4.1.6 Car Ownership

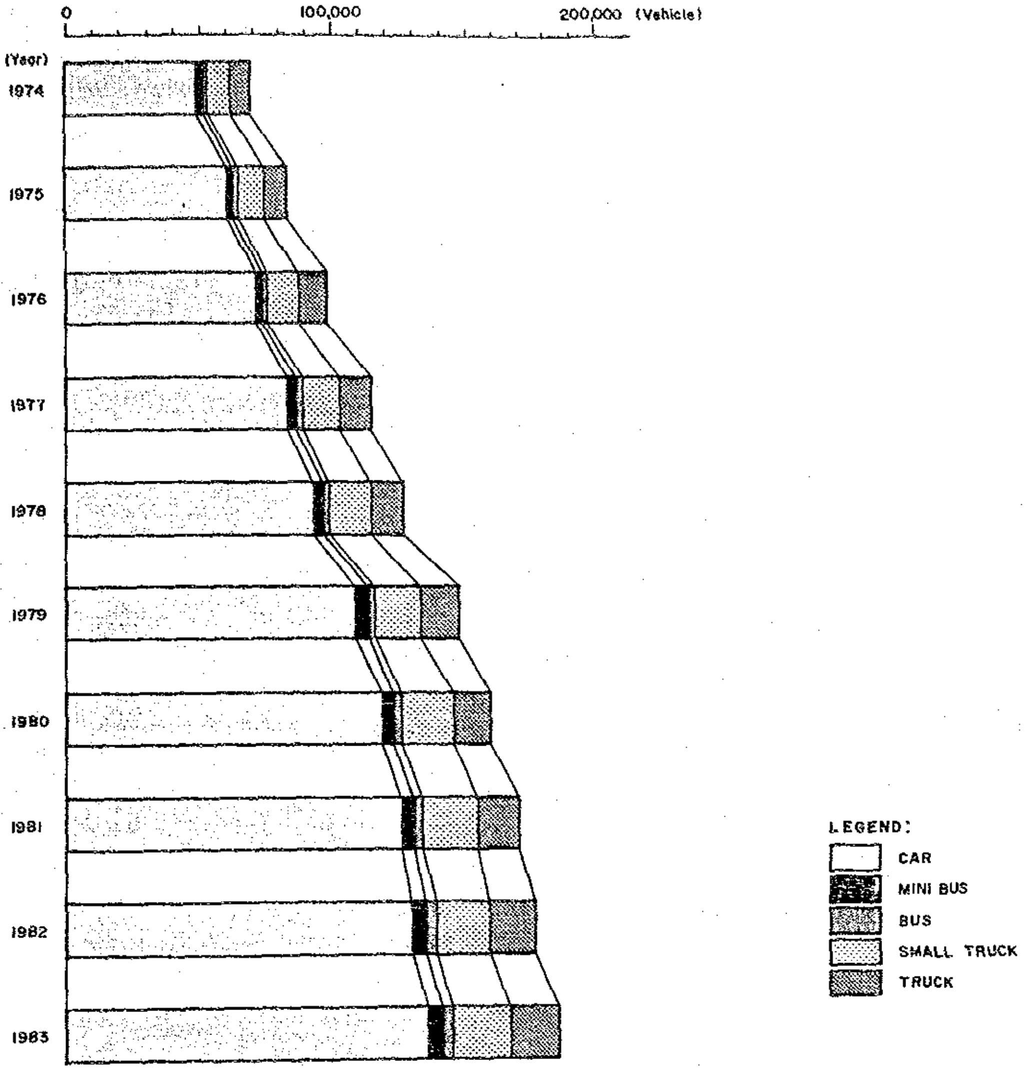
(1) Car Ownership by Types of Vehicles

In 1974, the total number of motor vehicles in Ankara Province was 69,938. In 1983 after 9 years, it grew to 185,107, almost 2.7 times. However, the annual growth rate slowed down from 20% in the 1970's to 10% in the 1980's. As to the type of vehicles, passenger cars constitutes more than 70% of the total followed by small trucks, trucks, mini-buses and buses. This proportion remained unchanged for the past 10 years, although the actual number of passenger cars had been growing slowly. (See Table 4.1.10 and Figures 4.1.10 and 4.1.11)

