

Implementation of IoT-based Service Platform Visualization Technology for Maintenance Operation of Heat Storage Combustion Oxidizer

Dal-Hwan Yoon*, Joon-Seung Lee**, Hoon-Min Park**, Hyun-Min Jung**,
Dae-Hee Lee**, Tae-Yeong Lim**, Myung-Ki Jang***, Chi-Young Jang****

*Department of Electronic Engineering, Semyung University, Jecheon, Chungcheong buk-do, Republic of Korea

**Department of Mechanical Systems Engineering, Kyonggi University, Suwon, Gyeonggi-do, Republic of Korea

***Emsolution Co. Ltd, Suwon, Gyeonggi-do, Republic of Korea

****Devicenet Co. Ltd, Anyang, Gyeonggi-do, Republic of Korea

*yoondh@semyung.ac.kr, jslee1@kyonggi.ac.kr, hmpark@emsolutions.co.kr, lezzang@devicekorea.net

Abstract— In this paper, a long-distance monitoring service technology is developed for maintenance of the Regenerative Thermal Oxidizer (RTO) and scrubber, an air pollution reduction device installed at a long distance. It is necessary to consider the operating conditions and maintenance working conditions of the system placed at a long distance, detect whether the device is abnormal and inform the manager. At this time, the RTO is operated according to the trip condition and is connected to the data management server based on the Edge-IoT interworking. Even in situations where it is not connected, the pre-alert function can be supported with an independent self-analysis function. In order to monitor the RTO equipment in real time, it intelligently supports low-delay analysis, judgment, prediction and visibility. It is also possible to provide an interactive remote service that can support not only field managers but also non-experts, initial users.

Keyword— RTO, VOCs, THC, Heat storage combustion, sensor-IoT

Manuscript received April 30, 2024. This work was supported by the Industrial Technology Innovation Program (20023721, Development of AI-based remote support service technology for the maintenance, repair, and operation (MRO) of Regenerative Thermal Oxidizer(RTO)) funded By the Ministry of Trade, Industry & Energy(MOTIE, Korea)

Dal-Hwan Yoon, Professor, Department of Electronic Engineering, Semyung University, Korea(corresponding author to provide phone: +82-43-649-1308; e-mail: yoondh@semyung.ac.kr

Joon-Seung Lee, Professor of Mechanical Engineering Major, Kyeonggi University, Korea, phone: +82-10-3725-1140; e-mail: jslee1@kyonggi.ac.kr.

Hoon-Min Park, Ph.D. program, Department of mechanical engineering, Kyeonggi University, Korea, CEO of Emsolution Co. Ltd., phone: +82-10-9096-4235; e-mail: hmpark@emsolutions.co.kr.

Hyun-Min Jung, Master Science Course, Department of Mechanical Eng. Kyeonggi University, Korea, phone: +82-10-2495-9539; e-mail: hmjung@emsolutions.co.kr.

Dae-Hee Lee, Master Science Course, Department of Mechanical Engineering, Kyeonggi University, Korea, phone: +82-10-6479-6934; e-mail: dhlee@emsolutions.co.kr.

Tae-Yeong Lim, Researcher, Emsolution Co. Ltd. Korea BS, Department of Electronic Engineering, Semyung University, phone: +82-43-649-1308; e-mail: tyelim@emsolutions.co.kr.

Myung-Ki Jang, CEO of Devicenet Co., Ltd., Korea. MS, Department of Semiconductor Engineering, ChungNam University, phone: +82-10-9306-5669; e-mail: leozang@devicekorea.net

Chi-Young Jang, Laboratory Director of Devicenet Co., Ltd. Korea, BS, KAIST. phone: +82-10-9874-7170, e-mail: jcy@devicekorea.net

I. INTRODUCTION

As the global carbon emission reduction policy expands, there is a demand for technology to advance systems and services for maintenance, repair, and operation of environment-related equipment. RTO devices, which operate 24 hours a day, 4 seasons a year, play a very important role in reducing carbon emissions generated from industrial processes. These RTOs prevent air pollution by oxidizing volatile organic compounds (VOCs), harmful air pollutants (HAPs), and other pollutants into carbon dioxide and water vapor. Figure 1 shows a system diagram that measures sensor IoT connected to the core area with RTO devices connected to various industrial plants, and it transmits them to the manager in real time [1, 2].

