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Unit-based SO_x emission values for fuels consumed in precast concrete production

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ABSTRACT: With the rise of acid rain issue as one of the largest environmental problems in the past few years, it is time to consider the SO_x emission being one of its major contributors in the emission inventory. By providing an up-to-date and more accurate inventory data, it is hoped that it can be used to support the environmental load reduction in the future. In the case of fuel combustion, the sulfur content is the only parameter that has a direct influence on the level of SO_x emission. By analyzing the sulfur contents according to Japan's present regulations, this paper will focus on determining the unit-based SO_x emission values of light oil and LPG as they are normally used nowadays as fuel in steam curing process in precast concrete production. It was found that unit-based SO_x emission values for light oil and LPG are 0.0174 g/liter and 0.1013 g/kg, respectively.

Keywords: Unit-based SO_x Emission Value, Precast Concrete, Fuel Combustion, Steam Curing, Diesel, LPG

1 INTRODUCTION

Acid rain is one of the largest environmental problems affecting the world so far. It is a broad term used to describe the acids which fall out of the atmosphere, either by wet or dry deposition. Acidic rain, snow, fog and mist are some forms of the wet deposition while acidic gases and particles are referring to dry deposition. Acid rain will affect and destroy a variety of plants, animal and things such as buildings, sculptures, cars, etc. as they can flow over and through the ground as well as easily scattered by wind. It has been known that the acid rain can be formed as results from both natural sources such as volcanoes, and man-made sources, primarily from the emissions of sulfur dioxide (SO_2) and nitrogen oxide (NO_x) generated from fossil fuel combustion. In 1990, the annual worldwide emission of sulphur produced by man was estimated at just over 70 million tonnes (Elvingson, P. and Ågren, C. 2004). This number is increasing, mainly due to the increased use of fossil fuels in some countries with rapid industrial expansion. It is expected that the current emissions will be double in few decades if no countermeasures are taken.

In precast concrete production, steam curing is normally used to accelerate the rate of strength gain and to provide additional heat and moisture to concrete in order to accomplish hydration, as in cold weather. A proper curing will affect the durability, strength, water tightness, abrasion resistance, volume stability and resistance to freezing and thawing of concrete in a good way. However, this curing method also has some disadvantages and one of them is its environmental impact. Steam curing method contributes a significant amount of emissions as a result of fuel consumption such as oil and gas for operating the steam-curing boilers. Focusing only on sulfur oxide (SO_x) emission from fuel combustion, it is generated in the forms of sulfur dioxide (SO_2) and sulfur trioxide (SO_3). Typically, about 95% of the sulfur in the fuel will be emitted as SO_2, 1–5% as SO_3 and 1–3% as sulfate particulate (Jaber 2006 & CCSD 2009). Nevertheless, sulfate particulate is not considered part of the total SO_x emissions but as part of particulate matter (PM) emissions. In this study, the unit-based values of SO_x emission for light oil and liquefied petroleum gas (LPG) will be determined by analyzing the sulfur (S) content of each type of fuel, converting it into the form of SO_2 and SO_3 and adding them as total SO_x emission.

2 OBJECTIVES AND SCOPE OF STUDY

Estimating the level of emissions is an important element of the efforts to promote the reduction of environmental load in concrete industry in the future. For this reason, in Japan, emission inventory has been prepared in recent years not only for carbon dioxide (CO_2) as one of the greenhouse gases (GHG), but also for acidifying substances such as NO_x and SO_2 in the form of SO_x. Along with those three, PM has also been taken into account in developing the inventory for its huge impact to the environment.

Emission inventory is defined as listing, by source, of the amounts of emissions actually or potentially discharged into the atmosphere of a community during a given time period (US EPA 2011). It normally consists of few aspects such as source or cause of the emission, details on each type of pollutant, coverage area, the period of estimation, and methodology used in determining the amount of emission. Emission inventory is developed for a variety of reasons, such as for scientific purpose, strategy development, policy and regulation making, and for general knowledge/information to the public.