Table 4.1.10 Car Ownership by Types of Vehicles

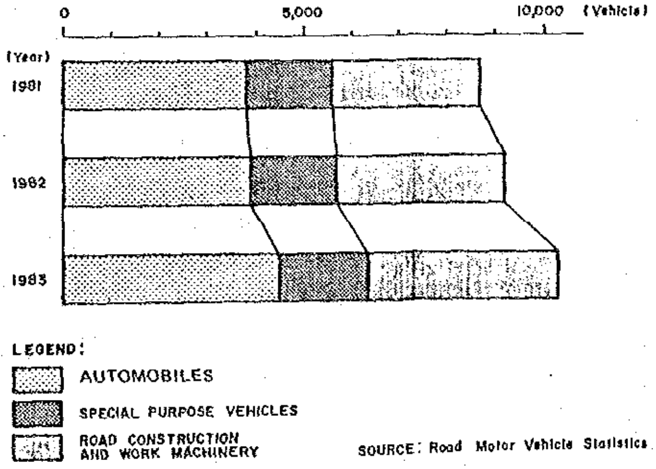
Item	Total						
Year	(Share)	Ratio	Car	Mini-bus	Bus	Small Truck	Truck
1974	69,938 (100.0)	1.00	49,458 (70.7)	1,832 (2.6)	1,488 (2.1)	9,138 (13.1)	8,022 (11.5)
1975	83,878 (100.0)	1.20	60,380 (72.0)	1,964 (2.3)	1,623 (1.9)	10,836 (12.9)	9,075 (10.8)
1976	98,365 (100.0)	1.41	71,186 (72.4)	2,319 (2.4)	1,803 (1.8)	12,836 (13.0)	10,221 (10.4)
1977	114,925 (100.0)	1.64	83,891 (73.0)	2,701 (2.4)	2,074 (1.8)	14,293 (12.4)	11,966 (10.4)
1978	127,364 (100.0)	1.82	93,750 (73.6)	3,464 (2.7)	2,156 (1.7)	15,289 (12.0)	12,705 (10.0)
1979	147,448 (100.0)	2.11	109,455 (74.2)	3,823 (2.6)	2,772 (1.9)	17,485 (11.9)	13,913 (9.4)
1980	159,176 (100.0)	2.28	118,603 (74.5)	4,687 (2.9)	2,660 (1.7)	18,773 (11.8)	14,453 (9.1)
1981	169,944 (100.0)	2.43	126,182 (74.2)	4,498 (2.6)	3,403 (2.5)	20,015 (11.8)	15,846 (9.3)
1982	176,219 (100.0)	2.52	130,034 (73.8)	4,817 (2.7)	3,710 (2.1)	20,630 (11.7)	17,028 (9.7)
1983	185,107 (100.0)	2.65	135,926 (73.4)	5,204 (2.8)	4,001 (2.2)	21,492 (11.6)	18,484 (10.0)

Source: Road Motor Vehicles Statistics (1974-1983)



SOURCE: Road Motor Vehicle Statistics
(1974 – 1983)

Figure 4.1.10 Car Ownership by Types of Vehicles



SOURCE: Road Motor Vehicle Statistics Census

Figure 4.1.11 Car Ownership Per Thousand of Population

(2) Car Ownership by Purposes

The proportion of automobiles, road construction vehicles, and special purpose vehicles being 40%, 40%, and 20%, respectively, for the period 1981 to 1983 remained unchanged. The numbers of the first two slightly increased. The number of automobiles used for commercial, official, and municipal purposes remained constant with the exception of private cars, which increased slightly.

