5) Summary and Comparison of Otto Methanol Engines

The comparison of typical methods for Otto engines is summarized as follows:

	Liquid Mthanol	Gasified Methanol
Conversion Difficulty	○	△
Max. Output	◎	△
Low Speed Torque	○	△
Thermal Efficiency	○	◎
Acceleration	○	○
Startability	△	×
Noise	○	○
NOx	◎	◎
HC (with catalyst)	◎	◎
CO (with catalyst)	◎	◎
Aldehyde (with catalyst)	○	○
Cylinder Wear	△	△
Reliability	○	○
Durability	○	○
System Cost	△	×

◎ : Superior, ○ : Comparable, △ : Slightly inferior, × : Inferior
as compared with gasoline engines

(2) Utilization of Methanol in Diesel Engine

The problem becomes much more complicated with diesel engines because of the unfavorable nature of methanol as observed in Section 7-4-2 (1).
The various technologies for methanol utilizatoin in diesel engines are based on the measures to overcome the most unfavorable nature of methanol, mainly the low cetane number. In diesel engines, generally known as the compression ignition engines, the fuel is ignited by itself without any auxiliary tools. This requires the fuel to possesses satisfactory autoignition characteristics, which is expressed as the cetane number. In ordinary diesel engines a cetane number over 30 is required for autoignition, therefore it is impossible to autoignite methanol with a low cetane number less than 10.

The methods to ignite methanol in diesel engines are viewed from several perspectives, and it is reasonable to classify those by three categories. The first is to ignite methanol by additional ignition devices, which enables the use of neat (100%) methanol and requires certain modification of engines. Using other ignitable fuel such as the pilot ignition fuel together with methanol is another way of igniting methanol, but enables only partial use of methanol and also requires further complicated modification of engines to provide two different fuel lines. The third category is to improve the ignition characteristic of methanol by chemical additives, which enables the use of almost 100% methanol and requires no or very little engine modification, but the penalty is that the fuel cost increases by the addition of additives. The typical methods in these classifications are shown in Table 7-4-6 with their relative advantages and disadvantages. In the following table these technologies are described in detail.

Table 7-4-6 Various Methods of Using Alcohol in Diesel Engines

		Ignition Stability	System Complexity	Easy to Convert	Cost	Efficiency	Reliability	Durability	Methanol Alternate Ratio	Multifuel Capability	Total Evaluation
100% Alcohol	Spark Assist	6	3	2	2	2	2	2	3	3	25
	Glow Plug Assist	4	3	2	3	2	2	2	3	2	23
	Catalyst Combustion	3	3	3	3	2	2	2	3	2	23
Dual Fuel	Dual Fuel	6	2	1	1	2	2	2	1	3	20
	Fumigation	6	2	2	2	1	3	3	1	1	21
	Dissociated Methanol	6	1	1	1	3	2	2	2	1	19
Fuel Modification	Emulsion	4	2	2	2	2	2	2	2	2	20
	Blended with Diesel Fuel	4	3	3	3	2	2	2	2	1	22
	Cetane Improver	6	3	3	1	2	3	3	3	1	23
		6. Easy 1. Difficult	3. Simple 1. Complex	3. Easy 1. Difficult	3. Low 1. High	3. High 1. Low	3. High 1. Low		3. 100% 1. Low	3. Capable 1. Incapable	

(Source) VIII International Symposium on Alcohol Fuels

1) Spark Assist

This method utilizes the spark plugs in addition to standard diesel engine configuration. The ignition is initiated by the electric spark and resultant combustion takes place all over the combustion chamber. Although it is possible to call it spark ignition, there is an essential difference from the gasoline (Otto) engines. In the Otto engines the fuel is premixed with air before entering the cylinders thus, if the compression ratio is too high, auto ignition may take place during the compression stroke, which may be called pre-ignition or knocking. On the contrary, in the spark assist diesel engines only the air is compressed during the compression stroke and the fuel is injected only near the Top Dead Center (TDC) just as in standard diesel engines, therefore it can use a high compression ratio (about 18 as compared with less than 10 for the Otto engines) without preignition. Therefore this method is intended for the utilization of methonal in the efficient diesel engine.

The difficulty of this method is to ensure stable ignition and combustion throughout the various operating loads and speed conditions particularly at the part load. The fuel is injected near the TDC and almost at the same time the electric spark is generated, thus it is less likely for the fuel to be distributed uniformly throughout the combustion chamber just before ignition in order to obtain efficient combustion. Also this condition often requires multi-spark generation so that the injected fuel never fails to meet the spark. This necessitates the provision of the special ignition system with multi-spark capability and intense spark, which then poses a problem in reliability and durability of the spark plugs. This system is schematically shown in Fig. 7-4-8, where the righthand side indicates the additional ignition system and the lefthand side the fuel line modified for the corrosivity and lower viscosity of methanol. In the middle of the picture the spark plug is located in the combustion chamber together with the injection nozzle. An example of the thermal efficiency is demonstrated in Fig. 7-4-9, where it is shown in comparison with a diesel engine. The hatched area indicates that methanol combustion is superior to that of diesel oil and it is observed that the efficiency at the light load is inferior. Other performance characteristics with this method are quite comparable with diesel engines with increased low speed torque as described previously. The startability in the cold weather is also as good as or better than diesel oil engines, which is a major advantage of this method over the Otto type methanol engines. It is thought that the benefit is brought about by the direct spark ignition to the fuel spray.

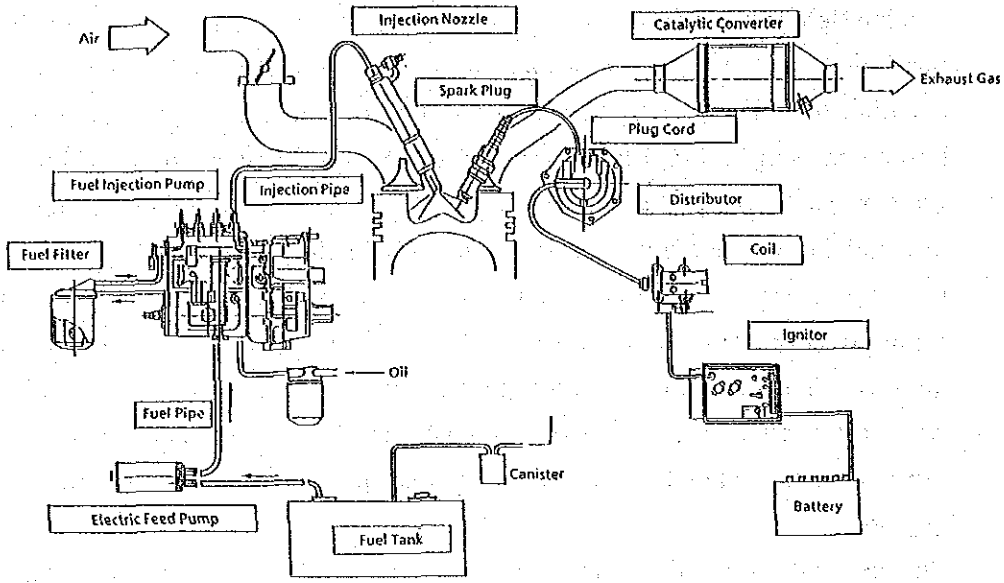


Fig. 7-4-8 Schematic of Spark Assist System

(Source) VIII International Symposium on Alcohol Fuels, 1988

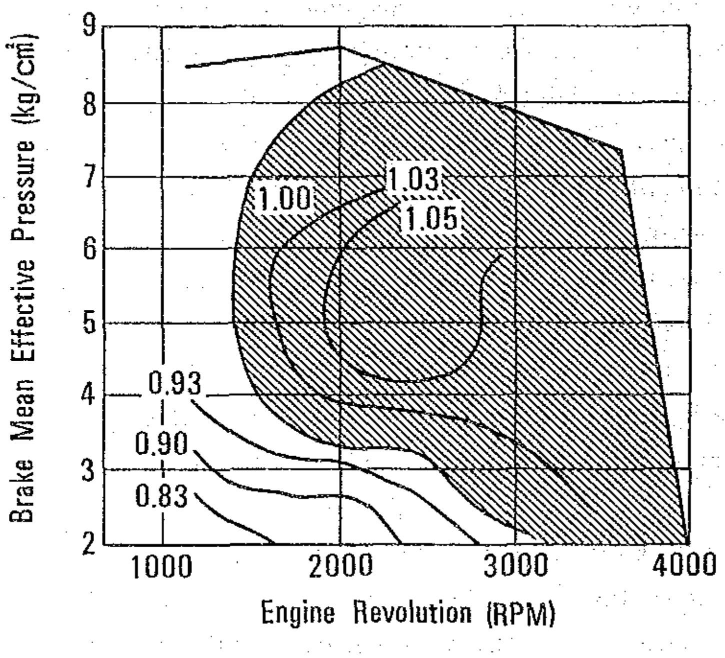


Fig. 7-4-9 Comparison of Thermal Efficiency between Spark Assist Methanol Diesel and Diesel (over 1.00, Methanol Exceed Diesel)

(Source) International Symposium on Introduction of Methanol-Powered Vehicles, 1987

In terms of durability, the spark plug is the major concern for further improvement as mentioned above. The injection system requires considerable work in order to utilize methanol but it could be solved in development effort.

Although the spark assist method still needs improvement in several area as discussed, among the other methods it is probably the closest to practical use overall. The method has been favorably adopted to the engine used for the fleet tests now conducted throughout the world, mainly in U.S.A., Japan, West Germany, and Canada. MAN (W. Germany) and Komatsu (Japan) supplied large and small engines, respectively.

2) Glow Plug Assist

Basically the glow plug assist method is similar to the spark assist method in concept but it is different in detail. It has an advantage in that the glow plug is always switched on during the operation therefore the injected fuel will not fail to meet the ignition source. On the other hand, the glow plug energy (temperature) is lower than the spark plug and it is more difficult to ignite the fuel consistently particularly at light load in the idling condition. Therefore it is more practical to consider it as a means to utilize methanol in 2 cycle engines where the hotter cylinder wall helps the ignition. DDA (now DDC) two cycle large engine (9 ℓ) converted from the ordinary diesel engine is the most well known attempt using this method. By controlling the amount of the hot residual gas in the cylinder during the scavenging stroke with a specialized device in the exhaust system, it is made possible to operate the engine stably at all loads and speed conditions. The engine was mounted on a city bus and tested for two years in California, U.S.A. The company is said to be ready for the production of methanol buses when and if the stringent particulate standards in 1991 in California become effective. This engine also suffers from the low thermal efficiency at light loads but the rest of the engine characteristics including performance and durability seem close to completion.

The glow plug assist is advantageous over the spark plug assist in that the ignition system becomes simple and the plug life extends. Therefore, the effort has been continued to apply it to four cycle engines where the cylinder wall is cooled down by fresh air in the intake stroke and the stable ignition by a glow plug becomes a difficult task.

Among them Caterpillar's system is unique in a way. Fig. 7-4-10 shows the combustion chamber configuration where the glow plug is located closer to the injection nozzle in the center, and one of the fuel sprays is aimed at the so called impingement pin on the piston in order to obtain transverse fuel distribution, thereby promoting flame propagation. This device plays an important role in improving the combustion at part load and thus stabilizing the ignition and reducing the unburned hydrocarbon. This suggests the glow plug technology will be promising for four cycle engines also.

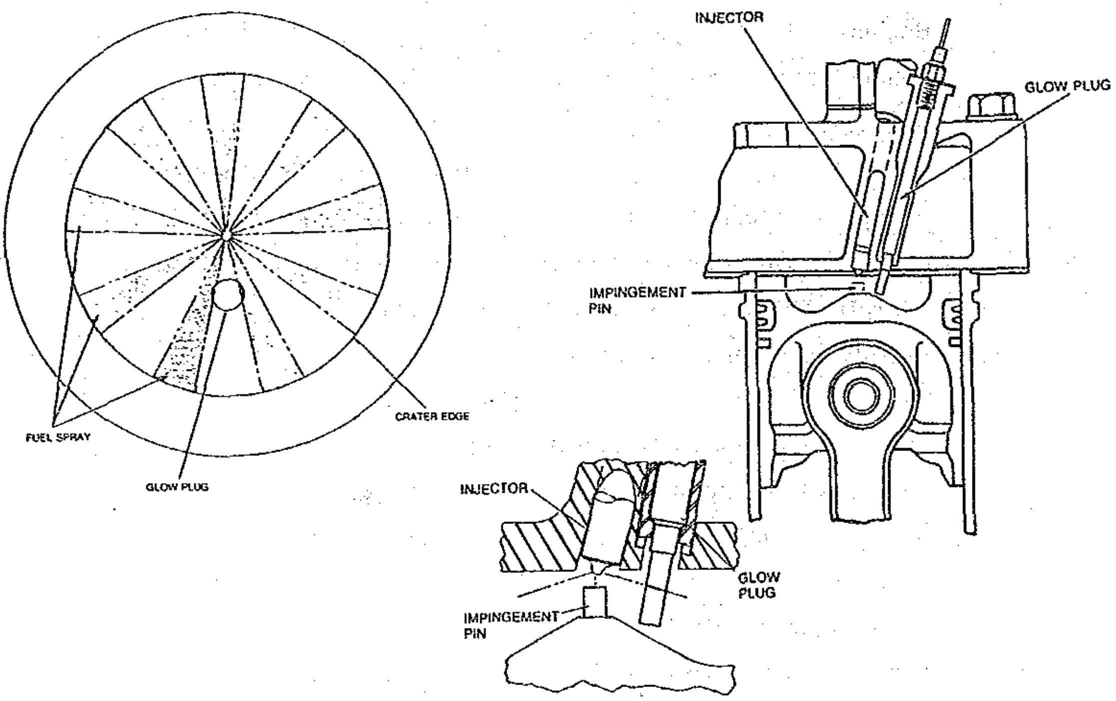


Fig. 7-4-10 Combustion Chamber of Caterpillar's Glow Plug Assist Methanol Engine

(Source) SAE Paper 861169, 1986

3) Dual Fuel System

As the typical method to initiate ignition of methanol by autoignition of the other fuel without resorting to auxiliary means, the pilot injection and ignition of diesel oil had been studied. The typical system requires two separate fuel lines, injection pumps, and injection nozzles for methanol and diesel fuel as in Fig. 7-4-11. A certain amount of diesel oil is injected prior to the methanol injection as the pilot ignition, and thus the alternative rate of methanol varies depending on the total amount of the fuel injected for the load condition.

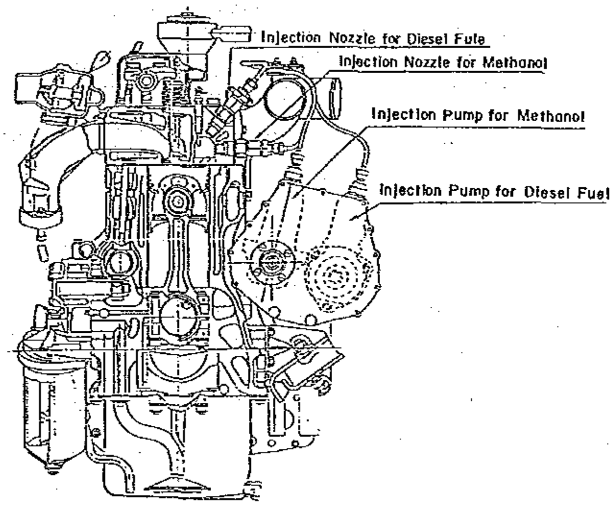


Fig. 7-4-11 Dual Fuel Engine Configuration

(Source) J.A.R.I. Technical Report, 1874

This situation is observed in Fig. 7-4-12 where the alternative rate varies from twenty to ninety percent. The system is advantageous in that the pilot ignition system is the standard diesel arrangement thus the ignition is stable at all conditions. However, the complexity of the system is a fatal drawback. The latest research works are concentrated on making the system less complicated, and a system with one common pump and one common nozzle for both methanol and diesel oil indicate quite acceptable results for the future.

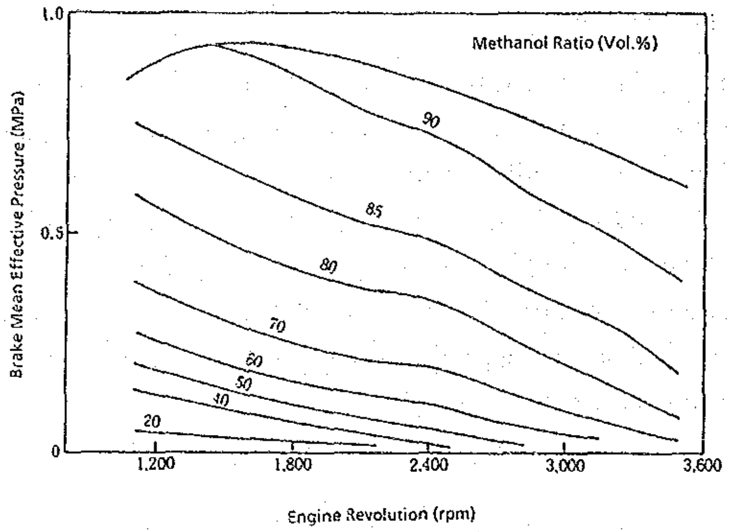


Fig. 7-4-12 Rate of Methanol used in Dual Fuel System

(Source) M.A.R.I. Technical Report, 1984

4) Cetane Improver

Among the methods to utilize methanol in diesel engines, addition of additives to methanol for ignition improvement is another approach. Usually they contain not only ignition improver but also lubricity improver and corrosion inhibitor. Also the unsafe properties of methanol such as toxity, flame luminosity and flammability may be dealt with by those additives.

Even so the additives are not necessarily without problems performance-wise. For instance, ignition delay with these fuels are not short enough compared with diesel engines. In addition to the required roles for the additives, consideration is necessary for the undesirable effect of additives such as the exhaust gas emission characteristics. Economically it is not easily compared with engine modification methods since the engine modification cost depends on the technology used, and the running cost of the fuel depends on the operating length.