Up to the present moment, the emission inventory data can be classified into six groups, i.e. energy, transportation, construction material, construction work/equipment, demolition work/equipment, and disposal and recycling with 48 detail items in total and 139 parameters included on them (JSCE 2004 & Kawai et. al. 2005). Initially, this emission inventory was developed specifically for infrastructure works that were very much done in Japan for a few last decades. However, the present inventory has been able to be used and further developed for any kind of works generally performed in the construction industry.

The term of unit-based emission value which is used in the emission inventory is defined as the average amount of a specific pollutant discharged into the atmosphere by a specific parameter such as fuel, equipment, process, or sources. It is expressed as number of grams (or kilograms) of emission per unit of the certain parameter. Although it is not completely done, the present inventory data collection has revealed most of the unit-based emission values for CO_2, SO_x, NO_x, and PM on each parameter. The efforts to fill up the rest and adding some other items and parameters for future use are still in progress.

So far, only unit-based CO_2 emission values from the use of fuels such as light oil, liquefied petroleum gas (LPG) and natural gas have been determined and used in calculating the environmental impact of concrete industry in Japan. With the facts that the emissions resulting from fuel usage have almost reached a quarter of total emission from all sources, it urges the need to determine the unit-based emission values for other types of emissions.

As one way to respond to the problem, this study aims to determine the unit-based values of SO_x emission for various types of fuel used in operating the steam-curing boiler, regardless of the emission generated from the mining activity. Furthermore, this unit-based emission value can subsequently be used to determine the total amount of SO_x emission in the specific area and time span based on the intensity of relevant activity. For long-term use, not only will the values be used as a basis for evaluating the environmental impact from fuel combustion in general cases, it will also help promoting the reduction of environmental load by knowing and choosing the type of fuel with low SO_x emission for various uses in all sectors. Light oil, LPG and natural gas will be discussed in detail in this paper considering the fact that these fuel types are commonly used nowadays throughout the world.

3 FUEL TYPES AND THE SULFUR CONTENTS

SO_x are considered as a pollutant because they react with water vapor and thus form sulfuric acid mist which is extremely corrosive and harmful to the environment. According to some references, the level of SO_x emissions from fuel combustion depends directly only on the sulfur content of the fuel (CCSD 2009).

The term of "light oil" in Japan is referred to diesel for English speakers. According to US classification, it can be included as No. 1 and No. 2 diesel fuel, but for general purpose in diesel engines it is more likely to be similar with the latter one. Japanese Industrial Standard – JIS K2204:2007 classifies the specification for light oil in Japan with the maximum sulfur content of 0.0010 % (by mass).

LPG has been used most likely to cover the disadvantages of natural gas. It has been known that natural gas is very popular used in the combustion process. Not only because of the high heating value, but looking at the situation right now with global warming, acid rain, etc. it also burns cleaner than the other fossil fuels such as coal and oil due to the highly efficient combustion process. This means natural gas produces very few by-products that are released into the atmosphere as pollutants. In fact, natural gas generates no SO_x emissions (OECD & IEA 2010). Other advantages such as relatively inexpensive cost when compared to coal, non-toxic and non poisonous to humans if inhaled in small volumes add the reasons why natural gas is a great alternative to reduce the environmental impact from this industry. However, major difficulties in transportation and storage of natural gas due to its low density have lead to the use of LPG at present time.

The main advantage of LPG products results from the fact that they can be stored in liquid state and used in gaseous state. Due to this reason, LPG is relatively more economical than natural gas. LPG also has some more advantages such as clean burning, meaning that it does not produce so much pollution, higher heat generation, stable, variety of its applications, etc. As stated in Japanese Industrial Standard – JIS K2240, the maximum sulfur content of LPG which is allowed in Japan is less than 0.005 % (by mass).

