7) Partial Dust Collector

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

8) Operation Room

A mimic panel, a operation console, a 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 a 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 the Coal Gasification Test Facilities

(1) Project Specification and Requisition

The technical specification of errection 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 on Oct., 1986.
Futhermore, JICA sent mechanical supervisors and electrical and instrumental supervisors to the site for construction period, from Oct. 1986 to Jan., 1987.

After the coal gasification facilities were built up, the trial runs such as non-loading test of each equipments, loading test of each equipments and hot commissioning had been conducted from Jan., 1987 to Mar., 1987.
Though there were a few minor mechanical troubles in the period, the trial runs were carried out successfully.

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

Table 8-1-1 (1) Design Condition

ITEM	DESIGN CONDITION	
1. Climate Data	Ambient Temperature	
	Daily maximum temperature	33.0°C
	Yearly maximum temperature	31.5°C
	Daily minimum temperature	21.0°C
	Yearly minimum temperature	22.5°C
	Daily normal/average temperature	24.0°C at 7:00
	Daily normal/average temperature	30°C at 13:00
	Daily normal/average temperature	26.5°C at 18:00
	Relative Humidity	
	Daily maximum humidity	96% 24°C at 7:00
	Daily minimum humidity	47% 32°C at 13:00
	Daily normal humidity	92% at 7:00
	Daily normal humidity	62% at 13:00
	Daily normal humidity	79% at 18:00
2. Materials		
(1) Coal	Moisture	Max. 35%
	Size	- 50 mm
(2) Calcined lime	Component	90% CaO over 4-8% CO_2
	Size	- 30 mm
(3) Scrapped iron	Component	Fe 93-96% C 3-3.5% Si 1-2%
	Size	about 110 mm dia.
3. Utilities		
(1) Oxygen	as cylinders	
	Purity	99% over
	Temperature	ambient temperature
	Pressure	10 kg/cm^{2}G
(2) Nitrogen	as cylinders	
	Purity	99% over
	Temperature	ambient temperature
	Pressure	10 kg/cm^{2}G

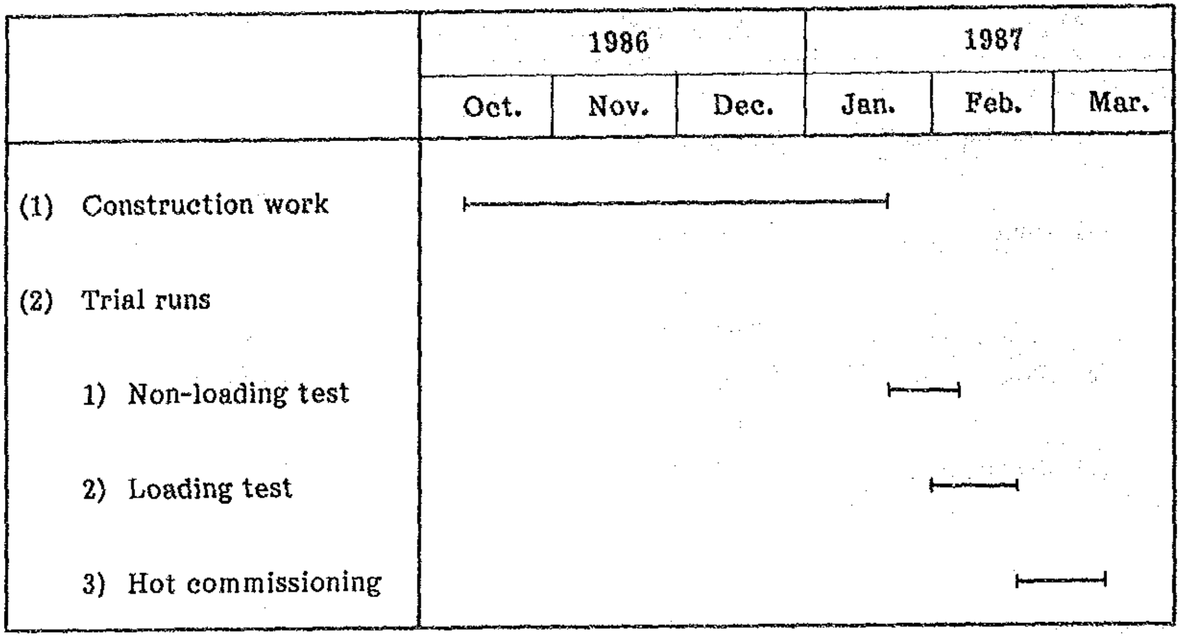
Table 8-1-1 (2) Design Condition

ITEM	DESIGN CONDITION	
(3) Electric Power	Frequency	50Hz
	Phase	3 phase
	Voltage	380 V ± 10%
	Power	Max. 350 KVA
(4) Compressed Air	Temperature	ambient temperature
	Pressure	Min. 6 kg/cm^{2}G
(5) Compressed Air for Instrumentation	Temperature	ambient temperature
	Pressure	Min. 6 kg/m^{2}G
	Dew point	0°C
(6) Cooling Water	Water analysis	
	Color	20 Pt.Co
	Turbidity	-
	Odor	No
	Taste	No
	PH	6.5
	Solid Content	4.1 ppm
	Conductivity	-
	Organic Contnet	4.4 ppm $KMnO_4$
	Free CO_2 Content	No
	Alkalinity	
	Phenol phtalein	0 ppm $CaCO_3$
	Methyl orange	40.0 ppm $CaCO_3$
	Carbonate	0 ppm $CaCO_3$
	Hydroxide	0 ppm $CaCO_3$
	Bicarbonate	40.0 ppm $CaCO_3$
	Hardness	
	Calcium	4.28 ppm Ca^{++}
	Magnesium	1.72 ppm Mg^{++}
	Iron content	negative
	Sulfate content	negative
	Phosphate	negative
	Ammonium content	negative
	Nitrate content	negative
	Silica content	-
	Chloride content	7.10 ppm Cl^-
	Residual chlorine	0.30 Cl_2
	Temperature	25-27°C
	Pressure	Min. 10 kg/cm^{2}G
(7) Liquefied Petroleum Gas	as cylinder	
	Calorific Value	24000 kcal/Nm^3 over
	Temperature	ambient temperature
	Pressure	2 kg/cm^{2}G

Table 8-1-1 (3) Design Condition

ITEM	DESIGN CONDITION	
4. Waste		
(1) Cooling water	Temperature	inlet temperature + Max. 10°C
(2) Dust	Component	Fe tot. 40 - 50% C 10 - 25%
	Flow rate	3 kg/h
(3) Slag	Basicity	CaO/SiO_2= 1.5
	Flow rate	2.4 kg/h
(4) Produced Gas	Flow Rate	64.5 Nm^3/h

Table 8-1-2 Schedule of Construction Work and Trial Runs



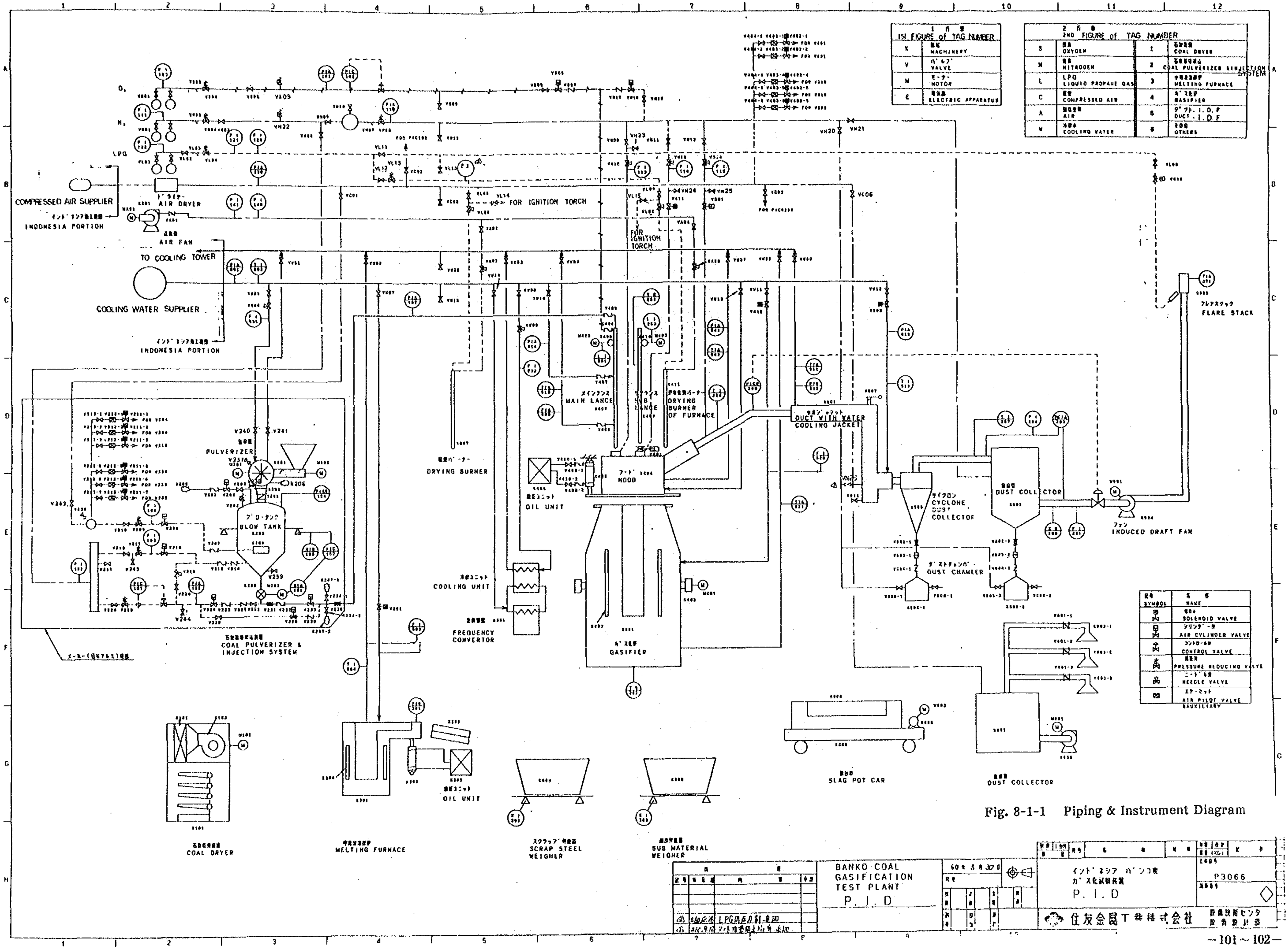


Fig. 8-1-1 Piping & Instrument Diagram

NAME	TAG NO	PHYSICAL PROPERTIES	UNIT	30kg/H COAL BLOWING	20kg/H COAL BLOWING	40kg/H COAL BLOWING
COAL	C-1	GRAIN SIZE	mm	10-25	→	→
		WATER CONTENT	%	5≧	→	→
	C-2	GRAIN SIZE	μm	74≧ 70%≦	→	→
PIG IRON	F-1	WEIGHT	kg	300	→	→
		TEMPERATURE	°C	1600~1700	→	→
	F-2	WEIGHT	kg	300	→	→
		TEMPERATURE	°C	1500~1550	→	→
QUICK LIME	Ca-1	WEIGHT	kg	1.8	1.2	2.4
O_2 OXYGEN	O-1	PRESSURE	kg/cm²G	10-12	→	→
	O-2	PRESSURE	kg/cm²G	4-8	→	→
		FLOW RATE	Nm³/H	18	12	24
N_2 NITROGEN	N-1	PRESSURE	kg/cm²G	10-12	→	→
		FLOW RATE	Nm³/H	65-75	→	→
	N-2	PRESSURE	kg/cm²G	8-10	→	→
	N-3	PRESSURE	kg/cm²G	6-8	→	→
	N-4	PRESSURE	kg/cm²G	6-8	→	→
	N-5	PRESSURE	kg/cm²G	4-8	→	→
		FLOW RATE	Nm³/H	10.8	7.2	14.2
	N-6	PRESSURE	kg/cm²G	6-8	→	→
		FLOW RATE	Nm³/H	36	→	→
	N-7	PRESSURE	kg/cm²G	6-8	→	→
		FLOW RATE	Nm³/H	39-40	→	→
	N-8	PRESSURE	kg/cm²G	6-8	→	→
		FLOW RATE	Nm³/H	28.8	→	→
	N-9	PRESSURE	kg/cm²G	6-8	→	→
		FLOW RATE	Nm³/H	6	→	→
LPG LIQUID PROPANE GAS	L-1	PRESSURE	kg/cm²G	1-2	→	→
	L-2	PRESSURE	mmAq	600	→	→
		FLOW RATE	Nm³/H	3	→	→
	L-3	PRESSURE	mmAq	600	→	→
		FLOW RATE	Nm³/H	0.83	→	→
	L-4	PRESSURE	kg/cm²G	2	→	→
		FLOW RATE	Nm³/H	1.5	→	→
COMPRESSED AIR	Ah-1	PRESSURE	kg/cm²G	5-7	→	→
		FLOW RATE	Nm³/H	67.2	→	→
	Ah-2	PRESSURE	kg/cm²G	3-6	→	→
		FLOW RATE	Nm³/H	53.7	→	→
	Ah-3	PRESSURE	kg/cm²G	5-7	→	→
		FLOW RATE	Nm³/H	13.5	→	→
AIR	Al-1	PRESSURE	mmAq	600	→	→
		FLOW RATE	Nm³/H	100	→	→
	Al-2	PRESSURE	mmAq	500-600	→	→
		FLOW RATE	Nm³/H	73	→	→
	Al-3	PRESSURE	mmAq	500-600	→	→
		FLOW RATE	Nm³/H	21	→	→
PRODUCED GAS	G-1	PRESSURE	mmAq	±100	→	→
		FLOW RATE	Nm³/H	64.5	43	86
		TEMPERATURE	°C	1300-1500	→	→
		CO	%	51.8	→	→
		CO_2	%	7.1	→	→
		H_2	%	24.1	→	→
		N_2	%	17.0	→	→
		DUST CONTENT	g/Nm³	50	→	→
	G-2	PRESSURE	mmAq	-110- -120	→	→
		TEMPERATURE	°C	150	→	→
	G-3	PRESSURE	mmAq	-220- -230	→	→
		DUST CONTENT	g/Nm³	25	→	→
	G-4	PRESSURE	mmAq	-420- -430	→	→
		DUST CONTENT	g/Nm³	0.05	→	→
	G-5	PRESSURE	mmAq	-460- -480	→	→
	G-6	PRESSURE	mmAq	30-60	→	→
DUST COLLECTION	K-1	PRESSURE	mmAq	-200	→	→
		FLOW RATE	Nm³/H	2800	→	→
COOLING WATER	W-1	PRESSURE	kg/cm²G	10	→	→
		FLOW RATE	m³/H	35.9	→	→
		TEMPERATURE	°C	32≧	→	→
	W-2	FLOW RATE	m³/H	6	→	→
	W-3	FLOW RATE	m³/H	20.4	→	→
	W-4	FLOW RATE	m³/H	8.4	→	→
		TEMPERATURE	°C	55≧	→	→
	W-5	PRESSURE	kg/cm²G	3.5	→	→
		FLOW RATE	m³/H	12.0	→	→
	W-6	FLOW RATE	m³/H	8.4	→	→
	W-7	FLOW RATE	m³/H	3.6	→	→
		TEMPERATURE	°C	55≧	→	→
	W-8	FLOW RATE	m³/H	1.7	→	→
		TEMPERATURE	°C	40	→	→
	W-9	FLOW RATE	m³/H	10.8	→	→
		TEMPERATURE	°C	64.6	→	→
	W-10	FLOW RATE	m³/H	7	→	→
		TEMPERATURE	°C	40	→	→
	W-11	FLOW RATE	m³/H	35.9	→	→
		TEMPERATURE	°C	50	→	→

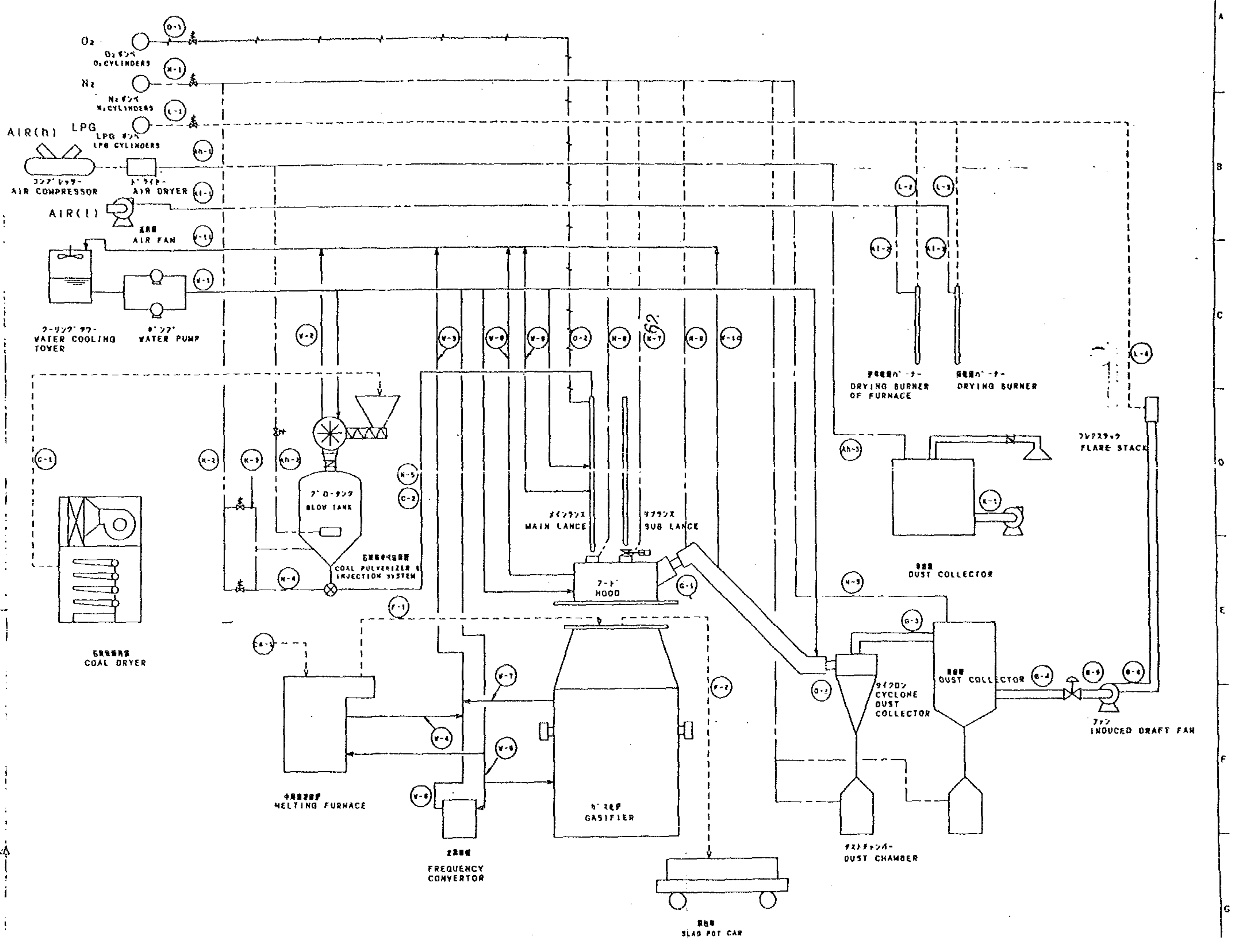


Fig. 8-1-2 Engineering Flow Diagram

BANKO COAL
GASIFICATION
TEST PLANT
E. F. D

83年8月30日

インドネシア バンコ炭
ガス化試験装置
E. F. D

住友金属工業株式会社
設備技術センタ
設備設計部

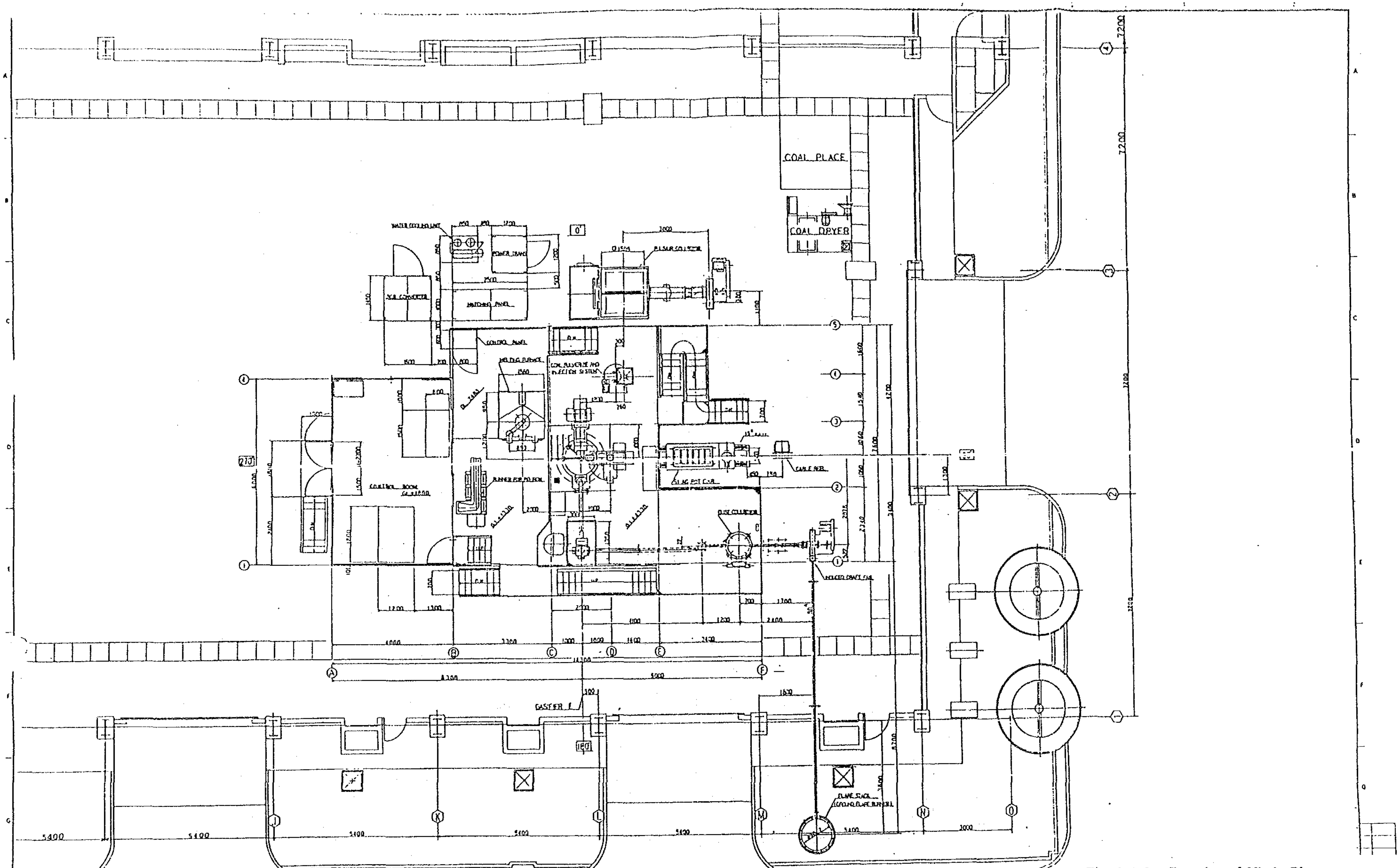


Fig. 8-1-3 Drawing of Whole Plan

REVISION		
NO	DATE	DESCRIPTION

DATE
AUG 13, 85'
SCALE
$\frac{1}{80}$

MANAGER OF DEP.
MANAGER
CHIEF
CHECKED BY
DRAWN BY

BANKO COAL GASIFICATION
TEST PLANT
ARRANGEMENT DRAWING

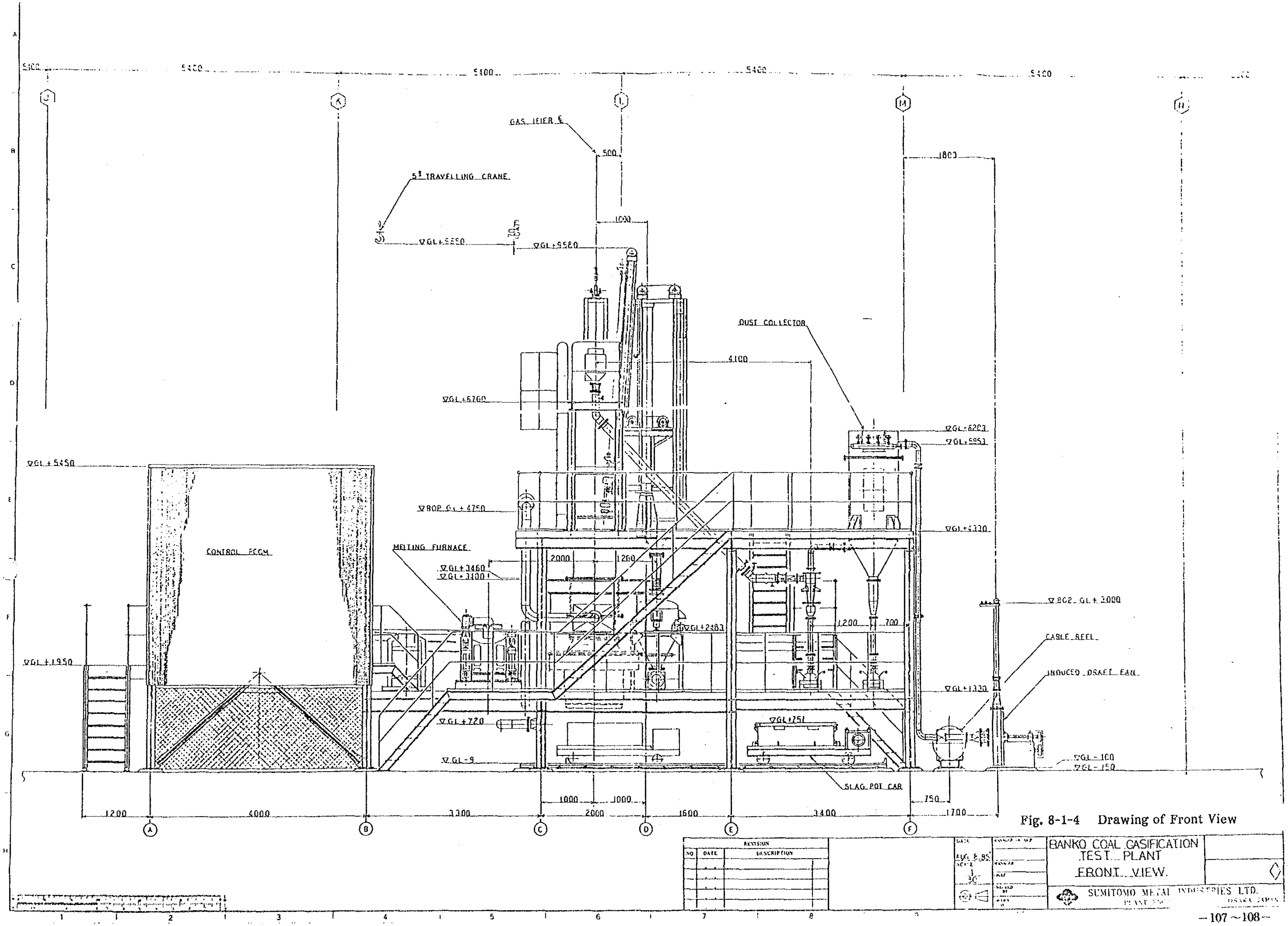


Fig. 8-1-4 Drawing of Front View

[illegible]	[illegible]	PARTIAL NAME	[illegible]	NO	DESCRIPTION	WEIGHT	REMA
1		GASIFIER		1			
2		PLUMMER BLOCK		1			
3		PLUMMER BLOCK		1			
4		COUPLING		1SET			
5		REDUCTION GEAR UNIT		1			
6		BASE		1			
7		BASE		1			
8		WATER-COOLED CABLE		2			
9		GUM HOSE		8			
10		GUM HOSE		11			
11		POWER PORT		1			
12		EXHAUST PORT		1			
13		PEEP WINDOW		3			