Recently, strategies to reflect carbon reduction in corporate environmental, social, and governance (ESG) are spreading to a global trend, and as the interest of all members of society, including consumers, investors, and the government, is increasing, it is emerging as a key factor in corporate survival and not a choice [3]. Figure 1 shows the VOCs emission device and the site of the VOCs gas explosion.



Fig. 1. The VOCs emission RTO and gas explosion

In this paper, for the maintenance and safe operation of RTO (Regenerative Thermal Oxidizer), the control unit controls the PLC unit according to trip information and builds a database for each sensor channel in real time through a sensor IoT device linked to the control group. The abnormalities are evaluated by analyzing the database of channels received for each sensor, and the abnormalities of the device are searched through the Bayesian algorithm, and then ubiquitous and predictive functions are performed through the final decision process.

II IMPLEMENTATION OF MRO SERVICE

A. The communication structure for MRO service

In the event of a failure due to 24-hour operation on weekdays, there are difficulties such as the exact location of the accident at the site, the treatment of VOC harmful substances, and immediate technical support services due to distance. In particular, if a complex equipment usage manual is immature, a lack of handover due to frequent turnover of field personnel, or a problem with factory operation occurs when it is located at a wide and long distance, such as a chemical complex, it cannot be immediately dealt with [4].

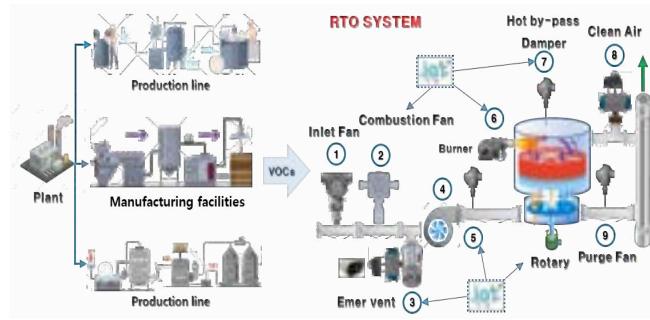


Fig. 2. The connection between sensor IoT and the RTO equipment

Figure 2 shows the connection between the production facility and the RTO equipment, and the circle number in the RTO device is a picture of the sensor IoT attached to the location to be managed. Data segmentation should be done from sensor number 1 fan to motor number 9 [5].

Figure 3 shows the on-site interactive service support, big data construction, and PC monitoring system diagram.

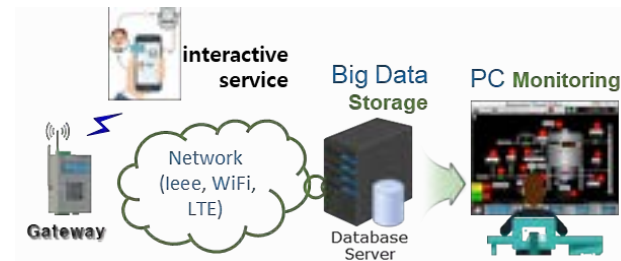


Fig. 3. On-site interactive service and PC monitoring system.

Gateways can be installed depending on the distance of the site or the amount of IoT installed. At this time, it is data base on the data server through on-site low data and data logging. Sensors connected to Edge-IoT send data with IEEE 485, LoRa, and WiFi modules depending on wired or wireless.

B. Service programs through data analysis

Table I shows the segmentation of RTO sensor IoT data acquisition in figure 2. In data segmentation, Level 0 is classified as an RTO facility, Level 1 is classified as a ventilation facility, Level 2 is classified as a ventilation facility-A to segmentation A-Z, and Level 3 is classified as an exhaust-A to segmentation A-Z.

TABLE I.
THE DATA SEGMENT OF SENSOR IOT

Level3 Master Components	Level3 Master Components Data	Level3 Detail	Level3 Child (Detailed specifications)	Data(Multi Line Insert construcion)	Algorithm (CBM/AI)	Priority (Rating)
Fan (Impeller)	Fan (Impeller)		Fan (Impeller)	Type	Temperature_Airplane	Minor
				Model number	Voltage_Motor	Critical
				Inhalation method	Voltage_Pump	Critical
				Driving method	Unbalanced Rate_Motor	Critical
				Production company	Motor talk	Critical
				Memo	Damper_loss ratio	Major
Motor		Motor	Power (KW)			
			Blast Current (A)			
			Number of rotations (rpm)			
			Production company			

