identified characteristics of acid gas and dust per unit process in order to investigate characteristics of unit processes.

3.1. Fuel for Use

Petroleum coke was used as fuel in this study. Table 1 and Figure 3 show the results of the component analysis that was performed by Korea Testing & Research Institute (KTR).

Table 1 Table of Component Analysis for Petroleum Coke

Test Item	Unit	Result Value	Test Method
Lower Heating Value	kcal/kg	7960	Ministry of Environment Notification No. 2014-135
Water Content	%	0.10	Ministry of Environment Notification No. 2014-135
Ash Content	%	0.47	Ministry of Environment Notification No. 2014-135
Sulphur Content	%	7.59	Ministry of Environment Notification No. 2014-135
C	%	85.1	Elemental Analyzer
H	%	3.8	Elemental Analyzer
N	%	1.3	Elemental Analyzer
O	%	1.4	Elemental Analyzer

Lower heating value was found to be 7960 kcal/kg, which was similar to the heating value of petroleum coke, 8000 kcal/kg, specified in Energy Conversion Factors. Table 2 shows the energy conversion factors. Among the analyzed components of petroleum coke, sulphur content was 7.59 (wt%). It is higher than generally known sulphur content in petroleum coke powder, which is 7.0 (wt%). This content was considered sufficient to generate the amount of SOx gas necessary for the study. The sulphur content goes through the combustion process, is converted to SOx, and then emitted as gas. If the sulphur content in petroleum coke is low, it could be a problem in the conduct of the study since SOx would not be sufficiently generated. The petroleum coke used in this study, however, has sufficiently high sulphur content and is considered to generate enough SOx gas required for this study.

3.2. Estimated Concentration Analysis

Based on the component analysis conducted in advance, we estimated the concentration of air pollutants by calculating the combustion. The concentration of SOx in the emitted gas is estimated to be around 4000 ppm, and in the first year, generated SOx was found to be 4000 to 4300. Concentration of dusts is estimated to be 2000 mg/m³ based on the combustion result in the first year. For the concentration of NOx, thermo NOx accounted the biggest part as in the first year, and the calculated



Figure 2 Measuring Equipment

Table 2 Energy Conversion Factors

Product	Unit	Lower Heating Value	Conversion to Equivalent MJ	Oil Equivalent Factor
Crude Oil	kg	10,100	42.3	1.01
Gasoline	ℓ	7,400	31	0.74
White Kerosene	ℓ	8,200	34.3	0.82
Red Kerosene	ℓ	8,350	35	0.835
Light Oil	ℓ	8,450	35.4	0.845
B-A Oil	ℓ	8,750	36.6	0.875
B-B Oil	ℓ	9,100	38.1	0.91
B-C Oil	ℓ	9,350	39.1	0.935
Propane	kg	11,050	46.3	1.105
Butane	kg	10,900	45.7	1.09
Naphtha	ℓ	7,450	31.2	0.745
Solvent	ℓ	7,350	30.8	0.735
Aviation Fuel	ℓ	8,200	34.3	0.82
Asphalt	kg	8,350	39.1	0.835
Lubricating Oil	ℓ	8,650	36.2	0.865
Petroleum Coke	kg	7,850	32.9	0.785
Hi-sene	ℓ	8,350	35	0.835
C9+	ℓ	9,200	38.5	0.92
Natural Gas (LNG)	kg	11,750	49.2	1.175
City Gas (LNG)	Nm ³	9,550	40	0.955
City Gas (LPG)	Nm ³	13,800	57.8	1.38
Domestic Anthracite	kg	4,600	19.3	0.46
Imported Anthracite	kg	6,400	26.8	0.64
Bituminous Coal (Fuel)	kg	5,950	24.9	0.595
Bituminous Coal (Raw Material)	kg	6,750	28.3	0.675
Subbituminous Coal	kg	5,000	20.9	0.5
Coke	kg	7,000	29.3	0.7
Power	kWh	2,150	9	0.215