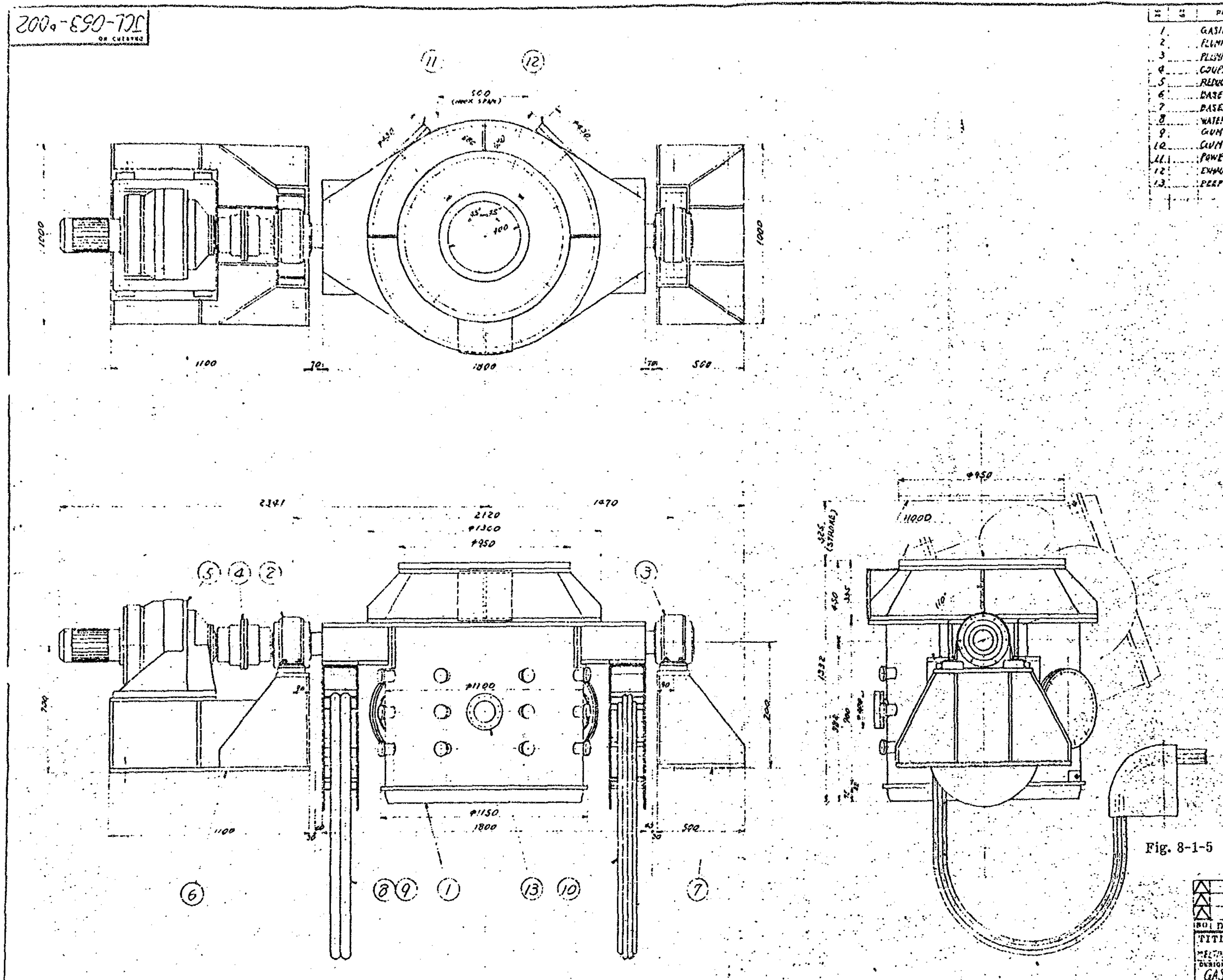
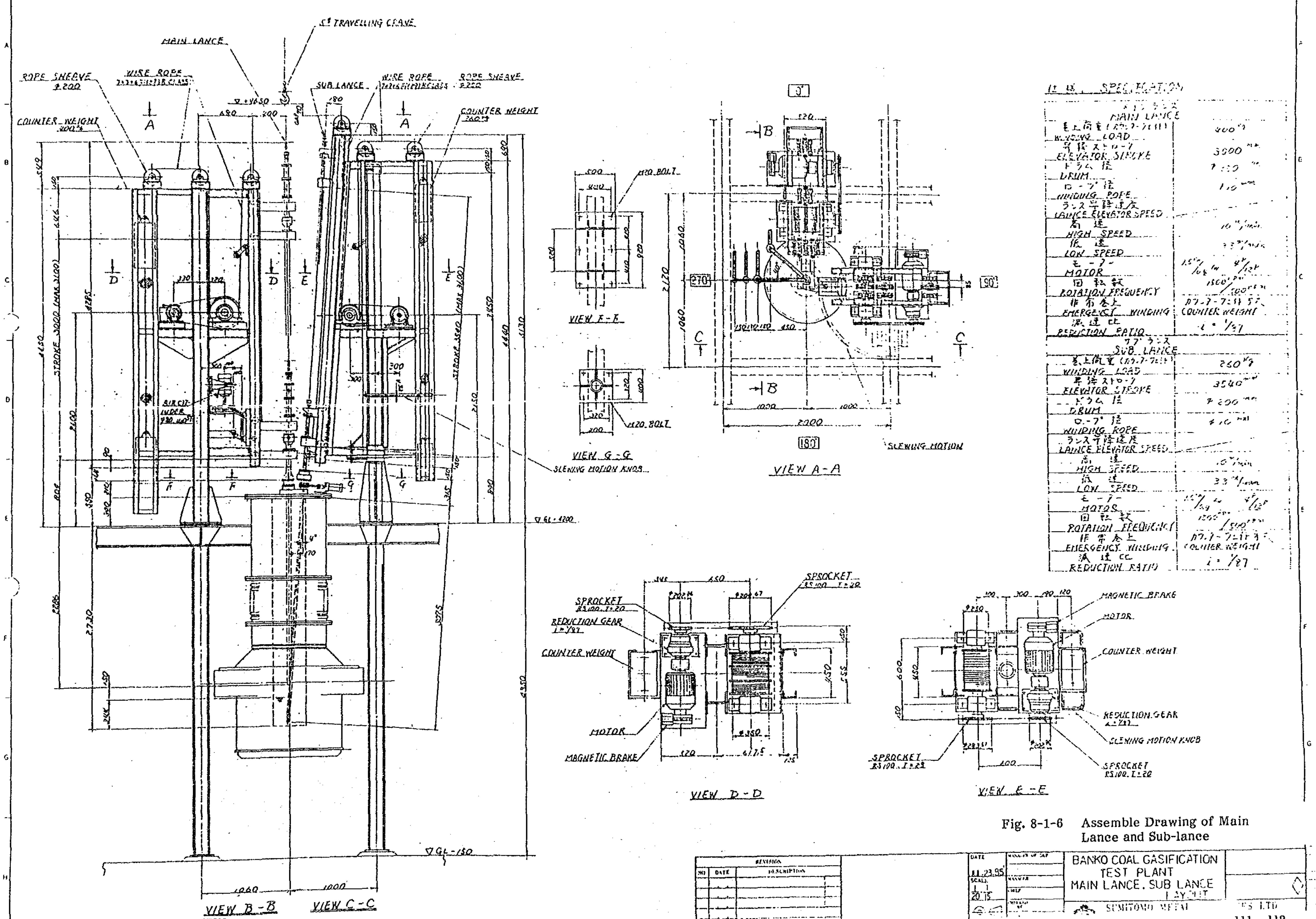


Fig. 8-1-5 Assemble Drawing of Gasifier

NO	DATE	REVISION	BY
△			
△			
△			

TITLE P/X 300t/d 250t/d 300t/d MELTING FURNACE / GASIFIER	SOURCE	SCALE	1/10
		DATE	Aug 14 '7
DESIGNATION GASIFIER ASSEMBLY	DRAWING NO JCL-063-002		
APPROVED BY / CHECKED BY / DESIGNED BY / DRAWN BY	FILM NO		



仕様 SPECIFICATION

メインランス MAIN LANCE	
巻上荷重（カウンターウエイト） WINDING LOAD	400 kg
昇降ストローク ELEVATOR STROKE	3000 mm
ドラム径 DRUM	φ 150 mm
ロープ径 WINDING ROPE	φ 10 mm
ランス昇降速度 LANCE ELEVATOR SPEED	
高速 HIGH SPEED	10 m/min
低速 LOW SPEED	3.3 m/min
モーター MOTOR	1.5 kW/6P 4P/12P
回転数 ROTATION FREQUENCY	1500 rpm/500 rpm
非常巻上 EMERGENCY WINDING	カウンターウエイト式 COUNTER WEIGHT
減速比 REDUCTION RATIO	i = 1/37
サブランス SUB LANCE	
巻上荷重（カウンターウエイト） WINDING LOAD	250 kg
昇降ストローク ELEVATOR STROKE	3540 mm
ドラム径 DRUM	φ 200 mm
ロープ径 WINDING ROPE	φ 10 mm
ランス昇降速度 LANCE ELEVATOR SPEED	
高速 HIGH SPEED	10 m/min
低速 LOW SPEED	3.3 m/min
モーター MOTOR	1.5 kW/4P 4P/12P
回転数 ROTATION FREQUENCY	1500 rpm/500 rpm
非常巻上 EMERGENCY WINDING	カウンターウエイト式 COUNTER WEIGHT
減速比 REDUCTION RATIO	i = 1/27

Fig. 8-1-6 Assemble Drawing of Main Lance and Sub-lance

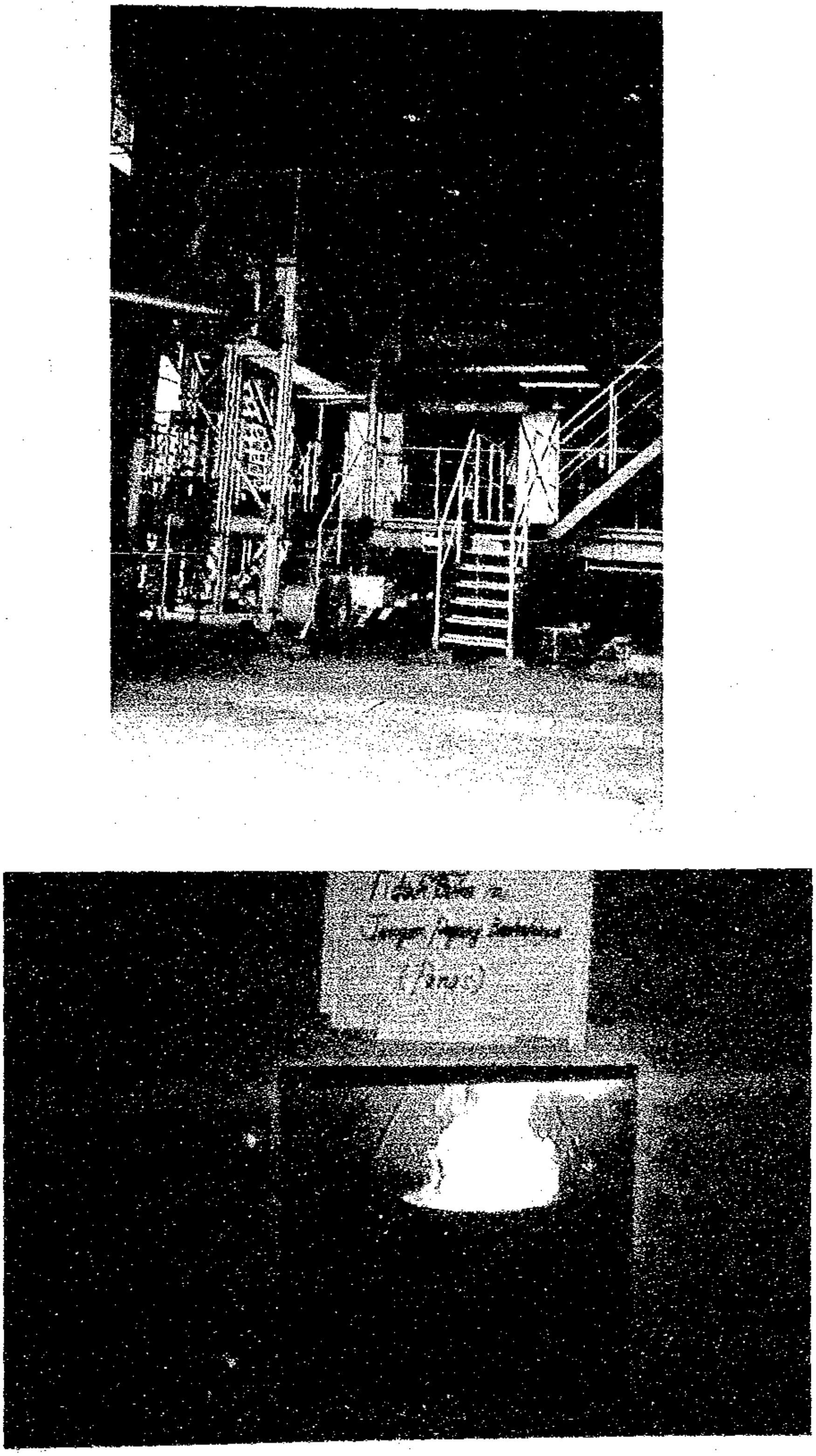
REVISION		
NO	DATE	DESCRIPTION

DATE 11.23.95
SCALE 1 : 20, 1 : 15

BANKO COAL GASIFICATION
TEST PLANT
MAIN LANCE. SUB LANCE
LAYOUT

SUMITOMO METAL [illegible] ES LTD

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



8-2 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 after confirming existense of outcrops or sub-outcrops of each coal seam by geological survey and overburden thickness over each coal seam by shallow hole drilling, dividing into two phases based on predetermined coal sampling program (see Fig. 7-3-4) by the means of large diameter core drilling principally to use for coal gasification test at Serpong, as referred to 7.3.

8-2-1 N.W. Banko

9 coal samples (in total about 2.2 tons, 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. 7-3-1' of ATTACHMENT 7-3) by the means of large diameter core drilling except C coal seam where drilling machine was not transportable to the proper place next to the outcrop from the nearest existing road for core drilling, because of severe undulation (for detail turn to 7.3).

Coal seam Part	A_1	A_2	B_1	B_2	C
Northern	o	o	o	o	o
Southern	o	o		o	o

Results of proximate, ultimated and ash component analysis are shown in Table 7-3-4 and Table 7-3-6.

8-2-2 Central Banko

5 coal samples (in total about 0.6 tons, see the following table), were obtained from each coal seam in the area in FY1987/88, by the means of large diameter core drilling at the predetermined sites, based on geological survey, carried out in FY1986/87 and FY1987/88, prior to coal sampling (for detail turn to 7.3)

A_1	A_2	B_1	B_2	C
o	o	o	o	o

Analysis results are shown in Table 7-3-5 and Table 7-3-6.

8-2-3 North Suban Jeriji

3 coal samples (in total about 0.4 tons, see the following table) were obtained in FY1987/88, based on the same idea and method applyed to Central Banko (for detail turn to 7.3)

Jelawatan	Enim 1	Enim 2
o	o	o

Analysis results are shown in Table 7-3-5 and Table 7-3-6.

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 gacificability with those of coal samples obtained in Banko area (including Suban Jeriji) after getting permission of DOC and PTBA under their kind cooperation. (for detail turn to 7.3)

8-3 COAL GASIFICATION TEST

8-3-1 Progress Made in Test Program

Table 8-3-1 and Table 8-3-2 show progress made in the test program. To save the cost for gasification test and also to increase test times during limitted schedule, 3 times of gasification test using 3 coal samples per one operation day were carried out.

Table 8-3-1 shows test program under open hood mode and Table 8-3-2 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 on-line gas sampling device, which was collected to on-line gas analyzer.

47 times of coal gasification test have been carried out by Dec. 2, 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 8-3-3. There are clear difference in oxygen content in coal among coal samples.

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 8-3-4 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 base of intermediate analysis and evaluation of test data. The details are explained in Section 8-3-2.

There was no personal damage as well as mechanical damage through the test operations.

Wearing rate in refractory of gasifier is shown in Fig. 8-3-1. It is clear that wearing rate was much slower than expected.

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 molten iron bath process.

Table 8-3-1 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. 03	CG003	BUIIIB2
4	Sep. 08	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. 06	CG010-1	CBC
18		CG010-2	CBA1
19		CG010-3	CBA2

Note: Coal samples tested in each run No. means as folows;

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

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 8-3-2 Progress Made in Test Program
(Operation under Closed Hood Mode)

No.	Date	Run No.	Coal sort
20	Oct. 09, '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. 05	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 8-3-3 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

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 Some possibility of change in quality due to coal samples by pitting (surface layer).

*2 Estimated on basis of drying condition.

*3 Some possibility of extraordinary value in ash content from the viewpoint of figure for columnar section of boreholes taken coal sample.

Table 8-3-4 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

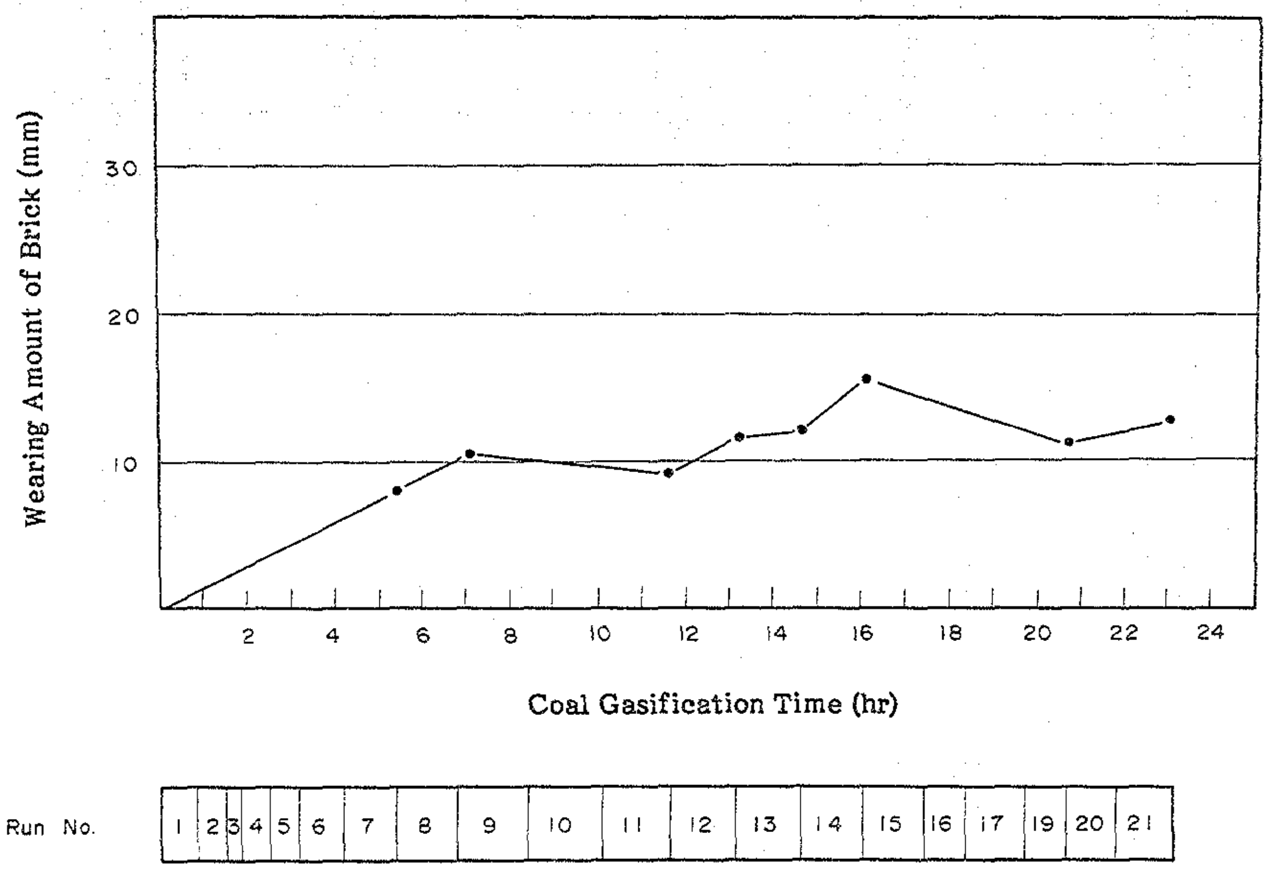
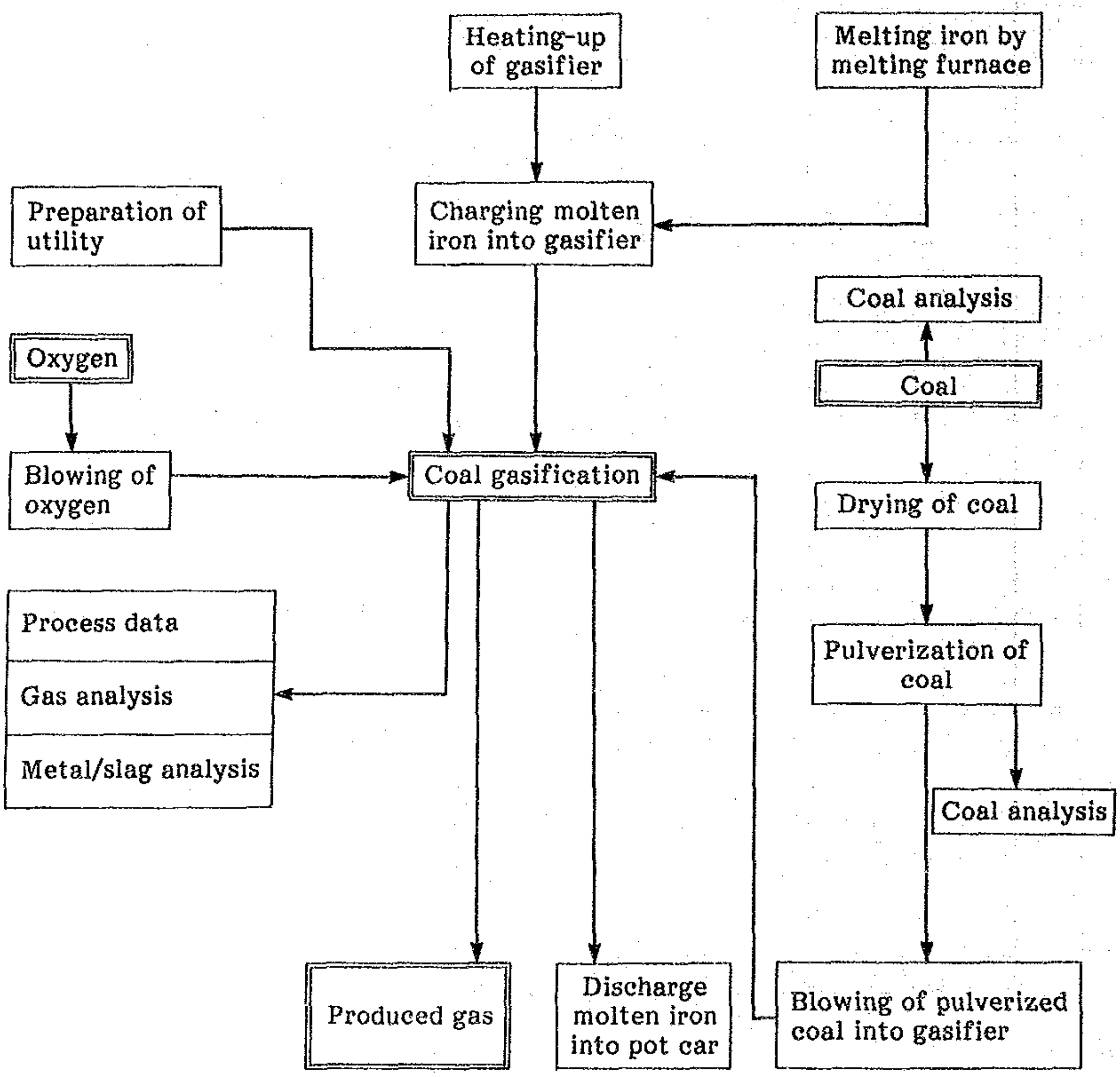


Fig. 8-3-1 Wearing Rate in Refractory of Gasifier

8-3-2 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 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 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 burn 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, external heating device is unnecessary for a commercial scale gasifier.