Table II shows the PLC-HMI mapping list. The analog value of RTO is real signal data and trip information. The analog value of the PLC mapping list becomes the nine sensor analog interfaces (AI) of the RTO. Trip information is a digital interface (DI) that has 12 Boolean algebra information and notifies an alarm by operation according to logic 0 or 1

TABLE II.
THE PLC-HMI MAPPING LIST

Tag Name	Description	Type	Range	I/O
Analog value	Combustion chamber temp.	Real	-	AI
	Combustion chamber value	Rea	-	AI
	Input temperature	Rea	-	AI
	Exhaust temperature	Rea	-	AI
	FD Fan: Frequency setting	Rea	0~60	AI
	FD FNA: Current value	Rea	-	AI
	Rotary: Frequency setting	Rea	0~60	AI
	Rotary: Current value	Rea	-	AI
	Fresh damper open value	Rea	0~100	AI
	Hot damper open value	Rea	0~100	AI
Trip information	FD Fan Trip	bool	0 or 1	DI
	Rotatory Trip	bool	0 or 1	DI
	Purge Fan Trip	bool	0 or 1	DI
	Combustion Fan Trip	bool	0 or 1	DI
	Fresh Damper Trip	bool	0 or 1	DI
	Hot Damper Trip	bool	0 or 1	DI
	Combustion chamber overheat	bool	0 or 1	DI
	Combustion chamber: high	bool	0 or 1	DI
	Combustion chamber: low	bool	0 or 1	DI
	Incoming temperature: High	bool	0 or 1	DI
	Exhaust temperature: High	bool	0 or 1	DI
	In GAS Trip	bool	0 or 1	DI

An integrated service solution is applied to support the type of failure, cause, and countermeasure through the DB According to the mapping list in Table 3, the PLC control group sets it to drive the RTO, and it builds a database through IoT connection. Figure 4 is a link between PLC-HMI's PLC-Edge-IoT-LTE-Gate terminal.

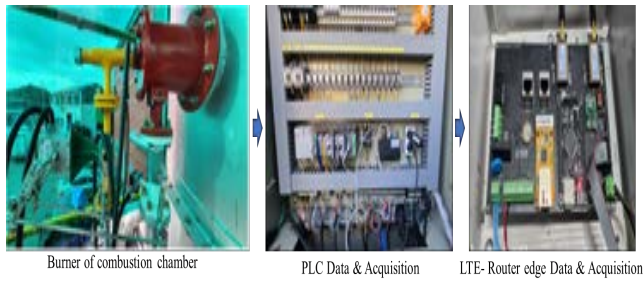


Fig. 4. PLC-Edge-IoT-LTE-Gate terminal for data acquisition.

Table III shows a failure phenomenon case according to the trip type in Table 3. Accordingly, the RTO may be monitored while notifying an alarm.

TABLE III.
FAILURE PHENOMENON CASE TO THE TRIP TYPE

Trip style	Out of order
Burner Trip	Burner off, Fresh Damper Close, Hot by pass Damper Close, RTO Fan Run, Purge Fan Run, Combustion Fan Run, Rotary Run, Main Fan Run
Combustion Trip	Burner off, Fresh Damper Open, Hot by pass damper Open, RTO Fan Stop, Purge Fan Stop, Combustion Fan Stop, Rotary Stop, Main Fan Run
Main Fan Trip	Burner off, Fresh Damper Open, Hot by pass Damper Open, RTO Fan Stop, , Purge Fan Stop, Combustion Fan Stop, Rotary Stop, Main Fan Stop

Figure 5 shows the configuration of the UART and the main MCU board in a form that can be combined or detached by cable. It can be installed anywhere inside the distribution panel using a bracket. It is also possible to prevent direct damage from fire by installing the main MCU board outside the distribution panel. UART is an integrated circuit that asynchronously communicates parallel data of the MCU as serial data. In the 8-bit data format, it is promised that synchronization signals can be found on the receiving side to process the start and end of the data in time. The 14 GPIO operates in real time on the user connection unit, the PC operation unit, and the 32 KHz oscillator (x-tal). The SPI is connected to a wireless communication antenna using the Lora module. These functions are processed by a command processor linked by a communication protocol.

