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無煙炭가스 中毒과 社會的 問題

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Health and Social Problems of Carbon Monoxide Poisoning from the Usage of Anthracite Coal in Korea

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INTRODUCTION

Carbon monoxide (CO) is released when anthracite briquette is burned. It is one of the most significant causes of indoor air pollution in Korea. Besides CO, sulfur dioxide, nitrogen oxides, and hydrogen sulfide are contained in anthracite coal gas; however, CO is the most dangerous due to its high concentration and persistence in the room air. Because CO is colorless, odourless, and not irritative, early detection of its existence is very difficult.

Hypoxia caused by CO is more severe than that by other asphyxiating gases due to the "double effects" of CO. That is, the affinity of CO for hemoglobin is 210 times higher than that of oxygen and therefore even low concentrations of CO in blood can saturate almost all of the hemoglobin, which then loses its oxygen carrying capacity. On the other hand, CO strengthens oxygen-hemoglobin bonds to reduce free oxygen in tissue[1]. Also, CO inhibits O_2 utilization by suppressing cell respiration by bonding to the iron of cytochrome oxidase.

Anthracite coal, the leading cause of CO, has been used as a fuel for heating and cooking since 1950 and its usage has continuously risen to 86% of urban households, 46% of rural households, and 68% overall in 1985[2]. The widespread use of anthracite coal is due to its abundant supply and cheap price. Therefore, CO poisoning occurs more frequently than any other disease in Korea and remains one of the major health problems which cannot be solved without fuel replacement or improved living conditions. CO poisoning more frequently affects low income groups than high income groups because most of the lower income groups cannot afford to replace the coal with fuels such as oil and also their living conditions are poor. Even though fuel replacement and improvement of housing structure and material have been implemented to some extent, there are sufficient dilemmas remaining which cause health problems, especially in low-income groups, at the present moment.

In this study, acute and chronic CO poisoning over the past 30 years are reviewed to emphasize the health problems. Supportive measures to prevent CO poisoning in Korea and other countries which have similar problems are also reviewed in this study.

TOXIC SUBSTANCES IN ANTHRACITE COAL GAS AND CONCENTRATION OF CO EMISSION

Toxic substances in anthracite coal gas are mainly CO and gases such as sulfur dioxide, nitrogen oxides, and hydrogen disulfide which has anesthetic action on the respiratory center (Table 1)[3].

Table 1. Toxic Gases Contained in Anthracite Coal Gas.

Toxic gas	Concentration
Carbon monoxide (CO)	3~5%
Sulfur dioxide (SO_2)	5~400 ppm
Nitrogen oxide (NO)	5~100 ppm
Nitrogen dioxide (NO_2)	5 ppm
Hydrogen sulfide (H_2S)	3~5 ppm

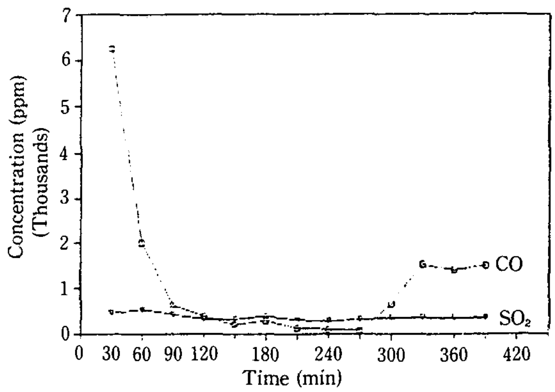
Source : Present status and preventive measures of CO poisoning. KMA, 1986

Table 2. Comparison of Carbon Monoxide Concentration.

