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A Study on the Enhancement of Inventories for Precursors (NOx, SOx) Released from Open Burning of Agricultural Waste Vinyl Causing the Secondary Generation of Particulate Matters

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ABSTRACT

Background and objective: While response measures to particulate matters in rural areas are limited due to poor inventory record keeping in the agricultural sector, it is necessary to control agricultural waste vinyl and the emission of precursors released from open burning and the secondary generation of particulate matters. Currently, the open burning emission calculation method uses the definition prescribed in CAPSS by the National Institute of Environmental Research.

Methods: This study presented an open burning emission calculation formula for agricultural waste vinyl, which is included as agricultural waste. As for activity data, the open burning ratio of agricultural waste vinyl, and the annual incineration volume provided in the Status Survey by the Ministry of Agriculture, Food, and Rural Affairs were applied. The emission factor was generated through incineration tests on three agricultural plastic film samples collected by the Korea Environment Corporation.

Results: Among precursors, SOx and NOx were selected and their emission features were monitored with incineration experiment infrastructure based on the EPA 5G method. The highest emission concentration by agricultural waste type was concentrated in the first and second quarters. As for emission factor of SO_2, it was calculated at 98.25 g/kg for mulching-use LDPE, 52.31 g/kg for greenhouse-use LDPE, and 14.40 g/kg for HDPE. As for NOx, it was calculated at 18.21 g/kg for mulching-use LDPE, 16.49 g/kg for greenhouse-use LDPE, and 10.67 g/kg for HDPE.

Conclusion: This test confirmed the incineration features of PE-based plastics, ascertained the SOx emission factor that had not been included in open burning in the past, and established that low NOx emission concentration is interfered by soil mixed with livestock excretions. The findings from this study are expected to contribute to improving the system for controlling air pollutants in rural environments.

Keywords: Emission factor, Emission calculation formula, Open Burning, Plastic film waste incineration test, Activity data

Introduction

Since the air quality issues due to particulate matters are widespread throughout the society, a systematic measure for the cause and response is required. In comparison to other industries, the agricultural industry has the largest range of emission correction through the modification of activity data (Greenhouse Gas Inventory and Research Center, 2019), which limits the establishment of air quality policies, deepening a concern for rural living environment. The representative and main cause for the generation of particulate matters in rural areas is open burning. According

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to the result of actual condition survey conducted by the Ministry of Agriculture, Food and Rural Affairs (2020), it is estimated that more than 20% of farmers have an experience in incinerating agricultural wastes such as waste vinyl. In particular, uncollected mulching agricultural waste vinyl contaminates soil organic matters, which can give a negative effect on agricultural productivity (Steinmetz et al., 2016); and it was reported that incineration of agricultural waste vinyl can cause a large amount of dioxin (2,228 pg/kg), a carcinogen, to deteriorate farmers' health (Kim, 2008). In this regard, the government plans to concentrate all its efforts on the prevention of illegal incineration through the cooperation with agricultural organizations and Korea Saemaul Undong Center through the "The 2nd Seasonal Particulate Matter Management System Implementation Plan (draft)" (Joint of Related Ministries, 2020) in November 2020.

Agricultural waste vinyl, which is incinerated in the open air, is a main source of air pollutants in rural areas and it can be considered as the agricultural waste requiring the establishment of inventories. Currently, the collection and recycling of agricultural waste vinyl are managed by the Korea Environment Corporation, and as of 2018, the amount of collection was 195,005 tons in comparison to the total amount of generation (318,775 tons), indicating that the collection rate was only 61% (Korea Environment Corporation, 2019). Among the target villages to be managed by the Korea Environment Corporation, rural villages with no common agricultural waste storage account to 16.7% and ones that do not operate relevant waste collection vehicles, 10.1% (Ministry of Agriculture, Food and Rural Affairs, 2020), so it is required to supplement agricultural waste management.

As of 2016, the national annual average concentration of particulate matters (PM_{10}) was 47㎍/㎥, showing a continuously decreasing tendency, but the concentration of fine particulate matters ($PM_{2.5}$) in the country was 26 ㎍/㎥ which was still higher in comparison to other advanced countries (Korea Environment Institute, 2017). Since 2/3 of the amount of fine particulate matters generated in the capital area result from the secondary generation due to the chemical reaction of sulfur oxides (SOx) or nitrogen oxides (NOx) (Ministry of Environment, 2016), gaseous precursors are considered to be an important cause. Pollutants generated from the incineration of agricultural waste vinyl can be classified into the primary particulate matters and major gaseous precursors including sulfur oxides (SOx), nitrogen oxides (NOx) and volatile organic compounds (VOCs) that contribute to the secondary generation of particulate matters. The National Institute of Environmental Research has reported that combustible industrial wastes (PE, PP, PS, etc.) include SOx in a dry condition and release a large amount of SOx at the time of incineration (National Institute of Environmental Research, 2012).