Table 3 Estimated Concentration of Air Pollutants in Combustion Gas of Petroleum Coke

Generated Gas	Concentration	Note
SOx	4000 ppm	- Air Ratio: 1.5 - Theoretical Amount of Supply Air: 8.5 Sm ³ /kg - Excessive Amount of Supply Air: 12.3 Sm ³ /kg
Dust	2300 mg/m ³	

Table 4 Air Ratio per Combustion Device

Combustion Device	m	Combustion Device	m	Combustion Device	m
Gas Burner	1.1 - 1.2	Pulverized Coal Burner	1.2 - 1.4	Horizontal Manual Grate	1.5 - 2.0
Oil Burner	1.2 - 1.4	Travelling Grate	1.3 - 1.6		

Table 5 Estimated Theoretical Amount of Supply Air per Fuel

Fuel	Theoretical Amount of Air A0 (Sm ³ /kg)	Fuel	Theoretical Amount of Air A0 (Sm ³ /kg)
Natural Gas (Wet)	11.4 - 12.1	Blast Furnace Gas	0.7 - 0.9
Natural Gas (Dry)	8.8 - 9.0	Producer Gas	0.9 - 1.2
Oil Gas	4.5 - 11.0	Coke	8.5
Fuel Oil	10.0 - 13	Charcoal	4.0 - 5.0
Bituminous Coal	7.5 - 8.5	Heavy Oil	10.8 - 11.0
Anthracite	9.0 - 10.0	Gasoline	11.3 - 11.5
LPG	29.7		
Coal Gas	4.5 - 5.5		

combustion value based on the fuel components was considered insignificant and excluded. Table 3 shows the estimated concentration of air pollutants in the combustion gas of petroleum coke. For theoretical amount of supply air, the amount of supply air generally necessary for cokes combustion was applied. For air ratio, considering the powder appearance of the petroleum coke and fuel input method, 1.5 was applied among intermediate values between pulverized coal burner and travelling grate air ratio. The following is the widely used theoretical amount of air and air ratio.

3.2. Performance Test of Treatment Device per Unit Process

3.2.1 Automatic Fuel Supply Device and Combustion Boiler

The furnace designed for the study has 1 unit of light oil burner each on the top and the bottom as in the first year, and the two burners were simultaneously operated to increase the temperature inside the furnace. When the temperature inside the furnace nearly reached 1000 °C, petroleum coke was supplied gradually. When the temperature inside the furnace

reached 1100 °C, the top burner remained operating while the bottom one was stopped. The petroleum coke was supplied in two types of powder type and grain type. The two types are different in their form but their component ratios of the fuels are similar. The reason for supplying 2 types of petroleum coke was to complement the disadvantages resulting from the fuel form. Petroleum coke in powder type has advantages of the increased surface area and the consequent high efficiency in combustion when compared to the grain type, but on the other hand, it cannot be combusted due to the combustion gas and combustion air and scattered backward. Petroleum coke in grain type did not scatter backward, but it showed smaller surface area and lower combustion efficiency than the powder type. To address this problem, 30% of petroleum coke in powder type and 70% of petroleum coke in grain type was mixed and supplied. The following is the table about the operation conditions of a combustion room. Table 7 shows the results of measuring combustion gas of petroleum coke. Measurement of combustion gas was performed for 30 minutes at intervals of 1 minute. Below are the averages of the measured data.