4 CALCULATION PROCEDURE

The unit-based SO_x emission value of each fuel type can be determined by using the data of sulfur content as mentioned earlier according to the following procedure. First, the amount of SO_2 and SO_3 per gram S based on their molecular weight (S = 32 and O = 16) is calculated. As a result, 1 g of S can be converted into

2 g of SO_2 and 2.5 g of SO_3. Next step, the amount of SO_2 and SO_3 produced from combustion process in curing activity is calculated based on the sulfur content of each fuel type. Unit adjustments and some assumptions regarding the density and the amount of energy produced per unit of each fuel type were made in this stage. The unit-based SO_x emission value is calculated by adding 95 % of SO_2 and 5 % of SO_3 generated per unit of each fuel type. As for comparison, the unit-based SO_x emission value of each fuel type has to be represented into the same unit of energy (MJ) produced by each type of fuel.

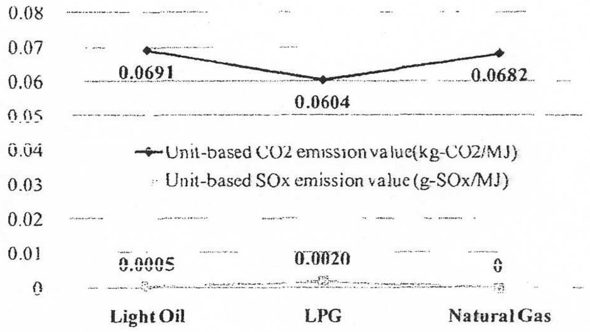


Figure 1. Unit-based CO_2 and SO_x emission values for different fuel types.

5 ANALYSIS AND DISCUSSION

5.1 *Unit-based SO_x emission value in Japan*

Following the procedures as stated earlier, the results show that light oil generates 0.0174 g of SO_x emission per liter and LPG generates 0.1013 g of SO_x emission per kg. In other words, 0.0020 g of SO_x emission is generated by LPG, and only 0.0005 g is generated by light oil in producing the same amount of energy (MJ).

According to *Assessment for Environmental Impact of Concrete: Part 2* (JSCE 2004), light oil, LPG and natural gas produce 2.64 kg/liter, 2.79 kg/Nm^3 and 3.03 kg/kg of CO_2 emission, respectively. In order to be able to make a comparison, these values were converted into the same unit for producing the same amount of energy (kg/MJ). The results of CO_2 and SO_x emissions which were generated by each type of fuel are shown in Figure 1. It can be seen that the pattern of both results shows a little difference where in the case of CO_2 emission, LPG was the fuel that produced the least emission from its combustion while in the case of SO_x emission, natural gas was the one which produced no SO_x emission.

Although as a common knowledge it has been known that LPG naturally emits less environmental impacts compared to oil and coal, the results above show a contradiction. In Figure 1, it shows that LPG generates SO_x emission 4 times greater than light oil although it still produces less CO_2 emission. The sulfur content on each fuel type is the only reason that underlies this phenomenon. In this case, the limits on sulfur content which have been considered in the calculation for fuel combustion in steam-curing boiler were the ones applied only on off-road and/or stationary engines based on the classification and definition in force in Japan at this moment. In other words, different results likely would be obtained if the calculation is done using different numbers prevailing in other countries. It should be noted that not all countries have a clear regulation on this matter and in fact, for some cases there are several regulations applied in one country that sometimes create ambiguous results in the calculation of its environmental impact. In addition, the classification and the definition of the use of fuels may also contribute to the difference in the results of the calculation of the environmental impact in one country to the others.

5.2 *Calculation of SO_x emission in real cases*

For further discussion about SO_x emission, investigations were conducted to some selected precast concrete plants around Chugoku area to illustrate the variety of plants in Japan. The types of plant can be classified by its product, i.e. popular product, large-sized product and small-sized product. 12 plants were chosen as case studies in which 3 of them were producing the small-sized products and the rests which divided almost equally were producing popular and large-sized products.