Increased uncertainty due to incomplete activity data (National Institute of Environmental Research, 2014) acts as a limiting factor in supporting decision-making for inventory-based fine dust policies. In particular, the activity data in the agricultural sector are relatively insufficient in comparison to other industries, and only a limited number of relevant studies have also been reported in the field of agricultural waste, which is in a similar situation. For open burning, a study on the establishment of emissions was reported through the calculation of emission factors of pollutants released from direct burning of specimens such as firewood, household waste and agricultural waste residue, and the investigation of activity data (Korea Environmental Industry and Technology Institute, 2013). Meanwhile, domestic studies related to agricultural waste vinyl mainly have focused on the emission characteristics of six pollutants such as paper, plastic, synthetic resins and agricultural residues, and the environmental impact assessment based on prediction modeling of air quality caused by open burning (National Institute of Environmental Research, 2008). In addition, the Ministry of Agriculture, Food and Rural Affairs is promoting an Actual Condition Survey of Agricultural By-products and Wastes in Rural Areas to collect basic information (Ministry of Agriculture, Food and Rural Affairs, 2020) since open burning persists despite various relevant educational activities.

Therefore, this study aimed to improve the calculation system of pollutant emissions from open burning of agricultural waste that requires systematic management in order to enhance the inventories in agricultural sector that limit the establishment of policies on particulate matters due to high uncertainty of activity data. To this end, the main types and samples of agricultural waste vinyl omitted in previous open burning studies are extracted and the emission factors are developed through the time series emission analysis of NOx and SOx that are main precursors contributing to the generation of the secondary particulate matters. In addition, an estimation method for gaseous pollutant emission from agricultural waste vinyl is presented in connection with activity data that can be normalized. Based on these results, the emission characteristics of precursors from open burning of agricultural waste vinyl, and the importance of agricultural waste management are examined.

Research Methods

Status of agricultural waste vinyl

Agricultural wastes are by-products from the disposal of materials required for crop production such as various vinyl products including pesticide bags, fertilizer sacks, shading nets, non-woven fabric, fruit bags and greenhouse vinyl, and support frames and brackets (Ministry of Agriculture, Food and Rural Affairs, 2020). By-products that account for a majority of agricultural waste are vinyl products and these vinyl products can be defined as agricultural waste vinyl. According to the Korea Environment Corporation, the amount of agricultural waste vinyl generated in 2018 was a total of 318,775 tons and 118,356 tons accounting for 37.1% were uncollected, as shown in Table 1. The amount of agricultural waste vinyl not collected by type of vinyl was 63,338 tons for greenhouse LDPE which was the largest, followed by 30,867 tons for mulching LDPE, 16,062 tons for HDPE, and 8,089 tons for other types of vinyl. On the other hand, the uncollected rate in comparison to the amount of generation was 92.1% for greenhouse LDPE which was the largest, and it is considered that such large uncollected rate resulted from the characteristics of usage that greenhouse plastic films are used over a number of years. Other high uncollected rates were 83.6% for other types of vinyl, 24.2% for mulching LDPE and 14.2% for HDPE in the order. In this study, 15kg of each three type of agricultural waste vinyl including greenhouse LDPE, mulching LDPE and HDPE collected from the Dangjin branch of Korea Environment Corporation were received and utilized as the samples for the incineration experiment except for other types of vinyl of various attributes with relatively low emissions.

Status of emission factors related to open burning in rural areas

The National Institute of Environmental Research classifies open burning as a sub-category under the category of biological combustion as shown in Table 2 below, and open burning and agricultural residues are classified separately. The emission factor for open burning which is a sub-category is defined only for household waste. However, the emissions calculation system for agricultural waste that is the main target for open burning in rural areas is currently not available. The Ministry of Agriculture, Food and Rural Affairs launched the “Actual Condition Survey of Agricultural By-products and Wastes in Rural Areas” (Ministry of Agriculture, Food and Rural Affairs, 2020) to classify the target waste for open burning into agricultural by-products, agricultural waste and household waste, and it is considered as a statistical support measure for

Table 1. Amount of generated and collected agricultural waste vinyl in 2018 (Korea Environment Corporation, 2019)

	Total Waste Generation(ton)	Total Waste Collection(ton)	Amount of vinyl not collected(ton)	Uncollected rate (%)
Greenhouse LDPE	68,758	5,420	63,338	92.1
Mulching LDPE	127,431	96,564	30,867	24.2
HDPE	112,909	96,847	16,062	14.2
e.t.c.(PVC, EVA, PO)	9,677	1,588	8,089	83.6
Sum	318,775	200,419	118,356	37.1

Table 2. Emission factor of incineration in open burning and agricultural residues during biological combustion (National Institute of Environmental Research, 2014) unit: g/kg

SCC (Source Classification Code)	Description	Sector	Classification	NOx	SOx
13010100	Open Burning	household waste		4.8	-
13020101	Orchard crops	Fruit trees	Pear	8.7	-
13020102			Apple	10.4	-
13020103			Peach	15	-
13020104			Grape	14.4	-
13020201		Beans	Bean	7.2	-
13020301		Grain	Corn[a]	4.9	-
13020401		Vegetable	Red Pepper	4.9	-
13020501		Special crop	Sesame seeds	6.5	-
13020502			Perilla seeds	8.6	-
13020503			Peanut[b]	7.2	-
13020601		Barley	Barley	5.2	-

Note. *Korea Environmental Industry and Technology Institute. 2014. Development of technology to improve air pollution emission data by biological combustion

* a : Apply Red Pepper Factor, b : Apply Bean Factor

this situation. Therefore, it be can seen that agricultural waste is omitted from the current air pollutant emissions calculation system despite the status of open burning in rural areas. In particular, since high air pollutant emissions are expected from the incineration of agricultural waste vinyl, practical emission factors for the relevant source of pollution omitted from the Clean Air Policy Support System (CAPSS) are proposed in this study.

