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A study on the concentration of CO by the length and the variation of the bent tube of the exhaust pipe for a household gas boiler

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Abstract

From time immemorial, there have been 3E problems of energy, economy and environment. In particular, problems of energy and environment become increasingly serious after the industrial revolution. The demand for gas as an eco-friendly energy source is also increasing. With the demand, the installation and the use of gas boilers have also increased, so the damage to human life by the waste gas (CO and CO_2) continues increasing every year. Hence, the aim of this study was to investigate the concentration of CO (Carbon Monoxide) by the length and the variation of the bent tube of the exhaust pipe by installing a boiler with the same method as a household boiler and to discover the harm to humans. For the effect of the length, the allowable concentration of CO is 50ppm, and the 3m of the once bent tube starts exceeding the allowable concentration of CO after 5 minutes, and the 4m and 5m starts exceeding after 3 minutes. In addition, the 1m of three times bent tube starts exceeding the allowable concentration of CO after 3 minutes.

Keywords: Human damage; CO Gas; Household gas boiler

1. Introduction

The technique of heating has dramatically changed with the development of industrialized society. Also, the energy source was also changed to gas for the convenience of human life style, and the status of the demand is shown in Table 1 [1]. Moreover, the installation of gas boilers increases sharply in proportion to the consumption of gas.

In this situation, the damage to human life from CO poisoning by the use of gas boilers has become quite serious.

For the last five years, accidents, their status and types for Korea, Japan and England are shown below in Tables 2 and 3 (according to the Ministry of Economy of Japan, Nuclear and industrial safety agency, the high Pressure Gas Safety Institute of Gas, Japan LPgas Association, the Japan Gas Association, Agency for Natural Resources and Energy, and British Petroleum [2-8].

During these 5 years, the accidents caused by imperfect facilities of the gas boiler have occurred as follows in Table 4.

Table 1. Energy consumption.

Section	2005	2004	2003	2002	2001
Energy Consumption	229.3	220.2	215.0	208.6	198.4
LNG	29.9	28.3	24.2	23.1	20.7
Oil (LPG)	101.5 (12.2)	100.6 (11.9)	102.4 (11.9)	102.4 (12.3)	100.4 (11.4)
Waterpower	1.33	1.46	1.72	1.33	1.04
Nuclear energy	36.69	32.67	32.41	29.77	28.03
Coal	54.79	53.12	51.11	49.09	45.71
Others	5.01	3.98	3.24	2.92	2.46

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Table 2. The present state of LPG accident (units : Ea).

Section	2005	2004	2003	2002	2001
Korea	88	82	92	84	92
Japan	99	105	120	90	87
England	174	153	116	130	161

* Data of England is sum of LPG and City gas

Table 3. Accident by CO toxicosis (units : Ea).

Section	2005	2004	2003	2002	2001
Korea	13 (62)	10 (65)	7 (84)	11 (78)	11 (86)
Japan	16 (98)	26 (129)	29 (169)	22 (125)	24 (101)
England	117 (36)	91 (34)	86 (30)	110 (43)	136 (38)

( ) : Explosion and Fire

Table 4. Boiler accidents.

Section	CO Poisoning	Explosion	Comparison (CO Poisoning/ Explosion etc)
Death Wound	43 64	- 4	- 16 times
Case number of the damage of human life	107 36	4 6	26.8 times 6 times
Damage rate for each accident	3.0	0.7	4.3 times

According to Korea Gas safety corporation (2006), the most prevalent case involves accidents related to ignoring of the installation standard, which is 15 cases (55.6 %), and next is 12 accidents of the coupling separation of exhaust pipe. This harm to human life by CO poisoning is 4.3 times higher than other types of accidents as shown in Table 4 [9].

Therefore, this study will be expected to contribute to the application of the appropriate installation method of exhaust pipe in the industrial field by finding the concentration of CO based on the installation method of the exhaust pipe for the household gas boiler. [10] Also, it will be used as basic data for establishing the rules of the installation method of the exhaust pipe.

