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Movable VOC Removal System: Enhancing Industrial Air Quality by Treating Exhaust Gas

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Abstract: In this study, we develop a mobile VOCs gas removal system that can remove volatile organic compound (VOCs) emissions from petrochemical facilities, metal painting factories, and surroundings of life, and can efficiently cope with situations occurring in the field. Regular repairs to petrochemical plants and semiconductor plants are carried out for a month every four to five years, and work such as replacing old pipes and repairing aging facilities, cleaning, removing residual gas, checking pipe connections and valves, and improving processes are carried out while the plant is shut down. During regular maintenance, a large-scale accident occurs in which gas remaining in the facility leaks or explodes due to rising pressure, and even after internal gas discharge and purge work is performed, it is scattered by the characteristics of raw materials remaining inside the pipe and reactor and discharged into the atmosphere. Therefore, there is always a possibility of causing safety accidents, and such accidents have a great socioeconomic impact as they are directly connected to the safety of workers as well as the safety of local residents. This system is designed to be adaptable according to the size of a number of outlets, and it is proposed to minimize the impact of VOCs harmful gases on the surroundings by developing it as a mobile type. The efficiency of collecting scattered VOCs gas is more than 90%, and the integrated operating system is demonstrated for 50 CMM class movable VOCs adsorption device, 5 CMM class treatment gas recirculation type non-flame waste heat recovery adsorbent regeneration treatment device, and two or more business sites.

Keywords: adsorption; carbon-free; regeneration; total hydro carbon; volatile organic compounds

1 INTRODUCTION

The agreement between 195 countries around the world to reduce greenhouse gases in response to climate change is to keep the global average temperature rise within 2 ℃. The content of the agreement to reduce greenhouse gas is to keep the global average temperature rise within 2 ℃ compared to the pre-industrial period and to achieve 1.5 ℃ in the long run. Various air pollution reduction policies are being promoted in order to minimize the effects of greenhouse gases, which are the main causes of climate change [1-4].

Petrochemical plants, which greatly affect air pollution, emit volatile organic compounds (VOCs), generate photochemical oxidants in the atmosphere, cause ozone (O3) and fine dust (PM2.5) and have a very harmful effect on the human body [5-9].

Most petrochemical plants, metal surface treatment, and plastic manufacturing systems are repaired at least once every four to five years for a month or less. At this time, while the factory is shut down, various improvements such as replacing old pipes, repairing old facilities, cleaning, removing residual gas, checking pipe connection areas and valves are made [10]. In particular, during repair and maintenance, an explosion accident occurs due to a leakage of residual gas in the facility or a pressure rise. To prevent this, internal gas discharge and purge work are performed in advance, and harmful gases remaining inside the pipe and reactor are discharged into the atmosphere afterwards.

In general, most of the VOCs emitted from industrial processes are emitted into the atmosphere through a Regenerative Thermal Oxidizer (RTO) or scrubber facilities operated by adsorption or combustion. These are advancing continuously the strengthening emission regulations through the development of high-efficiency reduction technologies [11-14].

Among the harmful gas removal technologies, the adsorption technology uses an adsorbent with high adsorption efficiency. However, secondary environmental pollution occurs due to adsorbent waste caused by periodic adsorption replacement. Since fires or explosions can occur due to high concentration of desorption gas generated during the adsorbent regeneration process, the adsorbent must be safely regenerated. In particular, the development of technology to remove pollutants by securing carbon tax emissions and improving filter performance is underway. VOCs removal technology through regenerative thermal oxidants (RTO) is a device to remove VOCs by burning a certain amount of fuel [15-17].

Dangerous facilities such as petrochemical plants are always prone to accidents, and such accidents have significant economic implications such as safety controversy and production because they are directly related to the safety of residents and workers around their lives. Design of collection ports that can adapt to pipes and nozzles of various sizes is required to handle regular maintenance and residual harmful gases (VOCs) at discharged industrial sites.

Technology for VOCs treatment has been developed, but technology for VOCs recovery and energy recycling is still in the research stage. Seoul National University of Science and Technology in Korea developed an energy-saving condensing device with 95 % solvent recovery at room temperature and atmospheric pressure in the study of adsorption source materials and gas separation processes for small-scale high-concentration emission VOCs [18].