Emissions calculation system

The emission sources of biological incineration including open burning began to be tallied as official statistics of emissions since 2015, and such sources are classified in a sub-category system including open burning, incineration of agricultural residues, grilled meat and fish, wood heater and boiler, furnace and charcoal kiln. Among these, open burning and incineration of agricultural residues are the types of open burning in rural areas, and open burning waste is classified into household waste and waste wood. The following formula 1 (National Institute of Environmental Research, 2014) presented by US EPA (2001, AP-42) is applied to the emissions calculation equation for open burning, and the emissions are calculated by applying the number of agricultural population, amount of waste incineration per person, open burning ratio and emission factor. Where, it is assumed that the open burning target is household waste discharged from rural areas.

$$E = P \times W \times B \times EF \qquad (1)$$

E : Emissions (kg/yr)

P : Number of agricultural population (number of households)

W : Amount of waste incineration per person (kg/yr)

B : Open Burning Ratio (%)

EF : Emission Factor (g/kg)

The following formula 2 (Lemieux, P. M., et al., 2004) is used for the emission factor of gaseous pollutants released from the incineration of agricultural waste, and the emission factor can be calculated by applying the average flow rate of dilution air into the duct, concentration of pollutants, burning time and mass of waste burned

$$EF = \frac{C_{sample} Q_{QBTF} \tau}{m_{burned}} \qquad (2)$$

EF : Emission factor (mg/kg)

C_{sample} : The concentration of the pollutant in the sample (g/m³)

Q_{OBTF} : the flow rate of dilution air into the OBTF (Open Burning Test Facility) (m³/min)

τ : The burn sampling time in minutes (min)
M : The mass of waste burned (kg)

Activity data setting

The emissions are calculated by applying the number of agricultural population (number of households), amount of waste incineration per person, open burning ratio and emission factor. The amount of waste incineration per person and the open burning ratio of agricultural waste vinyl were classified into house HDPE, LDPE for mulching, and HDPE based on Korea Environment Corporation as shown in Table 3 below, and then the corresponding classification system of the actual condition survey (Ministry of Agriculture, Food and Rural Affairs, 2020) was applied to the two factors; and data from Statistics Korea (2019) were applied to the number of agricultural population. The Ministry of Agriculture, Food and Rural Affairs's Actual Condition Survey of Incineration of Actual Agricultural Waste showed that out of 536 survey respondents, three farmers had experience in burning greenhouse vinyl and 76 farmers had experience in burning various other types of vinyl. The open burning ratio can be calculated through such data, and the emissions released from opening burning of agricultural waste can be defined as the following formula 3 by applying the calculation formula from the US EPA (2001, AP-42) based on such actual condition survey that can be actualized.

$$E_{fw} = P \times W_{fw} \times B_{fw} \times EF_{fw} \quad (3)$$

E_{fw} : Emissions(kg/yr)
P : Number of agricultural population (number of households)
W_{fw} : Amount of waste incineration per person (kg/yr, Survey on the agricultural wastes in the 2019)
B_{fw} : Open Burning Ratio(%, Survey on the incineration of agricultural byproducts and wastes in rural areas, 2020)
EF_{fw} : Emission Factor (g/kg)

Experiment method

The experiment environment was established based on the EPA Method 5G in this study to measure the concentration of gaseous pollutants during incineration of agricultural waste. The Method 5G provides the separation distance between the velocity traverse port (wind speed meter) and sampling ports perforated into a duct of 6-12 inch in diameter connected to the incinerator. The velocity traverse port is located on top of the duct which is separated by at least 12 inches from the incinerator in order to prevent turbulence due to the 90º elbow, and the sampling ports are separated from the velocity traverse port by at least 4 inches. If the outlet and the elbow are connected, EPA Method 5G provides that the sampling port should be at least 1 inch away from the elbow. By referring the relevant standard, the incineration experiment infrastructure was established in a laboratory of S University located in Chungcheongnam-do Province as shown in Fig. 1 below.

The duct with a total length of 7 m and a diameter of 150 cm was perforated at 10 cm intervals for the velocity traverse port and the sampling port, and the damper, filter box and blower were installed at the end of the outlet. The measuring probe (Testo, 0600 9761, Germany) connected to the gaseous pollutants analyzer box (Testo, 350k,

Table 3. Factors for calculating the activity level of outdoor incineration emission of agricultural waste

Classification criteria for agricultural waste vinyl		Amount of waste incineration per household (Ministry of Agriculture, Food and Rural Affairs, 2020)	Opne burning ratio (Ministry of Agriculture, Food and Rural Affairs, 2020; Korea Environment Corporation, 2020)	Number of agricultural population (National Statistical Office, 2019)
Korea Environment Corporation	Ministry of Agriculture, Food and Rural Affairs	kg/yr	%	Number of People
Greenhouse LDPE	Greenhouse vinyl	63.3	0.6	2,244,783
Mulching LDPE	Various kinds of vinyl	5.3	7.2	
HDPE			6.3	

Germany) was inserted into the Sampling port No. 4, and the pitot tube (Testo, 0635 2145, Germany) was inserted into the velocity traverse port to enable the measurement of wind velocity by a differential pressure. To monitor the incineration of agricultural waste vinyl, 0.25kg of each agricultural waste vinyl including mulching HDPE, mulching LDPE and greenhouse LDPE was weighed and incinerated once, and it was set to measure gaseous pollutants at an oxygen concentration of less than 20% by considering the normal atmospheric environment.