2. Equipment and CO characteristics

2.1 Equipment

The schematic of the measuring equipment of the boiler waste gas is shown in Fig. 1. There is a booth of a heat exchanger at the front lower part and a gas boiler at the upper part, and it can be used to change the length and the bent number of the exhaust pipe.

A gas container at the backside, has wheels in order to move easily without regard to location. Hence, this equipment can find the characteristics of the gas boiler in use which is installed outside as well as inside (General Rules and Law, 2005; Guide Book of Business, 2005). [11, 12]

In this study, CO measurement for imperfect combustion was done with applied sprint 2000. The specification of the measuring instrument is in Table 5 and

Table 5. The specification of measuring instrument.

Operating temperature range	-10 ℃ to 50 ℃
Battery	Rechargeable Ni-MH. Life > 6 hours.
Charger input voltage	115 V or 230 V, 50/60 ㎐ AC.
Fuels	Natural gas, LPG, Light oil, heavy oil.
Header	. Customer programmable.
Data logging	50 sets of readings for flue gas analysis 25 sets of reading for CO room test
Time and date	24 hour real clock.
Certification	Designed to meet BS7929 British standard for portable flue gas analyzers.

Table 6. The measuring range.

Gases	Range	Resolution	Accuracy
Oxygen	0-25 %	0.1 %	$\pm$0.3 %
Carbon Monoxide	0-10,000 ppm	$\pm$1ppm	<100 ppm : $\pm$5 ppm >100 ppm : $\pm$5 ppm
Carbon Dioxide	0-25 %		
CO/CO_2 ratio	0-0.9999		
Combustion efficiency	0-100 %		

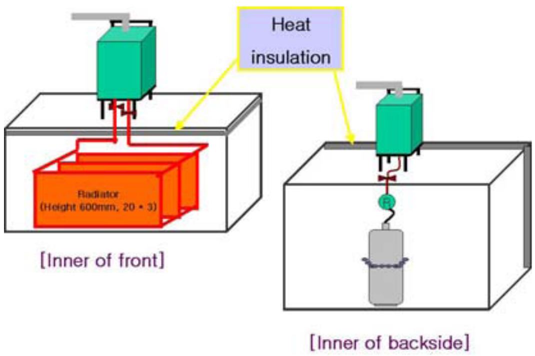

Fig. 1. View of equipment.

Table 7. Calculation.

Ingredient	A Contain volume in 1N m³	B Oxide equiva-lent	AB Oxide needed	Theoretical Air volume
C_2H_4	0.008		0.024	
C_3H_8	0.989	3 5 6.5	4.945	4.988/0.21 =23.75
C_4H_{10}	0.003		0.019	
Total	1.000		4.988	

Fig. 2. View of CO measurement.

the measuring range is shown in Table 6.

Fig. 2 shows the construction type of the exhaust pipe and displays the measuring figures at a settled place by using waste gas (CO and CO_2) and O_2 and the temperature measuring equipment (sprint 2000).

The experiments were carried out at night (19:00~22:00, 14-16 ℃) in December, 2006 because boilers are operated most at night in the winter.

2.2 Combustion theory

Combustion is a kind of oxidation reaction in which combustibles are combined with oxygen, but it means 'chemical reaction' which has flames and heat (Tatyana et al., 1998) [13]. According to Korea Gas & Petroleum Appliance Association (1994) [14], the combustion equation of hydrocarbon is as follows.

$$C_mH_n + \left(m + \frac{n}{4}\right)O_2 \rightarrow mCO_2 + \frac{n}{2}H_2O \quad (1)$$

This equation is called 'the theoretical air', which is the minimum air quantity for burning out 1 m^3 of air of the normal status. So, for example, that for propane gas (C_3H_8) can be by using the formula (1) and then obtaining formula (2).

Table 8. CO-hemoglobin and toxic symptoms in blood.