After CG011, test condition and operation method 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/hr to 35 kg/hr.
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 fun was controlled to minimize the absorbed air into the gasifier.
5) Measurement device of feed coal was modified.

By above mentioned modification of the method and procedure 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 or 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 8-3-5 shows typical test condition. (For details, see ATTACHMENT 8-3 Test Condition)

Table 8-3-5 (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 %	Si02	%
V.M.	46.08 %	H	6.03 %	Al203	%
F.C.	50.63 %	N	1.08 %	Ca0	%
	%	O	16.73 %	K20	%
		S	0.25 %	Na20	%

(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 %	Si02	%
V.M.	46.04 %	H	5.43 %	Al203	%
F.C.	52.06 %	N	1.36 %	Ca0	%
	%	O	18.26 %	K20	%
		S	0.45 %	Na20	%

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

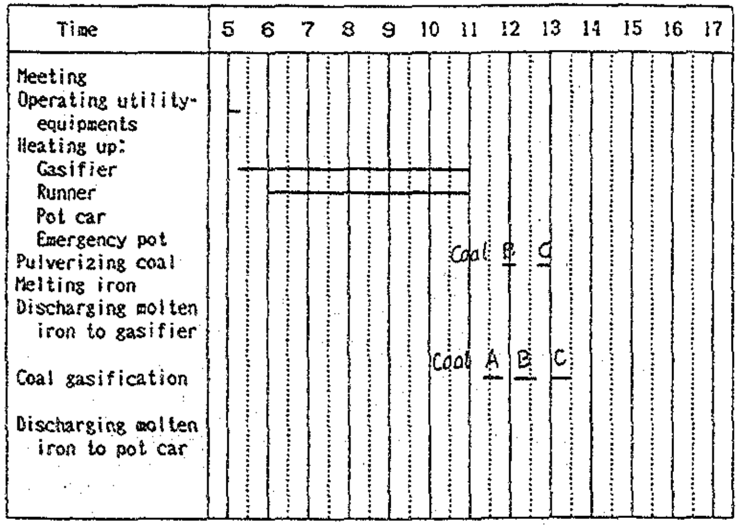
OPERATION CONDITION− B

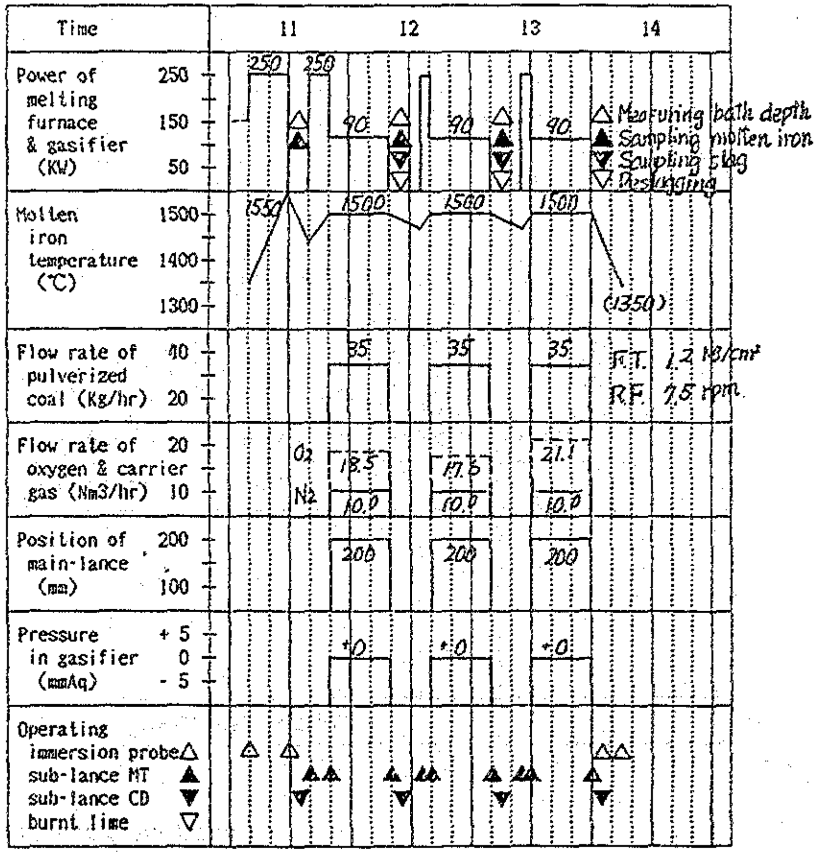
Weight of molten iron	300	Kg
Flow rate of Oxygen	17.6	Nm3/hr
Flow rate of carrier gas	10.0	Nm3/hr
Flow rate of pulverized coal	35.0	Kg/hr
Position of main-lance over bath surface	200	mm
Molten iron temperature		
on discharge to gasifier	--	℃
on coal gasification	1500	℃
on discharge to pot car	−	℃
Basicity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

Table 8-3-5 (2) Typical Test Condition

TEST000-2

4.SCHEDULE





8-3-3 Coal Gasification Data

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

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

Coal gasification 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 8-3-6	Major Test Conditions (Open Hood Mode)
Table 8-3-7	Major Test Conditions (Closed Hood Mode)
Table 8-3-8	Recorded Gas Composition (Open Hood Mode)
Table 8-3-9	Recorded Gas Composition (Closed Hood Mode)
Table 8-3-10	Analysis Results of Dust
Table 8-3-11	Analysis Results of Metal
Table 8-3-12	Analysis Results of Slag
Fig. 8-3-2	Typical Operation Results

Table 8-3-6 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

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

Table 8-3-7 Major Test Conditions (Closed 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)				
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

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

Table 8-3-8 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 8-3-9 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 8-3-10 (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

CY : Cyclone separator
BF : Bag filter

*1 Some possibility of extraordinary value in analysis results of dust.

Table 8-3-10 (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 8-3-11 Analysis Results of Metal

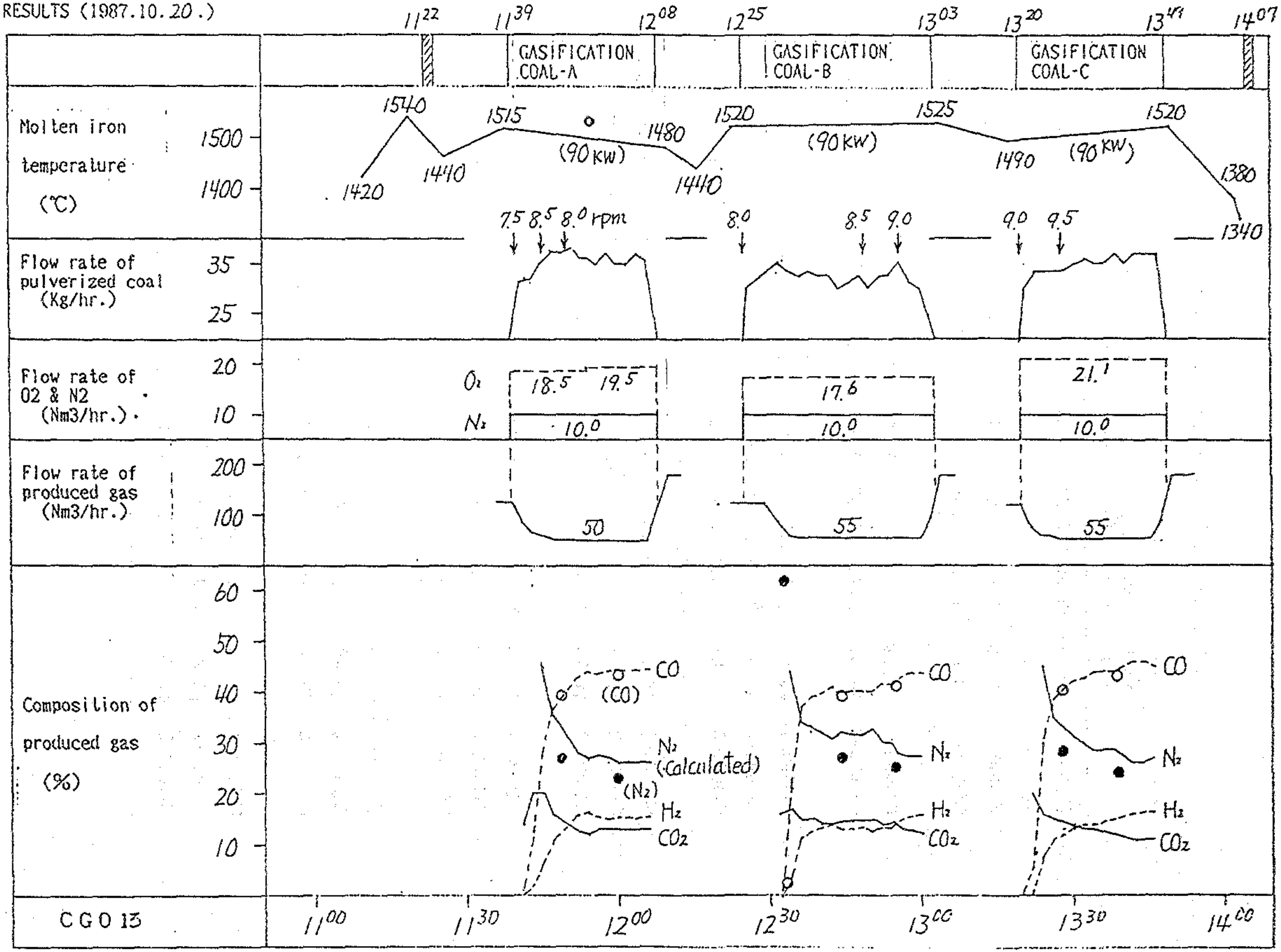
	C (%)	S (%)		C (%)	S (%)		C (%)	S (%)
CG004-1	3.76	0.046	CG010-1	3.89	0.046	CG015-1	3.83	0.049
CG004-2	4.00	0.052	CG010-2	3.82	0.052	CG015-2	4.13	0.051
CG005-1	3.83	0.050	CG010-3	3.76	0.087	CG015-3	4.26	0.060
CG005-2	4.03	0.059	CG010-4	3.69	0.092	CG015-4	4.39	0.117
CG006-1	3.86	0.045	CG011-1	3.84	0.046	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 8-3-12 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. 8-3-2 Typical Operation Result

OPERATION RESULTS (1987.10.20.)



8-4 ANALYSIS AND EVALUATION OF COAL GASIFICATION DATA

8-4-1 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 data test method was changed to closed hood mode operation after CG011.

All improvements for operation method and procedure described in Section 8-3-2 gave more stable and reasonable data with less fluctuation.

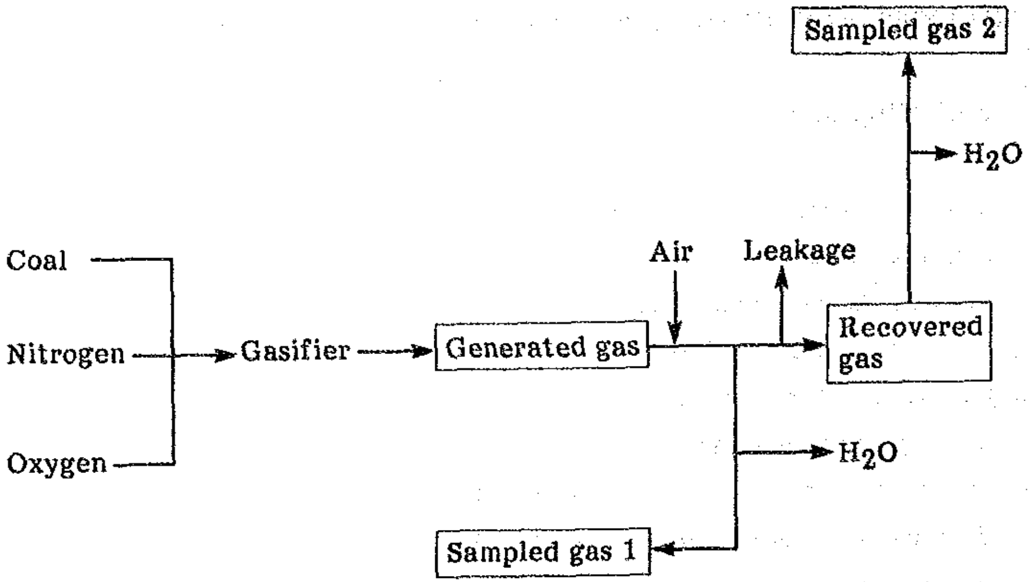
However as Table 8-3-8 and Table 8-3-9 show, there are still some fluctuations in gas composition even in such a modified test method and procedure.
It could be estimated that such a fluctuation in gas composition was mainly caused by unstable operation conditions of the gasifier and difficulty of gas 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.
Nextly whether it is reliable or not must be evaluated on the base of real gas compositions.

(1) Estimation of Real Gas Composition Generated in Gasifier

Recoorded 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 8-3-8 and Table 8-3-9 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 8-4).



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

Table 8-4-1 and Table 8-4-2 show estimation results of real generated composition based on the material balance.

Average values of recorded data in Table 8-3-8 and Table 8-3-9 were used for the estimation.

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

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

There were some run such as CG006 that real generated gas composition couldn't 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 8-4-1 and Table 8-4-2, it was confirmed that recorded gas compositions were effected by mixed air.

(2) Effect of Scale Factor on Gas Composition

As shown in Table 8-4-1 and Table 8-4-2, 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. 8-4-1.

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. 8-4-2 shows relationship between oxygen flow rate and gas ratio (CO/CO_2) which can be introduced from Fig. 8-4-1. The less oxygen flow rate is, the lower gas ratio (CO/CO_2) is.

According to past experiences of coal gasification test in larger scale test plants of molten iron bath process, nearly same tendency can be seen as shown in Fig. 8-4-2.

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

As it is clear in Fig. 8-4-2, the test data obtained in this test are highly reliable in view of CO/CO_2 range.

Furthermore gasification performance is easily estimated from Fig. 8-4-2, namely approximately 15 to 20 for ratio of CO/CO_2 can be expected in commercial scale gasification plant.

Table 8-4-1 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 8-4-2 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

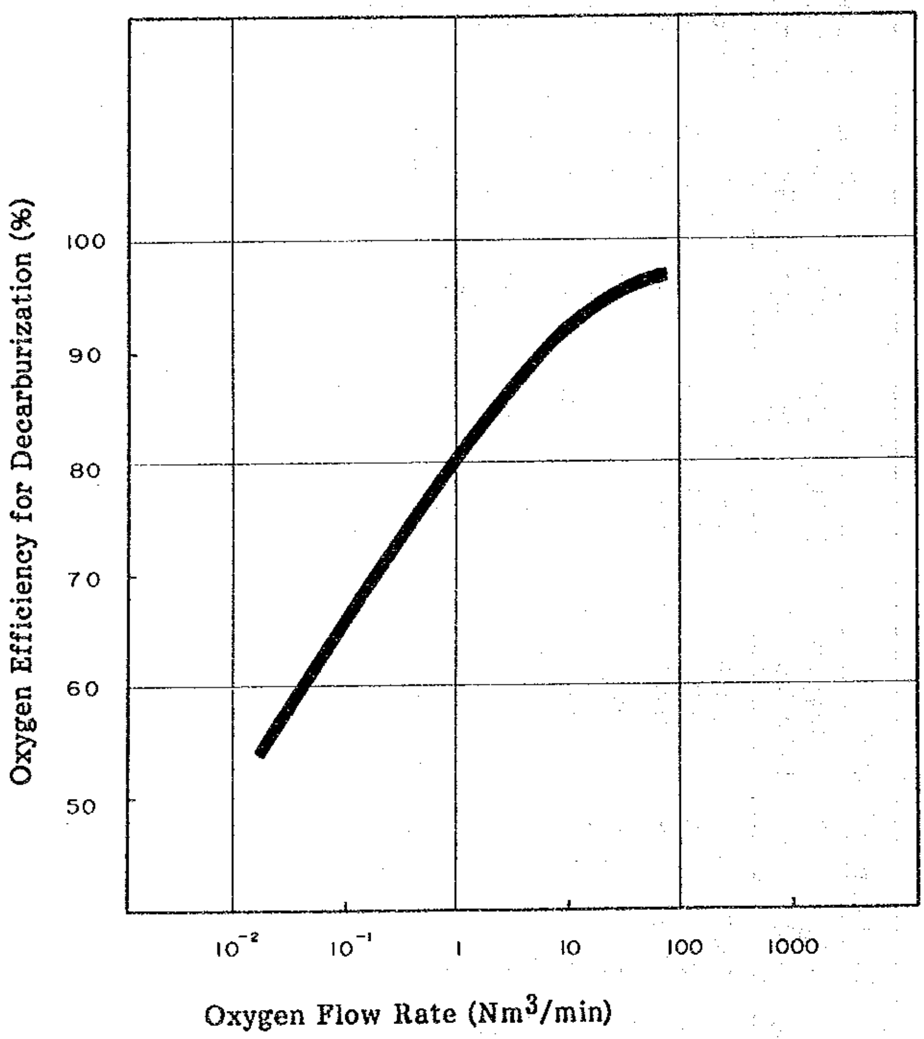


Fig. 8-4-1 Relationship between Oxygen Flow Rate and Oxygen Efficiency

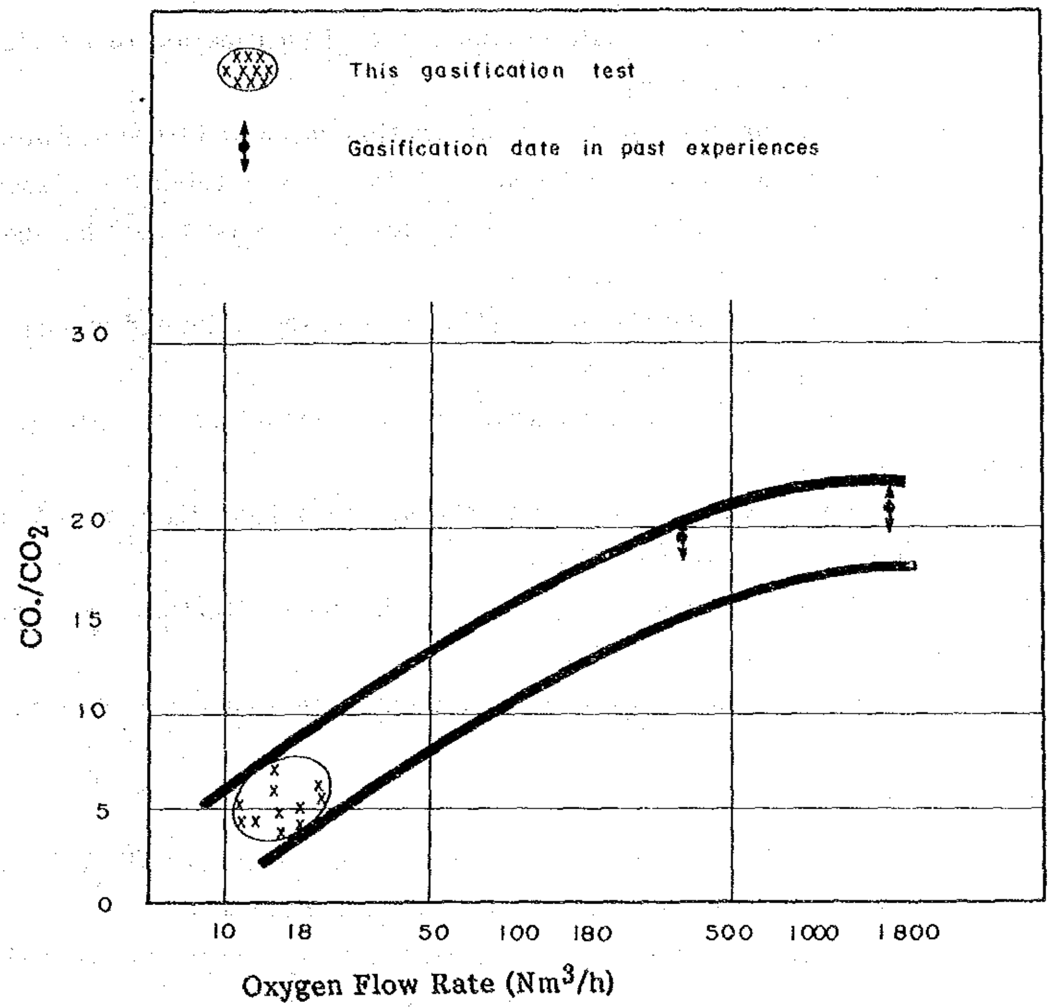


Fig. 8-4-2 Relationship between Oxygen Flow Rate and Gas Ratio, CO/CO_2

8-4-2 Correlation between Coal Quality and Characteristics of Gasification

As mentioned above the test data obtained in coal gasification test series from CG006 to CG020 are really reliable.

Table 8-4-1 and Table 8-4-2 show gas composition estimated by material balance based on recorded gas composition and test conditions. And Table 8-4-3 shows gas composition calculated on the basis of actual values which should be obtained under stoichiometric operation between O_2 and coal.

Furthermore Fig. 8-4-3 shows the effect of C/H in coal on the estimated and calculated gasification performance for each seam.

As it is clear in Fig. 8-4-3, the estimated gas component are correspond to the calculated gas component.

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

As clear from Fig. 8-4-3 and 8-4-4, gasification performance such as CO/H_2 in gas and generated gas amount is surely effected by coal quality.

Namely, the higher C/H (excluding hydrogen in moisture in coal) in coal is the higher CO/H_2 in gas becomes and the less ash content in coal is, the more generated gas amount is.