Results and Discussion

Time series analysis of incineration experiment

SO_2

The trend of SO_2 emissions from the incineration of agricultural waste vinyl was tallied as follows through five repeated experiments (Table 4). The specimen of greenhouse LDPE was completely burnt out at a concentration of 0.70±0.75g/m³ for 1589.0 seconds on average, and the maximum emission concentration after the beginning of the ex-

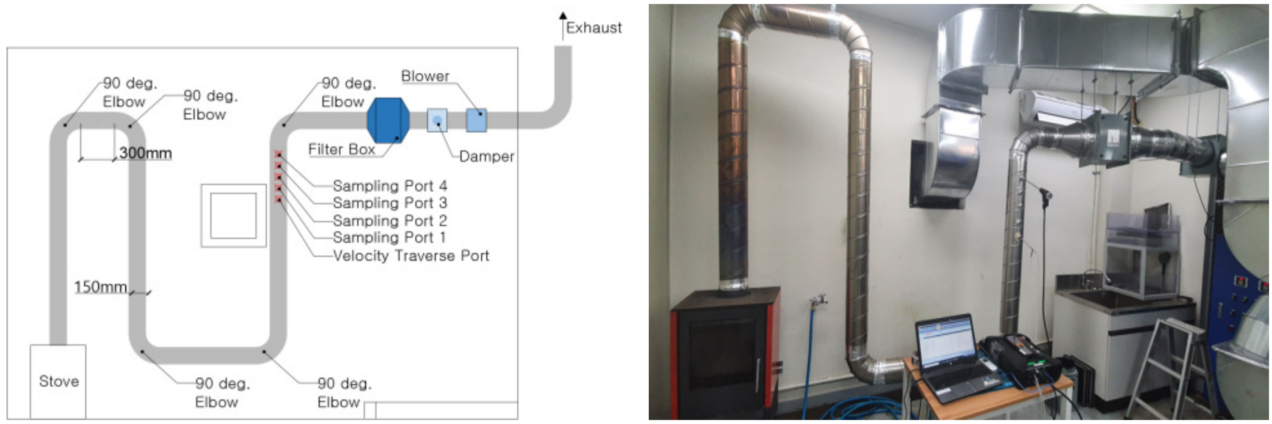

Fig. 1. Incineration experiment infrastructure for agricultural waste vinyl in a laboratory

Table 4. Measured SOx concentration of each vinyls

		unit	SO_2					
			1st	2nd	3rd	4th	5th	avg.
Greenhouse LDPE	times	sec	1,716	1,699	1,838	694	1,998	1,589.00
	avg.	g/m³	0.09	0.53	0.47	1.87	0.55	0.70
	max		1.42	3.22	4.18	16.00	4.77	5.92
	min		0.00	0.07	0.17	0.55	0.22	0.20
	sd		0.22	0.38	0.45	2.02	0.67	0.75
Mulching LDPE	times	sec	847	1,559	1,580	1,998	1,922	1,581.20
	avg.	g/m³	0.73	1.38	1.18	0.46	1.42	1.03
	max		3.25	13.95	10.49	3.27	2.53	6.70
	min		0.32	0.28	0.38	0.18	0.18	0.27
	sd		0.50	2.31	1.53	0.36	0.77	1.09
HDPE	times	sec	790	746	746	746	834	772.40
	avg.	g/m³	0.29	0.47	0.35	0.23	0.33	0.33
	max		1.00	3.42	1.21	2.60	2.48	2.14
	min		0.08	0.11	0.18	0.09	0.10	0.11
	sd		0.17	0.66	0.16	0.30	0.38	0.33

periment was 5.92 ± 5.17 g/㎥, which was confirmed to be concentrated in the first quarter (Q1) (Fig. 2). The specimen of mulching LDPE was completely burnt out at a concentration of 1.03 ± 1.09 g/㎥ for 1580.2 seconds on average, and the maximum emission concentration after the beginning of the experiment was 6.70 ± 4.65 g/㎥, which was confirmed to be concentrated in the first quarter (Q1) (Fig. 3). The specimen of HDPE was completely burnt out at a concentration of 0.33 ± 0.33 g/㎥ for 772.4 seconds on average, and the maximum emission concentration after the beginning of the experiment was 2.14 ± 0.91 g/㎥, which was confirmed to be concentrated in the first quarter (Q1) (Fig. 4).