Sources	Concentration of CO
Cigarette smoke	0.5%
Anthracite coal gas	3~5%
Vehicle exhaust	1~7%

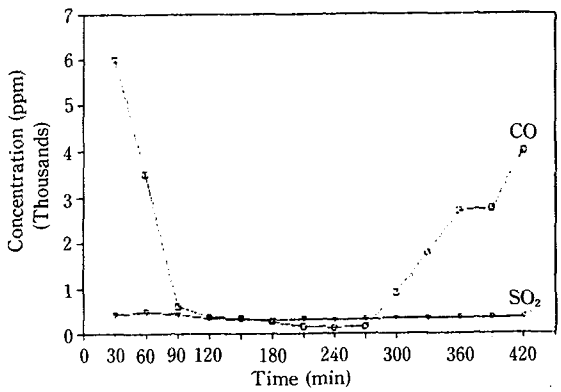
The concentration of CO in anthracite coal is 6 to 10 fold higher than that in cigarette smoke and is similar to the concentration of vehicle exhaust (Table 2). The most frequently used size of anthracite briquette emits 225 litres of CO during its 7 to 8 hours of burning time. The CO from one anthracite briquette can lead 376 people to death because the lethal amount of CO to human is 0.6 liter.

Kim *et al.* measured the amount of CO and SO_2 in the emissions from a smokestack by time interval and compared the persistence in the air of two toxic gases (Fig. 1, 2)[4]. A large amount of CO is produced at ignition and extinction. Pro-



*Source : Kim. DH, 1974

Fig. 1. Occurrence of Carbon Monoxide and Sulfur Dioxide from 19 Pore Anthracite Briquette by Time Interval.



*Source : Kim. DH, 1974

Fig. 2. Occurrence of Carbon Monoxide and Sulfur Dioxide from 31 Pore Anthracite Briquette by Time Interval.

duction of CO decreased abruptly after 90 minutes, decreased gradually till 4 to 4.5 hours after ignition and increased until completion of burning. On the other hand, the production of SO_2 did not vary according to time interval. 2000 ppm of CO exposed to conditions of 20 to 22℃ and 40% humidity was reduced to only half (1000 ppm) that amount after 48 hours; however, 350 ppm of SO_2 in the same atmospheric conditions decreased to 33 ppm after 24 hours.

TREND OF ANTHRACITE COAL CONSUMPTION AND TYPE OF HEATING FACILITIES

Consumption of residential and commercial anthracite increased 2.28 fold in 1985 compared to the consumption in 1971. The consumption of anthracite increased due to the population growth and rising energy consumption (Table 3).

Table 3. Anthracite Coal Consumption in Residential and Commercial Uses.

(unit : thousand M/T)

Year	Consumption	Proportion*
1971	10115	84.4
1972	10515	85.3
1973	13017	88.3
1974	13657	91.3
1975	13613	85.4
1976	14670	87.4
1977	16047	90.1
1978	16526	92.1
1979	16942	90.0
1980	18037	86.6
1981	18543	86.6
1982	17887	85.7
1983	18960	87.5
1984	21316	88.3
1985	23100	91.2

*Proportion : residential and commercial use/total use.

Source : Population and housing census report. EPB, 1985

Annual production of anthracite briquettes in Seoul, the largest city in Korea, exceeded 2.4 billion and per capita production was 252 in 1985 (Table 4). Despite socioeconomic development in large cities in Korea, production of anthracite did not decrease and this indicates that the energy replacement policy to oil or gases that cause less air pollution compared to anthracite coal is not effective. Thus, in large cities, although the energy policy is targeting energy sources other than coal, anthracite is still used continuously for space heating in houses and will be used for quite a long time, which does not diminish the population risk of CO poisoning.

Table 4. Production of Anthracite Coal Briquette in Seoul.

Year	No. of briquettes produced (×1000)	No. of briquettes per capita
1980	2,036,660	244
1981	2,054,278	238
1982	1,881,881	212
1983	1,952,763	214
1984	2,273,553	242
1985	2,427,297	252

Source : Statistical Yearbook. Seoul, 1985

The types of heating facilities in urban and rural areas in 1985 is shown in Table 5. The coal-briquette fuel hole system and piped coal-briquette boiler system was used in 85.6% of the urban areas, 46.1% of the rural areas and 67.8% overall in the whole country. The reason for low usage of coal-briquettes in rural areas is that the traditional fuel hole system using wood and fallen leaves as fuel is still relied on. In large cities, the percentage of houses using oil or gas boilers in Seoul was 21.4%, which was higher compared to Pusan, Taegu and the average rate for cities. Thus, the rate of anthracite use in Seoul was 78.2%, which was the lowest among large cities. These statistics indicates that most houses in urban areas have still not replaced anthracite coal with oil or gas for fuel; therefore, the risk of CO poisoning for most inhabitants in cities was not reduced.