Table 4.1.11 Car Ownership by Purposes

Item / Year	Total	AUTOMOBILES					Special Purpose Vehicle	Road Construction and Work machinery
		Sub-total	Private	Commercial	Official	Municipal		
1981	100.0 8,709 (1.00)	43.9 3,826 (1.00) 100.0	3,548 92.7	22 0.6	248 6.5	8 0.2	20.3 1,766 (1.00)	35.8 3,117 (1.00)
1982	100.0 9,241 (1.06)	42.4 3,919 (1.02) 100.0	3,635 92.8	25 0.6	251 6.4	8 0.2	19.3 1,783 (1.01)	38.3 3,539 (1.14)
1983	100.0 10,280 (1.18)	43.4 4,464 (1.17) 100.0	4,165 93.3	25 0.6	266 6.0	8 0.2	18.5 1,901 (1.08)	38.1 3,915 (1.26)

Source: Road Motor Vehicle Statistics (1981-1983)

4.2 TREND IN DEMAND AND SUPPLY OF ENERGY SOURCES

4.2.1 Total Primary Energy and Energy Mix

(1) Total Primary Energy

The trend in total primary energy consumption from 1978 to 1984 shows an increase of 2.1% per year as is clear from the figures in 1979 at 33,992 x 10^3 equivalent of tons of petroleum and in 1984 at 38,563 x 10^3 equivalent of tons of petroleum.

As to the forecast of energy demand, "the 5th Five-Year Development Plan (1985 -1989)" and "IEA/OECD Energy Balances of OECD Countries ('83)" are referred.

The 5th Five-Year Plan anticipates production and demand of total primary energy as shown in Table 4.2.1 and Table 4.2.2. According to the plan, the demand of total primary energy is anticipated to increase at an annual rate of 7.2% during 5 years from 1984 to 1989. As to the trend of share by the sources of energy, lignite and hydraulic power increase while petroleum and related energy are less resorted to as the basic policy.

The share of lignite is anticipated to change from 15.2% (1984) to 19.6% (1989), and hydraulic energy from 7.9% (1984) to 10.2% (1989).

Table 4.2.1 Trend of Primary Energy Production

Unit: equivalent of
1,000 tons of petroleum

	1978			1983			1984			1989		
	Quan.	Perc. distr. of Total	Perc. distr. of Groups	Quan.	Perc. distr. of Total	Perc. distr. of Groups	Quan.	Perc. distr. of Total	Perc. distr. of Groups	Quan.	Perc. distr. of Total	Perc. distr. of Groups
Hardcoal	2,620	14.8	20.8	2,158	11.3	16.6	2,501	12.7	18.2	2,867	10.0	12.7
Lignite	4,819	26.9	38.0	5,679	29.8	43.7	5,870	29.8	42.7	10,680	37.4	47.1
Petroleum Derivatives	2,873	16.1	22.6	2,314	12.1	17.8	2,310	11.7	16.8	2,861	10.0	12.6
Natural Gas	20	0.1	0.2	7	-	0.1	7	-	-	632	2.2	2.8
Hydraulic Energy	2,341	13.2	18.5	2,839	14.9	21.8	3,046	15.5	22.2	5,600	19.6	24.7
Geothermal Energy	-	-	-	-	-	-	14	0.1	0.1	23	0.1	0.1
Solar Energy	-	-	-	-	-	-	1	-	-	2	-	-
Total commet. energy	12,673	70.9	100.0	12,997	68.1	100.0	13,749	89.3	100.0	22,665	79.3	100.0
Wood	2,313	12.9	44.3	2,511	13.2	41.3	2,553	13.0	42.9	2,760	9.7	46.6
Animal and Veget. Wastes												
Total Non-commer. Energy	2,903	16.2	55.7	3,574	18.7	58.7	3,396	17.2	57.1	3,158	11.0	53.4
	5,216	29.1	100.0	6,085	31.9	100.0	5,948	30.2	100.0	5,918	20.7	100.0
GRAND TOTAL	17,889	100.0		19,082	100.0		19,697	100.0		28,583	100.0	