Among the studies of the combustion characteristics dur-

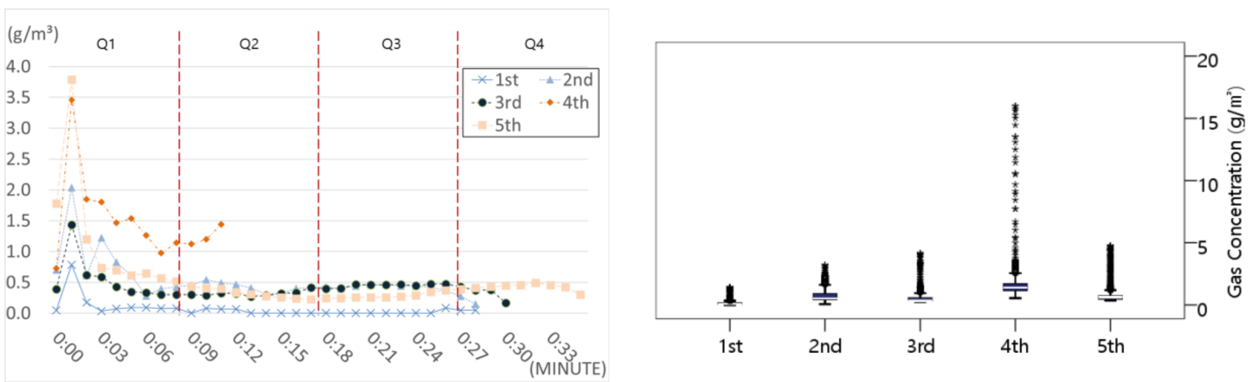

Fig. 2. SO_2 emissions monitoring from burning of Greenhouse LDPE.

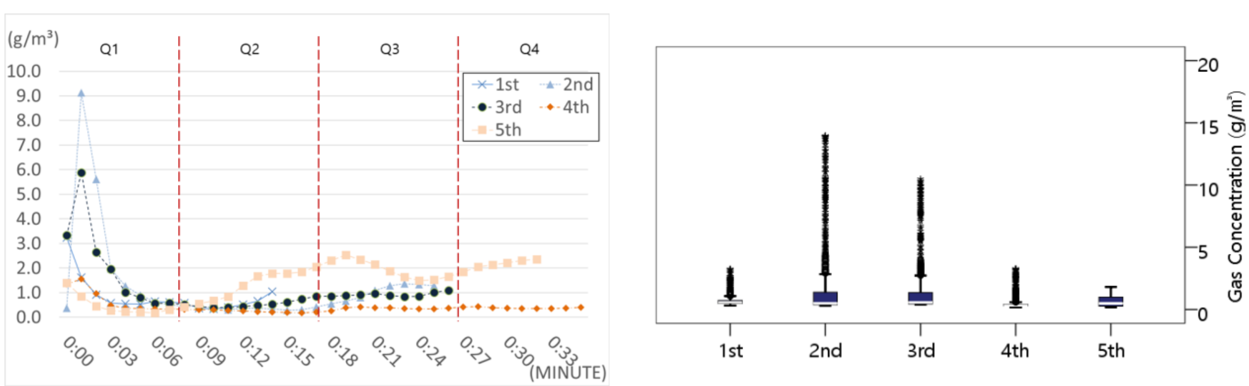

Fig. 3. SO_2 emissions monitoring from burning of Mulching LDPE.

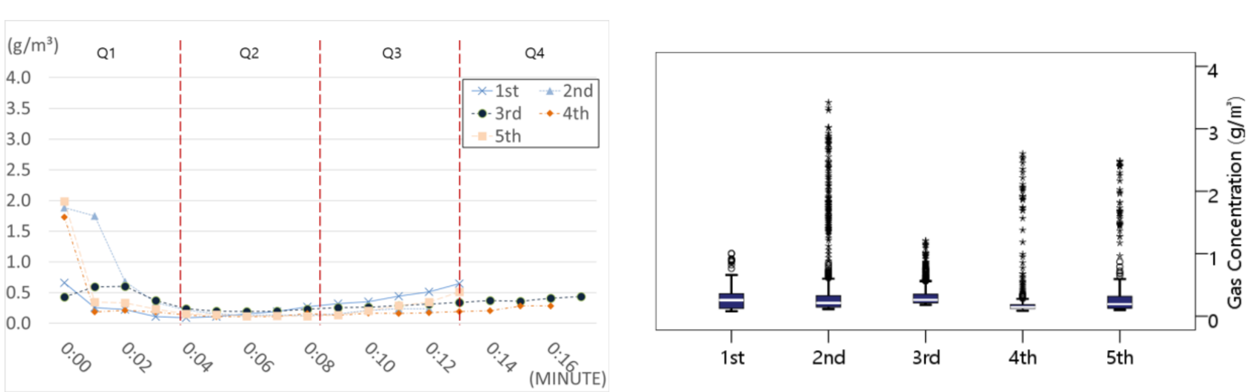

Fig. 4. SO_2 emissions monitoring from burning of HDPE.

ing incineration of low-density polyethylene (LDPE) and high-density polyethylene (HDPE), a study, which analyzed a change in the concentration of NO, SO_2 and NOx in the PE-based pipes with the same molecular structure (Lim Bo-soo, An Hyung-hwan, 2016) reported that the maximum average concentration of SO_2 recorded 68ppm. In this study, the maximum concentration of SO_2 released from the incineration of agricultural waste vinyl ranged 2.14g/㎥-6.70 g/㎥, which was 22.0%-82.7% in comparison to the previous study (Lim Bo-soo, An Hyung-hwan, 2016). It was considered to be an error that occurred due to the interference by impurities of contaminated agricultural waste vinyl at the time of incineration, and significant emission characteristics of SOx, which was a main precursor for the generation of the secondary particulate matters, were confirmed in the open-air incineration of agricultural waste vinyl.

