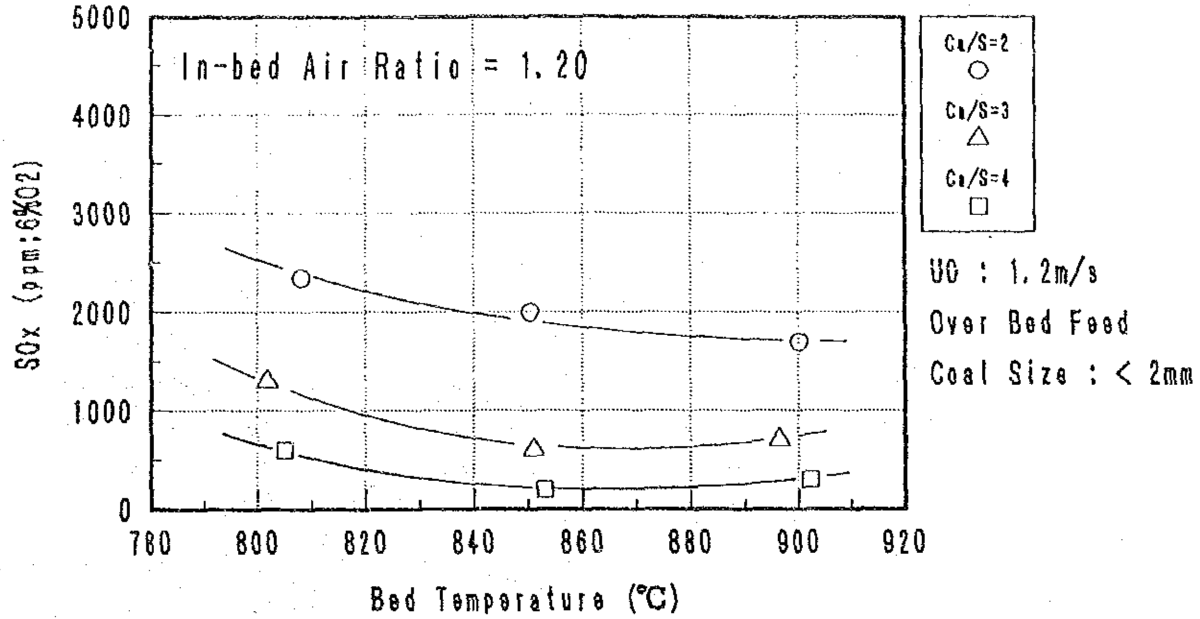
Table 8-8 Sin Pun Lignite Combustion Performance Test Data

Date		Oct. 21	Oct. 21	Oct. 22	Oct. 22	Oct. 24	Oct. 24	Oct. 28	Oct. 28	Oct. 29	Oct. 29	Oct. 30	Oct. 30	Nov. 5	Nov. 5	Nov. 6	Nov. 6	Nov. 7	Nov. 7
Time		1400-1500	1530-1615	1400-1500	1530-1630	1400-1440	1540-1620	1510-1600	1639-1730	1400-1450	1540-1610	1410-1500	1545-1630	1415-1500	1550-1530	1340-1430	1520-1550	1315-1400	1430-1515
RUN No		E-1-1	E-1-2	E-2-1	E-2-2	E-3-1	E-3-2	E-4-1	E-4-2	E-5-1	E-5-2	E-6-1	E-6-2	E-7-1	E-7-2	E-8-1	E-8-2	E-9-1	E-9-2
Coal Feeding		Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over
Coal Name		Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun	Sin Pun
Coal Size	mm	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0
Coal Initial Charge	kg	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Lime ston Name		Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham	Khao Tham
Lime ston Size	mm	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4
Lime ston Initial Charge	kg	3.20	3.20	3.20	3.20	3.20	3.20	4.90	4.90	4.90	4.90	4.90	4.90	6.50	6.50	6.50	6.50	6.50	6.50
Ca/S Molar Ratio	-	1.97	1.97	1.97	1.97	1.97	1.97	3.02	3.02	3.02	3.02	3.02	3.02	4.00	4.00	4.00	4.00	4.00	4.00
Gas Temp In-bed(1)	℃	809.1	807.0	850.6	850.7	900.2	903.8	802.0	801.1	851.1	852.5	896.5	896.4	805.1	807.3	853.2	861.0	902.3	902.9
Gas Temp In-bed(2)	℃	811.5	805.6	856.6	854.6	905.9	909.1	806.6	805.1	855.6	855.5	901.4	900.9	809.1	810.9	857.4	864.6	905.7	907.0
Gas Temp Freeboard(1)	℃	796.3	781.3	829.1	823.4	908.6	877.6	798.6	600.0	841.2	833.4	889.5	877.1	799.4	800.2	843.3	842.1	921.2	861.4
Gas Temp Freeboard(2)	℃	816.9	816.0	839.1	842.1	924.4	875.3	808.8	811.2	834.6	835.5	889.2	870.1	812.0	811.9	847.2	843.1	942.4	876.6
Gas Temp Freeboard(3)	℃	781.5	778.3	792.4	795.7	901.8	826.6	760.4	760.5	788.8	783.2	855.3	815.3	773.0	763.6	810.1	790.0	929.1	828.2
Gas Temp Freeboard(4)	℃	586.5	579.8	591.1	590.3	730.3	613.0	578.4	580.9	598.2	590.4	702.7	612.6	592.9	586.1	630.4	601.2	751.3	620.9
Gas Temp Freeboard(5)	℃	550.7	537.1	553.0	546.6	775.2	576.3	541.3	540.9	575.3	553.1	736.8	581.0	561.9	546.4	616.2	562.6	789.8	584.5
Gas Temp Freeboard(6)	℃	503.8	473.5	493.7	480.5	690.6	540.7	486.7	478.6	542.1	493.5	679.0	543.3	519.4	485.5	579.6	505.6	712.8	548.5
Gas Temp Freeboard(7)	℃	434.5	407.0	428.5	413.0	571.7	473.9	420.5	412.3	466.5	424.6	569.1	473.5	449.4	419.8	494.4	436.8	584.8	473.8
Gas Temp Wind Box	℃	48.0	47.1	51.8	51.1	54.5	57.0	50.4	49.8	55.0	53.7	56.5	56.7	46.7	47.6	49.3	51.1	53.2	55.9
Bed Pressure Drop	mmAq	175.8	159.6	159.7	128.5	146.1	140.3	171.3	184.3	185.5	156.4	162.9	164.0	167.7	180.0	175.3	185.9	147.5	159.7
Furnace Pressure	mmAq	89.8	89.2	77.0	81.5	80.4	93.8	91.4	94.0	71.7	77.9	76.2	73.8	95.6	95.0	81.5	80.2	79.7	74.3
Coal Feeder Power	-	0.297	0.327	0.278	0.296	0.254	0.269	0.291	0.302	0.243	0.268	0.223	0.246	0.265	0.272	0.235	0.254	0.212	0.218
Air Flow Fluidizing	Nm3/h	7.30	7.30	7.00	7.00	6.70	6.70	7.30	7.30	7.00	7.00	6.70	6.70	7.30	7.30	7.00	7.00	6.70	6.70
Air Flow Transporting	Nm3/h	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Air Flow Pres. Barancing	Nm3/h	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Air Flow Fluidizing(real)	Nm3/h	8.60	8.60	8.24	8.24	7.89	7.89	8.60	8.60	8.24	8.24	7.89	7.89	8.60	8.60	8.24	8.24	7.89	7.89
Gas Ana. O_2	%	7.095	5.637	6.615	5.290	6.628	5.815	6.267	5.532	6.967	5.128	6.924	5.330	6.639	5.261	6.833	5.502	6.710	5.374
Gas Ana. NOx	ppm	217.2	177.6	235.8	209.9	271.6	224.9	240.0	228.9	275.5	242.6	280.0	253.6	238.5	225.6	281.5	254.4	299.4	258.1
Gas Ana. SOx	ppm	1475.0	1476.2	1477.1	1377.2	1466.3	1474.6	990.4	759.9	454.2	576.7	80.4	366.2	587.3	656.8	11.5	-3.4	94.0	443.4
Gas Ana. SOx(Temporary)	ppm	2166.9	2965.6	1645.5	2015.4	1714.0	2597.0	1290.0	1302.3	656.0	818.7	651.3	1099.8	700.6	756.4	224.9	345.3	413.8	915.2
Furnace Air Ratio	-	1.51	1.37	1.46	1.34	1.45	1.38	1.43	1.36	1.50	1.32	1.49	1.34	1.45	1.33	1.48	1.35	1.47	1.34
In-bed Air Ratio	-	1.23	1.11	1.17	1.08	1.17	1.10	1.16	1.10	1.20	1.06	1.19	1.07	1.19	1.08	1.19	1.09	1.17	1.07
Superficial Velocity	m/s	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.21	1.20	1.20
NOx(Converted 6%O2)	ppm;6%	234	173	246	199	283	222	244	222	234	229	298	243	249	215	298	246	314	248
SOx(Converted 6%O2)	ppm;6%	1591	1441	1540	1315	1530	1457	1008	737	486	545	86	351	613	626	12	-3	99	426
SOx(Converted 6%O2)	ppm;6%	2340	2895	1924	1924	1789	2555	1313	1263	712	774	694	1053	732	721	239	335	434	679
Coal Feed Rate	kg/h	0.871	0.958	0.82	0.87	0.746	0.791	0.720	0.748	0.601	0.664	0.551	0.610	0.572	0.567	0.509	0.548	0.458	0.472
Limestone Feed Rate	kg/h	0.464	0.511	0.43	0.46	0.398	0.422	0.588	0.611	0.491	0.542	0.450	0.499	0.620	0.636	0.551	0.594	0.495	0.511
Cyclone Blowdown Rate	kg/h	0.35	0.45	0.40	0.30	0.35	0.30	0.35	0.35	0.40	0.45	0.40	0.45	0.60	0.65	0.50	0.60	0.35	0.40
Cyclone Unburned C	%	0.84	1.63	0.72	1.15	0.16	0.71	0.82	1.09	0.39	0.75	0.21	0.49	0.62	0.92	0.33	0.54	0.13	0.49
Cyclone CaO	%	14.0	13.6	19.9	19.3	20.5	22.0	16.4	9.8	25.6	23.2	24.9	25.8	17.5	12.7	24.0	26.2	29.1	26.2
Cyclone CaSO4	%	23.3	23.9	25.6	26.1	30.3	28.3	19.6	19.4	21.3	20.9	24.0	22.5	15.9	16.1	18.3	18.6	24.5	22.6
Cyclone CaCO3	%	26.4	28.9	18.7	16.5	9.5	10.7	31.6	35.5	24.8	23.5	17.4	18.6	35.0	36.8	26.9	26.5	13.5	17.5
Bed Mat. Blowdown Rate	kg/h	0.50	0.50	0.45	0.30	0.35	0.50	0.50	0.45	0.65	0.24	0.50	0.50	0.60	1.10	0.65	0.50	0.45	0.50
Bed Mat. Unburned C	%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Bed Mat. CaO	%	23.3	20.3	24.1	24.8	29.4	23.5	27.5	25.4	29.3	26.6	26.9	26.9	28.6	29.7	33.3	30.1	27.9	29.9
Bed Mat. CaSO4	%	41.8	41.0	43.2	43.3	44.4	43.4	39.4	36.0	40.2	41.9	40.7	40.3	34.3	34.0	35.0	35.5	34.6	35.6
Bed Mat. CaCO3	%	2.81	7.45	1.00	1.11	1.39	1.73	5.98	5.15	1.05	1.91	0.96	1.85	8.44	8.59	1.42	1.82	3.16	3.16
Combustion Efficiency	%	99.30	99.40	99.26	99.17	99.84	99.44	99.17	99.94	99.45	99.94	99.68	99.25	98.64	97.88	99.32	99.77	99.79	99.13
*1) In-bed Air ratio	-	1.20	1.10	1.20	1.10	1.20	1.10	1.20	1.10	1.20	1.10	1.20	1.10	1.20	1.10	1.20	1.10	1.20	1.10
*1) ηc	%	99.30	99.30	99.30	99.20	99.90	99.45	99.30	99.95	99.45	99.10	99.70	99.35	98.55	97.90	99.30	99.75	99.90	99.30
*1) NOx	ppm;6%	225	163	255	210	290	230	265	225	290	245	305	280	270	235	325	260	325	275
*1) SOx	ppm;6%	2350	2900	2000	2000	1700	2450	1300	1300	600	700	700	700	600	700	200	300	300	700
*1) ηs(TS base)	%	75.89	70.25	79.45	79.49	82.55	74.85	85.65	85.65	93.84	92.62	92.62	92.62	93.64	92.62	97.95	95.92	95.92	92.62
*1) ηs(CS base)	%	59.78	50.37	65.77	65.77	70.91	58.07	77.75	77.75	85.72	85.02	85.02	85.02	85.72	85.02	95.55	94.67	94.67	85.02

*1)Converted Air Ratio 1.20 or 1.10



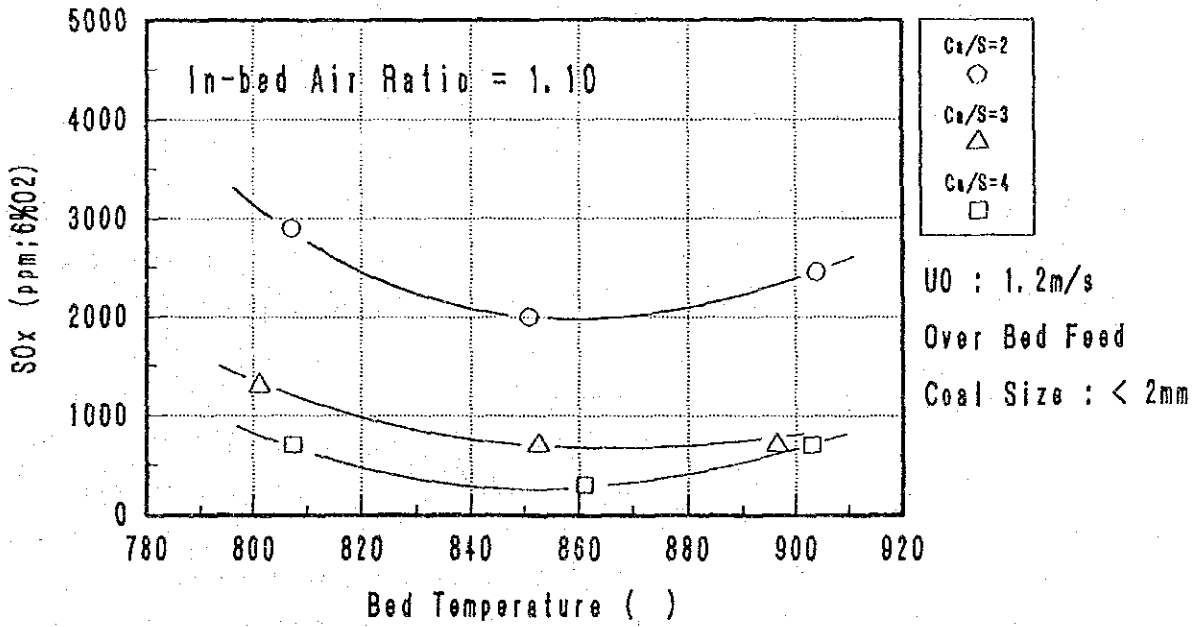


Fig 8-34 SOx emission with different bed temperatures and Ca/S molar ratio

Fig. 8-35 shows the relationship between the bed temperature and the desulfurizing efficiency by both the total sulfur base (T.S. Base) and the combustible sulfur base (C.S.Base). The increase of the Ca/S molar ratio from 3 to 4, further added to the increase in the desulfurizing efficiency. In comparison with conventional coal, much higher desulfurizing efficiency, namely, 98% on the T.S base, was obtained.

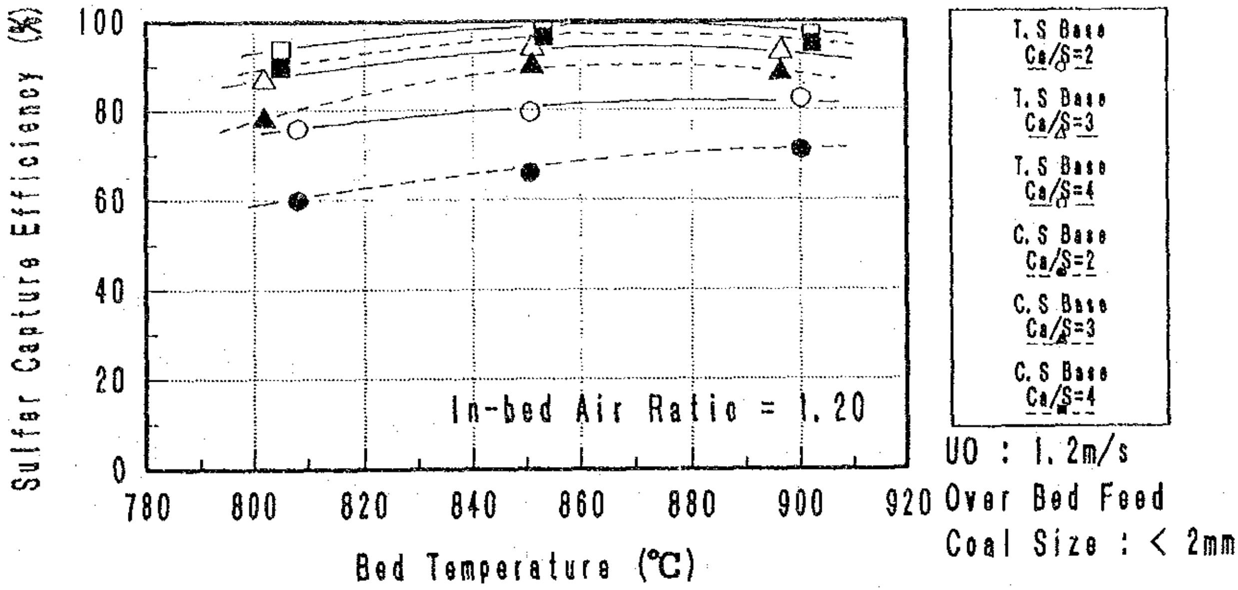
Fig. 8-36 shows the relationship between the bed temperature and NOx. The NOx increased as the temperature rose. It also decreased by about 50 ppm when the air ratio was reduced from 1.20 to 1.10. Furthermore, increasing the Ca/S from 2, to 3, generated a considerable increase in NOx emission. Further increasing the Ca/S to 4, however, caused no increase at all in the NOx.

Fig. 8-37 shows the relation between the bed temperature and the combustion efficiency. As the bed temperature increased, the combustion efficiency increased remarkably. Also, as the air ratio inside the bed decreased, the combustion efficiency equally decreased. With the bed temperature 850°C and the air ratio 1.20 inside the fluidized bed, we found that any efficiency higher than 98% could be obtained.

8.5.3 Combustion Performance Test for Krabi Lignite

Table 8-9 shows the results of the combustion performance test conducted on Krabi lignite. Explanations here are about the results of the Krabi combustion performance tests in comparison with results of similar tests on Sin Pun lignite.

Fig. 8-38 shows the relation between the bed temperature and SOx. In comparison with Sin Pun lignite, the Krabi lignite had a lower sulfur content in the fuel (namely about a third of what the Sin Pun lignite had). Nevertheless, the SOx level showed a higher value. This tendency was noticed especially in the higher temperature zones. We judge that this is associated with the kinds and brands of coal and limestone that were used. A possibility also exists that the delicate interaction of the coal and limestone caused this tendency.



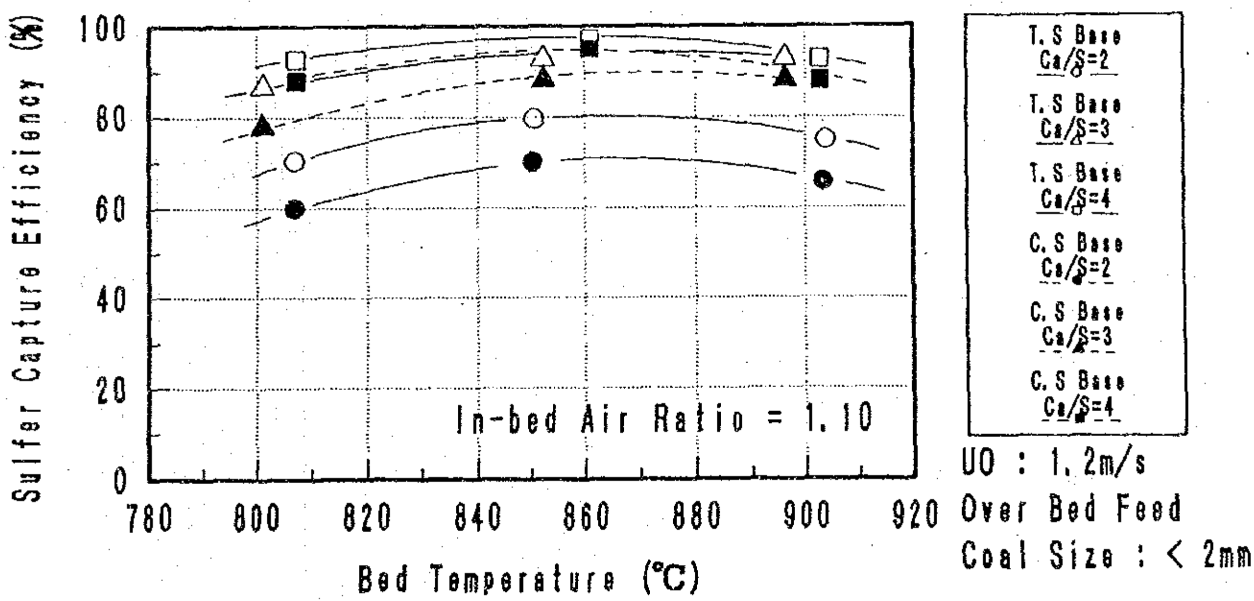
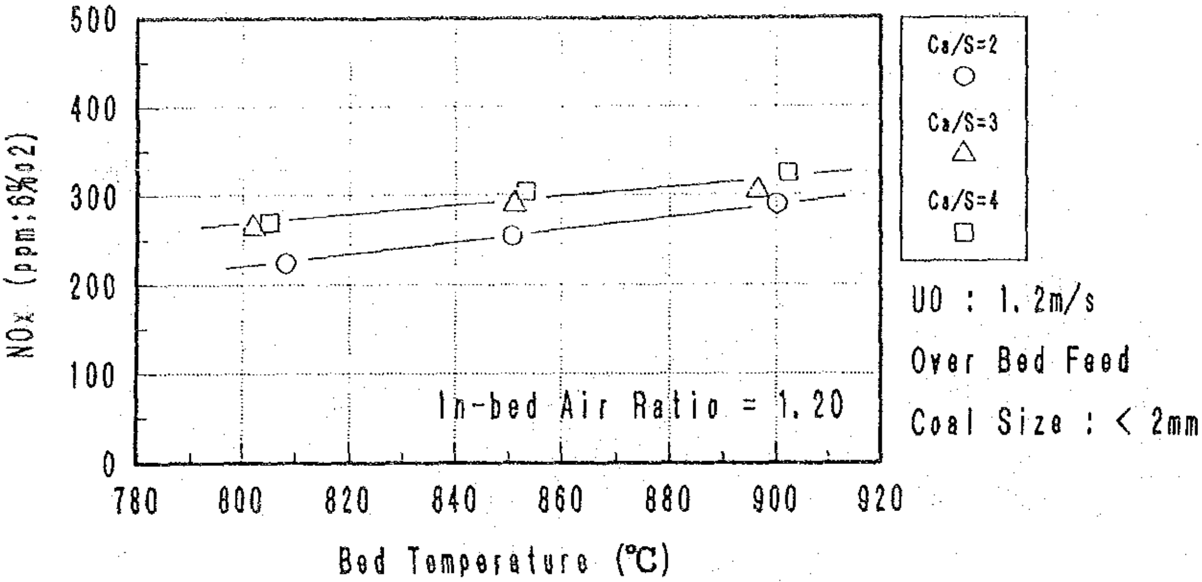


Fig 8-35 Sulfur capture efficiency with different bed temperatures and Ca/S molar ratio



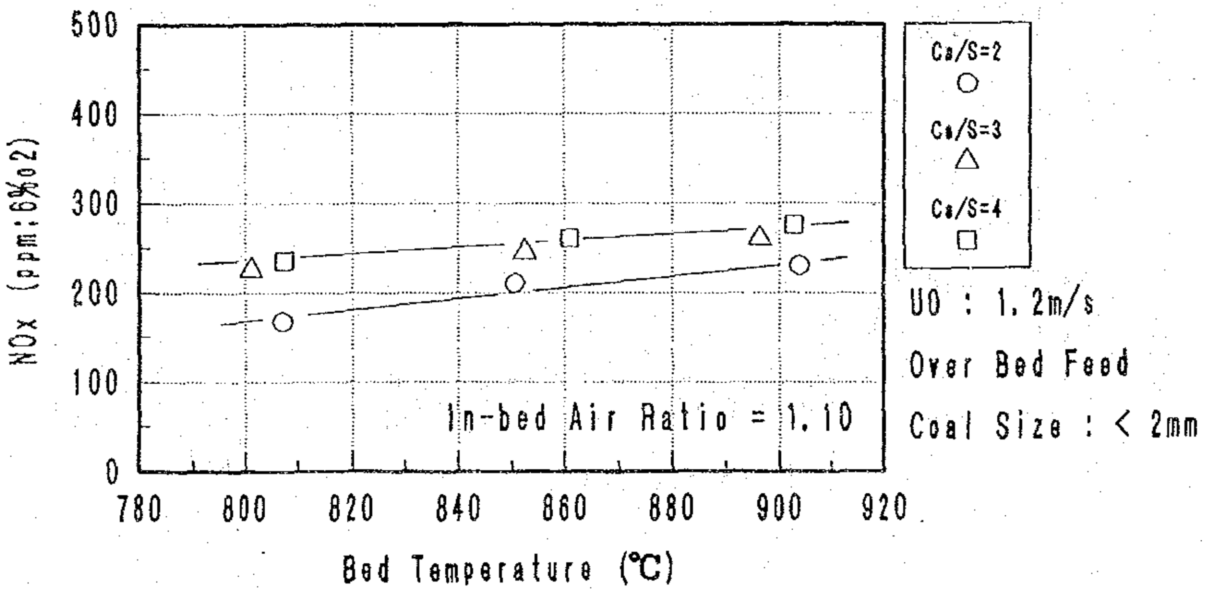
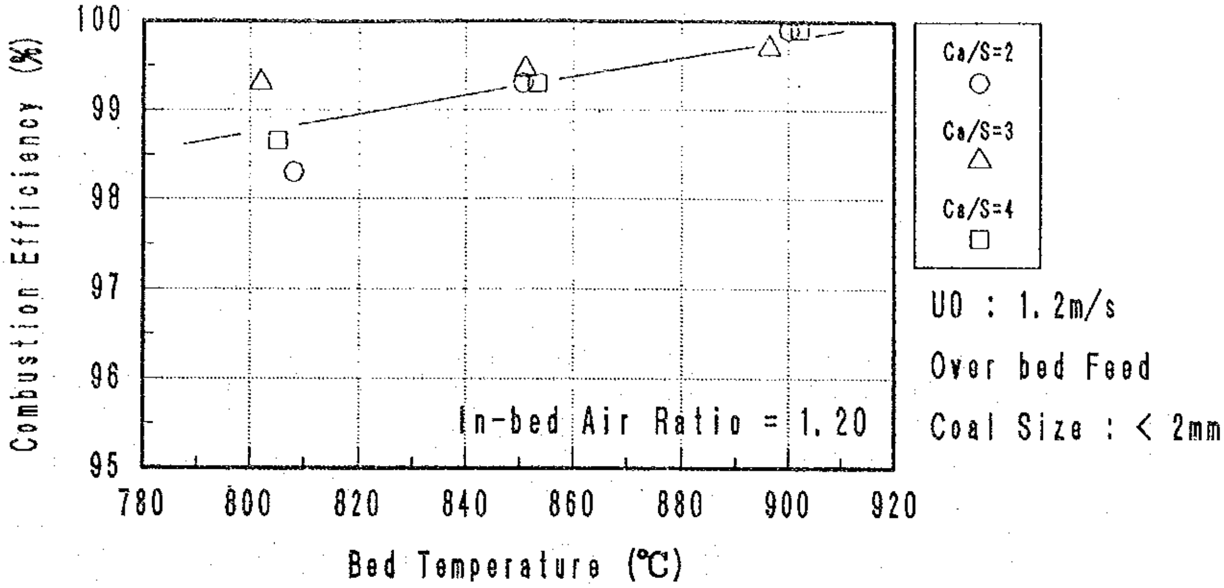


Fig 8-36 NOx emission with different bed temperatures



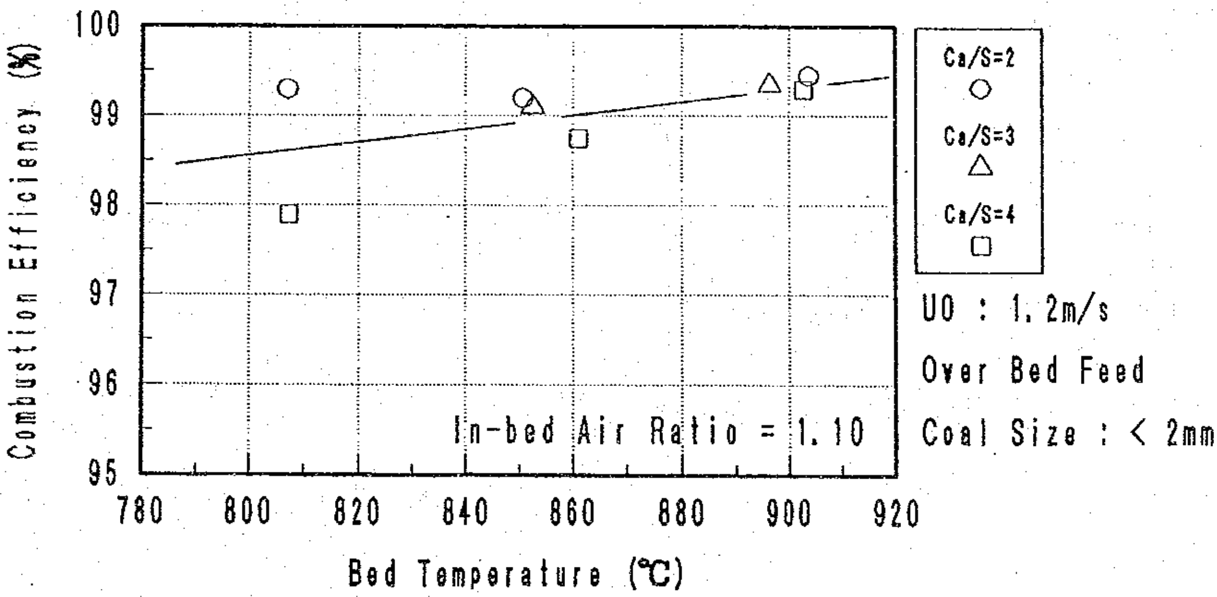
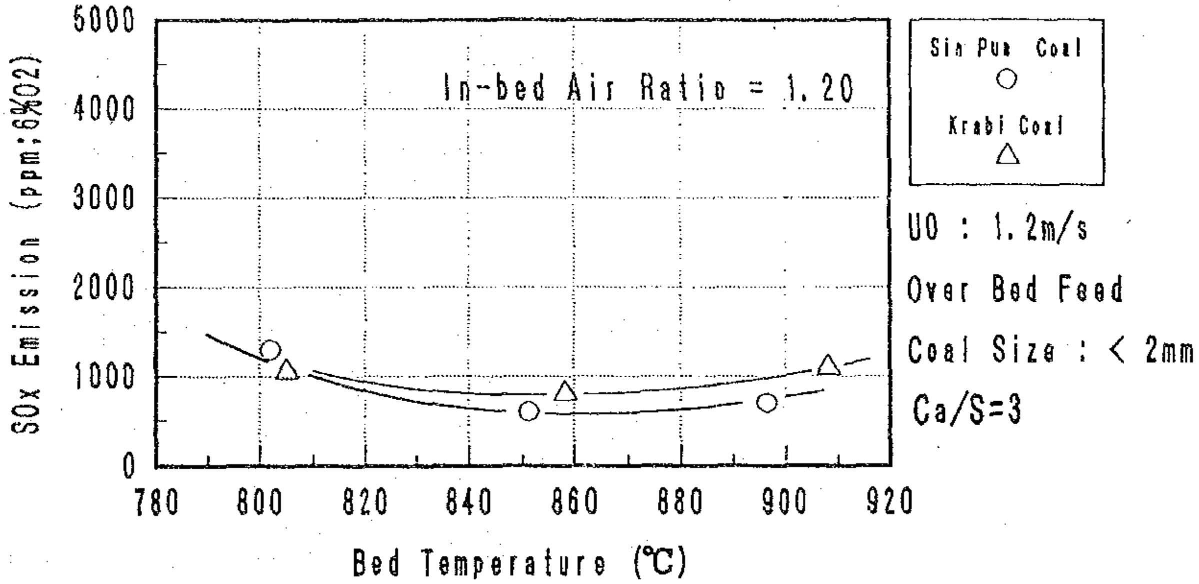