C&G Tech developed zeolite adsorbents and modules with excellent adsorption function and regeneration ability in large-scale painting process studies such as shipyards, and obtained test results of 99 % dust collection efficiency, 96.68 % adsorbent regeneration efficiency, and 92 % VOC removal efficiency of the demonstration device under 9,000 CMH conditions [19].

The Korea Institute of Energy Technology developed a low-cost, high-efficiency rotary VOC adsorption and catalytic combustion device using ceramic paper containing more than 40 % of ZSM-5 high-silica zeolite to remove less than 1,000 ppm of volatile organic compounds (VOCs) in the VOC adsorption and catalytic combustion process study [20].

VOC removal technology using photocatalysts has been actively studied in Japan, the United States, and Europe. However, in the US and European markets, Engelhard, Dupont, BASF, and Dow Chemical have occupied the market in this field for more than 50 years, and oxidation and adsorption technologies are used as traditional VOC removal technologies.

Ford, in the United States, has developed a technology to remove volatile organic compounds generated in painting factories in cooperation with DTE. With a system linking high concentration adsorption and desorption concentration system, and a reforming reactor using concentrated volatile organic compounds and fuel cell power generation, a technology that not only recovers volatile organic compounds but also utilizes them as an alternative energy source was developed [21].

EPA Company is actively promoting the resource conversion technology of volatile organic compounds by introducing them into the CO_2 reduction program. SRS Engineering in the United States has been fully automated and commercialized to recover volatile organic compounds generated in paint, coating, adhesives, ink, and petrochemical production processes [22].

The Capture & Control System supplied by Durr Environmental in Germany sells a system that heats and decomposes air containing volatile organic compounds by concentrating a large amount of volatile organic compounds by adsorption and then desorbing them [23].

Air Products' Cryo-Condap system commercialized a system to remove VOCs by lowering the temperature of volatile organic compounds using liquefied nitrogen, and which is concentrating and freezing them [24].

Japan's Kureha Techno Eng company has developed a technology to adsorb volatile organic compounds and desorb them with steam and inert gases [25].

The UK's Kurion Technologies Limited developed a RESx volatile organic compound adsorption system that combines fast regeneration technology by increasing the functionality of carbon or zeolite based on the adsorption process. At this time, it was applied to various volatile organic compound discharge processes ranging from small to large capacity [26].

VOCs are always prone to accidents, and such accidents are directly related to the safety of residents and workers around their lives, and have important socioeconomic implications such as safety controversy and productivity improvement. In this study, a mobile VOCs removal device is implemented. Design an adjustable variable collection port for application to outlets of various sizes. A multi-pipe is also proposed to efficiently collect contaminated gas scattered simultaneously from multiple outlets. At this time, a low concentration of VOC is adsorbed using activated carbon with a high specific surface area, and the adsorbent regeneration operation is performed through vacuum desorption under the heat supply condition of 70 °C in the adsorbent. The VOC discharged at a high concentration is transferred to a condensation reactor filled with the cooling liquid through a watertight vacuum pump and condenses in direct contact with the cooling liquid. VOCs are recovered by 90 % or more using the specific gravity difference of the layer separation device.

2 MOVABLE VOCS ADSORPTION DEVICE

Most petrochemical plants, metal surface treatment, and plastic manufacturing systems are shut down for repair and maintenance. During maintenance such as replacing old pipes, repairing old facilities, cleaning, removing residual gas, checking pipe connection parts and valves, attention should be paid to the safety of explosion accidents due to leakage of residual gas in the facility or pressure increase. Fig. 1 is the VOCs emission site and consists of a complex duct structure and lots of workers.

Figure 1 VOCs emission site with complex duct structure and multi-worker

Internal gas emission and purge operations are performed in advance to perform safe work, and then pipes and harmful gases remaining inside the reactor are emitted into the atmosphere. The local exhaust port used at this time should be designed with pipes and facilities of various sizes according to the size of the pollutant source. If a collector that does not fit the size of the outlet is used, pollution gas spreads around the operator, resulting in significant socioeconomic losses due to lack of safety response as well as environmental pollution. Fig. 2 shows a variable collection device and a design diagram designed to be applied to ducts of various sizes.