NOx

The trend of NOx emissions from the incineration of agricultural waste vinyl was tallied as follows through three repeated experiments (Table 5). The specimen of greenhouse LDPE was completely burnt out at a concentration of 0.19 ± 0.09g /㎥ for 1589.0 seconds on average, and the maximum emission concentration after the beginning of the experiment was 0.63 ± 0.40 g/㎥, which was confirmed to be concentrated in the first and second quarters (Q1-Q2) (Fig. 5). The specimen of mulching LDPE was completely burnt out at a concentration of 0.20 ± 0.10 g/㎥ for 1581.2 seconds on average, and the maximum emission concentration after the beginning of the experiment was 0.42 ± 0.13 g/㎥, which was confirmed to be concentrated in the first quarter (Q1) (Fig. 6). The specimen of HDPE was completely burnt out at a concentration of 0.20 ± 0.10g /㎥ for 772.4 seconds on average, and the maximum emission concentration after the beginning of the experiment was 0.53 ± 0.13 g/㎥, which was confirmed to be concentrated in the first quarter (Q1) (Fig. 7).

In a study on the combustion characteristics of PE-based pipes that have the same structure with agricultural waste vinyl (Lim Bo-soo, An Hyung-hwan, 2016), it was reported that NO and NOx emissions were at a concentration of 2 ppm that was insignificant, as a result of observing the decomposition temperature ranged 0-1,000℃ for the purpose of analyzing the combustion characteristics. In this study, mulching LDPE showed 1.1-1.7 times more NOx emissions than other agricultural waste vinyl, so a review of the effect of impurities of mulching LDPE is required

Table 5. Measured NOx concentration of each vinyls

		unit	NOx					
			1st	2nd	3rd	4th	5th	avg.
Greenhouse LDPE	times	sec	1,699	1,838	694	1,998	1,716	1,589.0
	avg.	g/m³	0.23	0.19	0.28	0.18	0.09	0.19
	max		0.44	0.39	0.50	0.39	1.42	0.63
	min		0.00	0.14	0.18	0.14	0.00	0.09
	sd		0.08	0.04	0.07	0.04	0.22	0.09
Mulching LDPE	times	sec	847	1,559	1,580	1,998	1,922	1,581.2
	avg.	g/m³	0.13	0.21	0.25	0.18	0.19	0.20
	max		0.17	0.48	0.52	0.44	0.49	0.42
	min		0.09	0.14	0.18	0.13	0.14	0.13
	sd		0.03	0.06	0.05	0.05	0.06	0.10
HDPE	times	sec	790	746	746	746	834	772.4
	avg.	g/m³	0.26	0.26	0.24	0.24	0.23	0.20
	max		0.55	0.77	0.43	0.49	0.43	0.53
	min		0.21	0.19	0.20	0.20	0.18	0.20
	sd		0.05	0.09	0.05	0.04	0.04	0.10

to be prioritized, which is discarded in a state of containing a large amount of soil and fertilizer. Scarascia-Mugnozza et al. (2004) reported that pollutants such as CO_2, CO, H_2S, SO_2, NH_3 and dioxin were released more from opening burning of agricultural plastic than in controlled environments.

As of 2018, mulching plastic film among agricultural waste vinyls was most widely used, and it was mainly collected with large amounts of soil and fertilizer as it came into high contact with the surface of farmland. Therefore, for agricultural waste vinyl for mulching, the effect of soil and fertilizer should be considered due to the characteristics of use environment in the examination of the emission

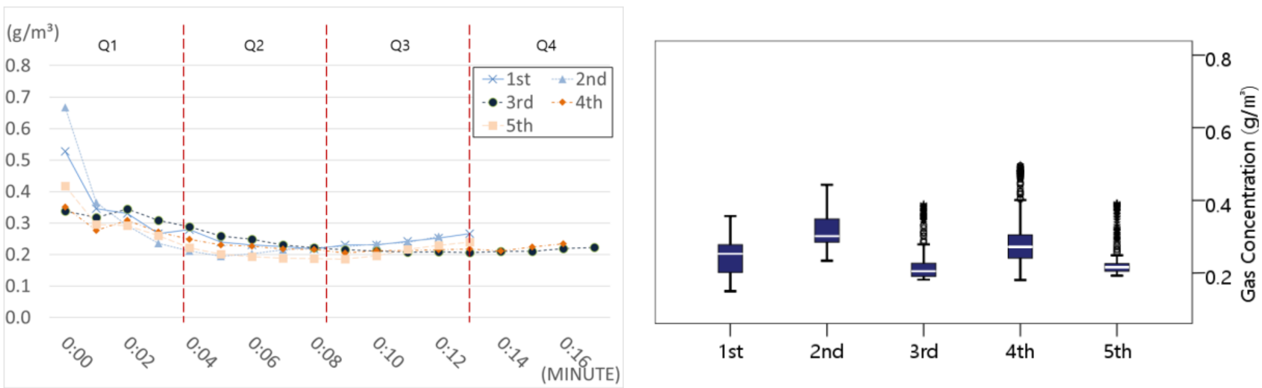

Fig. 5. NOx emissions monitoring from burning of Greenhouse LDPE.