Fig 8-37 Combustion efficiency with different bed temperatures

Table 8-9 Krabi Lignite Combustion Performance Test Data

Date			Nov. 11	Nov. 11	Nov. 11	Nov. 12	Nov. 12	Nov. 13	Nov. 13	Nov. 15	Nov. 15	Nov. 19	Nov. 19
Time			1400-1500	1530-1600	1630-1700	1300-1400	1430-1500	1300-1400	1430-1530	1400-1500	1530-1630	1300-1400	1500-1600
RUN No			F-1-1	F-1-2	F-1-3	F-2-1	F-2-2	F-3-1	F-3-2	F-4-1	F-4-2	F-5-1	F-5-2
Coal Feeding			Over	Over	Over	Over	Over	Over	Over	Over	Over	Over	Over
Coal	Name		Krabi	Krabi	Krabi	Krabi	Krabi	Krabi	Krabi	Krabi	Krabi	Krabi	Krabi
	Size	mm	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0	0-2.0
	Initial Charge	kg	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Lime ston	Name		Yod Po Sile	Yod Po Sile	Yod Po Sile	Yod Po Sile	Yod Po Sile	Yod Po Sile	Yod Po Sile	Yod Po Sile	Yod Po Sile	Yod Po Sile	Yod Po Sile
	Size	mm	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4	0-1.4
	Initial Charge	kg	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.30	1.30	2.70	2.70
Ca/S Molar Ratio		-	2.99	2.99	2.99	2.99	2.99	2.99	2.99	1.95	1.95	4.04	4.04
Gas Temp	In-bed(1)	°C	858.2	860.2	859.8	908.3	906.7	908.3	906.7	857.7	856.4	857.8	859.0
	In-bed(2)	°C	864.0	866.2	866.2	914.1	911.8	914.1	911.8	863.3	860.9	862.2	852.4
	Freeboard(1)	°C	849.5	844.5	858.3	887.6	881.9	887.6	881.9	840.1	831.8	847.3	857.4
	Freeboard(2)	°C	840.7	825.1	839.4	877.7	867.9	877.7	867.9	833.8	825.8	839.2	846.4
	Freeboard(3)	°C	787.0	765.4	777.8	829.3	803.8	829.3	803.8	782.1	769.7	787.8	790.1
	Freeboard(4)	°C	595.1	563.9	593.2	657.2	584.4	657.2	584.4	578.6	564.9	585.8	584.0
	Freeboard(5)	°C	555.6	530.1	563.9	672.0	551.4	672.0	551.4	551.1	529.8	558.9	552.9
	Freeboard(6)	°C	509.9	476.2	509.7	633.2	502.3	633.2	502.3	510.5	472.9	511.7	497.0
	Freeboard(7)	°C	436.8	409.7	447.3	525.7	431.5	525.7	431.5	439.8	409.4	439.3	431.4
	Wind Box	°C	46.4	48.3	49.5	67.3	71.9	67.3	71.9	57.5	55.9	58.3	61.8
Bed Pressure Drop		mmAq	154.3	155.9	156.4	156.6	159.7	156.6	159.7	155.8	160.8	159.3	179.8
Furnace Pressure		mmAq	92.5	88.2	148.3	90.5	84.4	90.5	84.4	97.5	87.3	81.7	84.3
Coal Feeder Power		-	0.218	0.183	0.231	0.210	0.227	0.210	0.227	0.223	0.239	0.253	0.264
Air Flow	Fluidizing	Nm3/h	7.00	7.00	8.75	6.70	6.70	7.30	7.30	7.00	7.00	7.00	7.00
	Transporting	Nm3/h	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
	Pres. Barancing	Nm3/h	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
	Fluidizing(real)	Nm3/h	8.24	8.24	10.31	7.89	7.89	8.60	8.60	8.24	8.24	8.24	8.24
Gas Ana.	O2	%	6.711	8.923	8.839	6.861	5.494	6.861	5.494	6.768	5.684	6.465	5.543
	NOx	ppm	305.6	301.6	329.9	289.5	266.2	289.5	266.2	274.0	257.5	271.8	257.1
	SOx	ppm	723.2	477.0	583.6	1000.5	1204.9	1000.5	1204.9	1444.0	1435.9	643.5	342.4
	SOx(Temporary)	ppm	728.5	632.1	670.4	1038.4	1251.0	1038.4	1251.0	1485.7	1313.6	704.7	569.5
Furnace Air Ratio		-	1.47	1.74	1.73	1.49	1.35	1.49	1.35	1.48	1.37	1.44	1.36
In-bed Air Ratio		-	1.18	1.40	1.45	1.18	1.08	1.20	1.10	1.19	1.10	1.16	1.09
Superficial Velocity		m/s	1.21	1.21	1.51	1.21	1.21	1.32	1.31	1.21	1.21	1.21	1.21
NOx(Converted 6%O2)		ppm;6%	321	375	407	307	257	307	258	289	252	281	249
SOx(Converted 6%O2)		ppm;6%	759	593	720	1061	1166	1061	1165	1522	1407	664	332
SOx(Converted 6%O2)		ppm;6%	765	785	827	1102	1210	1102	1209	1565	1286	727	553
Coal Feed Rate		kg/h	0.735	0.617	0.781	0.709	0.764	0.709	0.764	0.824	0.892	0.786	0.819
Limestone Feed Rate		kg/h	0.245	0.206	0.260	0.235	0.255	0.236	0.255	0.179	0.191	0.354	0.368
Cyc lone	Blowdown Rate	kg/h	0.45	0.40	0.54	0.40	0.35	0.40	0.35	0.45	0.45	0.55	0.65
	Unburned C	%	0.68	0.39	0.44	0.84	1.20	0.34	0.68	0.72	1.02	0.66	0.92
	CaO	%	9.5	8.5	6.0	3.9	4.4	11.0	10.7	6.3	5.7	14.6	11.7
	CaSO4	%	8.6	9.0	9.8	8.3	11.0	10.6	10.0	9.4	9.6	9.7	9.1
	CaCO3	%	11.9	12.1	9.6	17.7	10.7	8.2	7.9	7.6	6.6	6.4	11.2
Bed Mat.	Blowdown Rate	kg/h	0.29	0.40	0.40	0.25	0.4	0.3	0.54	0.32	0.50	0.40	0.40
	Unburned C	%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	CaO	%	30.3	27.4	25.5	24.2	20.1	20.6	21.2	15.2	15.0	20.1	21.2
	CaSO4	%	25.6	27.3	29.8	29.9	30.0	27.8	28.7	30.5	30.5	28.9	27.6
	CaCO3	%	1.33	1.18	1.24	2.49	4.26	0.75	1.05	1.10	1.23	1.26	2.25
Combustion Efficiency		%	98.76	99.25	99.10	98.59	98.37	99.43	99.09	98.63	98.45	98.63	97.63
*1)	In-bed Air ratio	-	1.20	1.40	1.40	1.20	1.10	1.20	1.10	1.20	1.10	1.20	1.10
	ηc	%	99.80	99.20	99.00	98.65	98.40	99.40	99.10	98.85	98.45	99.05	97.80
	NOx	ppm;6%	330	380	390	310	270	305	260	290	255	300	265
	SOx	ppm;6%	600	750	900	1050	1150	1100	1200	1500	1300	700	550
	ηs(TS base)	%	85.17	85.10	83.31	80.53	78.68	79.61	77.75	70.24	73.90	87.02	89.80
	ηs(CS base)	%	80.92	82.11	76.34	74.95	72.57	73.77	71.35	61.64	69.00	83.31	85.85

*1)Converted Air Ratio 1.20 or 1.10



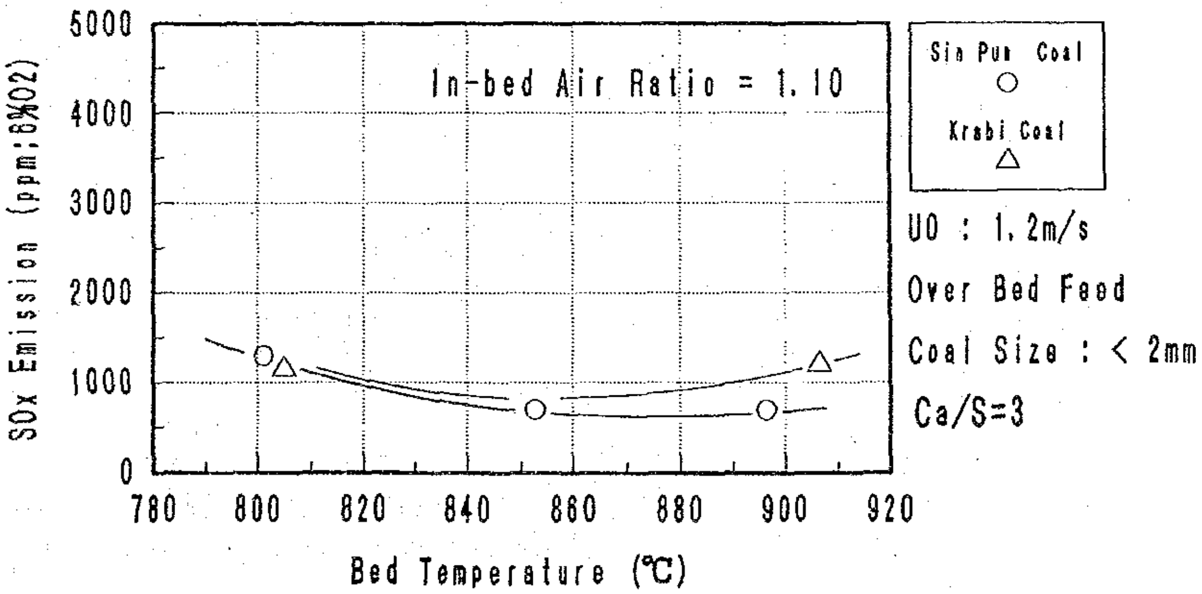


Fig 8-38 SOx emission with different bed temperatures

Fig. 8-39 shows the characteristics of the desulfurizing efficiency in relation to the bed temperatures. Under the optimum condition of the bed temperature of 850°C at the Ca/S molar ratio 3 and the air ratio 1.20 inside the fluidized bed, the resulting desulfurization ratio was 83%, which was lower than that of Sin Pun coal. A further increase in the molar ratio to 4, as shown in Fig. 8-41, did not cause the desulfurizing efficiency to reach the 90% level on the T.S. base.

Fig. 8-42 shows the NOx emission classified by kinds of coals. Under different bed temperatures and air ratios inside fluidized bed, the NOx emission of Krabi lignite showed higher values than NOx in the Sin Pun lignite. The NOx conversion ratio was 0.13~0.18 for the Sin Pun lignite and 0.1~0.13 for the Krabi lignite.

Fig. 8-43 shows combustion efficiency. The Sin Pun lignite again showed better performance in this area. Thus it was verified that the Sin Pun lignite was superior to the Krabi lignite in all respects, including desulfurization, NOx emission and combustion efficiency.

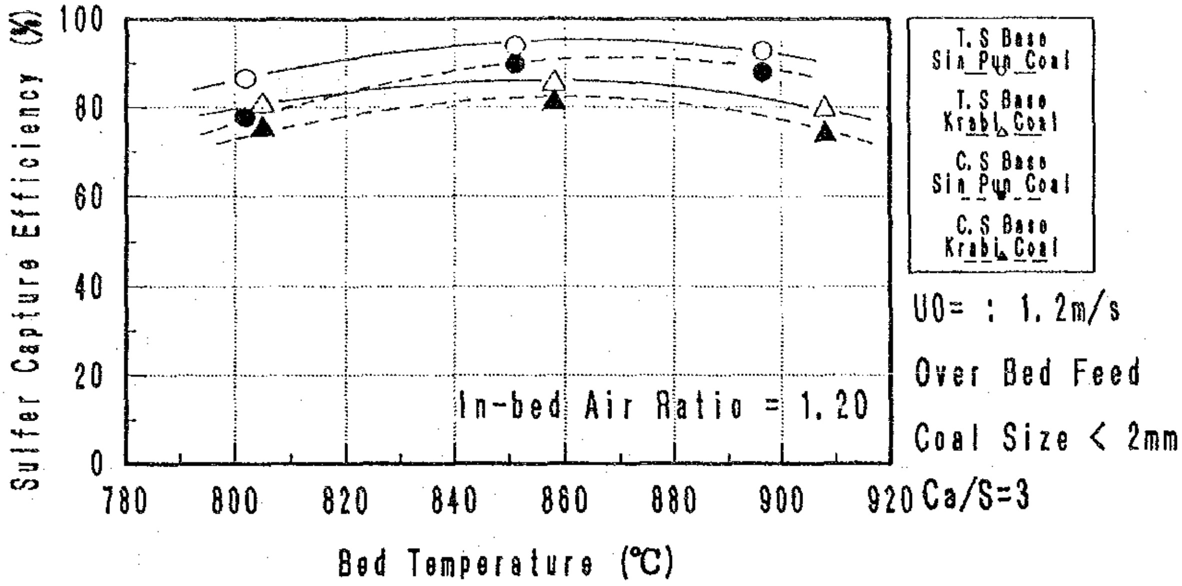
8.6 Evaluation of the Results

8.6.1 Characteristics of a Bench Scale Combustion Test Apparatus

The characteristics of the furnace ϕ100 were evaluated on the basis of past record.

Fig. 8-44 compares the sizes of the current test apparatus with those of other test apparatuses. The ϕ100 furnace had an inside diameter of 100 mm, and its height was about 2.5 m. The test was conducted by using a fluidized bed height of about 200 mm.

The 20 t/h pilot plant and the 50 MW demonstration plant came in the sizes shown in Fig. 8-44. Their fluidized bed height was 1.2~1.5 m, which is differ from that of a bench scale test furnace. In the actual evaluation, it is planned to consider the effect of this difference in the fluidized bed height by the pilot scale combustion test.



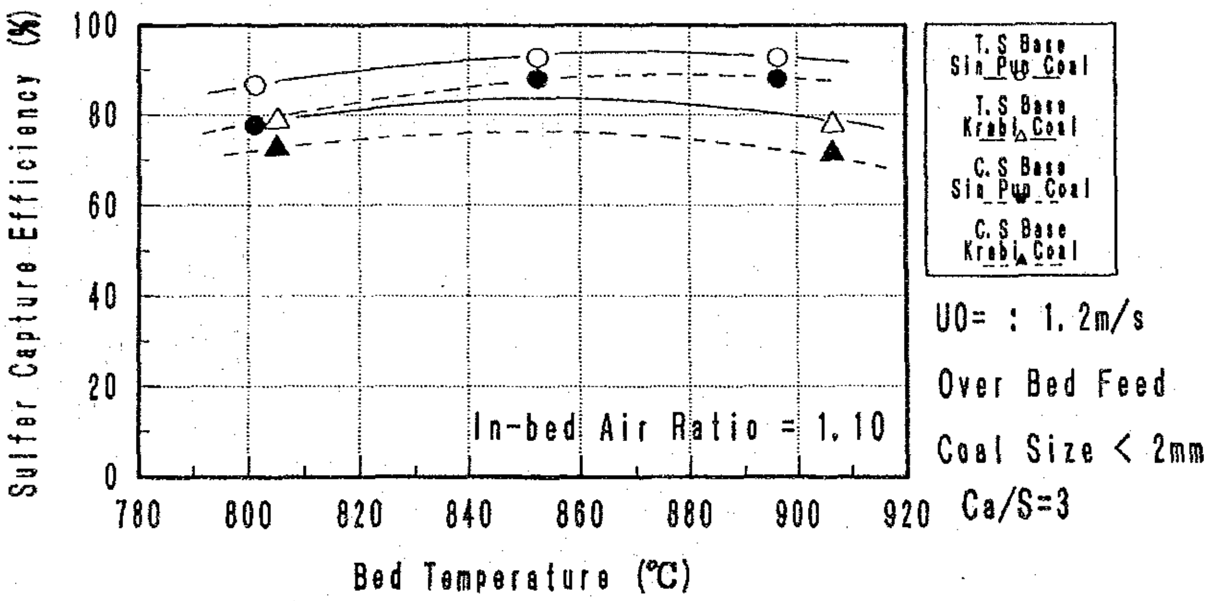
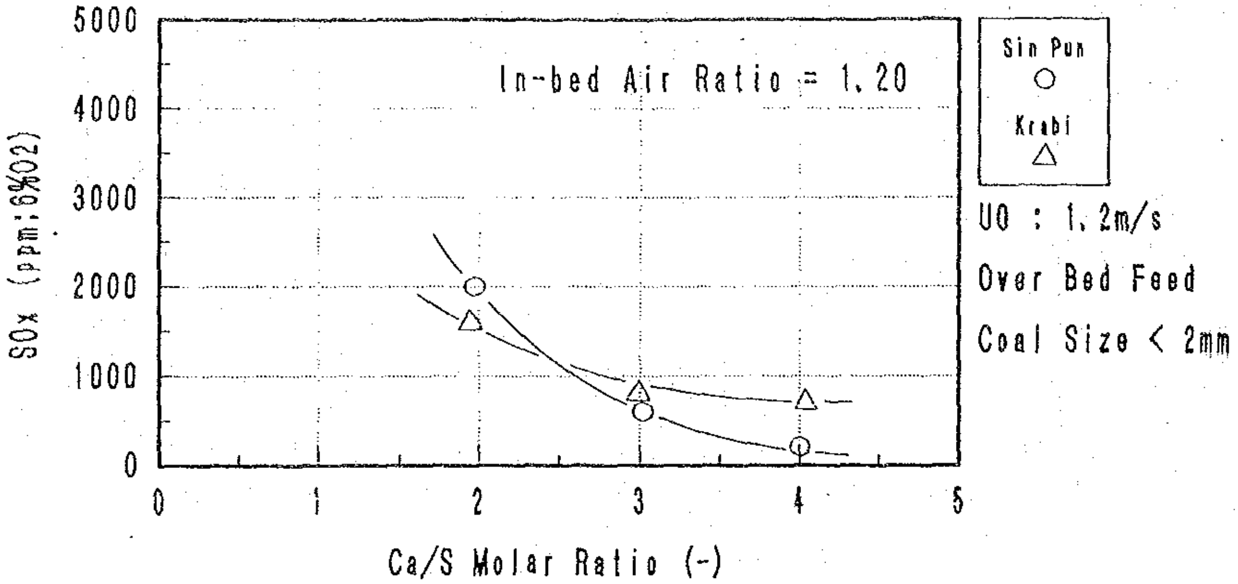


Fig 8-39 Sulfür capture efficiencywith different bed temperatures



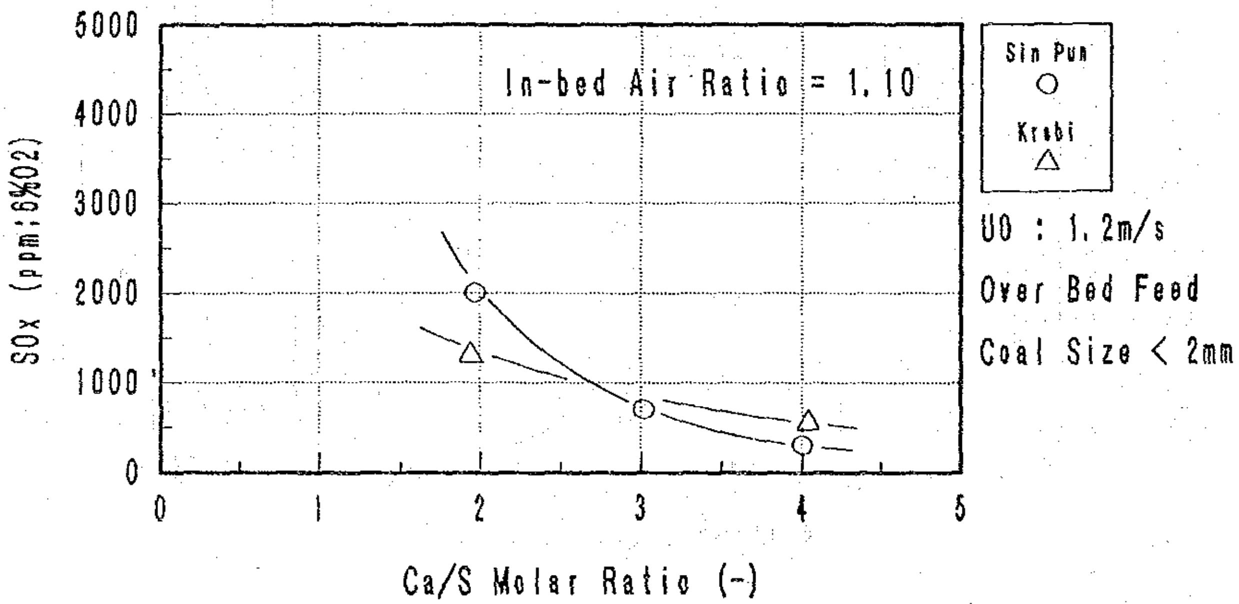
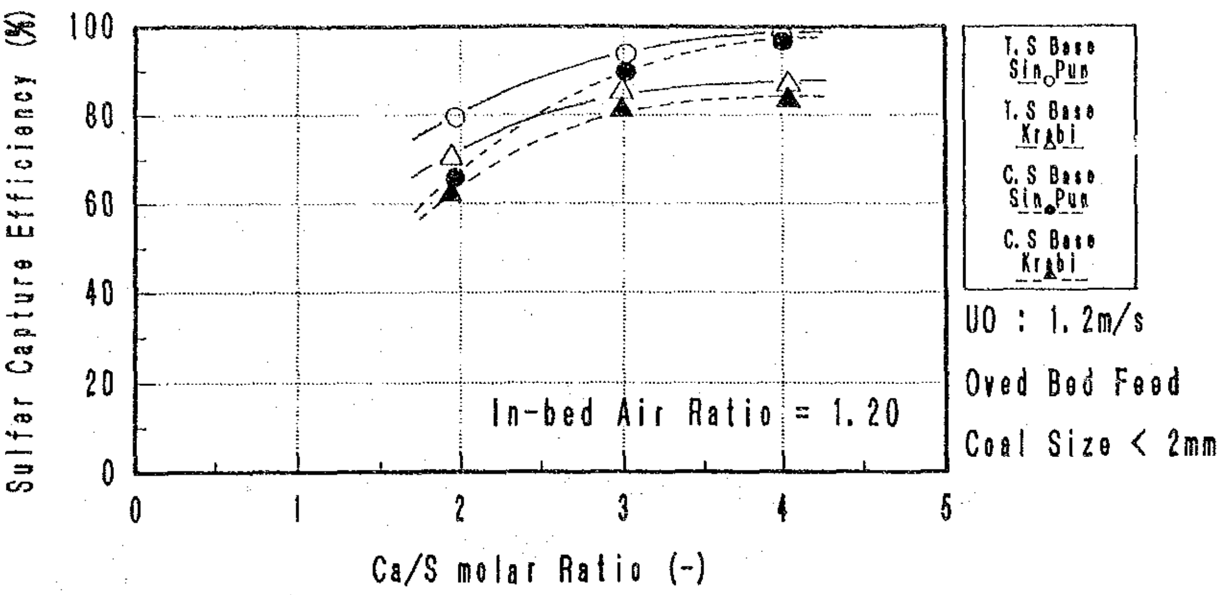


Fig 8-40 SOx emission with different Ca/S molar ratios



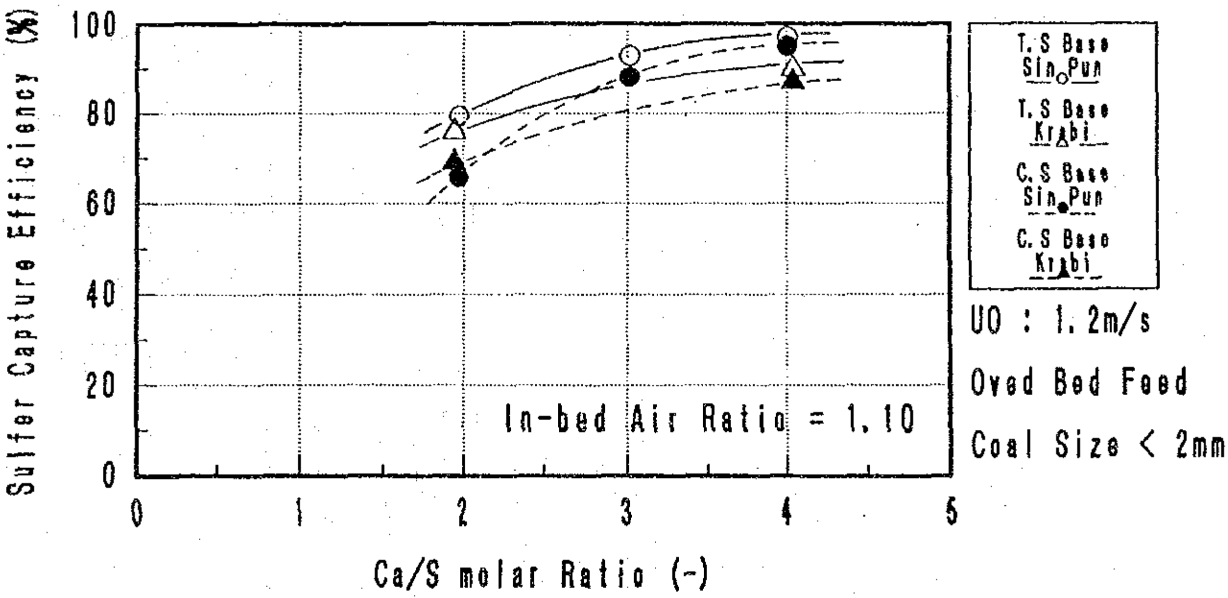
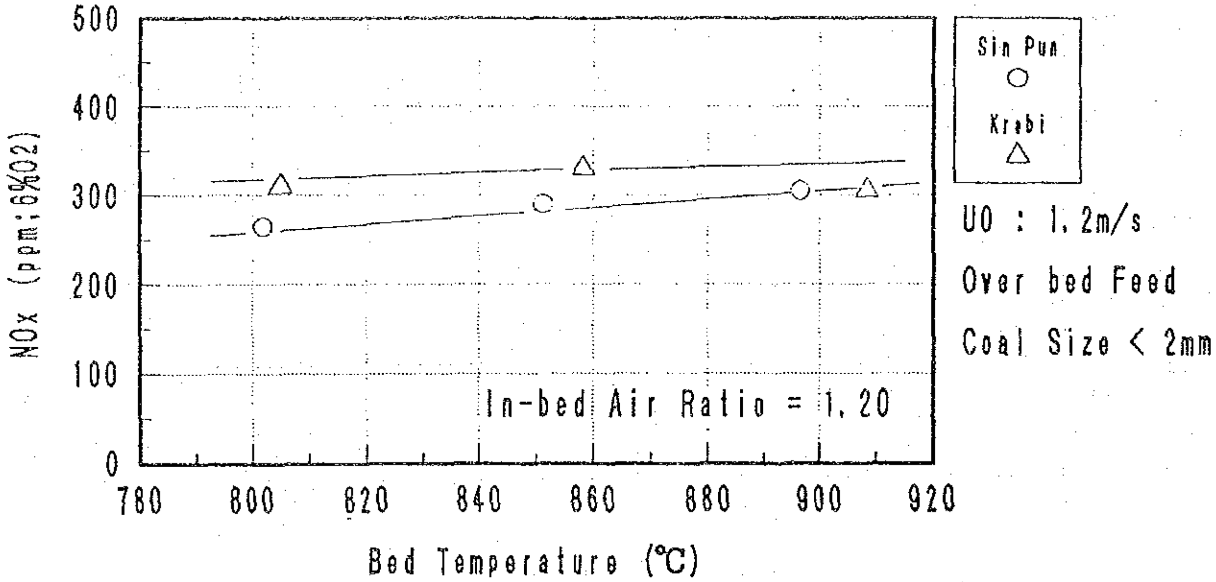


Fig 8-41 Sulfur capture efficiency with different Ca/S molar ratios



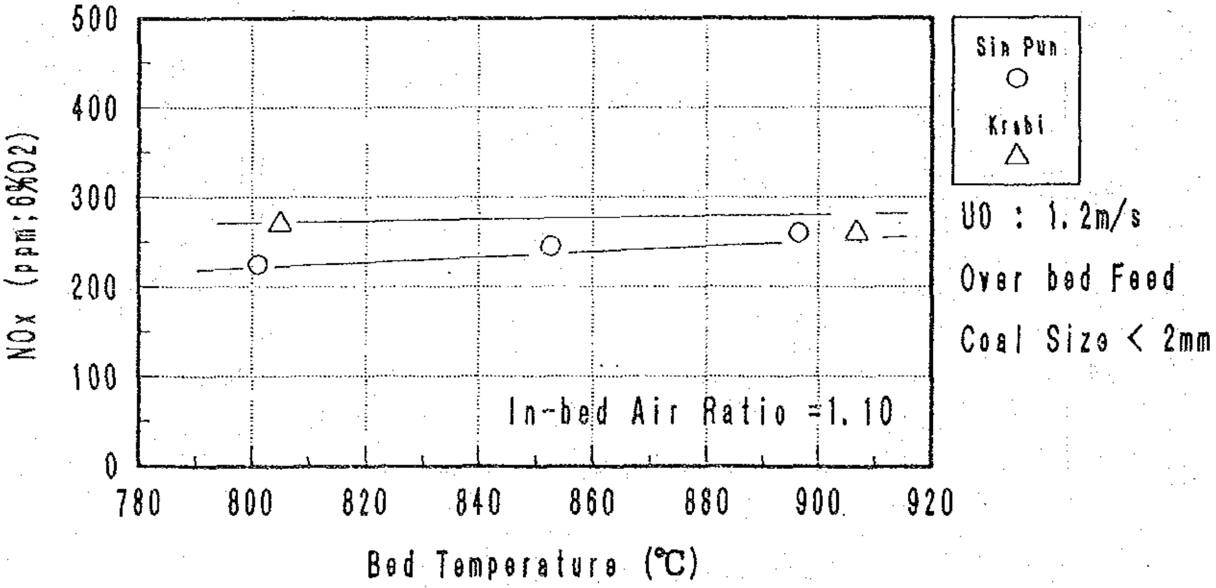
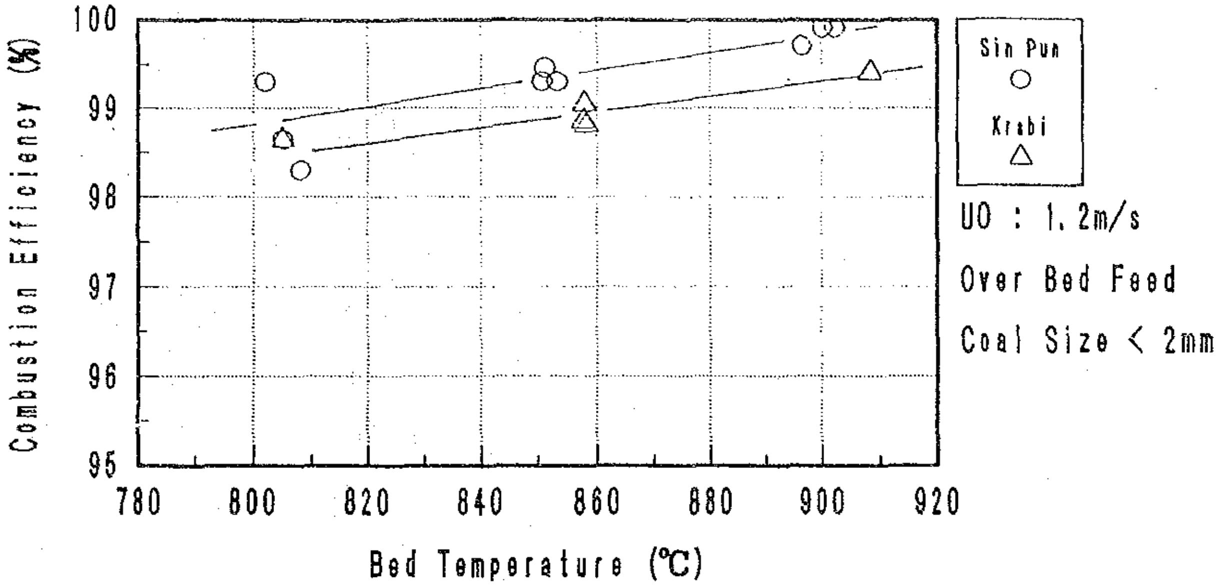


Fig 8-42 NOx emission with different bed temperatures



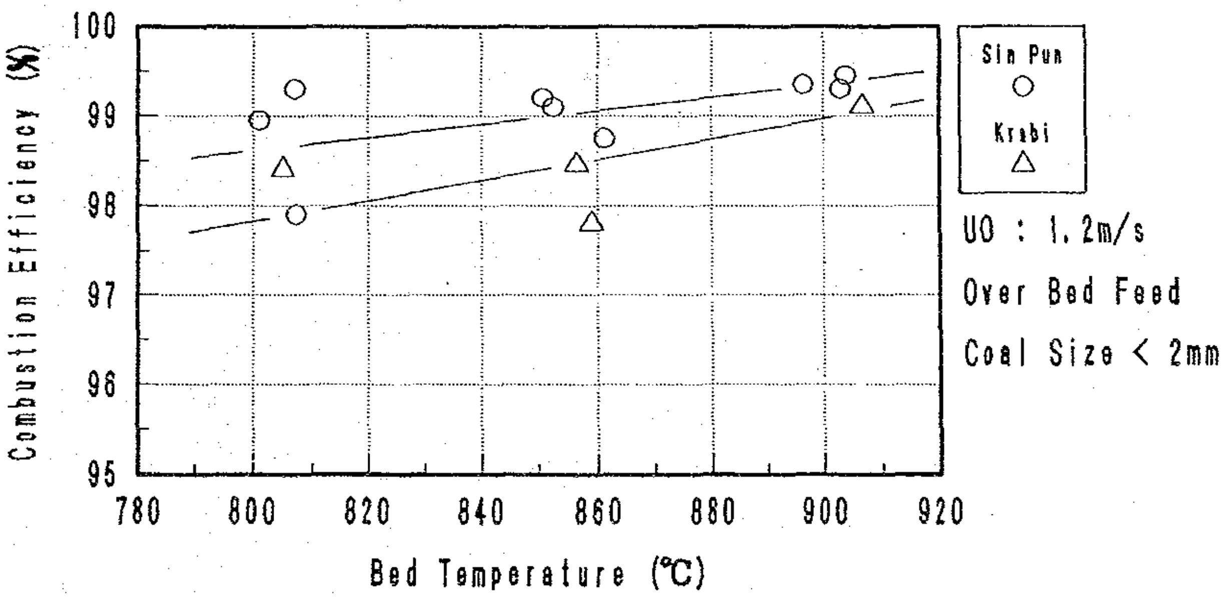
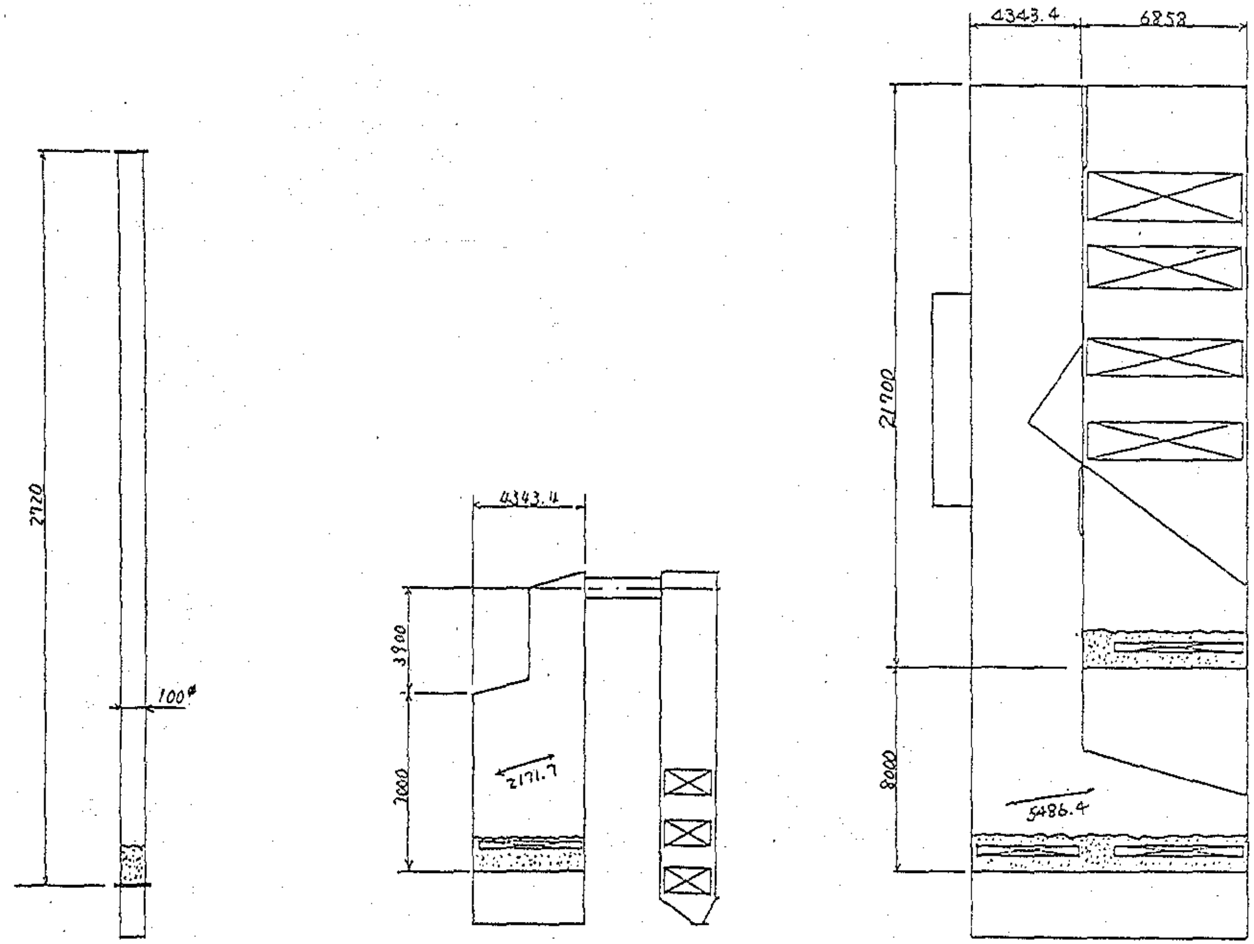


Fig 8-43 Combustion efficiency with different bed temperatures



φ100 bench scale test facility

20t/h pilot plant

50MW demonstration plant

Fig 8-44 FBC combustion test facilities

Fig. 8-45 shows the characteristics of desulfurizing performance in relation to bed temperatures. It is based on the Elmelo coal combustion test results. What is indicated in the figure is a close similarity between results involving the ϕ100 furnace and the 20 t/h pilot plant. The 50 MW demonstration plant showed an improvement in the desulfurization when compared with the ϕ100 furnace. This improvement is presumably attributed to the heat-transfer pipes laid out in much higher density, enabling a better prohibitory effect against the limestone scattering. Although the structure of low-temperature pipes must be considered when the absolute values are evaluated, considerable coincidence with a large furnace was observed not only in correlation to the bed temperatures, but also in the operational conditions, the kinds of coal, and the tendency values of limestone brands.