Table 6 Operation Conditions of Incineration Equipment

Operation Temperature	1000 ~ 1200 °C
Fuel for Use Supply	Petroleum Coke (Auxiliary fuel)
Amount of Fuel Supply	Petroleum Coke: 10 ~ 15 kg/hr
Amount of Combustion Air	2 ~ 4 m ³ /min

Table 7 Concentration of Pollutants Generated during Combustion of Petroleum Coke

SOx	3856.7
NOx	250.4
TSP	2426.9
PM10	953.6
PM2.5	479.6

3.2.2. Catalyst Exchanging Denitrification System

For the performance test of a selective catalytic reduction (SCR) device, the concentrations of gas inserted into and gas exhausted from the device were measured. The following is a table about change in concentration of pollutants after going through the SCR device. Measurement was performed for a total of 3 times for 10 minutes with intervals of 10 seconds per each measurement. Measured items were nitrogen oxide (NOx), sulphur dioxide (SOx), PM2.5, PM10 and total suspended particle (TSP).

The manufactured selective catalytic reduction device showed 75% of nitrogen oxide (NOx) treatment efficiency. The concentration of nitrogen oxide (NOx) entering into the device was decreased from around 250 ppm to 63 ppm, which is under 70 ppm of legal regulation for NOx and therefore acceptable. Table 8 and Figure 4 show change in concentration of pollutants after passing through the SCR device. Just as the first year’s study results, it was found that SOx gas was converted to SO3 due to influence by the catalyst which was installed inside the SCR device. The conversion of SOx to SO3 was confirmed by concentration decrease of SOx to around 46.4 ppm. In the second year, conversion rate from SOx to SO3 was examined after changing conditions such as the presence of catalyst, catalyst type, etc. When catalyst was not present, SOx concentration hardly changed, but when installable 9 catalysts were all present, SOx concentration decreased by 0.8 to 1%. When only 4 catalysts were present, SOx concentration did not remarkably change. It is considered due to the movement of most of the flow into the area with no catalyst installed.

Table 8 Change in Concentration of Each Pollutant after Passing through Catalyst Exchanging Denitrification System

	SOx (ppm)	NOx (ppm)	TSP (mg/m³)	PM10 (mg/m³)	PM2.5 (mg/m³)
IN	3856.7	250.4	2426.9	953	479
OUT	3810.3	63.3	2425	951	477
Efficiency (%)	1%	75%	0.1%	0%	0%

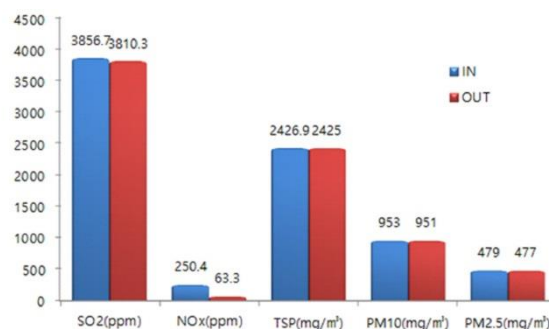


Figure 4 Change in Concentration of Each Pollutant after Passing through Catalyst Exchanging Denitrification System

3.2.3. Dry Electric Precipitator

For performance test of the manufactured dry electric precipitator (ESP), concentrations of gas inserted into and gas exhausted from the device were measured. Flow rate of the gas supplied into the device was 1 to 3 m/sec, and the supply temperature was 150 °C. Measurement was performed for a total of 3 times for 10 minutes with intervals of 10 seconds per each measurement. The measured pollutants were nitrogen oxide (NOx), sulphur dioxide (SOx), PM2.5, PM10 and total suspended particle (TSP). The manufactured dry electric precipitator (ESP) showed 5% of removal efficiency with 477 mg/m³ to 455 mg/m³ for PM2.5 (D<2.5 μm), and about 23% of removal efficiency with 951 mg/m³ to 736 mg/m³ for PM10 (D<10 μm). For total suspended particle (TSP), removal efficiency was 63% with 2425 mg/m³ to 895 mg/m³. Table 9 shows change in concentration of pollutants after going through SCR and Figure 5 shows change in concentration of dusts after going through SCR.