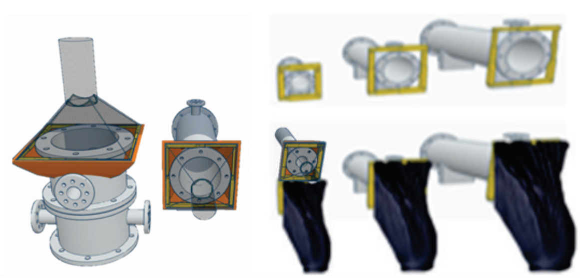

Figure 2 Variable collection device and design diagram to ducts of various sizes.

Multiple pipes are designed to efficiently collect contaminated gas scattered simultaneously from multiple outlets in order to collect gas suitable for the discharge amount of contaminated gas. A pressure sensor is configured in front of the gas conveying blower, and the load operation of the emitted blower is controlled to enable optimal pollutant treatment and efficient operation of the pollutant treatment facility. Fig. 3 is a diagram applying the shape design of a multi-channel gas transfer pipe and VOCs collector.

Figure 3 Diagram applying for the shape design of a multi-channel gas transfer pipe and VOCs collector.

Fig. 4 shows the adsorbent selection criteria. The adsorbent selection criteria include multiple adsorption performance, long-term adsorptions, and reliability with moving replaceable cartridge adsorption modules.

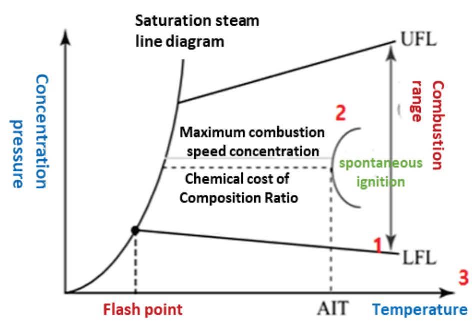

Figure 4 The adsorbent selection criteria

In Fig. 4, 1 (red) represents VOCs sensor, 2 (red) represents water spray and 3 (red) represents thermal imaging sensor.

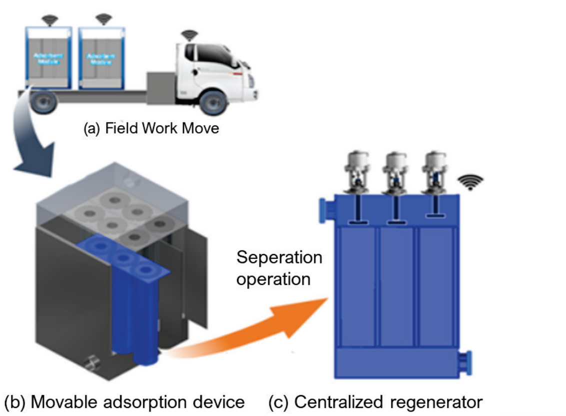

Figure 5 Sensor-based 50 CMM class VOCs adsorption device and a 5 CMM class regeneration device

Fig. 5 shows a sensor-based 50 CMM class movable VOCs adsorption device and a 5 CMM class non-flammable waste heat recovery type movable regeneration processing device with a gas treatment regeneration circulation method.

Fig. 6 shows in detail the adsorption device and regeneration device for VOC treatment in Fig. 5. The structural characteristics of this device are that three cylindrical cartridges constitute one module, and three modules of the transfer rotor are transported to one regeneration device. The adsorption module constituting the regeneration device supplies regeneration gas sequentially through nine valves and regenerates the adsorbent. The inside of the adsorption device is configured as a safety device that sprays water into the adsorption module through the water spray nozzle attached to the adsorption module and controls dangerous situations according to the detection of the thermal image sensor of the adsorbent.