Fig. 8-46 shows the NOx characteristics in relation to the bed temperatures. The evaluation is based on the same Elmelo coal. However, a big difference was noticed in the NOx values between the large and small furnaces, unlike the desulfurizing characteristics. This difference is presumed to be attributable to such factors as the slow NOx reduction process inside the fluidized bed because of the lower fluidized bed height and because of the NOx reduction going on at a relatively smaller scale in the free board zone. Another cause for this difference was possibly the gas temperature in free board zone of the small furnace, which was much lower than in the large furnace, as shown in Fig. 8-47. Most of the tests conducted for NOx, therefore, focused on the basic aspects, with special emphasis on understanding the tendency values in relation to a variety of influence factors, such as operational conditions, kinds of coals, and brand of limestone.

8.6.2 Performance Presume to the Actual Equipment

(1) Desulfurizing Performance

1) Bed Temperature

Concerning current desulfurizing performance of the Sin Pun lignite and the Krabi lignite produced in Thailand, the optimum point was obtained in the bed temperature range of about 850°C,

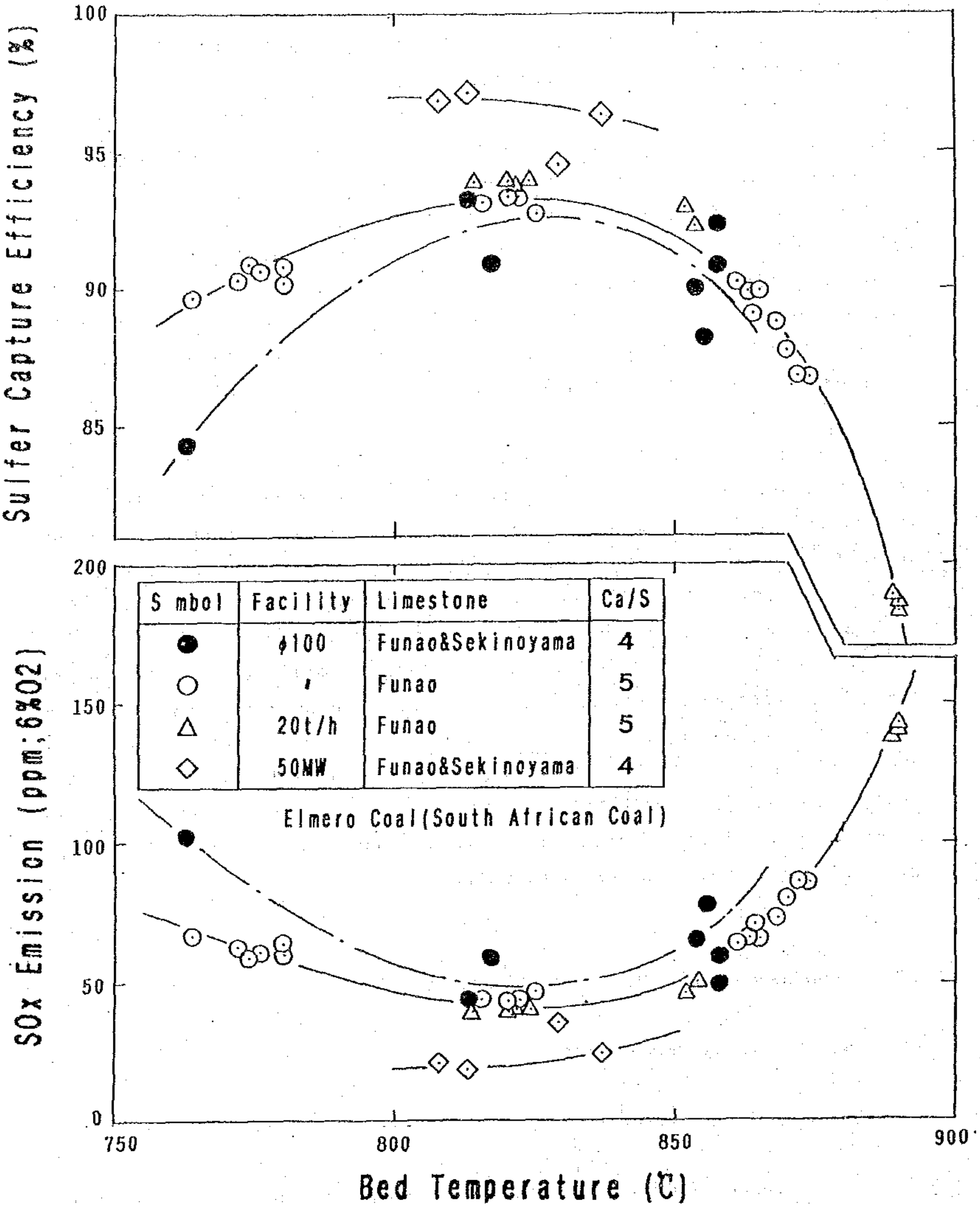


Fig 8-45 Desulfurization characteristic with different scale

S mbol	Facility	Limestone	Ca/S
●	ϕ100	Funao&Sekinoyama	4
○	′	Funao	5
△	20t/h	Funao	5
◇	50MW	Funao&Sekinoyama	4

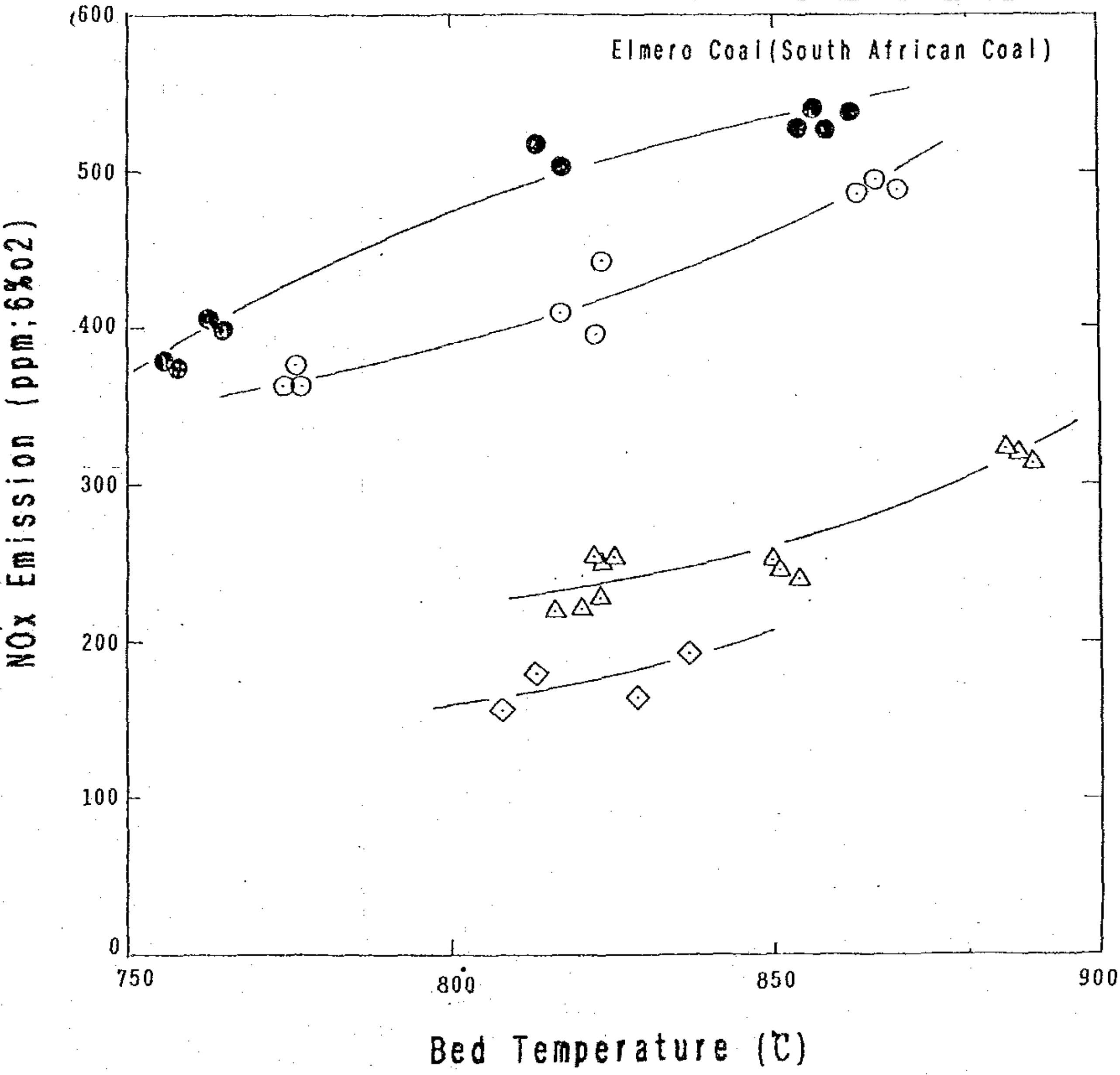


Fig 8-46 NOx emission characteristic with different scale

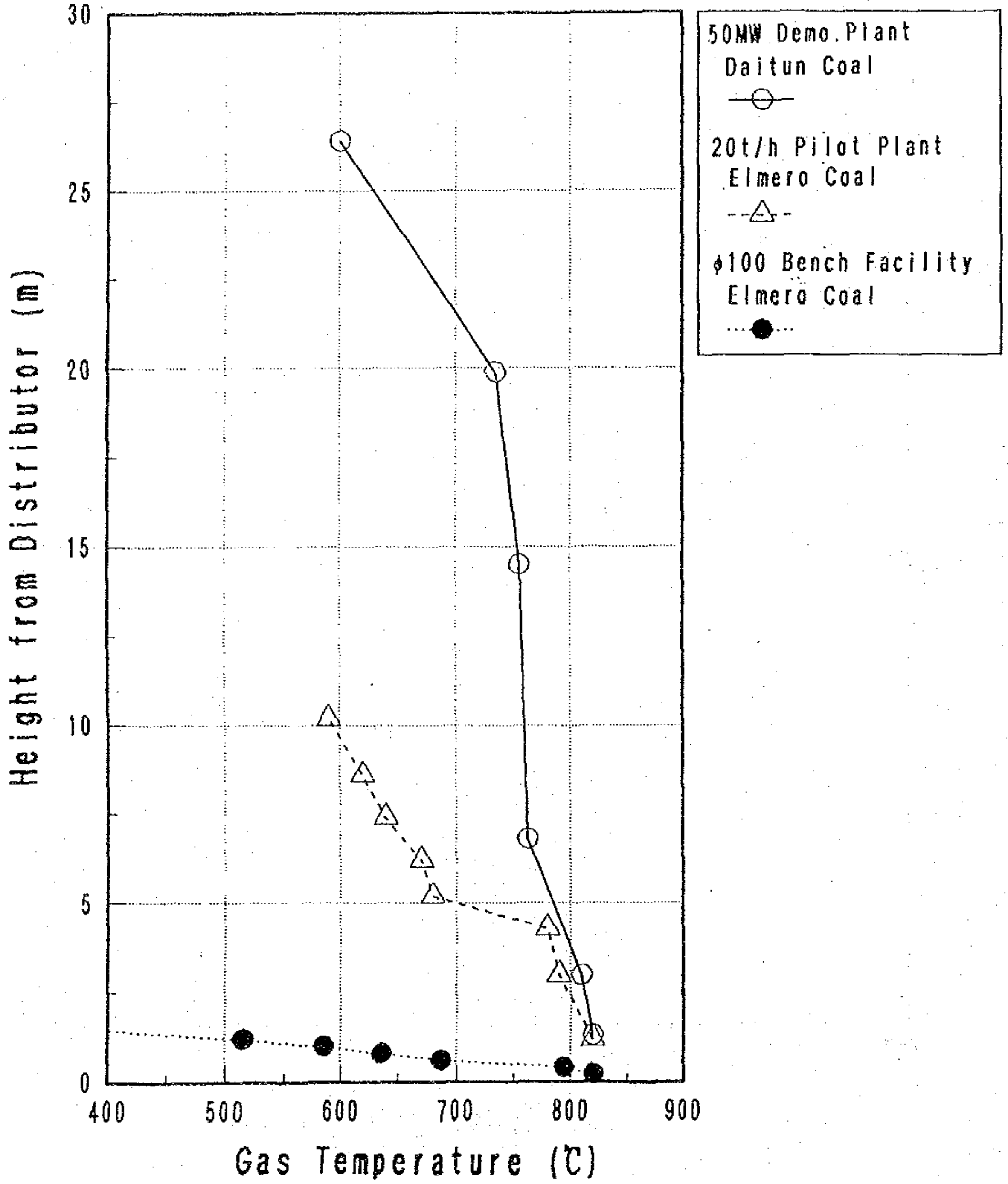


Fig 8-47 Gas temperature distribution in furnace

which was 40° higher in comparison with the generally accepted best point for the bitiminous coal in Japan. The characteristics of the bench scale furnace's desulfurization in relation to the bed temperatures corresponded in many ways to those of the large furnaces. The point around 850°C, therefore, was judged most likely to be the optimum temperature point for the scale of operation run by the actual equipment. However, this should be further verified through combustion tests conducted in a pilot scale combustion test. The factors that pushed the optimum point to higher degrees are the next subject to be dealt with in this section.

The following three points were unique to the present combustion tests in comparison with the tests already conducted in Japan. It was studied how this affects decarbonization reaction, desulfurization and $CaSO_4$ de-assembling related to desulfurization.

1. Brand of limestone
2. Coal with high S content
3. Coal with high volatility

For item 1, the brand of limestone was not to be the cause because the same phenomena were noticed in comparison with tests conducted on limestone produced in Funao and Sekinoyama.

For item 2, the high sulfur content would increase both the supply volume of limestone and the oxygen volume required for desulfurization. This would naturally cause the air supply to increase at the same time, thus affecting the characteristics of desulfurization. Since the increase in the volume of limestone equally increased the emission of CO_2 as a result of decarboxylation, the relation between the CO_2 ambient density and the density of decarbonization was investigated, as shown in Fig. 8-48. Fig. 8-49 shows the results of estimate calculation, which is intended to determine the temperature rise caused by the decarboxylation. The figure thus obtained indicated a rise of

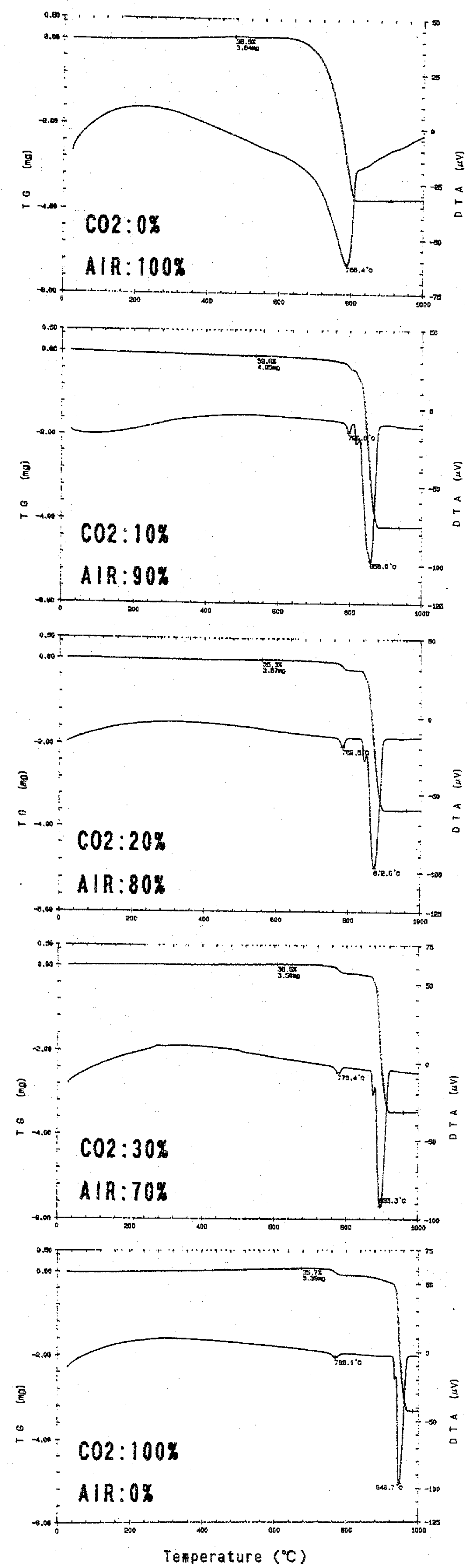


Fig 8-48 Differential Thermal Analysis with different CO2 conditions

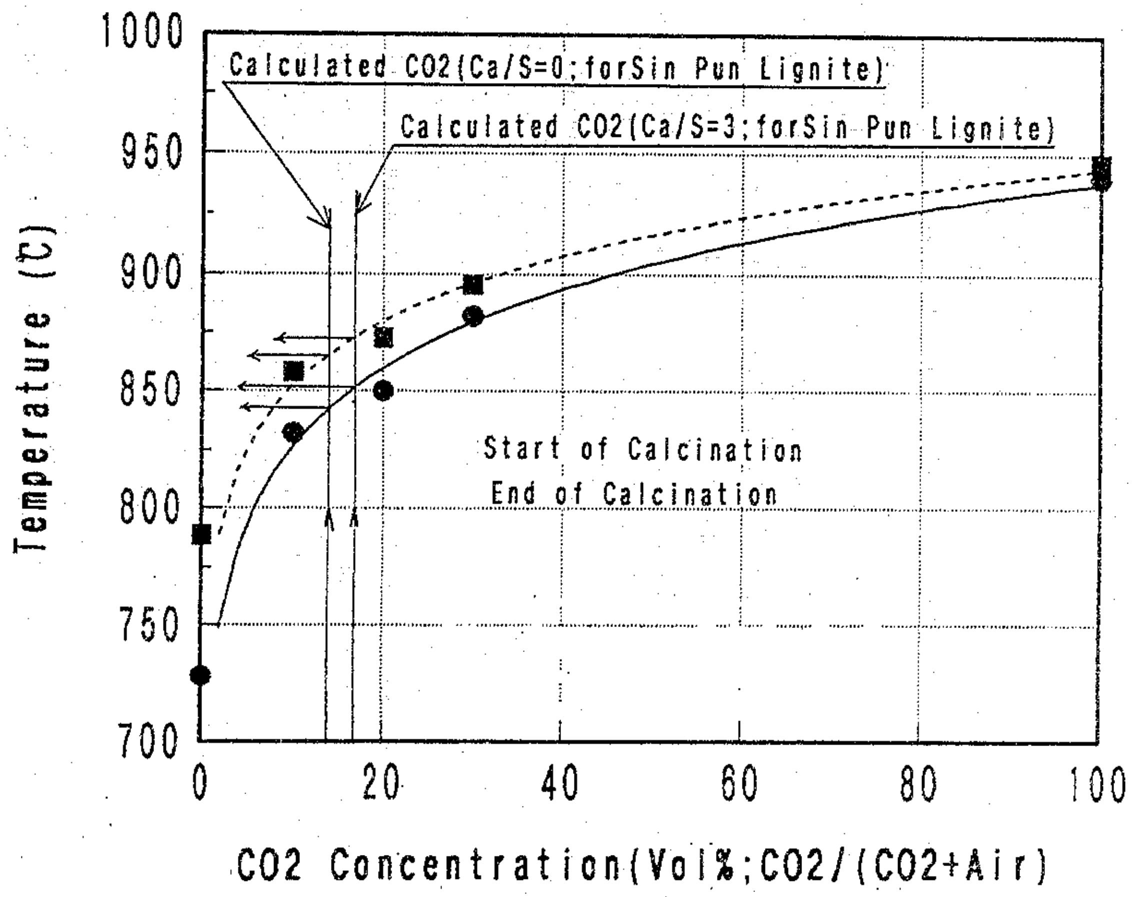


Fig 8-49 Calcination temperature with different CO_2 concentration

about 10°C, which we concluded would never be the cause for the high optimum point. To find out possible causes, the molar ratio of Ca/S was changed and the Krabi lignite of the lower sulfur content was used. All these tests, however, brought about the same phenomena, suggesting that such factors were not directly related to the higher optimum point.

In regard to an increase in oxygen volume, the estimate calculation shows that the air volume being blasted with the combustion air ratio of 1.20 (equivalent to O_2 density of 3.5% at the ϕ100 furnace outlet) corresponds to about 1.24 in terms of the fuel, including the oxygen volume absorbed during the desulfurizing reaction. Because of this, it is presumed that the regeneration reaction to ($CaO+SO_2+1/2O_2$) from the $CaSO_4$ was hindered at the high temperature side, and as a result the desulfurizing performance was maintained despite the high temperature. This reasoning is supported by test results of the combustion performance of Sin Pun lignite in Fig. 8-34, which shows the tendency of higher optimum temperatures as the air ratio increases.

In the demonstration tests conducted in Japan using higher air ratios, the phenomenon of the optimum desulfurizing temperature changing in relation to air ratio was not observed. However, with the present coal that had such high volatility, the portion around the coal supply nozzle would presumably be closer to the excessively reducing atmosphere, thereby establishing conditions for this phenomenon to occur.

Because of the faster combustion process at the coal supply portion and the factor of high volatility, it is presumed that the atmosphere will contain CO_2 of higher density around the fuel and limestone pouring in comparison with conventional coals. It is also presumed that the increase in the decarboxylating temperature was another factor causing the present phenomenon.

To investigate the SO_x generation side, the generation characteristics of SO_2 were studied by using the macro thermobalance. As Fig. 8-50 shows, no particular phenomena were noticed for Sin Pun lignite or Krabi lignite.

To summarize, our presumption is that the cause of the shift of the optimum desulfurizing reaction point to higher temperatures was the duplication of two factors: very high sulfur content and high volatility.

2) Ca/S molar ratio

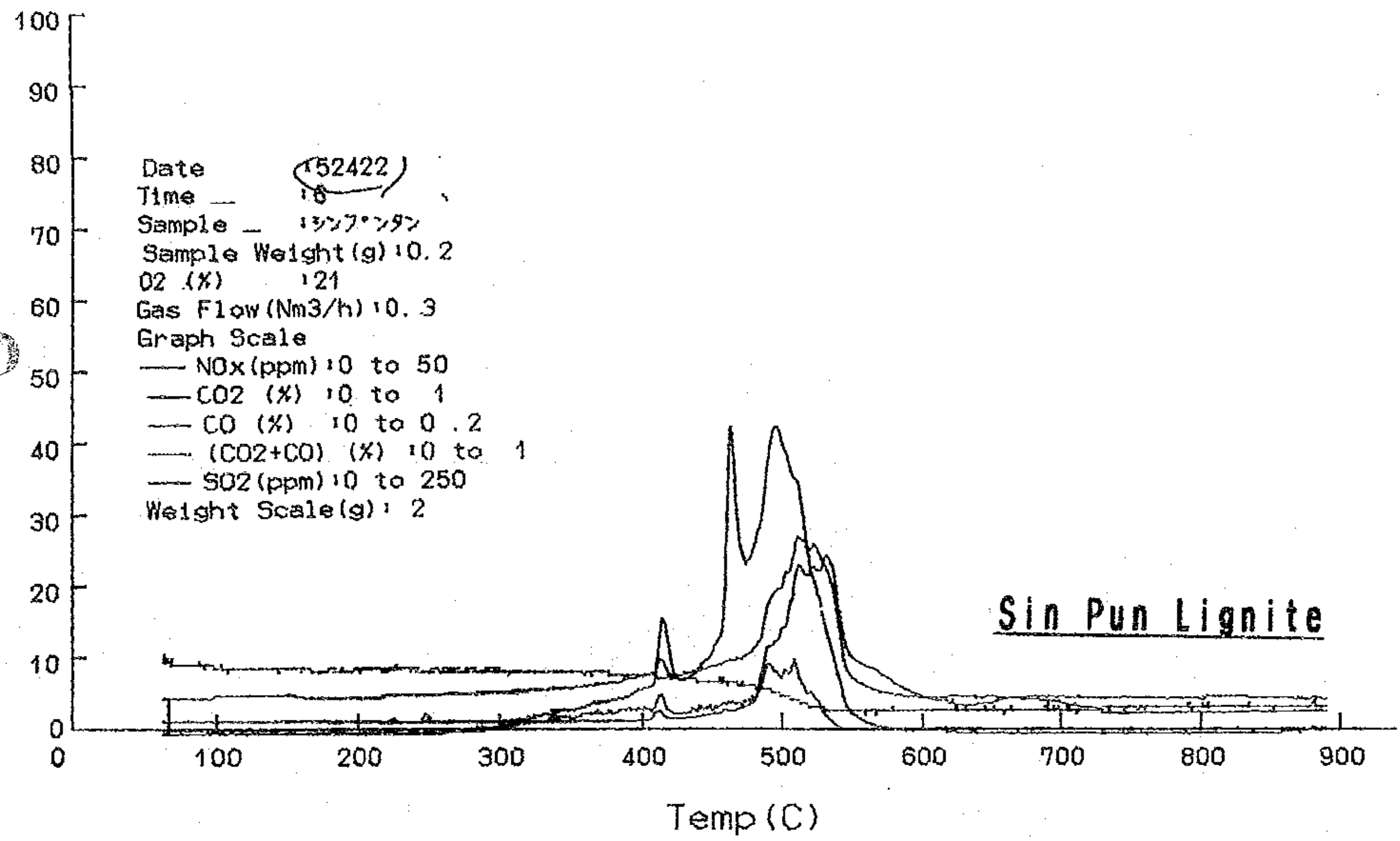
The present results of the Sin Pun coal combustion performance tests show that the initial target SOx<700 ppm is subject to change depending on the coal supply methods. The difference as described below will be equivalent to 1, which is obtained by relatively converting Ca/S to the molar ratio:

Over coal feed system: molar ratio ≥ 3 of Ca/S
Under coal feed system: molar ratio ≥ 2 of Ca/S

As the relation between the molar ratio and the SOx at the outlet of the fluidized bed shows in Fig. 8-51, both are correlated almost linearly on a logarithm table.

Also, the CaO content ratio in the B.M. and the SOx density at the outlet are closely interrelated as shown in Fig. 8-52. With the under coal feed system, the SOx density of less than 700 ppm at the outlet can be maintained at around the CaO content ratio of 25% by the molar ratio of Ca/S. The Sin Pun lignite, if combined with the limestone produced in Thailand, will exhibit excellent desulfurizing performance.

With the over coal feed system, the feeded coal scatters and burns before it enters the fluidized bed. It raises the SOx density only at the outlet without really contacting the BM, which works as a desulfurizing agent. Despite the CaO content



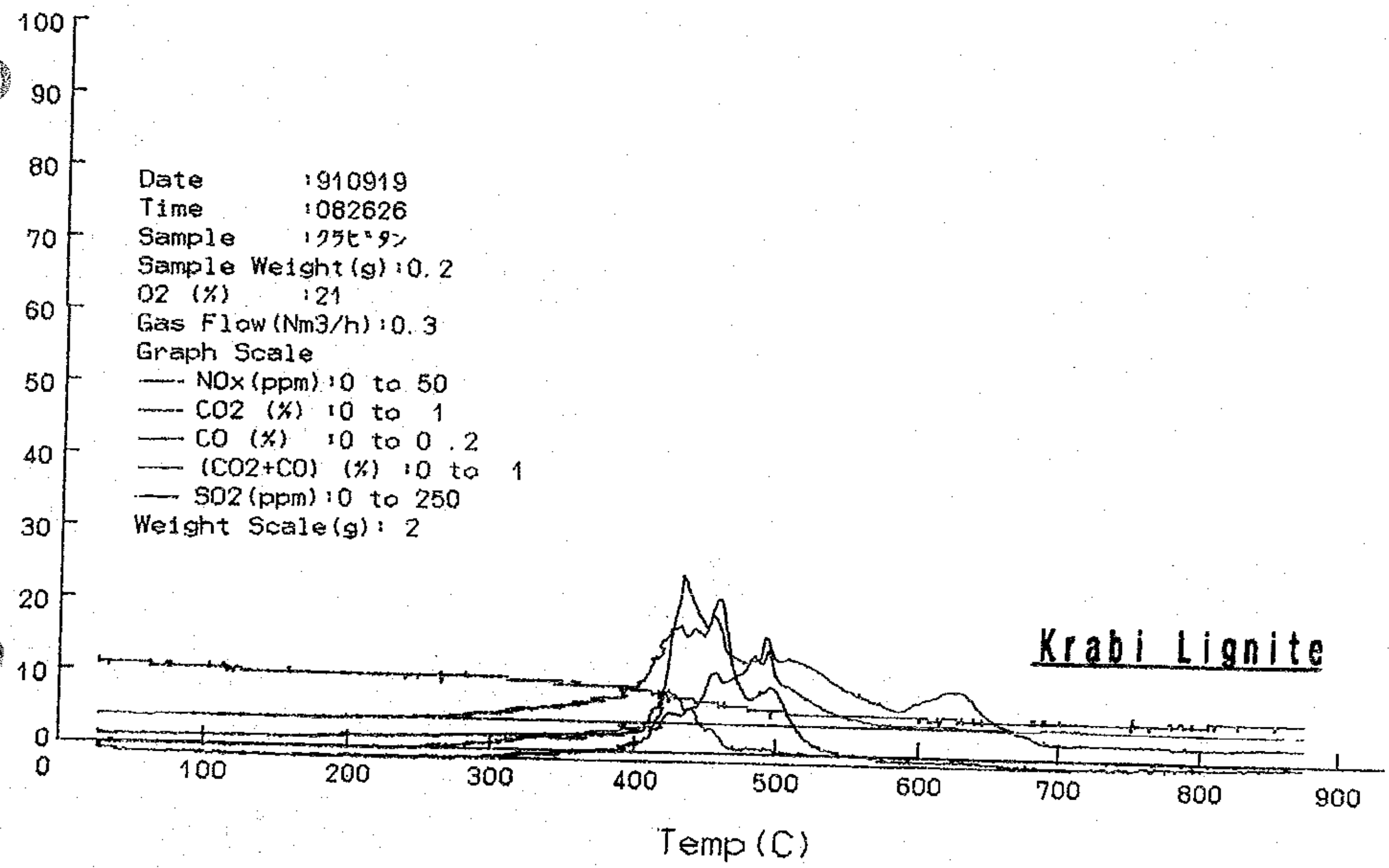


Fig 8-50 Macro Termobalance Analyzing Results

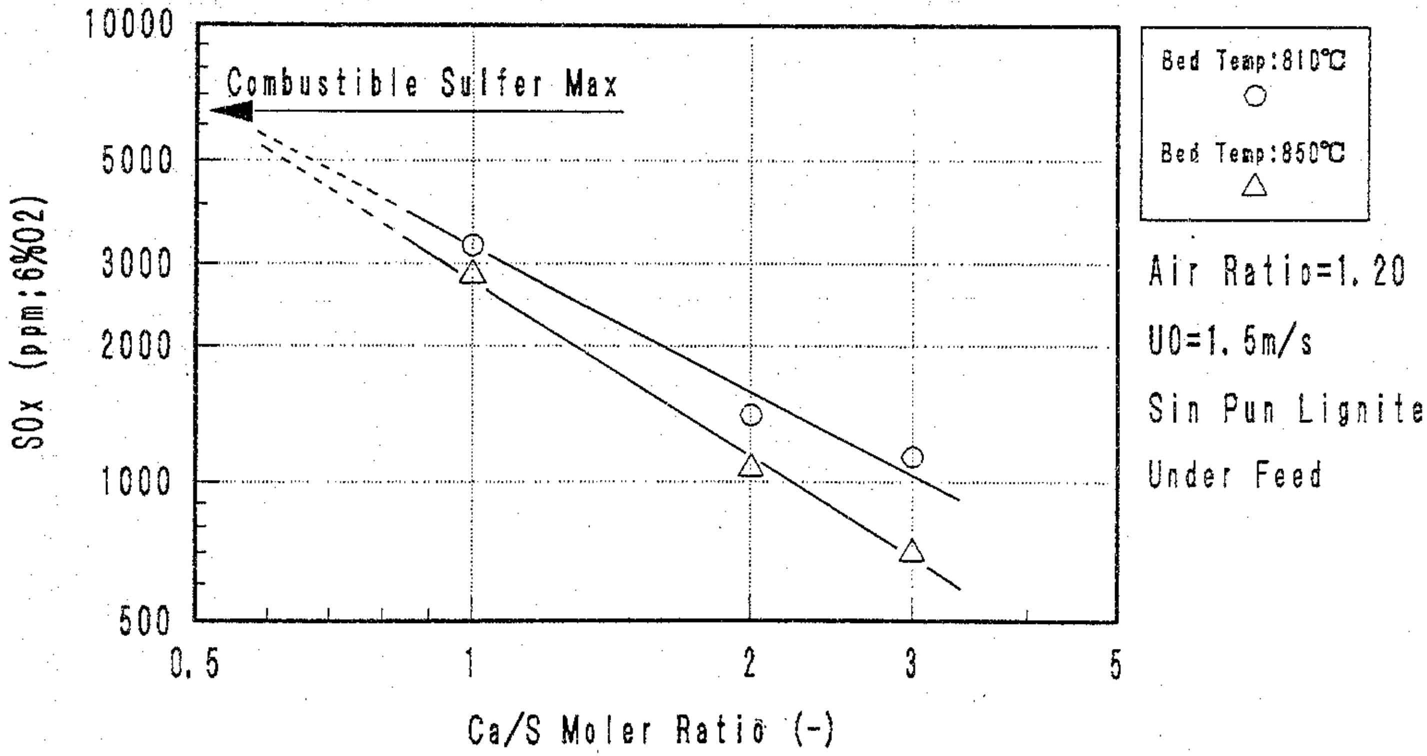


Fig 8-51 SOx emission with different Ca/S

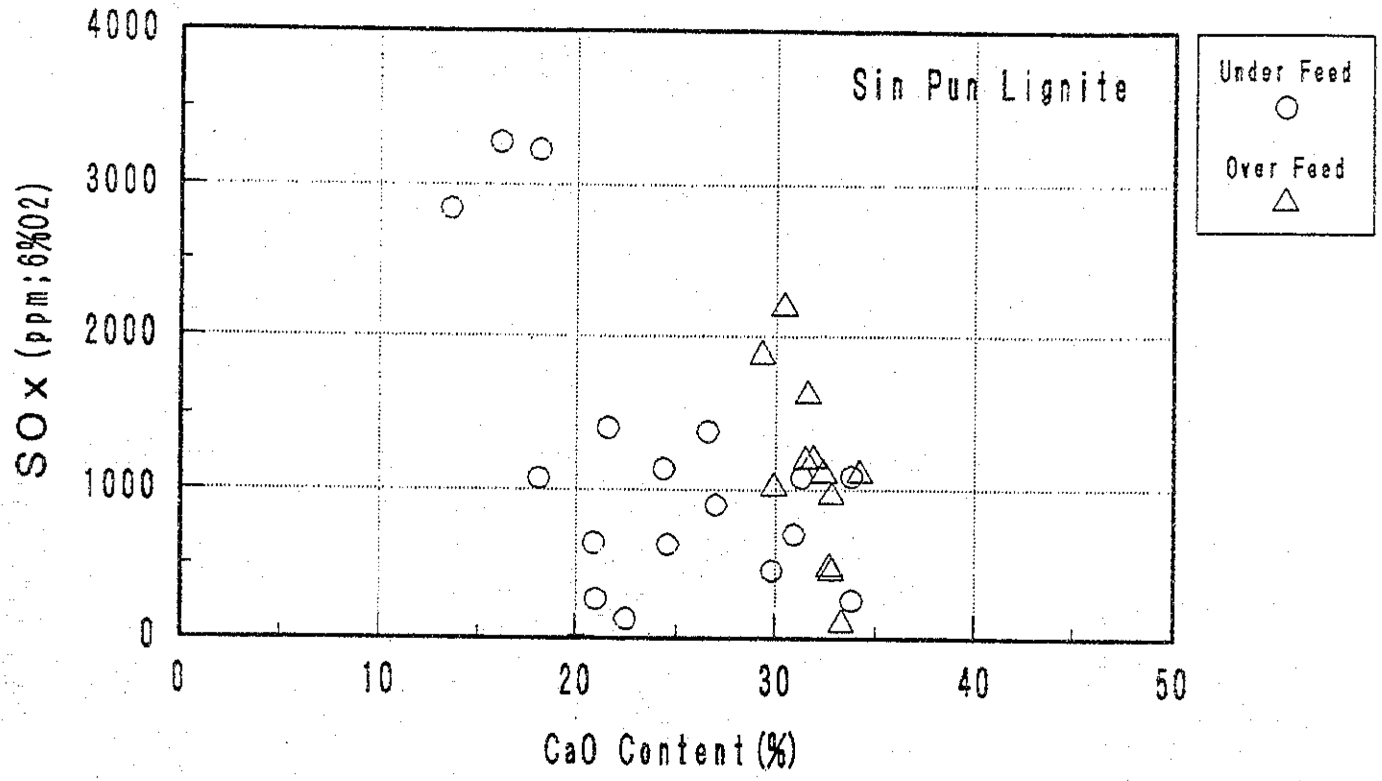


Fig 8-52 Effect of CaO content in bed material

ratio of about 30% in the B.M. by injecting limestone with the molar ratio 3, the SOx emission density turns to a level of about 700 ppm.