Table 9 Change in Concentration of Each Pollutant after Passing through Dry Electric Precipitator

	SOx (ppm)	NOx (ppm)	TSP (mg/m³)	PM10 (mg/m³)	PM2.5 (mg/m³)
IN	3810.3	63.3	2425	951	477
OUT	3810.3	63.3	895.0	736.5	455.6
Efficiency (%)	0%	0%	63%	23%	5%

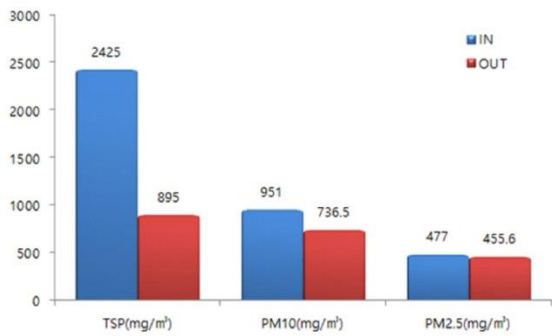


Figure 5 Change in Concentration of Each Dust after Passing through Dry Electric Precipitator

Removal efficiency of PM2.5 was a little lower when compared to TSP and PM10 as in the first year's bench scale experiment, which resulted from the specificity of dust grain size in removing dusts. Figure 6 shows a treatment efficiency curve based on the grain size of the air pollutants controlling device. Generally, the smaller the grain size is, the lower the treatment efficiency is.

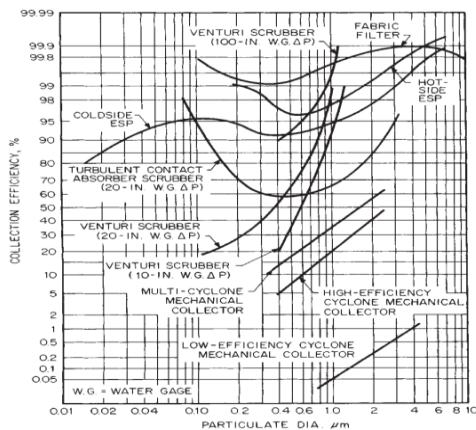


Figure 6 Treatment Efficiency Curve based on Grain Size of Air Pollutants Controlling Device

Figure 7 shows a graph about treatment efficiency per grain size of electric precipitators. Here, it is found that removal efficiency of particles with grain size of 0.1 to 3 µm is remarkably low. It is higher value when compared to PM2.5 removal efficiency of this equipment, but it is assumed that such treatment efficiency was enabled by the laboratory-sized experimental device designed to determine treatment efficiency per grain size. Electric precipitators applied in the industrial fields are middle- or large-sized equipments and their factors that influence removal efficiency are hard to adjust, so it is difficult to highly efficiently remove particles with grain size of 0.1 to 3 µm. Precipitation efficiency results were lower than the first year, which is considered to have resulted from increased air flow, consequent increase in the amount of supplied fuel and the amount of unburned matters that scatter backwards, and condensation of supplied gas in the second year. In the third year, it is expected that measures against dust load and unburned matters are necessary by preventing water condensation through heat insulation on the overall equipment and by adding centrifugal precipitation process before the dry electric precipitator stage so that the problems above can be improved.

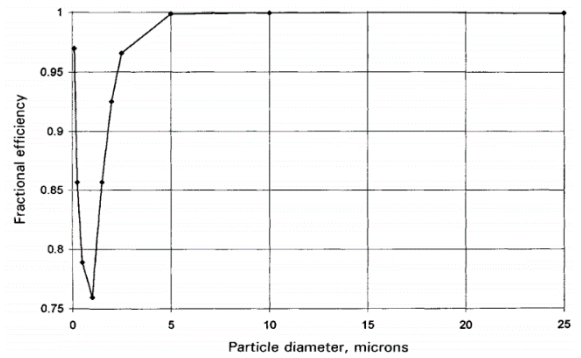


Figure 7 Treatment Efficiency per Grain Size of Electric Precipitator

3.2.4. Wet Scrubber

In the first year, we conducted an experiment by manufacturing vertical type equipment which combined wet scrubber and wet electric precipitator. This hybrid-concept equipment was manually handled for determining removal efficiency. In the second year, the hybrid type equipment was designed with wet scrubber and wet electric precipitator separated, which was for efficiency analysis and ease of operation according to locations of SO₃ removing process manufactured by KTL. Liquid gas ratio was 3 L/m³, the nozzle was spiral type, and the used chemical was NaOH 25 %.