This method is also being vehicle tested in certain governmetal fleet test programs and by several engine manufactures at the present moment.

5) Summary and Comparison of Diesel Methanol Engines

The comparison of the methods for diesel engines so far described is as follows:

	Auxiliary Ignition Aid	Dual Fuel	Fuel Additive
Conversion Difficulty	△	×	○
Max. Output	○	○	○
Low Speed Torque	◎	◎	◎
Thermal Efficiency			
Full Load	○	○	○
Part Load	△	○	○
Acceleration	○	○	○
Startability	○	○	○
Noise	○	○	○
NOx (with catalyst)	◎	○	◎
HC (with catalyst)	◎	○	◎
Aldehyde (with catalyst)	○	○	○
Reliability	△	△	○
Durability	△	△	△
System and Running Cost	△	×	×

◎ : Superior, ○ : Comparable, △ : Slightly inferior, × : Inferior
as compared with diesel engines

(3) Utilizatoin of Methanol in Gas Turbine (Brayton Cycle)

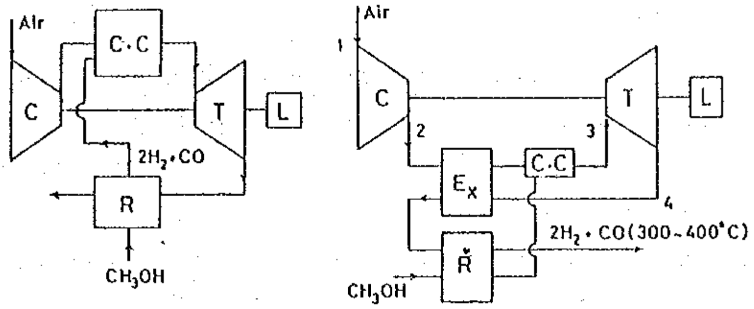
The combustion in the gas turbine is relatively simple compared with Otto or diesel engines. Fuel is ignited by a spark plug only at the starting and continuous combustion follows in a fixed combustion chamber without necessitating the reuse of the ignition aid as long as the engine is running, as opposed to the intermittent combustion in the non stationary combustion chamber in the case of reciprocating engines where the ignition is necessary at each combustion in the interval of milli-second order. Therefore virtually any kind of fuel can be used in the gas turbine without much difficulty.

1) Conventional Gas Turbine

In the conventional form of the gas turbine, some of the nature of methanol listed in Table 7-4-1 also has to be taken into consideration. These are as common with Otto engines, material selection against the corrosivity and increase in the pumping capacity against the lower calorific value, but the lubricity may not be a major concern. Except the fuel line the gas turbine itself does not require major modification. Apart from the technological view, the low calorific value of methanol does not pose a problem in using methanol in gas turbines, since the present gas turbines on land are mostly used for stationary power generation, and thus the increased weight and volume of the fuel is less important. In this application methanol is also superior in NOx emission but the aldehyde has to be properly handled as any other engine form.

2) Methanol Reforming Type Gas Turbine

Methanol can be reformed (steam reforming) or decomposed at a relatively lower temperature. A new system of gas turbine which is designed to improve thermal efficiency by reforming and decomposing methanol by using the exhaust heat of the gas turbine is now attracting attention.
The system fully utilizes the characteristics of alcohol, and it is expected that the efficiency will be widely improved by nearly 10% (the absolute value). This value is a theoretical calculation. It is desired to make detailed studies on this matter in the future. Fig. 7-4-13 and 7-4-14 shows a methanol reforming type gas turbine. The methanol reforming gas turbine causes a heating reaction of methanol by an exhaust gas heat of about 500°C and a reforming reaction at rather low temperatures of 250 to 350°C to decompose the methanol into H_2 and CO, and this reforms the methanol into H_2 and CO_2 in the water-vapor reforming process and then uses the reformed gas as its fuel.
The constituent elemental technologies are not new, and are just a combination of existing technologies, and so the methanol-reforming-type gas turbine will be ready for practical use without any major technical barriers. In Indonesia, many conventional gas turbines have been installed, and therefore fuel switching to methanol using this method seems to be promising.

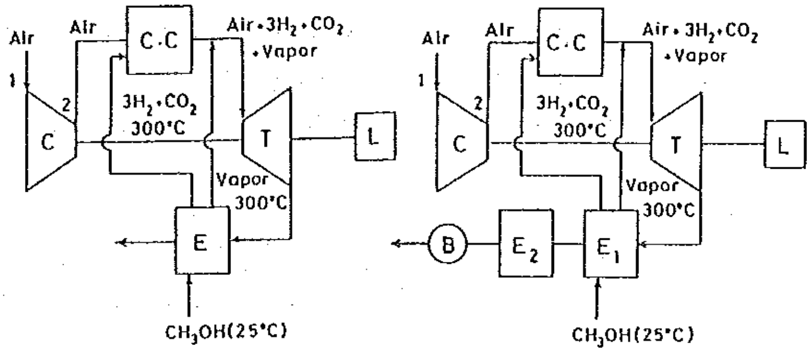


(a) (b)

Ex : Heat exchanger R: Reformer

Fig. 7-4-13 Gas Turbine System with Dissociating Methanol

(Source) VI International Symposium on Alcohol Fuels, 1984



(a) (b)

C : Compressor
T : Turbine
L : Load
B : Blower

C.C: Combustion chamber
E_1 : Reformer and boiler
E : Condenser

Fig. 7-4-14 Gas Turbine System with Steam Reforming Methanol

(Source) VI International Symposium on Alcohol Fuels, 1984

7-4-4 Development and Fleet Test in Various Countries

(1) F.R. Germany

F.R. Germany has been interested for a long time in the use of methanol in automobile engines, and with her advantage of having several well known engine manufactures, development and fleet test have been carried out on a private sector initiative basis.

The automobile application based on the gasoline engines had been tested in vehicle fleet mainly by VW since 1979, where five hundreds and eighty vehicles with M15 fuel had been in operation between 1979 and 1982 and eighty five vehicles with M100 fuel between 1981 and 1984. Also the same kind of fleet test had been conducted by Mercedes-Benz with fewer vehicles. Through those fleet tests, cold weather startability, internal engine wear, and aldehyde emission were mainly evaluated, and the technology is there for mass production as far as fuel economy requires the use of methanol engines.

In the field of heavy duty vehicles three engine manufacturers have developed their own technologies. MAN has been working with the spark assist diesel for 11 ℓ bus engine since late 1970 and accumulated around 500,000 km through the fleet test in buses around the world (F.R. Germany, U.S.A. and New Zealand). The latest technology enabled the development of turbocharged version for American market and ten of those buses have been put into operation in Seattle since 1987. Mercedes-Benz with its gasified methanol engine of 11 ℓ for buses has also accumulated about 1,000,000 km in city bus service since early 1980 mostly in F.R. Germany. In their view technologically they succeeded in the development in both performance and durability requirements and they are ready at any moment for production, if fuel situation brings methanol into the fuel market. KHD is another company involved in the methanol engine development with their own dual fuel technology. It also accumulated 800,000 km in five trucks in Berlin since 1981.

(2) Sweden

In Sweden which has no oil, gas, and coal resources, similar to Japan, large-scale tests on alcohol fuels in automobile Otto engines have been conducted by SDAB, which falls under a government-set frame. Fleet test on 1,000 vehicles with M15 fuel had been completed between 1980 and 1983 and five vehicles with M100 in the same periods. Following these tests, twenty-two vehicles with M100 had been put into another fleet test between 1984 and 1986, with the participation of Volvo, Saab-Scania, Ford, Toyota, Mitsubishi, and Mazda. In those tests attention was particularly focused on the startability in cold weather and wear of internal engine components in such cold regions. Also efficiency comparison between neat methanol and the blended one was a major concern.

In heavy duty application, Volvo's dual fuel engine was mounted on two buses and two trucks, and tested in 1980 to 1982. With the accumulated 16,000 km run by buses and 30,000 km by trucks, it was concluded both performance and durability were comparable with diesel.

(3) USA

Since United States can enjoy affluent energy supply both domestically and from abroad, her concern for methanol is greater in air pollution rather than energy conservation as opposed to European interest. For that reason the state of California have been playing a leading role in methanol utilization.

In the use of alcohol in automobile gasoline engines, the introduction of gasohol which is the mixture of lead free gasoline and about 10% ethanol, is probably the start of such attempt back in 1979. In early 1980, several companies participated in a part of the CEC (California Energy Commission) program where not only vehicle manufacturers but also vehicle users such as Bank of America and fuel suppliers such as Celanese Chemical Company were the participants. The fleet test in the area was further extended to five hundred Ford Escorts from 1983 for three years. From 1987, five thousand cars owned by the Federal Government are subjected to road test every year over four years. The latest interest is the strongest in the FFV which is considered a practical method in utilizing methanol fuel in the commercial market.

In heavy duty application, DDC (formerly DDA) glow plug assist engine used to be the only domestic development, and CEC started fleet test in this category in 1983 with one DDC bus and one MAN bus for two years around the Golden Gate Bridge district.

Also a unique private participator in the program was a Komatsu farm tractor, based on a construction machine, which was tested in the farmyard of certain university in California in the same period. The fleet test in heavey duty vehicles are being extended further on a larger scale in several other states. Those fleet tests in operation or in schedule are listed in Table 7-4-7.

Table 7-4-7 Fleet Test Scheme of Heavy Duty Vehicles in U.S.A.

Region	Vehicles	Engine Manufacturer and No. of Vehicles		Start of Fleet Test
San Francisco Golden Gate Bridge	Bus	GM MAN	1 1	2 years from 1984
Florida Jacksonville	Bus	GM (6V71N)	3	May - Nov., 1986 6 months extended
Seattle	Bus	MAN	10	Feb., 1987
SCRTD (South California)	Bus	MAN/GM/Cummins	30	May, 1988
New York City	Bus	GM Phase I Phase II Phase III	 1 6 26	 Until August, 1987 August, 1987 Feb., 1989
New York St. (Baffalo)	Bus	(GM)	6	Not determined
California (Los Angeles)	Truck	Manufacturer (not determined)	1 - 3	Middle of 1988
California Riverside	Bus	GM	3	March, 1987
California	Bus	GM	30	Summer of 1989

(Source) The Third Alcohol Fuel Special Committee, 1986

(4) Canada

Canada the major producer of methanol, is vigorously pursuing studies on the possible uses of methanol, and in particular the practical use of methanol fuel, in view of their huge resources of natural gas and coal, although they are not the manufacturer of any such vehicles.

Recently they joined such fleet test programs with six Ford Escorts in three pairs and FFV in view of low temperature startability.

In the bus and truck field, the Government project called MILE (Methanol In Large Engines) had started in 1985 and is scheduled to be continued until 1989. The scheme is listed in Table 7-4-8.

Table 7-4-8 Fleet Test Scheme in Canadian MILE Project

Base City	Test Region	Vehicles	Engine Manufacturer and No. of Vehicles	Start of Fleet Test
Winnipeg	Within City	Bus	GM 2 (6V92TA)	No. 1: Nov., 1986 No. 2: Dec., 1986
Medicin Hat	Within City	Bus	GM 2	No. 1: Dec., 1986 No. 2: Jan., 1987
Vancouver	Vancouver and Victoria	Bus	GM 2	No. 1: Feb., 1987 No. 2: Mar., 1987
Vancouver	Vancouver and Calgary	Truck	Caterpillar 2	Later than April, 1987
New York St.	(Buffalo)	Bus	GM 6	Not determined
(Toronto)	Not determined	Truck	Cummins 2-4	Not determined

(Source) The Third Alcohol Fuel Special Committee, 1986

(5) Japan

As the country who relies on 100% imported energy, the interest in alternative fuels was the strongest. However, because of stable petroleum supply and prices these days, methanol is not seriously considered as an alternative fuel, although the technological development had started in 1979 during the second fuel crisis. On the other hand Japan has the most stringent emission regulations in the world, and methanol is considered to be a favorable fuel to improve air pollution in big cities, and therefore fleet tests have recently been started by Ministry of Transport. The vehicles in operation are twenty two commerical vans converted from gasoline engines and thirty two commercial light truck with spark assist engines based on small diesel engines (3.3 ℓ) developed by Komatsu. The current situation of the diesel based methanol engines is shown in Table 7-4-9. Another fleet test for development of methanol cars is also planned by Ministry of International Trade and Industry, and as the part of it, the automobile fleet test was recently started in 1988.

Table 7-4-9 Fleet Test of Methanol Diesel Vehicles (As of July, 1988)

Region	Tokyo	Osaka	Kanagawa
No. of Vehicles	20	5	7
No. of Users	10	3	6
Vehicles Type	A, B	A	A
Test Period	3 years from Dec., 1986	2 years from Dec., 1987	3 years from May, 1988
Service Accum (km)			
Longest	42,000	16,000	7,000
Total	344,000	57,000	30,000
Average	17,200	11,400	4,300

(Source) VIII International Symposium on Alcohol Fuels, 1988

(6) Others

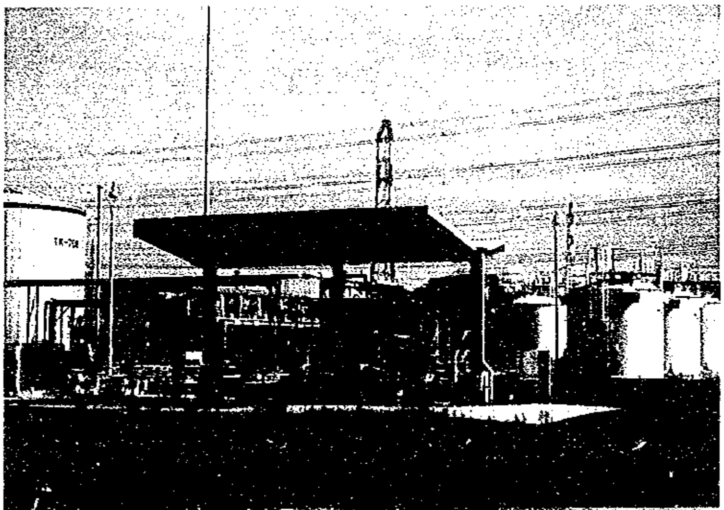
In Indonesia methanol utilization has been studied in Pertamina and Lemigas for blending into gasoline with/without an additive. This study is understood to have two backgrounds. One is the international trend of reducing or eliminating TEL in gasoline and the other one is the consideration of how to find the outlet for methanol from Bunyu.

In New Zealand, a new carburetor has been developed.

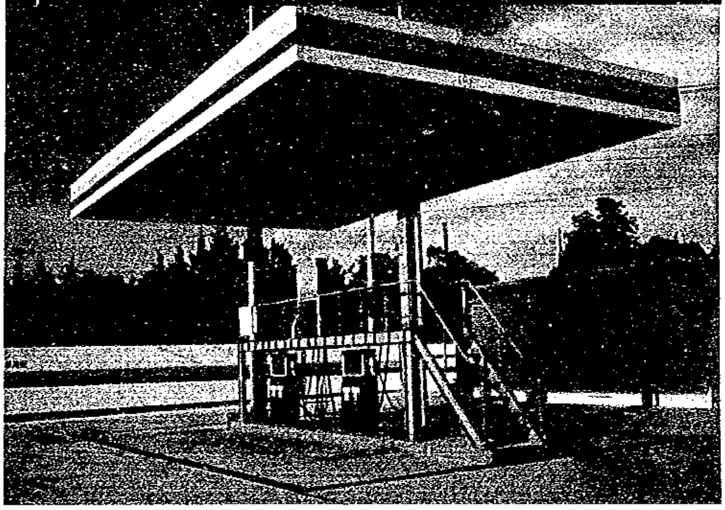
A road test of 80,000 km has been executed over two years, using a Toyota Corolla mounted with the newly developed carburetor. This caburetor is used for an FFV designed for using gasoline, methanol, and gas fuel. It has already been tested in Norway. Since there is no manufacturing plant for automobiles and engines in New Zealand, they find the gasoline based alcohol engine vehicle to be promising because a large-scale modification of the vehicle body is not required, and various kinds of fuel can be used.

Otto prototype vehicles running on M85 on the test track.

Fig. 7-4-15 Methanol - Fueled Vehicles



Blending facilities for near neat M85 fuel at the Kashima industrial complex in Ibaraki prefecture.



Filling station for near neat M85 fuel at Tsukuba Science City

Fig. 7-4-16 Fuel Methanol Supply Facilities

8. EVALUATION OF BANKO COAL CHARACTERISTICS BY GASIFICATION TEST

8-1 COAL GASIFICATION TEST FACILITIES

8-1-1 Introduction

The molten iron bath process was selected for coal gasification test facilities on the basis of the conclusion obtained by the study of the 1st stage.

The basic design was carried out on the basis of the concept of the test facilities designed on the Scope of Work.

The concept is as follows:

i) Capacity: Approximately 20 kg/h as coal, sufficient capacity necessary to grasp characteristics of gasification of brown coal

ii) Test facilities:
- Pretreatment unit of coal
- Gasification unit
- Post-treatment unit of produced gas
- Analysis equipment
- Utilities supply facilities
- Civil and architecture related above facilities
- Disposed treatment system, if necessary

8-1-2 Design on Coal Gasification Test Facilities

(1) Design Condition

1) Location

The facilities are constructed in the Pilot-Plant Building in PUSPIPTEK, Serpong, Jakarta, the Republic of Indonesia in accordance with the agreement on Scope of Work.

2) Capacity

The facilities have a capacity to generate minimum 40 Nm^3/h of produced gas, corresponding to minimum 20 kg/h feeding rate of pulverized coal, in order to make an accurate analysis of product gas component by minimizing the external disturbance.

Therefore the capacity of the test facilities is designed as follows:

i) maximum feeding rate of coal is 40 kg/h
ii) normal feeding rate of coal is 30 kg/h
iii) minimum feeding rate of coal is 20 kg/h

3) Other Design Conditions

The other design conditions such as climate data, materials, wastes and utilities are shown in Table 8-1-1 of ATTACHMENT 8-1.