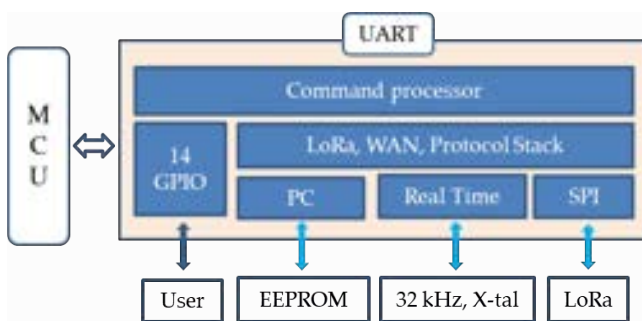


Fig. 5. Configuration of the UART and the main MCU board.

Figure 6 shows that sensor data from nine channels build a sensor database on a server. The right shows the database to be observed.

In figure 6, the data load → outlier correction → detection

value supplementation → target setting → game analysis and correlation analysis → data processing → stereoscopic data setting → machine learning application → generation algorithm, performance verification and selection process.



Fig. 6. Sensor database on a server

Block unit service modularization and service tool are configured for prebuilt service configuration, and block unit service modularization constitutes an efficient service of the service provider. At this time, the service is executed through analysis linkage between event-based logic and real-time data.

Table IV shows the database table specifications through data collection, intermediate transit data storage management, and metadata DB management of IoT equipment.

TABLE IV.
THE DATABASE TABLE SPECIFICATIONS

	Table code	Table name
1	TBL_COM_CODE	Common Code
2	TBL_USER	User
3	TBL_ORG	Organization
4	TBL_MATERIAL	Individual item
5	TBL_BOM	BOM
6	TBL_RT_DATA	Real Time Gathering Data
7	TBL_FULL_DATA	Total Project
8	TBL_IOT_MAP	RTO: IOT management

The data obtained from the sensor are data generated by physical sensors such as temperature, flow rate, and pressure of the RTO. By combining them, the concept of virtual sensors is applied to software calculate new indicator values such as the status of RTO emissions.

Figure 7 shows the service monitoring configuration diagram of the main server. The main service monitoring server program of each IoT is implemented as a middleware-based system for smooth monitoring between RTO operation status monitoring, control interface, and IoT devices installed in the field. At this time, location information, installation date, equipment replacement date, sensor replacement date, number of malfunctions, and alarm function using Flesh are added.

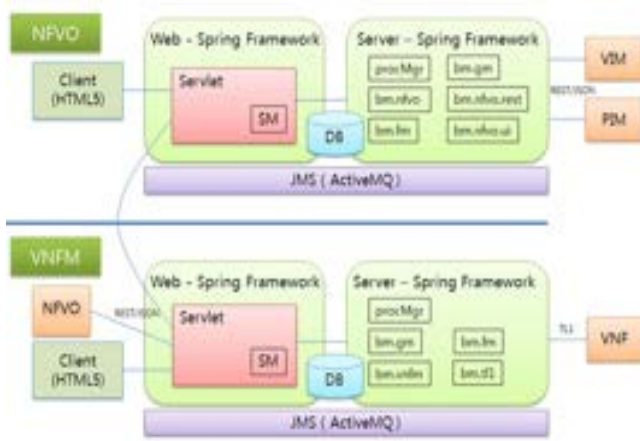


Fig. 7. Service monitoring of configuration diagram

At this time, the system-specific ID allocation, installation classification key, gateway access port are implemented, heartbeat processing per second, data network service (DNS), and the database is managed through the Graphic User Interface (GUI).

III. EXPERIMENTAL RESULTS

Figure 8 shows the plate configuration in the combustion chamber.

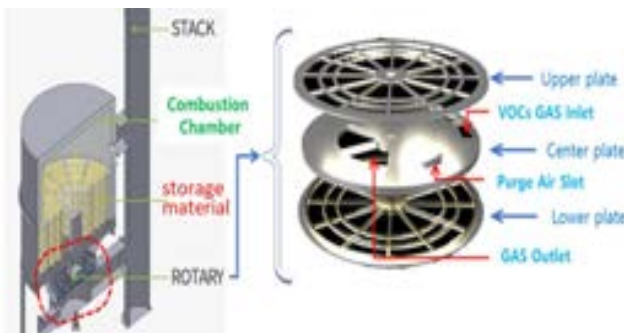


Fig. 8. Plate configuration in the combustion chamber.

Figure 9 shows the results of simulating the operation and characteristics of the combustion chamber constructed with a high heating element and a ceramic heat storage agent [6].