Table 5. Heating Systems in Houses in Korea (1985).

Area	Total (%)	*Coal-briquet fuel hole system	*Piped coal-briquet boiler system	**Traditional fuel hole system	Oil or gas boiler system	Others
Whole country	6,104,210 (100.0)	1,061,545 (17.4)	3,076,420 (50.4)	1,514,719 (24.8)	4,404,743 (7.2)	10,783 (0.2)
Urban	3,349,327 (100.0)	741,121 (22.1)	2,126,185 (63.5)	65,193 (1.9)	410,246 (12.3)	6,582 (0.2)
Rural	2,754,883 (100.0)	320,424 (11.6)	950,235 (34.5)	1,449,526 (52.6)	30,497 (1.1)	4,201 (0.2)
Seoul	1,176,162 (100.0)	265,144 (22.5)	654,490 (55.7)	2,496 (0.2)	251,817 (21.4)	2,215 (0.2)
Pusan	427,308 (100.0)	122,366 (28.6)	253,971 (59.4)	1,291 (0.3)	48,523 (11.4)	1,157 (0.3)
Taegu	245,551 (100.0)	37,334 (15.2)	185,890 (75.7)	3,674 (1.1)	19,306 (7.9)	347 (0.1)

* : "on dol" system, heating floor system

** : wood burning system

Source : Population and housing census report. EPB, 1985

EPIDEMIOLOGIC FEATURES OF CO POISONING

As mentioned in the previous section, although there have been improvements in economic and living conditions during the past years in Korea, the heating facilities in houses have not been improved except that coal-briquette fuel holes have been replaced by the safer piped coal-briquette boiler system.

The seriousness of this problem and incidence of CO poisoning is affected by socioeconomic factors, housing structure and materials, and climate conditions. Therefore not one, but many factors contribute to the problem, and thus all of these attributes are reviewed.

1. Incidence of CO Poisoning

Several epidemiological studies conducted in Korea date back as early as 1966. Cases reported in the newspaper[5,6] and by the police[7,8] have less validity and cannot be generalized due to limitation of the study population.

In 1975, Yun and Cho conducted a community-based survey in Seoul of 48,795 houses by stratified random sampling[9] and then Kim *et al.* surveyed CO poisoning cases in the urban slum areas in three cities during 1976 to 1977[10]. Cho *et al.* in 1984 conducted a well organized survey of 377,662 people in Seoul with a detailed questionnaire[11]. A brief summary of these studies is shown in Table 6.

Table 6. Summary of Epidemiological Study Results.

	Yun and Cho	Kim *et al.*	Cho *et al.*
Survey conducted	1975. 9	1977. 8~1978. 8	1984. 4
Survey period	1974. 1~1974. 12 (1 year)	1976. 8~1977. 7 1977. 8~1978. 7	—
Survey area	Seoul	Seoul, Pusan, Chunchon	Seoul
Risk houses surveyed	44,985	—	—
Risk household surveyed	111,450	2,310	67,740
No. of risk population surveyed	528,033	10,731	353,287
Survey tool	questionnaire	questionnaire	questionnaire
Survey items	No. of CO poisonings severity monthly variation of CO poisoning materials of house	No. of CO poisonings severity materials of house	No. of CO poisonings severity materials of house treatment sequelae
Incidence rate per 10,000 population	306	Total : 478 male : 453 female : 503	424
Age-adjusted incidence rate per 10,000 population	—	480	407
Severity (%)	mild : 79.8 severe : 14.5 death : 0.3 unknown : 5.4	mild : 52.2 severe : 47.8	mild : 86.5 severe : 13.2 death : 0.3
Remarks		surveyed in urban slum area	

Age adjusted incidence rates per 10,000 people were 407 in the general population in 1984 and 480 in the urban slum area in 1976 to 1977 and incidence rate in 1974 was 306. If the incidence rates from the research of Yun and Cho and Cho *et al.* are compared, it seems that the incidence rate has increased during the period of 10 years. However, this is not a real increase because these two researches differed from each other in survey unit, as one unit is a house and the other is a household. Therefore, if two or more households are present in one house, the one interviewee per house may not recall exactly the events of the other household which may lead to underestimation of the cases per house. Additionally, it is less plausible that the incidence has increased in spite of socioeconomic growth for the past 10 years. The rate of piped coal-briquette boiler system usages, which is safer than the coal-briquette fuel hole system, was 55.7% in 1985 which was a marked increase compared to 1974.