Because of the above, the feeded coal must be removed from the over coal feed system and a new method of supplying coal to the lower fluidized bed must then be considered (the ash recycle system is the one included in the bed). A facility must be developed that can maintain high desulfurization ratios even when the molar ratio of Ca/S is lowered.

Another consideration should be directed at the higher content of CaO and $CaCO_3$ in the fly ashes. These desulfurizing agents that have not completed the reaction process should be recycled so that further reduction in the consumption of limestone can be expected.

Using the combustion tests of a pilot scale, the material balance of the ash recycle facility should be confirmed and reflected in the economical design of the FBC system.

3) Space Velocity

With the present tests, the desulfurization performance was considerably affected by the space velocity. It was found that a speed of less than 1.2 m/s was required to achieve SOx emission 700 ppm with the over coal feed system. A limitation was evident in the scope of definable parameters for the present test because coal of much finer grain size than coal used in the actual equipment had to be used. This factor is understood to have greatly affected the test results. It is necessary to verify to what degree the SOx emission volume is affected by the space velocity by conducting pilot-scale tests.

(2) NOx

As against the 400~600 ppm NOx observed in the demonstration tests conducted in Japan, the NOx obtained with both Sin Pun lignite and Krabi lignite of Thailand was recorded to 200~300ppm, which is less than half the emission level in our knowledge during the demonstration test in Japan. It is understood that the cause for this was twofold: 1. The coal used for the test caused the gas temperature at the free board zone to rise very high as shown in Fig. 8-53, thereby facilitating the reaction of NOx reduction in the free board zone. 2. The volatility that was unusually high accelerated the reaction of NOx reduction in the fluidized bed at the coal supply portion.

With the present tests, according to the results of Fig. 8-27, a different coal feed system was tried and the phenomenon was noticed that a different coal feed system could provide a contrary result, depending on the air ratio. Here we will analyze the cause for this.

Fig. 8-53 shows the gas temperature distribution characteristics that were plotted by using the data of the coal supply methods and the air ratios. With the over coal feed system, a remarkable rise in gas temperature is noticed in comparison with the under coal feed system. Although this is presumably due to the combustion going on at the upper level of the fluidized bed, it is also presumed that the over feed system along with the air blast (about 15% of the total air used in the system) to prevent clogging in the coal supply pipes prompted combustion at the upper level and, at the same time, the NOx conversion process.

The air volume at the upper bed is stable regardless of the air ratio because it is supplied only in the flow rate required for coal conveyance. This leads to the understanding that the NOx emission volume is also stable at the upper bed no matter the air ratio.

Supposing that a certain NOx value is established that always contributes to higher tendency values, the rate at which NOx increases with the increase of air ratios inside the fluidized bed should become

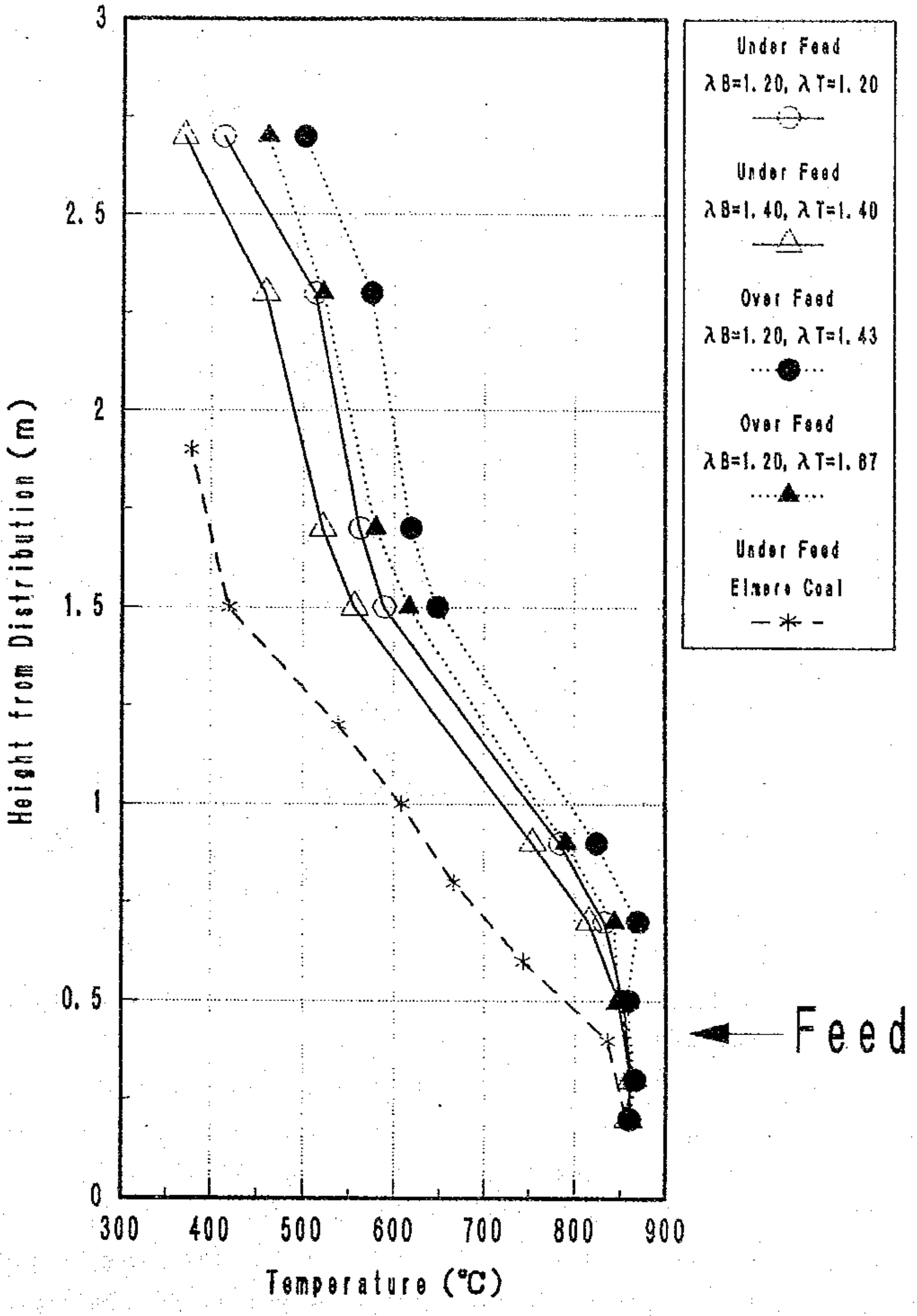


Fig 8-53 Gas temperature distribution in furnace

smaller. In other words, the rate, at which NOx increases with the increase of air ratios inside the fluidized bed will become relatively smaller under conditions of the over coal feed system than it will under those of the under coal feed system. It is presumed, therefore, that this explains why the reversed phenomena took place, as shown in Fig. 8-27.

With the NOx generated by the actual equipment, the exhaust volume varies depending on the reduction processes going on either inside the fluidized bed or on the fluidized bed. If the reduction inside the bed constitutes a major factor for the lower NOx, the NOx will tend to decrease when this particular coal is used with the actual machine. If the reduction on the bed causes the lower NOx, the NOx will not decrease with the actual equipment because the equipment already has higher gas temperatures. This point, however, needs to be further analyzed by evaluating the results of the pilot scale tests, which have temperature conditions of the free board zone much closer to those of the actual equipment.

Because the record shows that NOx volume of the actual equipment will never exceed that of bench scale furnaces, it is understood that 500 ppm or less may be achieved, which is the value proposed as the NOx emission target.

(3) Combustion Efficiency

The present test results using the ϕ100 furnace shows that a combustion efficiency greater than 98% was obtained with both the over and under coal feed system. In terms of standard correlativity with the actual equipment as previously explained, the combustion efficiency of the actual equipment will eventually fall below that of the test apparatus. Nevertheless, it is estimated that the combustion efficiency may still be maintained at better than 98%. We believe that this presumption can be verified by using the absolute values of combustion efficiency in pilot scale tests, which have temperature conditions in the free board zone and grain size conditions closer to those of the actual equipment.

Fig. 8-54 shows distribution of the gas temperature density inside the furnace in the lateral direction. The temperature inside the furnace as already explained tends to go higher at the upper coal supply portion in the over coal feeding conditions than in the under coal feeding conditions.

O_2 is almost stabilized over the 1,000 mm area on the distribution plate, which indicates completion of the combustion.

Judging from the measurement results of O_2 density distribution, it is noted that the combustion for over coal feed system is completed at a relatively lower position. The good contact efficiency between high-volatility coal and the air is presumed to have been realized by the sufficient air supplied from both the internal bed and the bed surface, thereby enabling higher combustion efficiency. However, this seems more dependent on the small size of the apparatus and also on the large volume of air supply from around the bed surface.

Fig. 8-55 shows the NOx density distributions inside the fluidized bed. The tendency of decreasing from the upper bed to the free board zone is seen with NOx, and NOx reduction is under way at the free board zone. In the over coal feed system, this reaction is completed over an area of about 800 mm on the distribution plate. In the under coal feed system, however, the area further expands over the area by as long as about 1,500 mm. Because of the difference discussed previously in the O_2 density distribution, the insufficient contact between the fuel and air is presumed to have caused the dull combustion process, or there existed many reducing substances such as charcoal on the bed, which facilitated the reaction of NOx reduction.

8.7 Summary and Problems to be Solved

(1) The desulfurizing performance has turned out to be in its optimum level at the bed temperature of approximately 850°C.

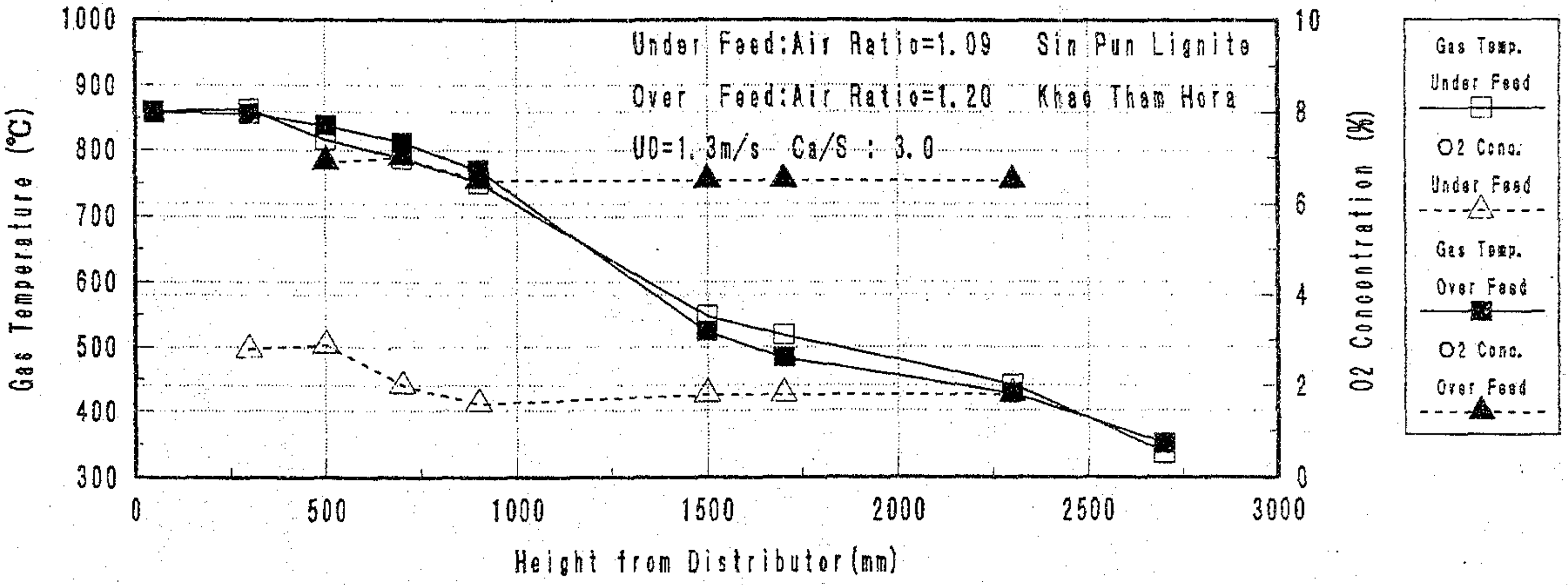


Fig 8-54 Temperature and O2 distribution in furnace

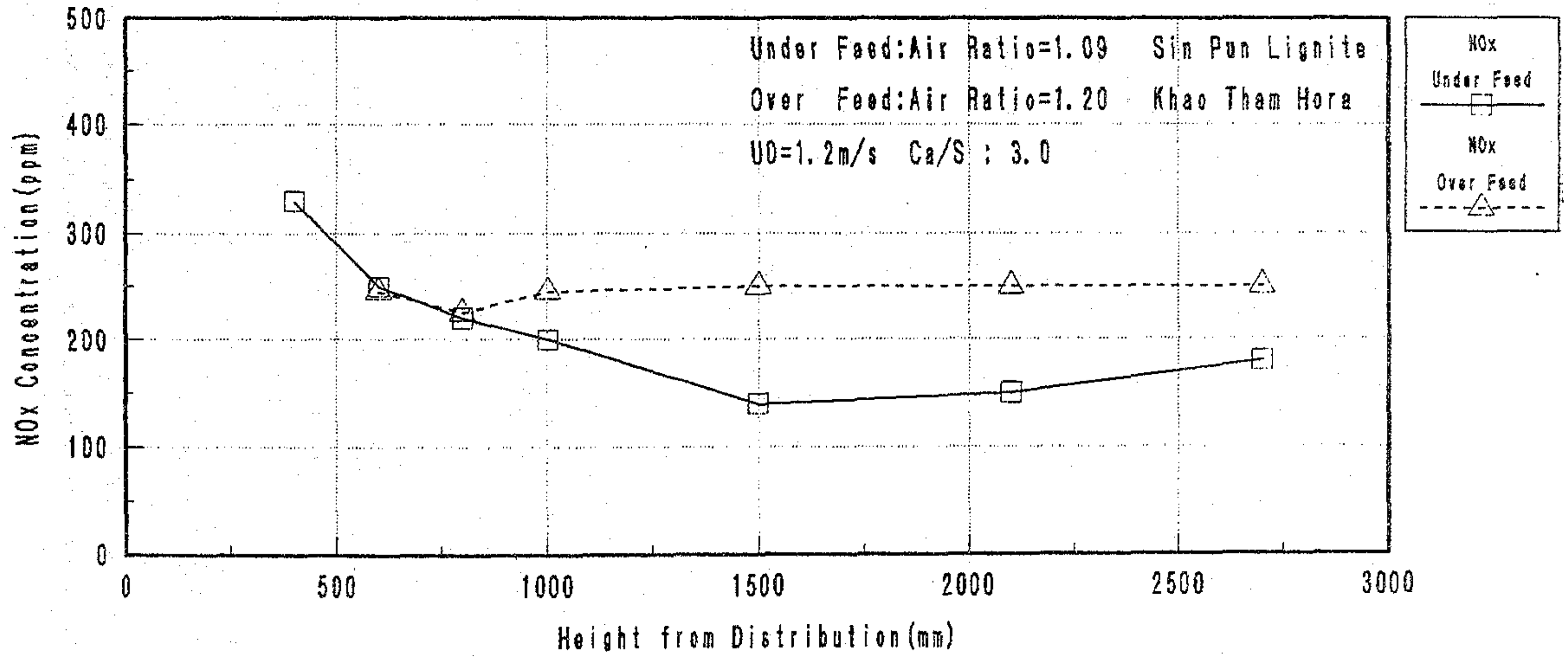


Fig 8-55 NOx concentration in furnace

Based on the results of the pilot scale tests, these results must be reflected in the selection of standard bed temperatures in the designs of actual machines.

(2) Concerning the brand of limestone, Khao Tham Hora is superior to Thung Song in the desulfurizing performance.

(3) Under the present target of SOx<700 ppm, the Ca/S molar ratio is 2 for the under coal feed system and 3 for the over coal feed system. In the under coal feed system, the limestone was reduced to an amount equivalent to the molar ratio 1 of Ca/S. It is further necessary to study the proper Ca/S molar ratios on the grounds of the test results of a pilot scale combustion test. In consideration of this, the survey of candidate sites and the layout of the power generation station were designed at the present development stage by using the molar ratio 2.5 of Ca/S.

(4) Although a remarkable improvement in the desulfurizing performance was noticed in the present tests when the space velocity were reduced, the improvement must still be verified by conducting a pilot test, which should be done by using the same coal and the same limestone as those used with the actual equipment.

(5) Because the NOx emission was 200~300 ppm with the ϕ100 furnace, a further decrease can be expected with the actual equipment. Thus it is understood that the current target of 500 ppm or lower can be achieved. This expectation, however, should be supported by the results of a pilot-scale test.

(6) Concerning combustion efficiency, the record of large furnaces shows that a level better than 98% can be expected. Also although no remarkable reduction in combustion efficiency was noticed with the over coal feed system, the absolute values of combustion efficiency should be verified by conducting pilot-scale tests.

(7) The comparative study of the Sin Pun lignite/Khao Tham Hora and the Krabi lignite/Yod Po Sile Thong reveals that the Sin Pun lignite/Khao

Tham Hora is much superior in all respects, including desulfurizing performance, NOx emission and combustion efficiency. And also the Sin Pun lignite has a superior in a respect of the fluidized action because of the less trouble caused by the settlement of large ash lump at the bottom of the fluidized bed in comparison with the Krabi lignite.

9. PILOT SCALE COMBUSTION TEST

CHAPTER 9 PILOT SCALE COMBUSTION TEST

CONTENTS

		Page
9.1	General	9 - 1
9.2	Test Facility	9 - 6
9.3	Chemical Analysis of Lignite and Limestone	9 - 25
9.4	Test Lignite and Limestone Size Distribution	9 - 32
9.5	Test Result	9 - 36
9.6	Evaluation of Result	9 - 87

List of Figures

Fig. 9-1	A-FBC System
Fig. 9-2	Fluidized Bed for Bubbling FBC and Pilot Scale Combustion Facility
Fig. 9-3a	Combustion Test Furnace
Fig. 9-3b	Schematic Diagram of AFBC Test Facility
Fig. 9-4	Size Distribution
Fig. 9-5	Size Distribution (Lime Stone)
Fig. 9-6	Pilot Scale Comb. Test Results: Effect of Heat Release Rate
Fig. 9-7	Temperature Profile (Effect of Heat Release Rate)
Fig. 9-8	Pilot Scale Comb. Test Results: Effect of Excess Air Ratio
Fig. 9-9	Pilot Scale Comb. Test Results: Effect of Bed Temperature
Fig. 9-10	NOx Emission (Effect of Bed Temperature)
Fig. 9-11	Pilot Scale Comb. Test Results: Effect of Ca/S Molar Ratio
Fig. 9-12	Pilot Scale Comb. Test Results: Effect of Ca/S Molar Ratio
Fig. 9-13	Pilot Scale Comb. Test Results: Effect of Ash Recycle Ratio
Fig. 9-14	Pilot Scale Comb. Test Results: Effect of Ash Recycle Ratio
Fig. 9-15	Pilot Scale Comb. Test Results: Effect of Ash Recycle Ratio
Fig. 9-16	SOx Emission (Effect of Ash Recycle Ratio)
Fig. 9-17	Pilot Scale Comb. Test Results: Effect of Coal Feed Method
Fig. 9-18	Temperature Profile (Effect of Coal Feed Method)
Fig. 9-19	Pilot Scale Comb. Test Results: Effect of Coal Size
Fig. 9-20	Pilot Scale Comb. Test Results: Effect of Coal Size
Fig. 9-21	Temperature Profile (Effect of Coal Size)
Fig. 9-22	Pilot Scale Comb. Test Results: Effect of Lime Stone Size
Fig. 9-23	Pilot Scale Comb. Test Results: Effect of Lime Stone Size
Fig. 9-24	BM Blow Rate (Effect of Superficial Velocities)
Fig. 9-25	Size Distribution of BM (Data No. T-11)
Fig. 9-26	Size Distribution of Cyclone Ash
Fig. 9-27	Size Distribution of Bag Filter Ash

List of Tables

Table 9-1a	Pilot Scale AFBC Combustion Test Schedule
Table 9-1b	Test Conditions for Pilot Plant Test (Step-1)
Table 9-1b	Test conditions for Pilot Plant Test (Step-2)
Table 9-2	Proximate Analysis of Lignite (EGAT data)
Table 9-3	Chemical Analysis of Lignite (JICA data) Blended Lignite (Sin Pun 4: Krabi 1)
Table 9-4	Ash Analysis of Blended Lignite (JICA data)
Table 9-5	Monitoring Results of Lignite Analysis
Table 9-6	Average Value of Ultimate Analysis (As-Fired of Blended Lignite)
Table 9-7	Chemical Analysis of Limestone
Table 9-8	Lignite Size for Test
Table 9-9	Small Particle Involvement of Limestone
Table 9-10a	Pilot Scale PFBC Test Data (Final)
Table 9-10b	Pilot Scale PFBC Test Data (Final)
Table 9-11	Size Distribution of Respective Ash and Limestone
Table 9-12	CO_3 Contents of Each Ash
Table 9-13	SiO_2 Content S/Ca & Fe/Si Molar Ratio
Table 9-14	Combustion Efficiency

9. Pilot Scale Combustion Test

9.1 General

The pilot combustion test purposes to confirm the technical availability of Sin Pun and Krabi lignite for A-FBC with the actual modeling furnace by the combination with the candidate limestone in Thailand under the actual particle size of lignite and limestone.

The test also purposes to get the necessary data for the feasibility design. Especially the limestone consumption affects greatly the economical feasibility of the study because the high sulfur and low heat value lignite consumes the huge amount of the limestone for the desulfurization.

The outline of the combustion test is shown in Fig. 9-1. The following items are confirmed in the test.

<u>Pre-test</u>

a. Chemical analysis of lignite and limestone
b. Size distribution check of lignite and limestone

<u>Test (Refer to the test schedule Table 9-1a, 9-1b)</u>

a. Heat release rate
b. Excess air ratio
c. Bed Temperature
d. Ca/S Molar Ratio
e. Ash Recycle Ratio
f. Lignite Feeding Method
g. Lignite Size
h. Limestone Size
i. Material Balance Check and Ash Chemical Analysis

As a result, it is confirmed that Sin Pun and Krabi lignite can be combusted in A-FBC with the desulfrurization efficiency 90% under the condition of the limestone injection of Ca/S molar ratio 2.

It is also assumed with the combination of the several test results that the desulfurization efficiency 94% (700 ppm SOx emission with the design lignite) could be achieved by the limestone injection of Ca/S molar ratio 2 under the ash recycle ratio 1.5. For NOx emission, it is confirmed that A-FBC can combust the lignite within the emission value 200 ppm which is much less value of Thai proposed regulation 1,000 mg/Nm^3 (abt. 500 ppm for NO_2).

For the combustion efficiency, it is also confirmed that A-FBC can combust the lignite with 99% over efficiency.

Fig. 9-1 A-FBC System

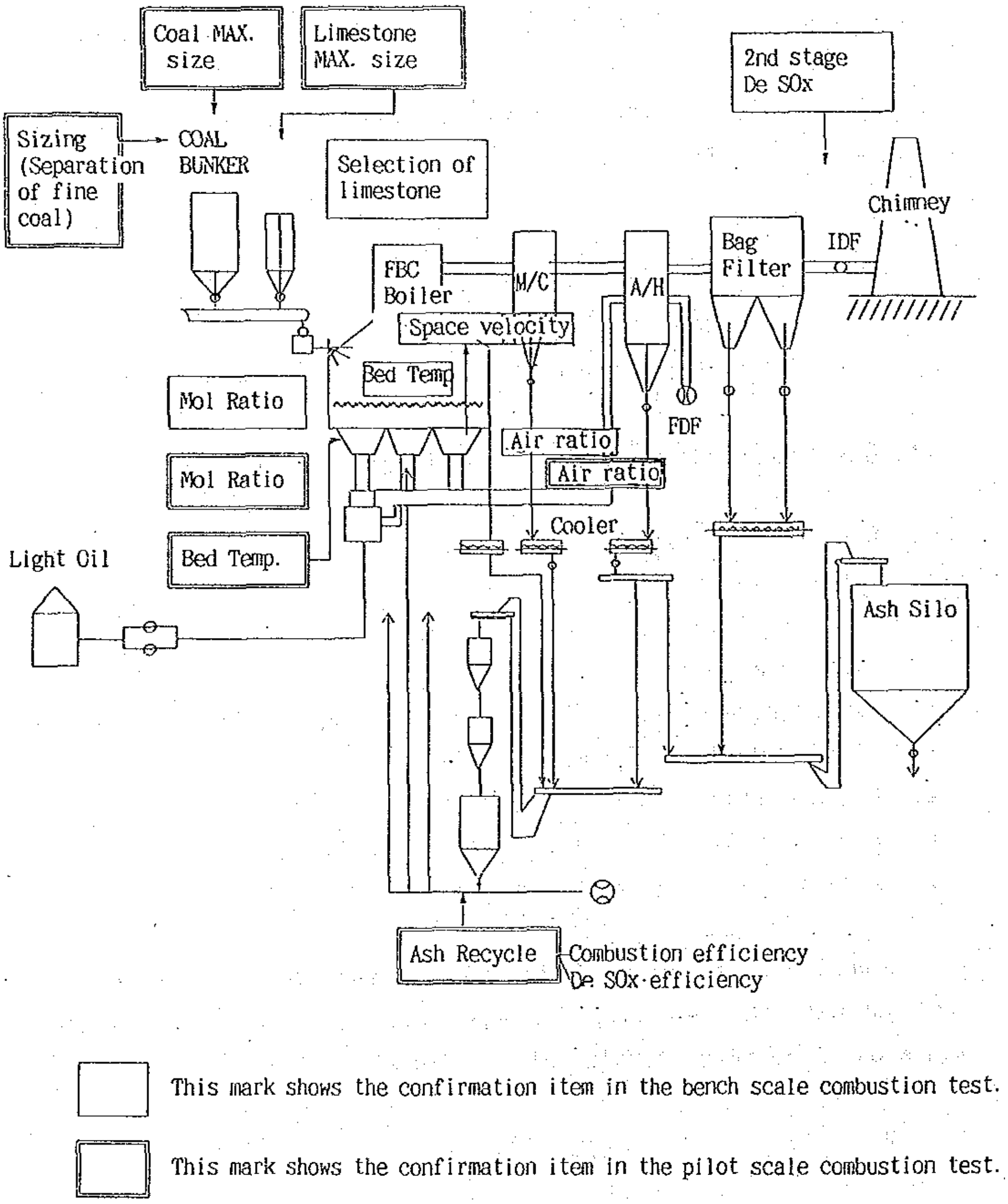


Table 9-1a Pilot Scale AFBC Combustion Test Schedule

	1992 Mar	1992 Apr	1992 May	1992 Jun
1. Crushing Lime-Stone	Arrival →	4/3 4/20		
2. Lignite Drying	Arrival →	4/3 4/28		
3. Lignite Sieving		4/22 4/28		
4. Lignite Blending		4/17	5/4	
5. Test Preparation				
6. Test Facility Tuning	Coal Combustion			
7. Test			Step 1 Step2	
8. Sample Analyzing				

Table 9-1b Test Conditions for Pilot Plant Test (Step-1)

Parameter / Date	5-11M	5-12/13 Tu/We	5-14 Th				5-15 Fr			5-16 Sa			5-17 Su
Data No.			1	2	3	4	5	6	7	8	9	10	11
Heat Release Rate (Q)		Q & λ Parameter Survey	Decide after Parameter survey test										
Total Air Ratio (λ_T)			1. 2	1. 4	1. 5	1. 5	1. 5	1. 5					
Bed Temperature (T_B)		850	850			800	850	880	850				
Ca/S Molar Ratio		1.8 - 3.6											
Cyclone Ash Recycle		Non Recycle										Recycle	Non Recycle
Coal Feed System		Over Feed							Under Feed		Over & Under	Over Feed	
Coal Size		-8.6 mm	+2.8 mm Crushing						-8.6 mm		+2.8CR -2.8 mm	+2.8 Crush	-20 mm
Lime Stone Size		-3 mm						-10 mm	-3 mm				
Remarks	15:00 Ignition 19:00 Coal Feed		5/13 15:00 Stop (Gas Leak) 23:00 Restart										

Table 9-1b Test Conditions for Pilot Plant Test (Step-2)

Parameters \ Date	5-19 Tu	5-20 W			5-21 Th				5-22 Fr			5-23 Sa		Remarks
	Test No.	T-12	T-13	T-14	T-15	T-16	T-17	T-18	T-19	T-20	T-21	T-22	T-23	
Heat Release Rate (Q)		0.8	1.0	1.2	1.2							1.2		x 10^6 kcal/m^2h
Total Air Ratio (λ_T)		1.3 (~ 1.4)										1.3		
Bed Temperature (T_B)					825°C							825°C		
Ca/S Molar Ratio		3.0			2.0				2.5			2.5		
Cyclone Ash Recycle Ratio		0			0.4		0.8	1.2	0.4	0.8	1.2	1.2		
Coal Feed System		Over Feed (80) / Under Feed (20)									OF	UF		
Coal Size		+2.8 mm Crushing/ -2.8 mm									-8.6 mm	-2.8 mm		
Lime Stone Size		-3 mm										-3mm	-3mm Fine	
Remarks	15:00 Ignition 19:00 Coal Feed	SO_2 Sampling after Bag Filter Hot Bunking												

9.2 Test Facility

The test facility of the pilot scale shall simulate the actual operating conditions such as the heat release rate, space velocity, etc. Fig. 9-2 shows the comparison between the actual fluidized bed of A-FBC and the pilot scale combustion bed.

The surface of the pilot scale combustion test facility is 0.5 m x 0.5 m and the bed height is 1.2 - 1.5 m as same as the actual fluidized bed.

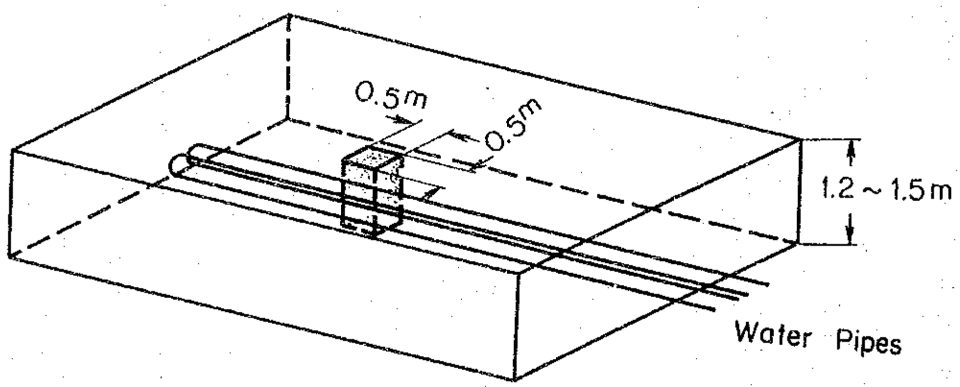


Fig. 9-2 Fluidized Bed for Bubbling FBC and Pilot Scale Combustion Facility

By using the pilot scale combustion facility, the characteristics of the lignite and limestone in the fluidized bed are checked correctly as same as the actual scale fluidized bed. The material balance of the ash from the fluidized bed and fly ash also be checked by this test facility. Fig. 9-3a and 9-3b shows the outline of the test facility. Photo 9-1 - 9-3 shows the photograph of the test facility.