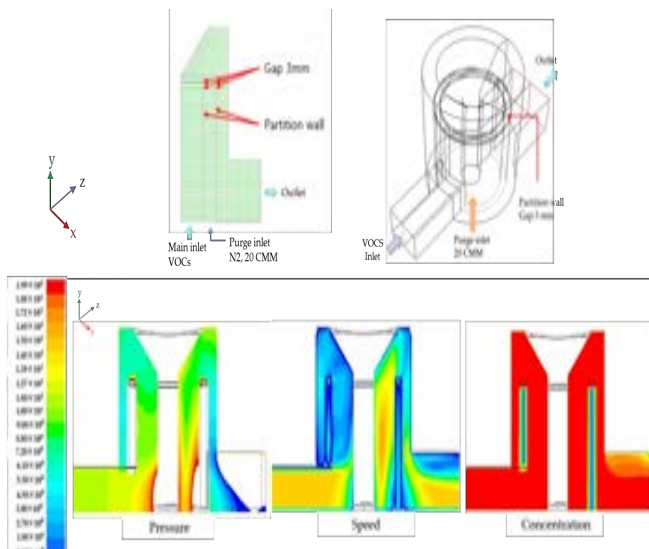


Fig..9. Operation characteristics of the combustion chamber

The streamline represents the flow of air. At this time, the given pressure, air velocity, and the corresponding VOCs gas concentration are shown. In each figure, the red part represents the larger part and the blue part represents the lower part.

Figure 10 shows the vector space for the air flow in Figure 8. The GAS inlet diameter can calculate the cross-sectional area A from air volume Q and passing wind speed V .

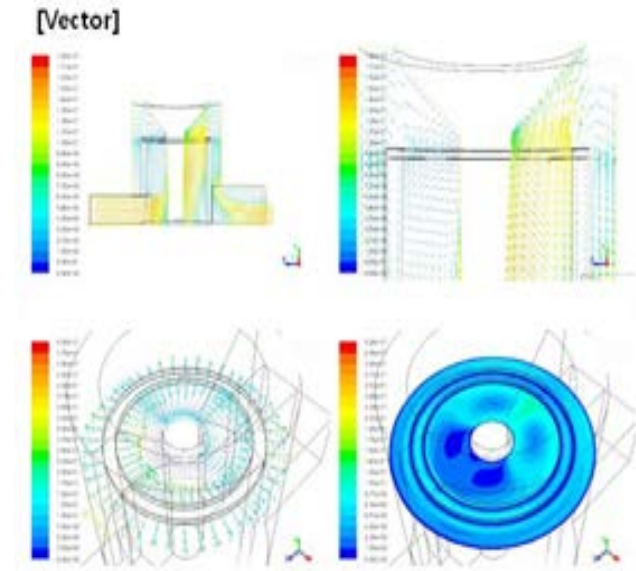


Fig. 10. Vector space for the air flow

Figure 11 shows the temperature distribution of the combustion chamber to which the burner is applied for and the unburned section of the VOCs gas occurs.

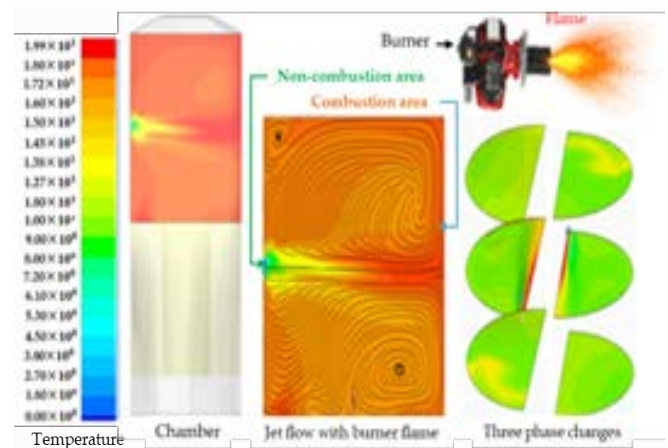


Fig. 11. Combustion chamber analysis

In order to test, the VOC gas that has passed through this layer is burned in the combustion chamber and generates heat at the same time, and it is oxidized and decomposed at 700 to 800°C with the calorific value. The exhaust gas stores high-temperature waste heat in the ceramic while passing through the heat storage material on the outlet side, and heat storage and heat dissipation are intersected at regular intervals according to the cycle. At this time, the heat recovery efficiency is 95%, the treatment efficiency is oxidized and decomposed by more than 98%, and it is discharged as a harmless and odorless clean gas of 60°C.

