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Effect on Pollutant Emission Concentration when Pollutants from Air Pollutant Emission Facilities are Mixed with Unpolluted Air

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Abstract

Some provisions of the Clean Air Conservation Act were enacted at a time when industrialization was accelerating, so it is difficult to properly reflect the current complex industrial site conditions. In particular, in the case of "the act of mixing clean air with pollutants exhausting from the emission facility to lower the level of pollution when operating the emission facility", which is prohibited under Article 31 (Operation of emission facilities and prevention facilities), the actor intentionally It can be applied even in situations where it is impossible to confirm whether the purpose is to lower the pollution level and whether the pollution level is actually lowered. This study aims to examine whether the level of pollution actually decreases when clean, unpolluted air is mixed with pollutants generated from emission facilities, thereby confirming the necessity of revising the Clean Air Conservation Act and suggesting directions for the enforcement of related laws.

Keywords : mixing clean air with pollutants, air dilution

1. Introduction

1.1. Study Purpose

This study aims to confirm cases in which a high level of punishment of "imprisonment for not more than 7 years or a fine of not more than 100 million won" was imposed for violating Article 5 (Responsibilities of Business Operators) Paragraph 1 of the Clean Air Conservation Act, which states, "When operating an emission facility, in order to lower the pollution level, the act of mixing air with the pollutants emitted from the emission facility (hereinafter "air dilution")," and to determine whether there is an air dilution effect when the pollutants are mixed with air and whether cases of violation of the prohibition of air dilution are in line with the intent of the enactment of the law on the prohibition of air dilution.

In addition, the purpose is to provide a basis for administrative agencies to enact regulations that specifically specify acts subject to punishment in relation to air dilution during inspections conducted on air pollutant emitting businesses by utilizing the results of the verification, and to provide information to enable business owners and related personnel to operate emission facilities and prevention facilities in accordance with the purpose of prohibiting air dilution.

1.2. Study Background

The 「Clean Air Conservation Act」, due to its nature as a law, is difficult to accurately reflect or predict the current or future situation and revise in advance, so it needs to be proactive in reflecting the development of science and technology or changes in the awareness of the government, the public, or stakeholders. Korea's air quality has developed and improved significantly in various fields over the past 20 years, and it is expected to improve in the future. However, some provisions of the 「Clean Air Conservation Act」 were enacted during the period of accelerated industrialization, making it difficult to properly reflect the current complex industrial conditions. In particular, in the case of "the act of mixing air with pollutants emitted from emission facilities to reduce the level of pollution when operating emission facilities," which is prohibited under Article 31 (Operation of Emission Facilities and Prevention Facilities), it can be applied regardless of the situation, as it is impossible to confirm whether the act is intentionally intended to reduce the level of pollution and whether the act actually reduces the level of pollution. In principle, the purpose of the act must be confirmed in order to punish such an act. However, it is also true that the administrative agency conducting the inspection must make a judgment based on various circumstantial evidence on site, as it is difficult to directly confirm the intention or purpose of the act.

1.3. Study Methods

The purpose of this study is to investigate the reasons for the prohibition of air dilution in the Clean Air Conservation Act and to study whether the design and operation of current air pollution prevention facilities are appropriate for the reasons and purpose of prohibiting air dilution.

In addition, when applying for a permit or report on the installation of air pollutant emission facilities by the central or local government, we aim to calculate whether the pollution level is theoretically reduced by assuming that clean air that is not polluted is mixed with the pollutants emitted from the emission facility, using the theory and the calculation formula for pollutant treatment efficiency used in the design recognized as a method of calculating the treatment efficiency of the prevention facility. In addition, we aim to confirm how cases of air dilution detected during inspections conducted by administrative agencies on businesses operating air pollutant emission facilities and cases indicted for air dilution in court are decided, and study how air dilution should actually be defined.

1.4. Scope of the study

First, we will review the laws and regulations on the p rohibition of air dilution in the Clean Air Conservation Act and study cases in which administrative agencies inspect a nd punish businesses that operate air pollutant emission fac ilities. In addition, we will review the theory and calculatio n formulas for the pollutant treatment efficiency of each pr evention facility in the process of administrative agencies a pproving the installation report or installation permit for air pollutant emission facilities and study the air dilution effe ct theoretically. In addition, we will review the court's decis ions on air dilution and study what content needs to be addi tionally reviewed when air dilution-related regulations are enacted in the future.

2. Air Dilution Related Laws

2.1. Enactment and Revision of the "Clean Air Conservation Act"

The Ministry of Government Legislation website explains the development process of environmental law in our country as follows.

The "Environmental Law" was enacted for the purpose of minimizing damage and disadvantage caused by environmental destruction by preventing infringement and destruction of the human living environment and natural environment. In Korea, legislation related to the environment began in the 1960s when the economic growth strategy through industrialization was being implemented. The "Five-Year Economic Development Plan" established in the early 1960s placed the growth engine of the national economy on industrialization centered on light industry, and as various uncontrolled pollutants discharged from early industrial facilities caused air pollution and river pollution, environmental pollution was recognized as a public hazard related to public health. The government's policy efforts to deal with this began in 1963 with the enactment of the "Pollution Prevention Act," Korea's first environmental law, and the systematization of domestic environmental laws.

Since the mid-1970s, when the government's intensive heavy chemical industry development policy was promoted, the Korean economy has been characterized by rapid urbanization and industrialization. During this period, the increase in nitrogen and sulfur oxides in the atmosphere due to the increased use of fossil fuels for industry and transportation and heating fuels, as well as the increase in industrial and domestic wastewater, not only demanded stronger environmental regulation standards, but also the issue of preserving the natural environment due to large-scale development projects emerged as a major policy issue. The Environmental Conservation Act enacted in 1977 reflected these policy demands. Since the late 1980s, when the country entered the peak of its high-growth period, the public demand for environmental protection has increased and environmental rights have been recognized as a fundamental right under the Constitution. As a result, changes have occurred in the environmental law system of Korea in the 1990s, with the Framework Act on Environmental Policy at the top, and countermeasure laws for individual environmental reasons being arranged. In the process of supplementing the environmental law system since the 1990s, individual laws related to the introduction of regulations by pollutant media, punishment provisions for environmental crimes, burden of environmental improvement costs, and environmental pollution prevention projects have been reorganized.