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

Table 8-4-3 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

* Except carrier gas amount

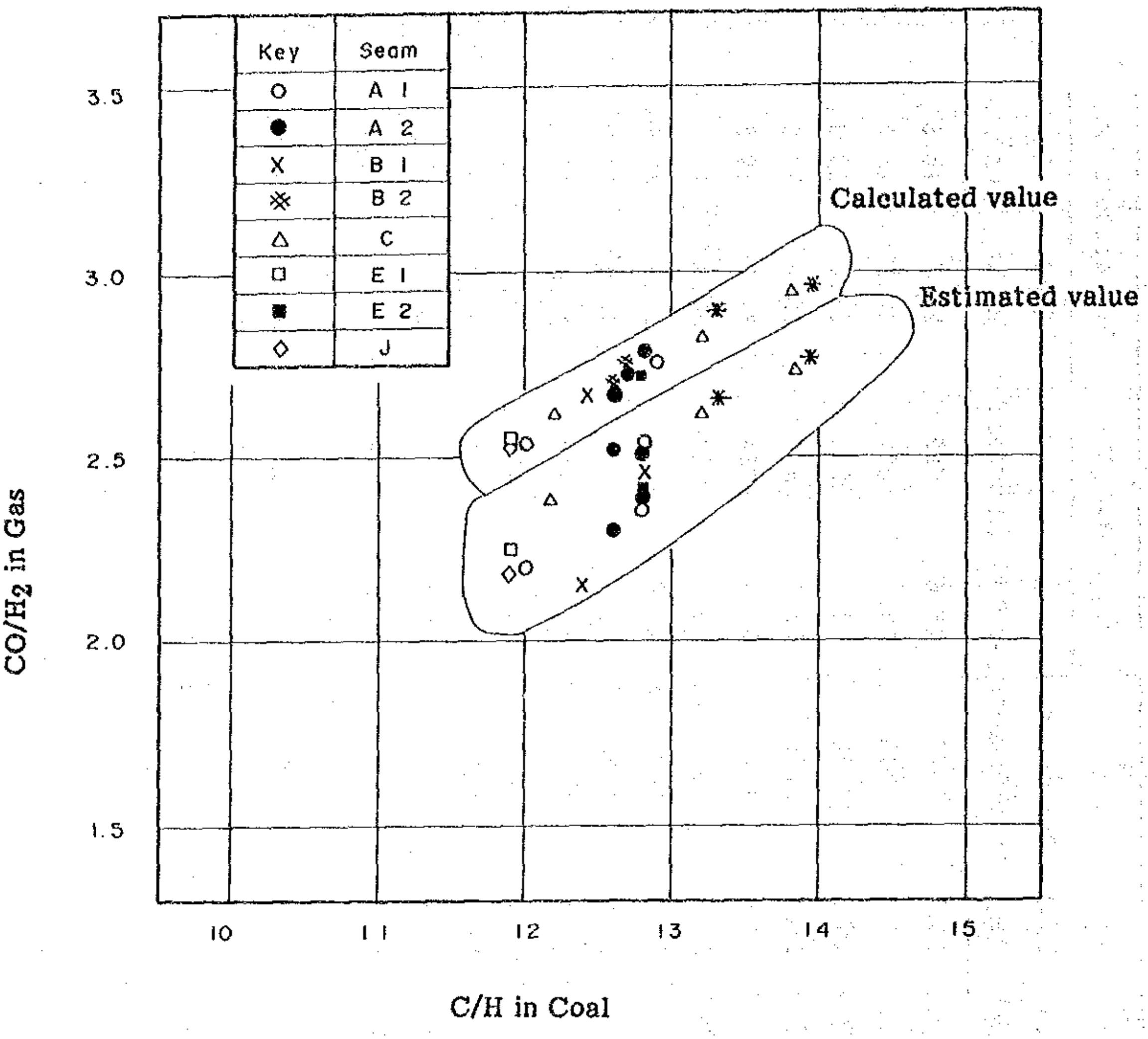


Fig. 8-4-3 Effect of C/H in Coal on Gasification Performance for Each Seam

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

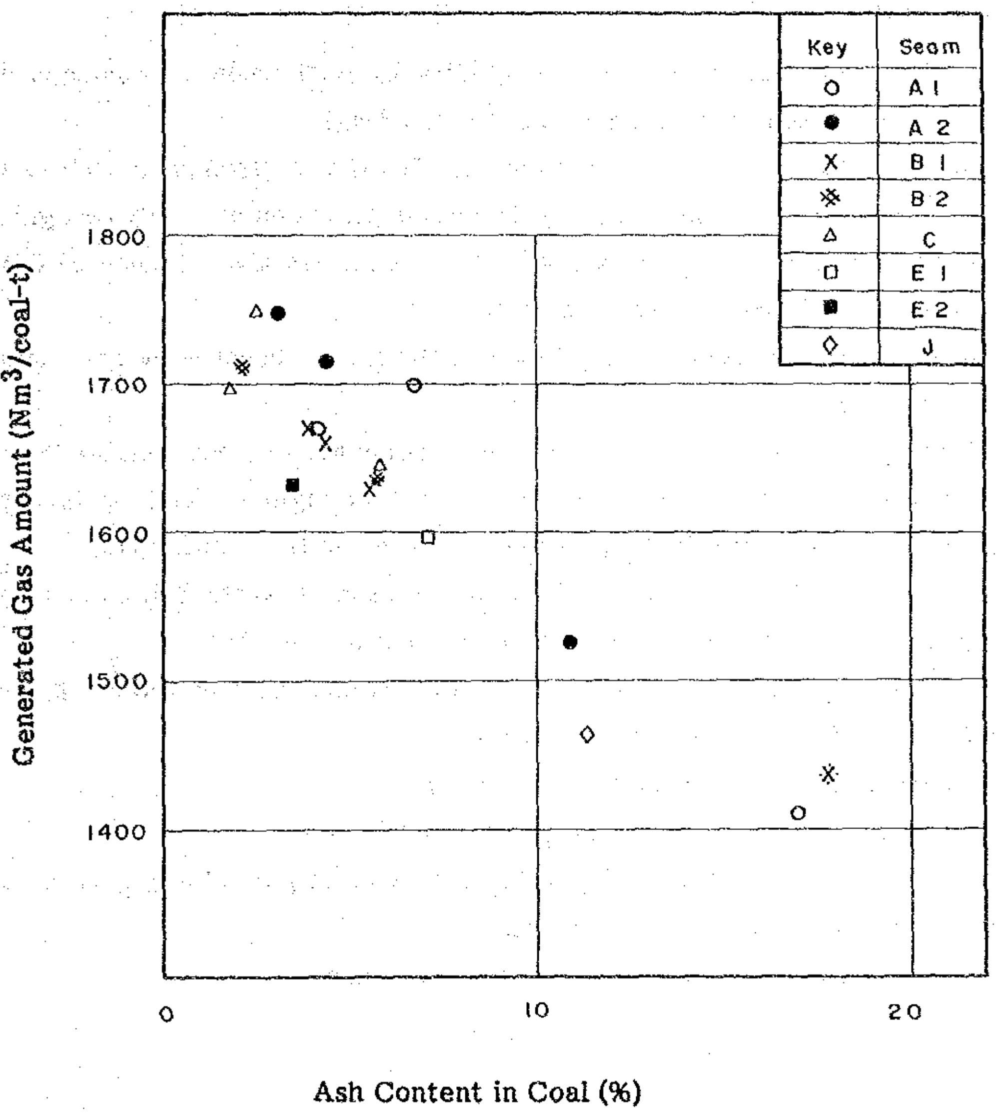


Fig. 8-4-4 Effect of Ash Content in Coal on Gasification Performance for Each Seam

Note: Coal marked with * has high probability of extraordinary value in ash content from the view-point of figure for columnar section of boreholes taken coal sampling

(2) By Coal Basin

In the same way effect of coal quality by coal basin on coal gasification performance are shown in Fig. 8-4-5, 8-4-6 and 8-4-7.
Correlation between coal basin and coal gasification performance such as CO/H_2 in gas, generated gas amount and oxygen consumption can be surely recognized.

At first as for CO/H_2 in gas, N.W Banko coal has highest ratio of CO/H_2 in all basins and C. Banko coal follows next.
In case of North S.J. coal, CO/H_2 in gas is the lowest because carbon included in it is rather small.

Next, generated gas amount are mostly dominated by ash content in coal. It looks that 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, 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. 8-4-7.

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.

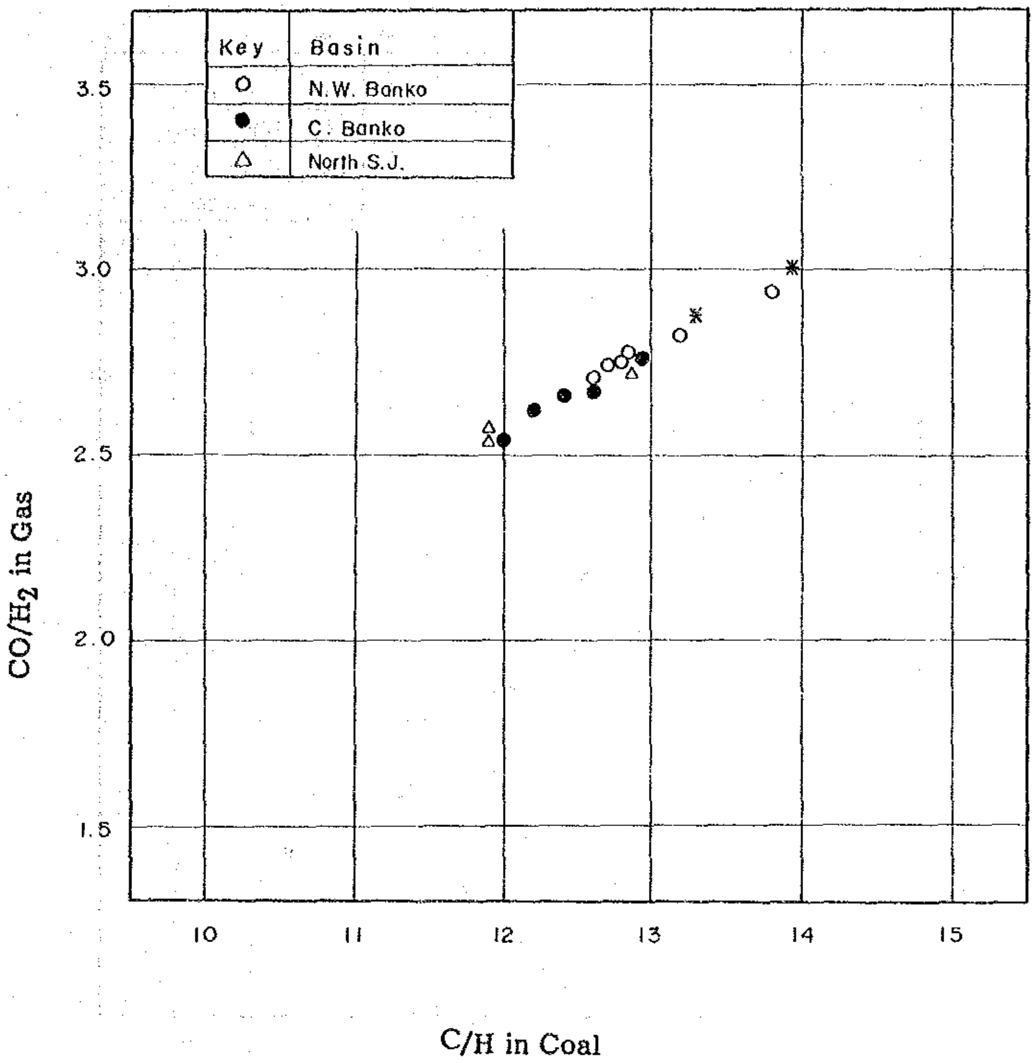


Fig. 8-4-5 Effect of C/H in Coal on Gasification Performance for Each Basin

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

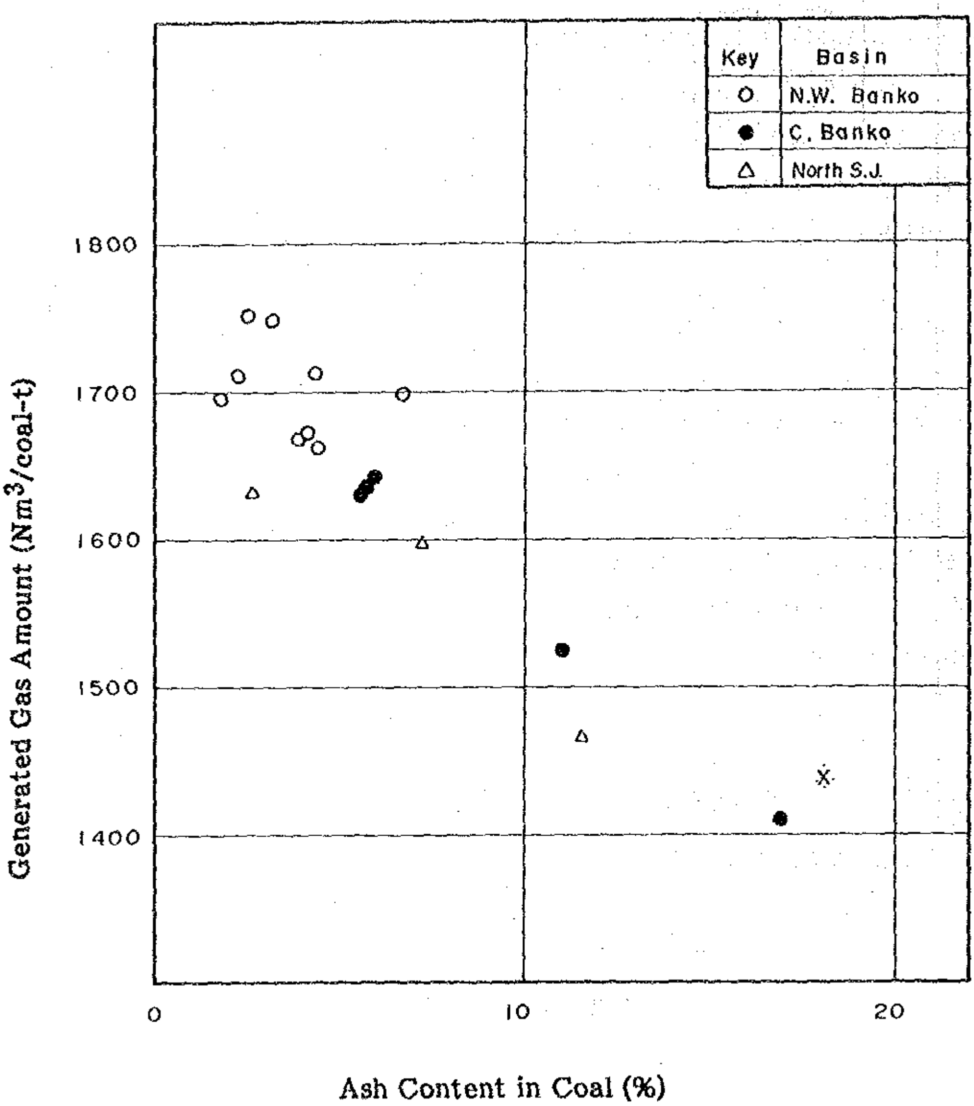


Fig. 8-4-6 Effect of Ash Content in Coal on Gasification Performance for Each Basin

Note: Coal marked with * has high probability of extraordinary value in ash content from the view-point of figure for columnar section of boreholes taken coal sampling.

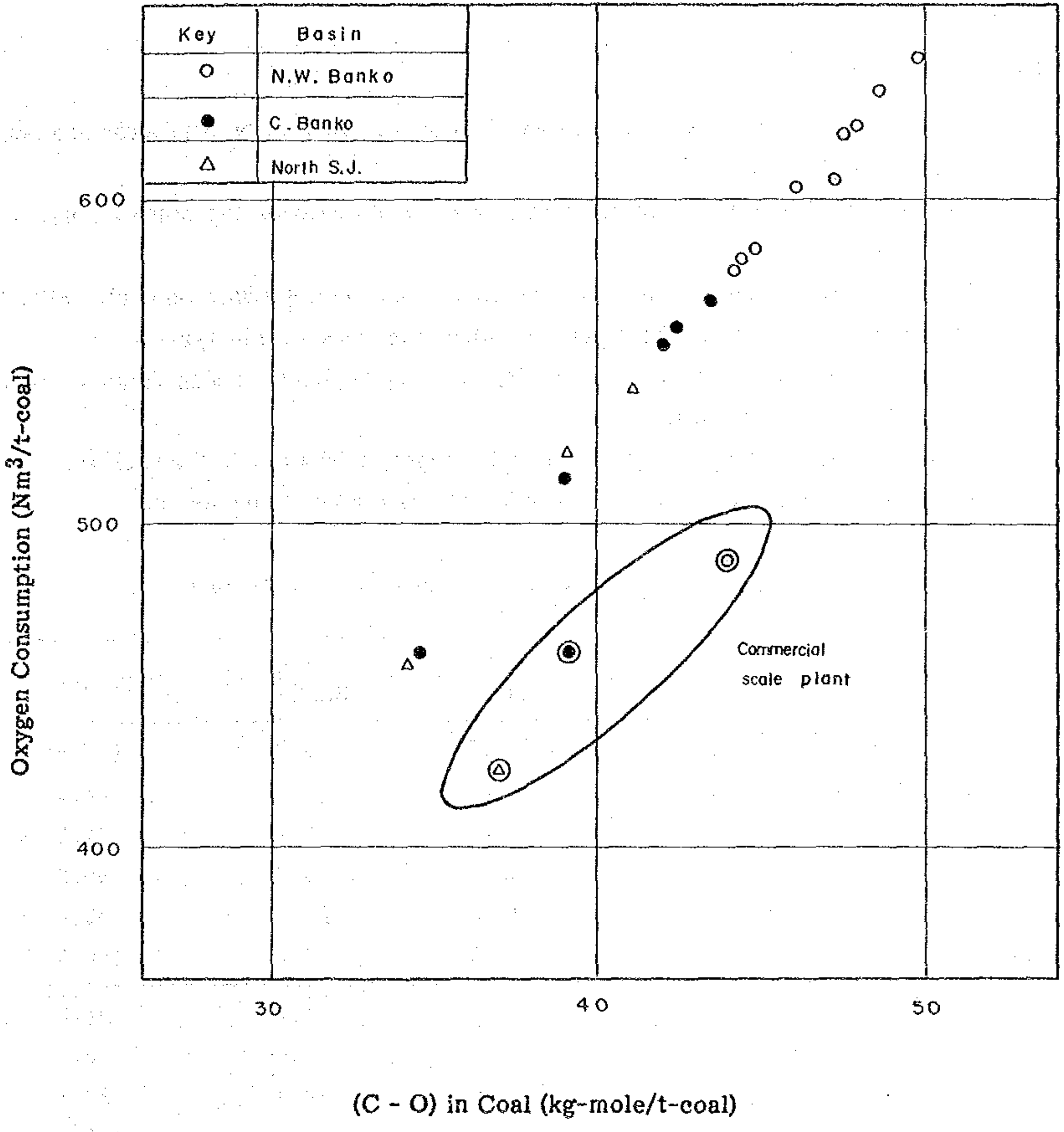


Fig. 8-4-7 Relationship between Oxygen Consumption and Coal Basin

8-4-3 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 stream.

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 8-4-4.

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 8-4-5 and Table 8-4-6.

Table 8-4-4 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 8-4-5 Quality of CaO

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

Table 8-4-6 Quality of Scrap

Metalic Fe (%)	Carbon (%)
99.7	0.3

Table 8-4-7 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. 8-4-8 shows the effect of moisture content in the feed coal on heat balance of a commercial scale gasifier (51.3 ton-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. 8-4-8, 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 8-4-7 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 8-4-7, overall material balance under well heat balance in gasifier were calculated.

Result of material balance is indicated in Table 8-4-8.

Note: Process data for each coal by basin is studied in Section 11-2.

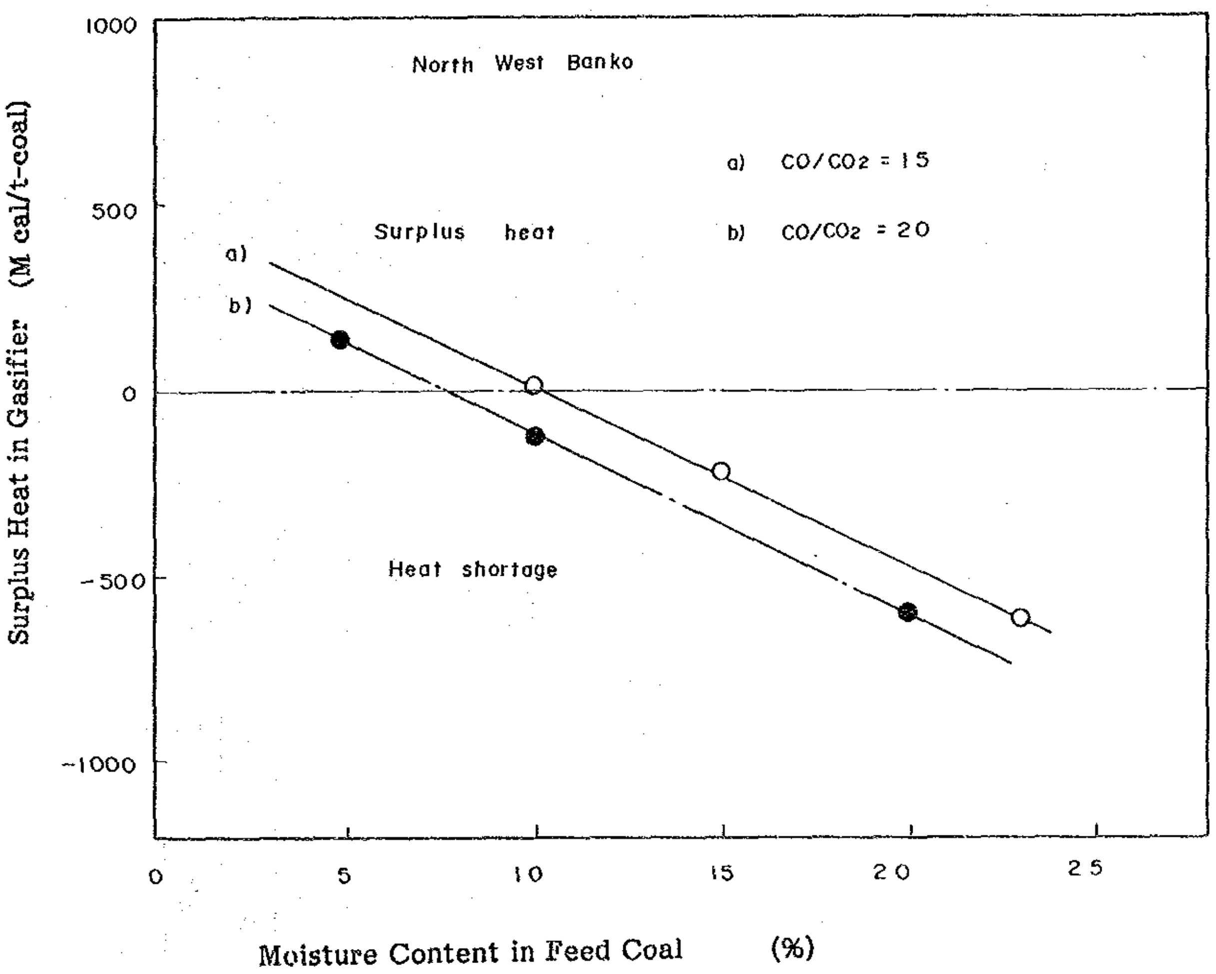


Fig. 8-4-8 Effect of Moisture Content in the Feed Coal on the Heat Balance

Table 8-4-8 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)	

9. RESULTS OF SURVEY ON BANKO COAL UTILIZATION TECHNOLOGY

9-1 TECHNOLOGY FOR COAL GASIFICATION

9-1-1 Preliminary Evaluation of Coal Gasification Technology

On the first stage, preliminary evaluation of coal gasification technology was carried out.

Gasification processes may be classified in a number of ways such as heat content of the gas, gasifying agents employed, ash removal methods and method of gas-solid contact etc.

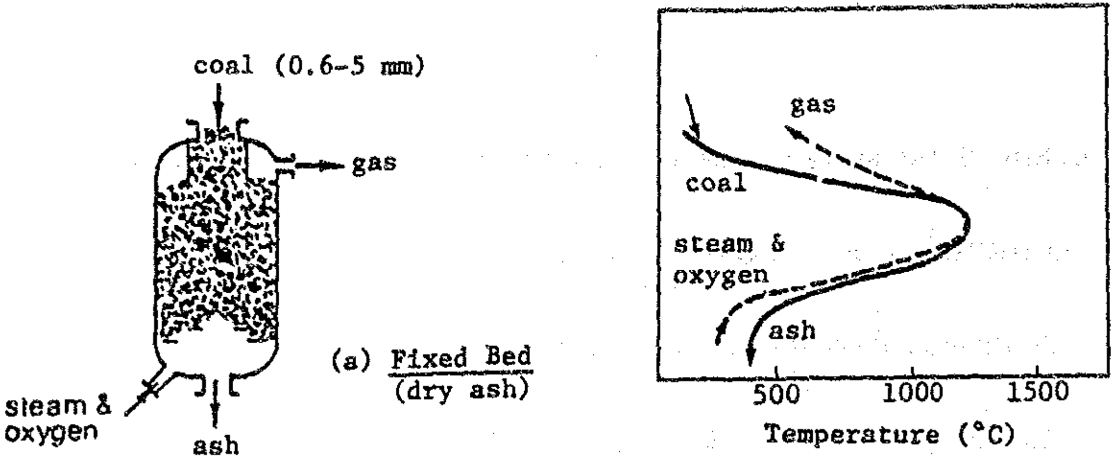
However, the most widely used classification is based on the mode of contact between the coal particles and the gas. The four main types of gasification process under this mode of classification are fixed bed, fluidized bed, entrained bed and molten iron bath.