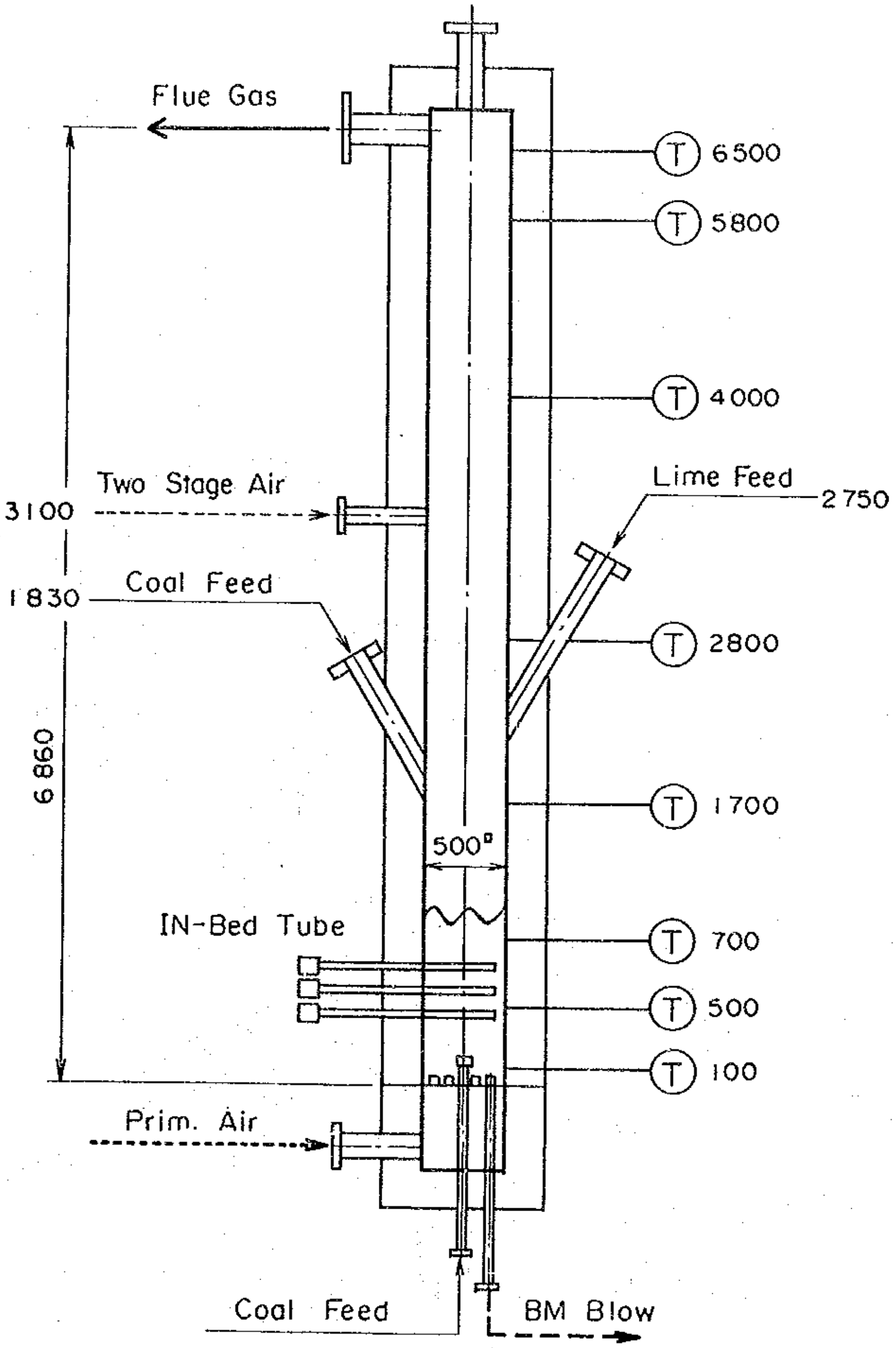


Fig. 9-3a Combustion Test Furnace

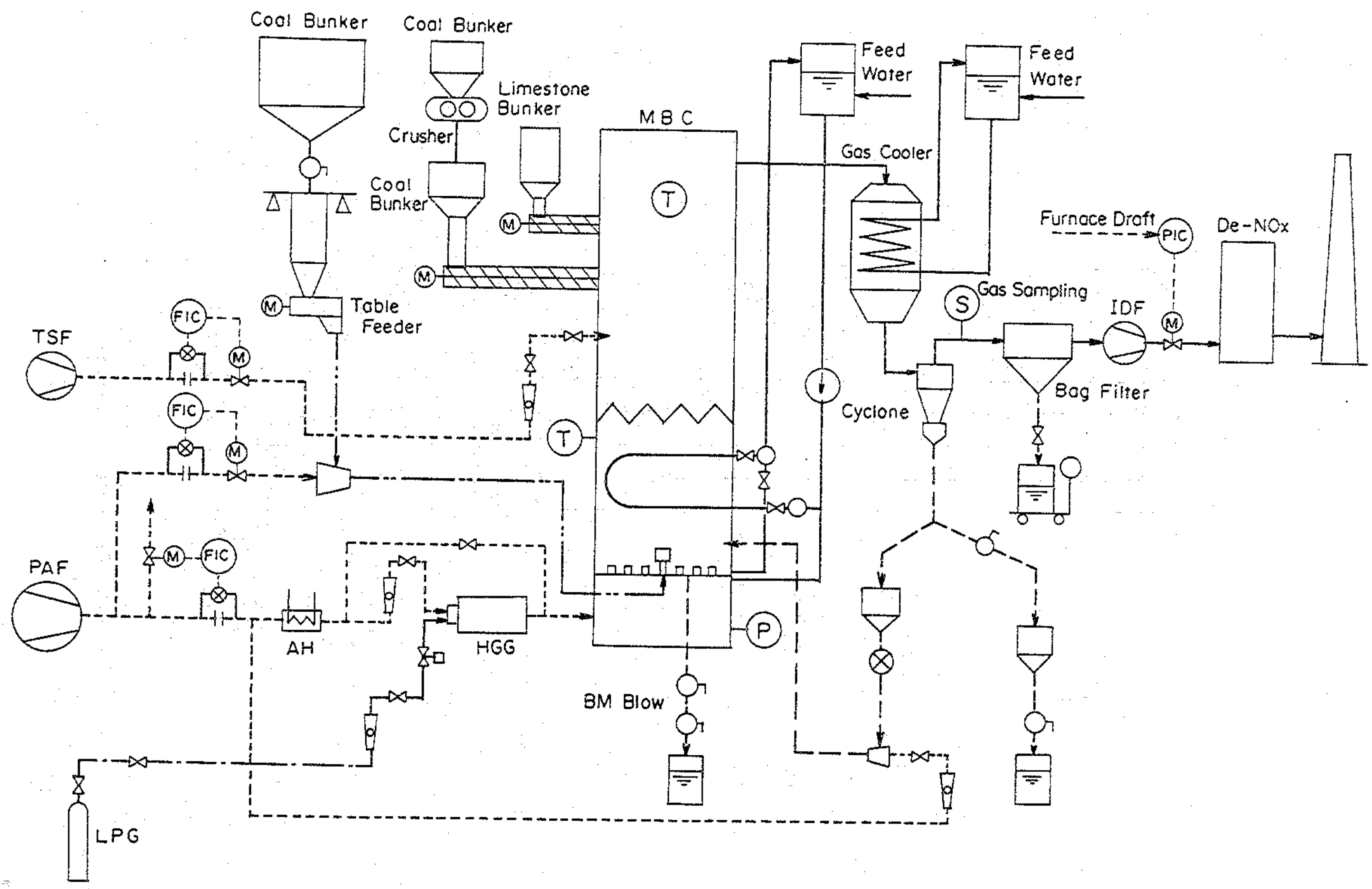
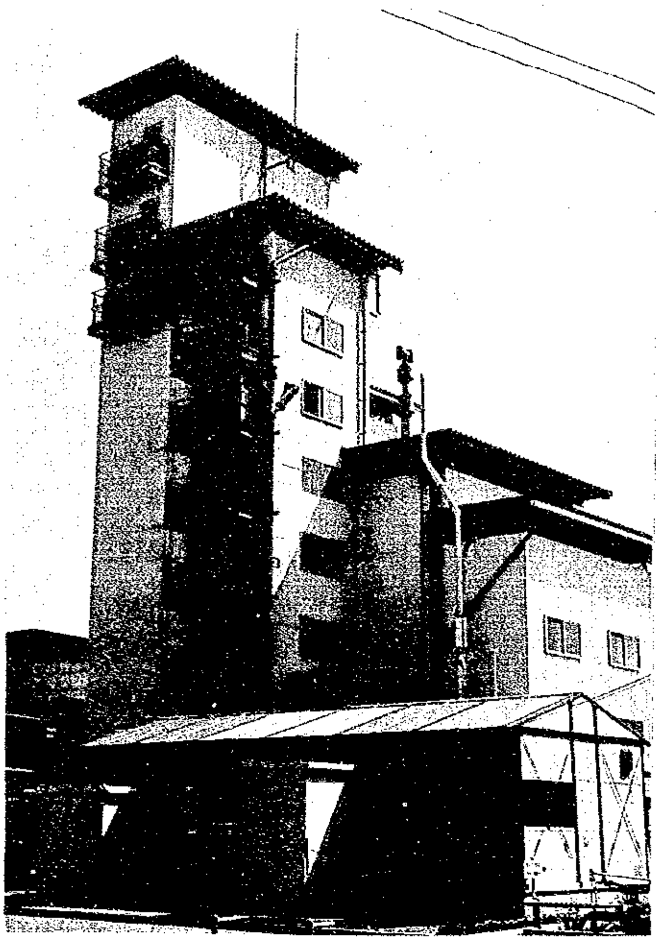
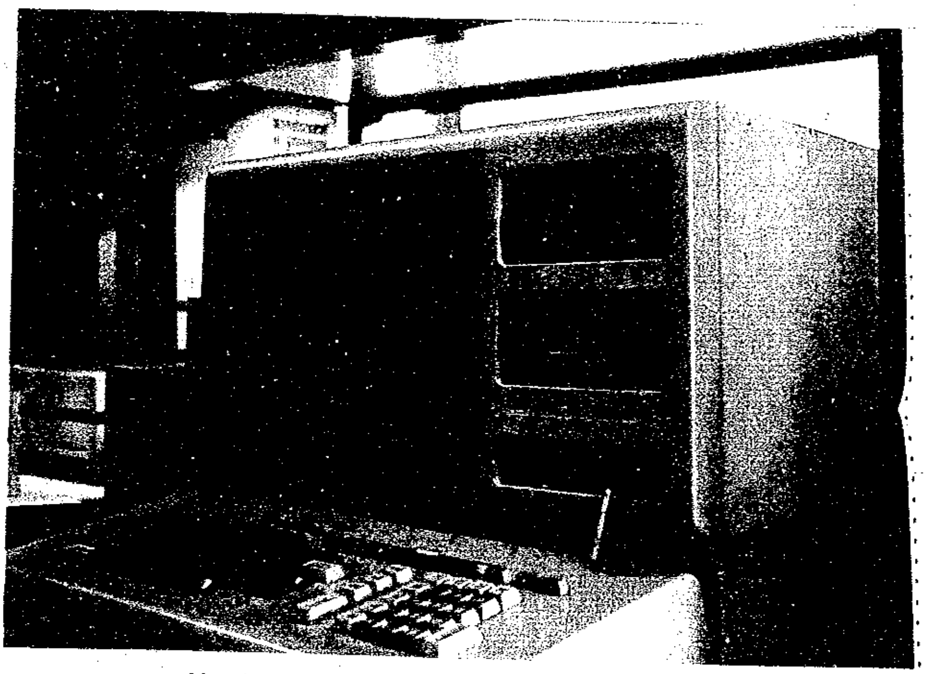


Fig. 9-3b Schematic Diagram of AFBC Test Facility

Photo 9-1



Tower for Combustion Test Furnace



Monitoring CRT for Combustion Test

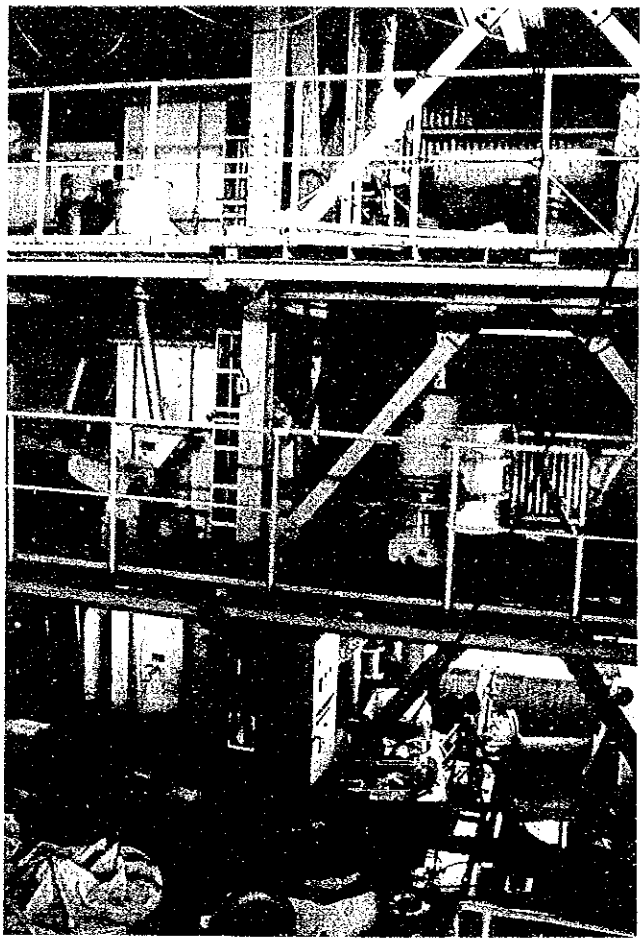
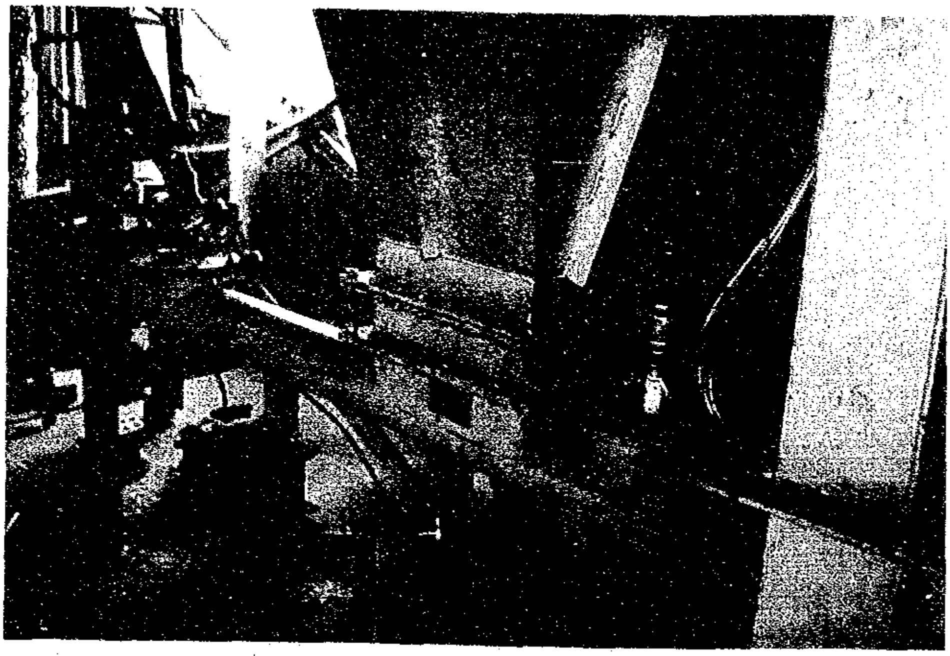


Photo 9-2

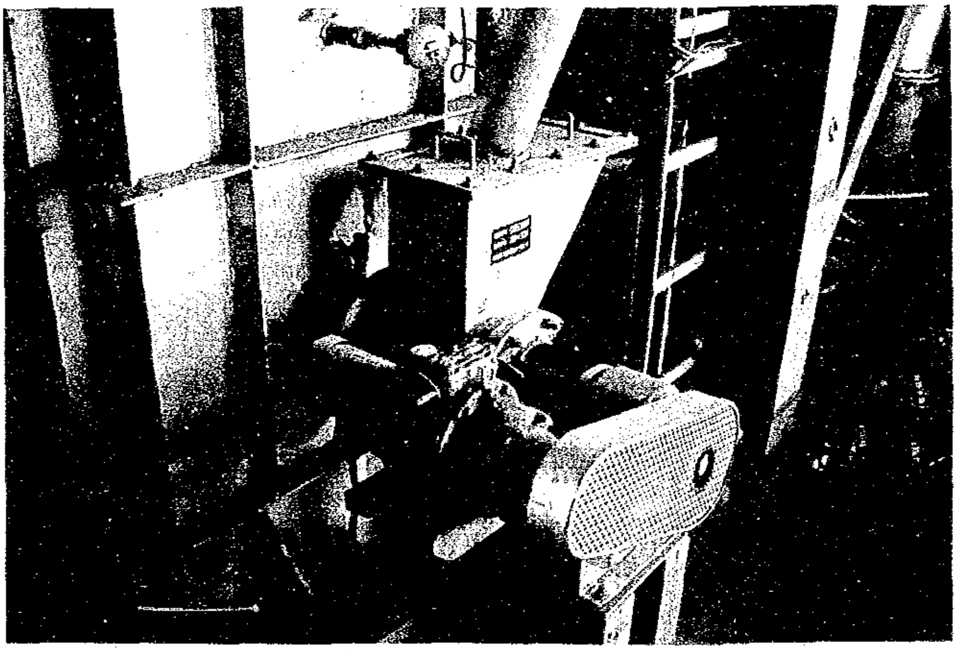
Test Furnace

Photo 9-3

Bottom of Test Furnace



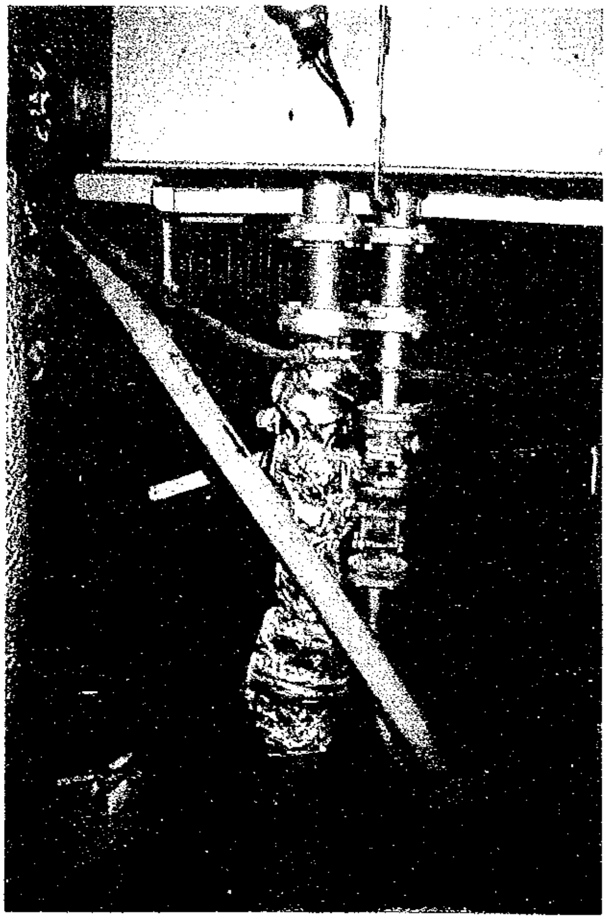
Coal Feeder (Screw Feeder)



Limestone Feeder (Screw Feeder)

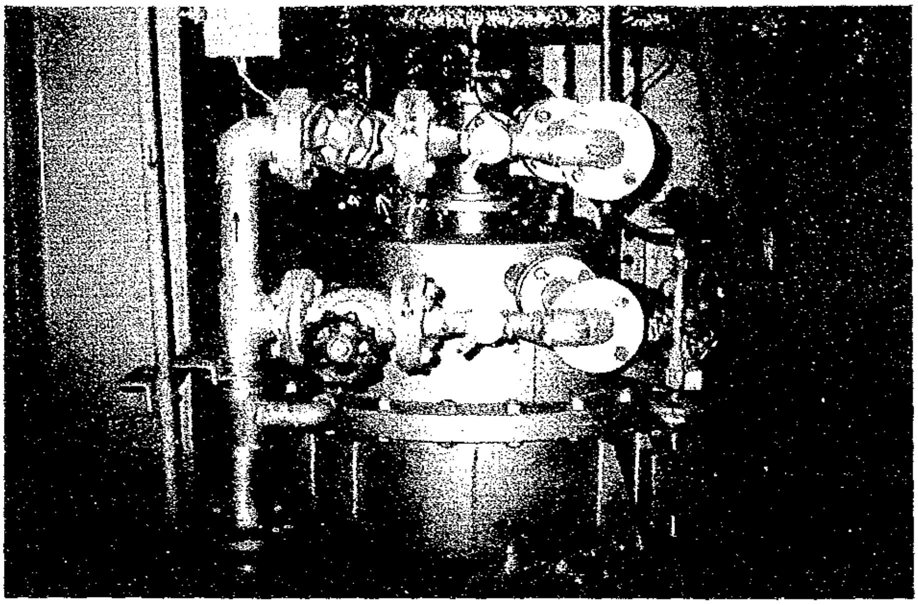
Blending Mixer

Crusher (Roller Crusher)



B.M. Ash Blow

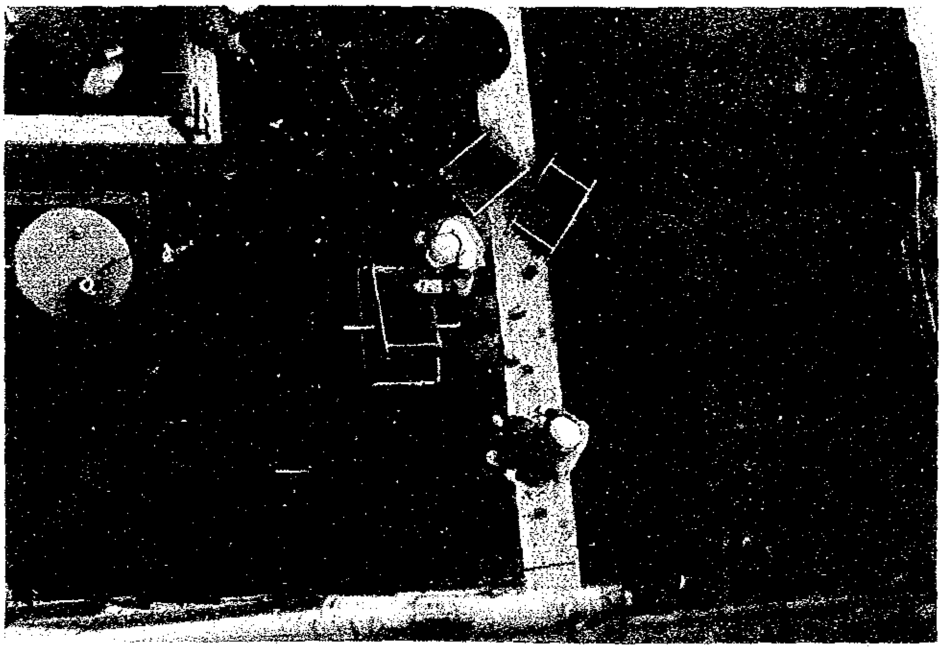
Mechanical Cyclone



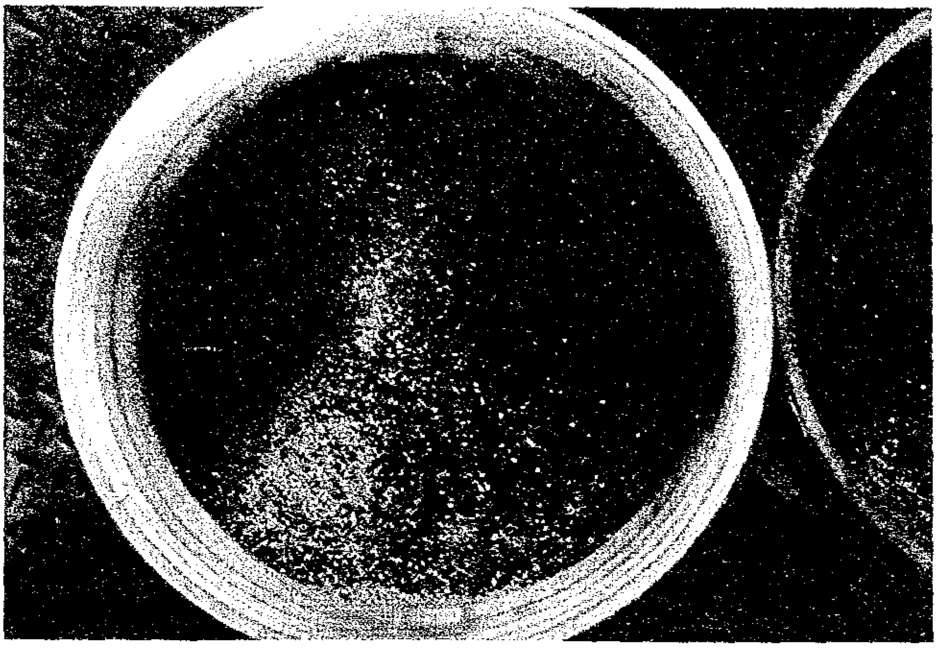
Starting Barner

Bed Temperature
Control Pipes

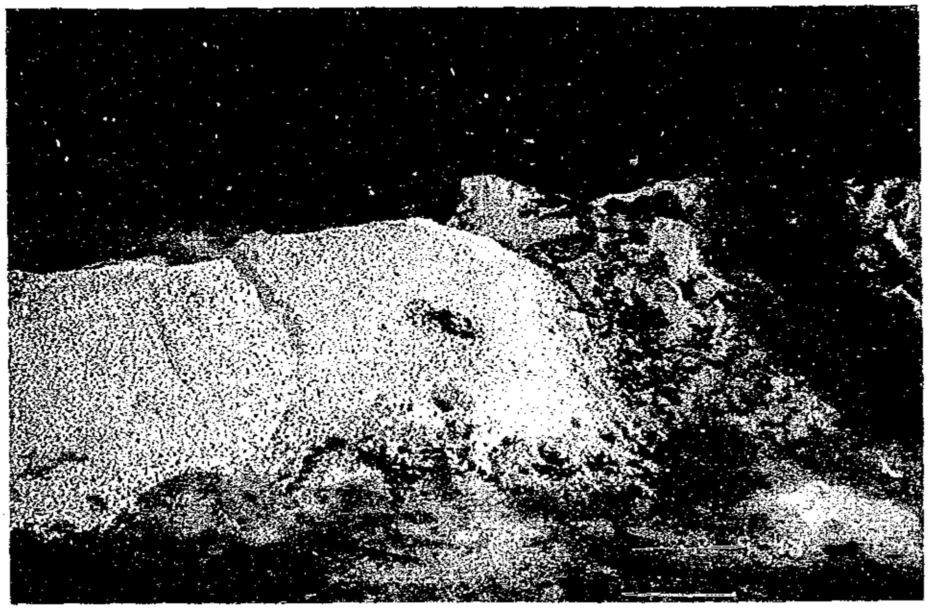
Lignite Sizing



Lignite Sizing (2.8 mm Sieve)



Testing Limestone



Ash (Left: Overflow B.M., Right: Cyclone Ash)

9.3 Chemical Analysis of Lignite and Limestone

The proximate analysis of the test lignite carried out by EGAT on February '92 is shown in Table 9-2.

Table 9-2 Proximate Analysis of Lignite (EGAT data)

Item		Krabi (Klongtone)	Sin Pun	Sin Pun 4 Krabi 1
Moisture Content	% A.R.	33.27	31.2	31.6
	(A.D.)	(9.14)	(13.06)	
Ash Content	% A.R.	25.09	9.78	12.8
	(D.B.)	(37.60)	(14.22)	
Volatile Matter	% A.R.	21.54	31.68	29.7
	(D.B.)	(32.28)	(46.06)	
Fixed Carbon	% A.R.	20.10	27.33	25.9
	(D.B.)	(30.12)	(39.72)	
Heat Value (HH.V.)	Kcal/Kg A.R.	2,518	3,863	3,594
	(D.B.)	(3,773)	(5,615)	
(LHV)	Kcal/kg A.R.	2,148	3,500	3,230
	(D.B.)	(3,520)	(5,362)	
Sulfur Content	A.R.	3.21	131	5.7
	(D.B.)	(4.81)	(9.17)	5.7
Relative Density (A.D.)		1.67	1.49	

Note) A.R. As Received Base
A.D. Air Dry Base
D.B. Dry Base

The above value shows that the ash content is relatively lower than that of the geological mean value, and consequently the heat value is higher than that of the geological mean valve. The sulfur content is also lower than that of the geological mean value.

The chemical analysis analyzed by JICA team is shown in Table 9-3 with the blended lignite base. (Krabi: Sin Pun = 1:4)

Table 9-3 Chemical Analysis of Lignite (JICA data)
Blended Lignite (Sin Pun 4: Krabi 1)

Proximate Analysis (Air Dry Base)		Calculated Value from Table 9-1
Total Moisture	15.6%	15.6% (Adjusted)
Ash Content	15.4%	15.8%
Volatile Matter	39.0%	36.6%
Fixed Carbon	30.0%	32.0%
Heat Value (HHU)	4,380 kcal/kg	4,435 kcal/kg
Sulfur Content		
Total	7.45%	--
Non combustible	0.5%	--
Combustible	6.95%	7.03%
Ultimate Analysis (Dry Base)		
Ash	18.3%	
Carbon	52.4%	
Hydrogen	4.3%	
Oxygen	15.67%	
Nitrogen	1.07%	
Combustible Sulfur	8.23%	
Fl	80 mg/kg	
Cl	155 mg/kg	
Grindability Test H.G.I.	45	

The proximate analysis results of EGAT and JICA are almost same as shown in the above Table 9-3, so that the data of JICA team is applied for the test evaluation since the JICA team gets the ultimate analysis also.

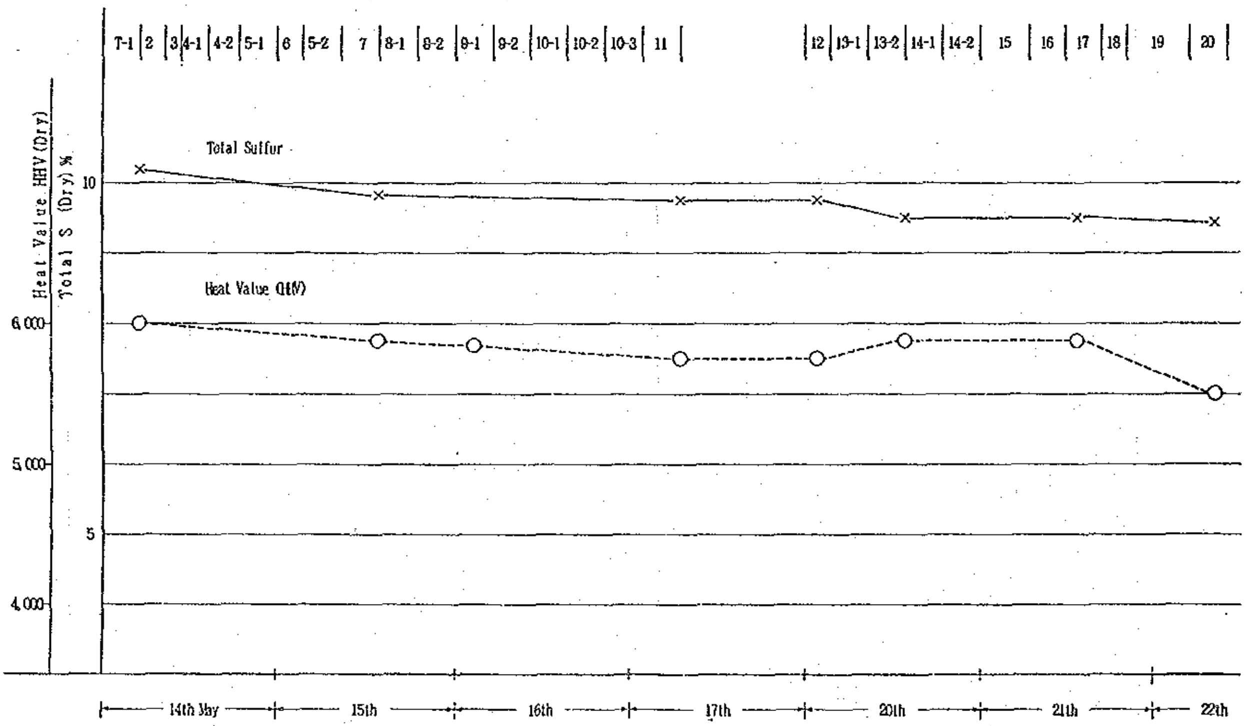
Table 9-4 shows the ash analysis result of the blended lignite.

Table 9-4 Ash Analysis of Blended Lignite (JICA data)

Fusion	Oxidization Atomosphare	Reducting Atomosphare
Initial Deformation Temp.	1,230°C	1,120°C
Softening Temp.	1,330°C	1,250°C
Hemispherical Temp.	1,350°C	1,290°C
Fluid Temp.	1,370°C	1,310°C
Proximate Analysis		
S_1O_2	48.5%	
Al_2O_2	18.1%	
Fe_2O_3	13.1%	
CaO	7.46%	
MgO	0.89%	
Na_2O	0.06%	
K_2O	1.32%	
SO_3	8.10%	
P_2O_5	0.10%	
TiO_2	0.56%	
MnO	400 mg/kg	
V_2O_5	280 mg/kg	
Button Index	0	

low to make the agglomeration problem. The ash fusion temperature is too high to making the slugging trouble. Therefore, the ash may not make the trouble in the fluidized bed except accumulation of the lumpy ash which is generated by the lumpy lignite. The problem of this lumpy ash is introduced in clause 9.6.

Table 9-5 shows the day by day monitoring of the lignite analysis during the test. The result has small fluctuation on the sulfur content and the heat value as shown in follows. Since the fluctuation value is small, the mean value as shown in Table 9-5 is applied for the adjustment of the Ca/S molar ratio and DeSOx efficiency in each test.



Trends for Characteristics of Blended Lignite

Table 9-5 Monitoring Results of Lignite Analysis

Sample Date	Item	Ttl H_2O (wet) %	Ash (dry) %	Ttl S (dry) %	HHV (dry) kcal/kg	Size Check	Remarks
4/28	Blended Lignite	28.6	18.3	8.82	5190	◎	Ulti. Analysis
4/28	Blended Lignite & crushing	28.4	14.1	9.56	5680	◎	
5/11	Blended Lignite & Crushing	--	--	--	5830	◎	
5/13	Blended Lignite & Crushing	25.0	20.7	8.95	4140	◎	
5/14	Blended Lignite & Crushing	26.1	11.4	10.16	6000	◎	
5/15	Blended Lignite & Crushing	27.4	11.6	9.79	5850	◎	Si, Fe
5/17	Blended Lignite & Crushing	--	17.4	9.64	5680	--	
5/20	Blended Lignite & Crushing	27.3	17.4	9.48	5800	--	
5/20	Blended Lignite & Crushing	--	--	9.64	5760	--	
5/21	Blended Lignite & Crushing	27.5	17.0	9.59	5850	--	Si, Fe
5/22	Blended Lignite & Crushing	--	--	9.33	5500	--	Si, Fe
5/14-22	Average Value	27.1	15.0	9.66	5777		
4/28	-8.6 mm Under Feed	23.5	19.3	8.80	5260	◎	
5/22	-2.8 mm Under Feed	--	--	8.11	4660	◎	
4/28	Sin Pun Lignite	28.0	14.7	9.91	5680	--	
4/28	Krabi Lignite	21.3	36.7	5.10	3880	--	
5/23	Krabi Lignite	--	--	5.57	4420	--	

(Dry base without Total H_2O)

Table 9-6 Average Value of Ultimate Analysis (As-Fired of Blended Lignite)

Items	Unit	Value	Calculation
Carbon	%	39.11	$37.4 \times \frac{54.92}{52.52}$
Hydrogen	%	3.24	$3.1 \times \frac{54.92}{52.52}$
Nitrogen	%	0.79	$0.76 \times \frac{54.92}{52.52}$
Sulfur	%	7.04	Average Value
Oxygen	%	22.78	$11.26 \times \frac{54.92}{52.52}$
Ash	%	10.94	Average Value
Moisture	%	27.10	Average Value
Higher Heating Value	kcal/kg	3,902	$3{,}706 \times \frac{4{,}183}{3{,}973}$

Note)

Ultimate Analysis Results	Average Data
C = 37.4%, H = 3.1%, N = 0.76%, O = 11.26% → 52.52%	100 - 45.08 = 54.92%
Ash = 13.00%	S = 9.66% (Dry) → 7.04% (Wet)
H_2O = 28.60%	Ash = 15.00% (Dry) → 10.94% (Wet) → 45.08% (S + Ash + H_2O)
3,706 kcal/kg (HHV)	H_2O = 27.1% (Wet)
Theoretical air 3,973 Nm^3/kg	

Table 9-7 shows the chemical analysis of limestone for the pilot scale combustion test.

Table 9-7 Chemical Analysis of Limestone

Items \ Sample Data		May 9	May 13 9:00	May 21 16:00	May 23 22:00
$CaCO_3$	%	88.13	--	--	--
CaO	%	1.15	--	--	--
$CaSO_4$	%	0.03	--	--	--
MgO	%	0.09	--	--	--
$MgCO_3$	%	5.84	--	--	--
SiO_2	%	2.06	--	--	--
Al_2O_3	%	0.10	--	--	--
Fe_2O_3	%	0.06	--	--	--
Na_2O	%	0.01	--	--	--
Total Ca	%	36.4	36.5	36.7	35.3
Ca Purity	%	Aver. Total Ca = (36.4+36.5+36.7+35.3)/4 = 36.225 Ca Purity = (36.225/40.1) * (100) = 90.34			

**) Distributions between $CaCO_3$ and $MgCO_3$ from CO_3 decided by Molar Ratio of Ca/Mg

9.4 Test Lignite and Limestone Size Distribution

The test lignites are crushed by the roller crusher after the drying under the sunshine. The raw lignite and the crushed lignite involve the considerable amount of powder under 0.5 mm size.

Four sizes of lignite are prepared for the test as shown in Table 9-8.

Table 9-8 Lignite Size for Test

	Size Distribution	Powder less than 0.5 mm
Raw Lignite (After drying)	0 - 250 mm	15%
- 8.6 mm	0 - 8.6 mm	23%
- 2.8 mm	0 - 2.8 mm	45%
2.8 - 8.6 mm	2.8 - 8.6 mm	0%
2.8 - 20 mm	2.8 - 20 mm	0%

For the crushing purpose, the lignite was dried under the sun and as a result, it is considered that the amount of powder lignite was increased in the raw lignite. To find out the affection of the powder lignite on the SOx emission, the powder lignite was eliminated from the some test lignite. Fig. 9-4 shows the size distribution curve of the above lignites.