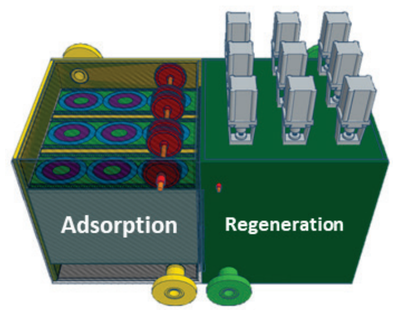

Figure 6 The VOCs adsorbent regeneration equipment

Fig. 7 shows the detailed structure that performs adsorption and regeneration functions. The regeneration device and the regeneration gas oxidation device are configured in a sealed form as one block.

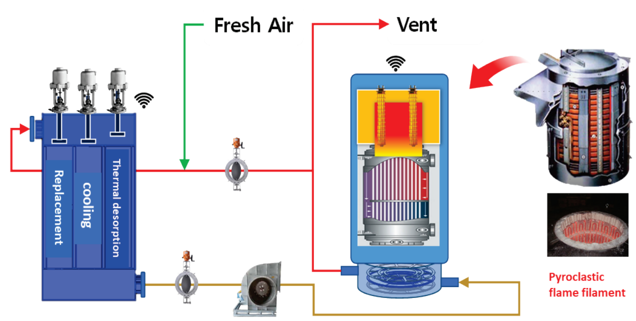

Figure 7 The detailed structure of the adsorption and regeneration device

The oxidation device uses a high-temperature heating element to oxidize volatile organic compounds containing regeneration gas. The temperature required to regenerate the adsorbent is supplied to the regeneration device. Regeneration gas continuously circulates between the regeneration device and the oxidation device and replaces the regeneration completed adsorption module and uses it for adsorption again. The device transfers the adsorption device to a state included in a block-shaped column so that the adsorbent is not exposed to the outside. The concentration of volatile organic compounds desorbed during the regeneration process can be adjusted by sequentially adjusting the valves built in the regeneration device, and the desorbed volatile organic compounds generate heat during combustion in the oxidation device, thereby reducing the energy cost required for the oxidation device.

3 EXPERIMENTAL RESULTS

Tab. 1 shows the operating conditions that the adsorption and regeneration device perform the condensation recovery shown in Fig. 7.

Table 1 The operating conditions of the condensation recovery

Test category		Unit	Operating condi.
Absorption	Inflow concentration	ppm	500~800
	Inflow flow rate	m^3/h	5,800
	Activated carbon t amount	kg/tank	79.8
	Emission concentration	ppm	200
Detachable	Flow rate	m^3/h	180
	Concentration	ppm	5,000~25,000
	Temperature	°C	170
	Pressure	mm H_2O	−167 ~ −210
Syngas material	Seasonal VOCs input	kg/h	3.33
	VOCs for combustion	kg/h	1.05
	Seasonal temperature	°C	600~800
Syngas power	Inflow flow rate	m^3/h	48
	Electricity output	kw/h	30

Tab. 2 shows the results of tests under various conditions using Tab. 1.

Table 2 The test results

Category	Unit	Test results		
		Tank1	Tank2	Tank3
VOCs adsorption amount	kg	32.85	32.18	33.00
VOCs adsorption capacity	g/g	0.41	0.40	0.41
VOCs desorption amount	kg	28.7	28.2	28.8
VOCs condensation efficiency	%	96.8	96.3	96.7
VOCs condensation recovery	L	43.64	69.51	99.38
Syngas production	m^3/h	12.19 ± 0.82		
Electricity output	kWh	751 (Operating time 31 h)		

Fig. 8 shows the concentration change during all simultaneous and continuous regeneration. Here, the sequential reproduction characteristics must change constantly over time.