CO Hemoglo-bin of Blood (%)	Symptoms	
	Sitting up straight	Working
0-10	No symptoms	No symptoms
10-20	No symptoms	Slight headache
20-30	Headache	Feel sick
30-40	Headache, Vomiting	Convulsions
40-50	Difficulty in eyesight, Hearing, Consciousness, etc.	Muscle decrease, Convulsions
50-60	Syncope	Syncope
60-70	Heart gets weak	Sometimes death
70-80	Pulse gets weak	Difficulty in breathing, Death

Table 9. CO and toxic symptoms in air.

In air (%)	Breathing Hour and Symptoms
0.02	Slight headache in 2-3 hours.
0.04	Front headache in 1-2 hours, back headache in 2.5-3.5 hours.
0.08	Headache, feel sick, vomiting in 45 minutes. Swoon in 2 hours
0.16	Headache, feel sick in 20 minutes. Death in 2 hours.
0.32	Headache, feel sick in 5-10 minutes. Death in 30 minutes.
0.64	Headache, feel sick in 1-2 minutes. Death in 10-15 minutes.
1.28	Death in 1-3 minutes.

* 0.02% in air is 200 ppm.
* The allowable concentration of CO is 50 ppm.

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \quad (2)$$

The calculation of the quantity of theoretical air of LP gas is shown in Table 7.

It is known that the theoretical quantity of each gas is almost the same as about 0.9-1.0 per 1000 kcal/m^3 of the caloric value [15].

In fact, however, perfect combustion cannot be made with the theoretical air quantity because the airand the gas are not fully mixed during the combustion. It leaves a gas ingredient that was not burned out or imperfectly makes a chemical reaction. Therefore, about 20-50 % of excess air is needed.

2.3 CO characteristics

When imperfect combustion occurs by operating the gas boiler, the damage to human life becomes serious because it has created CO.

If the waste gas, including CO, escapes to where humans are present, they may be poisoned by CO; then the CO speedily reacts with hemoglobin in the blood and interrupts the circulation of O_2, so suffocation or loss of life occurs (Cho, 1997; ACGIH, 1996; Carl L. Yaws, 2001) [16-19].

Table 8 shows the toxic symptoms of CO and hemoglobin, but they may be different from the conditions of individual health.

Also, according to MSDS, the toxic symptoms by the breathing hour and the concentration of CO in air are shown in Table 9 [20-23].

3. Results

Bent tubes and straight tubes are made with the method used in the real field by using the measuring equipment of the boiler waste gas. We studied the concentration of waste gas occurrence for each of them considering the change of time. We found the optimum decrease in the leakage of the waste gas.

This research performed the measurements for 5 minutes on 1 minute basis because the household gas boiler manufactured in Korea has a function which makes the boiler stop operating automatically after a set time. Then we observed the concentration of CO on the basis of the settled time (in 5 minutes).

3.1 The bent tube of the exhaust pipe

This study examined the change process based on the length from one to five minutes for making an exhaust pipe with three bent tubes.

For an exhaust pipe with three bent tubes, the concentration of CO by changing the length of the exhaust pipe from one to five meters is increased by the change of time shown in Fig. 3. This study by Cho et al. is supported by creating a strong secondary flow with charging the flow direction rapidly due to the bent part [24].

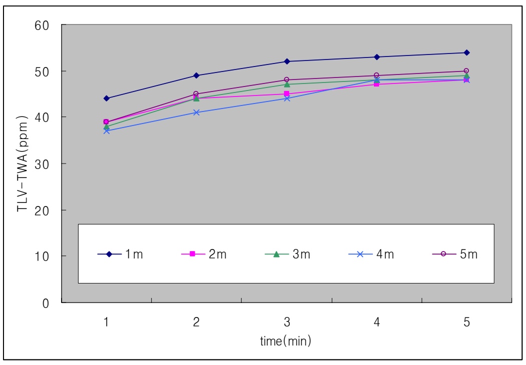

Fig. 3. CO concentration by bend tube.

Fig. 4 shows the percentage of CO_2 concentration on various bent tubes; in the case of making an exhaust pipe with three bent tubes, there is little change of the concentration of CO_2 by changing the length of the exhaust pipe from one to five meters and by the change of time.