For performance test of the manufactured wet scrubber, concentrations of gas inserted into and gas exhausted from the device were measured. Measurement was performed for a total of 3 times for 10 minutes with intervals of 10 seconds per each measurement. The measured pollutants were nitrogen oxide (NO_x), sulphur dioxide (SO_x), PM_{2.5}, PM₁₀ and total suspended particle (TSP). Table 10 and Figure 8 show change in concentration of pollutants after going through the wet scrubber. The wet scrubber had about 90 % of SO_x gas treatment efficiency and around 8 % of TSP treatment efficiency.

Table 10 Change in Concentration of Each Pollutant after Passing through Wet Scrubber

	SO _x (ppm)	NO _x (ppm)	TSP (mg/m ³)	PM ₁₀ (mg/m ³)	PM _{2.5} (mg/m ³)
IN	3810.3	63.3	895.0	736.5	455.6
OUT	385.7	63.3	824.7	722.4	455.6
Efficiency (%)	90%	0%	8%	2%	0%

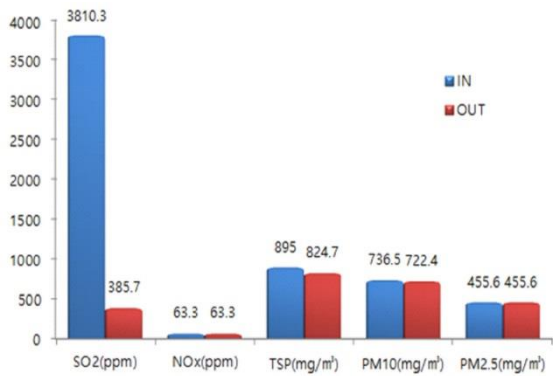


Figure 8 Change in Concentration of Each Pollutant after Passing through Wet Scrubber

3.2.5. Wet Electric Precipitator

For performance test of the manufactured wet electric precipitator (wet ESP), concentrations of gas inserted into and gas exhausted from the device were measured. Measurement was performed for a total of 3 times for 10 minutes with intervals of 10 seconds per each measurement. The measured pollutants were nitrogen oxide (NO_x), sulphur dioxide (SO_x), PM_{2.5}, PM₁₀ and total suspended particle (TSP). The manufactured wet electric precipitator showed 77% of removal efficiency with 455 mg/m³ to 106 mg/m³ for PM_{2.5} (D<2.5 μm), and about 75 % of removal efficiency with 722 mg/m³ to 177 mg/m³ for PM₁₀ (D<10 μm). For total suspended particle (TSP), removal efficiency was 77 % with 824 mg/m³ to 192 mg/m³. Different from the first year, PM_{2.5} removal efficiency was slightly high. The assumed cause for this is that dusts of higher than PM₁₀ were already removed through the preceding processes and ultrafine particles accounted for the most part of total dusts, which led to most of the removal efficiency of PM_{2.5} reflected in the removal efficiency of TSP and the consequent similar removal efficiency result.

Also, the removal efficiency of SO_x was 53% and it was because the wet scrubber was followed by wet ESP process, through which SO_x gas was absorbed and condensated into the water in the process and then collected into the wet ESP. Table 11 and Figure 9 how a table and a graph about change in concentration of pollutants after going through the wet electric precipitator.