The Air Quality Conservation Act was enacted in August 1990 and went into effect in February 1991 with the goal of maintaining a clean and clear air environment, preventing harm to the public health and the environment caused by air pollution, and guaranteeing the public health and a pleasant environment to live in. As such, the Air Quality Conservation Act Based on Article 35 of the Constitution of the Republic of Korea's right to the environment (All citizens have the right to live in a healthy and pleasant environment, and the state and citizens shall endeavor to preserve the environment), the Framework Act on Environmental Policy regulates emissions of air pollutants from business establishments, etc. for the purpose of Article 1 (Purpose) based on the content of "Article 5 (Responsibilities of Business Operators) Business operators shall take necessary measures to prevent environmental pollution and damage arising from their business activities, and shall have the responsibility to participate in and cooperate with the environmental preservation policies of the state or local governments."

The Air Quality Conservation Act has been revised 81 times as of October 2024, and like all laws, it has undergone many changes to reflect the current situation and conditions, as well as other related issues, and will continue to do so in the future.

2.2. Purpose of Prohibiting Air Dilution

The prohibition of "air dilution" prohibited in Article 31 (Operation of Emission Facilities and Prevention Facilities) of the Clean Air Conservation Act was enacted for the purpose of lowering the concentration of pollutants artificially emitted or limiting the emission of pollutants that have not been properly treated. Air dilution includes acts of directly lowering the pollution level of exhaust gas after passing through a prevention facility or increasing the amount of exhaust gas by introducing outside air so that the pollution level of exhaust gas can be within the permissible emission standards even if the treatment at the prevention facility is insufficient. Therefore, installing and operating a facility that introduces outside air during the process of pollutants generated at an emission facility flowing into a prevention facility is considered air dilution as it may prevent all pollutants from the emission facility from flowing into the prevention facility.

2.3. History of Revision of Laws Related to Air Dilution

The regulation of "air dilution," which is prohibited under Article 31 (Operation of Emission Facilities and Prevention Facilities) of the Clean Air Conservation Act, was first introduced on December 27, 1993 (effective date: June 28, 1994) as a partial revision of the Clean Air Conservation Act. On the same day (effective date), a law prohibiting "dilution" was enacted in the Water Quality and Environment Conservation Act. Afterwards, some of the details were supplemented and the final revision was made to state, "An act of mixing air with pollutants emitted from emission facilities and discharging them in order to lower the level of pollution. However, this does not apply in cases where the Minister of Environment recognizes that it is necessary to prevent accidents such as fires or explosions."

2.4. Changes in the Industrial Field

Since industrialization in the 1970s, Korea's industrial sites have undergone many changes. Industrialization, which began with a manual production method in the early days of industrialization, gradually began to mechanize and become larger, and through the development of the equipment industry in the 1980s and 1990s, it has surpassed automation in 2020 and is now entering the era of AI driving. However, regulations enacted in the 1990s, such as air dilution, seem difficult to maintain the purpose and reason for punishment in the current trend of advanced industrialization. In the current industrial sites, not only is the air quality of the workplace important for protecting the atmospheric environment, but there has also been great development in interest and regulations regarding the health and environment of workers. Air conditioners, which were installed to maintain a clean working environment, are being installed purely for the health and environment of workers, and air pollutant prevention facilities are also being installed not for exhaust and treatment of air pollutants, but also for the purpose of exhausting facilities other than the air quality of the workplace or air pollutant emission facilities. In this trend, the air dilution regulation is leading to the installation of double exhaust ducts at the site. This is because, for the sake of workers' health and environment, mixing air emitted from a facility that is not an air pollutant emitting facility with gas emitted from an air pollutant emitting facility constitutes air dilution.

Until now, it has been difficult to confirm the data on the air dilution effect of pollutants when mixed with unpolluted air. In that sense, the current time when automation of industrial sites is in progress is the optimal time for research on the air dilution effect.

2.5. Interpretation of Air Dilution by Administrative Agencies

The general opinion of environmental engineers at workplaces being inspected is that the method of applying air dilution when administrative agencies conduct guidance and inspections of the atmospheric environment of workplaces varies by administrative agency and individual inspectors. In addition, in the absence of precise regulations or guidelines from the Ministry of Environment or related organizations regarding the cases that constitute air dilution, trials are held in courts nationwide several times a year. In cases where administrative agencies have detected air dilution and requested a certificate, but have not proceeded with the trial for various reasons, there is no way to confirm specific information about the air dilution act. Therefore, an environmental consulting firm (YESE&C) has organized cases that can be interpreted as air dilution, and it can be expected in which cases administrative agencies apply air dilution. The cases are as follows in Figs. 1 to 7.

Figure1 is a situation where uncontaminated air can flow into the prevention facility when a damper is not installed in the hood and duct that collects pollutants emitted from the emission facility, or when a damper is installed but the emission facility is not in operation.

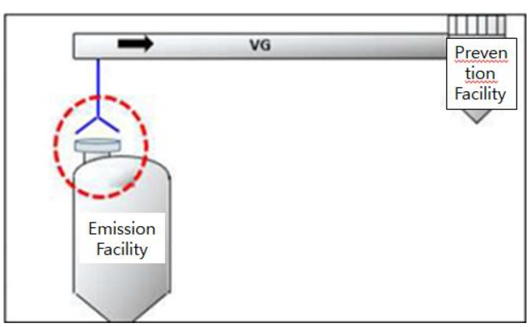

Figure 1: Air dilution case 1

Figure 2 applies to cases where there is no exhaust outlet from the exhaust facility or the exhaust outlet or raw material inlet is closed.