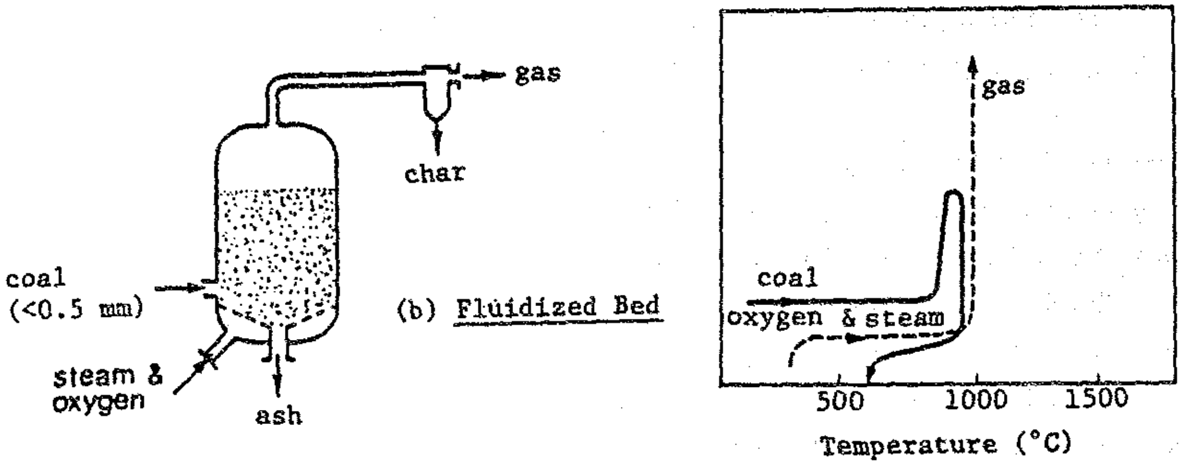
Fig. 9-1-1 shows the classification of principal coal gasification process and Table 9-1-1 to Table 9-1-4 show the typical performance of each gasification process.

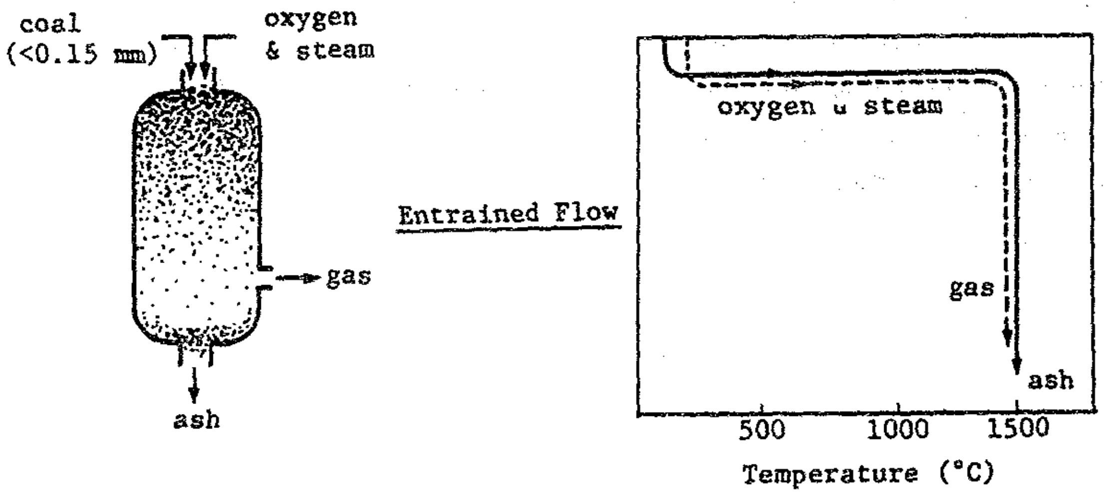
According to the preliminary evaluation, it was preliminary concluded that the best technology for producing synthesis gas was molten iron bath process and the best technology for producing fuel gas was fluidized bed process.

In this section, the current technical development of both processes after the preliminary evaluation was surveyed and the final overall evaluation of coal gasification technology (commercial scale) are studied to select the coal gasification process which is the most suitable for Banko coal.

Fig. 9-1-1 Classification of Principal Coal Gasifier Types


(a) Fixed Bed (dry ash)


(b) Fluidized Bed


Entrained Flow

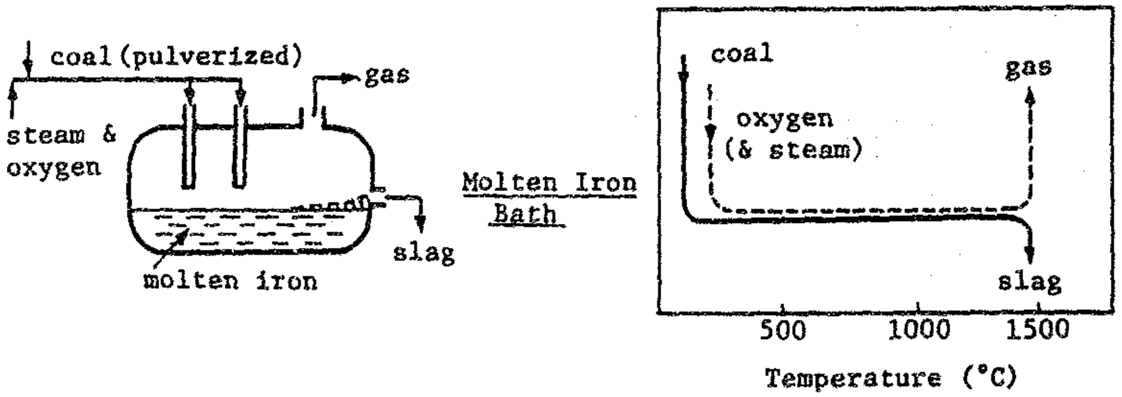

Molten Iron Bath

Table 9-1-1 Performance of Gasification Processes -FIXED BED-

	Lurgi	B.G Slagging Lurgi	Wellman-Galusha
1. Coal specification			
(a) Rank	Non-caking to mildly caking	All*1	All
(b) Size (mm)	6-40	6-40	25-50
2. Gasifier condition			
(a) Operating temperature (^{0}C)	700-900	1,500	1,000
(b) Pressure (bar)	20-30	20-30	Atomospheric
(c) Ash removal type	Dry	Slagging	Dry
3. Gas properties			
(a) Composition (vol.%-dry)			
CO	19.0	61.0	28.6
H_2	39.0	28.0	15.0
CO_2	30.0	2.6	3.4
CH_4	11.0	7.6	2.7
N_2 & others	rest	rest	rest
(b) Heating value (kcal/Nm^3)	2,247	3,290	1,500
4. Gasifying medium	Air/Oxygen & Steam	Oxygen & Steam	Air & Steam
5. Specific consumption			
(a) Oxygen (Nm^3/t-coal)	220-300	247	Air/Steam=6.0
(b) Steam (t/t-coal)	1.0-1.5	Less than non-slagging type	0.6
6. Carbon conversion (%)	85	99	NA
7. Thermal efficiency (%)	75	68	NA
8. Process developer	Lurgi Kohle & Mineralol-technik GmbH, W. Germany	British Gas Corporation & Lurgi	McKwell-Wellman Co., Ohio, & Wellman GalushaCo., UK

(Note) *1 : All means all types of coal which are classified as caking, mildly caking and non-caking.

Table 9-1-2 Performance of Gasification Processes -FLUIDIZED BED-

	Two Stage F.D	U-Gas	Hy-Gas
1. Coal specification			
(a) Rank	Non-caking	All	All
(b) Size (mm)	1.5	0-6 (-200 mesh not to exceed 10%)	0.15-2.4
2. Gasifier condition			
(a) Operating temperature (°C)	840-920	1,050	980
(b) Pressure (bar)	20	7-20	80
(c) Ash removal type	Dry	Agglomerate	Dry
3. Gas properties			
(a) Composition (vol.%-dry)			
CO	9.2	22.0	25.0
H_2	14.5	14.0	30.0
CO_2	16.5	6.0	25.0
CH_4	5.6	3.0	19.0
N_2 & others	53.3	rest	rest
(b) Heating value (kcal/Nm^3)	1,288	1,370	3,270
4. Gasifying medium	Air & Steam	Air/Oxygen & Steam	Oxygen & Steam
5. Specific consumption			
(a) Oxygen (Nm^3/t-coal)	Air 2100	MA	200-225
(b) Steam (t/t-coal)	1.0	NA	1.1
6. Carbon conversion (%)	94	98	98
7. Thermal efficiency (%)	71	NA	NA
8. Process developer	CMRC EPDC NEDO JAPAN	Institute of Gas Technology (IGT), Chicago Illinois, USA	I.G.T., Chicago, Illinois, USA

(Note) CMRC: Coal Mining Research Center
EPDC: Electric Power Develop Co.
NEDO: New Energy Development Organization

Table 9-1-3 Performance of Gasification Processes -ENTRAINED BED-

	Koppers-Totzek	Texaco	Babcock & Wilcox
1. Coal specification			
(a) Rank	All	All	All
(b) Size (mm)	-0.1	-0.1	-0.1
2. Gasifier condition			
(a) Operating temperature (°C)	1,800-1,900	1,320	1,650-1,850
(b) Pressure (bar)	1	20-80	1-20
(c) Ash removal type	Slagging	Slagging	Slagging
3. Gas properties			
(a) Composition (vol.%-dry)			
CO	52.5	46.5	65.3
H_2	36.0	33.1	27.9
CO_2	10.0	19.0	5.0
CH_4	-	0.1	-
N_2 & others	rest	rest	rest
(b) Heating value (kcal/Nm^3)	2,550	2,250	2,680
4. Gasifying medium	Oxygen & Steam	Oxygen & Steam	Oxygen & Steam
5. Specific consumption			
(a) Oxygen (Nm^3/t-coal)	540	700-800	600-700
(b) Steam (t/t-coal)	0.1-0.5	0.7	0.2
6. Carbon conversion (%)	96	90	80
7. Thermal efficiency (%)	75-85	70-85	NA
8. Process developer	Heinrich Koppers, GmbH, Essen W.Germany	Texaco Development Company, Cal., USA	US Bureau of Mines USA

Table 9-1-4 Performance of Gasification Processes -MOLTEN IRON BATH

	MIP
1. Coal specification	
(a) Rank	All
(b) Size (mm)	-0.1
2. Gasifier condition	
(a) Operating temperature (°C)	1,300-1,600
(b) Pressure (bar)	3
(c) Ash removal type	Slagging
3. Gas properties	
(a) Composition (vol.%-dry)	
CO	63.7
H_2	34.5
CO_2	1.0-3.0
CH_4	-
N_2 & others	rest
(b) Heating value (kcal/Nm^3)	2,800
4. Gasifying medium	Oxygen & Steam
5. Specific consumption	
(a) Oxygen (Nm^3/t-coal)	450-500
(b) Steam (t/t-coal)	nominal
6. Carbon conversion (%)	+98
7. Thermal efficiency (%)	75-85
8. Process developer	Sumitomo Metal Ind., Ltd., Japan & KHD Humboldt Wedag AG, W. Germany

9-1-2 Development and Current Status of Molten Iron Bath Process

Coal gasification in a molten iron bath is a logical extension of basic oxygen furnace (BOF) steel making technology.

The most promising of the development efforts is Sumitomo/KHD cooperative program.

Sumitomo Metal Industries Ltd., Osaka, Japan and KHD Humboldt Wedag AG, Cologne, West Germany started the development individually, SMI with the top-blowing technology and KHD with the bottom-blowing technology.

The top-blowing technique has been developed by SMI since 1978. After achieving successful results in laboratory trials, SMI established a pilot plant with a nominal capacity of 60 t of coal per day in Kashima Steel Works being supported financially by Japanese government.

The top-blowing technique provides for oxygen to be blown onto the iron bath at supersonic velocity through a specially designed lance together with CO_2 as a carrier gas. As in BOF process, a dimple is created at the point where the jet hits the bath surface. This is where O_2 and coal are blown and come into contact with the molten iron.

The reactions of injected oxygen and coal at the dimple are specific features of this process.

Gasification predominantly occurs within the iron bath. The coal impinging on the high-temperature molten iron is cracked almost instantaneously into the carbon dissolving in the molten iron and the hydrogen liberated as H_2.

$$\text{C (in coal)} \longrightarrow \text{C (in molten iron)}$$

$$\text{H (in coal)} \longrightarrow H_2 \text{ (gas)}$$

The gasification proceeds very rapidly, with the formation of CO by the reaction of oxygen and steam with the dissolved carbon.

It is estimated that the following reaction mainly takes place inside of the molten iron bath.

$$\text{C (in molten iron)} + 1/2\ O_2 \quad CO$$

In case of CO_2 and/or steam injection for temperature control, following reactions take place at the same time.

$$\text{C (in molten iron)} + CO_2 \quad 2CO$$

$$\text{C (in molten iron)} + H_2O \quad CO + H_2$$

The molten iron bath process provides the following benefits:

i) The molten iron bath completely cracks the blown coal in a short period of time and not only generates hydrogen gas but dissolves and absorbs the carbon produced by cracking.

ii) The molten iron reacts with blown oxygen and carbon dioxide and becomes FeO, but this FeO is immediately reduced by carbon contained in the molten iron and becomes Fe while generating carbon monoxide gas.

iii) Even if an excessive amount of coal is fed into the molten iron bath, the molten iron dissolves and absorbs an excessive amount of carbon preventing unoxidized carbon to escape from the gasifier.

iv) Even if an excessive amount of oxygen is supplied, carbon contained in the molten iron bath reacts with excess oxygen preventing the generation of carbon dioxide gas.

v) The molten iron dissolves and absorbs the sulfur contained in the coal and then transform into the molten slag.

According to above mentioned activity of the molten iron, the basic principle of coal gasification mechanism of the molten iron bath gasifier is basically different from that of other gasifiers.

On the other hand, KHD has developed the bottom-blowing technique since 1975. Small scale pilot tests had been carried out in a steel converter of 6 tons iron at the metallurgical research institute (MEFOS), Lurea, Sweden. These tests were conducted for 2 years.

By using the bottom-blowing technique, coal, oxygen, flux and a cooling gas are injected continuously through tuyeres into the bottom of a liquid iron bath. A solid porous metal called "MUSHROOM" is formed above the tuyeres, which protects the tuyere tip. The exothermic oxidation of the iron at the gas/molten iron interface induces a relatively high temperature.

The liquid iron oxide formed outside of this mushroom is continuously transfered into the liquid iron bulk generating CO and H_2 through the decomposition of injected coal and the reaction with dissolved carbon in the molten iron.

The gasification reaction is strongly effected by the bath turbulance and the resulted wide dispersion of coal particle and iron oxide in the reactor.

Through the top-blowing tests by SMI and the bottom-blowing tests by KHD, the following important advantages of molten iron bath coal gasification relative to other gasification systems were clarified

- extremely high yield of CO and H_2 with less CO_2
- hot desulfurization by slag and iron dust
- essentially no NH_3 or HCN formation
- all types of coal and other carbonaceous materials are easily gasified.

In 1983 Sumitomo and KHD combined forces for larger scale testing and development of the process which was named Molten Iron Pure gas (MIP).

A proto-type test plant with a capacity of 240 t of coal per day was built at MEFOS in Lulea, Sweden.

The erection of the proto-type test plant was completed by August 1985.

Fig. 9-1-2 illustrates the schematic process flow of the proto-type test plant.

Table 9-1-5 shows the general design aspects of the plant.

Fig. 9-1-3 shows the reactor (gasifier) of the plant

The reactor is designed for 240 t/d coal feed at 3 atmospheres pressure. The reactor is also designed for testing both top and bottom blowing operation.

Table 9-1-5 General Design Aspects of Proto-type Plant

Coal injection	240 t/d
Gas products	23,000 Nm^3/h
Pressure in reactor	3 bar (absolute)
Blowing method	Top or bottom
Reactor	Drum type 4.4 mϕ, 7.5 m length
Gas cooler	Boiler type 1,450°C to 400°C
Venturi scrubber	400°C to 60°C

The cylindric reactor is lined with special refractory and is equipped with several inlets for measuring and sampling purpose. The reactor has a diameter of 4.5 m, same scale of commercial size, and a length of 7.0 m, 1/2 to 1/3 scale of commercial size.

Fig. 9-1-2 Molten Iron Bath Coal Gasification Proto-type Plant (MIP Plant)

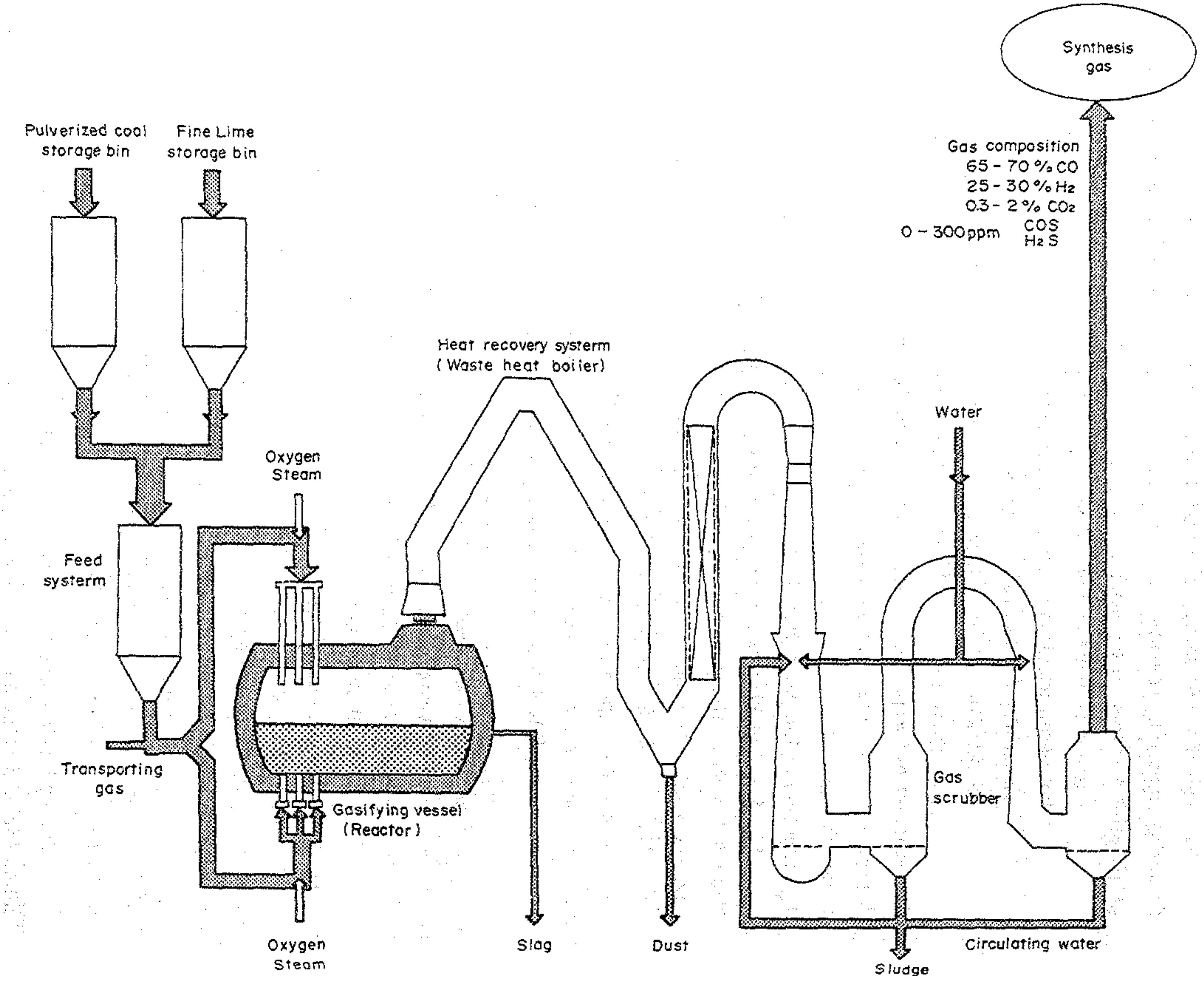
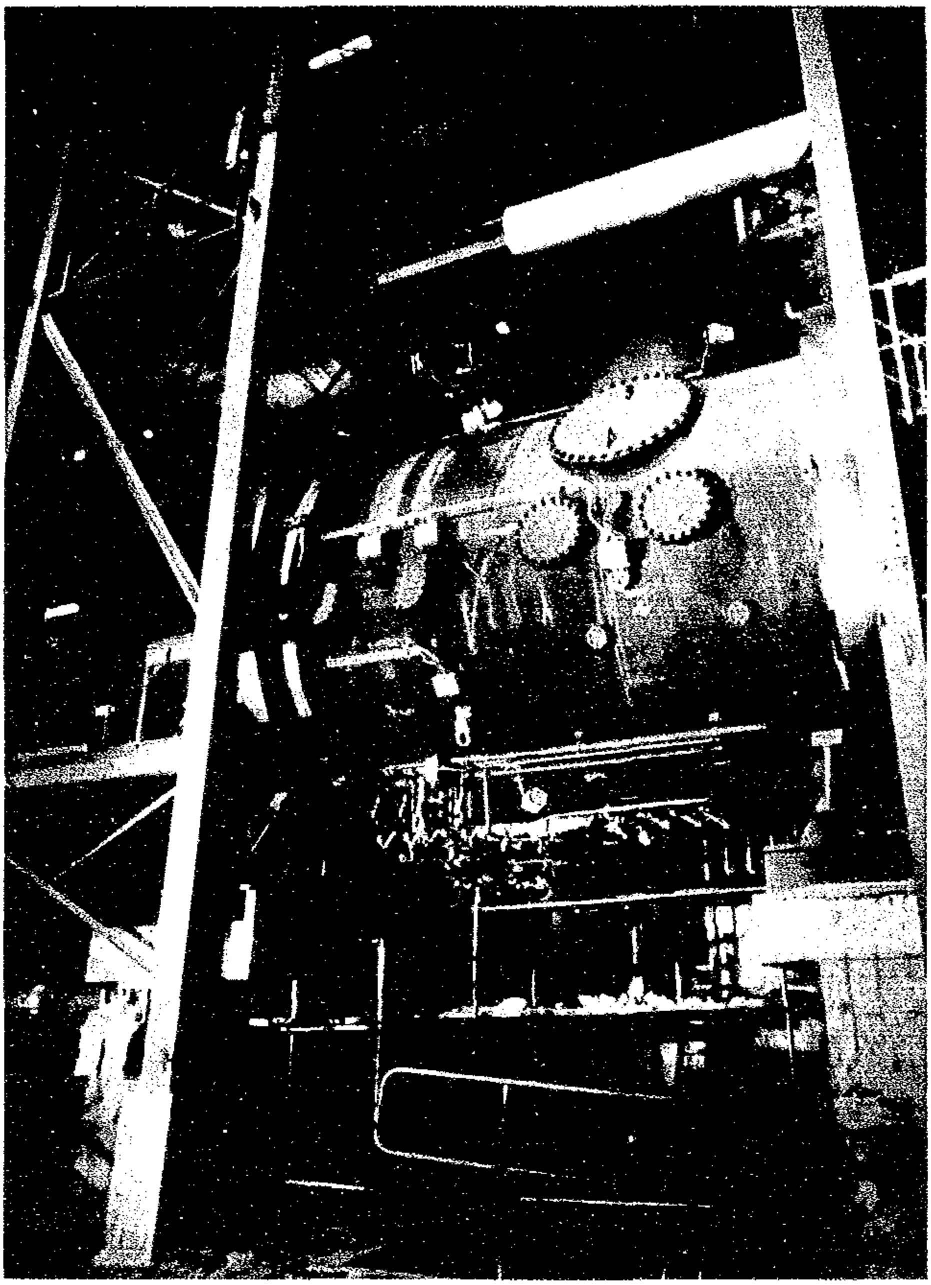


Fig. 9-1-3 Overview of the MIP Plant



Oxygen and coal are injected through top or bottom-blowing nozzles specially arranged at the reactor. Other materials required for the reaction, such as lime for adjusting the slag basicity and steam for temperature control can be supplied through the nozzle at the same time.