(2) Process Flow Diagram of Coal Gasification Test Facilities

Process flow diagram and piping and instrumentation diagram of test facilities are shown in Fig. 8-1-1 and Fig. 8-1-2 of ATTACHMENT 8-1.

(3) General Layout

The major test facilities are installed inside the Pilot-Plant Building in PUSPIPTEK as shown in Fig. 8-1-3 and Fig. 8-1-4 of ATTACHMENT 8-1.
On the other hand, some utility equipments such as water cooling tower and a flare stack are constructed outside the building.

(4) Description and Specification of Coal Gasification Test Facilities

1) Coal Drying System

100 kg of raw coal having 35% moisture is dried in a chassis-typed dryer until its moisture content is reduced down to 5% in approximately one hour. After that, the dried coal is charged to a hopper of the coal pulverizer.

2) Coal Pulverize and Coal Injection System

A coal pulverize and coal injection system is composed of a coal pulverizer and a coal injector.
After charging to the hopper, the dried coal is pulverized into 0.074 mm particle in a hammer-typed pulverizer and the pulverized coal is gathered in a blow tank.
And then it is fed out in a predetermined amount, approximately 30 kg/h of coal, by a rotary feeder and transported pneumatically to a coal blowing lance by means of a carrier gas and nitrogen gas.

3) Melting Furnace

The molten iron required for coal gasification test is produced in a medium-frequency induction furnace from scrapped iron in approximately two hours. The molten iron produced is transported to a gasifier through a runner after being adjusted for its chemical composition, mainly carbon content, and for temperature.

4) Gasifier

The gasifier is lined with magnesia refractory bricks on an internal wall and equipped with a lance, through which both coal and oxygen are blown, and an induction coil to maintain the temperature of molten iron constant.

30 kg/h of pulverized coal, blown at a high speed with oxygen onto the surface of molten iron bath in the gasifier, is instantaneously gasified and 64.5 Nm^3/h of gas is produced.

The assemble drawings of the gasifier and the main lance are shown in Fig. 8-1-5 and Fig. 8-1-6 of ATTACHMENT 8-1.

During gasification, temperature and carbon content of molten iron in the gasifier are measured by a sub-lance.

Further main chemical compositions of molten iron and slag are measured by a iron analyzer and a slag analyzer.

5) Produced Gas Filtration System

A produced gas filtration system is composed of a water-cooled duct, a cyclone and a bug filter.

The produced gas in the gasifier is recovered through a hood directly connected to the gasifier.

The recovered gas is cooled and dedusted by the water-cooled duct, the cyclone and the bug filter.

Finally, it is burned at a flare stack and released into the atmosphere.

Moreover the recovered gas is sampled by a gas sampling equipment and chemical compositions of it are measured by some types of gas analyzers.

6) Slag Treatment System

A slag treatment system is composed of a slag pot and a slag pot car.

After the coal gasification test, the molten iron is discharged to the slag pot and then the molten iron is cooled naturally.

7) Partial Dust Collector

Fumes generated during molten iron transportation and coal gasification test are recovered by a partial dust collector.

8) Operation Room

A mimic panel, an operation console, an instrument panel and an air conditioner are installed in an operation room. The operation states for each equipment are indicated at the mimic panel.

The coal injector, the gasifier, the main lance, the hood for the gasifier and an induced draft fan are operated at the operation console.

Further, the other equipments such as the coal dryer, the coal pulverizer, the melting furnace, the sub-lance and the dust filtration system are operated at local.

Moreover indicators, announciators and recorders are set at the instrument panel.

8-1-3 Engineering and Construction of Coal Gasification Test Facilities

(1) Project Specification and Requisition

The technical specification of erection work and requisition were studied as shown in ATTACHMENT 8-1.

(2) Procurement and Construction Work

Bids were invited by JICA Indonesia for the construction of the coal gasification test facilities, so that P.T. TAISEI INDONESIA CONSTRUCTION was selected as the constructor. The construction work was started in October 1986.

Futhermore, JICA sent mechanical supervisors and electrical and instrumental supervisors to the site for the construction period.

After the coal gasification facilities were built up, the trial runs such as non-loading and loading tests of each piece of equipment, and hot commissioning had been conducted from January 1987 to March 1987.

The trial runs were successfully carried out although minor mechanical troubles were seen in the initial stage.

The schedule of the construction work and the trial run is shown in Table 8-1-2 of ATTACHMENT 8-1 and the sideview of the coal gasification test facilities is shown in Fig. 8-1-7.

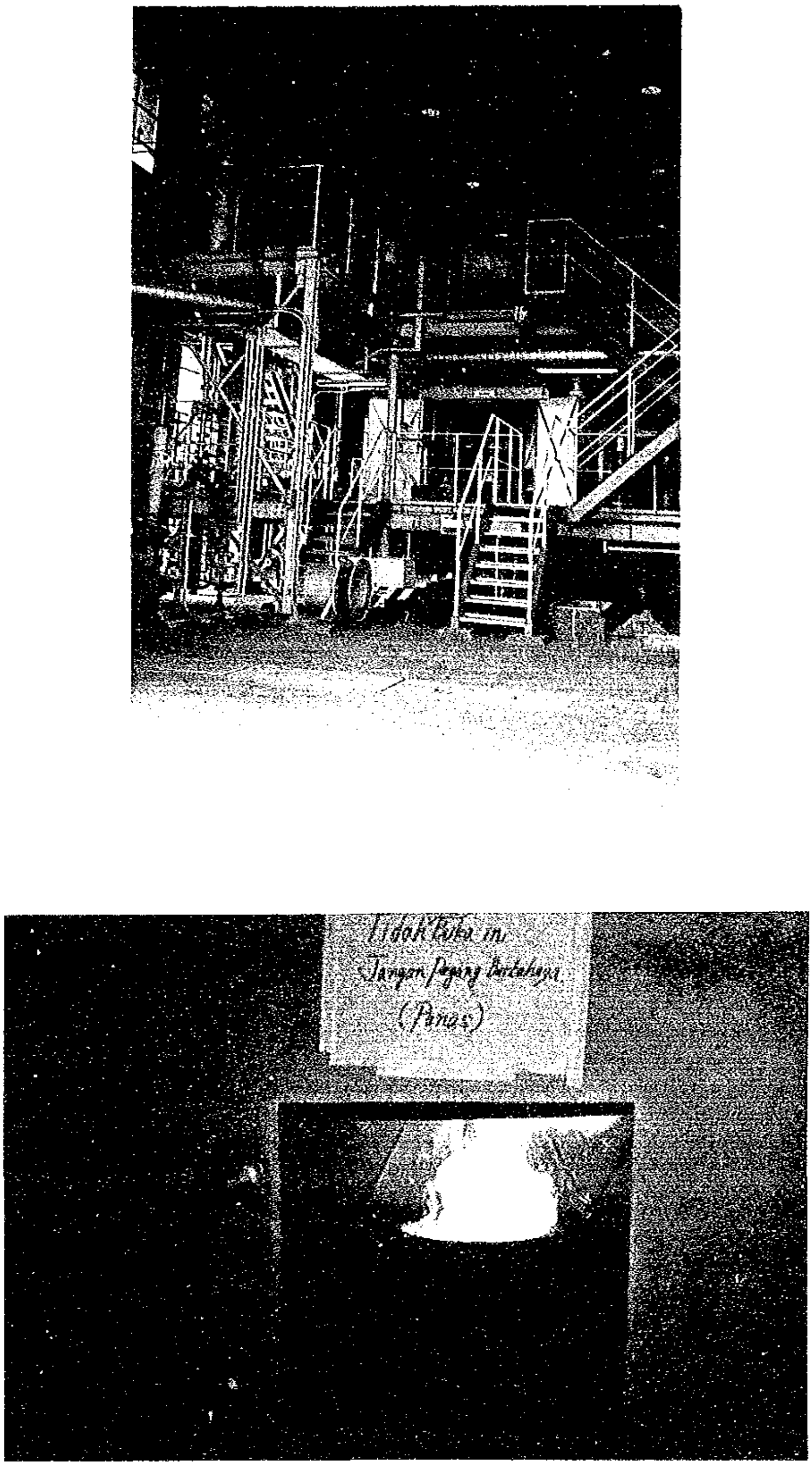


Fig. 8-1-7 Pictures of Coal Gasification Test Facilities

8-2 COAL GASIFICATION TEST

8-2-1 Progress Made in Test Program

Table 8-2-1 and Table 8-2-2 show progress made in the test program. To save the cost for gasification test and also to increase test times during limited schedules, 3 times of gasification test using 3 coal samples per one operation day were carried out. Table 8-2-1 shows the test program under open hood mode and Table 8-2-2 shows test program under closed hood mode.

During the open hood mode (up to CG010), gas samples were taken from the top of the gasifier by using a special gas sampling probe. In case of the closed hood mode (CG011 - CG021), gas samples were carried out through an on-line gas sampling device, which was connected to an on-line gas analyzer.

47 times of coal gasification test have been carried out in 1987, using 20 sorts of coal which were sampled at North West Banko (N.W. Banko), Central Banko (C. Banko) and North Suban Jeriji (North S.J.).

Characteristics of coal samples used in coal gasification tests are shown in Table 8-2-3. Outstanding difference can be found among coal samples in terms of oxygen content.

N.W. Banko coal has the lowest value but North S.J. coal the highest value. This is related to the difference in carbon content in coal which has completely opposite tendency. Table 8-2-4 shows analysis result of ash in each coal sample.

All of the coal samples were tested twice per coal samples, though some of the test may be excluded from data analysis because of too much fluctuation of data.

Test facilities were operated satisfactory through the test. However some of the test conditions and operation method were changed after CG010 on the basis of intermediate analysis and evaluation of test data. The details are explained in Section 8-2-2.

There was no personal damage as well as mechanical damage through the test operations. Wearing rate in refractory of gasifier is shown in Fig. 8-2-1. It is clear that wearing rate was much slower than expected as shown in Fig. 8-2-1. A fluidity of slag from ash which is one of the most important factors for commercialization of Banko coal gasification was also very good.

From these points of view, it can be expected that any technical difficulty would not be found in gasification of Banko coal by an molten iron bath process.

Table 8-2-1 Progress Made in Test Program
(Operation under Open Hood Mode)

No.	Date	Run No.	Coal samples
1	Aug. 19, '87	CG001	BUIA1/BUIIA1
2	Aug. 27	CG002	BSIA2/BSIIA2
3	Sep. 3	CG003	BUIIIB2
4	Sep. 8	CG004	BSIVB
5	Sep. 11	CG005	BSIC1
6	Sep. 16	CG006-1	BUIA2/BUIIA2
7		CG006-2	BUIIC1
8	Sep. 22	CG007-1	CBB1
9		CG007-2	CBB2
10		CG007-3	AR
11	Sep. 25	CG008-1	BUIIB1/BUIVB1/BUVB1
12		CG008-2	BSIA2/BSIIA2
13		CG008-3	AL
14	Sep. 30	CG009-1	SJE2
15		CG009-2	BJS
16		CG009-3	SJE1
17	Oct. 6	CG010-1	CBC
18		CG010-2	CBA1
19		CG010-3	CBA2

(Note) Coal samples tested in each run No. means as follows;

Coal basin name
BS: Southern part of N.W. Banko
BU: Northern part of N.W. Banko
CB: Central Banko
SJ: North Suban Jeriji
BJS: Banjarsari
AR: Arahan
AL: Airlaya

I : Drill hole number
II : ditto
III: ditto

Seam name
A1: Mangus I
A2: Mangus II
B1: Suban I
B2: Suban II
B: Suban I + Suban II
C: Petai
E1: Enim I
E2: Enim II
J: Jelawatan

Table 8-2-2 Progress Made in Test Program
(Operation under Closed Hood Mode)

No.	Date	Run No.	Coal sort
20	Oct. 9, '87	CG011-1	BSIA1/BSIIA1
21		CG011-2	BUIVA1
22		CG011-3	SJJ
23	Oct. 15	CG012-1	BUIIIB2
24		CG012-2	BSIC1
25		CG012-3	BSIVB
26	Oct. 20	CG013-1	BUIA2/BUIIA2
27		CG013-2	BUIIC1
28		CG013-3	BUIIB1/BUIVB1/BUVB1
29	Oct. 23	CG014-1	CBB1
30		CG014-2	CBC
31		CG014-3	SJJ
32	Oct. 27	CG015-1	AR
33		CG015-2	CBB2
34		CG015-3	AL
35	Oct. 30	CG016-1	BSIA2
36		CG016-2	SJE1
37	Nov. 5	CG017-1	CBA2
38		CG017-2	SJE2
39		CG017-3	CBA1
40	Nov. 18	CG019-1	BJS
41		CG019-2	BSIA1
42	Nov. 26	CG020-1	BSIVB
43		CG020-2	BSIIB2
44		CG020-3	BUIIA1
45	Dec. 2	CG021-1	BSIC1
46		CG021-2	BUIC1
47		CG021-3	CBC

Table 8-2-3 Characteristics of Feed Coal Samples just before Feeding to Gasifier

Coal basin		Seam	Analysis results (%)						
			Proximate		Ultimate (d.a.f)				
			Ash	Mois.*2	C	H	O	N	S
No. 1	BS I/II	A1	4.1	5.0	73.1	5.7	19.3	1.1	0.7
2	BS I/II	A2	4.3	5.0	75.7	5.9	17.0	1.2	0.2
3	BS I*1	C1	2.5	5.0	76.4	5.8	15.8	1.4	0.6
4	BS IV	B	4.3	5.0	73.1	5.7	19.7	1.1	0.3
5	BU I/II	A2	3.1	5.0	75.9	6.0	16.7	1.1	0.3
6	BU II*1	C1	1.8	5.0	74.5	5.4	18.3	1.4	0.5
7	BU II/IV/V	B1	3.9	5.0	73.2	5.7	19.0	1.2	1.0
8	BU III	B2	2.2	5.0	73.1	5.8	18.1	1.3	1.7
9	BU IV	A1	6.7	5.0	76.7	6.0	15.4	1.3	0.6
10	CB *3	A1	17.0	5.0	69.6	5.8	21.8	1.1	1.7
11	CB	A2	10.9	5.0	71.6	5.7	21.2	1.2	0.4
12	CB	B1	5.5	5.0	71.8	5.8	20.7	1.3	0.4
13	CB	B2	5.7	5.0	73.1	5.7	19.6	1.2	0.4
14	CB	C	5.8	5.0	72.2	5.9	20.1	1.5	0.4
15	SJ	E1	7.1	5.0	70.3	5.9	22.5	1.0	0.2
16	SJ	E2	2.5	5.0	70.4	5.5	22.8	1.1	0.2
17	SJ	J	11.4	5.0	67.8	5.7	25.2	1.1	0.3
18	BJS		4.0	5.0	68.5	5.7	24.1	1.2	0.5
19	AR		2.1	5.0	71.1	5.6	20.0	1.0	2.2
20	AL		14.4	5.0	73.2	6.1	17.2	1.2	2.3

(Note)

Coal basin
BS: Southern part of N.W. Banko
BU: Northern part of N.W. Banko
CB: Central Banko
SJ: North Suban Jeriji
BJS: Banjarsari
AR: Arahan
AL: Airlaya

Seam
A1: Mangus I
A2: Mangus II
B1: Suban I
B2: Suban II
B: Suban I + Suban II
C: Petai
E1: Enim I
E2: Enim II
J: Jelawatan

*1 There is some possibility of change in quality due to coal samples by pitting from surface layer.

*2 Estimated on basis of drying condition.

*3 There is some possibility of extraordinary value in ash content.