Table 11 Change in Concentration of Each Pollutant after Passing through Wet Electric Precipitator

	SO _x (ppm)	NO _x (ppm)	TSP (mg/m ³)	PM10 (mg/m ³)	PM2.5 (mg/m ³)
IN	385.7	63.3	824.7	722.4	455.6
OUT	181.2	62.1	192.6	177.2	105.9
Efficiency (%)	53%	2%	77%	75%	77%

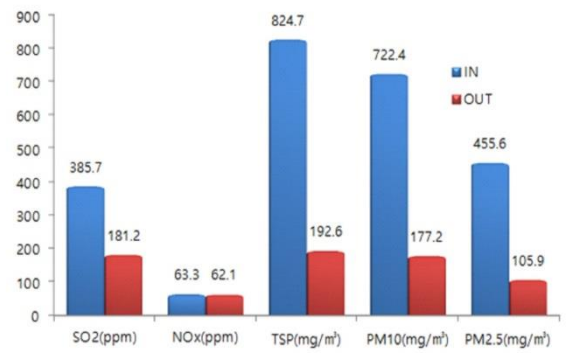


Figure 9 Change in Concentration of Each Pollutant after Passing through Wet Electric Precipitator

4. DISCUSSION

In this combined processes experiment, unlike the individual processes experiment, 2 methods were used by changing the process sequence in order to investigate efficiency of the overall process, and we aimed to find the final suggested process based on which is more effective of the two.

4.1. Comparison of Study Processes

The following is a diagram about the processes operated in this study.

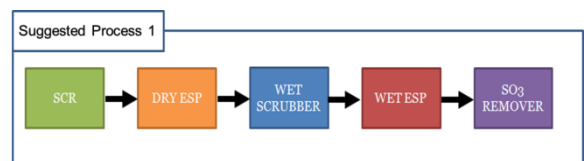


Figure 10 Suggested Process 1

Suggested process 1 is organized in order of furnace - SCR - dry ESP - wet scrubber - wet ESP - SO₃ treatment. This process removes SO_x in the exhaust gas by using the wet scrubber through the absorption method, removes SO₃ and ultrafine particles from the wet ESP, and then removes SO₃ through SO₃ treatment. The advantage of this process is that untreated exhaust SO₃ are selectively removed and therefore the reliability of the process is secured. Also, the finally exhausted SO₃ is likely to have low concentration, which leads to sufficient economic efficiency even when expensive drugs with high treatment efficiency are used. Table 12 and Figure 11 show the treatment efficiency of the suggested process 1.

Table 12 Treatment Efficiency of Suggested Process 1

	SO ₂ (ppm)	SO ₃ (ppm)	NO _x (ppm)	TSP (mg/m ³)	PM10 (mg/m ³)	PM2.5 (mg/m ³)
IN	385	46.	250	242	953	479
OUT	6.7	3	.4	6.9	.6	.6
Efficiency (%)	99	76	77	93	83	79

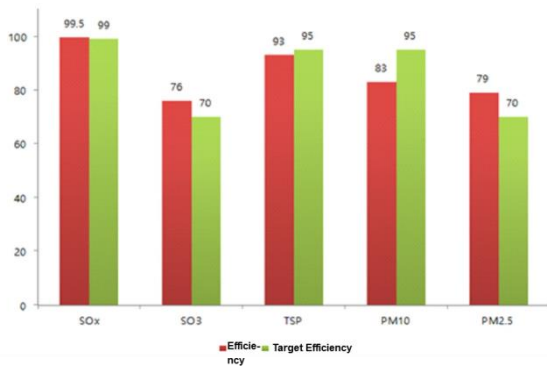


Figure 11 Treatment Efficiency of Suggested Process 1

Suggested process 2 is organized in order of furnace - SCR - dry ESP - SO₃ treatment - wet scrubber - wet ESP. It sprays the chemical developed by KTL toward the gas inserted for SO₃ treatment and removes SO₂ and SO₃ to a certain lower level of concentration. After that, it removes SO₂, SO₃ and ultrafine particles through the wet scrubber and wet ESP. The advantage of this process is that it can regenerate the residuals produced through the absorption method in SO₃ treatment and collect a certain amount of sulphur component for use, which helps reduce maintenance costs. Table 13 and Figure 13 show the treatment efficiency of the suggested process 2.