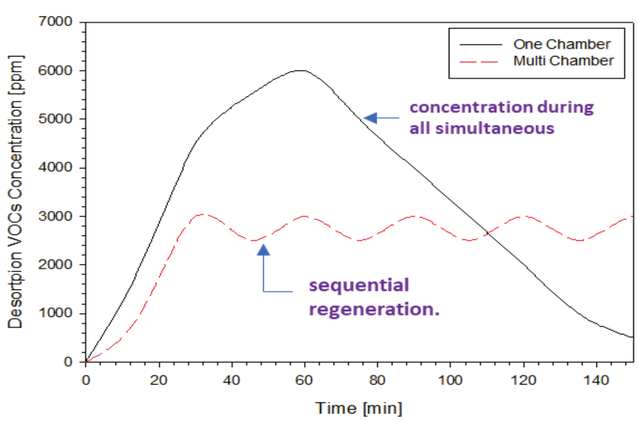

Figure 8 Desorption VOCs concentration during adsorbent regeneration

In the integrated control sequence, the operation of each chamber is basically controlled by the timer. The operation sequence of other chambers operated in connection is progressed based on the operating state of the chamber in which adsorption is performed. The blower operation is controlled by varying the number of revolutions to the Inverter according to the filter differential pressure, and which is controlled to maintain a constant exhaust gas flow rate. If the Inverter variable criterion is proceeded as a linked operation criterion, a change in the exhaust gas flow rate may occur due to a temporary measuring instrument error or the influence of a production facility, and the operation is controlled to be varied according to the difference between the average filter differential pressure value measured for 2 to 5 minutes and the standard differential pressure value. Fig. 9 shows the operation of sequentially controlling the adsorption chamber 1 and the other adsorption chamber 2 in the order of 10-minute adsorption, 7-minute steam, and 3-minute drying.

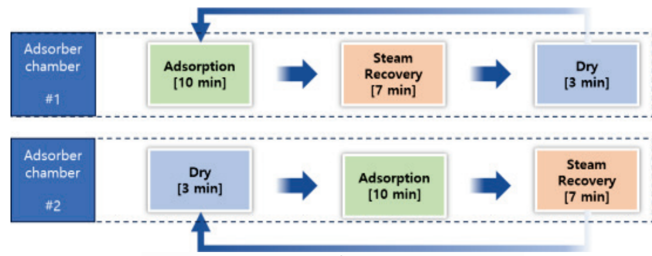

Figure 9 The operation of sequentially controlling

The computer analysis program used for steam flow analysis uses Solid Edge 2022 Classic version by Siemens. A standard steam supply of 350 kg/hr six times per hour is used for steam supply, reflecting the volume of steam supplied to commercial facilities. Fig. 10 shows the fluidity design of steam according to the filter shape.

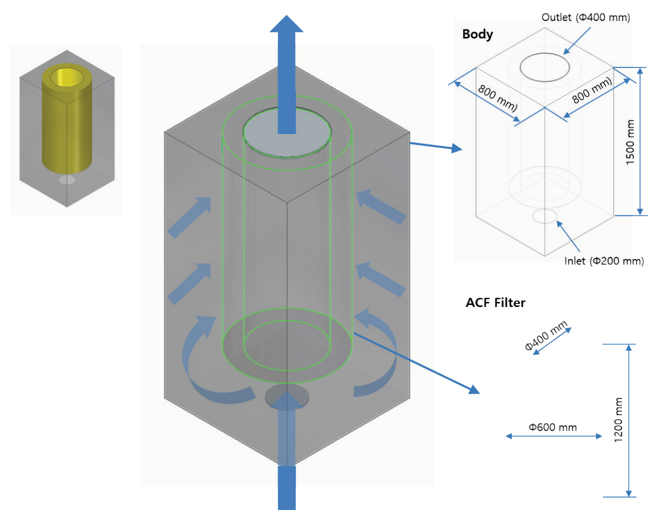

Figure 10 The fluidity analysis of steam according to the filter shape

Fig. 11 shows the flow analysis and flow trajectory of the adsorption filter. According to the results of the adsorption filter simulation, the treatment gas introduced into the lower side of the adsorption device has a strong swirling flow at the bottom of the filter, and according to the linear speed of the filter cross section, the treatment gas rotates inside the device, is evenly distributed throughout the filter and passes evenly. As the swirling flow moved to the upper filter, the swirling speed decreased.