Table 8-2-4 Analysis Results of Ash in Coal

Coal sort	Ash content (dry base)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	LOI
BSI/IIA1	4.3	57.3	23.9	8.6	0.7	2.4	1.0	0.6	0.1	0.1	2.4	1.5
BSI/IIA2	4.5	64.6	8.5	5.9	0.5	6.6	1.9	0.2	1.8	0.4	6.0	0.8
BSIC1	2.7	61.1	7.4	6.4	0.4	7.4	3.0	0.1	0.2	0.1	8.3	1.1
BSIVB	4.5	38.6	28.5	3.9	1.1	12.7	4.3	0.3	1.8	0.1	6.0	1.0
BUI/IIA2	3.3	48.4	20.3	6.5	1.2	7.0	2.7	0.3	0.8	0.7	7.4	1.9
BUIIC1	1.9	49.7	36.2	7.2	1.7	1.1	0.3	0.1	0.2	0.2	0.9	2.3
BUII/IV/VB1	4.1	59.9	18.9	4.4	0.6	5.3	1.8	0.2	0.3	0.1	4.9	1.4
BUIIIB2	2.3	41.5	37.0	7.1	3.1	1.8	0.6	0.5	0.2	0.1	0.4	2.7
BUIVA1	7.1	67.0	18.5	7.4	0.6	1.1	0.2	0.4	0.1	0.1	0.3	1.5
CBA1	17.0	52.0	24.2	6.1	1.0	3.6	1.6	2.4	0.7	0.1	4.3	2.2
CBA2	10.9	73.7	13.7	2.9	0.6	2.8	0.7	0.6	0.4	0.1	3.0	1.2
CBB1	5.8	53.5	24.2	4.2	1.0	5.2	1.8	0.3	0.3	0.4	6.0	2.4
CBB2	6.0	69.6	13.5	4.4	0.5	3.0	1.2	0.1	0.1	0.1	3.9	3.0
CBC	6.2	41.8	24.8	6.5	1.0	9.8	4.2	0.2	0.2	0.4	6.8	2.5
SJE1	7.5	59.2	28.6	2.9	1.3	2.1	0.5	0.2	0.1	0.1	1.3	1.5
SJE2	2.7	62.2	22.2	5.2	1.1	1.5	0.4	0.3	0.1	0.1	1.7	2.2
SJJ	12.0	56.7	23.6	5.3	1.4	3.6	0.9	0.4	0.1	0.1	3.4	2.4
BJS	4.2	17.1	11.9	28.7	0.9	14.9	2.5	0.4	0.4	0.1	17.6	3.2
AR	2.3	35.6	13.8	14.0	0.7	9.9	13.5	0.1	0.1	0.1	10.3	tt
AL	15.1	55.2	27.6	6.8	0.9	1.6	1.4	1.3	1.8	0.1	1.5	1.2

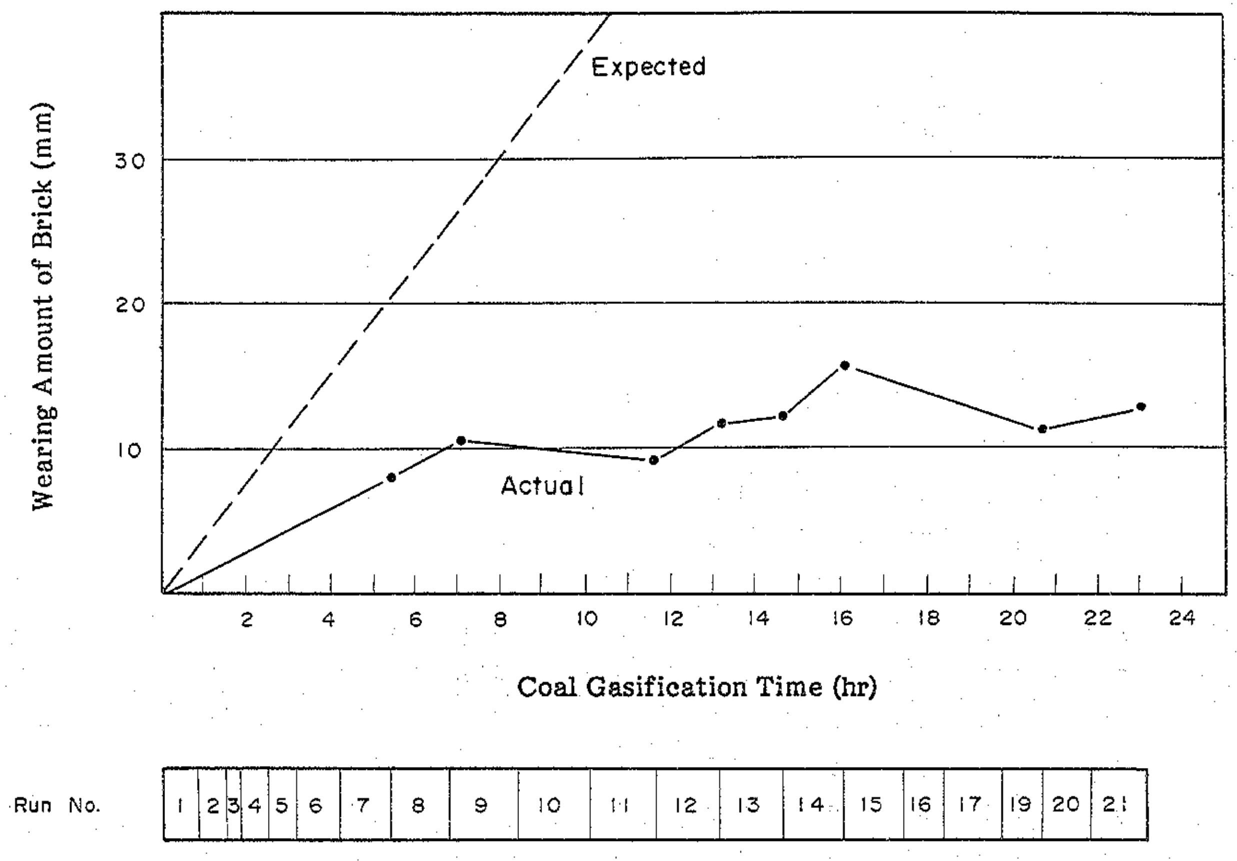
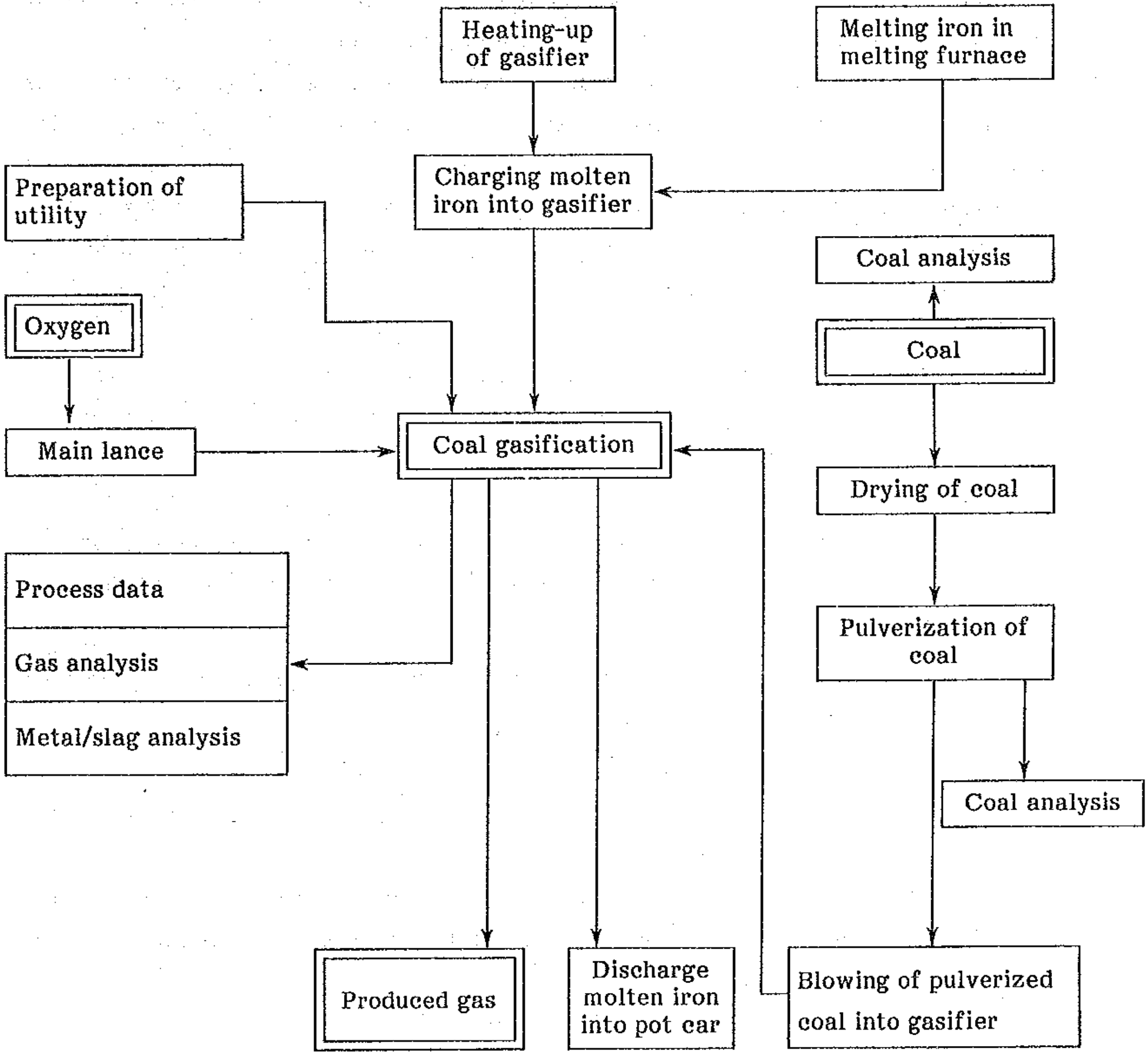


Fig. 8-2-1 Wearing Rate in Refractory of Gasifier

8-2-2 Method and Procedure of Test

Coal gasification tests were carried out based on the following procedure.



In advance to coal feed, 10~20 kg of raw coal is dried by coal dryer to the approximately 5% of free moisture and then pulverized below 200 mesh by coal pulverizer. Samples of pulverized coal are taken from the blow tank to be analyzed. Gasifier is preheated by LPG burner up to approximately 1,200°C and 300 kg of molten iron (approximately 1,550°C) is prepared by a melting furnace.

After charging molten iron into the gasifier, oxygen and thereafter pulverized coal is blown together onto molten iron with relatively high velocity through water cooled lance designed specially.

In case of open hood mode, the generated gas is completely mixed with induced air through clearance between the hood and gasifier and burn out. In case of closed hood mode, the hood is closed to recover generated gas and the gas is burnt out at a flare stack.

Normally gasification test is continued for 30 minutes for one coal sample. The gasifier is heated externally during gasification operation to maintain temperature of molten iron near to 1,500°C.

> Note: External heat device is required for small scale test facilities only because heat loss of a gasifier is larger in small scale than in large scale. Therefore, an external heating device is unnecessary for a commercial scale gasifier.

After CG011, test condition and operation methods were changed in order to achieve more steady and suitable operation of the gasifier as follows:

1) Coal feed rate was increased from 25 kg/h to 35 kg/h.
2) Washing of bag filter by pulsation of nitrogen gas was stopped during gasification operation.
3) Measurement of molten iron bath temperature by sub-lance was cancelled.
4) The flow rate of induced fan was controlled to minimize the absorbed air into the gasifier.
5) Measurement device of feed coal was modified.

By the above mentioned modifications of the methods and procedures of coal gasification operation, the data of generated gas composition (as recorded) showed obviously steady and reasonable values.

During and after coal gasification operation, the following materials were sampled to be analyzed.

Materials	Method for sampling
metal	from the gasifier by sub-lance and spoon
slag	from the gasifier by spoon
gas	from the gasifier by the probe or from gas cooler by on-line gas sampling device
dust	from bag filter and cyclone separator

Table 8-2-5 shows typical test condition. (For details, see ATTACHMENT 8-2 Test Condition.)

Table 8-2-5 (1) Typical Test Condition

TEST000-1

RUN	13 TH COAL GASIFICATION TEST RUN	RUN No.	CG013

DATE	1987.10. 20 . (Tue)

1.PURPOSE of RUN

1) INVESTIGATIONS of GASIFICATION-CHARACTERISTIC for BUIA2, BUIIC2 and BUIIB1

2.COAL SAMPLE and OPERATION CONDITION

COAL SAMPLE—A

Sample number	BUIA2, BUIIA2				
Proximate analysis		Ultimate analysis		Ash components	
Ash	3.29 %	C	75.91 %	SiO2	%
V.M.	46.08 %	H	6.03 %	Al2O3	%
F.C.	50.63 %	N	1.08 %	CaO	%
	%	O	16.73 %	K2O	%
		S	0.25 %	Na2O	%

(DRY BASE) (D.A.F)

OPERATION CONDITION—A

Weight of molten iron	300	Kg
Flow rate of Oxygen	18.5	Nm3/hr
Flow rate of carrier gas	10.0	Nm3/hr
Flow rate of pulverized coal	35.0	Kg/hr
Position of main-lance over bath surface	200	mm
Molten iron temperature		
on discharge to gasifier	1550	℃
on coal gasification	1500	℃
on discharge to pot car	—	℃
Basicity of slag	1.5	
Weight of coal	21	wet Kg
Weight of burnt lime	0	Kg

COAL SAMPLE— B

Sample number	BUIIC1				
Proximate analysis		Ultimate analysis		Ash components	
Ash	1.90 %	C	74.50 %	SiO2	%
V.M.	46.04 %	H	5.43 %	Al2O3	%
F.C.	52.06 %	N	1.36 %	CaO	%
	%	O	18.26 %	K2O	%
		S	0.45 %	Na2O	%

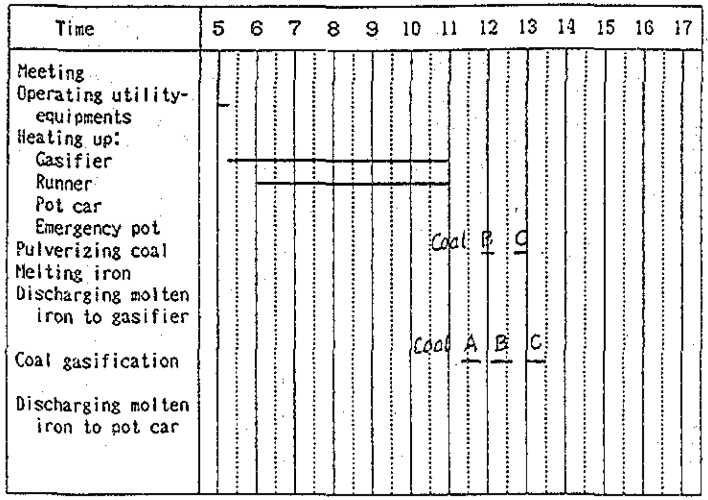
(DRY BASE) (D.A.F.)

OPERATION CONDITION— B

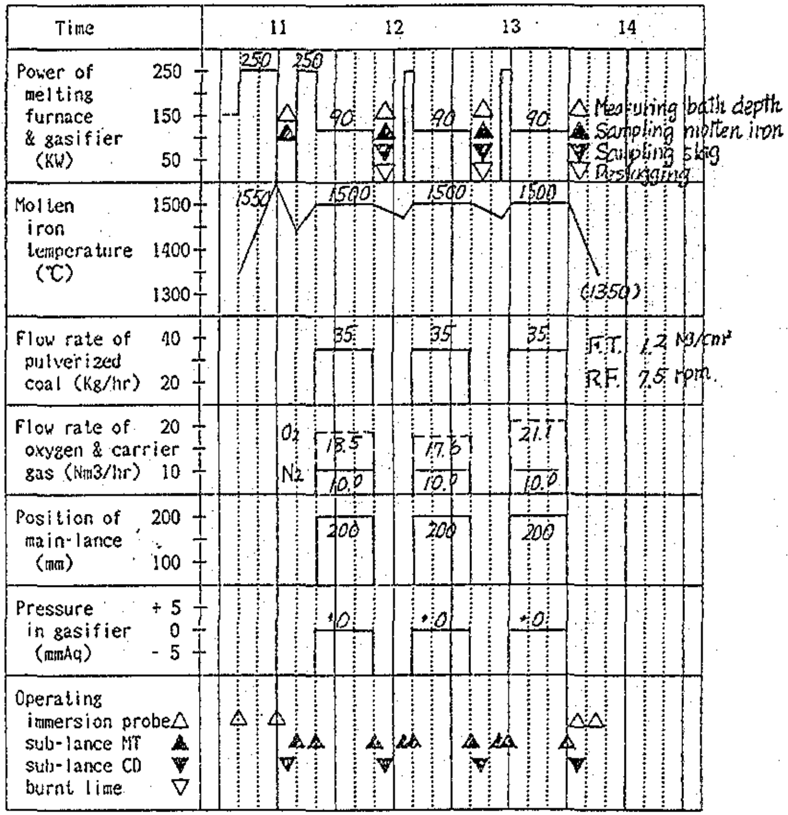
Weight of molten iron	300	Kg
Flow rate of Oxygen	17.6	Nm3/hr
Flow rate of carrier gas	10.0	Nm3/hr
Flow rate of pulverized coal	35.0	Kg/hr
Position of main-lance over bath surface	200	mm
Molten iron temperature		
on discharge to gasifier	--	℃
on coal gasification	1500	℃
on discharge to pot car	—	℃
Basicity of slag	1.5	
Weight of coal	21	wet Kg
Weight of burnt lime	0	Kg

Table 8-2-5 (2) Typical Test Condition

4.SCHEDULE



TEST000-2



8-2-3 Coal Samples for Coal Gasification Test

Coal Samples were obtained from North West Banko in FY1986/87, and, Central Banko and North Suban Jeriji in FY1987/88 by the means of large diameter core drilling principally to use for coal gasification tests at Serpong, as referred to Section 6-1-3.

(1) N.W.Banko

9 coal samples (in total about 2.2 t, see the following table), were obtained from the area in 1986/87, dividing the area into two parts i.e. northern and southern part (see Fig. 6-1-1) by the means of large diameter core drilling except C coal seam where a drilling machine was not transportable to the proper place next to the outcrop because of severe undulation (for details turn to Section 6-1-3).

<table>
<tr><th>Coal seam / Part</th><th>A_1</th><th>A_2</th><th>B_1</th><th>B_2</th><th>C</th></tr>
<tr><td>Northern</td><td>o</td><td>o</td><td>o</td><td>o</td><td>o</td></tr>
<tr><td>Southern</td><td>o</td><td>o</td><td colspan="2">o</td><td>o</td></tr>
</table>

Results of proximate, ultimated and ash component analysis are shown in Table 6-1-7 to Table 6-1-9.

(2) Central Banko

5 coal samples (in total about 0.6 t, see the following table), were obtained from each coal seam in the area in FY1987/88, by the means of large diameter core drilling (for details turn to Section 6-1-3).

A_1	A_2	B_1	B_2	C
o	o	o	o	o

Analysis results are shown in Table 6-1-7 and Table 6-1-8.

(3) North Suban Jeriji

3 coal samples (in total about 0.4 t, see the following table) were obtained in FY1987/88 (for details turn to Section 6-1-3).

Jelawatan	Enim 1	Enim 2
o	o	o

Analysis results are shown in Table 6-1-7 and Table 6-1-8.

Furthermore, 3 coal samples were obtained at Banjarsari (Enim 2 coal seam) Arahan (A_2 coal seam) and Air Laya pit of Bukit Asam Coal Mine to compare their gasification characteristics with those of coal samples obtained in the Banko area (including Suban Jeriji) after getting permission of DOC and PTBA.

8-2-4 Coal Gasification Data

The following test conditions can be regarded as typical values through the coal gasification tests:

Coal ; approximate 25 kg/h for CG001 - CG011
approximate 35 kg/h for CG012 - CG020
Carrier gas (N_2) ; approximate 10 Nm^3/h
Oxygen ; 8 - 21 Nm^3/h, depending on coal characteristics and coal feed rate
Molten iron temperature ; approximate 1,500°C
Carbon content in molten iron ; approximate 4%

Coal gasifications test up to CG005 should be regarded as reference because the tests were carried out in view point of hot commissioning (mechanical test through the gasifier operation) for test facilities.