2. Factors Attributing to CO Poisoning

① Socioeconomic status

The type of heating facilities, structure and environment of the house, and kinds of heating fuels are closely associated with the economic status of the household. Thus, low economic groups are most likely to be exposed to CO. Cho *et al.* revealed that households who rent on a monthly basis have a 2-fold greater risk than households who own the house. People who rent have lower incomes and less responsibility to improve the conditions of the house[11].

As shown in Table 6, the incidence of CO poisoning in the survey conducted in urban slum area was found to be higher compared to the other community-based studies. Furthermore, the severity of CO poisoned patients was about

3.5 times greater in the former study compared to the latter studies. Among the people in the slum areas, the incidence rate was found to be higher in the relatively low income group (Table 7).

Table 7. Incidence Rate of CO Poisoning by Socioeconomic Status 10,000 Population Surveyed in Urban Slum Area.

Socioeconomic status (relative value)	No. of population surveyed	No. poisoned*		Incidence rate**	
		Total	Grave	Total	Grave
High	440	8	1	181.8	22.7
Middle	6,031	148	71	245.4	117.7
Low	4,042	212	121	524.5	299.4
Unknown	218	5	0	—	—
Total	10,731	373	193	347.6	179.9

*$p<0.01$ **$p<0.01$

Socioeconomic status was derived from index which summarized scores of monthly income, house ownership, and goods of each household.

*Source : Kim. ID, 1972

Also, of the patients, 58.4% are in low income groups and almost all of the patients (98.2%) surveyed in the study on hospital in-patients admitted during 1969 to 1971. High school aged patients or higher were found to have 30.7% poisoning compared to 69.3% in junior high school or lower in this study[12].

② Materials and type of heating facilities of houses

It is cogent to review the most recent study because of the uprise of architecture. A high degree of CO poisoning was noticed in houses made of roofing tiles, slate, cement bricks, earth and as a whole in old houses. Therefore, it can be noted that the occurence of anthracite coal gas is associated with the housing materials.

③ Weather condition

It is assumed that the indoor concentration of CO can vary according to weather conditions because natural ventilation is influenced by outdoor atmospheric conditions. In a study conducted on 41 houses of the ventilation rate and indoor air quality, it was found that the degree of ventilation was predominantly influenced by the temperature difference between indoor and outdoor air. Fig. 3. shows that the ventilation rate increased when temperature difference rose between indoor and outdoor. As shown in Table 8, the incidence of CO poisoning was highest when atmospheric temperature was at its higg-

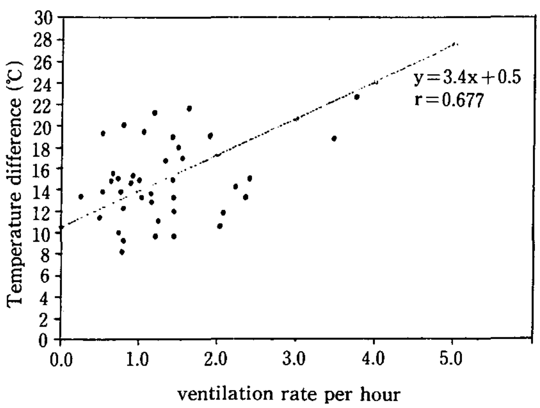


Fig. 3. Correlation of Temperature Difference of Indoor and Outdoor Air and Ventilation Rate.

Table 8. Occurrence of Poisoning and Weather Conditions.