Table 4.2.2 Trend of Primary Energy Consumption and Demand

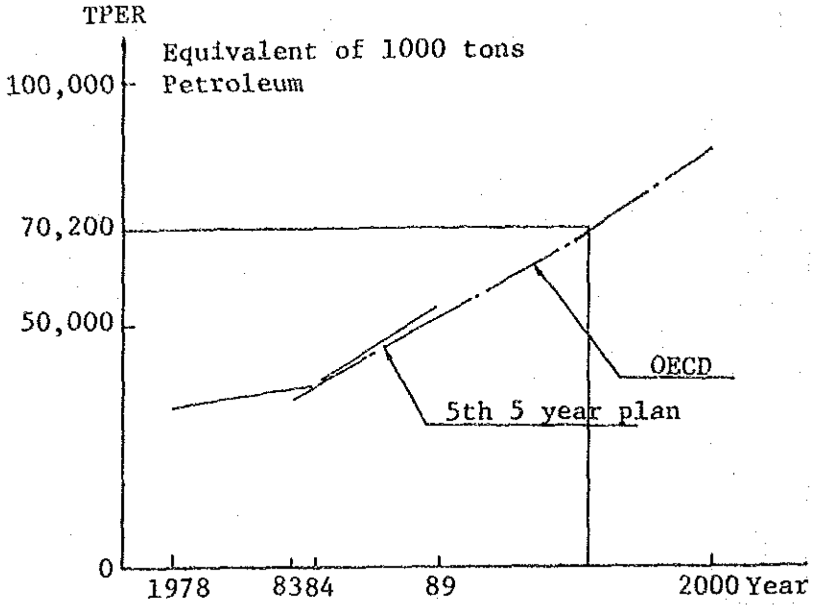
Unit: equivalent of
1,000 tons of petroleum

	1978			1983			1984			1989		
	Quan.	Perc. distr. of Total	Perc. distr. of Groups	Quan.	Perc. distr. of Total	Perc. distr. of Groups	Quan.	Perc. distr. of Total	Perc. distr. of Groups	Quan.	Perc. distr. of Total	Perc. distr. of Groups
Hardcoal	2,827	8.3	10.7	3,208	8.5	11.1	3,294	8.6	11.0	5,063	9.3	11.0
Lignite	4,056	11.9	15.3	5,597	14.8	19.3	5,870	15.2	19.6	10,680	19.6	23.2
Petroleum Derivatives	17,115	50.4	64.5	16,814	44.6	57.9	17,210	44.6	57.4	24,069	44.1	52.2
Natural Gas	20	-	0.1	7	-	-	7	-	-	632	1.2	1.4
Hydraulic Energy	2,341	6.9	8.0	2,839	7.5	9.8	3,046	7.9	10.2	5,600	10.2	12.2
Geothermal Energy	-	-	-	-	-	-	14	-		23	-	-
Electricity Imports	156	0.5	0.6	556	1.5	1.9	548	1.4	1.8	-	-	-
Solar Energy	-	-	-	-	-	-	1	-	-	2	-	-
TOTAL COMMER. EN.	26,515	78.0	100.0	29,021	76.9	100.0	29,990	77.8	100.0	46,069	84.4	100.0
Wood	4,574	13.5	61.2	3,126	13.6	58.9	5,177	13.	60.4	5,344	9.8	62.9
Animal and Veget. Wastes	2,903	8.5	38.8	3,574	9.5	41.1	3,396	8.8	39.6	3,158	5.8	37.1
TOTAL NON-COMMER. ENERGY	7,477	22.0	100.0	8,700	23.1	100.0	8,573	22.2	100.0	8,502	15.6	100.0
GRAND TOTAL	33,992	100.0		37,721	100.0		38,563	100.0		54,571	100.0	

Source; 5th Five-Year Development Plan

On the other hand, according to the data of "IEA/OECD Energy Balances of Turkey ('83)", an increase of 4.7% per year is anticipated for the total primary energy demand during 10 years from 1990 to 2000.

The demand of total primary energy in 1995, the target year of this Project, is estimated as the equivalent of 70,200 x 10^3 tons petroleum figured out from the "OECD TPER (total primary energy requirements) in Turkey" of OECD Report (Figure 4.2.1).