Major test data of each test run which seem representative are shown in following tables and figures:

Table 8-2-6	Major Test Conditions (Open Hood Mode)
Table 8-2-7	Major Test Conditions (Closed Hood Mode)
Table 8-2-8	Recorded Gas Composition (Open Hood Mode)
Table 8-2-9	Recorded Gas Composition (Closed Hood Mode)
Table 8-2-10	Analysis Results of Dust
Table 8-2-11	Analysis Results of Metal
Table 8-2-12	Analysis Results of Slag
Fig. 8-2-2	Typical Operation Results

Table 8-2-6 Major Test Conditions (Open Hood Mode)

Run No.	Feed and flow rate			Lance height (mm)	Metal temperature (°C)	Carbon content in metal (%) *	Gasification test period (minute)
	Coal (kg/h)	N_2 (Nm^3/h)	O_2 (Nm^3/h)				
CG001							46
CG002	26.0	10.0	9.9	200	1520		33
CG003	24.1	10.0	10.5	↓	1530		22
CG004	26.7	10.0	7.6		1520	3.76/4.00	38
CG005	32.5	10.1	14.7		1550/1490	3.83/4.03	27
CG006-1	27.8	10.1	13.9		1490/1510	3.86/3.92	22
CG006-2	25.9	10.1	14.1		1500/1550	3.92/4.01	38
CG007-1	23.0	10.0	11.9		1490/1520	3.79/3.82	27
CG007-2	24.0	10.1	12.9		1510/1550	3.82/3.80	23
CG007-3	24.5	10.0	12.9		1495/1530	3.80/3.83	27
CG008-1	26.5	10.0	13.0		1500	3.92/4.01	29
CG008-2	26.2	10.0	14.0		1520	4.01/3.84	25
CG008-3	22.6	10.0	12.2		1510/1530	3.83	40
CG009-1	26.2	10.0	12.1		1490/1480	3.81/3.83	26
CG009-2	24.3	10.0	11.5		1510	3.83/3.76	32
CG009-3	24.0	10.0	11.7		1480/1540	3.76/3.83	27
CG010-1	26.2	10.0	14.7		1500/1530	3.89/3.82	32
CG010-2	28.1	10.0	11.6		1490/1520	3.82/3.76	34
CG010-3	24.1	10.0	13.1		1540	3.76/3.69	36

(Note)

* Estimated with solidification temperature of metal by sub-lance.

Table 8-2-7 Major Test Conditions (Closed Hood Mode)

Run No.	Feed and flow rate			Lance height (mm)	Metal temperature ($^{\circ}$C)	Carbon content in metal (%) *	Gasification test period (minute)
	Coal (kg/h)	N_2 (Nm^3/h)	O_2 (Nm^3/h)				
CG011-1	25.7	10.1	15.8	200	1510/1540	3.8/4.0	31
CG011-2	25.5	10.0	16.1		1500/1565	4.0/3.8	30
CG011-3	24.8	10.0	11.5		1520	3.8/3.9	31
CG012-1	38.2	10.0	20.5		1490/1480	4.1	24
CG012-2	32.6	10.0	19.1		1505/1550	4.1/4.3	47
CG012-3	39.0	10.0	20.6		1510/1520	4.3	31
CG013-1	31.5	10.0	19.6		1515/1480	4.0/4.2	29
CG013-2	31.8	10.0	17.6		1520/1525	4.2/4.1	38
CG013-3	35.6	10.0	20.9		1490/1520	4.1/4.2	29
CG014-1	35.7	10.0	14.3		1500/1470	4.1/4.2	29
CG014-2	33.5	10.0	14.4		1510/1470	4.2/4.3	27
CG014-3	34.9	10.0	13.5		1500/1470	4.3	27
CG015-1	38.1	10.0	14.7		1505/1450	4.1/4.2	27
CG015-2	34.4	10.0	14.6		1500	4.2/4.1	28
CG015-3	39.0	10.0	13.8		1510/1490	(4.1)	28
CG016-1	37.3	10.0	15.7		1520/1490	4.1/4.2	26
CG016-2	37.5	10.4	13.9		1510/1490	4.2	24
CG017-1	37.6	10.4	13.7		1530/1540	4.3	25
CG017-2	42.9	10.2	16.0		1490/1510	4.2/4.3	24
CG017-3	31.2	10.0	12.2		1510/1560	4.3	30
CG019-1	39.0	10.0	13.5		1490/1500	4.1	27
CG019-2	34.0	10.1	18.2		1485/1490	4.1	26
CG020-1	38.6	10.3	15.0		1520/1500	4.1/3.9	27
CG020-2	39.9	10.0	15.4		1500/1510	3.9/4.1	22
CG020-3	35.0	10.4	16.4	↓	1500/1530	4.1/4.1	24

(Note)

* Estimated with solidification temperature of metal by sub-lance.

Table 8-2-8 Recorded Gas Composition (Open Hood Mode)

(dry base)

Run No.	CO (%)	CO_2 (%)	H_2 (%)	O_2 (%)	N_2 (%)	CO/CO_2 (-)	H_2S (ppm)	COS (ppm)
CG001								
CG002								
DG003								
CG004	26.2	10.7-12.5	9.1-10.5	0	49.6	2.3	-	-
CG005	26.1-33.9	14.6-15.5	7.6-10.4	0	39.1-48.5	2.0	-	-
CG006-1	22.4-28.9	14.5-17.3	6.3-9.9	0	48.1-48.5	1.6	-	-
CG006-2	15.9-23.4	15.2-17.0	4.5-7.4	0	44.2-57.9	1.2	-	-
CG007-1	15.6-22.8	16.0-18.4	4.7-7.5	0	52.4	1.1	-	-
CG007-2	12.7-27.6	17.9-19.7	1.5-7.7	0	44.2	1.1	-	-
CG007-3	24.4-35.7	14.4-16.6	8.1-10.9	0	42.5	1.9	-	-
CG008-1	29.3-38.1	12.4-14.9	10.7-14.1	0	31.2-43.5	2.5	-	-
CG008-2	26.0-33.4	12.2-15.6	9.0-19.2	0	34.5-41.8	2.1	-	-
CG008-3	25.4-35.4	15.0-17.0	8.2-10.9	0	35.9-41.1	1.9	-	-
CG009-1	21.5-31.3	14.1-18.2	8.7-12.9	0	33.5-43.6	1.7	-	-
CG009-2	27.8-37.2	13.3-14.8	11.0-14.6	0	27.0-37.8	2.4	-	-
CG009-3	24.0-31.3	14.6-17.3	8.4-11.1	0	35.7-37.2	1.7	-	-
CG010-1	13.4-19.4	18.0-20.4	2.2-3.9	0	63.2-63.9	0.9	-	-
CG010-2	14.8-26.5	14.6-18.3	3.6-7.0	0	51.6-64.7	1.3	-	-
CG010-3	10.1-31.3	16.6-21.8	1.7-9.4	0	48.7	1.3	-	-

Table 8-2-9 Recorded Gas Composition (Closed Hood Mode)

(dry base)

Run No.	CO (%)	CO_2 (%)	H_2 (%)	O_2 (%)	N_2 (%)	CO/CO_2 (-)	H_2S (ppm)	COS (ppm)
CG011-1	13.8-28.3	14.9-21.3	1.9-8.6	0.2-0.6	49.3-55.3	1.2	0	40
CG011-2	18.2-34.8	20.6-27.6	2.4-9.8	0.2	33.1-46.6	1.2	0	56
CG011-3	27.3-33.9	11.8-14.3	8.6-13.0	0.2-0.3	43.0-47.9	2.4	17	60
CG012-1	39.7-43.8	10.6-13.4	15.2-17.4	0.4-0.5	24.3-34.6	3.5	454	227
CG012-2	39.9-42.2	13.3-14.6	12.8-14.3	0.4-0.5	27.1-28.2	3.0	0	40
CG012-3	45.9-47.3	10.2-11.9	16.5-18.6	0.4-0.5	22.0	4.3	17	71
CG013-1	43.2-44.8	12.3-13.4	15.2-16.4	0.4	22.6-26.9	3.4	0	74
CG013-2	39.4-43.5	12.4-14.9	12.7-15.9	0.4-0.5	24.8-27.4	3.0	34	95
CG013-3	40.4-45.9	10.7-14.5	11.9-16.5	0.4-0.5	24.1-27.8	3.6	77	134
CG014-1	29.2-32.1	7.9-8.8	12.8-15.2	0.2-0.3	41.0-45.3	3.7	3	48
CG014-2	28.3-35.6	5.9-9.8	10.9-17.0	0.3	40.4-46.7	4.4	7	55
CG014-3	23.1-33.3	7.2-13.5	8.1-16.7	0.3-0.4	43.3-46.9	3.0	5	44
CG015-1	42.6-47.1	7.2-10.0	17.6-21.9	0.3	23.2-27.3	5.5	0	40
CG015-2	23.6-40.9	8.3-19.4	6.9-20.5	0.3	29.6-45.4	2.9	0	56
CG015-3	39.9-45.8	6.5-11.1	17.1-25.4	0.3	20.5-29.5	5.2	300	200
CG016-1	35.1-45.9	8.0-10.9	14.1-20.3	0.2-0.3	26.9-39.3	4.5	0	44
CG016-2	42.7-45.3	8.5-10.5	18.9-22.4	0.2	24.8	4.6	0	49
CG017-1	33.9-41.0	11.3-16.0	11.1-17.5	0.2	32.6	3.0	0	61
CG017-2	41.0-43.0	11.1-13.1	15.5-17.5	0.2	26.7	3.5	218	200
CG017-3	36.2-39.1	11.2-13.9	14.4-17.9	0.2	28.9-31.0	3.0	1	55
CG019-1	36.8-41.7	9.5-11.5	18.0-22.8	0.1	22.5	3.6	0	0
CG019-2	44.6-45.2	10.8-12.3	17.0-18.5	0.1	22.5	3.9	0	122
CG020-1	31.3-36.8	6.9-9.8	13.4-17.7	0.1	26.5	4.3	0	0
CG020-2	38.5-43.2	8.1-11.1	16.2-20.1	0.1	26.5	4.4	0	81
CG020-3	42.2-43.4	9.4-10.5	17.2-18.8	0.1	25.3-30.4	4.3	37	129

Table 8-2-10 (1) Analysis Results of Dust

Run No.	Sampling place	Dust amount (kg)	Proximate				Ultimate				
			Moisture (106°C)(%)	Ash (%)	V.M (%)	F.C (%)	S (%)	C (%)	H (%)	N (%)	O (%)
CG003	CY *1		54.0	23.9	12.7	9.4	0.8	18.2	6.1	0.5	50.5
	BF										
CG004	CY	0.2	1.5	74.7	20.5	3.3	0.5	18.2	0.5	0.4	5.7
	BF		1.9	40.1	18.6	39.4	1.3	49.7	0.4	1.0	7.6
CG005	CY		1.0	87.4	11.7	0.0	0.6	9.2	0.3	0.3	2.3
	BF		2.5	46.0	20.1	31.4	1.3	43.8	0.7	0.8	7.4
CG006	CY		1.6	81.8	16.6	0.0	0.4	14.7	0.3	0.4	2.4
	BF		1.4	58.5	22.0	18.1	1.3	33.3	0.4	0.7	5.8
CG007	CY	0.6	1.2	82.0	16.5	0.3	0.2	14.3	0.2	0.4	2.8
	BF		2.2	72.0	22.2	3.6	1.0	18.0	0.5	0.6	7.9
CG008	CY	1.3	1.0	81.8	13.4	3.8	0.3	14.8	0.3	0.2	2.5
	BF		1.9	75.8	22.3	0.0	0.8	18.0	0.2	0.4	4.8
CG009	CY	0.6	1.5	78.2	18.3	1.9	0.5	17.2	0.4	0.4	3.5
	BF		1.5	78.8	17.7	2.0	0.7	15.7	0.2	0.3	4.3
CG010	CY		1.2	82.3	16.5	0.0	0.9	13.2	0.4	0.4	2.8
	BF		1.4	79.1	16.2	3.3	0.7	15.1	0.3	0.4	4.5
CG011	CY *1	1.3	50.2	37.2	10.5	2.1	0.3	11.8	5.8	0.2	44.7
	BF		2.0	76.9	17.8	3.4	1.1	15.4	0.5	0.3	5.9
CG12	CY	1.4	6.7	68.8	19.0	5.5	1.2	23.7	1.0	1.1	4.2
	BF		2.5	64.3	16.9	16.4	1.5	28.9	0.5	0.5	4.3

(Note)

CY : Cyclone separator
BF : Bag filter

*1: Some possibility of extraordinary value in analysis result of dust.

Table 8-2-10 (2) Analysis Results of Dust

Run No.	Sampling place	Dust amount (kg)	Proximate				Ultimate				
			Moisture (106°C)(%)	Ash (%)	V.M (%)	F.C (%)	S (%)	C (%)	H (%)	N (%)	O (%)
CG013	CY	2.6	8.2	61.5	15.3	15.0	0.6	68.6	5.1	1.7	24.6
	BF		1.0	67.6	20.0	11.3	1.5	68.1	5.1	1.6	25.3
CG014	CY	2.9	1.3	56.6	19.8	22.5	0.3	68.0	5.1	1.4	25.5
	BF		1.1	51.6	12.4	34.6	0.7	68.0	5.0	1.3	25.6
CG015	CY	4.2	2.7	53.4	17.2	26.8	0.4	67.7	4.8	1.5	26.3
	BF		1.1	51.3	9.9	37.6	1.0	68.3	4.8	1.4	25.5
CG016	CY	2.5	1.2	78.2	19.8	0.8	0.4	68.6	4.8	1.4	25.2
	BF		1.7	62.3	14.7	21.3	1.4	67.1	4.8	1.4	25.9
CG017	CY	4.3	1.2	60.1	11.5	27.2	-	68.1	4.9	1.3	25.7
	BF		1.5	61.7	10.9	26.3	-	67.7	4.8	1.4	26.1
CG019	CY	2.7	1.5	63.4	10.7	24.4	-	-	-	-	-
	BF		1.2	62.3	11.0	25.6	-	-	-	-	-
CG020	CY	3.0	1.8	59.9	18.2	20.2	-	-	-	-	-
	BF		2.2	56.0	23.0	18.9	-	-	-	-	-

Table 8-2-11 Analysis Results of Metal

	C (%)	S (%)		C (%)	S (%)		C (%)	S (%)
CG004-1	3.76	0.046	CG010-1	3.89	0.046	CG015-1	3.83	0.049
CG004-2	4.00	0.052	CG010-2	3.82	0.052	CG015-2	4.13	0.051
CG005-1	3.83	0.050	CG010-3	3.76	0.087	CG015-3	4.26	0.060
CG005-2	4.03	0.059	CG010-4	3.69	0.092	CG015-4	4.39	0.117
CG006-1	3.86	0.045	CG011-1	3.84	0.046	CG016-1	3.84	0.048
CG006-2	3.92	0.050	CG011-2	3.84	0.060	CG016-2	4.17	0.054
CG006-3	4.01	0.059	CG011-3	3.66	0.063	CG016-3	4.25	0.059
CG007-1	3.79	0.047	CG011-4	3.81	0.078			
CG007-2	3.82	0.053	CG012-1	4.33	0.046	CG017-1	4.05	0.052
CG007-3	3.80	0.057	CG012-2	4.31	0.092	CG017-2	4.06	0.059
CG007-4	3.83	0.059	CG012-3	4.19	0.106	CG017-3	4.06	0.091
CG008-1	3.92	0.062	CG012-4	4.08	0.108	CG017-4	4.00	0.092
CG008-2	3.99	0.068	CG013-1	3.88	0.049	CG019-1	3.81	0.046
CG008-3	3.83	0.118	CG013-2	4.19	0.057	CG019-2	3.89	0.041
CG009-1	3.81	0.045	CG013-3	4.30	0.068	CG019-3	4.23	0.065
CG009-2	3.83	0.048	CG013-4	4.39	0.090			
CG009-3	3.76	0.062	CG014-1	3.89	0.047	CG020-1	3.82	0.041
CG009-4	3.82	0.057	CG014-2	4.08	0.058	CG020-2	3.99	0.062
			CG014-3	4.21	0.065	CG020-3	4.22	0.072
			CG014-4	4.18	0.069	CG020-4	4.35	0.096

Table 8-2-12 Analysis Results of Slag

	SiO_2 (%)	CaO (%)	Al_2O_3 (%)	P_2O_5 (%)	MgO (%)	MnO (%)	T.Fe (%)	S (%)
CG004	42.81	3.92	13.81	0.101	24.80	6.39	3.53	0.044
CG005-1	50.86	2.80	7.67	0.111	22.29	8.67	4.52	0.053
CG005-2	50.84	1.95	5.86	0.105	18.43	11.04	8.54	0.051
CG006-1	47.37	2.82	11.03	0.092	25.27	7.36	2.94	0.048
CG006-2	46.07	2.28	10.88	0.086	26.57	7.30	4.25	0.051
CG007-1	43.92	5.10	19.63	0.114	16.53	5.91	4.05	0.031
CG007-2	45.35	2.98	11.90	0.117	20.89	8.05	6.15	0.036
CG007-3	46.02	3.80	6.53	0.124	17.44	9.63	13.24	0.037
CG008-1	43.61	3.35	12.92	0.105	20.74	7.98	4.65	0.052
CG008-2	44.28	2.96	14.93	0.102	19.15	8.43	4.09	0.050
CG008-3	42.76	1.38	11.96	0.101	15.69	10.24	11.61	0.065
CG009-1	46.55	2.00	13.23	0.096	14.69	9.56	8.48	0.034
CG009-2	46.79	4.18	15.78	0.111	13.76	8.95	5.08	0.042
CG009-3	45.27	2.57	15.91	0.108	11.74	10.30	7.63	0.035
CG010-1	40.73	3.62	23.74	0.103	14.94	8.61	4.23	0.034
CG010-2	46.46	3.09	20.60	0.101	11.01	9.08	5.71	0.054
CG010-3	50.38	2.25	13.48	0.094	13.24	10.53	6.97	0.047
CG011-1	43.63	1.86	14.85	0.096	13.38	10.53	11.98	0.036
CG011-2	44.27	2.05	12.96	0.088	10.31	12.12	11.82	0.038
CG011-3	47.34	1.32	12.34	0.086	11.98	10.59	11.28	0.040