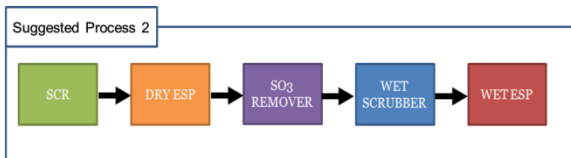


Figure 12 Suggested Process 2

Table 13 Treatment Efficiency of Suggested Process 2

	SO ₂ (ppm)	SO ₃ (ppm)	NO _x (ppm)	TSP (mg/m ³)	PM ₁₀ (mg/m ³)	PM _{2.5} (mg/m ³)
IN	3856.1	42.5	253.1	2404.8	960.1	476.0
OUT	2.5	1.7	63.2	124.7	95.1	74.2
Efficiency (%)	99%	96%	75%	94.8%	90%	84.4%

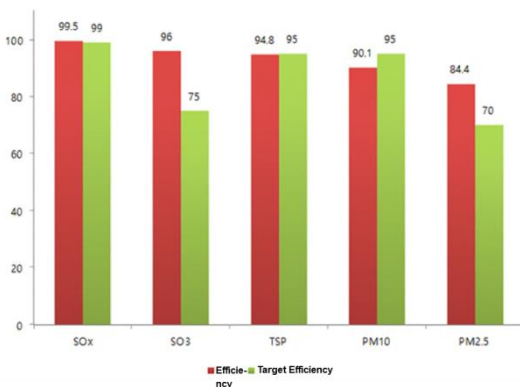


Figure 13 Treatment Efficiency of Suggested Process 2

4.2. Consideration on Removal Efficiency of Suggested Processes 1 and 2

The difference between the two processes lies on after which process the SO₃ treatment occurs. The reason why the process sequence is so important is that the load of inserted pollutants determines the size of treatment equipments, which consequently makes differences in the size of accessory equipments and the amount of chemicals used. In the suggested process 1, SO₃ treatment process showed 14% higher removal efficiency for SO₂ and 7% higher removal

efficiency than the suggested process 2. However, when the overall processes were compared rather than individual processes, a different pattern was shown. In the suggested process 1, a total of 20 ppm of SO₂ was finally exhausted, but in the suggested process 2, 2.5 ppm was exhausted, which means 8 times more SO₂ was exhausted in the suggested process 1 when compared to the suggested process 2. Moreover, a total of 11.2 ppm of SO₃ was exhausted in the suggested process 1, and 1.7 ppm in the suggested process 2, which indicates that there are around 7 times more exhaust in the suggested process 1. Table 14 shows comparison of SO₃ treatment efficiency of suggested processes 1 and 2.

Table 14 Comparison of SO₃ Treatment Efficiency between Suggested Processes 1 and 2

	Suggested Process 1		Suggested Process 2	
	SO ₂ (ppm)	SO ₃ (ppm)	SO ₂ (ppm)	SO ₃ (ppm)
IN	181.2	40.8	3813	42.8
OUT	20	11.2	954.3	14.5
Efficiency (%)	89%	73%	75%	66%

Such difference in removal efficiency could be estimated through the overall process. In the suggested process where SO₃ process was done after the wet ESP, the amount of disturbing factors for treatment efficiency such as dusts, unburned matters, etc. and pollutants load were less than the suggested process 2 where SO₃ process was done after the dry ESP, which is considered to have contributed to these results.

As mentioned before, when concentration of SO₃ is under 5 ppm, it is known that blue lead and yellow lead are not generated. If the suggested process 1 is applied, it will be hard to completely suppress generation of blue lead. It is expected that higher removal efficiency can be secured, of course, if chemicals or operation conditions are changed, but when we are to select an appropriate process based on the treatment efficiency calculated from the current study equipments, the suggested process 2 seems more suitable than the suggested process 1.