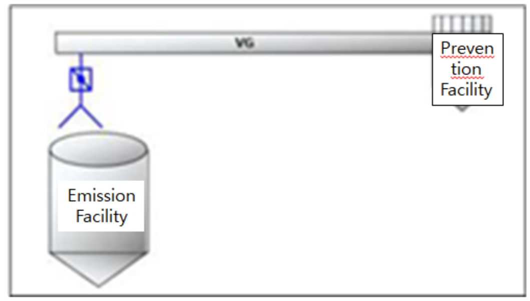

Figure 2: Air dilution case 2

Figure 3 is the case where the hood and duct that capture and transport pollutants are installed and operated as before while the emission facility is closed or no longer in operation.

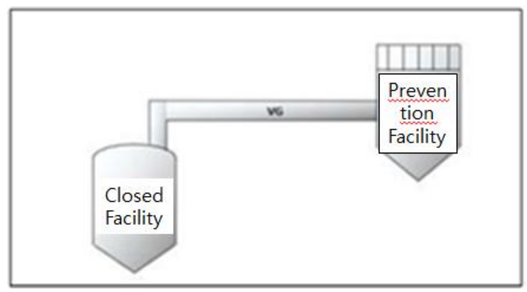

Figure 3: Air dilution case 3

Figure 4 is a case where an inappropriate type of hood is installed, in which an excessive amount of outside air flows into the hood in addition to the exhaust gas emitted from the exhaust facility.

Figure 4: Air dilution case 4

Figure 5 applies to cases where gas emitted from unreported facilities, such as sealed facilities, is introduced into a prevention facility during a continuous process in a sealed state during the product production process.

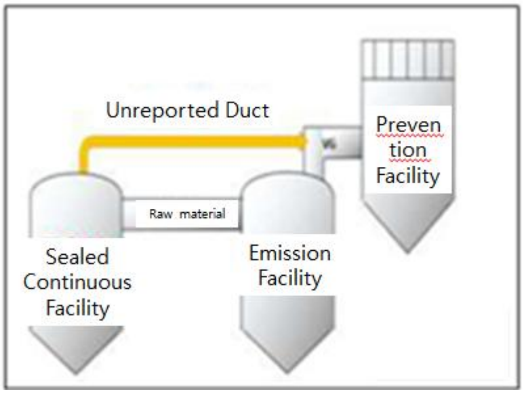

Figure 5: Air dilution case 5

Figure 6 applies to cases where outside air flows into the prevention facility through a bread valve, pressure regulating valve, control valve, rupture disc, or safety valve installed for safety reasons without the approval of the Minister of Environment.

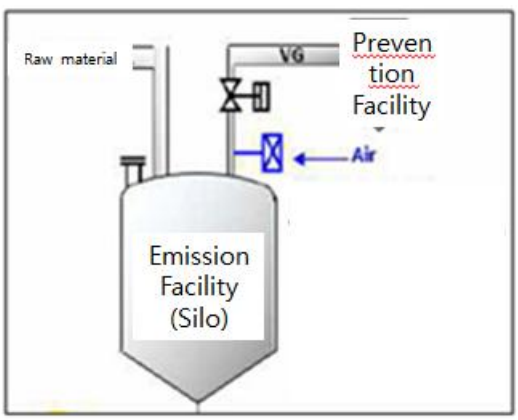

Figure 6: Air dilution case 6

Figure 7 applies to cases where the end of the duct transporting pollutants was improperly finished or the prevention facility was operated with the condensate discharge port or cleaning port open, or when the prevention facility was operated with the duct in a corroded/damaged state.

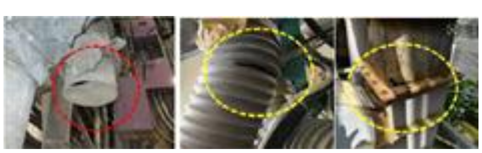

Figure 7: Air dilution case 7

2.6. Cases Punished by Administrative Agencies for Air Dilution

The cases punished for air dilution by the Nak-dong River Regional Office of the Ministry of Environment and Won-ju Regional Environmental Office are as shown in Figure 8 and Figure 9, and are similar to the contents explained previously from Figure 1 to Figure 7.

Figure 8 applies to the case where the prevention facility was operated without closing the duct section that was connected to the existing discharge facility while the discharge facility was closed.

Figure 8: Air dilution case 8. Cases punished by the Nak-dong River Regional Office of the Ministry of Environment

Figure 9 applies to cases where some sections of the duct connected to the prevention facility are not closed when the existing facility is closed, or where air from the workplace is sucked into the prevention facility through a duct connected to an inoperable exhaust facility.

Figure 9: Air dilution case 9. Cases punished by the Won-ju Regional Environmental Office of the Ministry of Environment

3. Theoretical Effect of Air Dilution

Since treatment efficiency is calculated differently depending on the type of prevention facility, there are facilities that can theoretically calculate the efficiency of prevention facilities, and there are also cases where the efficiency of prevention facilities must be estimated through actual measurement and analysis.

In this study, it would be a priority to identify the correlation between how air dilution affects the efficiency of prevention facilities and the reasons for legal prohibition. If we assume a case where prevention facilities are not installed, if pollutants discharged from the emission facility are mixed with uncontaminated air, assuming that there is no special reaction or treatment, the concentration of pollutants at the outlet will decrease in proportion to the amount of diluted air. In this case, legally restricting air dilution is consistent with the purpose of enacting the law. However, when air uncontaminated with pollutants is mixed into the prevention facility, the situation unfolds differently. This is because the treatment efficiency of the prevention facility generally decreases when the amount of air flowing into the prevention facility increases, and it is not guaranteed that the concentration of pollutants emitted at the outlet will decrease even if air dilution occurs. If the operator of the emission and prevention facilities is not certain that the concentration of pollutants will decrease at the rear of the prevention facility when the wind speed increases, and if there is a possibility that air dilution will increase the concentration of pollutants at the rear of the prevention facility, the operator of the emission and prevention facilities will be very unlikely to intentionally attempt air dilution. Furthermore, if air dilution occurs unintentionally, it is questionable whether the violation of the air dilution ban can be punished simply because air dilution occurred.