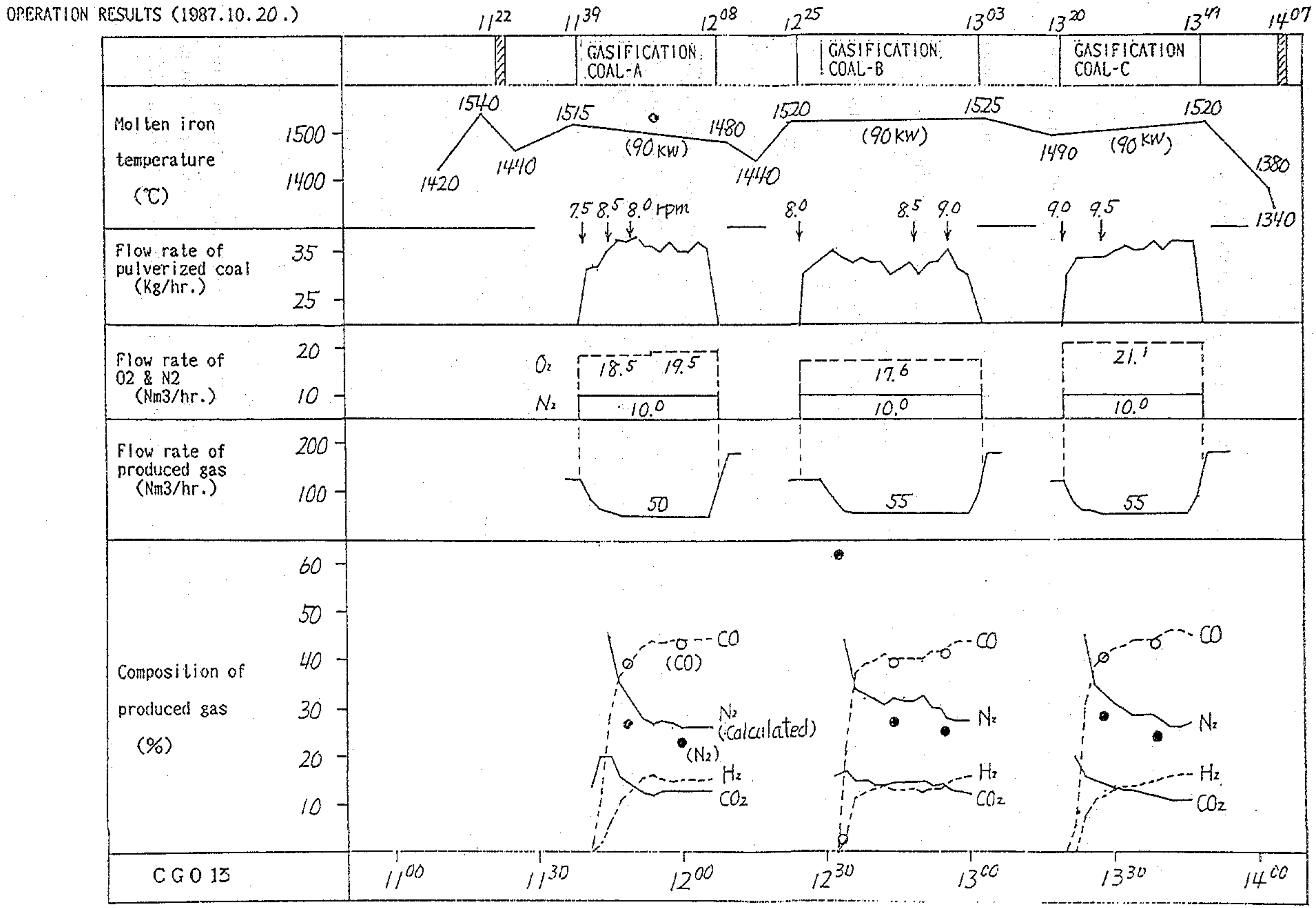


Fig. 8-2-2 Typical Operation Result

8-3 ANALYSIS AND EVALUATION OF COAL GASIFICATION DATA

8-3-1 Reliability of Test Data

Almost of test operation were successful.

However, test data obtained by open hood mode operation (up to CG010) shows some fluctuations in the gas compositions.

In order to get high reliability of test the data, test method was changed to closed hood mode operation after CG011.

All improvements for operation method and procedure described in Section 8-2-2 gave more stable and reasonable data with less fluctuation.

However as Table 8-2-8 and Table 8-2-9 show, there are still some fluctuations in gas composition even in such a modified test method and procedure.

It could be estimated that such a fluctuation in gas composition was mainly caused by unstable operation conditions of the gasifier and difficulty of gas sampling of real generated gas.

In particular, gas composition sampled should be effected by the amount of induced air from clearance between the hood and the gasifier. Therefore at first real gas compositions generated in the gasifier must be estimated. Next reliability must be evaluated on the basis of real gas compositions.

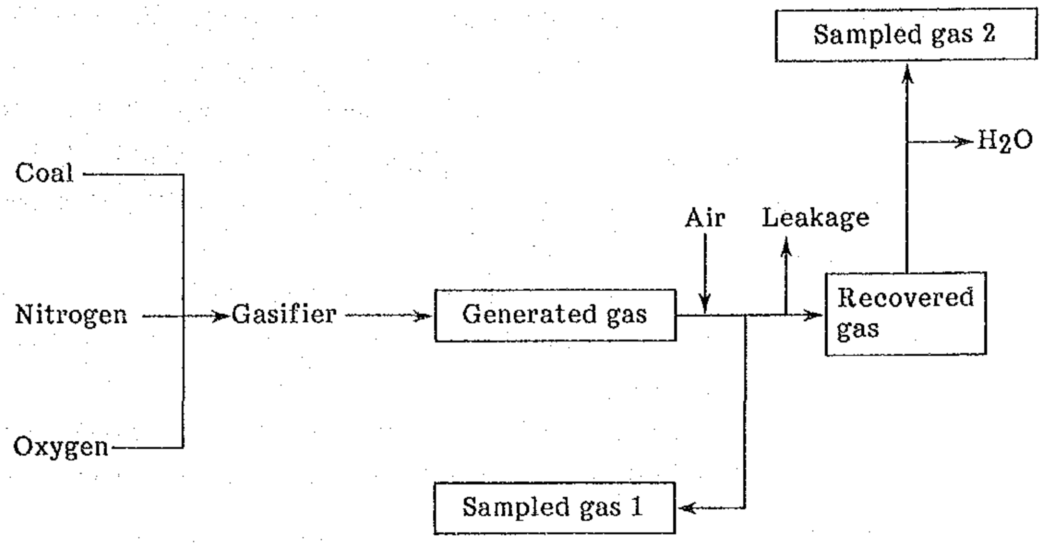
(1) Estimation of Real Gas Composition Generated in Gasifier

Recorded test data show a relatively high content of CO_2 and N_2 in sampled gas as well as fluctuation of the data, especially in the case of open hood operations.

This can be explained by assuming that an air induced into generated gas through the hood burns partially CO and H_2 in generated gas before gas is sampled.

Therefore, gas components indicated in Table 8-2-8 and Table 8-2-9 are not evaluated as representative of real generated gas.

Real generated gas compositions can be estimated from sampled gas (recorded gas) by mean of material balance for H_2, O_2 and N_2 based on the following material flow. The details of calculation method are shown in ATTACHMENT 8-3.



Sampled gas 1 and 2 means sampled gas composition under open hood mode and closed hood mode, respectively.

Table 8-3-1 and Table 8-3-2 show estimation results of real generated composition based on the material balance.

Average values of recorded data in Table 8-2-8 and Table 8-2-9 were used for the estimation.

Ratio of CO/CO_2 is one of the most important items to estimate reliability of coal gasification test data.

In these tests, CO/CO_2 ratio ranges roughly from 3 to 8.

There were some runs such as CG006 that real generated gas composition could not be estimated because ratio of O_2/coal was not reasonable, too small compared with past experience.

As it can be easily understood by the data of these Table 8-3-1 and Table 8-3-2, it was confirmed that recorded gas compositions were effected by mixed air.

(2) Effects of Scale Factor on Gas Composition

As shown in Table 8-3-1 and Table 8-3-2, content of CO_2 in gas seems still rather higher than that of expected values through past experience in large scale test plants.

This can be explained by taking an effect of scale factor into consideration.

According to some investigations related to Basic Oxygen Furnace (BOF) in steel making field, oxygen efficiency for decarburization depends very much on oxygen flow rate which corresponds to the converter scale of BOF as shown in Fig. 8-3-1. It decreases rapidly when oxygen flow rate is low. This means oxygen has much bigger possibility to react with generated CO instead reacting with C in molten iron in small scale.

Fig. 8-3-2 shows relationship between oxygen flow rate and gas ratio (CO/CO_2) which can be introduced from Fig. 8-3-1. The less the oxygen flow rate is, the lower the gas ratio (CO/CO_2) is.

According to past experiences of coal gasification tests in larger scale test plants of molten iron bath process, nearly the same tendency can be seen as shown in Fig. 8-3-2.

In the above-mentioned gasification test, the oxygen flow rate was widely changed from 8 Nm^3/h to 21 Nm^3/h, resulting the value of CO/CO_2 in the range of 3 to 7.

As it is clear in Fig. 8-3-2, the test data obtained in this test is highly reliable in view of CO/CO_2 range. Furthermore gasification performance is easily estimated from Fig. 8-3-2, namely approximately 15 to 20 for ratio of CO/CO_2 can be expected in commercial scale gasification plant.

Table 8-3-1 Estimation Results of Real Gas Generated in Gasifier (Open Hood Mode)

Run No.	Real gas estimated										
	CO (%)	CO_2 (%)	H_2 (%)	N_2 (%)	H_2O (%)	Amount (Nm^3/coal-t)	CO/CO_2 -	H_2S (ppm)	COS (ppm)	Mixed air (Nm^3/h)	Leakage gas (Nm^3/h)
C G006-1											
C G006-2	44.0	6.4	19.8	19.4	10.5	2210	6.9	-	-	35.4	-
C G007-1	42.3	6.2	21.0	21.0	9.5	2300	6.8	-	-	34.2	-
C G007-2	37.0	8.2	14.7	22.1	17.9	1970	4.5	-	-	25.5	-
C G007-3	35.2	8.9	14.6	21.9	19.4	1620	3.9	-	-	12.7	-
C G008-1	34.4	8.4	15.4	21.5	20.4	1430	4.1	-	-	9.1	-
C G008-2	41.0	7.6	22.8	19.1	9.5	1830	5.4	-	-	19.1	
C G008-3	31.8	10.1	12.3	24.6	21.2	1470	3.2	-	-	7.9	-
C G009-1	35.0	9.0	17.5	21.4	17.2	1610	3.9	-	-	15.7	-
C G009-2	32.6	9.2	14.0	23.0	21.2	1440	3.5	-	-	6.8	-
C G009-3	32.1	9.3	13.8	23.3	21.5	1550	3.5	-	-	11.8	-
C G010-1	45.5	5.4	19.2	18.5	11.5	2350	8.5	-	-	47.8	-
C G010-2	37.0	6.6	16.4	22.0	18.1	1660	5.6	-	-	25.6	-
C G010-3	38.8	8.9	15.6	21.7	15.1	1880	4.4	-	-	22.1	-

Table 8-3-2 Estimation Results of Real Gas Generated in Gasifier (Closed Hood Mode)

Run No.	Real gas estimated										
	CO (%)	CO_2 (%)	H_2 (%)	N_2 (%)	H_2O (%)	Amount (Nm^3/coal-t)	CO/CO_2 -	H_2S (ppm)	COS (ppm)	Mixed air (Nm^3/h)	Leakage gas (Nm^3/h)
C G011-1	44.1	9.5	19.5	18.7	7.9	2150	4.7	0	0	35.4	25.2
C G011-1	24.3	17.8	6.6	23.3	27.9	1720	1.4	0	40	2.8	4.3
C G011-3	40.5	8.2	17.7	22.0	11.3	1860	4.9	17	61	12.2	15.3
C G012-1	44.9	7.4	19.0	14.6	13.6	1850	6.1	0	0	12.8	21.1
C G012-2	40.9	9.2	15.4	17.1	17.1	1880	4.4	0	33	8.7	7.8
C G012-3	45.2	7.6	18.3	14.5	13.9	1820	5.9	14	60	7.0	12.5
C G013-1	41.9	9.5	15.8	16.6	15.9	1960	4.4	0	55	5.8	9.6
C G013-2	40.4	9.8	15.1	17.9	16.4	1820	4.1	0	81	7.0	4.9
C G013-3	46.0	8.2	17.2	15.0	13.2	1930	5.6	67	117	11.0	17.2
C G014-1	31.0	7.6	14.6	19.2	27.3	1500	4.1	0	46	0.1	4.6
C G014-2	37.1	5.9	17.8	18.6	20.4	1660	6.3	7	57	0.7	1.5
C G014-3	35.1	6.4	17.7	17.9	22.6	1650	5.4	5	45	3.0	5.0
C G015-1	39.2	5.6	18.1	17.4	19.6	1550	7.0	0	31	3.3	3.6
C G015-2	39.8	6.7	18.5	18.2	16.5	1650	6.0	3	46	13.0	11.4
C G015-3	38.5	6.0	21.1	21.1	19.1	1380	6.4	289	170	1.1	1.4
C G016-1	39.6	5.3	18.0	17.3	19.6	1590	7.4	0	32	7.5	9.0
C G016-2	34.7	7.2	16.2	18.9	22.9	1500	4.9	0	37	0.8	2.0
C G017-1	31.3	8.4	13.0	20.4	26.7	1390	3.7	0	43	3.3	2.1
C G017-2	35.6	7.7	14.8	17.0	24.7	1450	4.6	158	145	5.0	12.9
C G017-3	36.2	8.5	16.9	21.4	16.9	1540	4.3	7	43	5.6	5.1
C G019-1	35.0	9.0	17.5	21.4	17.2	1550	3.9	0	0	15.7	0.0
C G019-2	43.7	8.4	18.2	16.3	13.3	1860	5.2	0	101	6.1	14.2
C G020-1	33.8	5.7	16.3	18.0	26.1	1530	5.9	0	0	2.8	2.1
C G020-2	33.2	5.6	15.7	17.7	27.9	1470	6.1	0	0	1.7	5.4
C G020-3	33.5	7.7	14.2	19.3	25.3	1590	4.4	0	0	0.3	2.8