Elements	Changes	Days	CO poisoning occurred 2 or more times in a day			
			Event	%	No. poisoned	%
Temperature	lowest	17	2	5.7	2	2.2
	increasing	17	9	25.7	24	27.0
	highest	15	18	51.5	39	43.8
	decreasing	13	6	17.1	24	27.0
	total	62	35	100.0	89	100.0
Wind speed	lowest	20	14	40.0	31	34.7
	increasing	13	17	48.6	44	49.5
	highest	20	2	5.7	10	11.3
	decreasing	9	2	5.7	4	4.5
	total	62	35	100.0	89	100.0
Atmospheric pressure	lowest	14	17	48.5	51	57.3
	increasing	17	5	14.3	14	15.7
	highest	19	13	37.2	24	27.0
	decreasing	12	—	—	—	—
	total	62	35	100.0	89	100.0
Relative humidity	lowest	17	7	20.0	11	12.3
	increasing	15	—	—	—	—
	highest	15	17	48.6	44	49.5
	decreasing	15	11	31.4	34	38.2
	total	62	35	100.0	89	100.0

est while atmospheric pressure was at its lowest. There were no significant differences of CO poisoning incidence according to windspeed or relative humidity.

As the room temperature remains almost constant in the same season, elevation of atmospheric temperature in the winter will cause a reduction in the ventilation rate, and therefore, an increase of CO exposure to humans in the room will cause CO poisoning.

INDOOR CONCENTRATION OF CO AND CARBOXYHEMOGLOBIN IN BLOOD

CO concentration in the living room and kitchen shows that pollution levels of CO and SO_2 in the kitchen were higher than the living room (Table 9). Detailed findings revealed that the average concentration of CO in the living room was about 58 ppm, which was 5.8 times higher than the indoor air quality standard within 8 hours. In the kitchen, it was 112 ppm which was almost 4 times higher than the standard within 3 hours.

Nineteen housewives were examined for carboxyhemoglobin levels in blood, based on the assumption that women are more dangerous to CO poisoning than men. The reason for this is simple; the kitchen is the most risky site for CO poisoning compared to any other room and women working in the kitchen are easily exposed to various degrees of CO. The average concentration of CO in the kitchen was 245 ppm and the average level of carboxyhemoglobin

(COHb) in blood was 11.2% which can sufficiently cause adverse health effects in healthy persons as well as sensitive persons (Table 10)[13]. 15 out of 19 subjects were above 5% COHb and 8 out of those 15 had greater than 10% COHb in blood.

~3.0% is recommended for the protection of the general population, including sensitive groups[14].

In another study conducted recently, carbon monoxide concentrations ranged from 5 to 59 ppm in a market area without mechanical ventilation[15].

Table 9. Percent Distribution of Toxic Gases from Anthracite Coal.

Toxic gases	Concentration	Living room	Kitchen
SO_2 (ppm)	0	66.0(56)	22.2(16)
	0.001~1.0	31.7(27)	45.9(33)
	1.1~10.0	2.3(2)	31.9(23)
	mean concentration	0.24	0.81
CO_2 (Vols. %)	0.1	32.9(25)	50.0(35)
	0.11~0.5	67.1(51)	50.0(35)
	mean concentration	0.15	0.12
CO (ppm)	0	14.3(13)	15.5(14)
	1~50	51.6(47)	21.1(19)
	51~100	34.1(31)	63.4(57)
	mean concentration	58.0	112.0

( ) : No. of houses

Table 10. General Characteristics and Amount of Saturated Carboxyhemoglobin.

Serial No.	Age	Years of work	CO (ppm) in kitchen	CO conc. in blood (Vol %)	% of saturated CO-Hb
1	19	3	400	0.2	1.5
2	15	1	—	0.9	4.4
3	20	1	1200	1.8	10.4
4	17	2	150	1.1	5.8
5	19	3	10	1.8	12.0
6	19	1	200	0.8	5.2
7	45	27	200	3.8	14.7
8	20	3	200	6.1	34.2
9	23	8	200	5.3	26.0
10	22	5	—	1.2	6.1
11	20	2	—	1.6	8.7
12	24	2	—	0.7	4.5
13	22	8	50	5.0	28.1
14	21	1	—	1.6	7.6
15	16	4	200	1.9	11.8
16	13	2	—	0.9	4.8
17	20	5	—	2.0	11.0
18	17	3	50	1.6	8.3
19	36	10	80	1.6	7.7