Figure 12 shows the average inlet gas concentration (ppm) according to the operating temperature of the combustion chamber.

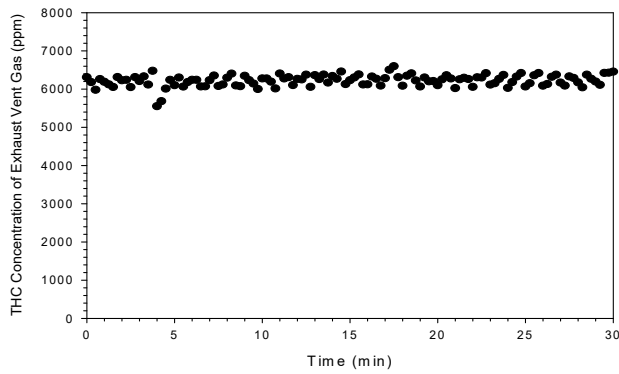


Fig. 12. Average inlet gas concentration (ppm)

Figure 13 shows the maximum and minimum temperature variation widths and periodic variation characteristics of the combustion chamber.

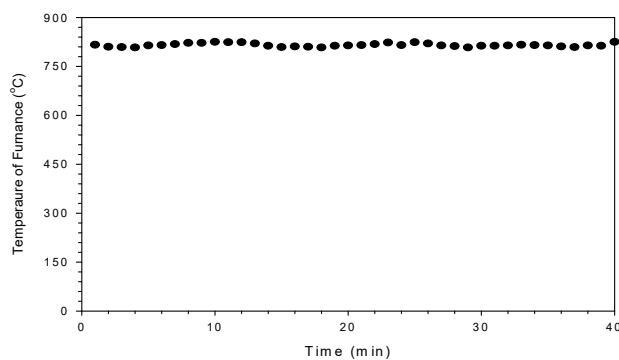


Fig. 13. Maximum and minimum temperature widths and periodic

Figure 14 is an explosion risk when driving in a rapidly increasing section of CO, so it monitors and generates an alarm.

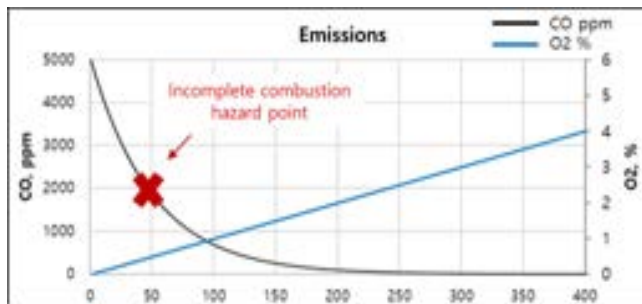


Fig. 14. Incomplete combustion hazard point

The reliability of the sensor is increased by using the correction value in case of a failure of the measurement sensor related to combustion efficiency. Figure 15 shows the correction algorithm flow chart when the combustion efficiency measurement sensor fails.

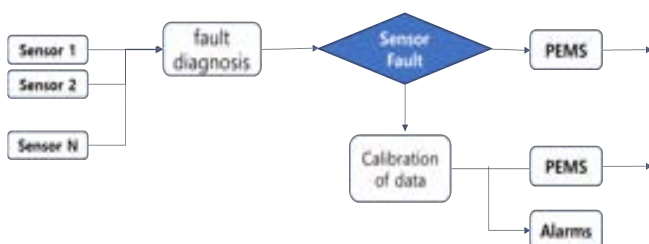


Fig. 15. Correction algorithm flow chart

Table V shows sensor data measurement and prediction and correction data.

TABLE V.
SENSOR DATA MEASUREMENT, PREDICTION AND CORRECTION

	Measured value	Predicted value	Diff.	Out	Correction value
Outlet	610.5	667.45	57.05	X	610.5
Outlet Air P	21.00	25.00	4.00	X	21.00
Outlet Air T	410.50	330.00	80.50	X	410.50
Supplied fuel	60.60	83.00	12.40	X	60.60
Post fuel	145.00	215.00	70.00	O	215.00
O2	13.10	14.20	1.1	-	-

Figure 16 is a visualization diagram showing the amount of decrease in VOC.