Fig. 5 shows the percentage of O_2 concentration on various bent tubes; in case of making an exhaust pipe with three bent tubes, the concentration of O_2 by changing the length of the exhaust pipe from one to five meters gets decreased as the length gets longer. There is little change of the concentration of O_2 at over two meters by the change of the time.

According to Fig. 6, for an exhaust pipe with three bent tubes, the change of the inner temperature of the exhaust pipe by changing the length of the exhaust pipe from one to five meters has no relation to the

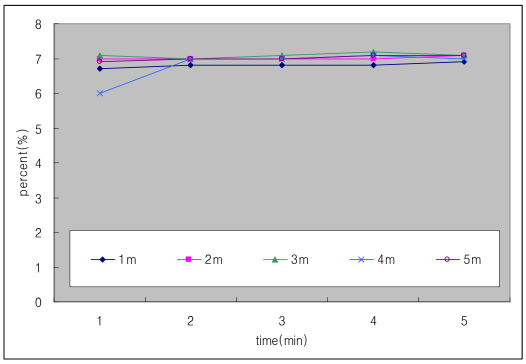

Fig. 4. CO_2 concentration by bend tube.

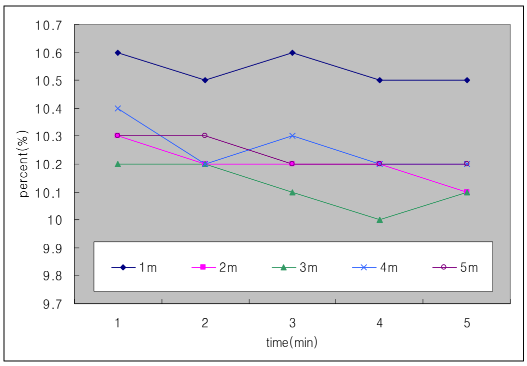

Fig. 5. O_2 concentration by bend tube.

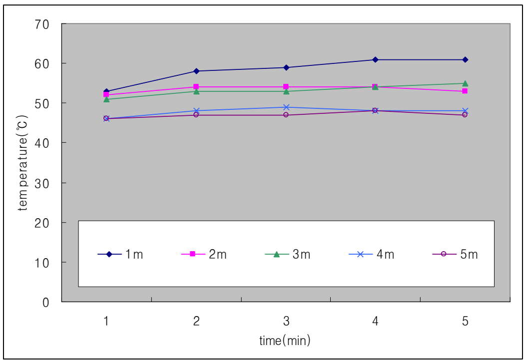

Fig. 6. Variation of temperature by bend tube.

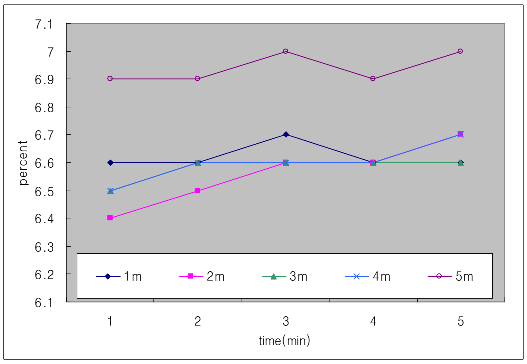

Fig. 8. CO_2 concentration by straight tube.

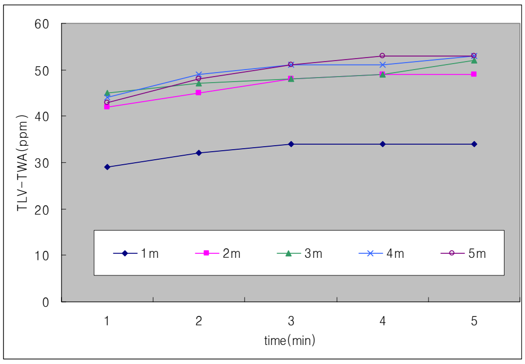

Fig. 7. CO concentration by straight tube.