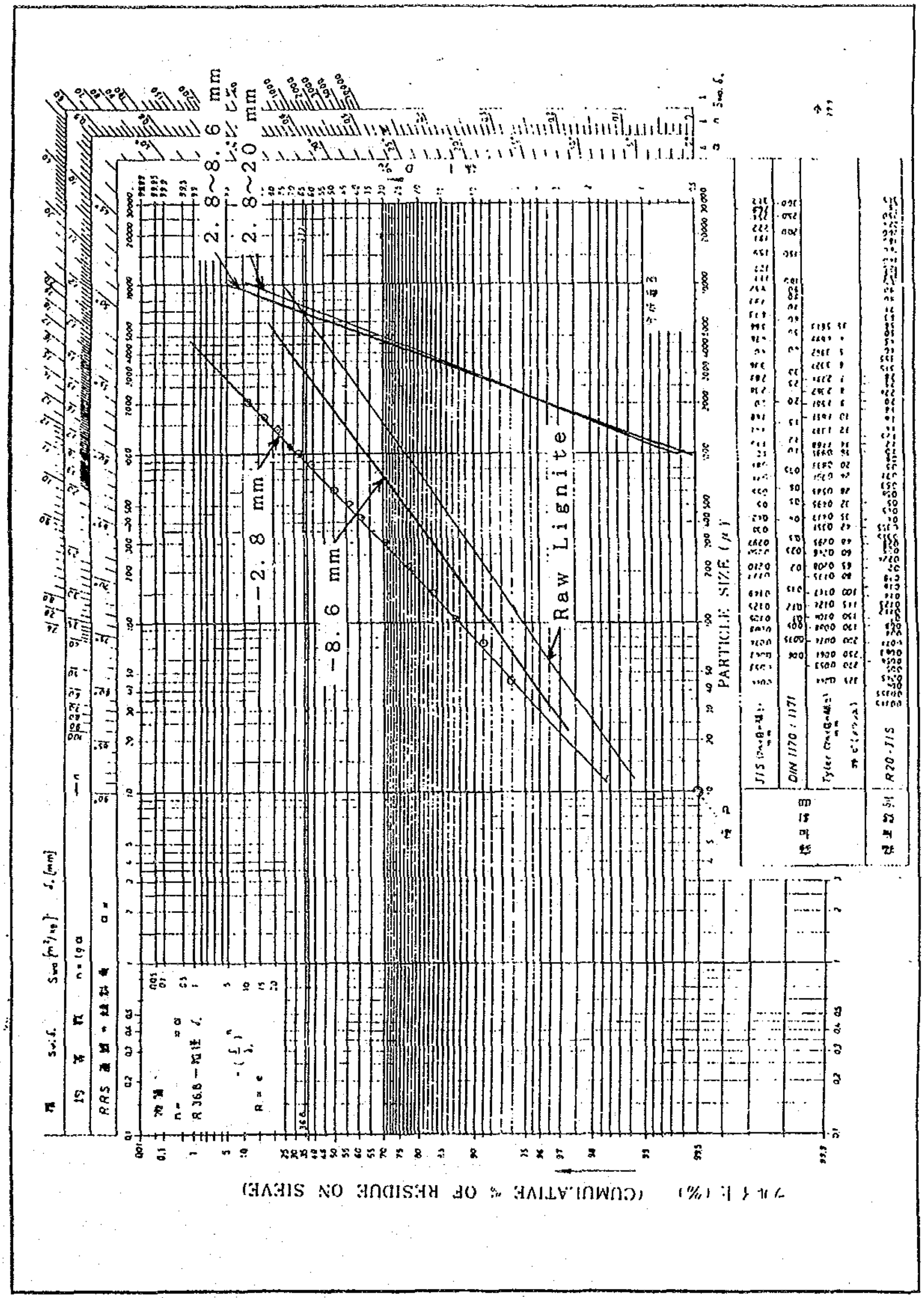


Fig. 9-4 Size Distribution

The test limestones are crushed by the hummer crusher. The limestone size distribution curve is shown in Fig. 9-5. Three kinds of size are prepared for the test.

Table 9-9 shows the small particle involvement of the respective size distribution.

Table 9-9 Small Particle Involvement of Limestone

Size	0 - 0.5 mm	0 - 1.0 mm	0 - 1.5 mm
- 3 mm (0-3 mm)	30%	55%	70%
-3 mm Fine	43%	60%	70%
-10 mm (0-3 mm)	22%	38%	50%

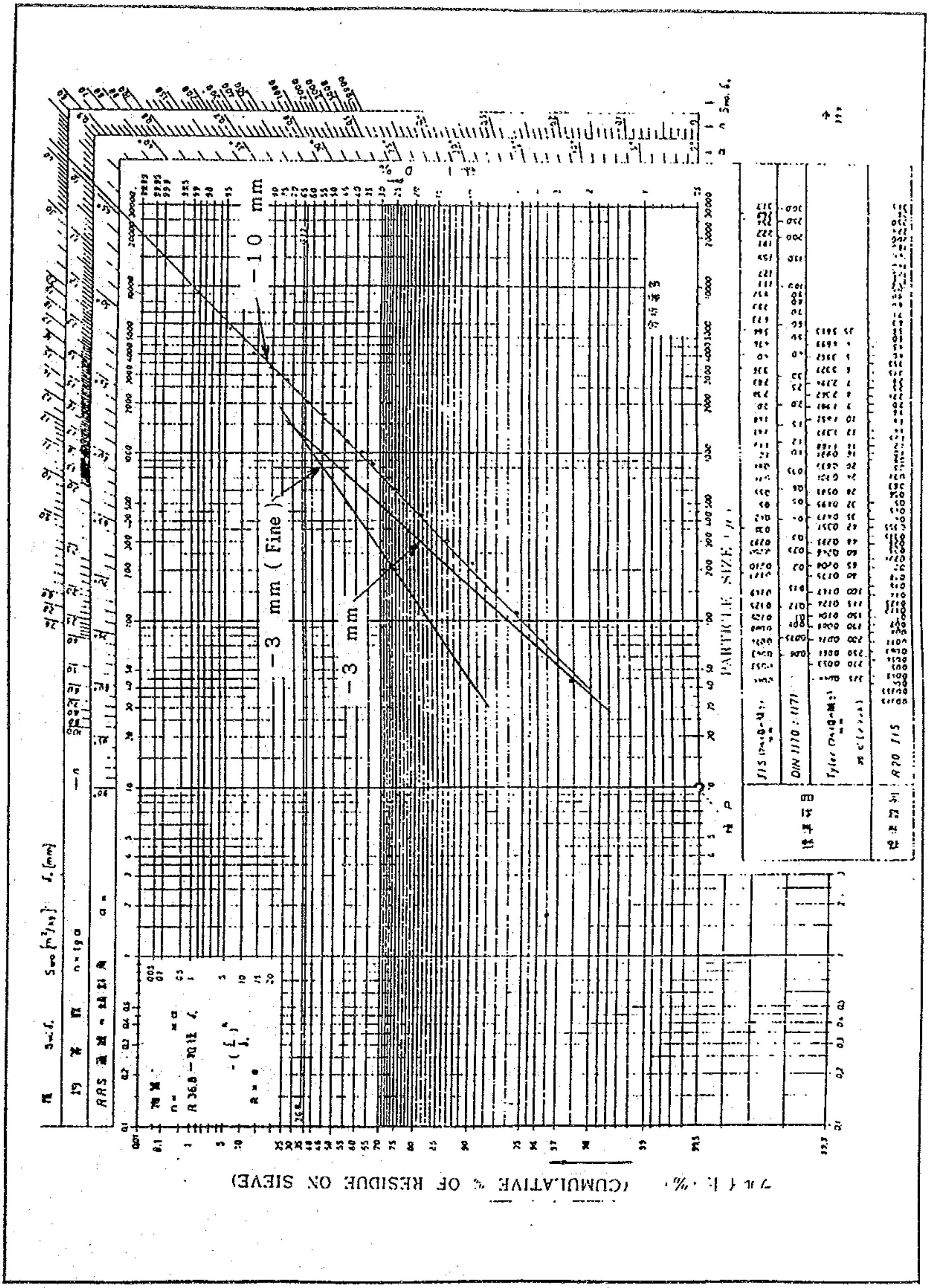


Fig. 9-5 Size Distribution

(Lime Stone)

9.5 Test Result

The test results are summarized in Table 9-10a and 10b. the respective test results are explained as follows:

(1) Heat Release Rate

The bubbling type FBC boiler capacity is proportion to the multiplication of the heat release rate and the surface area of the fluidized bed, so that the higher heat release rate is consequent to the smaller boiler design. Wakamatsu A-FBC demonstration plant (50 MW) applied the heat release rate 1.2×10^6 $kcal/m^2h$ with the space velocity 1.5 m/s. Montana-Dakota A-FBC plant (80 MW) applied the heat release rate 2.48×10^6 $kcal/m^2h$ with the space velocity 3.6 m/s.

The bench scale combustion test were carried out by the heat release rate $0.7\text{-}0.9 \times 10^6$ $kcal/m^2h$. During the parameter survey test on 12th, 13th May '92, it is confirmed that the heat release rate does not affect the SOx emission, so that the heat release parameter test is carried out under the condition 0.8×10^6 $kcal/m^2h$, 1.0×10^6 $kcal/m^2h$ and 1.2×10^6 $kcal/m^2h$ which is the maximum heat release rate of the test furnace. The result is shown in Fig. 9-6.

1) SOx Emission

There is no significant difference of the SOx emission on the heat release parameter from $0.8\text{-}1.2 \times 10^6$ $kcal/m^2h$.

2) NOx Emission

There is the increasing tenancy of NOx emission according to the increase of the heat release rate.

Table 9-10a Pilot Scale PFBC Test Data (Final)

Test Date / Time		5/14 12:00	15:00	16:20	20:00	23:00	5/15 00:00	2:00	5:00	12:00	21:00	5/16 00:00	3:00	8:00	12:00	18:00	22:00	5/17 0:00	5:00	
Item / Test NO.		T-1	T-2	T-3	T-4-1	T-4-2	T-5-1	T-6	T-5-2	T-7	T-8-1	T-8-2	T-8-3	T-9-1	T-9-2	T-10-1	T-10-2	T-10-3	T-11	
Coal Feed System	-	O	←	←	←	←	←	←	←	←	U	←	←	U & O	←	O	←	←	←	
Coal Size	mm	*1	←	←	←	←	←	←	←	←	-8.6	←	←	*2	←	*1	←	←	-20	
O.F.Coal Feed Rate U.F.Coal Feed Rate Total Coal Feed Rate	kg/h kg/h kg/h	57.1 0 57.1	56.3 0 56.3	57.3 0 57.3	50.9 0 50.9	60.1 0 60.1	64.1 0 64.1	65.0 0 65.0	54.9 0 54.9	60.1 0 60.1	0 69.4 69.4	0 74.8 74.8	0 72.5 72.5	35.0 33.0 68.0	47.8 17.8 65.6	61.9 0 61.9	58.9 0 58.9	59.0 0 59.0	59.0 0 59.0	
Lime Feed System	-	O	←	←	←	←	←	←	←	←	←	←	←	←	←	←	←	←	←	
Lime Size	mm	-3	←	←	←	←	←	←	←	-10	-3	←	←	←	←	←	←	←	←	
Lime Feed Rate	kg/h	25	25	25	38.5	48	48	48	38.5	38.5	38.5	48	57	48	48	48	38.5	29	48	
Ash Recycle Ratio	-	0	←	←	←	←	←	←	←	←	←	←	←	←	←	0.87	0.92	0.92	0	
Heat Release Rate	kcal/m³h	0.87	0.96	1.05	←	←	←	←	←	←	1.14	←	←	←	←	1.05	←	←	←	$\times 10^6$
Ca/S Molar Ratio	-	1.80	1.80	1.79	3.10	3.28	3.07	3.03	2.88	2.63	2.50	2.88	3.54	3.03	3.08	3.18	2.68	2.02	3.41	
Fluid. Air Rate	Nm³/h	305	335	365	←	←	←	←	←	←	397	←	←	←	←	365	←	←	←	
Bed Temperature	℃	860	850	840	790	828	855	885	830	840	840	850	850	830	830	820	820	813	830	
Freeboard Out Temp.	℃	873	860	852	794	832	868	880	838	850	798	806	820	812	817	830	838	836	830	
Excess Air Ratio	-	1.28	1.42	1.52	1.71	1.45	1.36	1.34	1.59	1.45	1.50	1.39	1.44	1.46	1.48	1.41	1.48	1.48	1.57	
O_2	%	4.25	6.0	7.0	8.5	6.2	5.2	5.0	7.5	6.25	6.75	5.5	6.0	6.25	6.5	5.7	6.5	6.5	6.75	
NO_x (6 % O_2 base)	ppm	132	162	193	228	182	161	160	217	192	247	198	205	208	181	162	186	163	194	
SO_2 (6 % O_2 base)	ppm	2080	2160	2100	2520	970	1070	1240	1045	1960	1474	813	440	681	682	314	641	878	926	
Sulfur Removal Eff.	%	75.1	74.2	74.9	69.5	88.2	87.0	85.0	87.4	76.4	82.3	90.2	94.6	91.8	91.7	96.2	92.3	89.5	88.7	
Combustion Eff.	%	98.9	—	—	—	98.8	—	98.5	98.4	99.2	99.5	—	—	—	—	—	—	—	—	
BM Ash Bottm Blow Rate Cyclone Ash Rate Bag Filter Ash Rate	kg/h kg/h kg/h	15.8 11.2 1.5	13.4 12.9 1.5	11.2 14.5 1.5	20.0 15.8 1.5	20.4 20.7 1.5	19.7 24.0 1.5	19.7 24.0 1.5	19.2 16.6 1.5	21.0 13.6 1.5	15.8 23.5 1.5	21.0 24.5 1.5	24.3 29.0 1.5	22.6 31.4 1.5	22.6 26.1 1.5	23.5 17.7 3.5	24.2 13.3 3.5	20.0 11.3 2.5	22.4 18.7 1.4	
Ash Sampling	-	Y	Y	N	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	

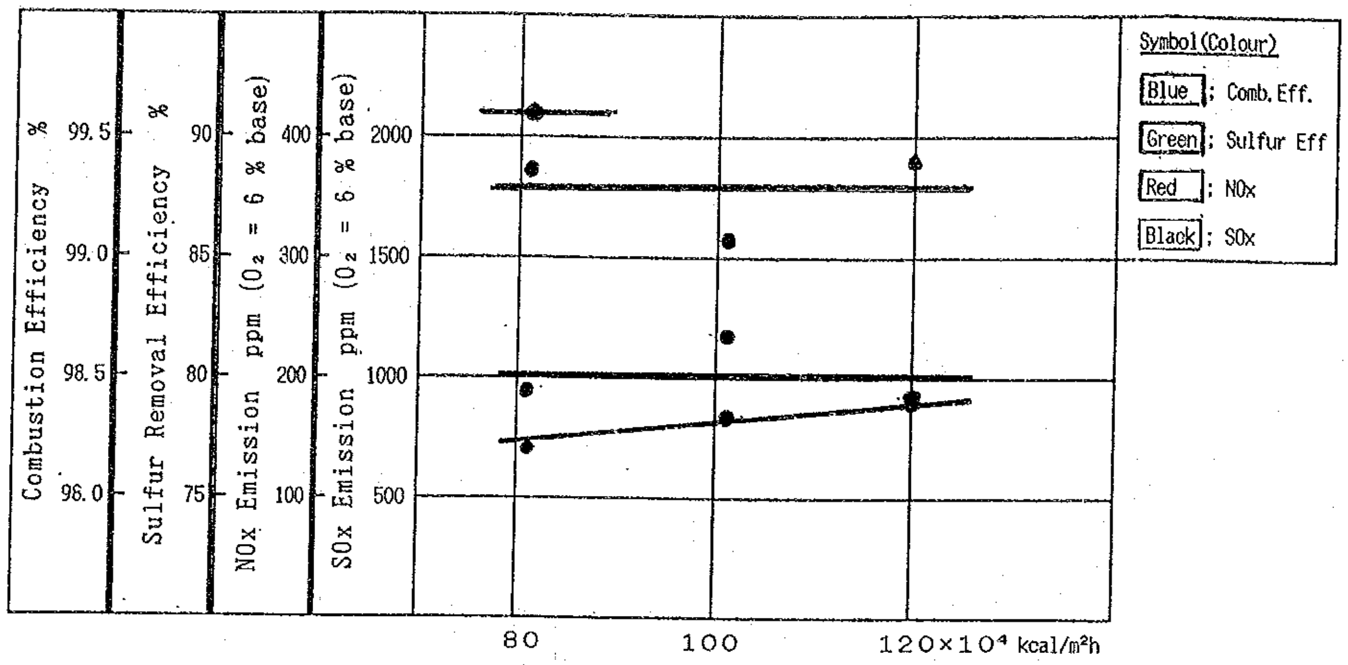
Remarks: O: Over Feed, U: Under Feed
*1: O: Crushing after sieving over 2.8 mm
*2: U: −2.8 mm
O: Crushing after sieving over 2.8 mm

Table 9-10b Pilot Scale PFBC Test Data (Final)

Item	Test Date / Time		5/20 13:00	16:00	18:30	21:00	5/21 0:00	7:00	12:00	17:30	21:00	5/22 7:00	13:30	17:00		5/23 16:00	5/24 0:00	5:00		
Item	Test NO.		T-12	T-13-1	T-13-2	T-14-1	T-14-2	T-15	T-16	T-17	T-18	T-19	T-20	T-21		T-22	T-23	T-24		
Coal Feed System	-		U & O	←	←	←	←	←	←	←	←	←	←	O		U	←	←		
Coal Size	mm		*2	←	←	←	←	←	←	←	←	←	←	-8.6		-2.8	←	←		
O.F. Coal Feed Rate	kg/h		41.3	48.0	51.4	59.8	59.8	55.3	55.0	57.1	56.2	54.8	56.5	69.8		0	0	0		
U.F. Coal Feed Rate	kg/h		11.0	16.0	19.0	15.0	15.0	17.0	18.5	18.5	18.5	18.5	18.5	0		76.9	75.9	74.7		
Total Coal Feed Rate	kg/h		52.3	64.0	70.4	74.8	74.8	72.3	73.5	75.6	74.7	73.3	75.0	69.8		76.9	75.9	74.7		
Lime Feed System	-		O	←	←	←	←	←	←	←	←	←	←	←		O	←	←		
Lime Size	mm		-3	←	←	←	←	←	←	←	←	←	←	←		-3	←	←		
Lime Feed Rate	kg/h		34	44.6	46	51	51	35	35	36	42.5	←	←	36		35	←	28		
Ash Recycle Ratio	-		0	←	←	←	←	0.58	0.97	1.26	0.56	0.98	1.27	1.31		1.45	1.49	1.51		
Heat Release Rate	kcal/m²h		0.81	1.01	1.11	1.20	←	←	←	←	←	←	←	←		1.02	←	←		×10⁶
Ca/S Molar Ratio	-		2.78	3.01	2.83	2.91	2.91	2.08	2.06	2.05	2.45	2.50	2.44	2.12		2.31	2.35	1.91		
Fluid. Air Rate	Nm³/h		282	353	387	417	←	←	←	←	←	←	←	←		355	←	←		
Bed Temperature	℃		828	835	820	820	840	835	825	817	830	815	820	810		820	830	823		
Freeboard Out Temp.	℃		792	817	818	838	840	850	852	849	843	829	838	858		772	784	788		
Excess Air Ratio	-		1.34	1.39	1.39	1.39	1.39	1.44	1.43	1.38	1.40	1.43	1.39	1.43		1.37	1.39	1.41		
O_2	%		5.0	5.5	5.5	5.5	5.5	6.2	6.0	5.5	5.7	6.0	5.6	6.0		5.3	5.5	5.8		
NO_x (6 % O_2 base)	ppm		140	169	169	174	174	177	165	145	162	162	155	165		155	166	178		
SO_2 (5 % O_2 base)	ppm		937	1180	1180	920	1045	1610	1540	1103	1275	1175	974	1100		726	629	1302		
Sulfur Removal Eff.	%		88.7	85.7	85.7	88.9	87.4	78.9	81.5	86.8	84.6	85.8	88.0	86.8		91.3	92.4	84.4		
Combustion Eff.	%		99.6	—	—	—	—	—	—	99.5	—	—	99.2	—		—	—	—		
BM Ash Bottm Blow Rate	kg/h		20.0	21.0	21.0	21.8	21.8	24.5	24.0	24.0	22.5	23.0	23.8	21.8		18.5	18.5	15.0		
Cyclone Ash Rate	kg/h		13.4	22.1	20.1	26.3	26.3	13.9	13.6	12.6	18.0	14.5	14.4	14.2		17.9	18.5	14.3		
Bag Filter Ash Rate	kg/h		1.2	1.3	1.4	0.7	0.7	3.1	3.6	3.6	2.8	3.8	4.1	3.8		5.1	4.9	5.1		
Ash Sampling	-		Yes	Y	No	N	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y		

Remarks: O: Over Feed, U: Under Feed
*1: O: Crushing after sieving over 2.8 mm
*2: U: -2.8 mm
O: Crushing after sieving over 2.8 mm

Fig. 9-6 Pilot Scale Comb. Test Results ; Effect of Heat Release Rate



Test Data

Data NO. T-12 : 1992-May-20
Data NO. T-13-1: 1992-May-20
Data NO. T-14-1: 1992-May-20

Operating Conditions

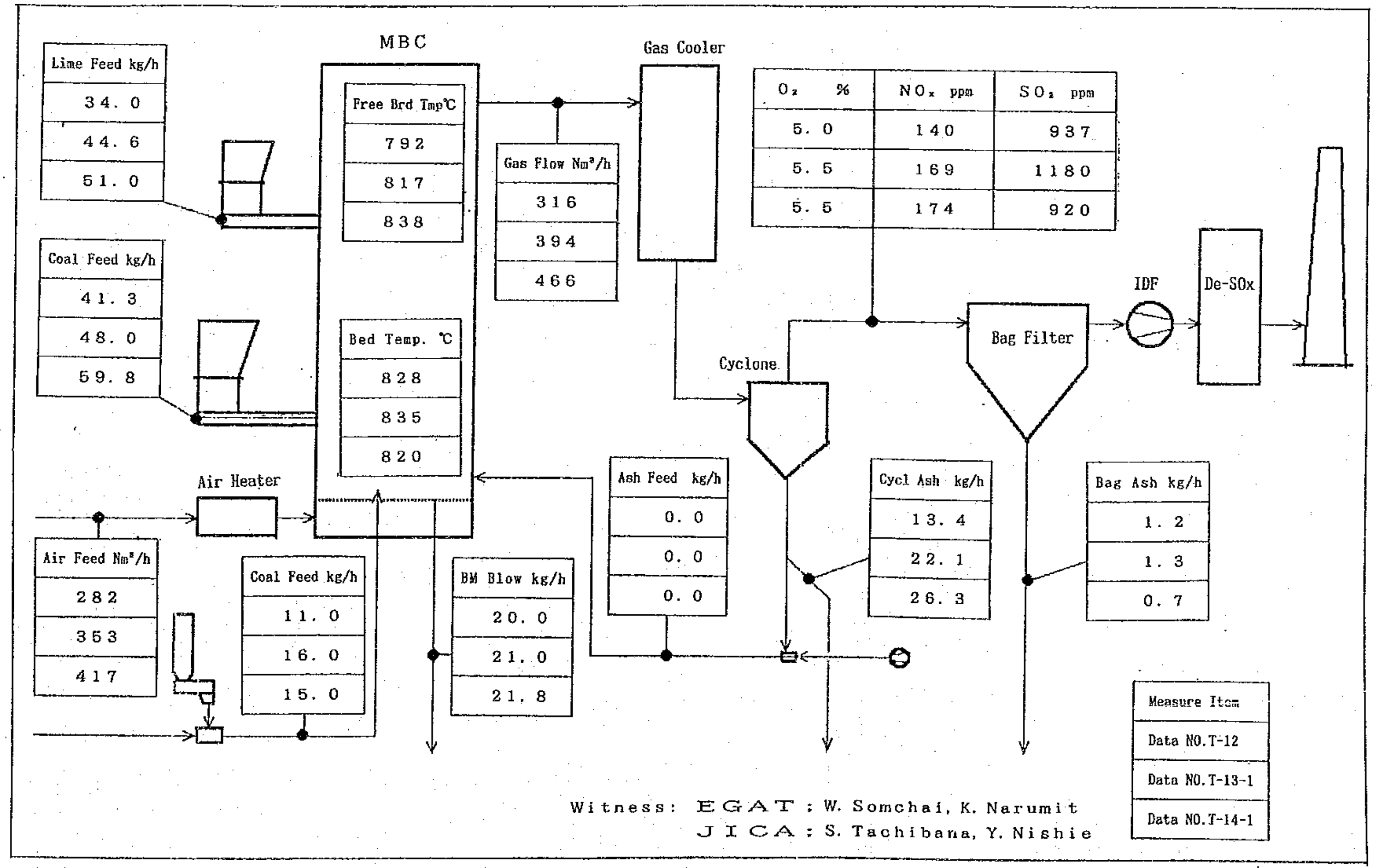
		Data NO. T-12	Data NO. T-13-1	Data NO. T-14-1
Heat Release Rate	kcal/m²h	0.81×10^6	1.01×10^6	1.20×10^6
Bed Temperature	℃	828	835	820
Excess Air Ratio	--	1. 34	1. 39	1. 39
Ca/S Molar Ratio	--	2. 78	3. 01	2. 91
Ash Recycle Ratio	--	0. 0	0. 0	0. 0
Coal Feed Method	--	Over & Under	Over & Under	Over & Under
Coal Size	mm	+2.8~-8.6 /-2.8	+2.8~-8.6 /-2.8	+2.8~-8.6 /-2.8
Lime Stone Size	mm	-3	-3	-3

Material Balance

		Data NO. T-12	Data NO. T-13-1	Data NO. T-14-1
Coal Feed Rate	kg/h	52. 3	64. 0	74. 8
Lime Feed Rate	kg/h	34. 0	44. 6	51. 0
Ash Recycle	kg/h	0. 0	0. 0	0. 0
BM Over Ash	kg/h	20. 0	21. 0	21. 8
Cyclone Ash	kg/h	13. 4	22. 1	26. 3
Bag Filter Ash	kg/h	1. 2	1. 3	0. 7

Data of Ash Analysis

		Data NO. T-12			Data NO. T-13-1			Data NO. T-14-1		
		BM	Cycln	Bag	BM	Cycln	Bag	BM	Cycln	Bag
CaO	%	-	-	-	-	-	-	-	-	-
$CaCO_3$	%	-	-	-	-	-	-	-	-	-
$CaSO_4$	%	-	-	-	-	-	-	-	-	-
SiO_2	%	-	-	-	-	-	-	-	-	-
Fe_2O_3	%	-	-	-	-	-	-	-	-	-
Na_2O	%	-	-	-	-	-	-	-	-	-



This tenancy accords to the test result of Wakamatsu 20 t/h pilot plant which uses the bituminous coal for the test.

The emission value is relatively lower than that of the bench test result which emits NOx with the range 200-300 ppm.

The free boards zone temperature effects on the reduction of NOx emission as shown in Fig. 9-7. This reduction effect of NOx emission can be expected on the actual plant also, so that the further countermeasure for NOx emission may not be requested at this moment since Thai regulation of NOx emission is 1,000 mg/Nm^3 i.e. equivalent

$$\frac{1,000\,mg/Nm^3}{46g(NO_2)} \times 0.0224\ Nm^3/mol = 487\ ppm\ for\ NO_2.$$

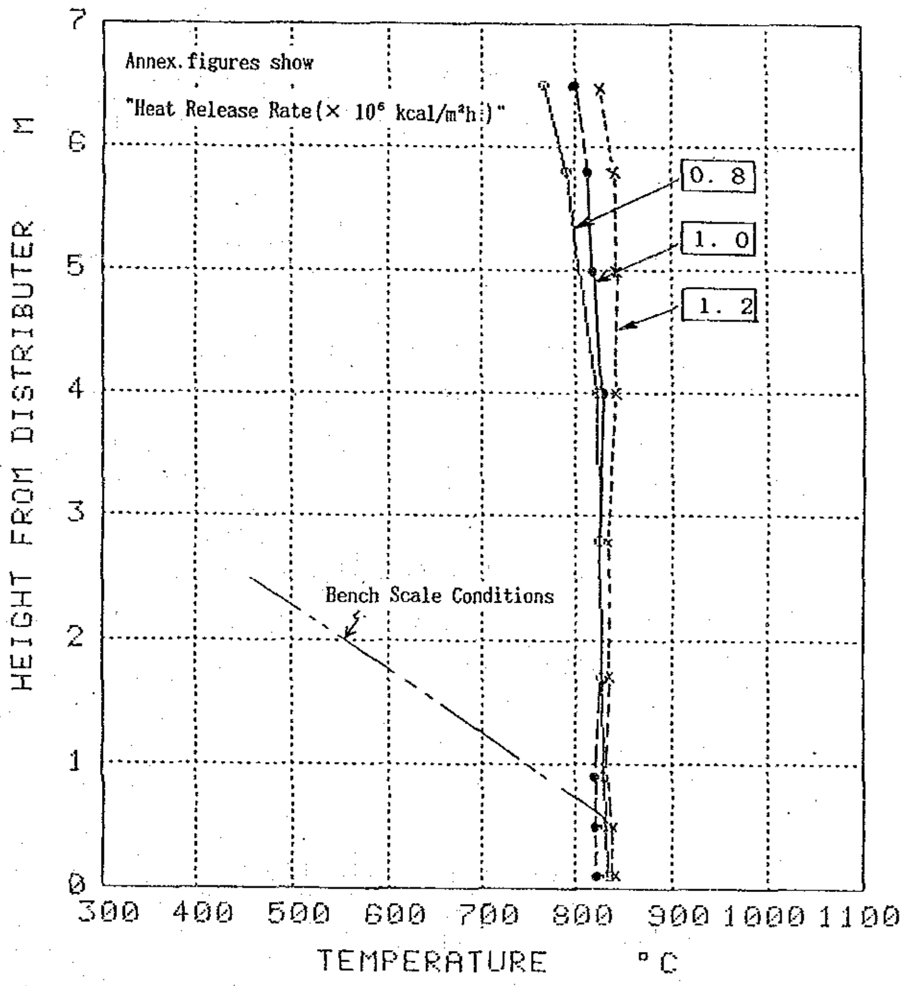


Fig. 9-7 Temperature Profile (Effect of Heat Release Rate)

(2) Excess Air Ratio

The higher excess air ratio causes the higher flue gas heat loss, and it is preferable to get the lower excess air ratio.

However, the some excess air is requested by the desulfurization reaction and the lower excess air ratio causes the higher SOx emission as follows;

$$CaSO_4 \rightarrow CaO + SO_2 + \frac{1}{2}O_2 \uparrow$$

During the parameter survey test on 12th and 13th May '92, it is confirmed that the excess air ratio below 1.2 causes the high SOx emission as noticed in the bench scale test.

The excess air ratio test is carried out with the parameter range of excess air ratio 1.24, 1.4 and 1.5 as shown in Fig. 9-8. The results are as follows;

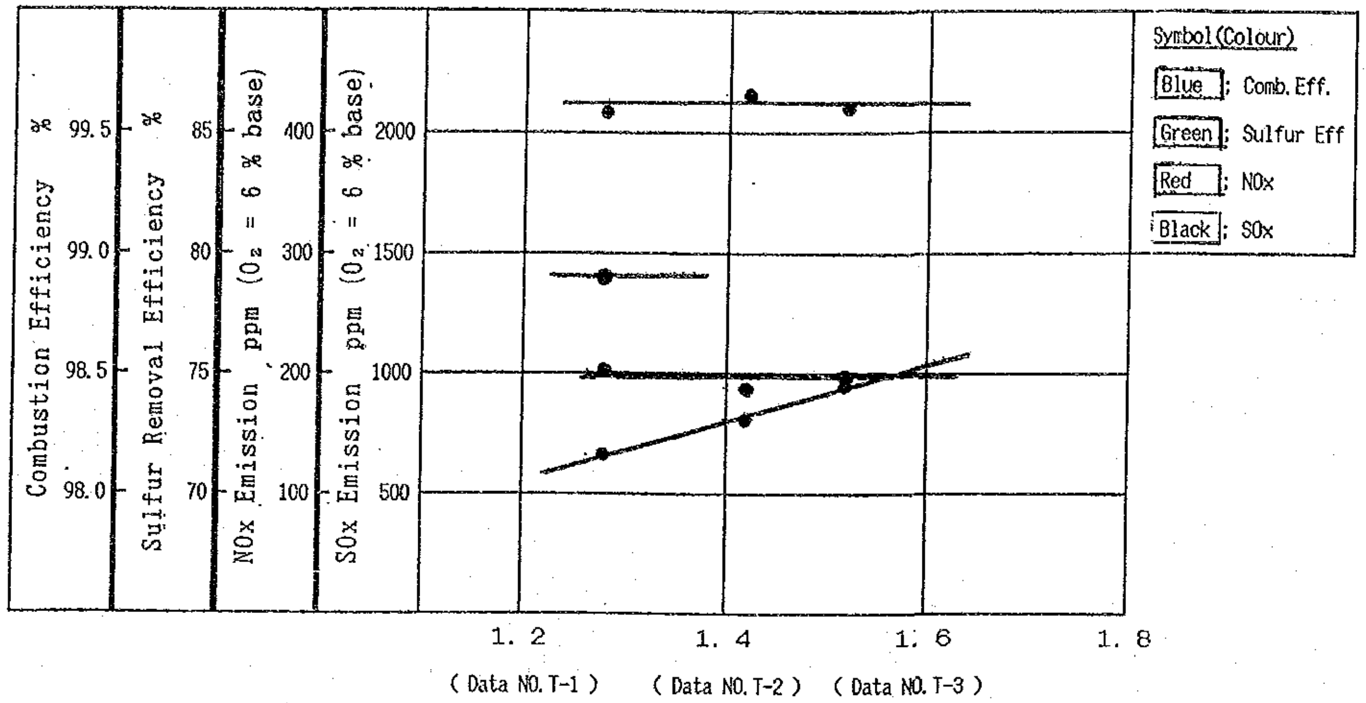
1) SOx Emission

There are no significant difference of SOx emission between the excess air ratio 1.24, 1.4 and 1.5.

2) NOx Emission

The emission value of NOx is increased according to the excess air ratio from 132 ppm to 193 ppm. This tenancy accords to the experience in Wakamatsu demonstration plant.