The product gas leaving the reactor has a temperature of 1400° to 1500°C and is firstly passed over a cooler with heat recovery system and afterwards dedusted by a two-stage venturi scrubber.

The slag accumulated over the iron bath is removed as uniformely as possible using conventional slag discharging devices and then subjected to a secondary treatment.

Operation of the proto-type test plant was started at September 1985 and several bottom-blowing test campaigns have been conducted up to now.

Typical test results obtained are summarised in Table 9-1-7.

Summing up the test results, it can be stated that all of the following mechanical facilities functioned well.

- coal and lime storage and mixing system
- coal injection system
- gasifier (reactor)
- produced gas recovery system
  (waste heat boiler)
- gas scrubber
- measurement and control units

During the blowing periods the gasification system was stable. The deslagging under pressure was performed without interruption of the gasification operation.

The product gas contained 62-66% CO, 31-35% H_2 and 0.1-1.6% CO_2. In general, the CO/CO_2 ratio in the product gas was higher in the gasification of higher grade coal than in case of lower grade coal, because excess oxygen is required, in case of lower grade coal, to keep the temperature of molten iron bath constant, resulting higher CO_2 formation.

The impurities in the gas were very low as shown in Table 9-1-7.

The gas quality is superior to those of all other coal gasification process.

The lower content of sulfur compounds in the gas and no tarlly materials are one of decisive advantage of the MIP coal gasification technology.

Because of the steady operation and mechanical reliability attained in the commercial scale proto-type plant, it can be expected that gasifier capacity of 1,500 - 2,000 ton coal per day will be achieved in a commercial gasifier having 200 - 300 ton of molten iron inside gasifier by enlarging the length of gasifier tested.

The both test results in the MIP proto-type plant and in PUSPIPTEK test facility show that even lower grade coal such as Banko coal can easily be gasified by molten iron bath process in commercial scale plant.

Furthermore, a molten iron bath process has unique feature that the iron dust from the gasifier is useful as a catalyst for coal direct liquefaction and various chemical processes.

Table 9-1-6 Composition of the Coal used in the MIP Plant

a) Ultimate Analysis

		Swedish Coal (A)	Swedish Coal (B)
Carbon	(%)	81.2	76.5
Oxygen	(%)	7.6	4.4
Hydrogen	(%)	4.7	5.7
Nitrogen	(%)	1.2	3.7
Sulphur	(%)	0.5	1.1
Ash	(%)	3.3	7.3
Moisture	(%)	1.5	1.5
Total	(%)	100.0	100.0

b) Ash Analysis

		Swedish Coal (A)	Swedish Coal (B)
Al_2O_3	(%)	0.86	1.65
SiO_2	(%)	1.11	3.77
CaO	(%)	0.29	0.21
Fe_2O_3	(%)	0.58	1.44
K_2O	(%)	0.05	0.06
MgO	(%)	0.13	0.09
Na_2O	(%)	0.03	0.05
P_2O_5	(%)	0.04	-
Others	(%)	0.21	-
Total	(%)	3.30	7.27

Table 9-1-7 Test Results

Temperature of the iron bath	(°C)	1,350 - 1,400	1,380 - 1,440
% C in molten iron	(%)	3.6 - 4.1	4.1 - 4.7
Slag basicity		1.0 - 1.8	1.6 - 1.7
Coal injection	(t/h)	3.8 - 4.3	4.5 - 6.0
Coal/oxygen ratio		2.0	1.3 - 1.4
Gas pressure	bar	1.1 - 1.4	1.1 - 2.0
Gas composition	*)		
CO	(%)	63.7 - 65.5	62.5 - 66.6
CO_2	(%)	1.1 - 1.6	0.1 - 0.6
H_2	(%)	32.8 - 35.2	31.2 - 34.7
H_2S - COS	(ppm)	10 - 40	Ca. 10

* dry & nitrogen free base

9-1-3 Development and Current Status of Texaco Process

Initial development of the Texaco coal gasification process was conducted in the 1940s at Texaco's Montebello, California.
However, the availability of cheaper oil and gas in the late 1950s caused Texaco to direct its development efforts toward partial oxidation of oil and gas.
Because of favorable economics, over 80 commercial Texaco partial oxidation plant of oil and gas were constructed worldwide by 1982.
The oil price increases and supply disruptions after the first oil crisis have created interest in the Texaco partial oxidation process for gasification of coal.

Since the early 1970s, the research works at the Montebello laboratory have been concentrated on development of the Texaco coal gasification process.
Initial work was completed in the moderate pressure, 15 tons coal per day gasifier at the site.

Since that time two additional gasifiers have been added at Montebello. Approximately 20 different coals have been tested in the last five years.

In 1977, Ruhrkohle A.G. and Ruhrchemie started up a 165 tons per day proto-type plant at their Oberhausen-Holten, West Germany. Development efforts at Oberhausen have concentrated on development of refractory materials, synthesis gas cooler and coal injection device.

The extensive research and development efforts undertaken at Montebello and Oberhausen over the last five years have provided a basis for scalling up the Texaco coal gasification technology to the commercial size gasifier.

Recently, Texaco coal gasification plants were adopted for the Tennessee Eastman methanol plant, Ube ammonia plant and the Cool Water gasification combined cycle power demonstration plant.

The gasifiers for the Tennessee Eastman plant, the Ube Plant and the Cool Water Project have a coal handling capacity of 900 to 1,000 tons per day.

The plant in the Cool Water Project began to operate in mid-May, 1984 and has been operated successfully.

Fig. 9-1-4 is a schematic process flow of the pressurized, downflow, entrained Texaco gasifier. The feed coal is crushed and slurried in wet rod mills. The slurry water consists of recycled condensate from raw gas cooling together with make-up water. Carbon that is not converted in the gasifier can be recovered and recycled to the gasifier feed via the slurrying operation.

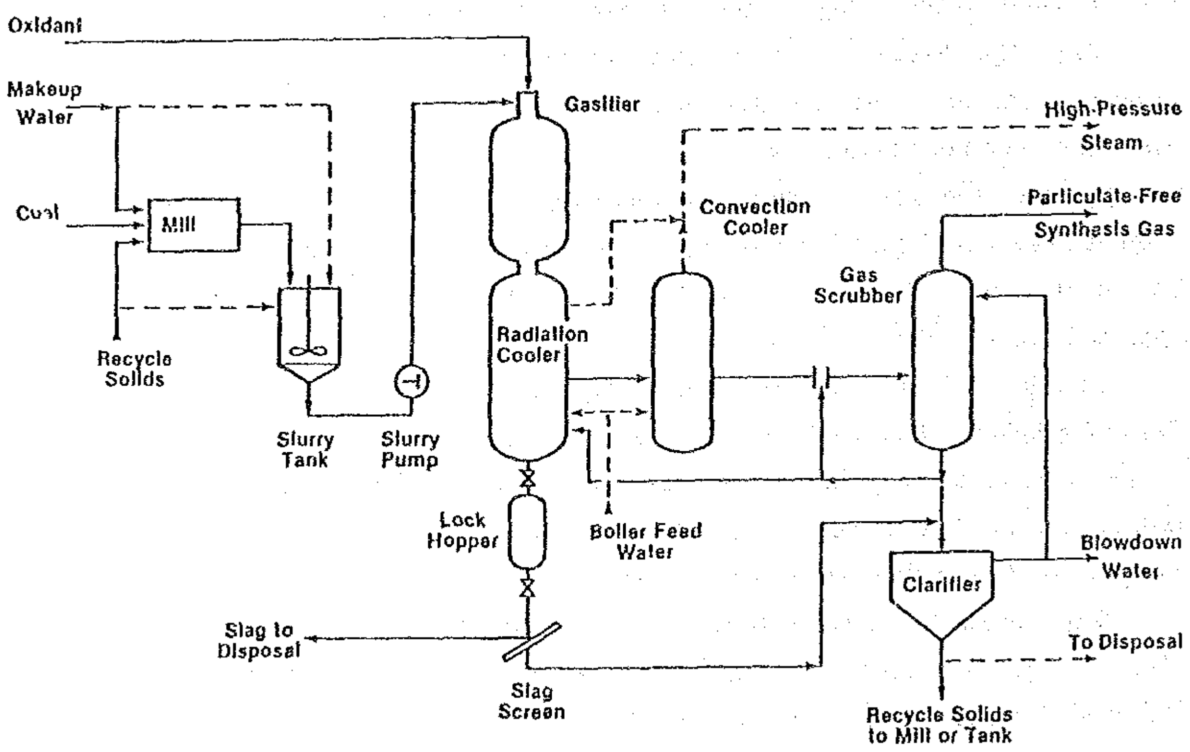
The coal/water slurry is pumped into the gasifier burner together with oxygen (or air). The gasification takes place rapidly at temperatures in excess of 1,260°C under which conditions the coal is converted primarily to H_2, CO and CO_2 with no liquid hydrocarbons being found in the gas. The water in the coal slurry not only serves to convey the coal to the gasifier, but also moderates the gasifier temperature so that excessively high temperatures are not experienced.

The crude raw gas leaving the gasifier at 1,260°C - 1,480°C contains a small quantity of unburned carbon and a significant portion of molten ash. Depending on the end use, this gas stream would either be directly quenched in water (to cool the gas and remove solidified ash particles) or would be cooled in radiant and convection boilers for sensible heat recovery (via high-pressure saturated steam generation) prior to water scrubbing.

As mentioned above, in Texaco gasifier, water with coal (coal/water slurry) is fed to gasifier, so that in the case of low grade coal, higher excess oxygen is required to keep minimum gasifier temperature, resulting extremely lower CO/CO_2 ratio of product gas.

Therefore, Texaco gasifier process is not suitable for gasifing low grade coals (low carolific coal).

Fig. 9-1-4 Texaco Coal Gasification Process



9-1-4 Technology Available for Banko Coal Utilization

According to the results on preliminary survey on market the most prospective markets of produced gas are feedstock for synthetic fuel oil, fuel methanol and urea, which are derived from synthesis gas.

At the same time, from the results of survey on Banko coal quality, followings are pointed out as the general features of Banko coal.

- high total moisture
- low calorific value
- high volatile material
- non coking coal
- high Na_2O content in ash and a wide range of ash fusion temperature
- quite brittle and difficult to get lump coal

Taking the above mentioned Banko coal quality and fields of Banko coal utilization, oxygen blow coal gasifiction technology for production of synthesis gas was evaluated in miscallanious and overall points of view.

i) Availability for Banko coal

Banko coal has a wide variety of its quality, sodium content in ash and ash fusion temperature (1,150°C - more than 1,500°C). A molten iron bath gasifier has an enough flexibility for such a wide variety of coal. A fluidized bed gasifier follows next place. Other types of gasifier have serious problems for Banko coal.

As discussed in the chapter 8-3, 20 kinds of Banko coal which were sampled at North West Banko, Central Banko and North Suban Jeriji were tested in the Puspiptek coal gasification test facilities.

Through these tests, it was proved that all kinds of Banko coal can be easily gasified by the molten iron bath gasification process.

ii) Gas Composition

Product gas come from a gasifier contains generally hydrogen carbon monoxide, carbon dioxide, steam, methane, ethane, nitrogen and small amount of impurities. For production of derivatives, product gas will be treated to remove undesirable materials for synthesis reaction such as carbon dioxide and impurities. However, methane, ethane and nitrogen are difficult to remove, and therefore accumulated gas in synthesis reactor must be purged from the synthesis process. As obvious from above discussion, the most desirable gas composition of product gas is a mixture of hydrogen and carbon monoxide, and other materials are undesirable components.

As seen in Table 9-1-7, product gas from the molten iron bath gasification process shows extremely high content of CO and H_2 with less undesirable gas components.

In view of product gas composition, an oxygen blow-molten iron bath gasifier is the most superior for synthesis gas production and an oxygen blow-entrained flow gasifier follows.

An oxygen blow-fixed bed gasifier and a fluidized gasifier are not suitable for the purpose of synthesis gas production, because the product gas contains much undesirable materials.

iii) Impurity

Product gas contains a small amount of impurities such as hydrogen sulphide (H_2S), carbonyl sulphide (COS) and ammonia (NH_3) which are catalyst poison. Therefore these impurities must be completely removed by chemical treatment.

In view of impurities, a molten iron bath gasifier has better performance, because 90% of sulfur contained in coal is absorbed into slag and iron dust.

Moreover, NH_3 and HCN are not formed.

It is estimated that Banko coal can be gasified also by a fluidized bed gasifier though the produced gas is not suitable to synthesis purpose.

iv) Energy Efficiency

If outlet temperature of product gas from heat recovery system is assumed to be same level, energy efficiency of gasifier depends on each carbon conversion efficiency and amount of effluent steam in generated gas. A molten iron bath gasifier is the most superior to other type of gasifier, because of the highest carbon conversion efficiency, and less effluent steam.

An entrained flow gasifier shows the lowest energy efficiency because of coal/water sulurry feed system.

v) Gas Pressure

Required gas pressure in synthesis reaction is generally higher than 30 kg/cm^{2}G.

3 kg/cm^{2}G of a molten iron bath gasifier is inferior to that of other gasifiers.

vi) Operatability and Safety

An entrained flow gasifier has no surplus carbon inside of gasifier. Therefore steady operation may be easily disturbed by minor deviation of feed rate of oxygen and coal. A molten iron bath gasifier hold surplus carbon in the molten iron and effluent carbon is negligiblely small amount, therefore stability and safety can be achieved.

vii) Construction Cost

It is difficult to evaluate the construction cost, because concrete cost data are not investigated at the present. However, in view of simplified process flow scheme and low pressure operation, the construction cost of a molten iron bath process is expected to be cheeper, though the maintenance cost of refractory in the gasifier may be a little expensive.

viii) Commercial Experience

A molten iron bath process has no commercial experience, though many of similar type of commercial plants are operated in steel industry.

All taking into the consideration, overall evaluation shows that oxygen blow-molten iron bath gasifier is superior for production of synthesis gas from Banko coal.

High pressure molten iron bath gasifier (higher than 3 kg/cm^{2}G) will be better, if such a technology will be developed.

Table 9-1-8 Evaluation of Coal Gasification Technology for Synthesis Gas Production

	Fixed bed (dry ash)	Fludizied bed	Entrained flow	Molten iron bath
Availability for Banko coal	10	1	10	1
Gas composition	5	5	2	1
Impurity	4	3	2	1
Overall thermal efficiency	3	2	3	1
Gas pressure	1	1	1	3
Operatability and safety	1	1	3	1
Construction cost	3	2	2	1
Commerical experience	1	1	1	2
Total	28	16	24	11
Overall evaluation (ranking)	4	2	3	1

(Note) Lower number is better in performance.

9-2 TECHNOLOGY FOR DERIVATIVE PRODUCTION

9-2-1 Technical Possibility of Synthesis Gas Utilization

Synthesis-gas-based chemistry can roughly be classified into following categories by chemical reaction.

Alcohol synthesis
Fischer-Tropsch (F/T) synthesis
Oxo-synthesis
Methanol-to-gasoline synthesis
C_1 chemistry

In regard to alcohol synthesis, an excellent example of synthesis-gas-based chemistry, methanol synthesis has already been industrialized, while efforts are now made for the development of fuel alcohol as well as higher alcohol to be used as chemical feedstocks.

Methanol is used in following fields;

- Substitute fuel oil (Neat or Blend, MTBE and MTG feedstock)
- Chemicals feedstock
- SCP feedstock

F/T synthesis was put into practical use for gasoline synthesis with Fe-catalysts in the 1950s, but gasoline yield is low because olefin and alcohol are simultaneously produced. To increase gasoline fraction or diesel fraction, the development of improved processes are now under way.

Oxo-synthesis is to synthesize, from synthesis gas and olefin, aldehyde of which carbon number is larger than olefin by one. This process, which can also manufacture alcohol by hydrogenation, has already been industrialized.

Employing special zeolite as a catalysis, Mobil developed a process to synthesize gasoline from methanol.

Based on new catalysts technologies, such as rhodium and zeolite catalysts, involved in the aforementioned technologies, C_1 chemistry is now under development to produce such oxygen-containing compound as ethanol, ethylene glycol and acetic acid.

Chemicals, to be directly processed from synthesis gas, as well as other utilization of synthesis gas are illustrated in Fig. 9-2-1. Chemicals to be processed from methanol are also shown in Fig. 9-2-2. These figures are prepared in regardless of that processes have been already commercialized or under development.

Chemistry, technology and its development history of the above mentioned categories were reported in the Interim Report (1st Stage), dated May 1985.

Additional information obtained in the 2nd Stage is explained in the following subsections.

Fig. 9-2-1 Utilization of Synthetic Gas

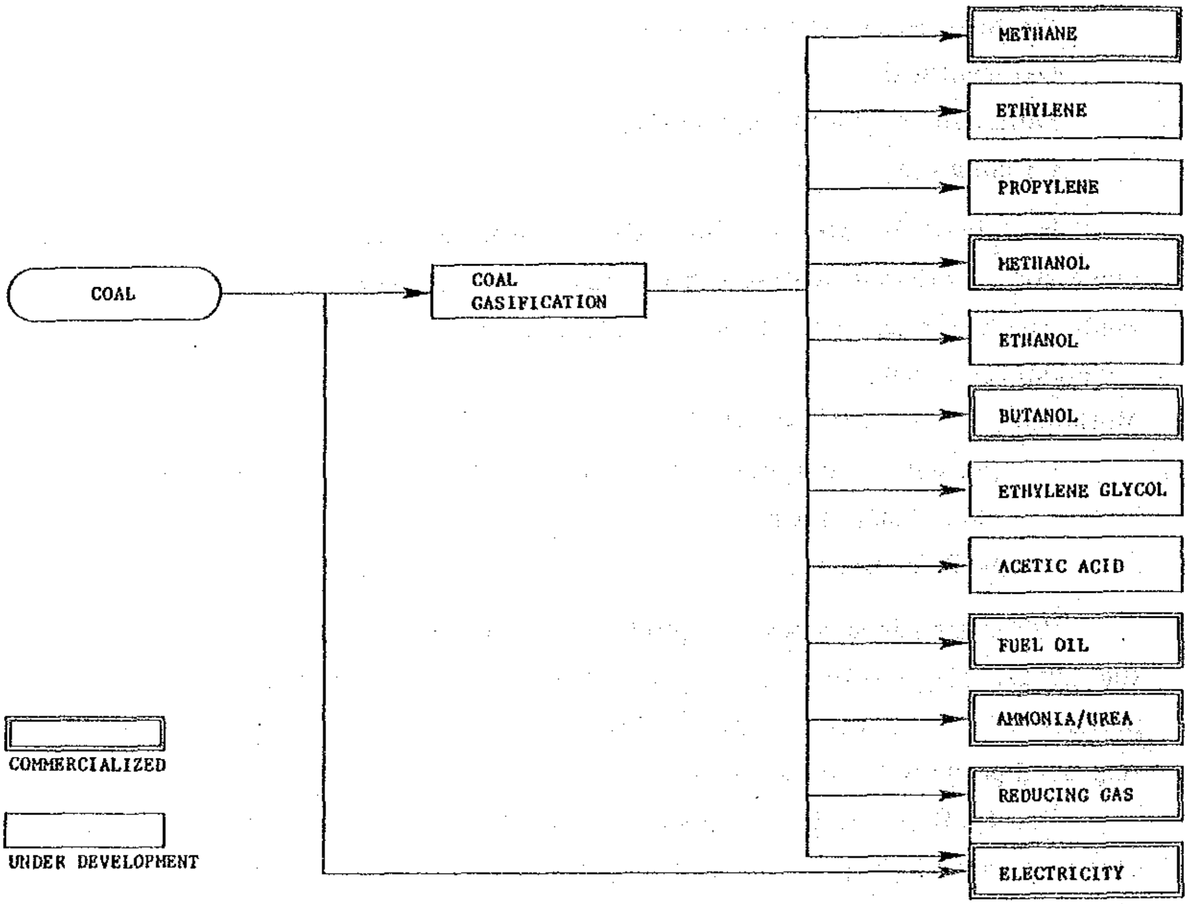
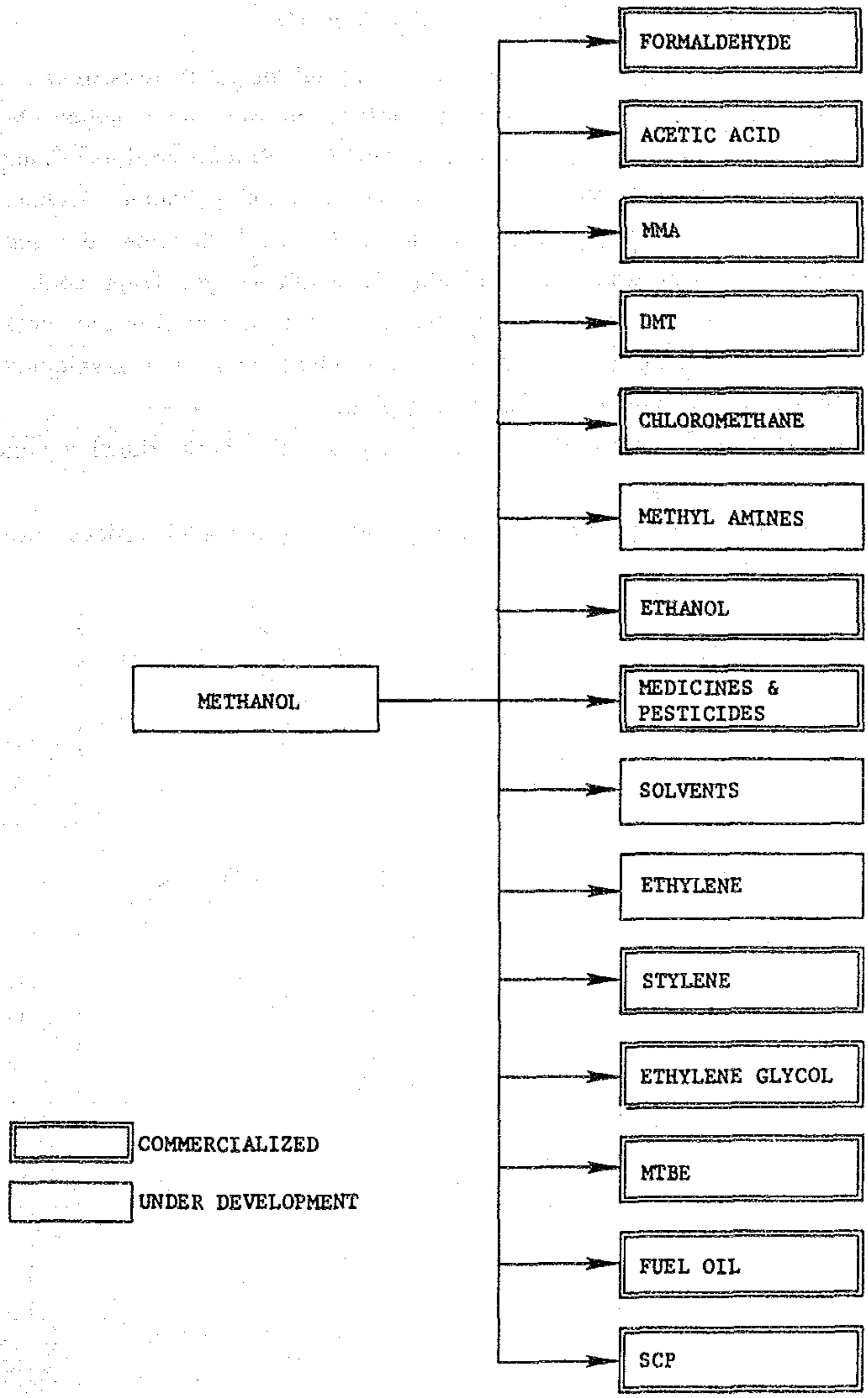


Fig. 9-2-2 Derivatives from Methanol



9-2-2 Additional Information on Technology for Derivative Production

(1) Synthesis of Methanol Containing Higher Alcohols

Alcohol is expected to be one of the most promising substitutes to oil.
In Europe, with the necessity of an octane booster, some major chemical and engineering companies such as Snamprogetti, I.F.P. and Lurgi have achieved their original processes to synthesize methanol containing higher alcohols (C_2 - C_5 alcohols) from synthesis gas. In the U.S., Dow Chemical developed sulfer-resistive catalyst which is applicable to synthesis gas from coal. In Japan, RAPAD (Research Association for Petroleum Alternative Development) developed Ni catalyst which produces much higher alcohols than other developing processes in the product and confirmed with pilot plant.
Fig. 9-2-3 gives a flow diagram of Snamprogetti process showing mixed alcohol production from synthesis gas.
Typical data under verious operating conditions for each process are shown in Table 9-2-1.