Therefore, the most reasonable way to confirm the dilution effect would be to compare the concentration of pollutants by changing the type of pollutant, design concentration of the prevention facility, and air volume ratio according to the type of air pollution prevention facility. However, in this paper, the air dilution effect of each type of representative prevention facility was theoretically confirmed.

3.1. Air Dilution Effect according to Physicochemical Treatment Method

3.1.1. Physical Processing

The treatment efficiency of a prevention facility targeting common air pollutants is calculated as the ratio of the concentration of pollutants reduced to the inflow concentration, as in Equation (1).

$$\eta = \left(1 - \frac{C_{\text{out}}}{C_{\text{in}}}\right) \times 100 \quad (1)$$

The theoretical treatment efficiency for each prevention facility is calculated differently depending on the pollutant treatment principle for each prevention facility and is covered in "3.2 Theoretical air dilution effect by type of prevention facility."

3.1.2. Chemical treatment

The treatment efficiency of the prevention facility can be separated physically, chemically, or biologically, and if the treatment of pollutants goes through a chemical reaction, it can be expressed as 0th, 1st, 2nd, and nth-order reactions depending on the reaction path. However, in actual air pollution prevention facilities, there are facilities where the treatment efficiency does not change with the reaction time, so it is difficult to calculate the treatment efficiency of all prevention facilities using a chemical reaction formula. Here, we will examine how the treatment efficiency can change according to the change in the inlet concentration and flow rate of pollutants in the case of prevention facilities that apply the chemical treatment principle. The chemical reaction in the air pollution prevention facility can generally have characteristics similar to the PFR (Plug Flow Reactor) method. The PFR method assumes that the fluid flows consistently during the residence time in the reactor, and the concentration gradually decreases according to the reaction. In other words, it assumes that the gas flow moves evenly in a laminar state. Representative PFR prevention facilities include absorption facilities, cleaning-type dust collection facilities, and oxidation reactors. However, most prevention facilities are designed to expand the gas passage area at the entrance of the prevention facility to secure sufficient reaction time to improve treatment efficiency, so they cannot be said to be completely compatible with the PFR method. Nevertheless, this study assumes that the PFR method is suitable for understanding the pollutant treatment efficiency in prevention facilities as a chemical reaction method, and calculates the treatment efficiency by the PFR method according to the reaction order.

(1) 0th order reaction: A 0th order reaction is a reaction in which the reaction rate is not affected by the concentration of the reactant, and the reaction rate of the pollutant introduced per unit time remains constant, so the reaction rate does not change even if the concentration of the reactant decreases. This can be expressed as a formula as shown in Equation (2).

$$\frac{dC}{dt} = -k \quad (2)$$

$$C_{\text{out}} = C_{\text{in}} - k \cdot \frac{V}{Q} \quad (3)$$

That is, when the flow rate (Q) increases, the residence time in the prevention facility (t = V/Q) decreases and the pollutant emission concentration (C_{out}) increases. Conversely, when the flow rate (Q) decreases, the residence time in the prevention facility increases and the pollutant emission concentration (C_{out}) decreases.

In the case where pollutants flow into the prevention facility at the same rate as unpolluted air in the zero-order reaction, the air dilution effect was calculated. That is, when air dilution occurs where the inflow rate doubles and the inflow concentration decreases by half, the air dilution effect is calculated as in Equations (4) and (5).

$$Q' = 2Q \quad (4)$$

$$C'_{\text{in}} = \frac{C_{\text{in}}}{2} \quad (5)$$

The flow rate after air dilution is twice that before air dilution, and the inlet concentration is twice that after air dilution.

The reaction time after air dilution is half that before air dilution, as in Equation (6).

$$\tau' = \frac{V}{Q'} = \frac{V}{2Q} = \frac{\tau}{2} \quad (6)$$

The reaction equations after air dilution are organized as Equations (7), (8), (9), and (10).

$$C_{\text{out}} = C_{\text{in}} - k\tau \quad (7)$$

$$C'_{\text{out}} = C'_{\text{in}} - k\tau' \quad (8)$$

$$= \frac{C_{\text{in}}}{2} - k \cdot \frac{\tau}{2} \quad (9)$$

$$= \frac{C_{\text{in}}}{2} - \frac{k\tau}{2} \quad (10)$$

Therefore, as in Equation (11), the concentration of pollutants at the exhaust port after air dilution is discharged at a concentration reduced by 50%, the same as the air dilution effect.

$$C'_{\text{out}} = \frac{1}{2}\left(C_{\text{in}} - k\tau\right) = \frac{1}{2}C_{\text{out}} \quad (11)$$

That is, the air dilution effect occurs accurately.

(2) First-order reaction: A reaction in which the reaction rate is proportional to the concentration of the reactants. In other words, the reaction rate is expressed as a first-order function of the concentration of the reactants.

$$\frac{dC}{dt} = -kC \quad (12)$$

since

$$C_{\text{out}} = C_{\text{in}} e^{-kV/Q} \quad (13)$$

In the first-order reaction, when the flow rate (Q) increases, the residence time in the prevention facility (t = V/Q) decreases and the pollutant emission concentration (C_{out}) increases. Conversely, when the flow rate (Q) decreases, the residence time in the prevention facility increases and the pollutant emission concentration (C_{out}) decreases.