Fig. 9-8 Pilot Scale Comb. Test Results : Effect of Excess Air Ratio



Test Data

Data NO. T-1 : 1992-May-14
Data NO. T-2 : 1992-May-14
Data NO. T-3 : 1992-May-14

Operating Conditions

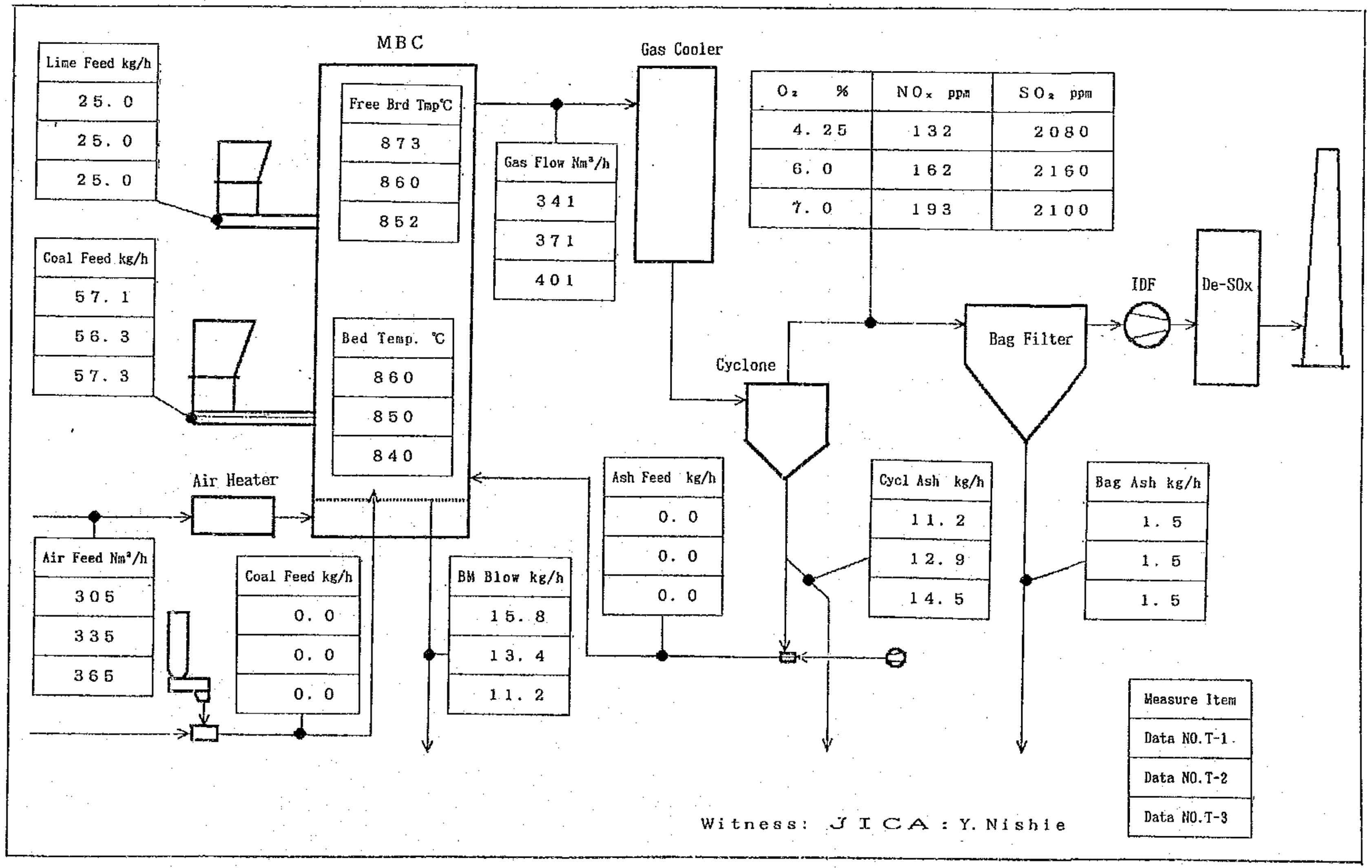
		Data NO. T-1	Data NO. T-2	Data NO. T-3
Heat Release Rate	kcal/m²h	0. 87×10⁶	0. 96×10⁶	1. 05×10⁶
Bed Temperature	℃	860	850	840
Excess Air Ratio	--	1. 28	1. 42	1. 52
Ca/S Molar Ratio	--	1. 80	1. 80	1. 79
Ash Recycle Ratio	--	0. 0	0. 0	0. 0
Coal Feed Method	--	Over Feed	Over Feed	Over Feed
Coal Size	mm	+2.8~-8.6	+2.8~-8.6	+2.8~-8.6
Lime Stone Size	mm	-3	-3	-3

Material Balance

		Data NO. T-1	Data NO. T-2	Data NO. T-3
Coal Feed Rate	kg/h	57. 1	56. 3	57. 3
Lime Feed Rate	kg/h	25. 0	25. 0	25. 0
Ash Recycle	kg/h	0. 0	0. 0	0. 0
BM Over Ash	kg/h	15. 8	13. 4	11. 2
Cyclone Ash	kg/h	11. 2	12. 9	14. 5
Bag Filter Ash	kg/h	1. 5	1. 5	1. 5

Data of Ash Analysis

		Data NO. T-12			Data NO. T-13-1			Data NO. T-14-1		
		BM	Cycln	Bag	BM	Cycln	Bag	BM	Cycln	Bag
CaO	%	29.93	26.25	8.31	-	-	-	-	-	-
$CaCO_3$	%	0.80	8.68	2.64	-	-	-	-	-	-
$CaSO_4$	%	51.89	31.09	42.11	-	-	-	-	-	-
SiO_2	%	11.76	13.01	11.59	-	-	-	-	-	-
Fe_2O_3	%	1.36	8.14	12.91	-	-	-	-	-	-
Na_2O	%	0.08	0.13	0.11	-	-	-	-	-	-



Witness: JICA : Y. Nishie

(3) Bed Temperature

The bench scale combustion test shows that the best temperature for the desulfurization reaction in the fluidized bed is around 850°C.

The pilot scale combustion test confirmed the best temperature for the desulfurization reaction and as a result, it is confirmed that the best temperature is around 830°C - 840°C.

1) SOx Emission

As shown in Fig. 9-9, the best temperature is located between 830°C - 840°C.

It is noticed during the test, that the bed temperature 850°C generates the higher SOx emission.

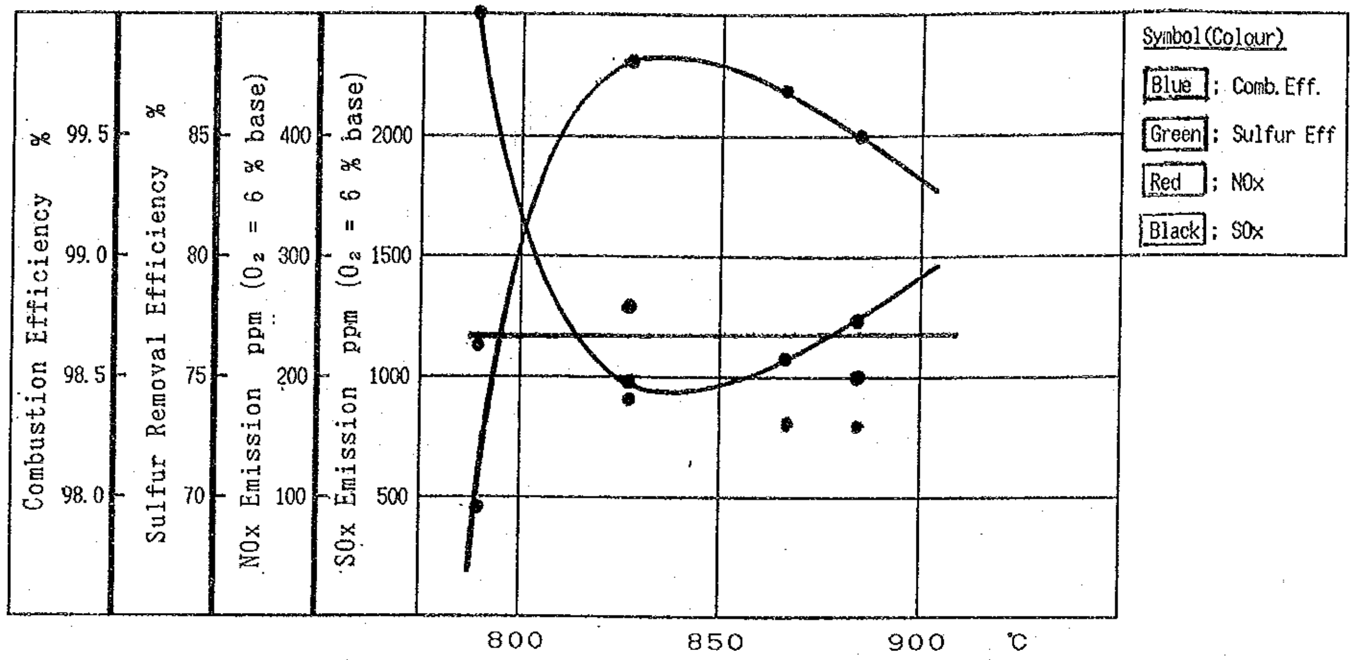
As a pilot scale combustion test, it is concluded 830°C to be best temperature.

2) NOx Emission

The tenancy of NOx emission can not be gotten from Fig. 9-9 since the excess air ratio is varied in the respective test. From the relation of NOx and the excess air ratio, the NOx emission and bed temperature relation is amended as shown in Fig. 9-10.

From Fig. 9-10, it is recognized that the higher bed temperature causes the higher NOx emission. This tenancy also accords to Wakamatsu demonstration plant results.

Fig. 9-9 Pilot Scale Comb. Test Results : Effect of Bed Temperature



(Data NO. T-4-1) (Data NO. T-4-2) (Data NO. T-5-1) (Data NO. T-6)

Test Data

Data NO. T-4-1 : 1992-May-14
Data NO. T-4-2 : 1992-May-14
Data NO. T-6 : 1992-May-15

Operating Conditions

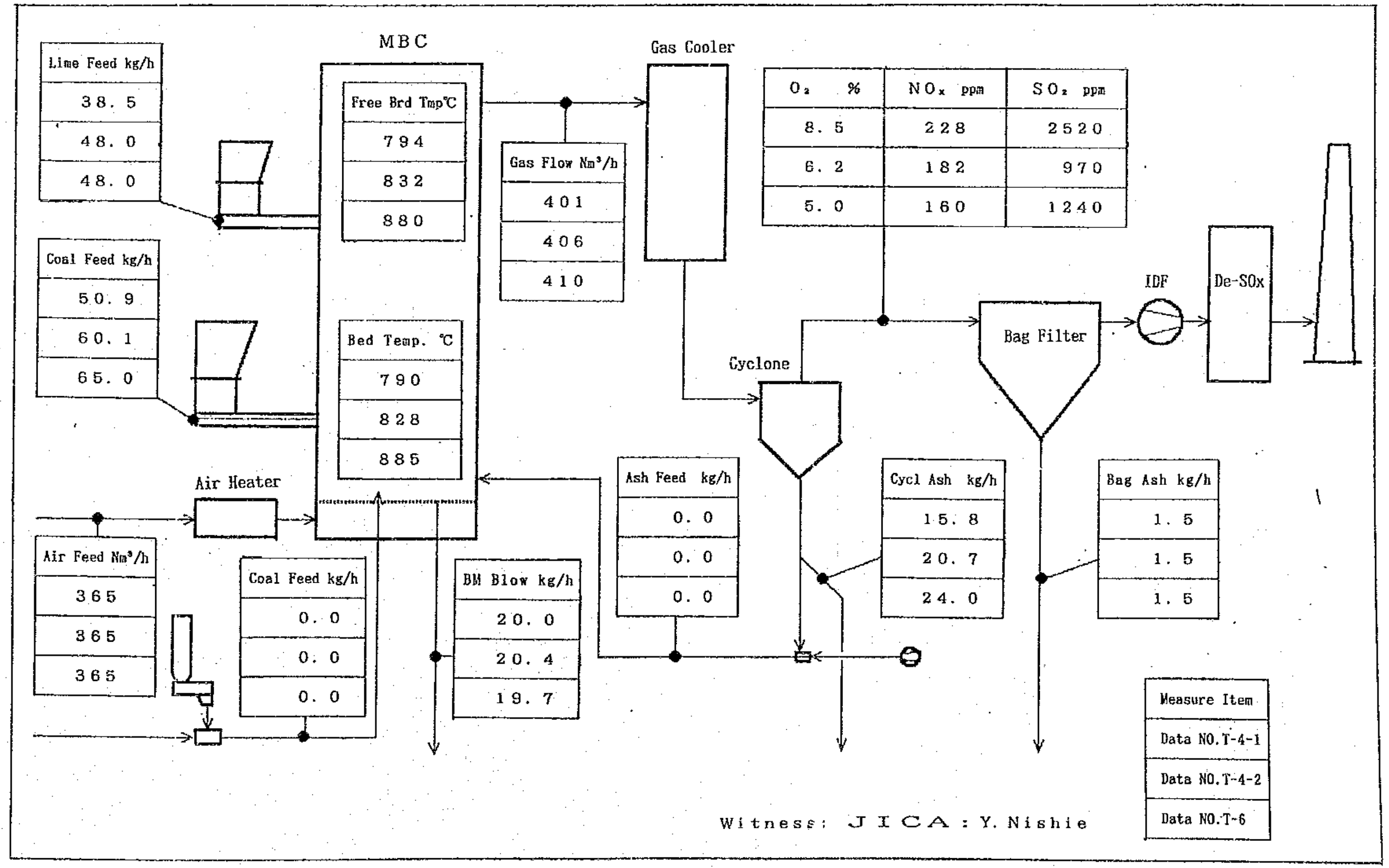
		Data NO. T-4-1	Data NO. T-4-2	Data NO. T-6
Heat Release Rate	kcal/m²h	1. 05×10⁶	1. 05×10⁶	1. 05×10⁶
Bed Temperature	℃	790	828	885
Excess Air Ratio	--	1. 71	1. 45	1. 34
Ca/S Molar Ratio	--	3. 10	3. 28	3. 03
Ash Recycle Ratio	--	0. 0	0. 0	0. 0
Coal Feed Method	--	Over Feed	Over Feed	Over Feed
Coal Size	mm	+2.8~-8.6	+2.8~-8.6	+2.8~-8.6
Lime Stone Size	mm	-3	-3	-3

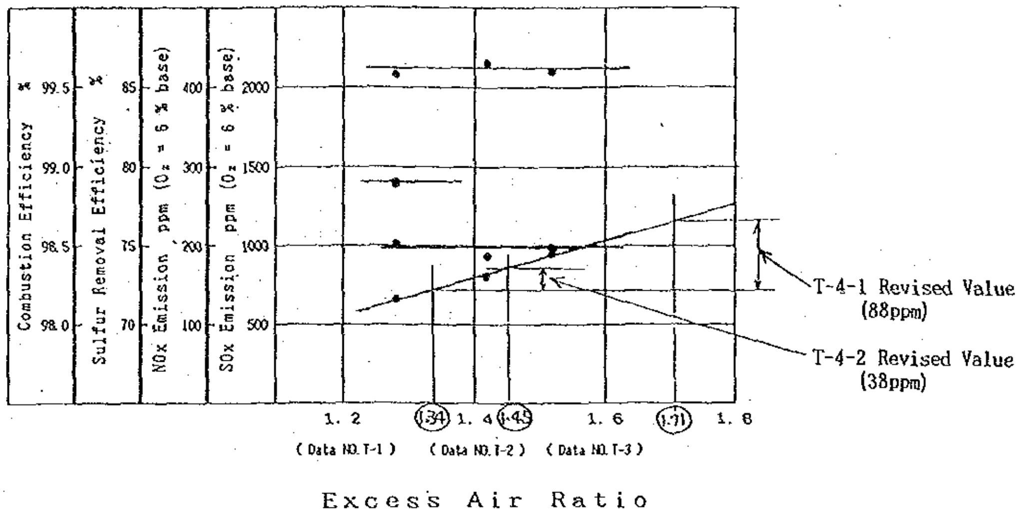
Material Balance

		Data NO. T-4-1	Data NO. T-4-2	Data NO. T-6
Coal Feed Rate	kg/h	50. 9	60. 1	65. 0
Lime Feed Rate	kg/h	38. 5	48. 0	48. 0
Ash Recycle	kg/h	0. 0	0. 0	0. 0
BM Over Ash	kg/h	20. 0	20. 4	19. 7
Cyclone Ash	kg/h	15. 8	20. 7	24. 0
Bag Filter Ash	kg/h	1. 5	1. 5	1. 5

Data of Ash Analysis

		Data NO. T-4-1			Data NO. T-4-2			Data NO. T-6		
		BM	Cycln	Bag	BM	Cycln	Bag	BM	Cycln	Bag
CaO	%	-	-	-	34.81	26.36	7.02	34.56	34.57	8.61
$CaCO_3$	%	-	-	-	3.25	21.52	2.25	0.58	8.02	3.02
$CaSO_4$	%	-	-	-	50.61	29.98	43.38	53.16	33.51	44.23
SiO_2	%	-	-	-	5.81	8.21	11.87	6.51	9.73	10.74
Fe_2O_3	%	-	-	-	0.84	4.69	13.36	0.93	4.93	13.39
Na_2O	%	-	-	-	0.01	0.03	0.12	0.01	0.02	0.28





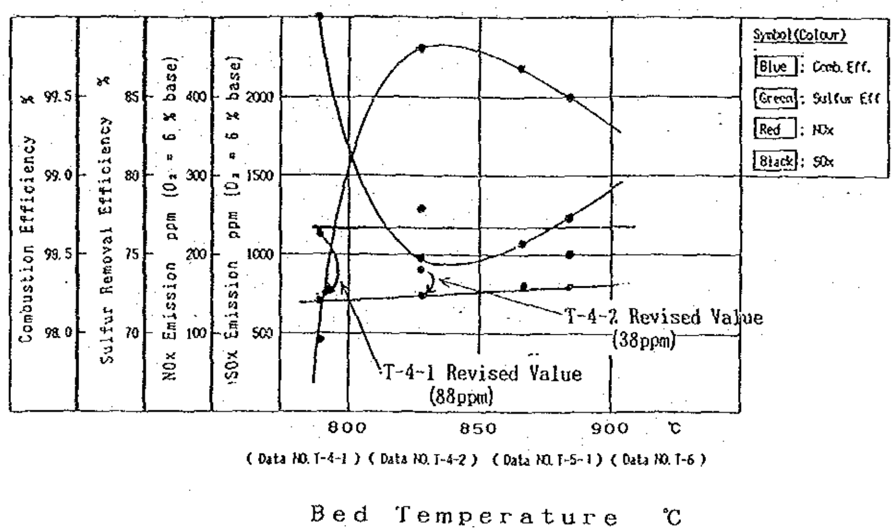


Fig. 9-10 NOx Emission (Effect of Bed Temperature)

(4) Ca/S Molar Ratio

During the parameter survey test, it is noticed that 90% De SOx efficiency would be achieved by the Ca/S molar ratio 3 without the ash recycle. Therefore, the test is carried out with the molar ratio 2.5, 3.0 and 3.5 for the non ash recycle system. The results are shown in Fig. 9-11.

It is also noticed during the parameter survey test that the powder lignite emits the higher SOx than the large particle lignite with the over feeding method. The malar ratio tests 2.0, 2.5 and 3.0 also are carried out with the large particle lignite and the ash recycle mode to confirm how small molar ratio can achieve 90% De SOx efficiency. The results are shown in Fig. 9-12.

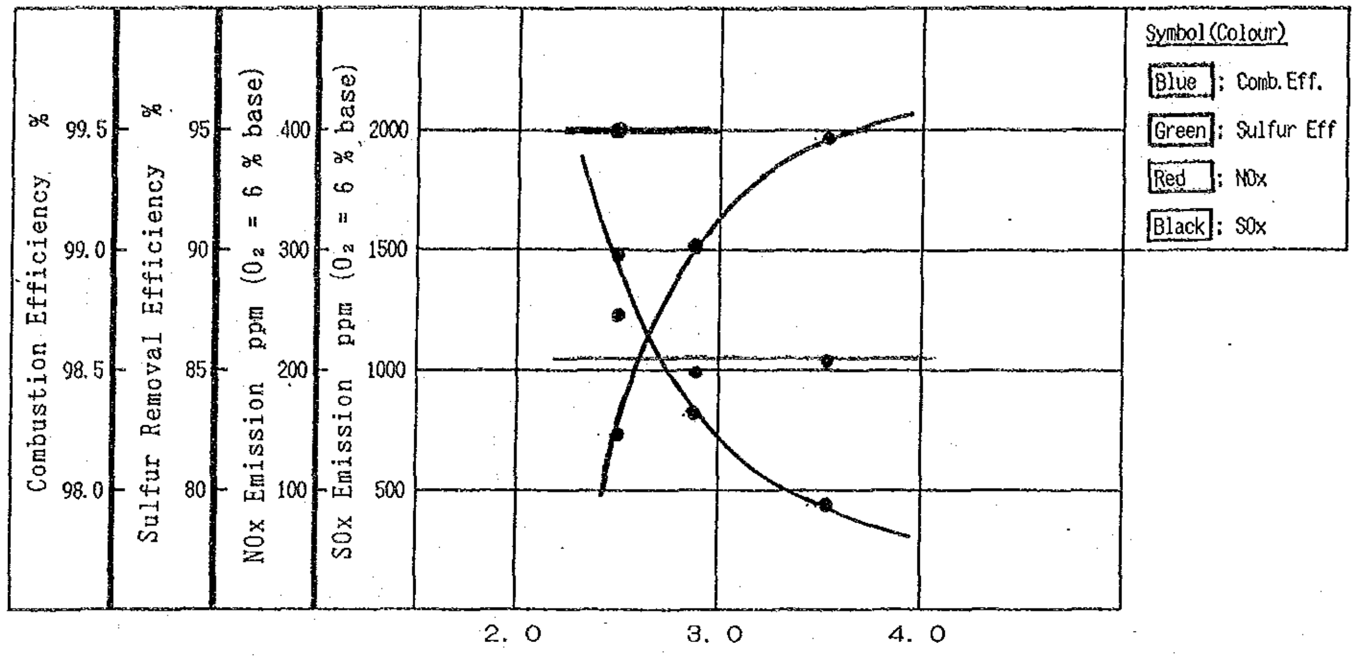
1) SOx Emission

Higher molar ratio effects on the lower SOx emission as confirmed by the bench scale combustion test. 95% De SOx efficiency is confirmed by the Ca/S molar ratio 3.54 without the ash recycle. With the ash recycle ratio about 0.9, 89% De SOx efficiency is confirmed by the Ca/S molar ratio 2.02 with the over feeding method of the large particle lignite.

2) NOx Emission

The effect of the molar ratio can not be recognized on NOx emission.

Fig. 9-11 Pilot Scale Comb. Test Results : Effect of Ca/S Molar Ratio



Test Data

Data NO. T-8-1 : 1992-May-15
Data NO. T-8-2 : 1992-May-15
Data NO. T-8-3 : 1992-May-16

Operating Conditions

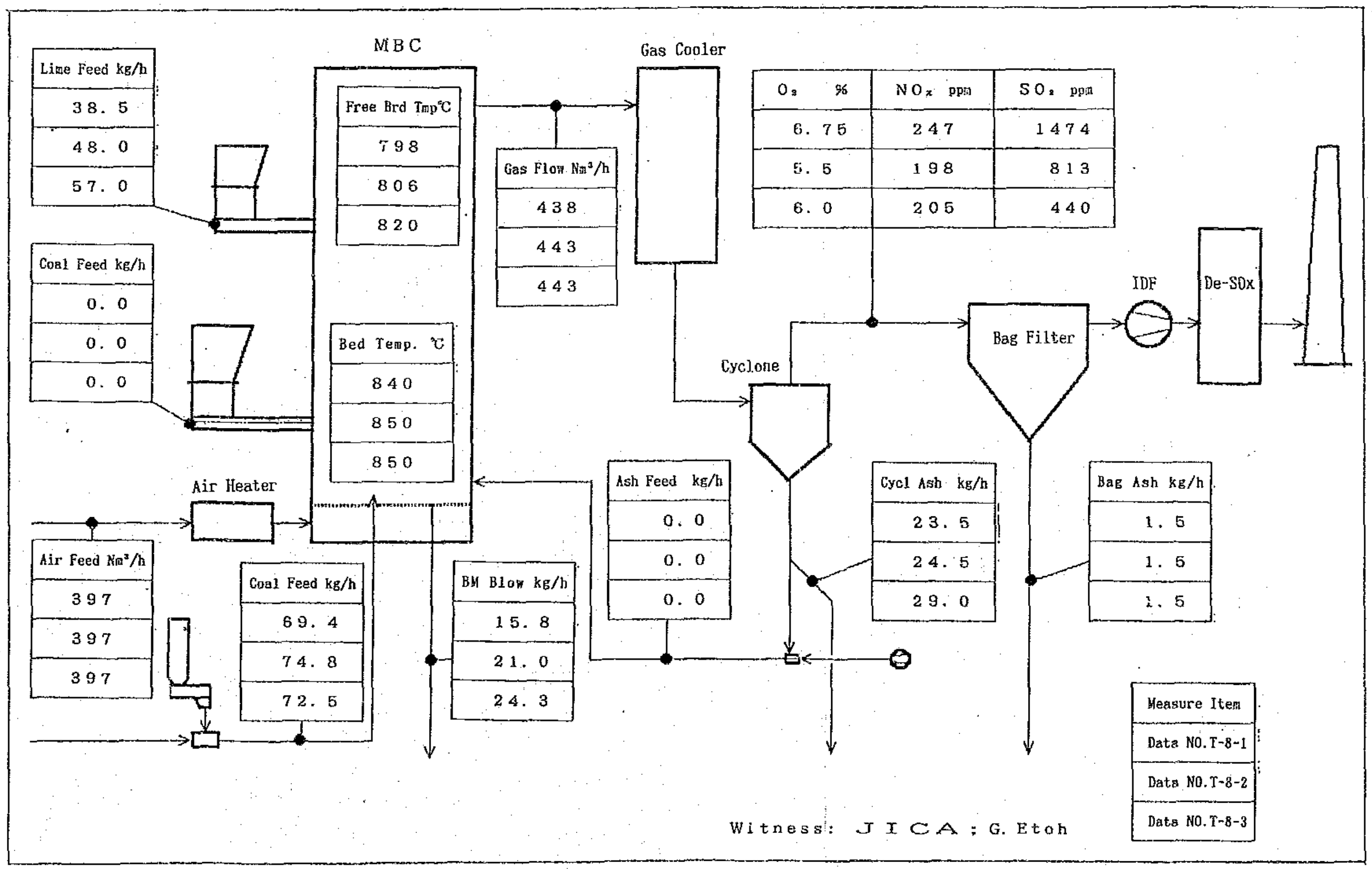
		Data NO. T-8-1	Data NO. T-8-2	Data NO. T-8-3
Heat Release Rate	kcal/m²h	1. 14×10⁶	1. 14×10⁶	1. 14×10⁶
Bed Temperature	℃	840	850	850
Excess Air Ratio	--	1. 50	1. 39	1. 44
Ca/S Molar Ratio	--	2. 50	2. 88	3. 54
Ash Recycle Ratio	--	0. 0	0. 0	0. 0
Coal Feed Method	--	Under Feed	Under Feed	Under Feed
Coal Size	mm	-8. 6	-8. 6	-8. 6
Lime Stone Size	mm	-3	-3	-3

Material Balance

		Data NO. T-8-1	Data NO. T-8-2	Data NO. T-8-3
Coal Feed Rate	kg/h	69. 4	74. 8	72. 5
Lime Feed Rate	kg/h	38. 5	48. 0	57. 0
Ash Recycle	kg/h	0. 0	0. 0	0. 0
BM Over Ash	kg/h	15. 8	21. 0	24. 3
Cyclone Ash	kg/h	23. 5	24. 5	29. 0
Bag Filter Ash	kg/h	1. 5	1. 5	1. 5

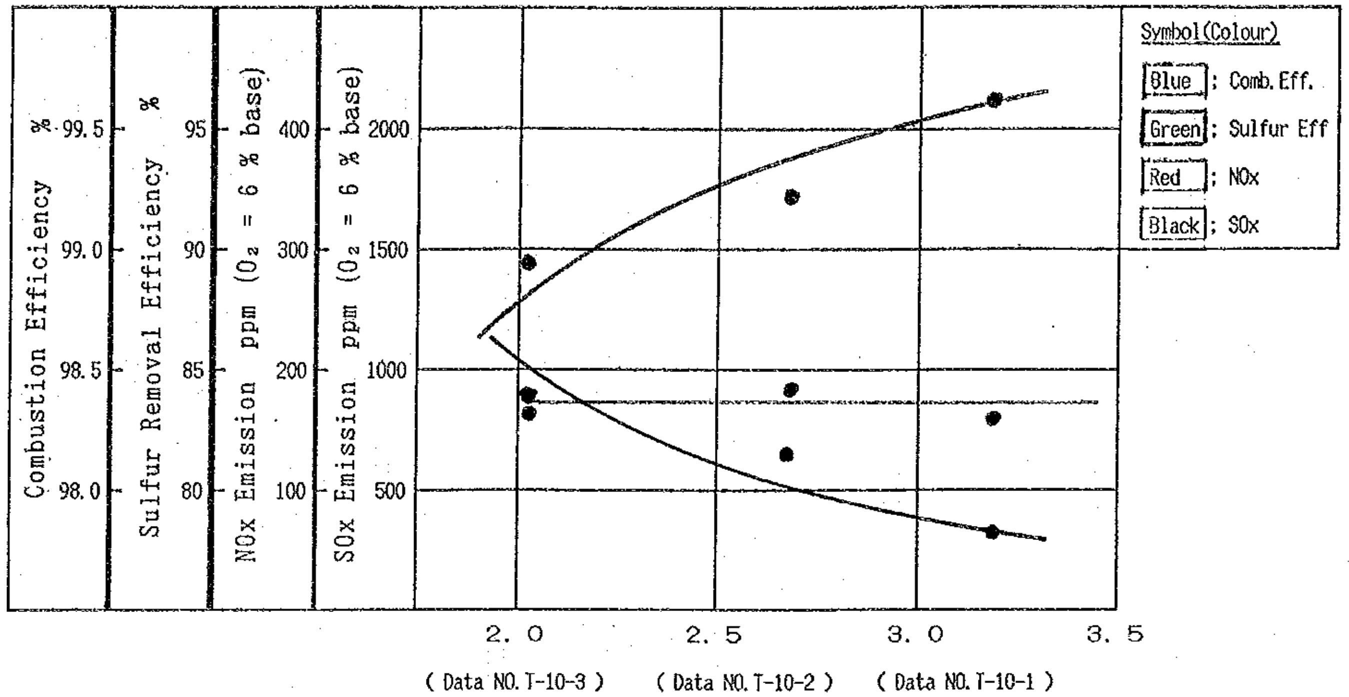
Data of Ash Analysis

		Data NO. T-8-1			Data NO. T-8-2			Data NO. T-8-3		
		BM	Cycln	Bag	BM	Cycln	Bag	BM	Cycln	Bag
CaO	%	31. 65	18. 71	4. 65	-	-	-	-	-	-
$CaCO_3$	%	0. 97	18. 02	4. 05	-	-	-	-	-	-
$CaSO_4$	%	55. 29	25. 14	39. 21	-	-	-	-	-	-
SiO_2	%	6. 51	21. 24	15. 51	-	-	-	-	-	-
Fe_2O_3	%	1. 16	5. 57	13. 13	-	-	-	-	-	-
Na_2O	%	0. 03	0. 04	0. 11	-	-	-	-	-	-



Witness: JICA : G. Etoh

Fig. 9-12 Pilot Scale COmb. Test Results : Effect of Ca/S Molar Ratio



Test Data

Data NO. T-10-3 : 1992-May-16
Data NO. T-10-2 : 1992-May-16
Data NO. T-10-1 : 1992-May-16

Operating Conditions

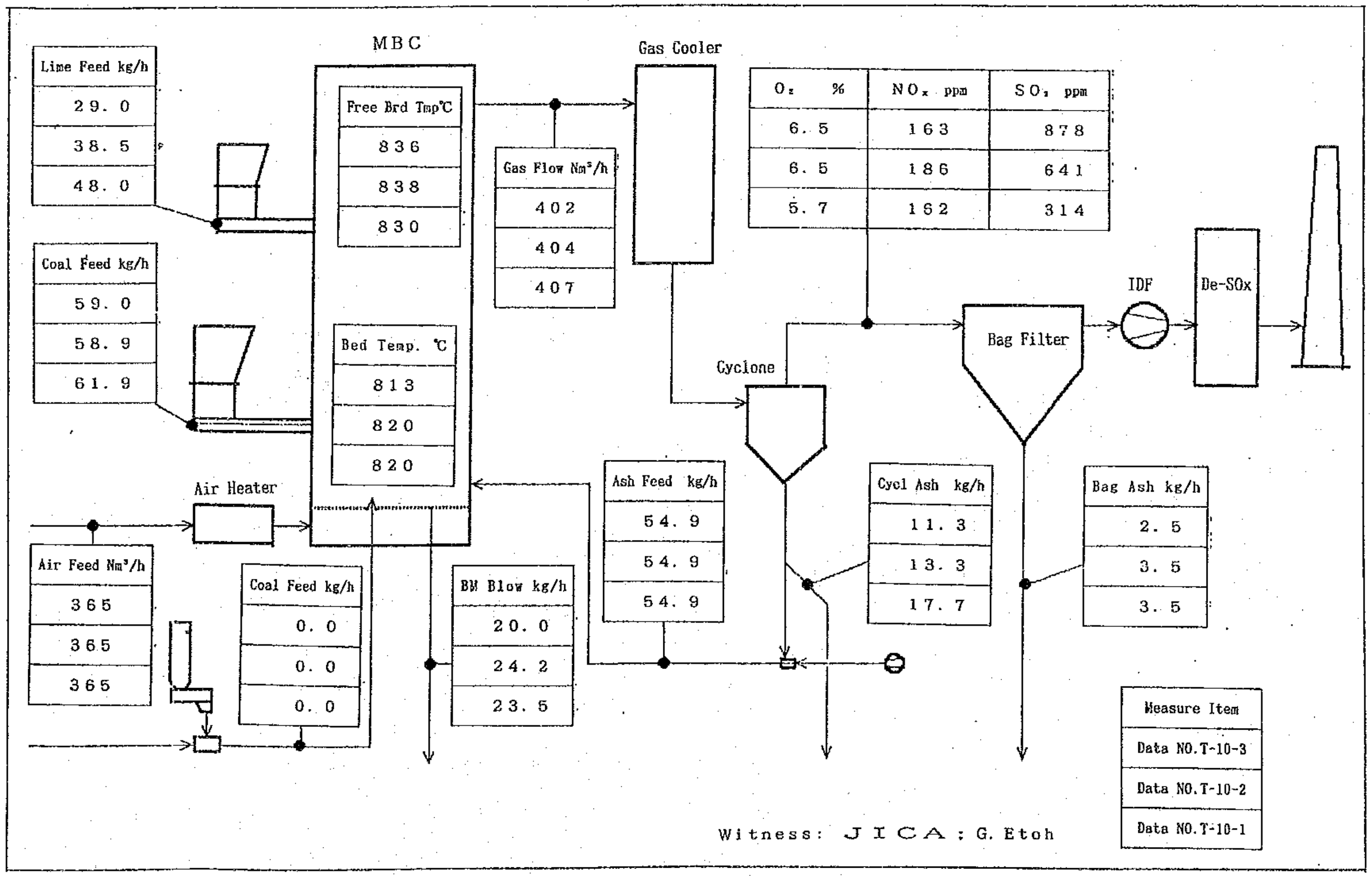
		Data NO. T-10-3	Data NO. T-10-2	Data NO. T-10-1
Heat Release Rate	kcal/m²h	1.05×10^6	1.05×10^6	1.05×10^6
Bed Temperature	℃	813	820	820
Excess Air Ratio	--	1. 48	1. 48	1. 41
Ca/S Molar Ratio	--	2. 02	2. 68	3. 18
Ash Recycle Ratio	--	0. 92	0. 92	0. 87
Coal Feed Method	--	Over Feed	Over Feed	Over Feed
Coal Size	mm	+2.8 ~ -8.6	+2.8 ~ -8.6	+2.8 ~ -8.6
Lime Stone Size	mm	-3	-3	-3

Material Balance

		Data NO. T-10-1	Data NO. T-10-2	Data NO. T-10-1
Coal Feed Rate	kg/h	59. 0	58. 9	61. 9
Lime Feed Rate	kg/h	29. 0	38. 5	48. 0
Ash Recycle	kg/h	54. 9	54. 9	54. 9
BM Over Ash	kg/h	20. 0	24. 2	23. 5
Cyclone Ash	kg/h	11. 3	13. 3	17. 7
Bag Filter Ash	kg/h	2. 5	3. 5	3. 5

Data of Ash Analysis

		Data NO. T-10-3			Data NO. T-10-2			Data NO. T-10-1		
		BM	Cycln	Bag	BM	Cycln	Bag	BM	Cycln	Bag
CaO	%	-	-	-	-	-	-	-	-	-
$CaCO_3$	%	-	-	-	-	-	-	-	-	-
$CaSO_4$	%	-	-	-	-	-	-	-	-	-
SiO_2	%	-	-	-	-	-	-	-	-	-
Fe_2O_3	%	-	-	-	-	-	-	-	-	-
Na_2O	%	-	-	-	-	-	-	-	-	-



Witness: JICA : G. Etoh

(5) Ash Recycle Ratio

The ash recycle effects very much on De SOx efficiency. The tests are carried out with Ca/S molar ratio 2.0 and 2.5. The ash recycle ratio is varied with 0.6, 1.0, 1.3. The results are shown in Fig. 9-13 to Fig. 9-15. Fig. 9-16 is summary of the above result.