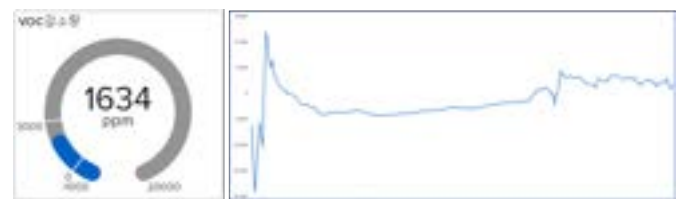


Fig. 16. Showing the amount of decrease in VOC

Figure 17 shows the visualization of temperature, gas and pressure and humidity.



Fig. 17. View of temperature, gas and pressure and humidity

After the RTO reaches a stable operating state, the test results obtained by continuously measuring for 30 minutes were as shown in Table VI. Here, the nitrogen oxide is an actual value not corrected by the standard oxygen concentration [7, 8].

TABLE VI.
TEST RESULTS

Sortation	Unit	Inlet	Outlet
Total hydrocarbon	ppm	6,221.27	155.55
nitrogen oxide	ppm	-	2.49
Exhaust gas temperature	°C	-	70.13

In the RTO simulation, the average concentration of inflow gas according to the operating temperature of the combustion chamber was 6,224 ppm (THC), and the temperature of the RTO combustion chamber was 815°C. The range of change in the temperature of the combustion chamber was the lowest 808°C, and the characteristic of changing periodically up to 825°C be shown in Figure 10.

Figure 18 shows the pattern analysis service through the view of various information in Figure 18. Sign patterns are registered and set through the graph.



Fig. 18. The pattern analysis service

At this time, you can check the Log-based normal or abnormal tagging data collected by the MODBUS Polling Program.

IV. CONCLUSION

As a result of the experiment, the heat generated by VOC combustion was 346,766 kcal/h, and the exhaust loss heat was 185,758 kcal/h using the operating inflow gas temperature (49°C) and emission gas temperature (70°C). Therefore, considering only the generated heat and exhaust loss heat from VOC oxidation, it is calculated that 171,008 kcal/h heat is used as a "regenerated heat energy" inside the RTO system. IoT/ICT technology acquires data from sensors, and machine learning algorithms are used to predict the condition of facilities and equipment before failures occur, and maintenance is planned in advancement to minimize equipment downtime. In the process of predicting, analyzing, and coping with failure causes of equipment in advance, we can expect to grow together with new materials and coating-related technologies that are more resistant to wear and corrosion.

In order to more accurately measure the condition of the facility, the resolution and precision of the sensor are required, and technologies related to the development of higher-performance sensors can be advanced. In addition, by establishing a hardware foundation, a foundation has been created for various algorithms to be developed and applied.

It is expected that the use of failure recognition and prediction of integrated solutions will minimize the stable supply of parts and the shutdown of facilities due to failure, and that VOC will improve public health welfare and respond to the Serious Accident Punishment Act.

ACKNOWLEDGMENT

This study is a knowledge service industry technology development project supported by the Korea Evaluation Institute of Industrial Technology (KEIT), Ministry of Trade, Industry and Energy (No. 20023721). This study was jointly conducted by the Industry-Academic Collaboration Group.