In the first reaction, the air dilution effect was calculated when pollutants flow into the prevention facility at the same rate as unpolluted air. That is, when air dilution occurs in which the inflow rate doubles and the inflow concentration decreases by half, the air dilution effect is calculated as in Equations (14), (15), (16), (17), (18), (19), (20), and (21).

$$Q' = 2Q \quad (14)$$

$$C'_{\text{in}} = \frac{C_{\text{in}}}{2} \quad (15)$$

As in Equations (14) and (15), the flow rate introduced into the prevention facility after air dilution was calculated as twice the flow rate before air dilution, and the concentration introduced into the prevention facility was calculated as twice lower after air dilution.

$$\tau' = \frac{V}{Q'} = \frac{V}{2Q} = \frac{\tau}{2} \quad (16)$$

$$C_{\text{out}} = C_{\text{in}} e^{-k\tau} \quad (17)$$

$$C'_{\text{out}} = C'_{\text{in}} e^{-k\tau'} \quad (18)$$

$$= \left(\frac{C_{\text{in}}}{2}\right) e^{-k\frac{\tau}{2}} \quad (19)$$

$$= \frac{C_{\text{in}}}{2} e^{-k\tau/2} \quad (20)$$

$$\frac{C'_{\text{out}}}{C_{\text{out}}} = \frac{\frac{C_{\text{in}}}{2} e^{-k\tau/2}}{C_{\text{in}} e^{-k\tau}} = \frac{1}{2} e^{k\tau/2} \quad (21)$$

According to the calculation, the concentration of pollutants emitted from the prevention facility after air dilution $\frac{1}{2}e^{k\tau/2}$ increases by times that of the state without air dilution. Excluding the air dilution effect of 1/2, an exponential increase effect occurs, so that an additional $e^{k\tau/2}$ pollutant removal effect of times occurs after air dilution. Therefore, $k\tau$ if this is 0.1 or more, the effect of increased flow rate becomes greater, and the emission concentration increases when there is air dilution compared to the emission concentration when there is no air dilution. If $k\tau \gg 1$ this becomes the case and the reaction time becomes long (when the reaction progresses a lot), the air dilution effect may be weakened and the concentration may increase compared to before air dilution.

In the first reaction, if the reaction time (residence time in the prevention facility) is short, an air dilution effect may occur, but the longer the reaction time, the smaller the air dilution effect.

(3) Second-order reaction: This refers to a reaction in which the reaction rate is proportional to the square of the concentration of the reactants or to the product of the concentrations of two reactants. In this study, reactions in which the reaction rate is proportional to the square of the concentration of the reactants were applied as in Equations (22) and (23).

$$\frac{dC}{dt} = -kC^2 \tag{22}$$

$$\frac{1}{C} = \frac{1}{C_0} + kt \tag{23}$$

A characteristic of the second-order reaction of PFR is that the half-life becomes shorter as the initial concentration increases.

$$t_{1/2} = \frac{1}{kC_0} \tag{24}$$

That is, the higher the concentration, the faster the reaction proceeds.

When the secondary reaction rate (Q) increases, the residence time in the prevention facility (t = V/Q) decreases and the pollutant emission concentration (C_{out}) increases. Conversely, when the flow rate (Q) decreases, the residence time in the prevention facility increases and the pollutant emission concentration (C_{out}) decreases.

In the case where the pollutants flow into the prevention facility at the same rate as the unpolluted air in the secondary reaction, the air dilution effect was calculated. That is, when air dilution occurs where the inflow rate doubles and the inflow concentration decreases by half, the air dilution effect is calculated as in Equations (25), (26), (27), (28), (29), (30), (31), (32), (33), and (34).

$$Q' = 2Q \tag{25}$$

$$C'_{\text{in}} = \frac{C_{\text{in}}}{2} \tag{26}$$

$$\tau' = \frac{V}{Q'} = \frac{V}{2Q} = \frac{\tau}{2} \tag{27}$$

$$\frac{1}{C_{\text{out}}} = \frac{1}{C_{\text{in}}} + k\tau \tag{28}$$

$$\frac{1}{C'_{\text{out}}} = \frac{1}{C'_{\text{in}}} + k\tau' \tag{29}$$

$$= \frac{1}{\frac{C_{\text{in}}}{2}} + k \cdot \frac{\tau}{2} \tag{30}$$

$$= \frac{2}{C_{\text{in}}} + \frac{k\tau}{2} \tag{31}$$

$$= 2\left(\frac{1}{C_{\text{in}}} + \frac{k\tau}{4}\right) \tag{32}$$

$$= 2 \cdot \frac{1}{4}\left(\frac{4}{C_{\text{in}}} + k\tau\right) \tag{33}$$

$$= \frac{2}{C_{\text{out}}} + \frac{k\tau}{2} \tag{34}$$

Therefore, if we compare when there is air dilution and when there is no air dilution,

$$\frac{C'_{\text{out}}}{C_{\text{out}}} = \frac{\frac{1}{\frac{2}{C_{\text{in}}} + \frac{k\tau}{2}}}{\frac{1}{\frac{1}{C_{\text{in}}} + k\tau}} \tag{35}$$

$$= \frac{2 + 2\,C_{\text{in}}\,k\tau}{4 + C_{\text{in}}\,k\tau} \tag{36}$$

In the second reaction, when comparing the half-life and equation (36), the discharge concentration is lowered more significantly by a decrease in the inflow concentration than by an increase in the inflow rate.

In other words, the lower the concentration entering the prevention facility, the higher the emission concentration is than the effect of air dilution, so it is difficult to expect the expected air dilution effect because the expected emission concentration due to air dilution is high. In addition, the higher the concentration of pollutants entering the prevention facility, the lower the concentration of exhaust gas is than the effect of air dilution, so there is no need to dilute the concentration of pollutants entering the prevention facility in an attempt to forcibly achieve the air dilution effect.