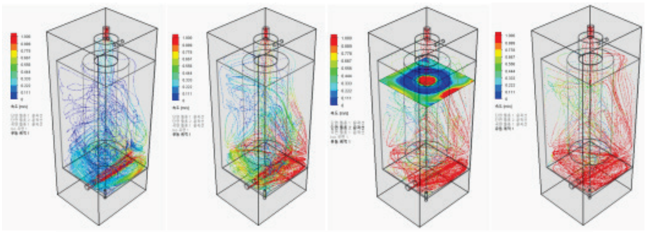

Figure 11 The flow analysis and flow trajectory of the adsorption filter

Fig. 12 shows the flow analysis of steam. In the filter design, when the lower opening length is smaller than that of the top, it is considered to be the most efficient for adsorption filter regeneration using a steam supplier. At this time, steam is supplied from the top to the bottom of the filter, and the amount of steam passing through the supplied steam increases by about twice as much as that of the bottom of the filter.

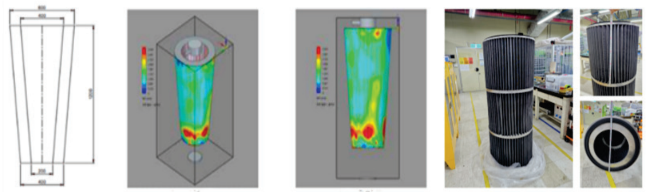

Figure 12 The fluidity simulation of steam to the adsorption filter

In Fig. 13, when the amount of dry air was 42 L/min, the supply position of dry air was adjusted to the upper part, lower part of the reactor and the lower part of the heat exchanger to compare the regeneration characteristics under each condition [10].

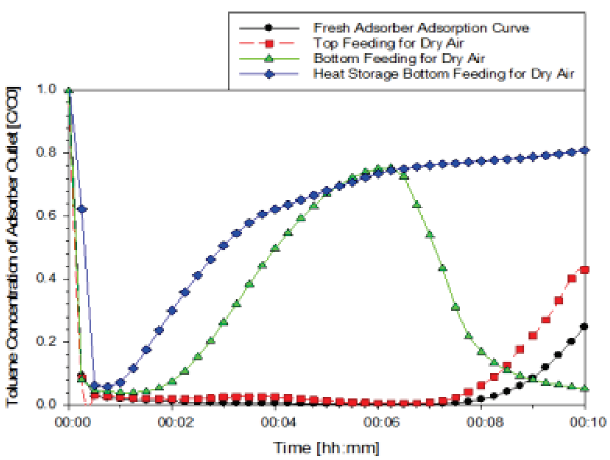

Figure 13 Comparison of regeneration characteristics by location of dry air

When supplying the upper part of the reactor, the regeneration efficiency decreased by about 96.4 % of the initial adsorption performance, and by 69.8 % and 42.2 % in the order of the lower part of the reactor and the lower part of the heat exchanger, respectively. When dry air is supplied to the lower part of the heat exchanger, the drying performance decreases due to the residual moisture inside the heat exchanger, and the regeneration performance of the adsorbent decreases

Fig. 14 shows the state in which the adsorption module inside the adsorption device moves to the regeneration device. In the adsorption module, the regeneration and adsorption devices are brought into close contact with the adsorption. Then the door open and the adsorption module moves to the regeneration device. The adsorbent is regenerated while working with the regeneration and oxidation devices. These processes work in order; each device can be operated through one control system.

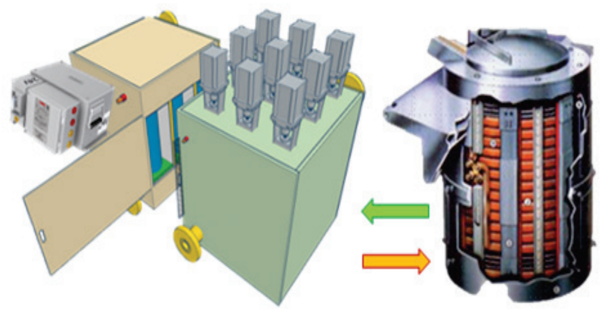

Figure 14 Movable VOCs processing system

Fig. 15 compares the adsorption characteristics of VOCs after 10 minutes of steam regeneration and the adsorption characteristics after 10 minutes of drying after 10 minutes of steam regeneration in the pilot test device [27].