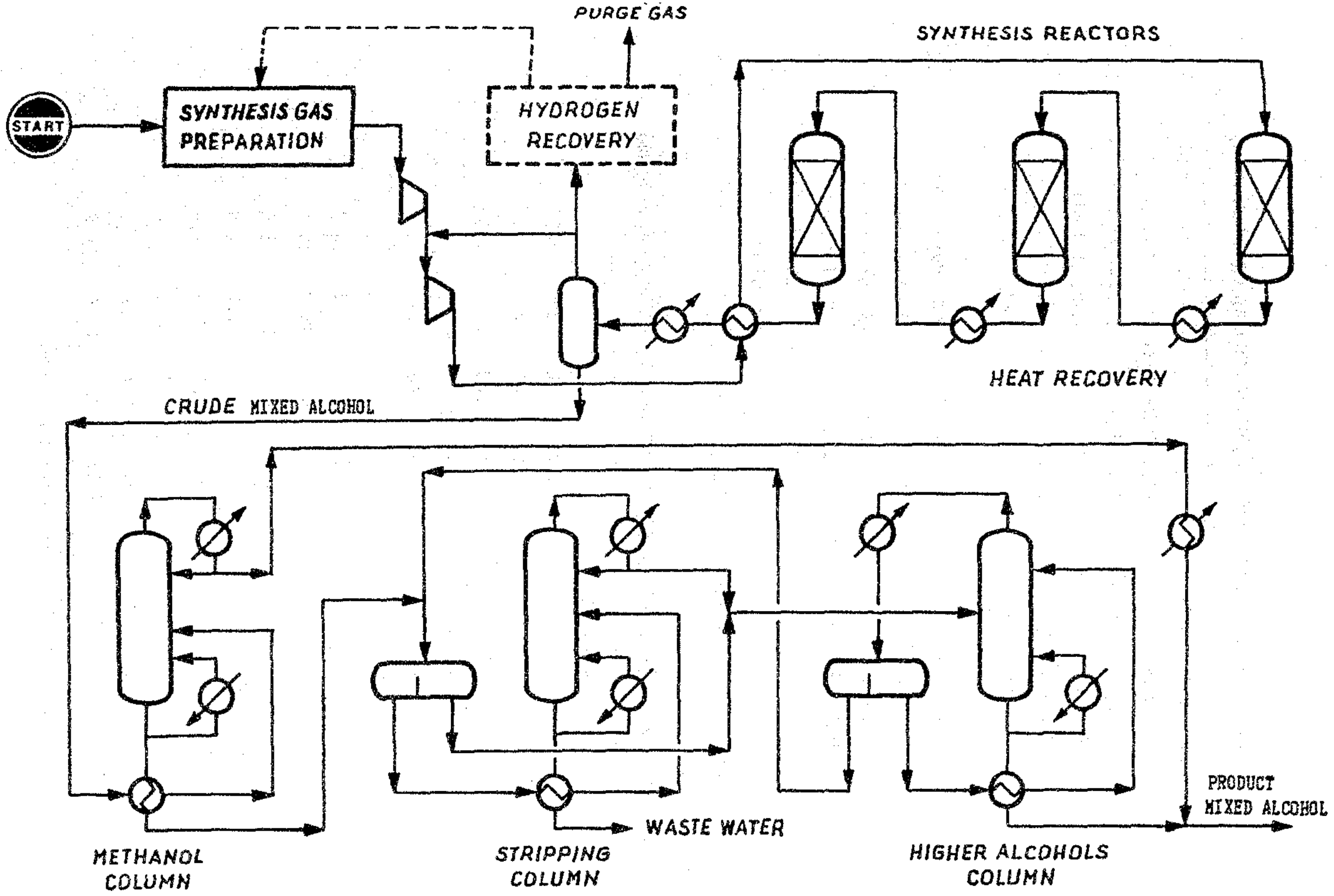


Fig. 9-2-3 Snamprogetti Process

Table 9-2-1 (a) Mixed Alcohol Synthesis (Snamprogetti Process)

Operating Condition		
Catalyst	$ZnO-CrO_3-K_2O$	
Temperature, °C	410 - 422	(330 - 430)
Pressure, atm	70	(90 - 180)
Space Velocity, h^{-1}	11,700	
H_2/CO Ratio	2.4	(< 1)
Yields, wt%		
Methanol	46.3	(68 - 72)
Ethanol	3.9	(2 - 3)
Propanol	9.4	(3 - 5)
Butanol	22.4	(10 - 15)
C_5^+ alcohol	17.7	(7 - 12)
H_2O	0.3	(< 0.1)

Note; ( ) Demonstration Plant Deta

Table 9-2-1 (b) Mixed Alcohol Synthesis (Dow Chemical Process)

Operating Condition				
Temperature, °C	302	268	296	320
Pressure, atm	200	100	208	173
Space Velocity, h^{-1}	3,348	1,980	2,310	2,500
H_2/CO Ratio	1.14	←	←	←
H_2S, ppm	0	40	110	138
Yields, wt%				
Methanol	50.8	36.7	24.7	16.1
Ethanol	22.3	30.4	36.8	30.3
Propanol	6.6	8.9	13.1	14.4
Butanol	1.6	1.0	3.7	4.8
C_5^+ alcohol	0.1	0.1	1.0	1.4
CH_4	12.6	19.6	13.9	-
C_2^+ hydrocarbon	4.7	3.7	4.6	-
CO Conversion, %	26.3	8.0	17.0	21.2

Note; Catalyst: MoS-KOH-VIII Metal Comp.

Table 9-2-1 (c) Mixed Alcohol Synthesis (I.F.P. Process)

Operating Condition	
Catalyst	Cu·Co (Base) - Al·Ce·Cr·Fe·La·Mn
Temperature, °C	260 - 320
Pressure, atm	60 - 100
Space Velocity, h^{-1}	3,000 - 6,000
H_2/CO Ratio	2 - 2.5
CO_2, %	0 - 10
Yields, wt%	
Methanol	50 - 70
Ethanol	16 - 23
Propanol	8 - 14
Butanol	4 - 7
C_5 alcohol	2 - 3
C_6^+ alcohol	1.5 - 3
CO Conversion, %	12 - 18
Alcohol Selectivity, %	70 - 75

Table 9-2-1 (d) Mixed Alcohol Synthesis (RAPAD Process)

Operating Condition				
Catalyst	Cu·Ni·Ti	Ni·Ti	Cu·Co·Al·Na	Cu·Ni·Ba
Temperature, °C	297	292	303	280
Pressure, kg/cm^2	61	60	61	61
Space Velocity, h^{-1}	4,000	←	←	←
H_2/CO Ratio	2	←	←	←
Yields, wt%				
Methanol	56	44	45	38
Ethanol	31	37	38	46
Propanol	4	13	10	9
C_4^+ alcohol	4	6	7	-
CO Conversion, %	19	19	-	19
Oxygenates Selectivity	63	44	57	69

(2) Production of Gasoline from Methanol

The MTG process at Motunui (North Island, New Zealand) has began the commerical operation on March 1986.

The plant which has been constructed and operated by NZSFC (New Zealand Synthetic Fuels Corporation), produces 570,000 tons of gasoline per year from 1 billion m^3 of natural gas.

The process for producing gasoline from natural gas is as follows;

1) Natural gas is introduced with pipe line from Maui which is one of the world largest off-shore gas field.

2) The natural gas is converted to methanol with two trains of conventional ICI methanol synthesis process.

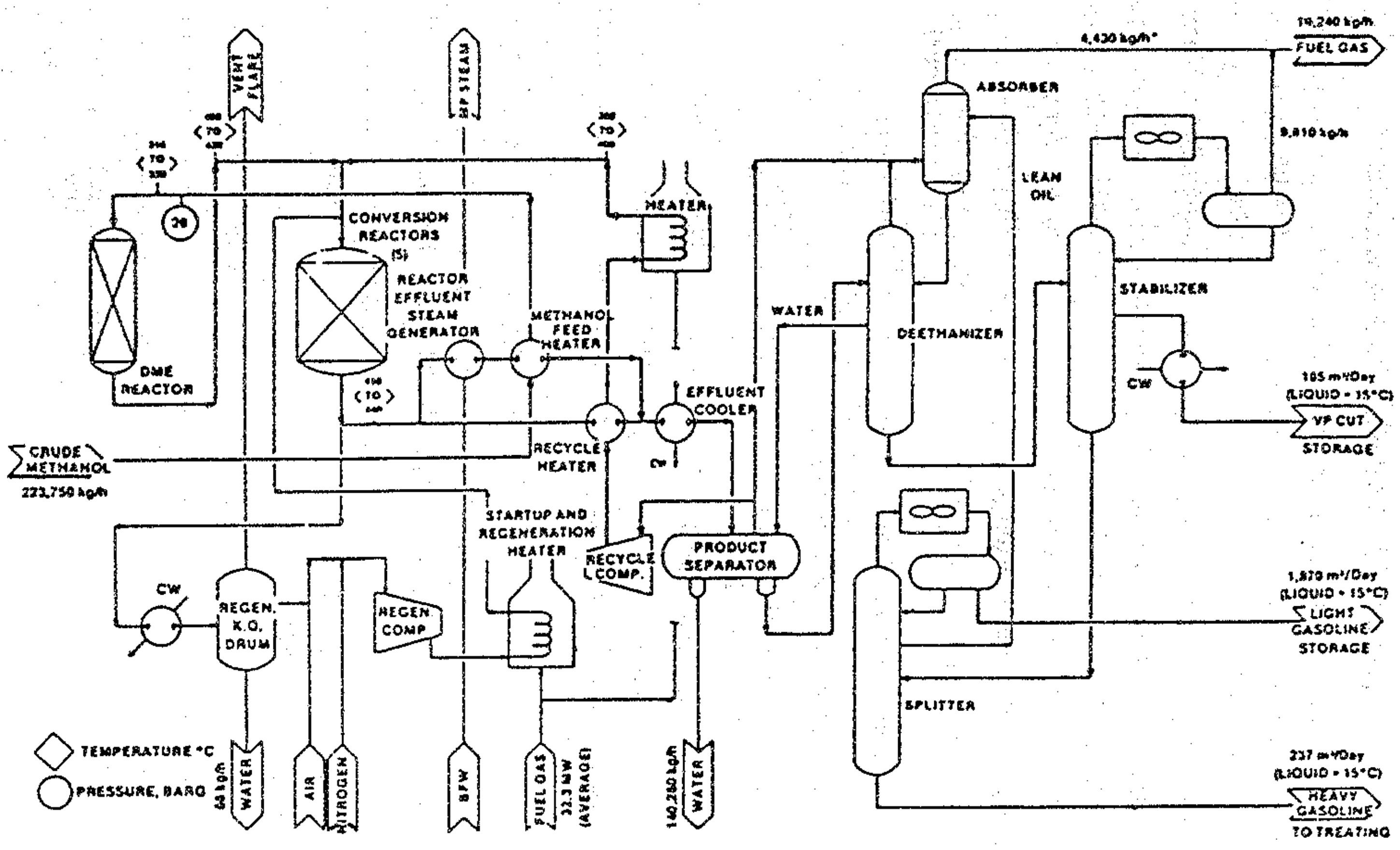
3) Crude methanol from the methanol plants is converted to gasoline with MTG process.

The process flow diagram and production capacities are shown in Fig. 9-2-4 and Table 9-2-2.

The MTG process converts methanol to hydrocarbon mixture composed of aromatic rich fraction at around 400°C and under pressure, using a special zeolite (ZSM-5) developed by Mobil Corporation. The process gives high octane gasoline (RON 97) accompanied by small amount of LPG. Table 9-2-3 shows the properties of product gasoline.

The conversion efficiency (energy base) of natural gas to synthetic fuel is estimated to be 56% (gasoline plus LPG) or 50% (gasoline only).

Fig. 9-2-4 MTG Process Flow Diagram in New Zealand



* ADJUSTED FROM 5,150 kg/h ON FWEC BALANCES BASED ON DMC CRUDE METHANOL COMPOSITION

(AVERAGE SUMMER/WINTER)

Table 9-2-2 MTG Plant in New Zealand

Plant Area	170 ha
Total Employee	280
Feed Natural Gas Consumption	3,000,000 m^3/day
Methanol Production (2 trains)	
Crude Methanol Product	5,370 t/day
Refined Methanol Equivalent	4,400 t/day
Purity of Product Methanol	80 - 82 %
Gasoline Production	1,680 t/day (570,000 t/year)
LPG Production (for Home Fuel)	235 t/day
Energy Conversion Efficiecny	
Up to Methanol	60%
Up to Synthetic Fuel	
Gasoline + LPG	56%
Gasoline	50%

Table 9-2-3 Properties of MTG Gasoline

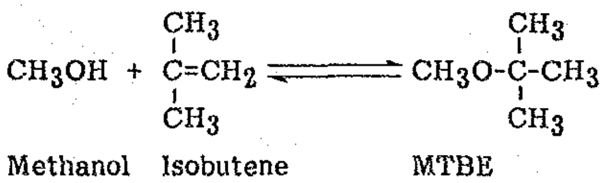
Specific Gravity (15/4°C)	0.730
Composition, wt%	
Paraffins	56
Olefins	7
Naphthenes	4
Aromatics	33
	100
Octane No.	
RON (Clear)	97
MON (Clear)	88

(3) Production of Methyl Tertiary Butyl Ether (MTBE)

MTBE is a high octane blending agent for motor gasoline. The Research octane number (RON) and the Motor octane number (MON) of MTBE is 117 and 101, respectively.

MTBE is already blended into gasoline as octane booster in France, West Germany, Italy, Canada and U.S.A. Worldwide production capacity as of 1986 amounts to more than 6 million tons/year including planning plants as shown in Table 9-2-4.

The synthesis of MTBE by the reaction of methanol and isobutene is an exothermic reversible reaction which is catalyzed by acidic catalysts.



$$CH_3OH + \underset{CH_3}{\overset{CH_3}{C}}{=}CH_2 \rightleftharpoons CH_3O{-}\underset{CH_3}{\overset{CH_3}{C}}{-}CH_3$$

The selectivity for MTBE may reach 100% depending on the catalyst and the reaction temperature. The main byproducts are tertiary butyl alcohol formed from the reaction of isobutene and water, and di-butene formed from the dimerization of isobutene.

The current commerical practice in the production of MTBE is by reacting methanol with isobutene containing C_4 mixtures obtained from steam crackers, fluid crackers, or butane isomerization/dehydrogenation. The reaction is conducted in the liquid phase at 70-100°C over acidic cation exchange resins in packed bed. The reaction temperature is maintained below 100°C to increase the isobutene equilibrium conversion, decrease byproducts formation and prolong catalyst life which varies from one to two years.

MTBE processes developed by many companies are in operation. The main differences between various technologies are:

- i) Methanol/isobutene feed ratio
- ii) Reactor configuration
- iii) Number of reactor stage
- iv) Isobutene conversion level
- v) Methanol contamination in hydrocarbon raffinate
- vi) Purity of MTBE product

The technical comparison for typical MTBE process and simplified flow diagram are shown in Table 9-2-5 and Fig. 9-2-5 (a) and (b).

Table 9-2-4 World MTBE Plants

Company	Location	Capacity (metric ton/yr.)	Licensor	Contractor	Start up Date
ANIC	Ravenna, Italy	100,000	Snamprogetti	Snamprogetti	1973
Huels	Marl, West Germany	120,000	Huels	-	1978
ARCO Chemical	Chaunelview, Tex., USA	200,000	ARCO	-	1979
Phillips	Borger, Tex., USA	20,000	Phillips	-	1979
Deutsche Texaco	Heide, West Germany	12,000	Edeleanu GmbH	-	1980
Neste Oy	Porvoo, Finland	80,000	Snamprogetti	-	1980
Good Hope Refineries	Good Hope, La, USA	90,000	Huels	-	1980
Petrotex	Houston, Tex., USA	280,000	Snamprogetti	-	1980
Fabrika SKO	Zrenjanin, Yugoslavia	38,000	Snamprogetti	-	1980
Phillips	Sweeny, Tex., USA	100,000	Phillips	Procon Intl.	1981
Dutch State Mines (DMS)	Geleen, Netherlands	75,000	Snamprogetti	-	1981
Schenectady Chemical	Freeport, Tex., USA	50,000	Schenectady	-	1981
Charter-International	Houston, Tex., USA	50,000	CR&L Neochem	-	1981
Technoexport	Kralupy, Czechoslovakia	90,000	Huels	KDH Engineering	1981
VEAHB Industrieniagen-Import	Leuna, East Germany	45,000	Huels	KDH Engineering	1982
Shell Nederland Chemic	Pernis, Netherlands	75,000	Shell International	-	1982
Texaco	Port Neches, Tex., USA	250,000	Deutsche Texaco	-	1982
Exxon Chemical	Baytown, Tex., USA	105,000	Huels	Davy McKee	1982
Champlin Petroleum	Corpus Christe, Tex., USA	68,000	Huels	Davy McKee	1982
Chemokoplex	Leninvaros, Hungary	30,000	Snamprogetti	Snamprogetti	1983
OMV	Schivechat, Austria	50,000	Snamprogetti	Lurgi	1983
Mitsui Petrochemical	Chiba, Japan	5,000	Huels	-	1983
SIBP	Antwarp, Belgium	100,000	Phillips	Crawford & Russel	1983
FSK	Zrenjanin, Yugoslavia	35,000	Snamprogetti	Snamprogetti	1984
Neftochim Complex	Burgas, Bulgaria	80,000	Huels	Neftochim Projekt	1985
Petronor	Sommorrosto, Spain	45,000	Huels	UOP	1986
Erdolchemie	Cologne, West Germany	30,000	Erdolchemie	-	1986
Petrofina/Total	Grimsby, U.K.	150,000	-	-	1986
Enichem	Ravena, Italy	125,000	Snamprogetti	Snamprogetti	1986
Sun Refinery	Marcus Hook, Pa., USA	120,000	-	-	1987
Elf Aquitaine	Feyzin, France	40,000	-	-	1987
Amoco	Yorktown, Pa., USA	34,000	CR&L/Necehem	Kellog	1987
SABIC/NESTE/ENI/Apicorp	Al-Jubail, Saudi Arabia	500,000	Snamprogetti	-	1988
Shell/Petronas	Kuantan, Malasia	300,000	-	-	1990
Hellenic	Aspropyrgos Ref., Greece	65,000	Snamprogetti	Snamprogetti	Planned
The Petrochemical Corp. of Singapore	Singapore	50,000	-	-	Planned
Caribbean Development & Commerce	Lago, Aruba	400,000	-	Sener/Fish Engr. & Const.	Planned
Statoil/Veba	Norway/West Germany	-	-	-	Planned
Lindsay Oil Refinery	Grimsby, U.K	100,000	-	-	Planned
Alberta Natural Gas	Scotford, Al., Canada	500,000	-	-	Planned
Carbohyde Ireland Ltd.	Cork, Ireland	500,00	-	-	Planned
Petroguimica General	Ensenada, Argentina	40,000	Snamprogetti	Snamprogetti	Planned
Motoroil Hellas	Corinth, Greece	34,000	Snamprogetti	Technipetrol	Planned
Co. National Petroguimica	Sines, Portugal.	40,000	-	-	Planned
RASCO	Ras Lanuf, Libya	60,000	-	Technimont	Planned
Emprusa Colombian Petroleum	Barranchabermesa, Columbia	120,000	-	-	Planned
	USSR	1,000,000	-	-	Planned
Total world capacity		6,400,000			

Table 9-2-5 Comparison of MTBE Production Process

Licenser		ARCO CHEMICALS	CHEMISCHE WERKE HÜLS	SNAMPROGETTI, ANIC	EC ERDÖLCHEMIE/ LURGI
Tech- nology	Reactor	Single stage fixed bed tubular reactor	Two stages, water cooled fixed bed, tubular reactor and shaft furnace type	Single stage fixed bed tubublar reactor	Two stages up-stream reactor
	Reaction Temp. (°C)	100 - 155	< 100	< 100	< 100
	Reaction Press. (K/G)	15.5	< 8		
	Isobutylene Conversion (%)	Single Case 95 Two Stage Case 99	95 - 99.9	97 - 98 (standard) 99.9 (ultra-high-Conv.)	
	Catalyst	Commercially available Amberlyst 15	Acidic ion exchange resin catalyst		BAYER-catalyst
	Feed stock availability	FCC Off Gas, Spent B-B, C_4 Cut before Butadiene extraction	FCC Off Gas, Spent B-B, C_4 Cut before Butadiene extraction	FCC Off Gas, Spent B-B, C_4 Cut before Butadiene extraction	FCC Off Gas, Spent B-B
Raw Material & Utility	Isobutylene Kg/ton	663	647	* 685	635
	Methanol Kg/ton	361	392	361	365
	Elec. (KWH/Ton)	9	8	10	4.8
	Steam (Ton/Ton)	0.51	0.4	0.36	0.26
	C.W. (M^3/Ton)	18	26	30	12.8
	Fuel (10^6Kcal/Ton)	-	-	-	-
	Catalyst (US$/Ton)			0.3	
Note				* Iso-butene Conv. →94% Case	

Fig. 9-2-5 (a) MTBE Process (Snamprogetti)

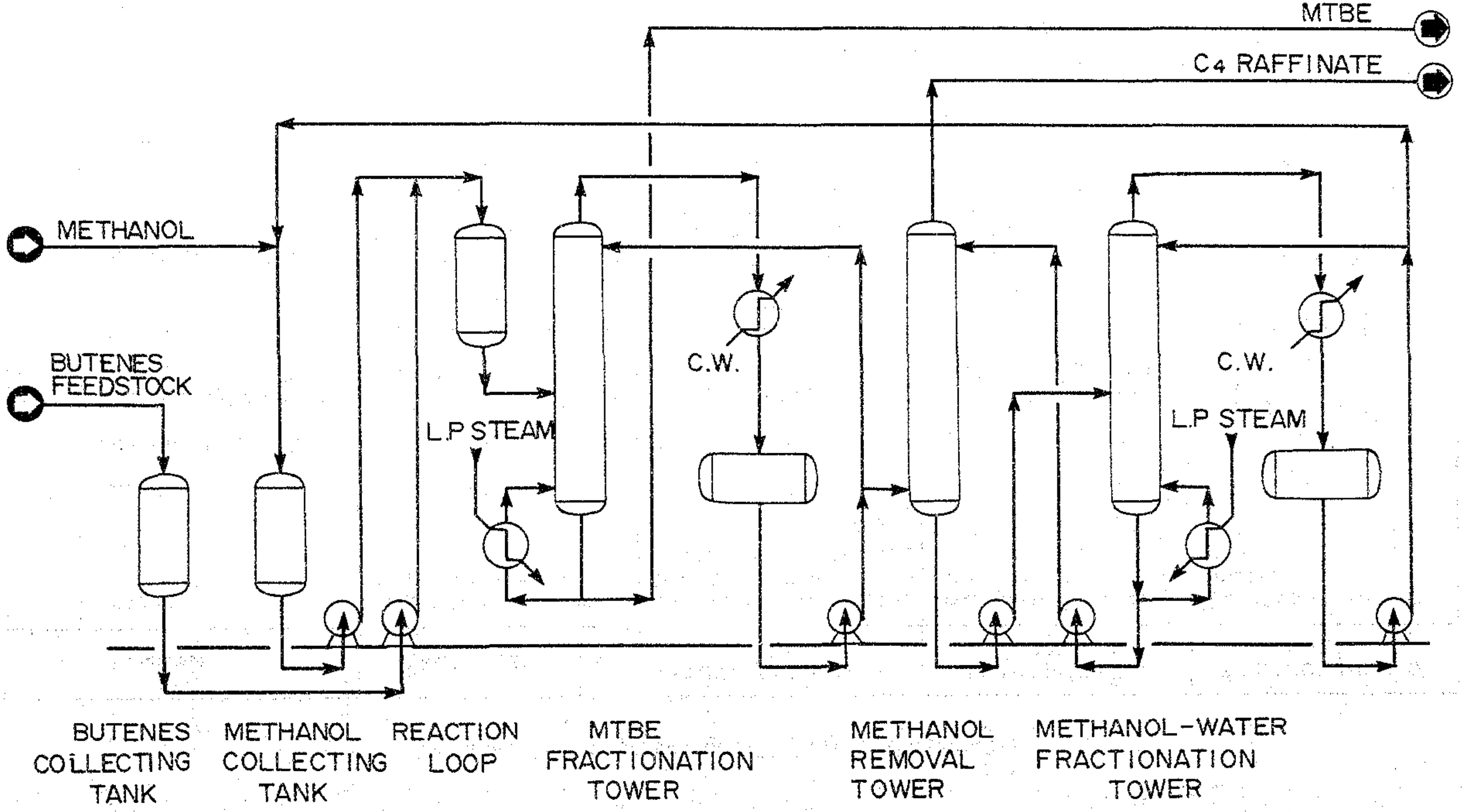
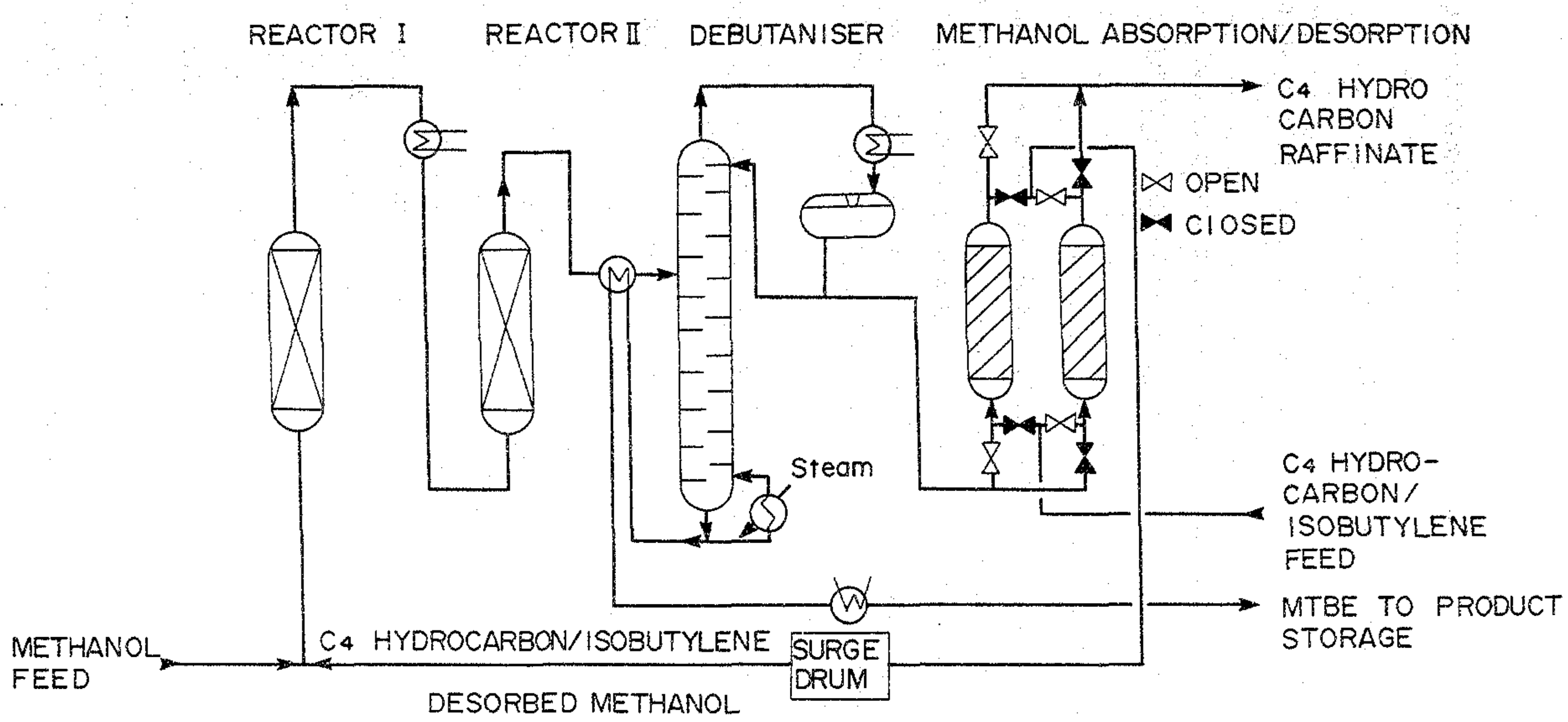


Fig. 9-2-5 (b) MTBE Process (EC Erdölchemie)



9-3 TECHNOLOGY FOR ELECTRICITY POWER GENERATION

9-3-1 Pulverized Coal Combustion System

There are many commercial experiences of a pulverized coal combustion system utilizing brown coal as fuel.