So far, when the flow rate into the prevention facility is doubled and the concentration of pollutants is doubled, the emission concentration of pollutants after passing through the prevention facility has been calculated assuming that the 0th, 1st, and 2nd chemical reactions occur in the prevention facility. As a result, in each of the 0th, 1st, and 2nd reactions, when the amount of air flowing into the prevention facility increases, an air dilution effect exists in the prevention facility. However, the case where the air dilution effect occurs precisely depending on the amount of air flowing into the prevention facility and the inflow concentration is limited to the 0th reaction. The 1st reaction reacts sensitively to the reaction time of the inflowing pollutants, and the 2nd reaction reacts sensitively to the concentration of the inflowing pollutants. That is, in the case of the 1st and 2nd reactions, the expected concentration may be emitted at a lower or higher concentration than the expected concentration due to air dilution depending on the reaction time or inflow concentration.

3.2. Theoretical Air Dilution Effect by Type of Prevention Facility

The air dilution effect when the amount of air flowing into the prevention facility increases was confirmed by using the equation for calculating the treatment efficiency of pollutants used when designing the prevention facility by type of representative prevention facility.

3.2.1. Gravity dust collector

The treatment efficiency of a gravity dust collector can be expressed by equations (37), (38), and (39). Assuming that all facility and environmental conditions are the same and that there are only changes in the flow rate and concentration flowing into the prevention facility, the treatment efficiency of a gravity dust collector varies depending on the gas flow rate (U). That is, when the gas flow rate increases, the dust treatment efficiency decreases, and when the flow rate increases beyond the design limit, the concentration of the emitted dust may increase rapidly. Therefore, in a gravity dust collector, the air dilution effect of dust exists to some extent when the flow rate is low, and as the flow rate increases, the air dilution effect decreases. However, when the flow rate increases beyond a certain level, the air dilution effect disappears and the emission concentration of pollutants in the exhaust gas may increase.

$$\eta = \frac{v_s \cdot t}{H} \quad (37)$$

$$v_s = \frac{g(\rho_p - \rho_f)d_p^2}{18\mu} \quad (38)$$

$$t = \frac{L}{U} \quad (39)$$

3.2.2. Inertial force dust collector

The treatment efficiency of an inertial force dust collector can be expressed by equations (40), (41), and (42). Assuming that all conditions such as facilities and environments are the same and that there are only changes in the flow rate and concentration flowing into the prevention facility, the treatment efficiency of an inertial force dust collector increases with the gas flow rate (U). That is, when the gas flow rate increases, the dust treatment efficiency increases, and except when the flow rate increases beyond the design limit, the concentration of the emitted dust decreases as the flow rate increases. Therefore, the air dilution effect of the dust in the inertial force dust collector is greater than the amount or ratio of the air dilution, thereby lowering the emission concentration of pollutants.

$$\eta = 1 - e^{-K} \quad (40)$$

$$K = C \cdot Stk^n \quad (41)$$

C, n are experimental constants

$$Stk = \frac{\rho_p d_p^2 U}{18\mu D} \quad (42)$$

D: Length of channel or material [m]

3.2.3. Centrifugal dust collection facility

The treatment efficiency of a centrifugal dust collector can be expressed by equations (43) and (44). Assuming that all conditions such as facilities and environments are the same and that there are only changes in the flow rate and concentration flowing into the prevention facility, the treatment efficiency of a centrifugal dust collector increases with the gas flow rate (U). That is, when the gas flow rate increases, the dust treatment efficiency increases, and except when the flow rate increases beyond the design limit, the concentration of the emitted dust decreases as the flow rate increases. Therefore, the air dilution effect of a centrifugal dust collector is greater than the amount or ratio of air dilution, thereby lowering the emission concentration of pollutants.

$$\eta = 1 - e^{-K} \quad (43)$$

$$K = \frac{3CQ}{\pi d_c^3 V_t} \quad (44)$$

C: coefficient determined experimentally
Q: Gas flow rate [m^3/s]
d_c: cyclone diameter [m]

In addition, the removal efficiency for the partial collection rate by particle diameter can be expressed by Equation (45). Even when calculated by Equation (45), the partial collection rate of particles also increases in proportion to the treatment flow rate.

$$\eta = \frac{d^{2} * \pi * V * (\rho s - \rho) * N}{9 * \mu * B} * 100(\%) \quad (45)$$

Therefore, when air dilution occurs in a centrifugal dust collection facility, it was calculated that a much smaller amount of dust would be emitted than the expected dust emission concentration in proportion to the amount of air dilution.

3.2.4. Facilities for dust collection and absorption

Scrubber-type dust collectors and absorption-type dust collectors are collectively called Wet Scrubbers in Korea, but they are called differently depending on the type of pollutant they are intended to treat. Scrubber-type dust collectors are dust collectors targeting dust, while absorption-type dust collectors are preventive facilities used to treat not only dust but also gaseous pollutants. The treatment efficiency of scrubbers applies various methods based on the contact between gas and liquid, and can be divided into spray towers, venturi scrubbers, packed tower scrubbers, and centrifugal scrubbers depending on the shape and contact method. In addition, the treatment efficiency can also be corrected with experimental and environmental data depending on the type of pollutant to be treated. Although there are differences in the method of calculating the treatment efficiency depending on the treatment method and principle of each type of scrubber, in this study, we will study the treatment efficiency of pollutants by collectively calling them Wet Scrubbers. Chat GPT Search Results If the scrubber is operated under normal operating conditions and multiple operations are in the same state, the experimental treatment efficiency calculation formula, such as Equation (46), can be applied or the pollutant treatment efficiency of the scrubber can be calculated as in Equations (47) and (48).

$$\eta = \left(\frac{C_{\text{in}} - C_{\text{out}}}{C_{\text{in}}} \right) \times 100 \quad (46)$$

In Chat GPT, the equation (48) is recommended as a calculation formula for the treatment efficiency of pollutants by applying the collision theory of water bubbles to the treatment efficiency of pollutants in the scrubber.

$$\eta = 1 - e^{\left(-\frac{KV}{Q}\right)} \quad (47)$$

K: Washing coefficient [m/s], particle and droplet Coefficient indicating collision