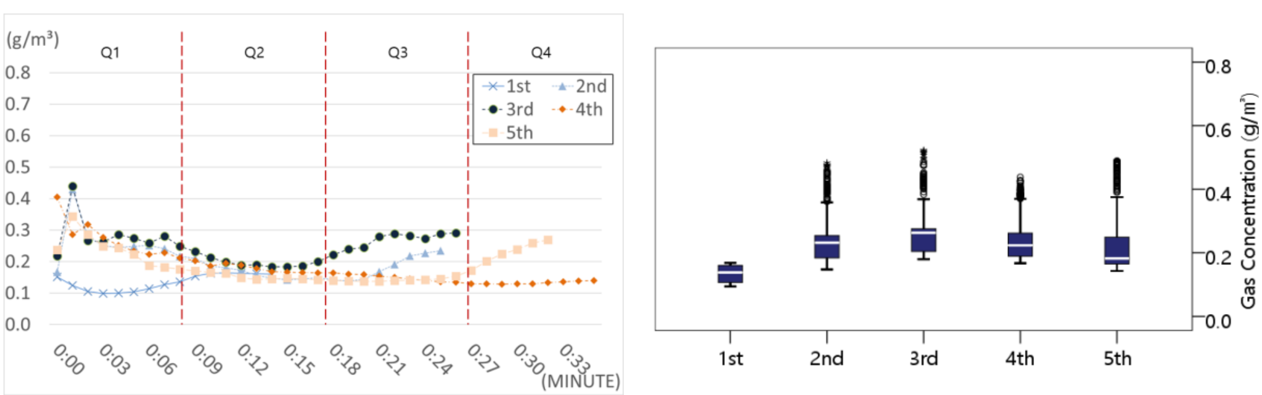

Fig. 6. NOx emissions monitoring from burning of Mulching LDPE.

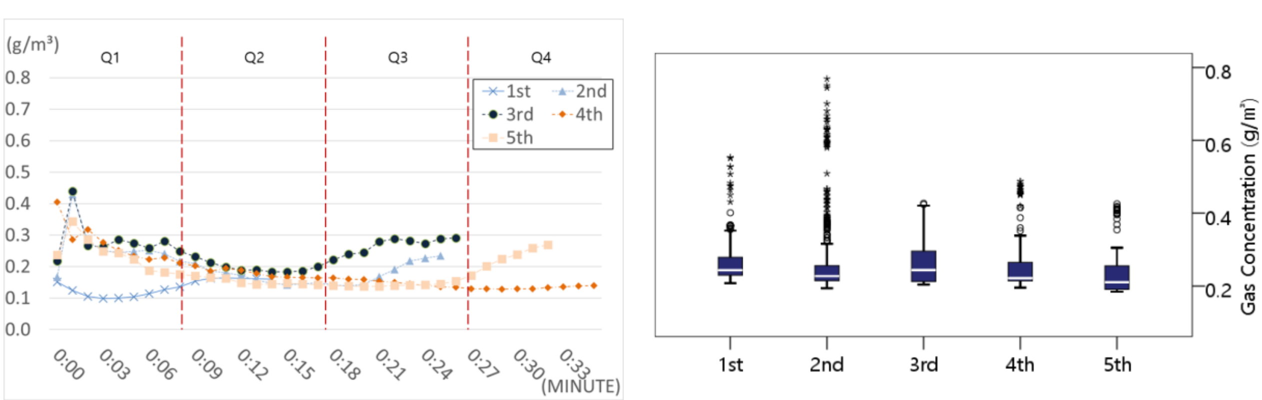

Fig. 7 NOx emissions monitoring from burning of HDPE.

Table 6. Calculated emission factor for each vinyls

	Time(min)	Air Flow Rate(m^3/s)	SO2(g/kg)	NOx(g/kg)
Greenhouse LDPE	26.86	0.69	52.31	16.49
Mulching LDPE	27.34	0.87	98.25	18.21
HDPE	12.87	0.84	14.40	10.67

characteristics of air pollutants from incineration. A study on the use of animal manure as fuel for heating facilities was carried out in the EU WP6 Energy potentials project, and the emission characteristics due to the incineration of fertilizer were also reported. Kristensen et al. (2009) compared the incineration of fuel mixed with pig manure and straw, and that of straw only, and NOx emissions ranged from 345 ppm to 462 ppm, indicating that the results were similar. On the other hand, it was reported that CO was released at a concentration of 405-1,279 ppm, and particulate pollutants, 1,496 mg/Nm^3-2,586 mg/Nm^3, indicating 1.4-2.7 times and 2.3-3.0 times more emissions, respectively, than those from the incineration of straw only. Perttersson et al. incinerated and compared fuel mixed with horse manure and sawdust at a dry matter content of 43%, and woodchip, and presented the findings that NOx concentrations released from fuel including horse manure ranged 362 mg/Nm^3-438 mg/Nm^3, which was 2.9-3.0 times more emissions than those of woodchip. As such, combustion of livestock excretions may cause NOx emissions, and in consideration of combustion characteristics of PE-based plastics, it is considered that an increase in NOx emissions was caused by soil and fertilizer ingredients.

Calculation of emission factor

EPA's calculation formula of particulate and gaseous pollutants was applied to emission factors from the incineration of agricultural waste vinyl in the “Research on the current state of open burning such as agricultural and fishing village waste and reduction measure”(National Institute of Environmental Research, 2008). The calculation formula calculates emission factors for volatile, semi-volatile and particulate pollutants by extracting plastic combustion samples based on the Volatile Organic Sampling Train (VOST) in the open burning section of AP-42. Linak et al. (1989) determined the biochemical characteristics of incomplete combustion residues from open burning of agricultural plastics using the emission factor calculation method. They presented the combustion emissions from the incineration of agricultural plastics, the types of pesticides within the plastics, and the effects of air pollutants discharged by the decomposition. Based on these, the calculation method of emission factor for each type of pollutant was defined, and Lemieux et al. (2004) advanced the emission factor calculation method for pollutants from open burning through a laboratory unit simulation using the Flux Chamber method. U.S. EPA's National Risk Management Research Laboratory also applies the method to the operation of test programs at the Open Burning Test Facility (OBTF). In this study, the emission factors of NOx and SOx, which are main precursors contributing to the generation of secondary particulate matters, was drawn by applying the emission factor calculation formula.