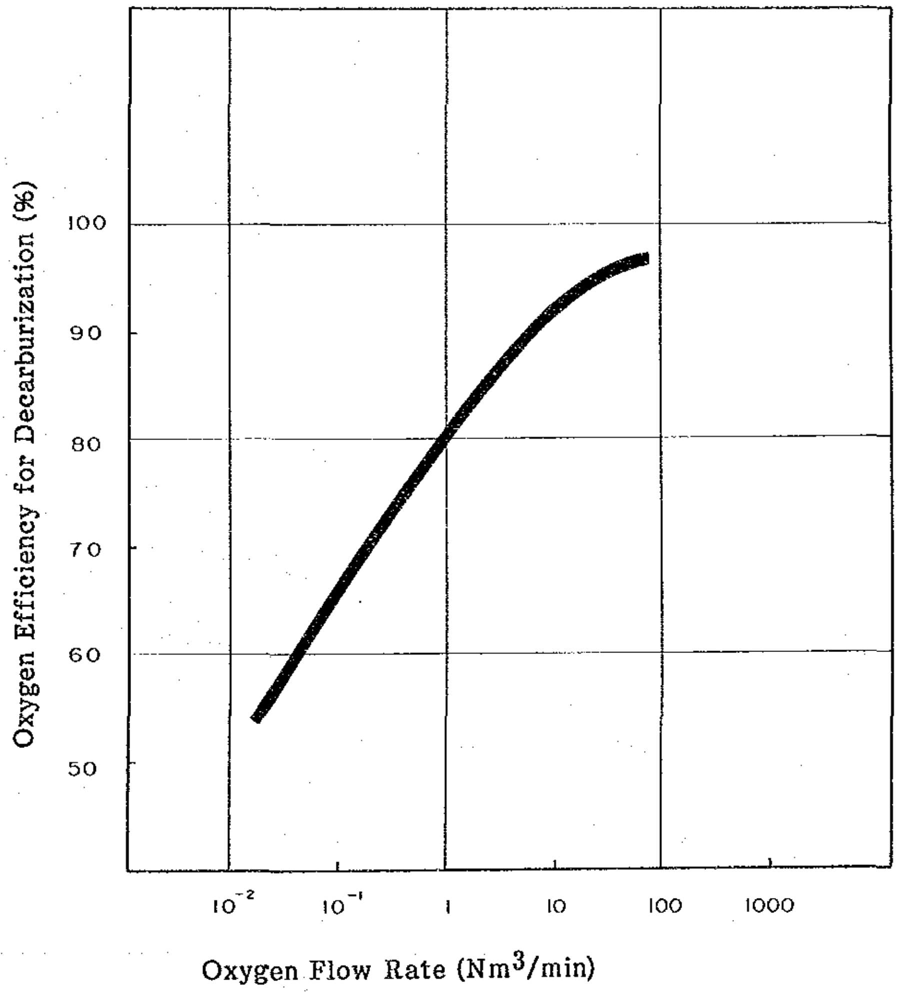


Fig. 8-3-1 Relationship between Oxygen Flow Rate and Oxygen Efficiency

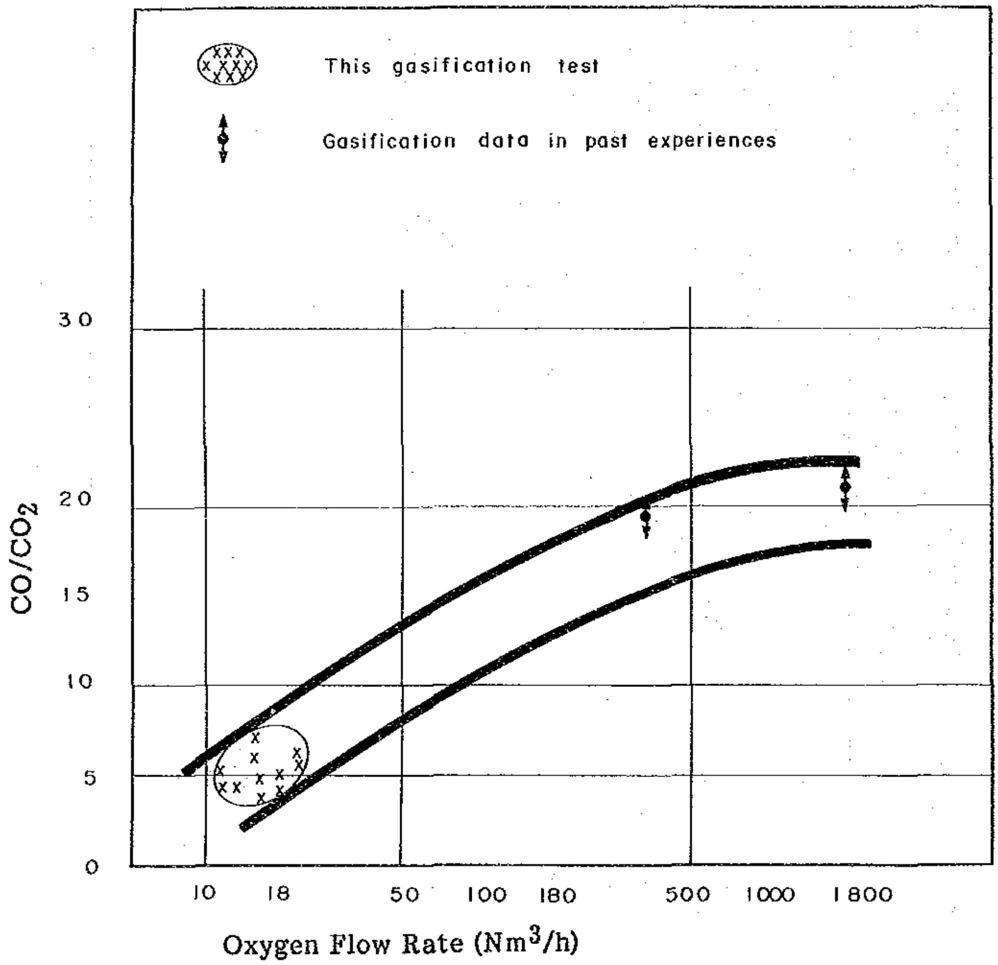


Fig. 8-3-2 Relationship between Oxygen Flow Rate and Gas Ratio, CO/CO_2

8-3-2 Correlation between Coal Quality and Characteristics of Gasification

As mentioned above the test data obtained in coal gasification test series from CG006 to CG020 is really reliable. Table 8-3-1 and Table 8-3-2 show gas composition estimated by material balance based on recorded gas composition and test conditions. Table 8-3-3 shows gas composition calculated on the basis of actual values which should be obtained under stoichiometric operation between O_2 and coal.

Furthermore Fig. 8-3-3 shows the effect of C/H ratio in coal on the estimated and calculated gasification performance for each seam. There still remain some factors to be corrected in the estimated value. However, the estimation value meets very well with calculation one as a basic trend.

Therefore the calculated values are used as the value to investigate on correlation between coal quality and characteristics of gasification. In coal gasification performances, items to be paid attention are CO/H_2 ratio in generated gas and generated gas amount.

In the following gasification performance are investigated for coal seam and coal basin.

(1) By Coal Seam

Fig. 8-3-3 and 8-3-4 show effect of coal quality such as C/H ratio and ash content in coal on gasification performance for respective seams.

As clear from Fig. 8-3-3 and 8-3-4, gasification performance such as CO/H_2 ratio in gas and generated gas amount is surely effected by coal quality. Namely, the higher C/H ratio (excluding hydrogen in moisture in coal) in coal is the higher CO/H_2 ratio in gas becomes and the less ash content in coal is, the more generated gas amount is.

However as far as C/H ratio in coal is concerned, there is little distinct correlation between coal quality and coal seam in the Banko area, if it is compared with subbituminus coal and bituminus coal.

Table 8-3-3 Calculated Values under Stoichiometric Operation

Coal	CO (%)	CO_2 (%)	H_2 (%)	N_2 (%)	H_2O (%)	Gas amount (Nm^3/coal-t)	O_2 consumption (Nm^3/h)	O_2 consumption (Nm^3/coal-t)	Actual operation Coal (kg/h)	Actual operation O_2 (Nm^3/h)
BSI/IIA1	44.3	7.5	16.2	19.5	12.3	1670	15.0	582	25.7	15.8
BSI/IIA2	45.0	7.6	16.3	18.6	12.4	1713	16.2	620	26.2	15.7
BSIC1	47.1	8.0	16.7	15.4	12.6	1750	21.0	644	32.6	19.0
BSIVB	47.6	8.0	17.3	13.8	13.1	1659	22.6	578	39.0	20.6
BUI/IIA2	46.4	7.8	17.0	15.7	12.9	1747	20.0	634	31.5	19.6
BUIIC1	47.3	8.0	16.1	16.2	12.2	1695	19.3	607	31.8	17.6
BUII/IV/VB1	46.9	7.9	17.1	14.8	12.9	1670	20.8	585	35.6	20.9
BUIIIB2	47.1	8.0	17.4	13.7	13.2	1713	23.1	604	38.2	20.5
BUIVA1	44.6	7.5	16.2	19.2	12.3	1697	15.9	623	25.5	16.1
CBA1	42.5	7.2	16.7	20.5	12.6	1411	12.9	460	28.1	11.6
CBA2	42.7	7.2	16.0	21.8	12.1	1524	12.4	513	24.1	13.1
CBB1	46.2	7.8	17.4	15.2	13.2	1630	19.8	555	35.7	14.3
CBB2	46.6	7.9	17.0	15.6	12.9	1635	19.5	569	34.4	14.6
CBC	45.6	7.7	17.4	16.0	13.2	1637	18.8	561	33.5	14.4
SJE1	45.6	7.7	17.9	15.2	13.5	1595	19.6	523	37.5	13.9
SJE2	44.4	7.5	16.3	19.4	12.3	1629	14.2	542	26.2	12.1
SJJ	41.8	7.1	16.5	22.0	12.5	1464	11.4	458	24.8	11.5
BJS	42.6	7.2	16.6	20.9	12.6	1598	12.5	513	24.3	11.5
AR	47.0	7.9	17.3	14.0	13.1	1671	21.8	572	38.1	14.7
AL	45.6	7.7	17.8	14.8	13.5	1530	20.8	534	39.0	13.8

(Note) Except carrier gas amount

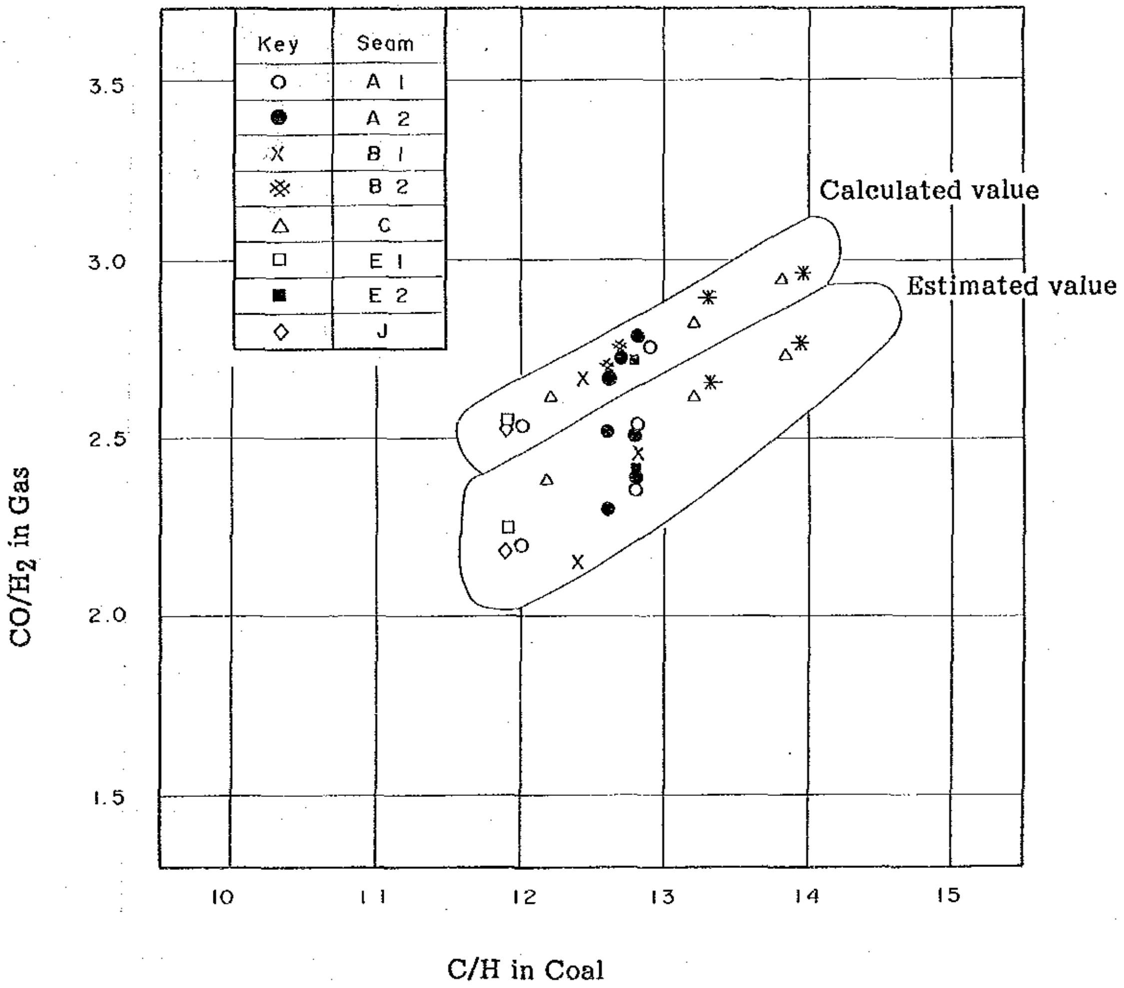


Fig. 8-3-3 Effect of C/H in Coal on Gasification Performance for Each Seam

(Note) Coal marked with * has high probability of aging in quality due to coal samples by pitting.

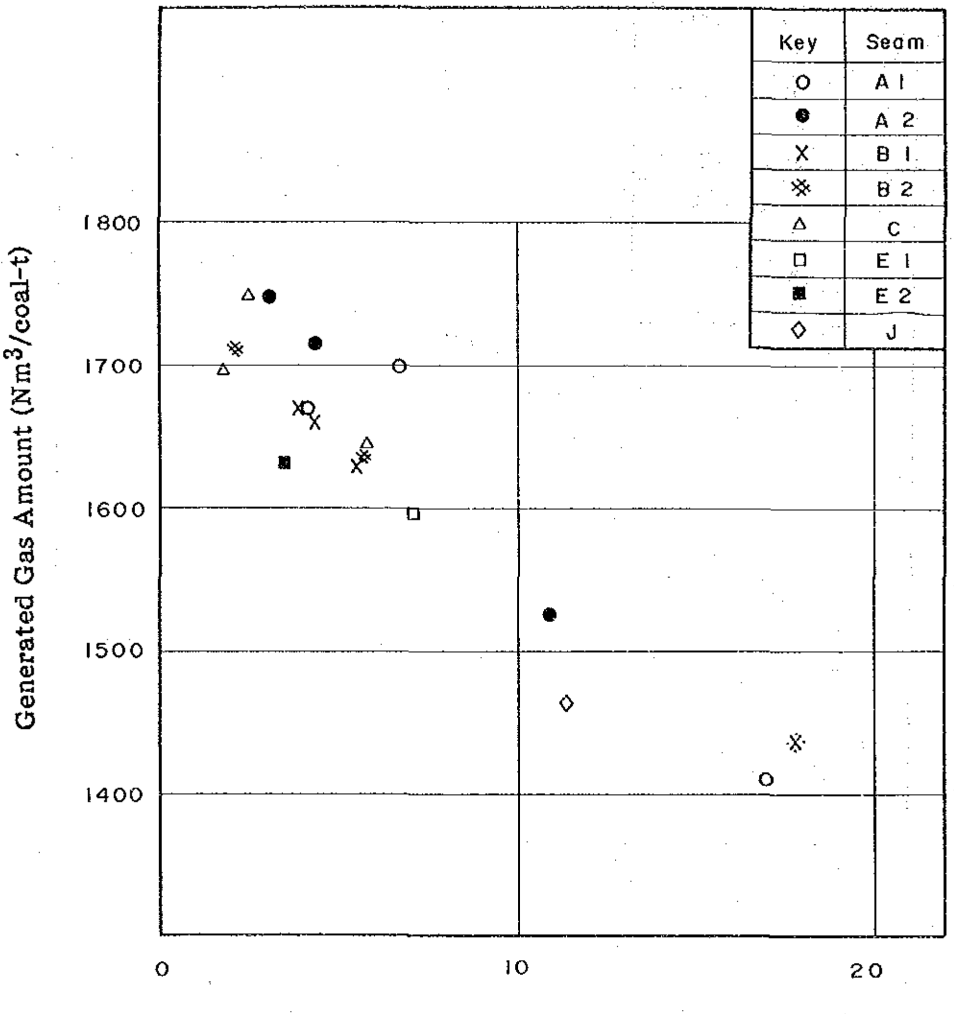


Fig. 8-3-4 Effect of Ash Content in Coal on Gasification Performance for Each Seam

(Note) Coal marked with * has high probability of extraordinary value in ash content.

(2) By Coal Basin

In the same way the effects of coal quality by coal basin on coal gasification performance are shown in Fig. 8-3-5, 8-3-6 and 8-3-7.

Correlation between coal basin and coal gasification performance such as CO/H_2 ratio in gas, generated gas amount and oxygen consumption can be surely recognized.

At first as for CO/H_2 ratio in gas, N.W Banko coal has highest ratio of CO/H_2 in all basins and C. Banko coal follows next.

In the case of North S.J. coal, CO/H_2 ratio in gas is the lowest because carbon included in it is rather small.

Next, generated gas amounts are mostly dominated by ash content in coal. It looks as though some influence of coal basin is not negligible. That is to say N.W. Banko coal can generate the biggest amount of gas in three coal basins.

C. Banko coal occupies second position and in case of North S.J. coal, the generated gas amount is the smallest due to high oxygen content in coal.

Finally, oxygen consumption can be determined by the following modified carbon amount in coal as shown in Fig. 8-3-7.

Modified carbon amount (kg mole/t-coal)
= carbon amount in coal - oxygen amount in coal

From the view-point of coal basin, N.W. Banko coal requires the largest amount of oxygen to be blown for coal gasification.

C. Banko coal and North S.J. coal follows next place.

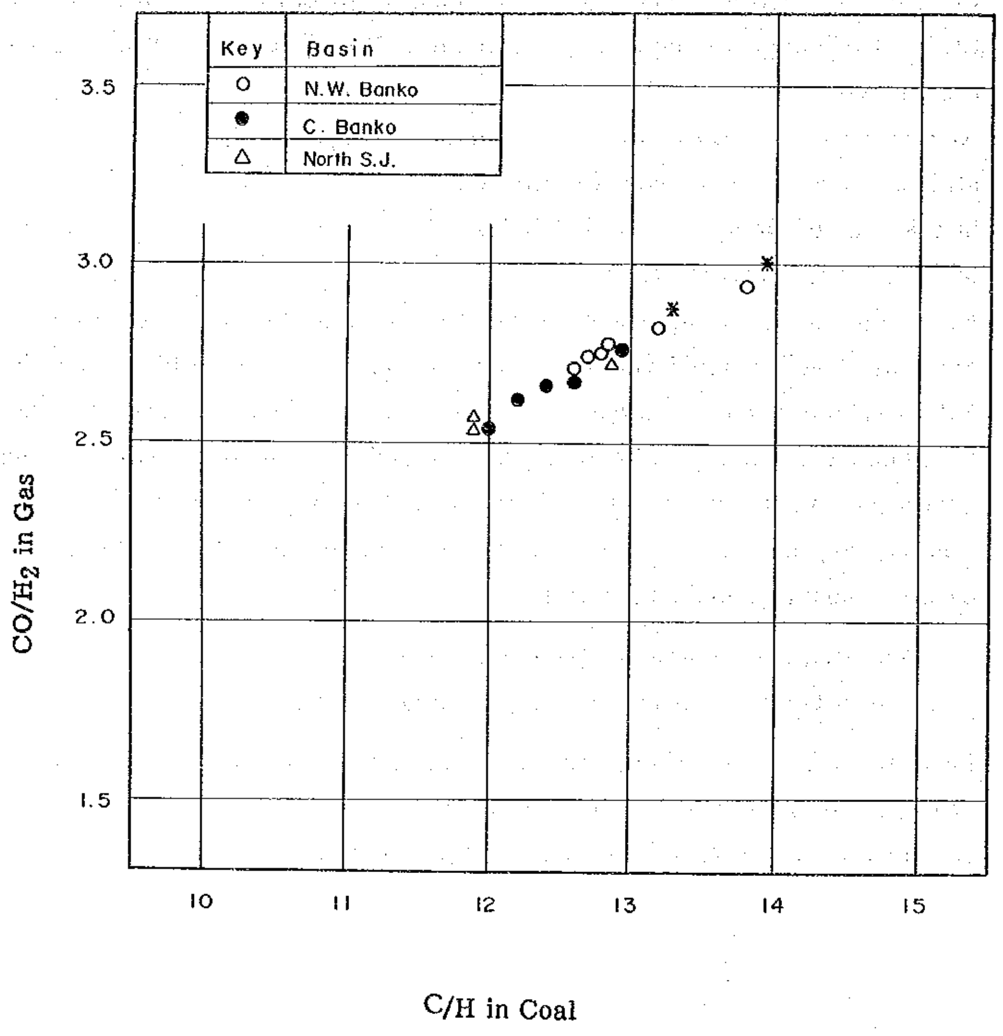


Fig. 8-3-5 Effect of C/H in Coal on Gasification Performance for Each Basin

(Note) Coal marked with * has high probability of aging in quality due to coal samples by pitting.