V: Volume in contact with the cleaning solution

In addition, in actual field, the empirical formulas (Colburn & Hougen formula) of equations (48) and (49) were recommended for the pollutant treatment efficiency of the scrubber.

$$\eta = 1 - e^{-N} \quad (48)$$

$$N = \frac{AV_g}{Q} \quad (49)$$

V: Gas velocity [m/s]

Both the calculation formula using the collision theory of the water droplet and the Colburn & Hougen formula show that as the gas flow rate increases, the treatment efficiency of the prevention facility increases. Of course, as the concentration of pollutants increases, the cleaning coefficient (K) related to the treatment efficiency is also expected to increase, but it is interpreted that the effect of the gas flow rate on the treatment efficiency is greater and has a direct effect. Therefore, the effect of air dilution in the scrubber exists, and when the air is diluted, that is, as the flow rate increases, the concentration of pollutants at the outlet of the prevention facility decreases more than the expected concentration of pollutants at the diluted ratio.

3.2.5. Filtration and dust collection facility

The air dilution effect of the filtering and collection facility is summarized in Table 1 as an example of a business that was actually punished for air dilution. This business was operating an 850 ㎥ /nin filtering and collection facility, but installed a factory floor cleaning hood that was not reported as an emission facility to clean dust from the factory floor, and used it to suck up dust that fell on the factory floor, and was caught for air dilution by the administrative agency.

Table 1: Air dilution effect of filtration and dust collection facilities

division	Normal operation	For floor cleaning Use of Hood (air dilution)
Wind power [㎥/min]	349.31	559.9
Measurement value [㎎/S ㎥]	0.3	1.4
※ 1. Emission standard 30 mg/S ㎥ 2. Other conditions are the same		

When testing the air dilution effect of the facility corresponding to Table 1, the facility was operated with the floor cleaning damper opened or closed, and no actual floor dust was inhaled. It was operated with no other changes made. As shown in Table 1 above, it is true that the air volume increases when the floor cleaning hood is operated, but the pollutant emission concentration also increases more significantly.

The dust treatment efficiency of a filtering facility is expressed by a general formula as in Equation (50).

$$\eta = \left(\frac{C_{\text{in}} - C_{\text{out}}}{C_{\text{in}}} \right) \times 100 \quad (50)$$

In addition, the processing efficiency of individual particles can be calculated as in Equations (51) and (52), which show that the processing efficiency increases as the filter area increases and the gas velocity decreases.

$$\eta_p = 1 - e^{-J} \quad (51)$$

$$J = \frac{A \cdot V}{Q} \tag{52}$$

V: Particle residence time or collision probability

As shown in Table 1 and Equation (51), the air dilution effect on dust in a filter collection facility is that as the flow rate increases, the concentration of pollutants at the outlet of the prevention facility decreases more than the expected concentration of pollutants at the diluted ratio.

3.2.6. Electric precipitator

The dust treatment efficiency of an electric precipitator is expressed by Equation (53).

$$\eta = 1 - e^{\left(-\frac{A \cdot W}{Q}\right)} \tag{53}$$

The air dilution effect of the electrostatic precipitator on dust is such that as the flow rate increases, the concentration of pollutants at the outlet of the prevention facility decreases more than the expected concentration of pollutants at the diluted rate, as shown in Equation (53).

3.2.7. Facilities by adsorption

The calculation of the facility's pollutant treatment efficiency by adsorption is expressed by a general empirical formula as in Equation (54).

$$\eta = \left(\frac{C_{\text{in}} - C_{\text{out}}}{C_{\text{in}}}\right) \times 100 \tag{54}$$

In the case of facilities using adsorption, there is no requirement to design the height of the packing layer to prevent flooding phenomenon like in the case of a packed scrubber. Only the appropriate flow rate and the thickness of the adsorption layer are standardized. Therefore, unlike other prevention facilities, the adsorption tower is expected to be more affected by other design factors such as Equation (55) than by the flow rate, flow rate, or concentration of pollutants.

$$q = \frac{V \cdot (C_{\text{in}} - C_{\text{out}})}{m_{\text{ads}}} \tag{55}$$

However, the results from Chat GPT suggest that the flow rate is a more important variable than the concentration of pollutants. The reason why the flow rate is important is that when the flow rate increases, the contact time with the adsorbent shortens proportionally to the flow rate due to the thickness of the activated carbon layer with limited capacity.

Variables to consider in practical application

Adsorbent type : Activated carbon, zeolite, etc.
Adsorption temperature and humidity : Adsorption efficiency may decrease as temperature rises
Air flow rate : If it is too high, the contact time will be short and efficiency will decrease.
Saturation : Efficiency decreases when the adsorbent becomes saturated

Figure 10: Variables to consider when actually applying the processing efficiency of adsorption detection (ChatGPT search results)

4. Research Results and Discussion

4.1. Air Dilution Research Results

It has been theoretically proven that, depending on the type of prevention facility or the treatment principle, if uncontaminated air is mixed in with pollutants, the pollutant emission concentration may be lower than the concentration calculated by the dilution rate even when the dilution effect is taken into account, but it may also increase. If the capacity of the prevention facility is designed to match the maximum fan airflow when the maximum airflow of the exhaust fan is set, it will be difficult to conclude that the air dilution effect occurs because uncontaminated air is introduced in front of the prevention facility. In order to confirm the air dilution effect under such circumstances, more detailed experiments and analyses will be needed to investigate how the air dilution effect varies depending on the type of pollutant or prevention facility, airflow, and the concentration of air pollutants. In addition, if the pollutant treatment efficiency is more sensitive to the inflow concentration than the air dilution after the pollutant is treated in the prevention facility or the airflow increases in some prevention facilities, the pollutant emission concentration at the outlet will decrease.

4.2. Impact of Air Dilution on the Environment

The main purpose of prohibiting air dilution is to artificially lower the concentration of pollutants emitted or to prevent the emission of untreated pollutants. In other words, it can be said that the purpose is to prevent acts that may be harmful to the environment or to hide acts that may cause harm.