Source; 5th Five Year Development Plan
IEA/OECD Energy Balances and IEA
Country Submissions. (1983)

Figure 4.2.1 Anticipated Demand for Total Primary Energy

(2) Energy Mix

In forecasting constituent of energy sources, emphasis was placed on the basic lines of thinking in the long-term energy policy of the government.

In the energy mix according to the 5th Five-Year Plan, the rate of petroleum-dependent energy is lowered by development of lignite and hydraulic power-dependent energy, so that share of non-commercial energy sources is lowered.

In forecasting energy mix in 1995, the shares by coal, lignite, and petroleum are assumed to be 9.3%, 19.6%, and 44.1% respectively, according to the energy mix in the 5th Five-Year Plan, so that share of the non-commercial energy be reduced to 12% and that the reduction be covered by hydraulic energy (cf. Figure 4.2.2). The demand for various energy sources is as shown in Table 4.2.3.

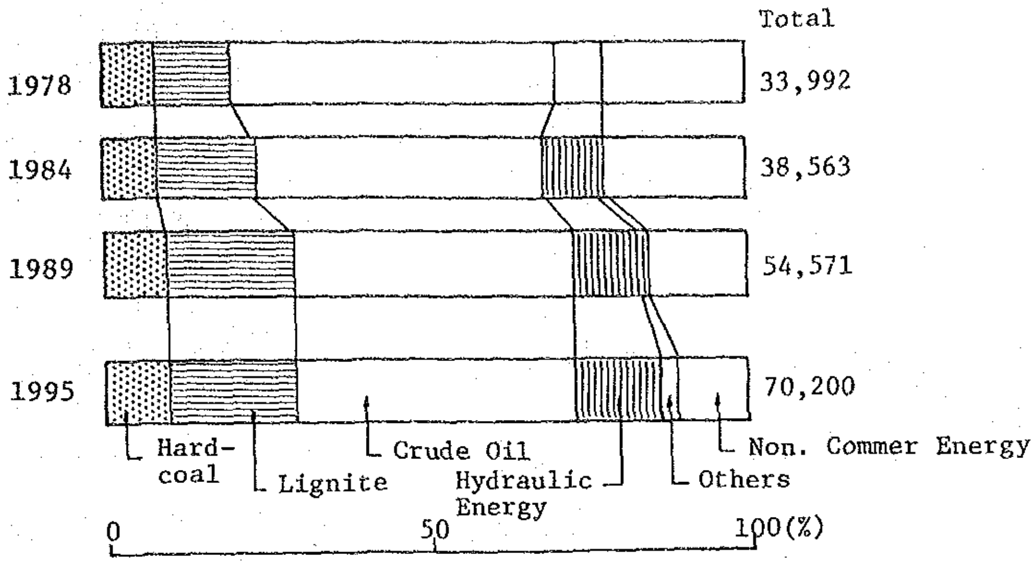
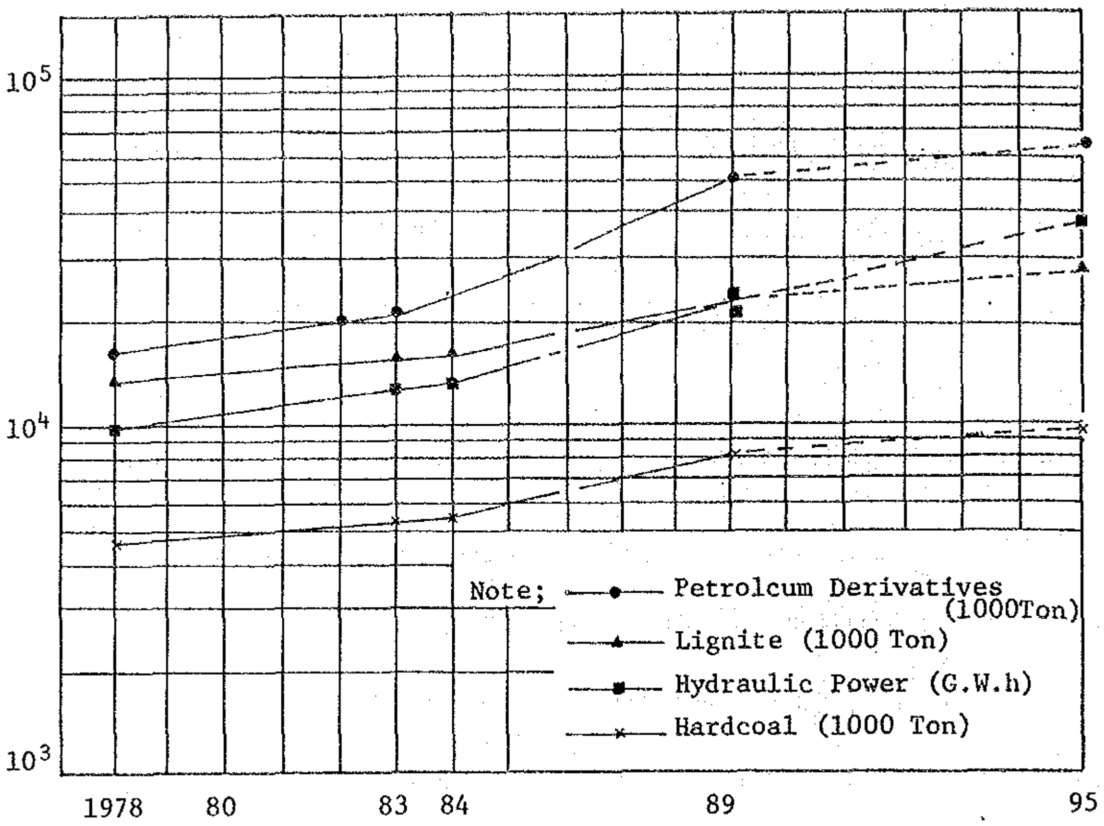