4.3. Consideration on Improvement of Suggested Process 2

Based on the study results as specified above, the suggested process 2 was considered a suitable process. However, the problem of the suggested process 2 was that the organization of this process had duplication between the SO₃ treatment device in the form of a wet scrubber and the wet scrubber in the process. The duplication problem of the process causes increase in related accessory equipments, increase in the volume of waste water, etc. which consequently lead to introduction costs and maintenance costs problems, degrading the economic efficiency. Thus, by combining the SO₃ treatment device and wet scrubber, the process 3 was suggested as seen in Figure 14.

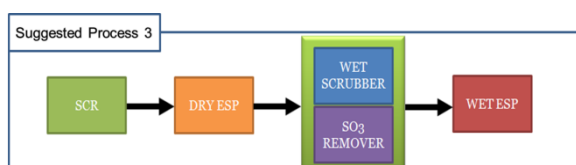


Figure 14 Comparison of SO₃ Treatment Efficiency between Suggested Processes 1 and 2

The suggested process 3 is organized in order of furnace - SCR - dry ESP - SO₃ treatment - wet ESP, in which the wet ESP (modified) is applied excluding the wet scrubber. The advantage of this process is that exclusion of the wet scrubber reduces accessory equipments and waste water, which leads to saving introduction costs and maintenance costs. This process can selectively remove inserted SO₂ gas using the modified scrubber developed by KTL and the chemical that is being developed as well as remove SO₃ gas which is hard to control in the original wet scrubber.

4.4. Consideration on the Final Suggested Process

The common problem found in the suggested processes 1 and 2 was dramatic decrease in the removal efficiency of downstream equipments due to unburned matters and dusts. The unburned matters are generated during combustion because petroleum coke has high combustion temperature. This generated unburned matters constantly accumulated in the downstream equipments, causing problems. To improve these problems, we visited and investigated some industrial fields that currently use petroleum coke. As a result, we found that the similar problems have occurred and that fuel reduction and process stabilization were achieved through collecting and re-burning unburned matters. Based on this, we solved the problems by adding a cyclone process which can primarily remove particle materials such as unburned matters in the suggested process 3. Figure 15 shows a finally established suggested process.

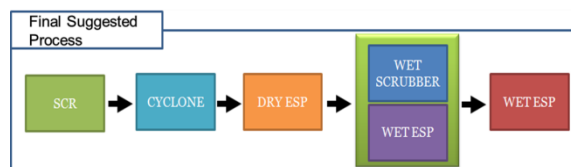


Figure 15 Final Suggested Process

The final suggested process is organized in order of furnace - SCR - cyclone - dry ESP - SO₃ treatment - wet ESP. The advantage of this process is that the cyclone primarily removes the inserted dusts and reduces the size of the dry ESP, which leads to low introduction costs. Moreover, the petroleum coke which is collected from unburned matters through the cyclone is re-supplied to the furnace and then combusted so that maintenance costs can be reduced.

5. CONCLUSION

Through this experiment, presence pattern of SO₃ and fine particle per individual process equipment was identified, and it was found that the treatment efficiency can be greatly improved through process changes. Through the final suggested process of this experiment, if a process designed to include a SO₃ remover instead of the absorber which was used in the original process is applied, it is expected that SO₃ gas can be removed with less costs than that which was incurred in the original process due to installation of multiple wet electric precipitators for removing SO₃. Also, with the use of a wet ESP to which a modified discharge electrode is applied, dusts (including PM 2.5) as well as SO₃ can be highly efficiently removed with a smaller site through miniaturizing equipments, which contributes to usability of this designed process for the industrial fields. However, in order to raise the usability for the industrial fields, complement studies seem necessary to optimize the process by reducing costs incurred in the process while operating the SO₃ remover such as minimizing used amount of chemicals and generated volume of waste water.

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