REFERENCES

- [1] J. H. Yoon, Transboundary Air Pollution and Global Governance: Singapore's Network Strategy to Tackle the Indonesian Haze, *Korean Society for Regional Studies*, Republic of Korea, Vol.34, No.1, 5179, Jan.2016, www.dbpia.co.kr/Journal/articleDetail?nodeId=NODE08788063
- [2] Colbeck, I. & Mackenzie, A. R. (1994). Air pollution by photochemical oxidants. *Elsevier, Amsterdam*. [https://doi.org/10.1016/0269-7491\(95\)90028-4](https://doi.org/10.1016/0269-7491(95)90028-4)
- [3] J. H. Yoon, H. M. Park, D. H. Jeon, D. H. Yoon, Movable VOC Removal System: Enhancing Industrial Air Quality by Treating Exhaust Gas, *Technical Journal (Accepted)*, /doi.org/10.31803/tg-20231212064304
- [4] D. H. Yoon, H. M. Park, "VOCs Oxidation Treatment and Waste Heat Recovery Technology through the Implementation of Heat Storage Type Combustion Oxidation Device," *Journal of Korean of Safety Culture Forum*, Vol.17, p.285-298, 2022
- [5] D. K. Park, D. H. Jeon, "A Numerical Study on Heat Storage System for Recovering Waste Heat from a Volatile Organic Compounds Thermal Storage Type Combustion Oxidizer (RTO)," *Korean Society of Waste Resources Circulation*, 2021
- [6] H. M. Park, D. H. Yoon, H. M. Jeong, H. G. Min, D. H. Jeon, "Development of porous plate scrubbers and simulation of IPA treatment efficiency to improve dust collection and deodorization," *Safety and Culture Research*, Vol.13 No.1, p.339-349, 2021
- [7] D. H. Jeon and S. W. Jung, "Pre-treatment Method of Irregular Process Emissions for High-Efficiency Combustion Treatment of Volatile Organic Compounds," *Autumn Conference of the Korea Gas Association*, 2021
- [8] D. H. Yoon, H. M. Park, B. S. Han, etc., "Implementation of 100CMM Thermal Storage Combustion Oxidizer for VOCs Reduction," **2022 The 22nd International Conference on Control, Automation and Systems (ICCAS 2022)** BEXCO, Busan, Korea, Nov. 27~Dec. 01, 2022



1994: Ph.D Graduate School of Electronic Eng., Hanyang University. Korea 1987~1993: Professor of Electronic Eng., KMA. 2001~2003: Director, Institute of Industrial Technology, Semyung University. 2004~ 2009: CEO, Hi-win Co., Ltd. 2010~2015: CTO, Shinwoo Hi-Tech Co., Ltd. 2019~: Vice Chairman, Safety and Culture Forum. 1995.03~: Professor, Dept. of Electronic Eng., Semyung University



1986: SungKyunKwan Univ., Mechanical Eng. (B.S.), 1988: SungKyunKwan Univ., Mechanical Eng. (M.S.), Korea, 1995: The Tokyo University, Japan (Ph.D.) 1996: Professor, Dept. of Mechanical System Engineering, Kyonggi University, Member of the Korean Society of Mechanics



2001: Specialized Bachelor in Construction Eng. Anyang College of Science. 2019: Bachelor, Business Administration, Korea Cyber University. 2021: MBA, IT Business Administration, Ajou University. 2023. Ph. D Course, Department of Mechanical Engineering, Kyonggi University. 2002: Acting Section Chief. D.K Environment Co., Ltd. 2016 ~: CEO, Emsolution Co., Ltd. Major Area: Environment System



2014: Bachelor, Department of Environmental System, at Korea University, Korea. 2024: MS Course, Department of Mechanical Engineering, Kyonggi University.

2016: Supervisor, Kumho Eng. Co., Ltd. 2023 Now, General Manager, Emsolution Co., Ltd. Interests Area: Standby environments and devices, RTOs, Scrubber, Member of the Korean Society for Safety and Culture



2013: Bachelor, School of Civil and Environmental Engineering at Gacheon University. Korea. 2024: MS Course, Department of Mechanical Engineering, Kyonggi University. 2022: Deputy General Manager of Environmental Department, Kumho Environment Co., Ltd. 2022 ~: General Manager of Environmental Department. Emsolution Co., Ltd. Interests area: Environmental Facility Design



2022: Bachelor, Department of Electronic Engineering, Semyung University. Korea. 2023: Environmental System Researcher, Emsolution Co., Ltd. Member of the Korean Society for Safety and Culture Interests Area: Sensor IoT, Standby environments and devices, RTOs, Scrubber



2006: B.S. Electrical & Electronic Engineering, KAIST. 2008~2010: Developer, KMAC Co.,ltd. 2011~2014: CEO, M2MKOREA Co.,ltd.. 2014~: CTO, Devicenet Co.Ltd. Member of the Korean Society for Safety and Culture Major Area : Measurement & Control System Interests Area.: USN System, IoT Network System



2001: Bachelor, Department of Semiconductor Eng., Chungbuk National University, Korea. 2007: MBA Business Strategy, Graduate School of Business, Ajou University, Korea, 2008: Sales manager of LeCory Korea Ltd. 2008~: CEO of LAONURI Co., Ltd. 2022~: CEO of Devicenet. Co., Ltd. 2023~: CEO of IntellyScent Co., Ltd. Interests area: Semiconductor Design, IoT Network