The emission factor was calculated as shown in Table 6 below, by applying the emission information of each gaseous pollutant, which was aggregated through the incineration experiment for each type of agricultural waste vinyl, to the formula 3. In case of SO_2, mulching LDPE was calculated as the highest emission factor at 98.25 g/kg, while HDPE as the lowest emission factor at 14.40 g/kg. In case of NOx, mulching HDPE was calculated as the highest emission factor at 18.21 g/kg while greenhouse LDPE as the lowest emission factor at 10.67 g/kg.

Emission calculation

The national emissions of air pollutants are calculated based on the Clean Air Policy Support System (CAPSS), and an inventory for air pollutants due to open burning in rural areas are also provided. The National Institute of Environmental Research calculated the emission factor for air pollutants by applying plastics to open burning (National Institute of Environmental Research, 2008). The Korea

Table 7. Estimated emissions by pollutants unit: ton

Pollutant	Greenhouse LDPE	Mulching LDPE	HDPE	Sum of Emissions	2017 Household Waste Emissions*	Ratio(%)
SO2	42	84	11	136	-	-
NOx	13	16	8	37	519	7.1%

Note. *National Air Emission Inventory and Research Center. 2020. Air pollutant emissions 2017

Environmental Industry and Technology Institute only presented the emission factor of NOx since no or only a very small amount of NO_2 and SO_2 was detected from open burning of domestic waste (Korea Environmental Industry and Technology Institute, 2013). In that study, plastic and vinyl were classified as 6.3% and 24.4% respectively, but specific emissions information was not presented since no subdivision according to the type of vinyl was applied.

The emissions of gaseous pollutants from agricultural waste vinyl were calculated as shown in Table 7 below by applying the emission factor reflecting the actual condition survey (Ministry of Agriculture, Food and Rural Affairs, 2020) shown in Table 6, to the formula 3 established based on US EPA(2001, AP-42)'s calculation formula. In case of SO_2 emissions from the burning of uncollected agricultural waste vinyl, mulching LDPE showed the largest emissions at 84 ton/yr while HDPE, the smallest emissions at 11ton/yr. In case of NOx emissions, mulching LDPE showed the largest emissions at 16 ton/yr while HDPE, the smallest emissions at 8 ton/yr. If the emissions calculated through this study are reflected in the CAPSS-based emissions by pollutants released from the incineration of household waste as of 2017, the SOx emissions will net increase by 136 ton as no emission factor was provided, and the NOx emissions will also increase by 7.1% (Table 7).

Conclusion

In this study, we attempted to link reliable statistical data that could be reflected in the activity level in order to advance the inventory of particulate matters in agricultural sector. Agricultural waste excluded from CAPSS's open burning emission calculation system was collected by the “Agricultural Waste Survey,” Korea Environment Corporation's nationally approved statistics (Approval No. 392005). The amount of waste emissions that could be incinerated outdoors was confirmed from the total amount of uncollected agricultural waste vinyl in the relevant approved statistics. The Ministry of Agriculture, Food and Rural Affairs also carried out the “Actual Condition Survey of Agricultural By-products and Wastes in Rural Areas” that classified agricultural waste into agricultural by-products, agricultural waste and household waste in 2020. In this study, the emissions from opening burning of agricultural waste vinyl were calculated by applying the incineration experience rate among the relevant actual condition survey data and the emission calculation formula for air pollutants released from opening burning presented by US EPA (2001, AP-42).

In addition, the emission characteristics of gaseous precursors from opening burning of agricultural waste were examined in this study by reflecting the importance of the secondary generation mechanism that lead to generating fine particulate matters. Significant emission characteristics of SOx and NOx from the incineration of agricultural waste vinyl were confirmed, and these characteristics are expected to contribute to the improvement of the CAPSS-based classification system of open burning emission source that is currently limited to household waste and waste wood. The importance of normalized statistical data was also confirmed for continuous advancement of relevant inventory. The actual condition survey which has not been established yet was initiated by the Ministry of Agriculture, Food and Rural Affairs, and it is considered that Korea Environment Corporation's approved statistics preparation plan and classification system should be the main targets for review with great importance. In the future, to establish efficient agricultural policies on particulate matters, an activity DB table linkage measure between relevant authorities should be prioritized considering industrial characteristics centered on competent authorities.

On the other hand, the laboratory-based EPA Method

5G was applied to this study to measure the concentration of gaseous pollutants, but the experimental structure, which makes it difficult to reproduce the control conditions of external environment reflected in open burning, is regarded as a limitation in this study. Furthermore, it is thought that studies should be followed such as: regarding volatile organic compounds (VOCs), of which data could not be obtained even with a type-approval instrument (Testo, 350k, Germany) of the National Institute of Environmental Research under the Ministry of Environment, among pollutants from incomplete combustion of agricultural waste vinyl; and environmental dynamics of NOx and SOx concentration changes.

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