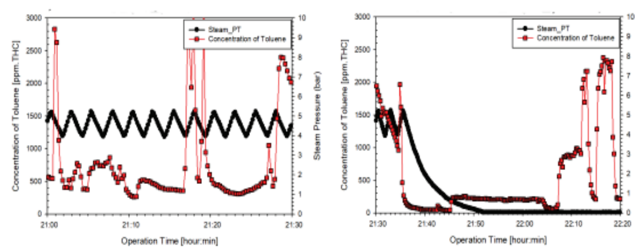

Figure 15 Comparison of the VOCs adsorption characteristics

The material used in the adsorption test was supplied with 400 ppm of Toluene, one of the types of VOCs, at a flow rate of 90 mL/min. In order to supply liquid Toluene in a gaseous state, it is supplied to the test gas inlet pipe in a atomized state. The steam supply is supplied at a cumulative flow rate of 146 kg/h, and the re-adsorption performance is confirmed through the adsorbent regeneration operation. The adsorption efficiency was 86% at 300 ppm after 10 minutes of steam regeneration, but when comparing adsorption after 10 minutes of steam and 10 minutes of drying treatment, the outlet concentration is 200 ppm, which is confirmed to be 90%. Note that when the ambient temperature decreases to below zero and the drying efficiency decreases, the adsorption effect also decreases.

Fig. 16 shows a movable adsorption and regeneration device using an inverter. In the figure, not only the blower operation but also the pollution gas collection speed can be constantly adjusted with the collector through the pressure gauge in front of the blower. A differential pressure sensor is built-in to control the appropriate flow rate and required power.

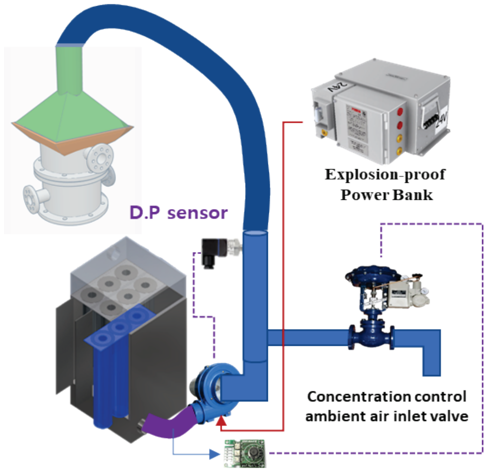

Figure 16 Movable adsorption and regeneration device

4 CONCLUSION

Most petrochemical plants, metal surface treatment, and plastic manufacturing systems are shut down for repair and maintenance. When maintaining old pipes, repair old facilities, cleaning, removal of residual gas, inspection of pipe connection parts and valves, etc., the safety of explosion accidents due to residual gas leakage or pressure rise in the facilities should be noted. During gas removal, internal gas discharge and purge are performed in advance, and then pipes and harmful gases remaining inside the reactor are discharged into the atmosphere. The local exhaust port used at this time should be designed with pipes and facilities of various sizes according to the size of the pollutant source. When a collector that is not suitable for the size of the outlet is used, pollutant gases spread around the driver, resulting in great socioeconomic losses due to environmental pollution as well as insufficient safety response.

This development technology implemented and tested optimal pollutant treatment and efficient pollutant treatment facilities by configuring a number of pipes to collect gases suitable for pollutant discharge and efficiently collect pollutant gases scattered from various outlets at the same time. Based on the CFD simulation and test results, adsorption and regeneration efficiency of 90 % or more were achieved. In particular, through the development of an adsorption regeneration filter, localization was achieved, and a plan to protect safe workplaces and lives from the dangers of VOCs gas was prepared. In particular, the variable collection port customized to the shape of the outlet of the maintenance facility secured the technology used to control the amount of processing gas transport. In addition, the distribution of diffusion discharge VOCs is detected using a differential pressure sensor, and the location of the collection port is selected and applied to the removal of mobile VOC gas.

During the pilot operation of the test device, there is a risk of fire and explosion due to the frictional heat of the pressure pump cylinder during the pressurization operation of the high-concentration VOC-containing gas, which requires attention. In addition, the condensed VOC of the condensing reactor had difficulty in maintaining the VOC separation layer due to flow when the incoming cooling liquid and the mixed liquid were introduced.

Acknowledgments

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