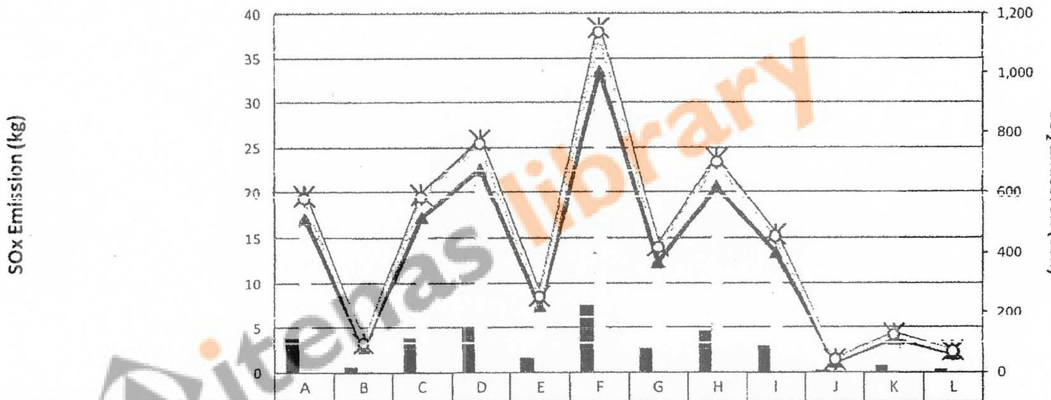
Popular product is described as a product that normally used in infrastructure work in Japan, such as the hollow block pipe, drainage products, and the boundary block to separate footpath and traffic lane. A big size and/or heavy weight product such as culvert slab and special product is classified into large-sized product. As for small-sized product, it is described as product that can easily be carried like the one that is usually sold at a home centre such as small drainage block, gardening block, etc.

This section will show the procedure of determining the amount of SO_x emissions generated in these case studies. Table 1 shows the amount of concrete production and fuel used for operating steam-curing boiler on each plant in a year. From the observations, it has been found that all plants in this study were using heavy oil (type A) as the fuel for their steam-curing boiler. For further comparison, Table 1 also shows the conversion of the amount of other fuel types such as light oil and LPG as if they are used as replacement of heavy oil to produce the same amount of energy. Furthermore, the amount of SO_x emissions per year from the use of those types of fuels were determined using unit-based emission values approach. Figure 2 shows the comparison of the patterns of CO_2 and SO_x emissions using light oil, LPG and natural gas on each plant.

The line graphs show the total emissions of CO_2 while the bar graphs indicate the amount of SO_x emissions produced on each plant within one year of production. It can be seen that the SO_x emissions generated by three types of plants are in fluctuant results. The results from large-sized product plants (F, G, H and I) and popular plants (A, B, C, D and E) show a noticeable difference compared with the ones from

Table 1. Details of each plant per year production.

No.	Plant	Amount of Production (t)	Amount of heavy oil A (ltr)*1	Amount of light oil (ltr)*2	Amount of LPG (kg)*3
Popular Product Plant					
1	A	46,346.0	216,758	221,864.9	168,829.4
2	B	1,455.0	36,035	36,884.0	28,067.1
3	C	33,377.0	218,600	223,750.3	170,264.1
4	D	39,384.0	285,686	292,416.8	222,516.4
5	E	10,046.0	94,000	96,214.7	73,215.1
Large-sized Product Plant					
6	F	47,476.8	426,000	436,036.6	331,804.8
7	G	23,191.2	155,450	159,112.4	121,077.6
8	H	32,311.2	262,000	268,172.8	204,067.7
9	I	26,748.0	169,500	173,493.5	132,020.9
Small-sized Product Plant					
10	J	10,181.0	14,900	15,251.0	11,605.4
11	K	11,999.0	46,600	47,697.9	36,296.0
12	L	9,784.0	25,200	25,793.7	19,627.9