However, the application of the conventional pulverized coal combustion system to Banko coal should be avoided by the reason described below.

(1) Combustion Characteristics of Banko Coal

The Banko coal is likely to exhibit similar combustion characteristics to typical brown coals currently used in power station boilers. However, Shell report has pointed out that "the following indicative analysis of the Banko coal, particularly the high sodium levels found in the lower seams, suggests that it should be regarded as a problem coal which could result in severe fouling and slagging in utility boilers".

Table 9-3-1 Ash Analysis of Banko Coals (by Shell)

	(% wt)
SiO_2	20.0 - 61.0
Al_2O_3	19.0 - 41.0
Fe_2O_3	0.8 - 17.0
TiO_2	0.8 - 17.0
CaO	0.6 - 1.3
MgO	0.2 - 6.6
Na_2O	0.2 - 20.0
K_2O	0.2 - 0.6
Mn_3O_4	0.04 - 0.79
P_2O_5	0.04 - 0.79
SO_3	0.58 - 13.0

(2) Present Situation of Pulverized Coal Combustion Technology for Coal Containing High Sodium-in-ash

In the U.S.A., firing of low grade coals on pulverized fuel units got off to a slow start and it was the 1960s before the first units were being put into operation. These were desgned with sodium in ash contents of up to 5% in mind and major operational problems were experienced when higher percentage sodium in ash fuels were actually encountered. The fuels to be used for the series of new generation boilers include coals of up to 10% sodium in ash. To cater for these difficult coals much more conservative boiler designs are being used with lowly rated furnaces and specific provisions for flexibility in furnace operation. From the viewpoint of such experiences, the question of slagging and fouling with such coals of high sodium-in-ash as Banko coal can be summarized in the following way:

i) In the light of world experience it can be said that proven technology and considerable operational experience are available for the use of fuels with up to 5% sodium-in-ash.

ii) Technology has been developed but experience is still being gained with fuels containing 10% sodium-in-ash.

iii) Fuels containing more than 10% sodium-in-ash are now being considered for new power projects but it will be the late 1980s before they become commercial propositions.

9-3-2 Fluidized Bed Combustion System

(1) Features of Fluidized Bed Combustion System

Though it is expected that modified technology of conventional coal firing system, available for the use of more than 10% sodium-in-ash, will be developed, fluidized-bed combustion system for electric power generation is more prospective because the technology has a versatility for various fules including difficult-burn coal and high sodium-in-ash coal.

Fluidized-bed combustion can burn coal efficiently at a temperature low enough, in range of 700 - 900°C, to avoid many of the problems caused by sodium-in-ash.

A low bed temperatures held eliminates the potential for slag formation on the water-cooled walls of the furnace. Another benefit is the formation of lower levels of nitrogen oxides compared to other combustion methods.

The outstanding advantage of fluidized-bed combustion (FBC), then, it its ability to burn high-sulfur coal in an environmentally acceptable manner without the use of flue-gas scrubbers.

The atmospheric fluidized bed (AFB) technology for steam and electric generation got a big boost recent years when three electric utilities in USA decided to install demonstration plants, ranging in size from 110 to 160 MW.

As for the industrial field, fluidized bed combustion boilers are already going into commercial stage as shown in Fig. 9-3-1.

(2) Classification of Fluidized Bed Boiler

AFB technology is generally classified into two type - bubbling bed type and circulating bed type.

The bubbling bed boiler is also called as the classic fluidized bed and the circulating fluidized bed boiler is called as the 2nd generation fluidized bed according to the development time lag.

The latter is superior to the former concerning the combustibility, NOx emission and consumption rate of absorbent, although the initial cost of the latter is said to be higher than the former in the range of small capacity. Fig. 9-3-2 is an example of a schematic diagram of the bubbling bed fluidized bed boilers.

Fig. 9-3-3 shows an example of the circulating fluidized bed boiler aiming at high combustibility and low NOx and SO_2 emission simultaneously, whereas the recirculating convective cyclone section is changed from the high temperature type to the middle temperature type resulting in the decrease of cyclone trouble.

The fluidized bed boiler would be one of the best choise for the Banko coal which contains high sodium in ash.

Fig. 9-3-1 Installed Numbers of FBB in the World

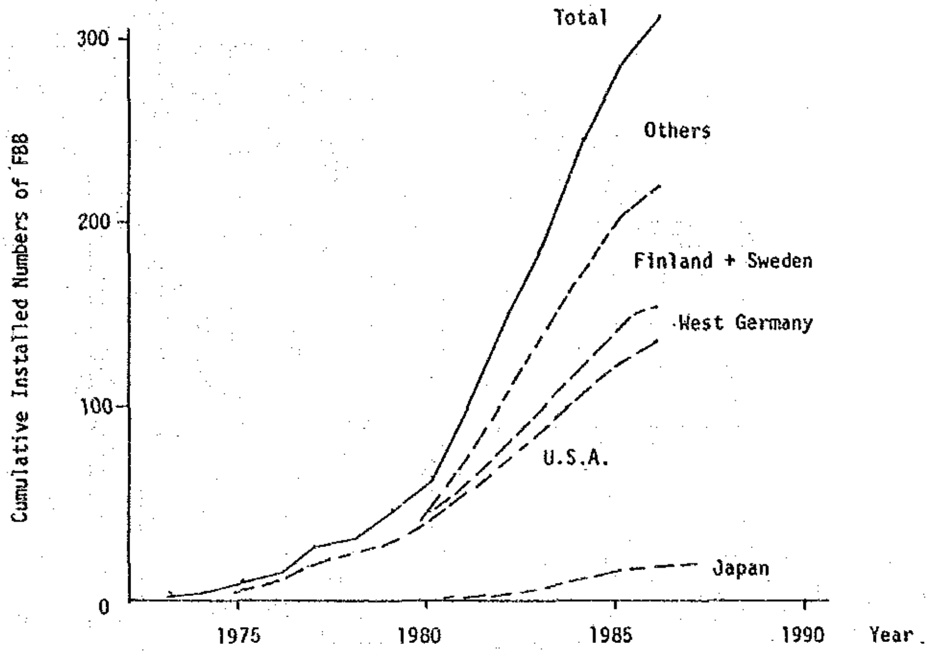
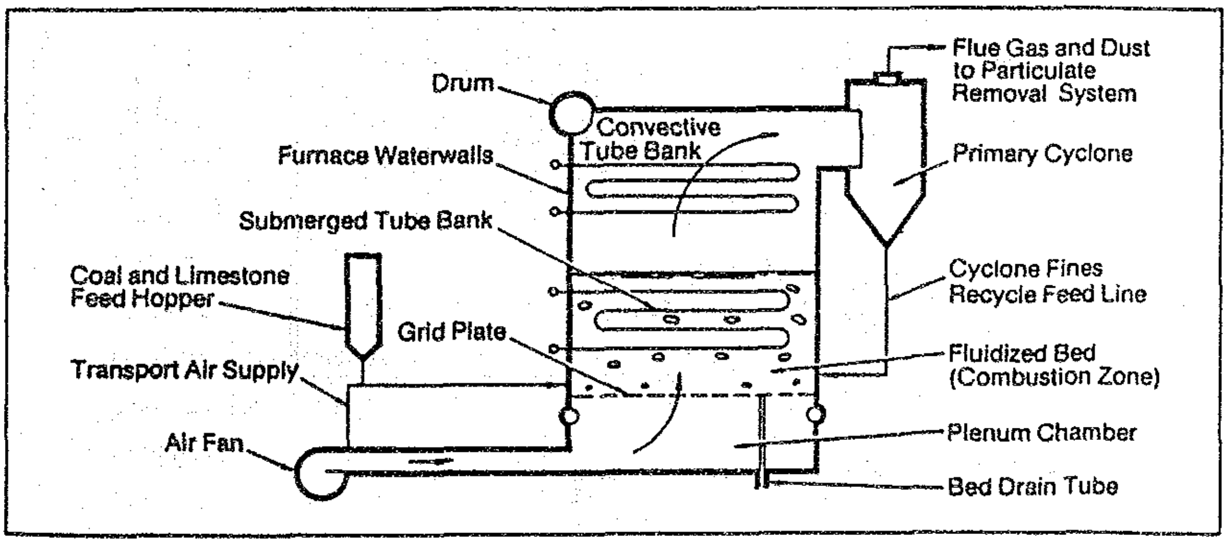
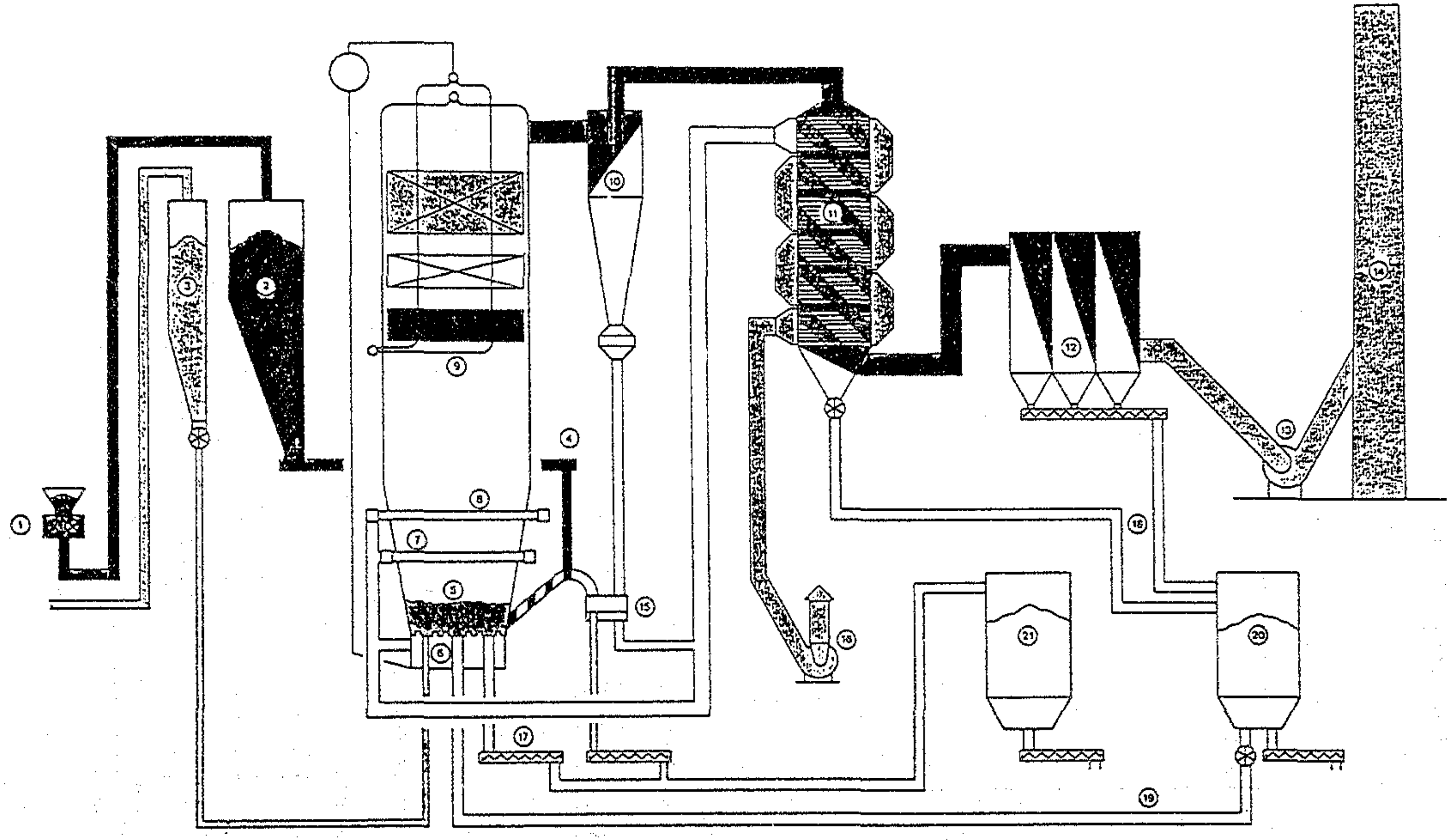


Fig. 9-3-2 Scheme of Bubbling Fluidized Bed Boiler





1 Coal Crusher
2 Coal Bunker
3 Limestone Bunker
4 Coal Feed
5 Fluidized Bed
6 Primary Air
7 Secondary Air
8 Tertiary Air
9 Steam Generator
10 Cyclone
11 Air Preheater
12 Bag Filter
13 IDF
14 Stack
15 Ash Siphon
16 FDF
17 Bed Ash
18 Fly Ash
19 Fly Ash Recycle
20 Fly Ash Silo
21 Bed Ash Silo

Fig. 9-3-3 Scheme of Advanced Fluidized Bed Boiler

9-3-3 Coal Gasification Combined Cycle System

(1) Features of Coal Gasification Combined-Cycle Power Plant

On Coal Gasification Combined-Cycle (CGCC) for power generation as shown in Fig. 9-3-4, the gasification system is part of a two-stage coal combustion process. In the first, or gasification stage, the coal is partially reacted with a deficiency of oxygen to produce a low-calorific-value (LCV) fuel gas that can be readily cleaned.

Pollution control before combustion is accomplished by partial oxidation of the coal to produce a clean gas. Sulfur and ash are removed in the processes, minimizing problems caused by Na_2O in ash.

In the second stage, the cleaned fuel gas is burned in a gas turbine for the generation of electric power. Heat produced in the gasification stage is recovered by generating steam.

(2) Development of Coal Gasification Combined-Cycle Power Plant

The Coal Gasification Combined-Cycle which has advantage of performance and environmental effect has been worldwidely developed to raise security of power source.

In USA, Cool Water Project of CGCC was promoted and plant operation started in 1985.

The net thermal efficiency of Cool Water Project is estimated to be approximately 31 percent, comparatively lower than 37 percent of conventional coal-firing steam cycle system, because the project applies coal water slurry system, wet gas-cleanup system and oxygen as oxidant. However the project is notably watched through the world because it is the first demonstration plant of CGCC system.

In Japan, CGCC development and technical research is promoted with 40 t/d fluidized-bed gasification test plant by Sunshine Project and 2 t/d entrained-bed gasification test plant by CRIEPI (Central Research Institute Electric Power Industry).

The development of Advanced Gas Turbine of 1,300°C class and dry clean-up system has been promoted in Japan as well as in USA, one of which is by Sunshine Project of Japan.

(3) Prospects of Coal Gasification Combined-Cycle Power Plant

The topic of technical development of the CGCC is on technology of advanced gas turbine as well as gasification and dry gas-cleanup system.

For gas turbine inlet temperature, thermal efficiency of the CGCC is promised to be improved as the temperature is rising, as shown in Fig. 9-3-5, indicating the possibility of realization of high efficiency power plant.

As a conclusion, it is understood that the prospects of CGCC system for Banko coal depends on technical development of the above mentioned systems in future.

Fig. 9-3-4 Scheme of Coal Gasification Combined-Cycle Power Plant (Integrated)

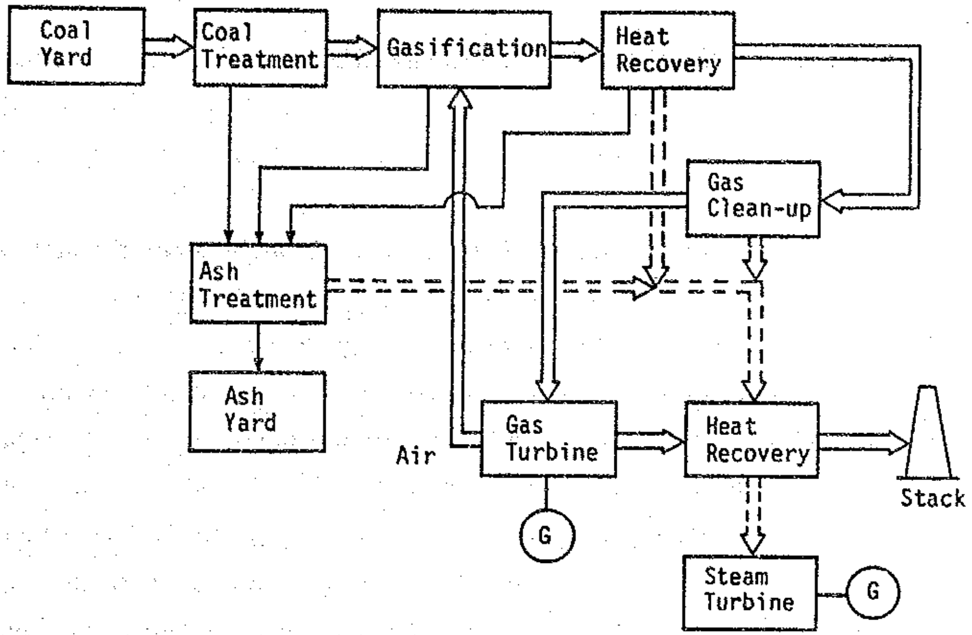
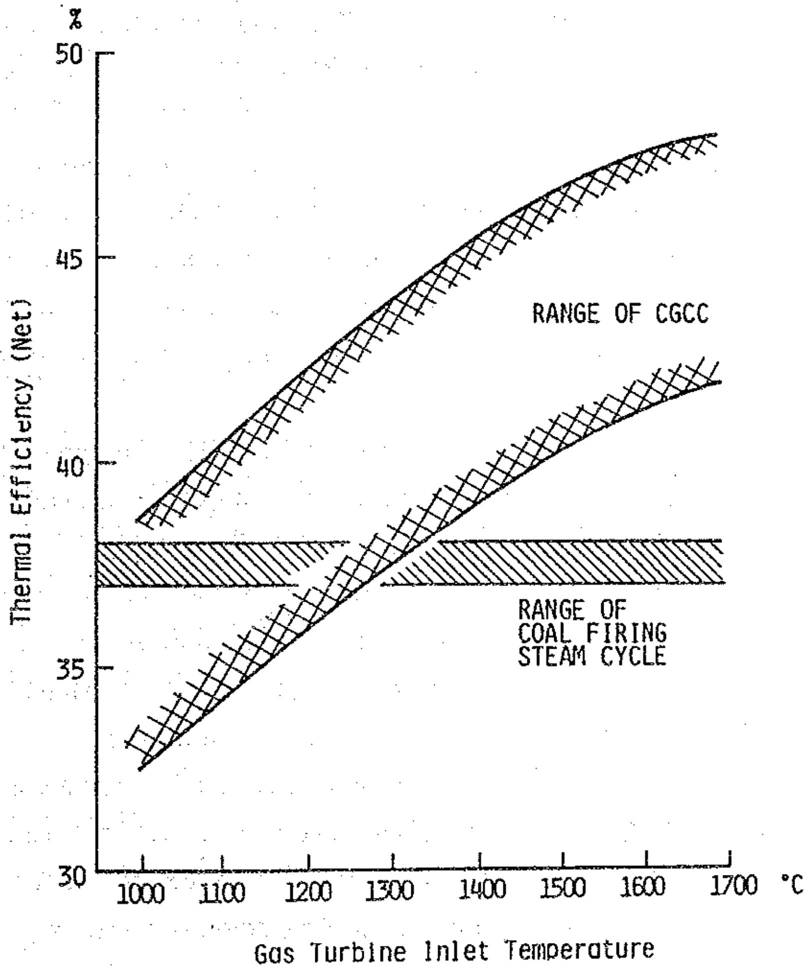


Fig. 9-3-5 Thermal Efficiency of Coal Gasification Combined-Cycle



9-4 TECHNOLOGY FOR METHANOL UTILIZATION

9-4-1 Introduction

With the world oil crisis in 1973, research and development on petroleum-alternative fuels have been energetically carried out for energy sources in all industries. As an alternative for meeting energy needs, particularly for automobiles, alcohol fuels are considered the most promising. Namely, various countries have shown keen interest in fuel alcohol, especially in fuel methanol, as a preferable alternative automobile fuel, because fuel alcohol can feasibly be stabilized and used as an alternative fuel, and a steady supply can be secured at a competitive price, moreover, features such as the ease of applying it to automobile engines, higher thermal efficiency as a fuel, ease of use, reduced environmental impact, and increased safety make it attractive.

At present, ethanol is used in one million vehicles and distributed at ten thousand service stations in Brazil. Furthermore technical know-how has been accumulated from fleet tests on thousands of methanol vehicles in the U.S.A., European countries and Japan.

Fuel Methanol is used by mixing it, at a low ratio with gasoline, or as "neat" or in high blend (100 to 85%). The first is used in the U.S. and Europe, by mixing 3% methanol with gasoline to produce a high-octane, lead free gasoline.

For the latter large-scale fleet tests for determining the applicability of neat or high-blend fuel methanol to gasoline engines are being carried out in the U.S.A., Europe and Japan.

For using metanol fuel in diesel engines, various technical system are being studied. Research and development are being carried out, including practical-use tests for methanol fuel uses in buses, trucks, etc.

Fuel alcohol can be used not only in automobiles but also in various industries and for power generation. Viewed from the timing and scale of its use, methanol for power generation is as feasible as that for automobile use. Methanol fuel for power generation is used either in small-output power generation employing converted gasoline engines or in small - or medium - scale power generation using diesel engines, or in large-output power generation using gas turbines and steam turbines.

For power generation with the gas turbine and boilers for steam turbines R&D on the technical feasibility were already completed several years ago, and no difficult