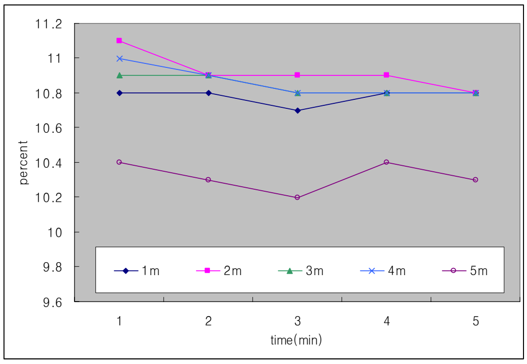

Fig. 9. O_2 concentration by straight tube.

change of length and time.

3.2 The straight tube of the exhaust pipe

This study examined the change process based on the length from one to five minutes for an exhaust pipe with one bent tube.

Fig. 7 shows CO concentration by straight tube. For marking an exhaust pipe with one bent tube, the concentration of CO by changing the length of the exhaust pipe from one to five meters gets increased and also the concentration of CO is changed little by little as time passes. The result for Lee et al. is supported by increasing the density in downstream region depending on residence time [25].

Fig. 8 shows CO_2 concentration by straight tube; for an exhaust pipe with one bent tube, the concentration of CO_2 was increased at five meters as the length of the exhaust pipe is changed from one to five meters, and also the concentration of CO_2 is changed little by little as time passes.

Fig. 9 shows O_2 concentration by straight tube; for an exhaust pipe with one bent tube, the concentration of O_2 is decreased as the length of the exhaust pipe gets longer as time passes.

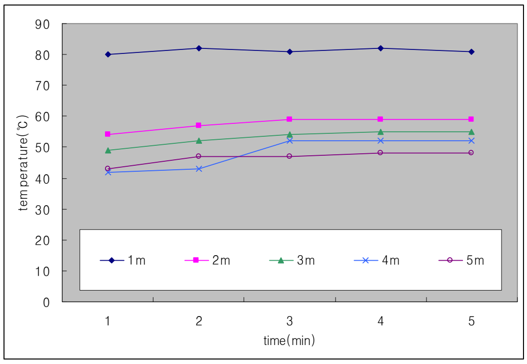

Fig. 10. Variation of temperature by straight tube.

According to Fig. 10, for an exhaust pipe with one bent tube, there is no change of the inner temperature of the exhaust pipe by changing the length of the exhaust pipe from one to five meters, but the temperature gets higher a little bit at over two meters as time passes.

4. Conclusions

From the above experiments, the following are the conclusions on the effect of the bent tube and the straight tube for the exhaust pipe of the boiler.

The result of this research is an average of 35, which is more than the minimum data of 30 giving the meaning of probability for the measuring data, so we judge that this data is available.

4.1 The effects of the bent tube

(1) CO causes the most damage to human life in case of a boiler accident. The length for the allowable concentration of 50 ppm is one meter of three times bent tube. At this length, the allowable concentration exceeds the time that passes three minutes.

(2) The concentration of O_2 for death from suffocation maintains a fixed value regardless of the change of the length and the time at the three time bent tube.

(3) The inner temperature of the exhaust pipe which has an influence with making the condensed water maintaining 40-70 ℃ when the outside temperature is 14 ℃. Therefore, much condensed water is made.

4.2 The effect of a straight tube

(1) The length for 50ppm of the allowable concentration of CO is three meters of one time bent tube. At this length, the allowable concentration exceeds the time passing five minutes, and at four and five meters, the concentration of CO exceeds the time passing three minutes.

(2) The concentration of O_2 is fixed regardless of the change of the length and time at the one time bent tube.

(3) The inner temperature of the exhaust pipe is 40-85℃, and it is increased as time passes. Also, condensed water is made.

This research shows that construction with a straight tube is safer than with a curved tube. Also if the length exceeds the settled length, the concentration of CO is exceeded within a little time. Therefore, for constructing an exhaust pipe, it may be safe to construct the shortest length with a straight tube.

Finally, further study is required on the spouting influence of waste gas and the exhaust capability by the installation condition (upward and downward) for winding and the length of the exhaust pipe after more data are collected.

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