	A	B	C	D	E	F	G	H	I	J	K	L
SOx Emission - Light Oil (kg)	3.86	0.64	3.89	5.09	1.67	7.59	2.77	4.67	3.02	0.27	0.83	0.45
SOx Emission - LPG (kg)	17.10	2.84	17.25	22.54	7.42	33.61	12.27	20.67	13.37	1.18	3.68	1.99
SOx Emission - Natural Gas (kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2 Emission - Light Oil (ton)	585.72	97.37	590.70	771.98	254.01	1,151.1	420.06	707.98	458.02	40.26	125.92	68.10
CO2 Emission - LPG (ton)	511.55	85.04	515.90	674.22	221.84	1,005.3	366.87	618.33	400.02	35.16	109.98	59.47
O CO2 Emission - Natural Gas (ton)	578.14	96.11	583.05	761.99	250.72	1,136.2	414.62	698.81	452.09	39.74	124.29	67.21

*1 Energy produced per liter of heavy oil type A 39.1 MJ
*2 Energy produced per liter of light oil 38.2 MJ
*3 Energy produced per kg of LPG 50.2 MJ
*4 Energy produced per Nm^3 of natural gas 40.9 MJ

Figure 2. CO_2 emission per year (ton/year) and SO_x emission per year (kg/year) in some concrete plants in Japan using light oil, LPG and natural gas as comparison.

small-sized product plants (J, K and L). The difference can be explained by the situation where steam-curing boiler is more widely used in those both types of plants rather than in small-sized product plants, which prefer kerosene fueled-jet heater. In addition, according to the results in Figure 2, the use of other types of fuels such as light oil, LPG and also natural gas needs to be considered in these case studies for future use due to the less SO_x emission produced by these fuel types compared to that of heavy oil (type A).

According to the figure, LPG led in the production of SO_x emission, followed by light oil and natural gas but on the contrary, it generated the least CO_2 emissions while light oil produced the most. However, different patterns of CO_2 and SO_x emissions may be obtained in different situation. Although the same steam-curing boiler, fuel and even method of curing are used in the curing process, there is a possibility that the amount of emissions produced would be different. It can be influenced by the curing efficiency.

Based on the observations in several case studies, unlike in the small-sized product plants where fixed-sized chamber was used in the curing process, unfixed chamber was mostly likely to be used on the large-sized product plants as well as on popular product plants. This situation results on higher curing efficiency in small-sized product plant compared to those in other types of product plants. The energy loss produced from the flue system for providing the steam seemed to be greater in the large-sized product and popular product plants. In addition, the fact that small-sized product can be fitted into fixed-sized chamber in greater amount compared to the other two types of products in unfixed chamber may also results in higher curing efficiency. Ultimately, the amount of emissions produced would be less if the curing efficiency is greater.

6 CONCLUSIONS

1. It has been found that the unit-based SO_x emission values for light oil and LPG are 0.0174 g/liter and 0.1013 g/kg, respectively. In producing the same amount of energy (MJ), LPG generates 0.0020 g of SO_x emission and only 0.0005 g for light oil. In other words, LPG generates SO_x emission 4 times greater than light oil.
2. The patterns of CO_2 and SO_x emissions from the use of light oil, LPG and natural gas showed a contradiction result compared to those as a common knowledge. The classification and the definition of the use of fuels may also contribute to the difference in the results of the calculation of the environmental impact in one country to the others due to different limits of sulfur contents.
3. The efficiency of curing plays an important role in determining the amount of emissions. It was proven that small-sized product plants produced less emission than the other two types of plants. The less energy loss produced from the flue system in small-sized product plant using fixed-sized chamber and the greater amount of products that could be fitted in it were the factors that results in higher curing efficiency of this type of plant compared to those of large-sized product and popular product plant.
4. Limited to these case studies, the plants preferred to use heavy oil (type A) as the fuel for operating the steam-curing boiler mostly because of some factors such as cost and availability. However, these plants are so encouraged to choose other types of fuels as discussed here in this paper as alternatives to reduce the environmental load in the future.
5. The unit-based SO_x emission values can be used not only for estimating but also for evaluating the amount of SO_x emission resulting from the fuel combustion in steam curing process in any concrete production. By knowing the type of fuel with low SO_x emission, it is hoped that it will help promoting the reduction of environmental load in the future. The proper planning of emission reduction strategies can be carried out within the framework of available resources.

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