If air dilution occurs without a prevention facility, the concentration of pollutants emitted will be low, making it seem as if there is no harm to the environment, so prohibiting air dilution seems reasonable for its purpose. However, as seen in the theoretical air dilution effect by prevention facility above, there are prevention facilities where pollutants can be reduced through air dilution, but pollutants can actually increase in concentration. This is because treatment efficiency can decrease when the wind speed increases in the prevention facility. In this way, in some prevention facilities, the concentration of pollutants can actually increase when air dilution occurs, and in that case, the operators of the emission facility and prevention facility will not benefit but suffer losses, and it will not be advantageous in terms of environmental management. In cases where the concentration of pollutants increases in prevention facilities due to air dilution, it would be much more effective to provide technical support or information to prevent air dilution rather than punishing them for air dilution. This is because there is no reason for operators to artificially engage in acts that cause losses. On the other hand, if the emission concentration of pollutants is reduced more than the air dilution effect in some prevention facilities, it will be necessary to review whether air dilution is subject to punishment. The purpose of installing prevention facilities is to treat pollutants and reduce the amount of pollutants discharged into the environment, so if air dilution has the effect of increasing prevention facilities, encouragement should be given priority over punishment.

In this way, when ① the emission concentration of pollutants increases due to air dilution compared to when there is no air dilution, and ② the emission concentration of pollutants from the prevention facility decreases by a greater amount than the effect of air dilution, the purpose of prohibiting air dilution is different and a different response method must be used. In the case of punishment by air dilution, which is stipulated to be very high punishment such as “imprisonment for not more than 7 years or a fine not exceeding 100 million won,” it probably means that the emission concentration of pollutants from the prevention facility is limited to the amount of the effect of air dilution.

4.3. Court Interpretation of Air Dilution

Supreme Court 2014.9.26.. Decision 2014do9030 and subsequent 2019.5.22. The judgment of the 3rd Criminal Division of Changwon District Court (2018 No. 2668) states that “since the burden of proof for the facts constituting the elements of the crime for which the indictment was filed in a criminal trial lies with the prosecutor, the prosecutor must prove that the business operator had the awareness of ‘reducing the level of pollution’, and such proof must be through strict proof that creates a certain level of certainty that leaves the judge without any room for reasonable doubt, and if such proof is not available, it cannot help but be judged in favor of the defendant.” This judgment means that there must be evidence that there was an intention to mix air with air pollutants or a purpose to reduce the level of pollution. In order to apply the violation of the ban on air dilution, the administrative agency or prosecutor must prove that there is a significant relationship between the air dilution device or facility and the pollution reduction effect, so even if some air is introduced to the pollutants, evidence will also be needed of how much the concentration of the pollutants is reduced. If the pollutants are normally emitted at a concentration far below the permissible emission standard, it would be difficult to see that there was an intention to mix air with the pollutants and emit them using an air dilution device. Therefore, Administrative agencies and prosecutors have the burden of proof to determine whether there is a purpose to reduce pollution levels through air dilution, as indirect or circumstantial facts, and in the absence of such proof of criminal homicide, they will say that air dilution cannot be applied.

In addition, since the ruling of the 3rd Criminal Division of Changwon District Court on May 22, 2019 (2018 No. 2668), most court rulings on air dilution have shown the same results.

4.4. Considerations

There are some differences among scholars on how to understand the basic principles of environmental law, but generally speaking, the three principles of environmental protection are the principle of ① precautionary care, ② principle of causal responsibility, and ③ principle of cooperation, according to the organization of the environmental report submitted by the German government in 1976. Recently, it is common to add the principle of ④ sustainable development to these. Here, the concepts of precautionary care and precautionary prevention need to be distinguished. While precautionary care refers to potential risks, precautionary care refers to confirmed risks. In comparison, the principle of precautionary care has a more active and formal meaning than the principle of prevention, and is sometimes specified in the form of environmental regulation legislation. The fact that air dilution is prohibited by law based on these principles of environmental law has academically sound grounds. However, despite the theoretical basis for applying the principle of precautionary care, when considering the court's judgment on air dilution, there is still a large gap between the legal interpretation of air dilution based on the current inspection method of administrative agencies and the understanding in industrial sites. Therefore, in order to achieve the task of environmental conservation, the principle of cooperation, which requires that the state, local governments, businesses, and society including the public cooperate in the decision-making and decision-making process, should be applied more broadly. To this end, it seems necessary to clearly establish application standards through communication with business owners, who are the direct stakeholders, for areas where the application of the law is ambiguous.

5. Conclusion

As the research results show, when an administrative agency intends to punish for violation of the ban on air dilution, the purpose and specific evidence of air dilution must be provided by the administrative agency or prosecutor. However, reflecting this court ruling, it is difficult to confirm the regulations or rules established by the administrative agency regarding air dilution, and even if they exist, it is very difficult for the general public to find them.

All laws, including environmental regulations, will be the result of reflecting the recognition of the need for appropriate regulation at the time the relevant laws were enacted or revised, and there will naturally be a corresponding legitimacy. In particular, there is a clear reason to still prohibit air dilution, which artificially introduces clean air that is not contaminated with the pollutants being emitted, thereby lowering the concentration of the pollutants being emitted, and thus actually aggravating environmental pollution, contrary to the purpose of the enactment of the ban on air dilution, which is to install and operate appropriate prevention facilities to ensure that pollutants are emitted in compliance with the emission standards.

As time goes by, the surrounding environment, the objects to be protected, and the interests of citizens change, excessive regulations should be revised or supplemented to reflect the phenomenon of the times. Considering the size of the punishment for violations and the impact on the business, if the situations, forms, conditions, and guidance inspection procedures that may be considered air dilution are stipulated by broad social consensus, it will be clear that the purpose of the legislation will be achieved and the law will be much more advantageous in achieving its value as a means of environmental protection.

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