*Source : Sohn. DM, 1967

Adverse health effects due to indoor CO pollution include 1) cardiovascular effects, 2) neurobehavioral effects, 3) fibrinolysis effects and 4) perinatal effects. Cardiovascular and neurobehavioral effects can occur above 5% COHb. With regard to cardiovascular effects, a decreased oxygen uptake capacity and the resultant decreased work capacity under maximal exercise conditions have been clearly shown to occur in healthy young adults starting at 5.0%, and statistically significant impairment of vigilance tasks have been described at carboxyhemoglobin levels about 5% COHb. Therefore, a maximum carboxyhemoglobin level of 2.5

NEUROLOGICAL SEQUELAE OF ACUTE CO POISONING

Among several complications of acute CO poisoning, delayed sequelae has attracted much interest because of its characteristic progress in which the recovery of patients to a mentally clear state will be aggravated by mental deterioration such as memory disturbance, incontinence, hypokinetic mutism. This has led to death in a few cases; however, most cases will be ameliorated after one or two months[16].

Because there is a sufficient number of cases complicated by CO in Korea, valid data from epidemiological surveys can be obtained. The total cumulative incidence of neurological sequelae was 41.2 per 100 patients which was calculated from 444 patients who were accessible for investigation among all the CO poisoned patients in a year in Seoul (Table 11). The incidence of neurological sequelae was higher in the older age group than the younger, and higher in females than in males. Also, a higher incidence among patients who were admitted due to severe poisoning than non-admitted patients was observed and the incidence was higher in proportion to the duration of CO exposure and unconsciousness[17].

Table 11. Cumulative Incidence Rate of Neurological Sequelae of Acute CO Poisoning by Follow-up Interval.

Observed interval	Total number of patients	Number of occurrences	Number of withdrawals	Probability of incidence within the interval	Cumulative incidence per 100 patients
0	221	58	—	26.2	26.2
0~1	163	18	—	11.0	34.4
1~2	145	6	—	4.1	37.1
2~3	139	5	3	3.6	39.3
3~4	131	1	5	0.8	39.8
4~5	125	1	15	0.9	40.3
5~6	109	—	32	0.0	40.3
6~7	77	1	22	1.5	41.2
7~8	54	—	11	0.0	41.2
8~9	43	—	15	0.0	41.2

*Source : Park. BJ *et al*, 1984

The high incidence rate and early occurrence of neurological sequelae within 2 or 3 months after poisoning is due to late detection of poisoned patients and inadequate treatment of the patients. Adequate and reasonable treatment guidelines are needed to reduce the occurrence of delayed sequelae of CO poisoning.

PREVENTIVE MEASURES FOR CO POISONING

Several preventive measures for CO poisoning in Korea can be suggested on the basis of health and social problems of CO poisoning reviewed in this research. The preventive measures suggested are divided into the following two parts: firstly, control measures to suppress the occurrence of CO gas and to reduce the number of accidents of CO poisoning, and secondly, early detection of patients and research for reasonable treatment as a means of secondary prevention.

First stage measures are comprised of energy replacement, improvement of the quality of anthracite briquettes, and development of a safe furnace for the briquette hole system. Energy replacement means replacing anthracite coal with other energy sources such as oil, which is far safer. Improvements for a safer furnace consist of using a safer piped anthracite coal boiler system and exhaust duct. The development of a safe furnace and briquette hole system can be carried out with further concern and awareness for safety against CO poisoning. Health education is very helpful in arousing the concern needed in taking safety measures, such as developing awareness of the importance of good ventilation during warm days in winter. The number of CO patients can be reduced dramatically when health education is firmly established and the growing social awareness and concern causes action to be taken.

For the second stage prevention, emergency care systems for CO poisoning and supportive measures for complete treatment are needed. Such suggested measures require investment and effort and have their own limitations, therefore, priorities must be set for implementation.

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