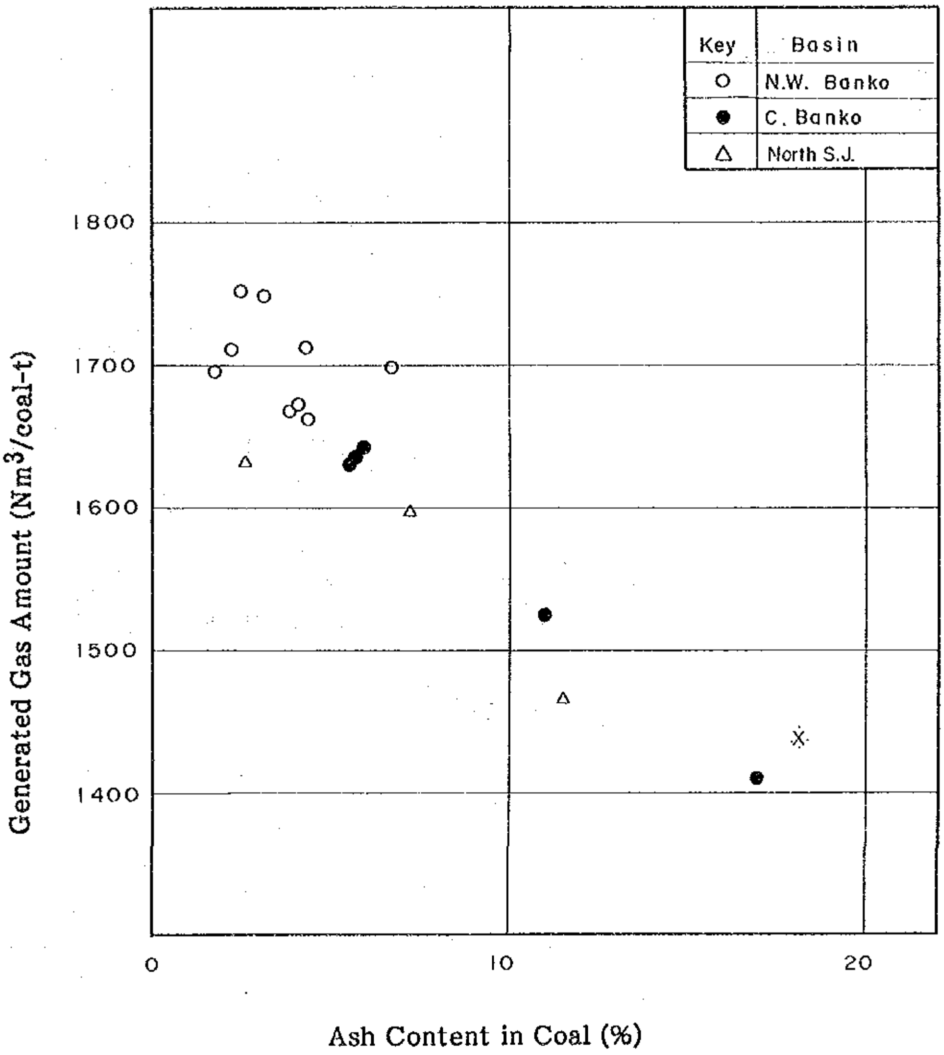


Fig. 8-3-6 Effect of Ash Content in Coal on Gasification Performance for Each Basin.

(Note) Coal marked with * has high probability of extraordinary value in ash content.

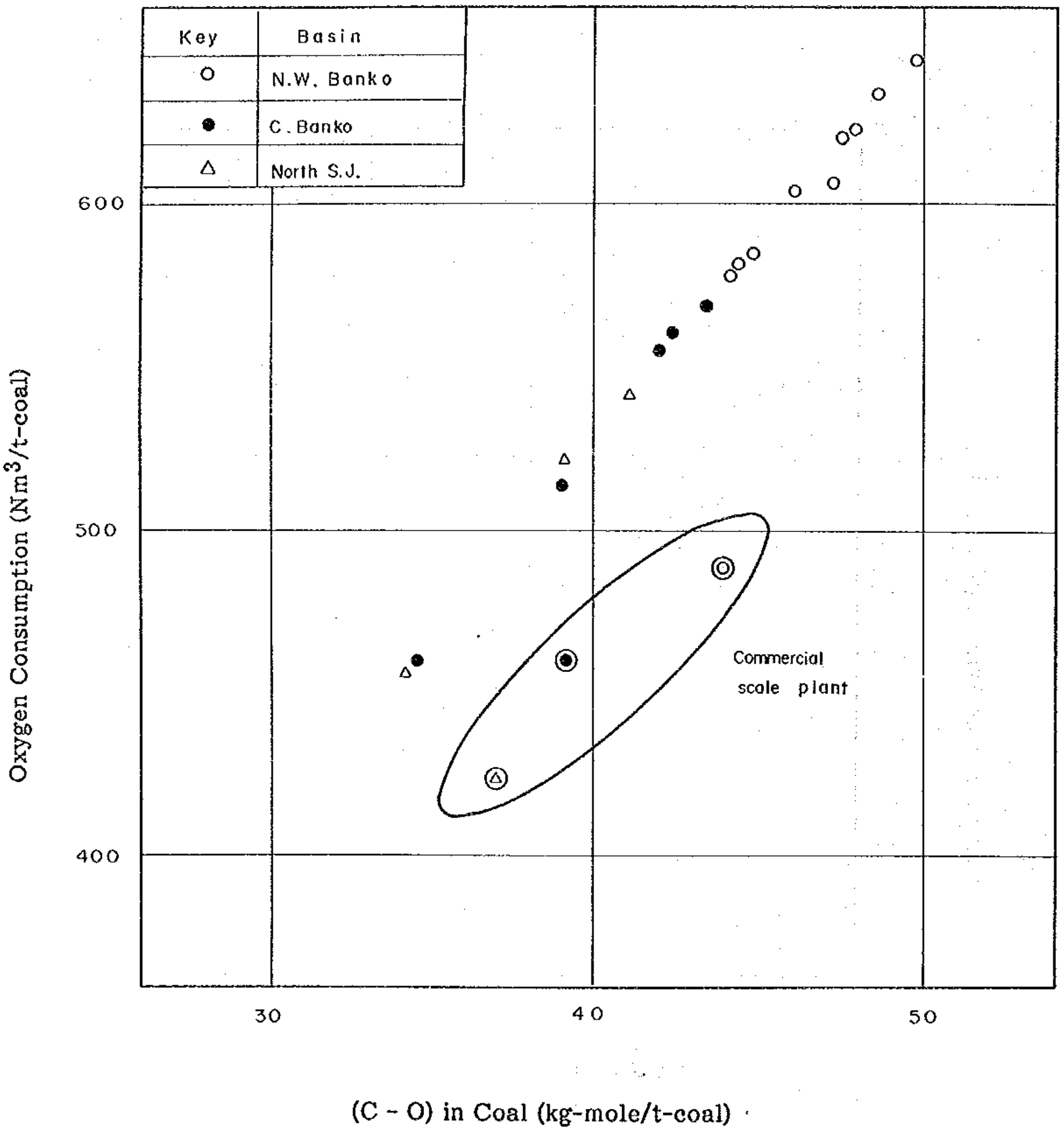


Fig. 8-3-7 Relationship between Oxygen Consumption and Coal Basin

8-3-3 Basic Process Data for Plan of Commercial Scale Gasification Plant

(1) Raw Materials

The main raw materials required in the molten iron bath process are coal, lime and iron scrap.

Coal reserved in Banko area has a wide variety of qualities depending on area and coal seam.

However, for the purpose of the feasibility study, average data on coal quality in each area were obtained from coal sampling study as shown in Table 8-3-4.

Lime is used for adjusting molten slag basicity to improve slag fluidity and to reduce reaction with refractory.

Scrap is used as a supplemental material for molten iron loss in the gasifier.

Qualities of lime and scrap are shown in Table 8-3-5 and Table 8-3-6.

Table 8-3-4 Average Data on Coal Quality in Banko Area

		N.W. Banko	Central Banko	North S.J
Proximate Analysis (%)	Moisture (as mined)	(27.6)	(36.7)	(42.5)
	Moisture (plant gate)	23.1	25.3	26.8
	Ash	3.0	5.7	4.6
	V.M.	35.6	34.4	36.6
	F.C.	38.3	34.6	32.0
	Total	100.0	100.0	100.0
Ultimate Analysis (%)	C	74.4	71.7	69.9
	H	5.8	6.6	5.7
	O	17.9	19.9	23.1
	N	1.2	1.4	1.1
	S	0.7	0.4	0.2
	Total	100.0	100.0	100.0
Lower Heating Value of as mined coal (kcal/kg)		4,652	3,793	3,148

Table 8-3-5 Quality of CaO

CaO (%)	$CaCO_3$ (%)	MgO (%)	SiO_2 (%)	Al_2O_3 (%)
69.7	6.6	6.5	13.1	4.1

Table 8-3-6 Quality of Scrap

Metalic Fe (%)	Carbon (%)	Si (%)
93.0 - 96.0	3.0 - 3.5	1.0 - 2.0

Table 8-3-7 Quality of Feed Coal just before Gasifier

		N.W. Banko		Central Banko		North S.J.	
Total moisture	(%)	10.0	5.0	10.0	5.0	10.0	5.0
Ash	(%)	3.5	3.7	6.8	7.2	5.7	6.0
V.M.	(%)	41.7	44.0	41.5	43.8	45.0	47.5
F.C.	(%)	44.8	47.3	41.7	44.0	39.3	41.5
Total	(%)	100.0	100.0	100.0	100.0	100.0	100.0
C	(%)	74.4		71.7		69.9	
H	(%)	5.8		6.6		5.7	
O	(%)	17.9		19.9		23.1	
N	(%)	1.2		1.4		1.1	
S	(%)	0.7		0.4		0.2	
Total	(%)	100.0		100.0		100.0	

(2) Carrier Gas

Nitrogen gas was used as a carrier gas of feed coal in the laboratory test in Puspiptek because N_2 gas can be easily obtained from market.
However this causes increase in N_2 content in product gas which is unfavorable for synthesis gas in a commerical plant.
Therefore CO_2 gas produced in acid gas removal equipment will be used in a commercial plant to reduce N_2 content in product gas.
For the calculation of basic process data for a commercial plant, CO_2 gas is used as a carrier gas.

(3) Material and Heat Balance

In the molten iron bath gasification process, moisture and ash contents in the feed coal give significant effects on heat balance of a gasifier.

Banko coals are in general high in total moisture content, 25-40% in the raw coal as mined, but relatively low in ash content. High content of moisture causes a heat shortage in heat balance in the gasifier. Fig. 8-3-8 shows the effect of moisture content in the feed coal on heat balance of a commercial scale gasifier (51.3 t-coal/h).
For keeping desired heat balance in the gasifier, moisture content must be reduced to less than around 10% before the coal is injected into the gasifier.
The heat balance can be also controlled by adjusting oxygen blowing rate, resulting the control of the CO/CO_2 ratio in the produced gas as shown in Fig. 8-3-8, line a) and line b).
If the feed coal is dried to the moisture content of 5%, the gasifier has still some excess heat by gasifying the coal under the more effective condition of 20 in the CO/CO_2 ratio. If the feed coal is dried to the moisture content of 10%, the CO/CO_2 ratio in the product gas must be decreased to 15 by increasing the oxygen blowing rate, resulting in lower CO content and higher CO_2 content in the product gas.
Drying of Banko coal to the moisture content of 5 to 10% is easy by a conventional technology utilizing low temperature thermal energy of product gas. Table 8-3-7 shows the quality of dried coals which will be gasified in the commercial scale gasifier in both cases of 5% and 10% moisture contents.
Based on the feed coals specified in Table 8-3-7, overall material balance under well heat balance in gasifier were calculated.
Result of material balance is indicated in Table 8-3-8.

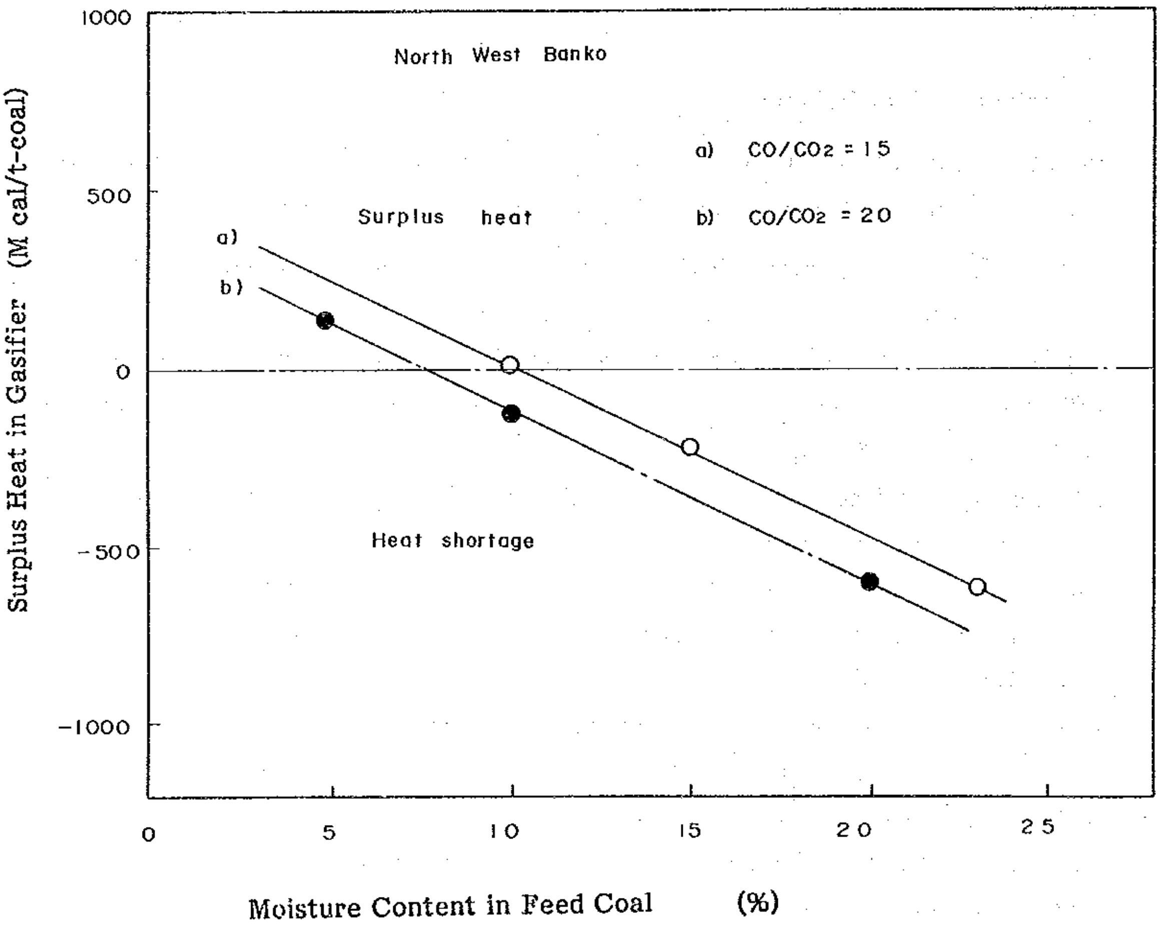


Fig. 8-3-8 Effect of Moisture Content in the Feed Coal on the Heat Balance

Table 8-3-8 Gasification Performance for Three Coal Basins in Commercial Scale Plant

		Unit		N.W. Banko		C. Banko		North S.J.		Remarks
Material	Coal		(t/h)		(51.3)		(51.3)		(51.3)	
	Oxygen	Nm^3/t-coal	(Nm^3/h)	489	(25100)	460	(23620)	423	(21730)	
	Steam	kg/t-coal	(kg/h)	6.1	(310)	0	(0)	0	(0)	Thermal control
	CO_2	Nm^3/t-coal	(Nm^3/h)	50	(2570)	50	(2570)	50	(2570)	Carriage gas
	Scrap	kg/t-coal	(kg/h)	32	(1650)	36	(1850)	35	(1780)	
	Lime	kg/t-coal	(kg/h)	7.5	(390)	34.6	(1780)	25.2	(1300)	
Generated gas	Amount	Nm^3/t-coal (as mined)		1530	(Total mois.=27.6%)	1310	(Total mois.=36.7%)	1130	(Total mois.=42.5%)	
		Nm^3/t-coal (dry base)	(Nm^3/h)	1900	(97580)	1863	(95630)	1766	(90670)	Total mois. =10% (after drying)
	CO		%		59.0		55.2		57.5	
	CO_2		%		3.9		4.3		4.5	
	H_2		%		28.1		29.6		27.8	
	H_2O		%		8.4		10.3		9.7	
	N_2		%		0.4		0.5		0.4	
Slag		kg/t-coal	(kg/h)	18	(920)	83	(4250)	60	(3100)	
Dust		kg/t-coal	(kg/h)	57	(2930)	57	(2930)	57	(2930)	

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