1) SOx Emission

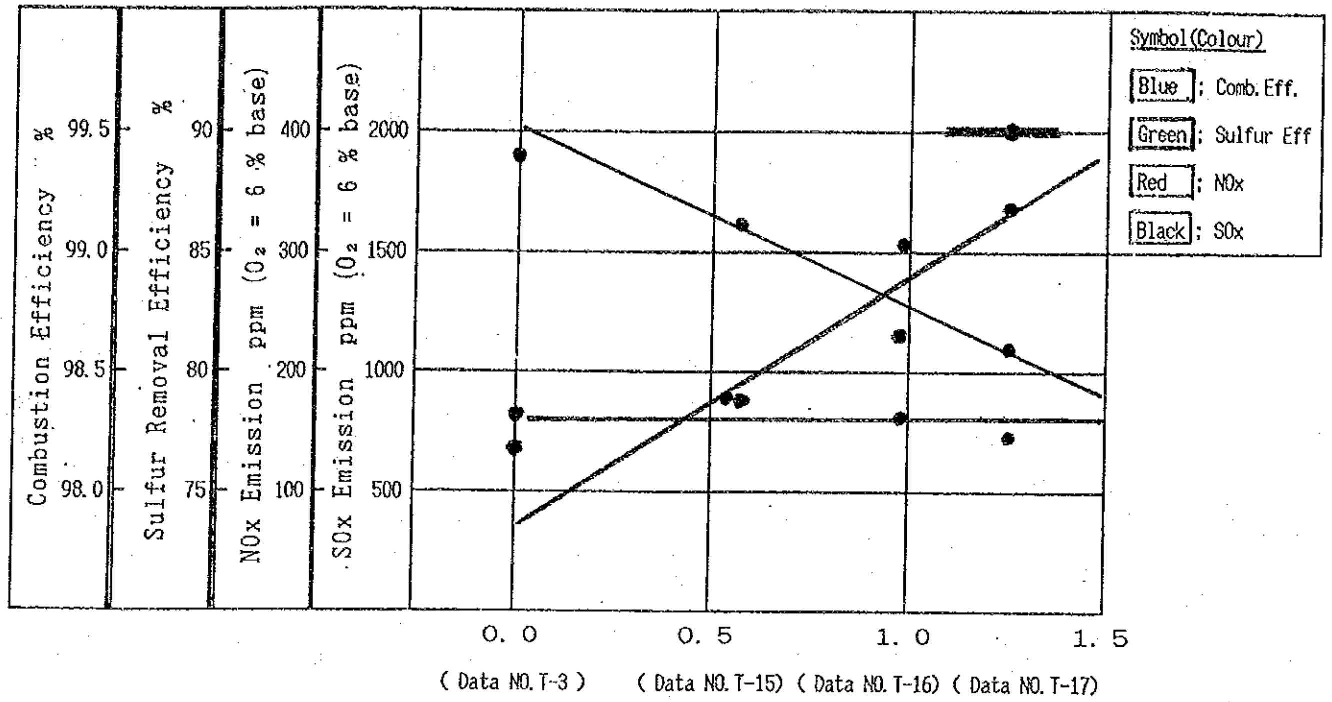
SOx emission is decreased according to the ash recycle ratio.

By applying the recycle ratio 1.5, the emission value would decrease 50% of the non recycle value under the molar ratio 2.0.

2) NOx Emission

The ash recycle ratio is not effected on NOx emission.

Fig. 9-13 Pilot Scale Comb. Test Results : Effect of Ash Recycle Ratio



Test Data

Data NO. T-15 : 1992-May-21
Data NO. T-16 : 1992-May-21
Data NO. T-17 : 1992-May-21

Operating Conditions

		Data NO. T-15	Data NO. T-16	Data NO. T-17
Heat Release Rate	kcal/m²h	1.2×10^6	1.2×10^6	1.2×10^6
Bed Temperature	℃	835	825	817
Excess Air Ratio	--	1.32	1.40	1.35
Ca/S Molar Ratio	--	2.08	2.06	2.05
Ash Recycle Ratio	--	0.58	0.97	1.26
Coal Feed Method	--	Over & Under	Over & Under	Over & Under
Coal Size	mm	+2.8~-8.6 /-2.8	+2.8~-8.6 /-2.8	+2.8~-8.6 /-2.8
Lime Stone Size	mm	-3	-3	-3

Material Balance

		Data NO. T-15	Data NO. T-16	Data NO. T-17
Coal Feed Rate	kg/h	72.3	73.4	75.6
Lime Feed Rate	kg/h	35.0	35.0	36.0
Ash Recycle	kg/h	40.0	58.0	91.0
BM Over Ash	kg/h	24.5	24.0	24.0
Cyclone Ash	kg/h	13.9	13.6	12.6
Bag Filter Ash	kg/h	3.1	3.6	3.6

Data of Ash Analysis

		Data NO. T-15			Data NO. T-16			Data NO. T-17		
		BM	Cycln	Bag	BM	Cycln	Bag	BM	Cycln	Bag
CaO	%	-	-	-	-	-	-	33.17	23.19	11.64
$CaCO_3$	%	-	-	-	-	-	-	1.00	4.62	1.25
$CaSO_4$	%	-	-	-	-	-	-	56.99	34.20	41.00
SiO_2	%	-	-	-	-	-	-	4.54	20.23	15.21
Fe_2O_3	%	-	-	-	-	-	-	0.81	6.84	13.51
Na_2O	%	-	-	-	-	-	-	0.01	0.05	0.08

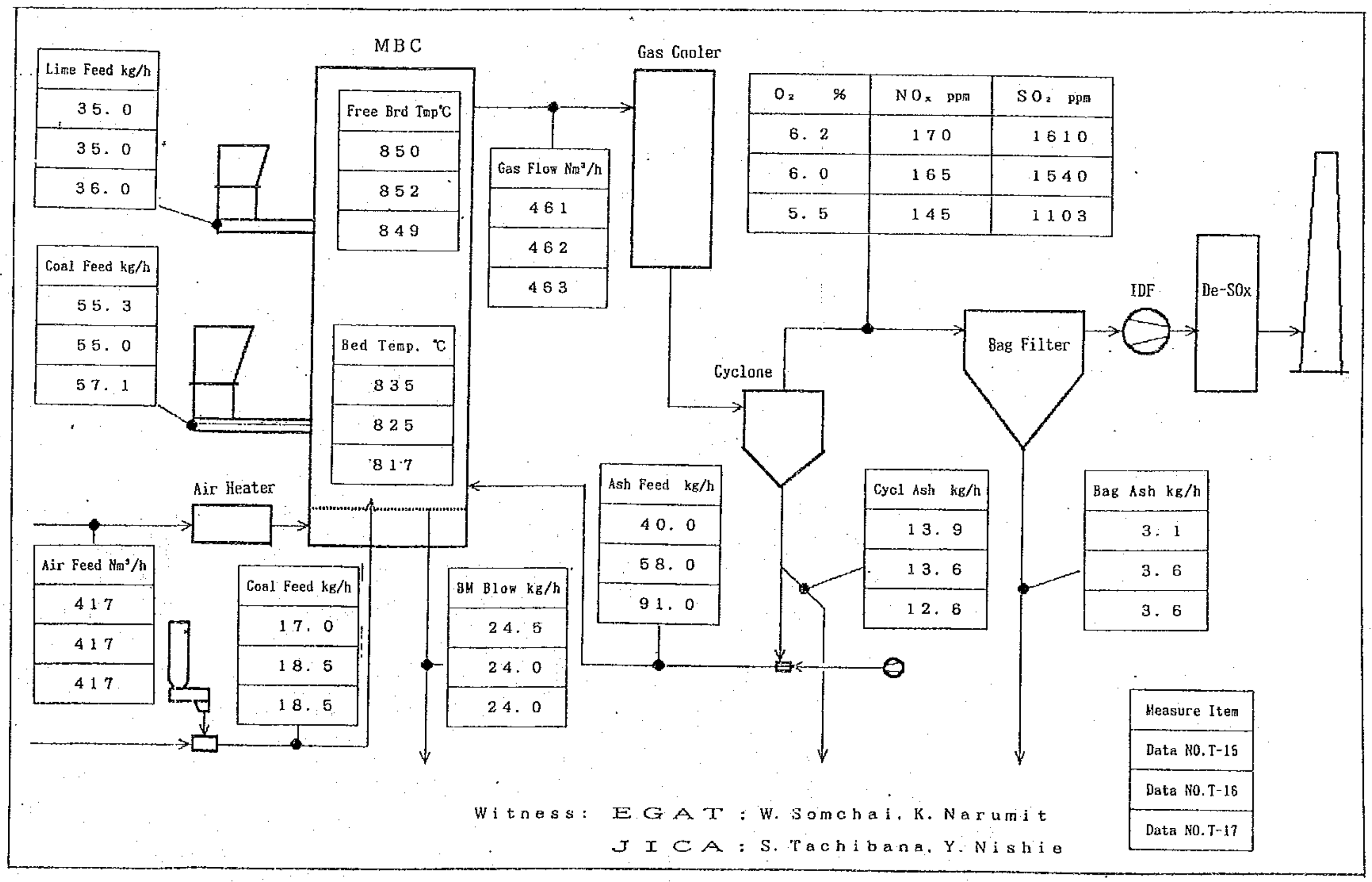
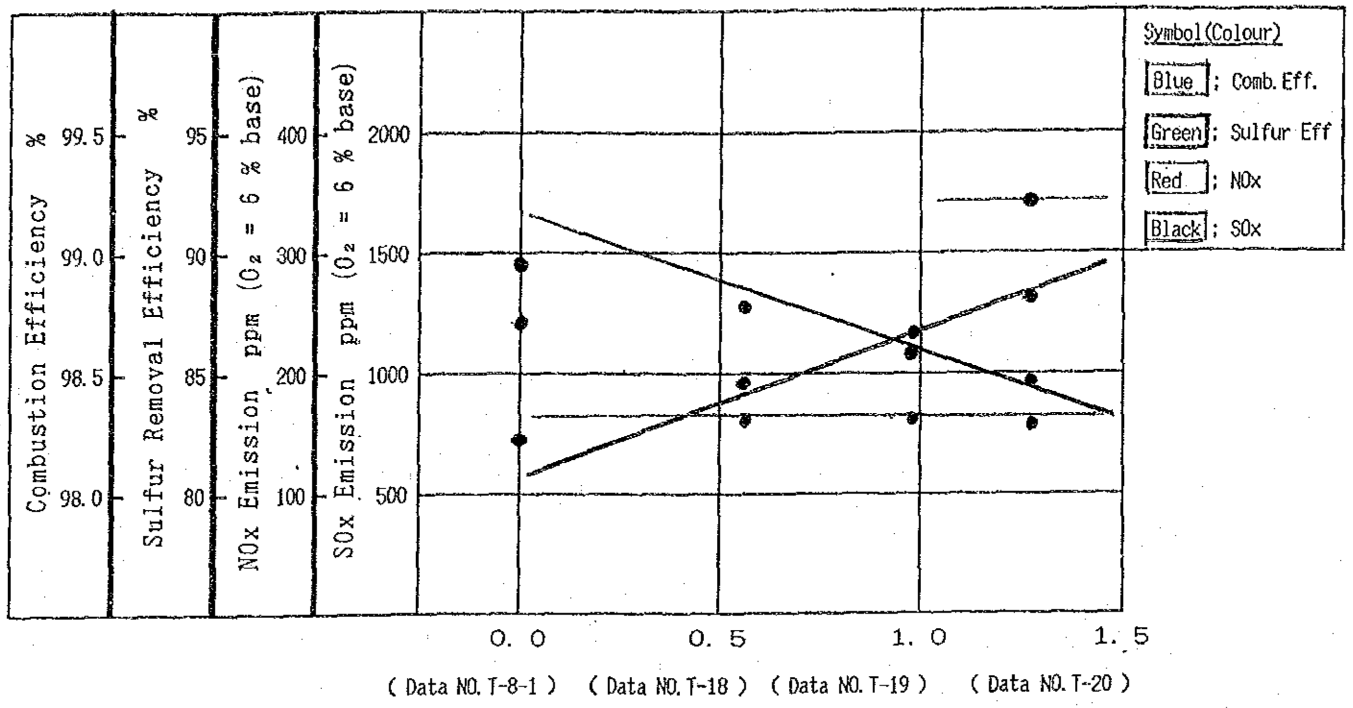


Fig. 9-14 Pilot Scale Comb. Test Results : Effect of Ash Recycle Ratio



Test Data

Data NO. T-18 : 1992-May-21
Data NO. T-19 : 1992-May-22
Data NO. T-20 : 1992-May-22

Operating Conditions

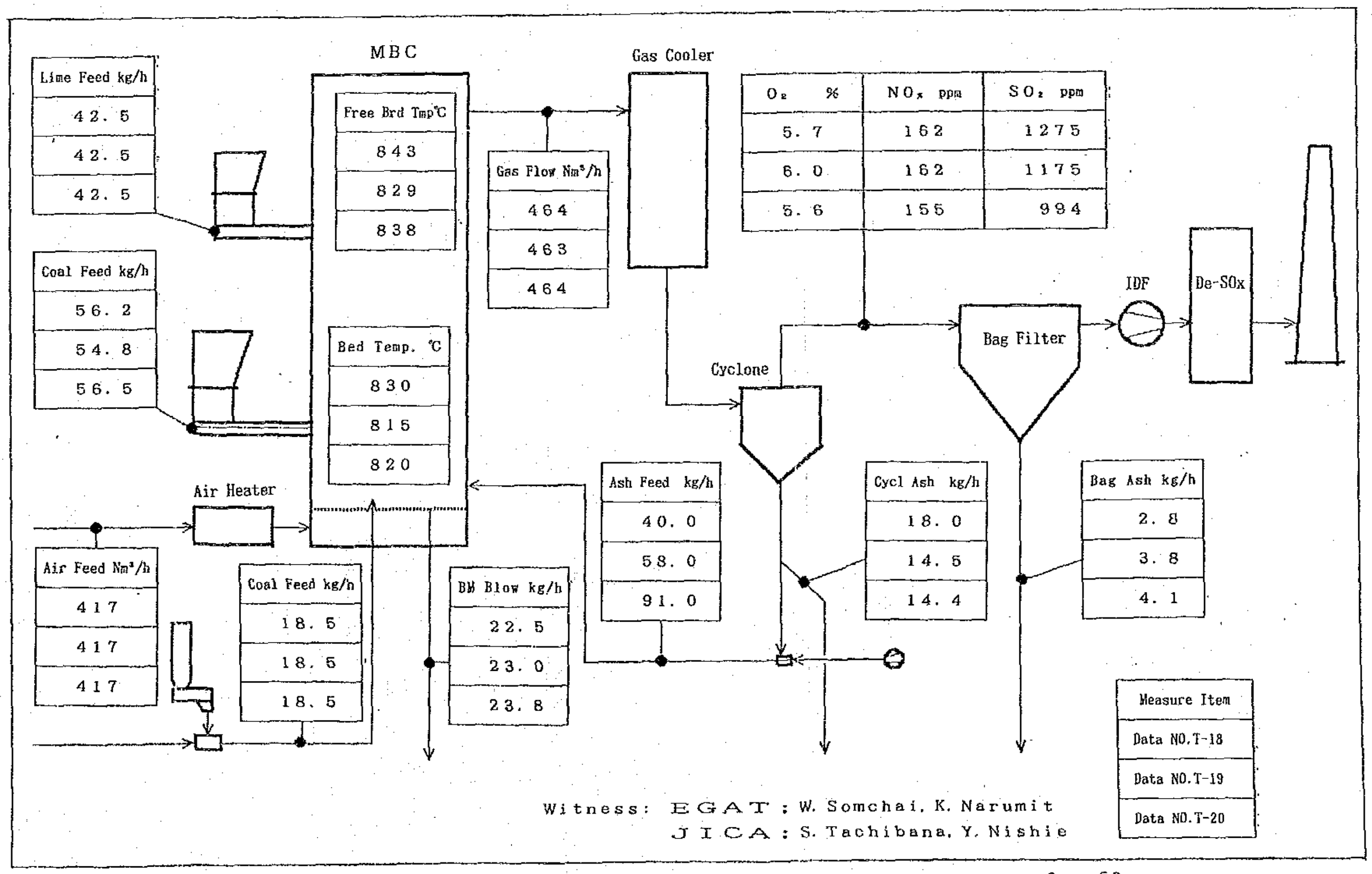
		Data NO. T-18	Data NO. T-19	Data NO. T-20
Heat Release Rate	kcal/m²h	1. 20×10⁶	1. 20×10⁶	1. 20×10⁶
Bed Temperature	℃	830	815	820
Excess Air Ratio	--	1. 40	1. 43	1. 39
Ca/S Molar Ratio	--	2. 45	2. 50	2. 44
Ash Recycle Ratio	--	0. 56	0. 98	1. 27
Coal Feed Method	--	O & U Feed	O & U Feed	O & U Feed
Coal Size	mm	+2.8~-8.6/-2.8	+2.8~-8.6/-2.8	+2.8~-8.6/-2.8
Lime Stone Size	mm	-3	-3	-3

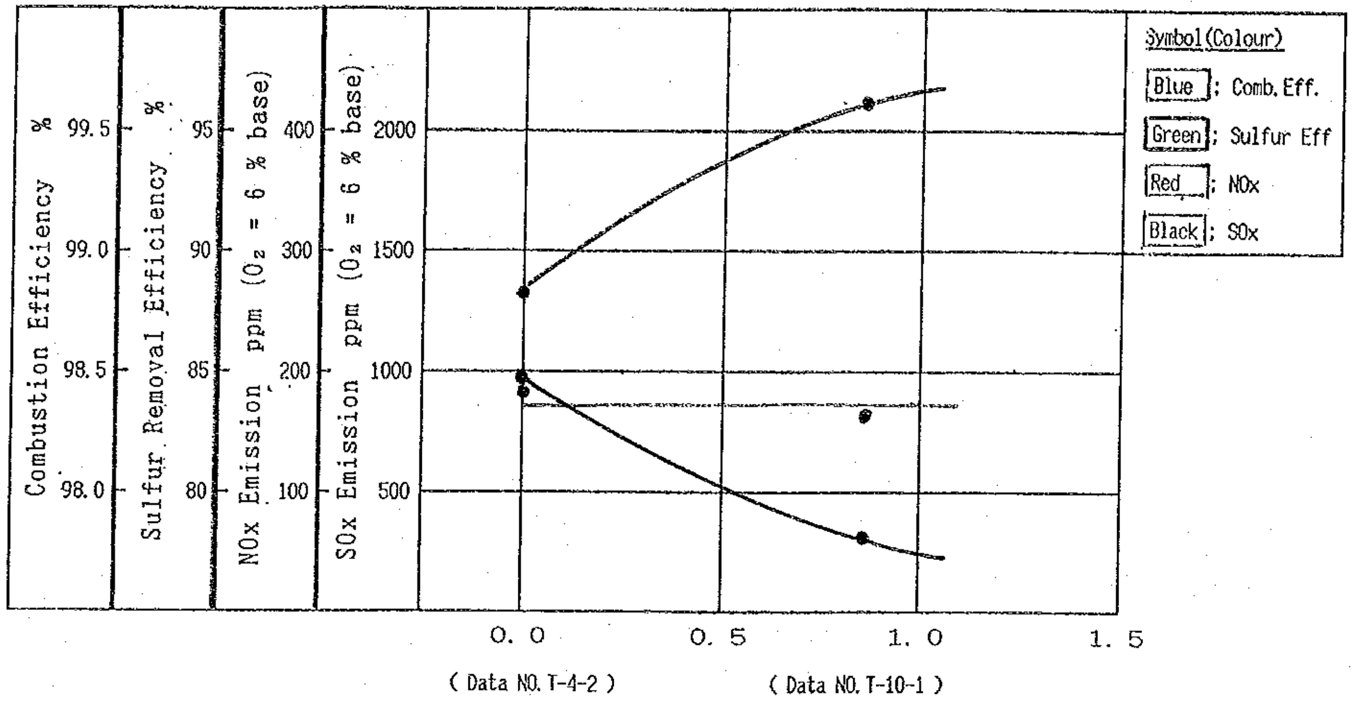
Material Balance

		Data NO. T-18	Data NO. T-19	Data NO. T-20
Coal Feed Rate	kg/h	74. 7	73. 3	75. 0
Lime Feed Rate	kg/h	42. 5	42. 5	42. 5
Ash Recycle	kg/h	40. 0	58. 0	91. 0
BM Over Ash	kg/h	22. 5	23. 0	23. 8
Cyclone Ash	kg/h	18. 0	14. 5	17. 4
Bag Filter Ash	kg/h	2. 8	3. 8	4. 1

Data of Ash Analysis

		Data NO. T-18			Data NO. T-19			Data NO. T-20		
		BM	Cycln	Bag	BM	Cycln	Bag	BM	Cycln	Bag
CaO	%	-	-	-	-	-	-	31. 71	24. 67	10. 16
$CaCO_3$	%	-	-	-	-	-	-	4. 22	6. 87	1. 84
$CaSO_4$	%	-	-	-	-	-	-	56. 14	36. 70	41. 43
SiO_2	%	-	-	-	-	-	-	3. 28	17. 29	15. 49
Fe_2O_3	%	-	-	-	-	-	-	0. 79	5. 67	13. 67
Na_2O	%	-	-	-	-	-	-	0. 01	0. 03	0. 08





Test Data

Data NO. T-4-2 : 1992-May-14
Data NO. T-10-1 : 1992-May-16
Data NO. — : —

Operating Conditions

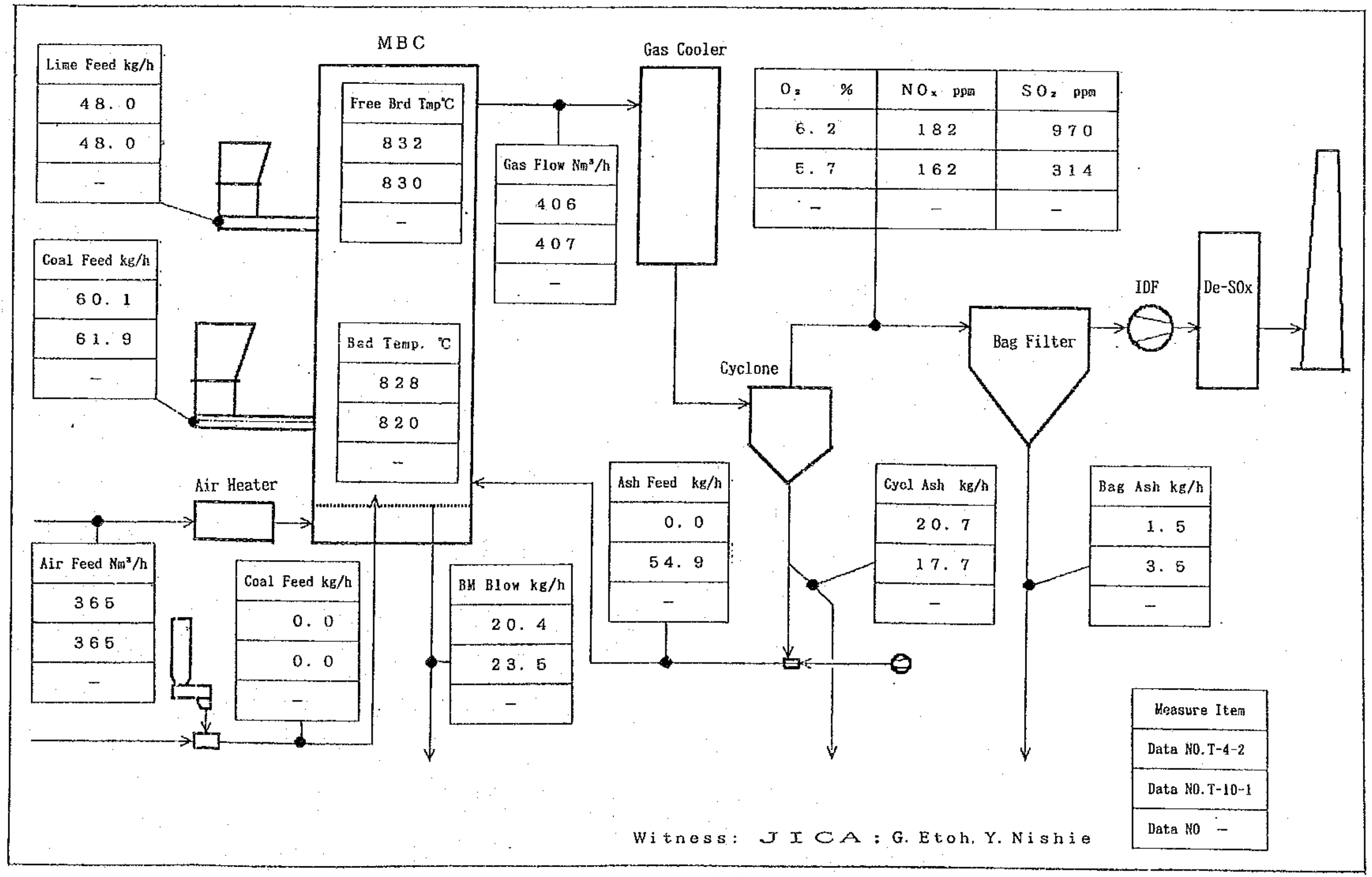
		Data NO. T-4-2	Data NO. T-10-1	Data NO. —
Heat Release Rate	kcal/m²h	1. 05×10⁶	1. 05×10⁶	--
Bed Temperature	℃	828	820	--
Excess Air Ratio	--	1. 45	1. 41	--
Ca/S Molar Ratio	--	3. 28	3. 18	--
Ash Recycle Ratio	--	0. 0	0. 87	--
Coal Feed Method	--	Over Feed	Over Feed	--
Coal Size	mm	+2.8 ~ -8.6	+2.8 ~ -8.6	--
Lime Stone Size	mm	-3	-3	--

Material Balance

		Data NO. T-4-2	Data NO. T-10-1	Data NO. —
Coal Feed Rate	kg/h	60. 1	61. 9	--
Lime Feed Rate	kg/h	48. 0	48. 0	--
Ash Recycle	kg/h	0. 0	54. 9	--
BM Over Ash	kg/h	20. 4	23. 5	--
Cyclone Ash	kg/h	20. 7	17. 7	--
Bag Filter Ash	kg/h	1. 5	3. 5	--

Data of Ash Analysis

		Data NO. T-4-2			Data NO. T-10-1			Data NO. —		
		BM	Cycln	Bag	BM	Cycln	Bag	BM	Cycln	Bag
CaO	%	34. 81	26. 36	7. 02	-	-	-	-	-	-
$CaCO_3$	%	3. 25	21. 52	2. 25	-	-	-	-	-	-
$CaSO_4$	%	50. 61	29. 98	43. 38	-	-	-	-	-	-
SiO_2	%	5. 81	8. 21	11. 87	-	-	-	-	-	-
Fe_2O_3	%	0. 84	4. 69	13. 36	-	-	-	-	-	-
Na_2O	%	0. 01	0. 03	0. 12	-	-	-	-	-	-



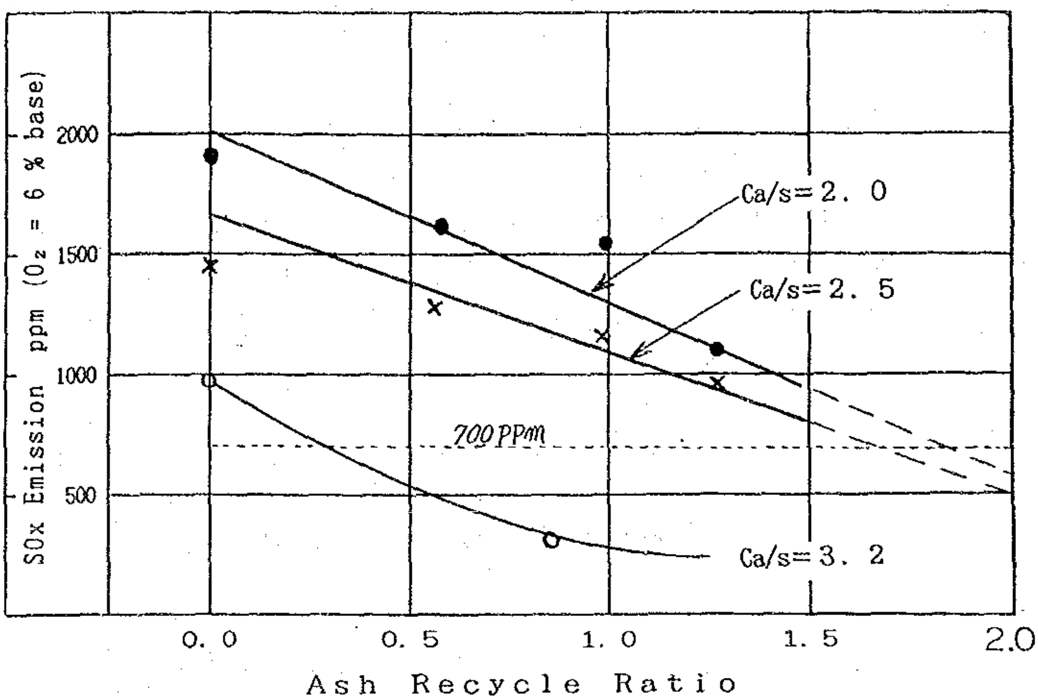


Fig. 9-16 SOx Emission

(Effect of Ash Recycle Ratio)

(6) Lignite Feeding Method .

The under feeding method and the over feeding method are compared. The combination feeding method also is checked by the test. The results are shown in Fig. 9-17.

1) SOx Emission

The under feeding method has good effect on the desulfurization efficiency compared with the over feeding method.

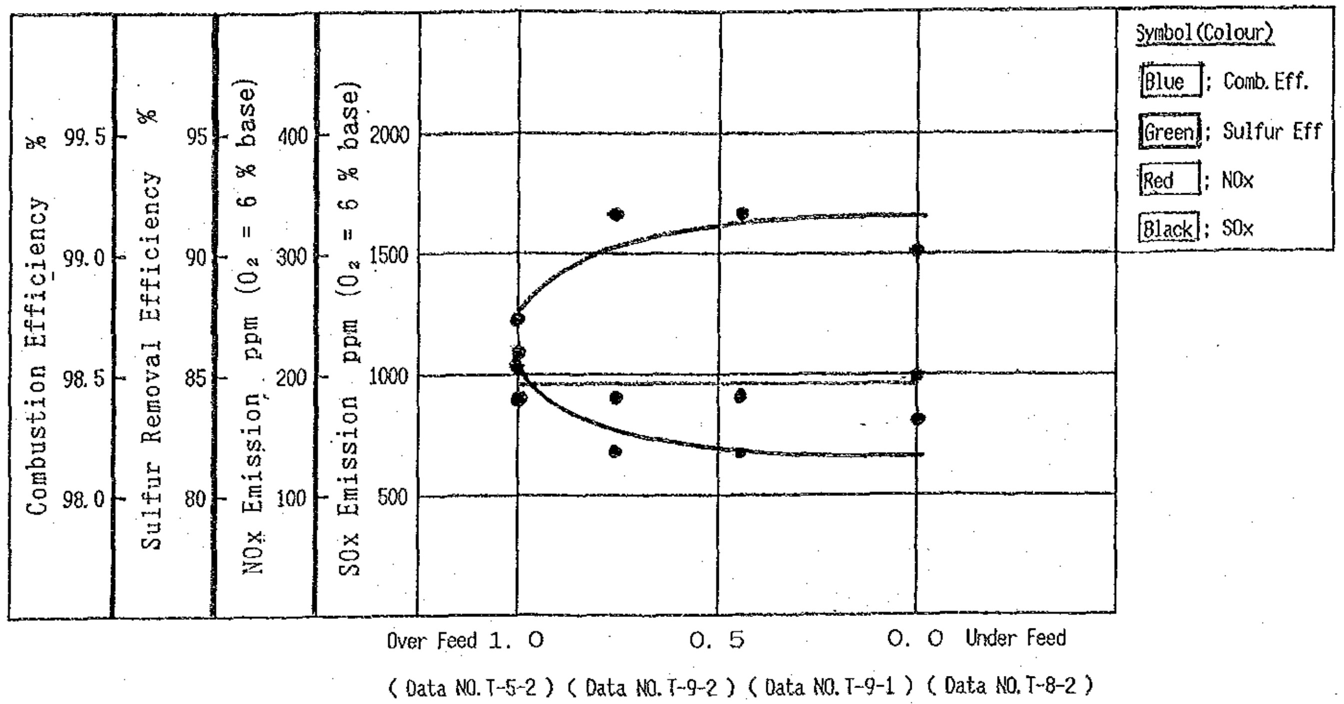
Fig. 9-18 shows the temperature profiles on the free board zone. From these profiles, it can be confirmed that the powder lignite is burn and rize up the temperature in the free board zone for the over feeding method, while the temperature profile of the under feeding method is decreased according to the height from the fluidized bed.

Therefore, the increased SOx emission value for the overfeeding method is considered to be derived from the powder lignite burnt over the fluidized bed without touching the desulfurizer in the bed.

2) NOx Emission

No significant difference is recognized on NOx emission by the lignite feeding method.

Fig. 9-17 Pilot Scale Comb. Test Results : Effect of Coal Feed Method



Test Data

Data NO. T-5-2 : 1992-May-15
Data NO. T-9-2 : 1992-May-16
Data NO. T-8-2 : 1992-May-15

Operating Conditions

		Data NO. T-5-2	Data NO. T-9-2	Data NO. T-8-2
Heat Release Rate	kcal/m²h	1. 05×10⁶	1. 14×10⁶	1. 14×10⁶
Bed Temperature	℃	830	830	850
Excess Air Ratio	--	1. 59	1. 48	1. 38
Ca/S Molar Ratio	--	2. 88	3. 08	2. 88
Ash Recycle Ratio	--	0. 0	0. 0	0. 0
Coal Feed Method	--	Over Feed	U & O Feed	Under Feed
Coal Size	mm	+2.8 ~ -8.6	+2.8~-8.6/-2.8	-8.6
Lime Stone Size	mm	-3	-3	-3

Material Balance

		Data NO. T-5-2	Data NO. T-9-2	Data NO. T-8-2
Coal Feed Rate	kg/h	54. 9	65. 6	74. 8
Lime Feed Rate	kg/h	38. 5	48. 0	48. 0
Ash Recycle	kg/h	0. 0	0. 0	0. 0
BM Over Ash	kg/h	19. 2	22. 6	21. 0
Cyclone Ash	kg/h	16. 6	26. 1	24. 5
Bag Filter Ash	kg/h	1. 5	1. 5	1. 5

Data of Ash Analysis

		Data NO. T-5-2			Data NO. T-9-2			Data NO. T-8-2		
		BM	Cycln	Bag	BM	Cycln	Bag	BM	Cycln	Bag
CaO	%	33. 84	31. 55	11. 76	-	-	-	-	-	-
$CaCO_3$	%	1. 00	14. 88	4. 87	-	-	-	-	-	-
$CaSO_4$	%	52. 31	30. 15	42. 23	-	-	-	-	-	-
SiO_2	%	4. 78	9. 84	10. 63	-	-	-	-	-	-
Fe_2O_3	%	0. 76	4. 87	12. 24	-	-	-	-	-	-
Na_2O	%	0. 01	0. 08	0. 12	-	-	-	-	-	-