Figure 4.2.2 Trend of Shares of Primary Energy

Table 4.2.3 Trend of Consumption of Various Energy and Anticipated Requirement

	1978	1983	Ann. Aver. Perc. Incr.	1984	1989	Ann. Aver. Perc. Incr.	1995	Ann. Aver. Perc. Incr.
Hardcoal (1000 T)	4,634	5,259	2.6	5,400	8,300	9.0	10,600	4.2
Lignite (1000 T)	13,522	20,730	8.9	22,870	51,885	17.8	66,900	4.3
Petroleum Derivatives (1000 T)	16,070	15,786	-0.3	16,160	22,600	6.9	29,100	4.3
Natural Gas (Mill cub. mt.)	22	8	-18.3	8	710	245.3	950	5.0
Hydraulic Power (GWh)	9,365	11,354	3.9	12,185	22,400	12.9	38,900	9.6
Hydraulic Power (GWh)	-	-	-	57	90	9.6		
Electricity Imports (GWh)	621	2,223	28.9	2,190	-	-		
Wood (1000 T) (1)	15,248	17,086	2.3	17,258	17,815	0.6	18,466	0.6
Animal and Vegetal Wastes (1000 T) (t)	12,620	15,541	4.3	14,766	13,730	-1.4	12,616	-1.4
Solar Energy (1000 TEP)	-	-	-	1	2	14.9		
TOTAL (1000 TEP)	33,992	37,721	2.1	36,563	54,571	7.2	70,200	4.3



Year

Figure 4.2.3 Anticipated Trend of Consumption and Demand for Principal Energies

(3) Sectoral Breakdown of Primary Energy Demand

Consumption of primary energy by sector in 1983 and anticipated demand in 1989 according to the 5th Five-Year Plan are as shown in Table 4.2.4 and Table 4.2.5, respectively. The figures show that about 75% of the total primary energy was consumed for room heating (33%), industry (22%), and power plant (20%) in 1983. The tendency as a whole is assumed to be the same in 1989, although the figures are assumed to change into 25% for room heating, 26% for industry, and 25% for power plant, to show an increase in power plant and industry.

On the other hand, the trend of sectoral shares of energy sources shows no remarkable change between 1983 and 1989 in coal and petroleum, but lignite shows a large increase in power plant from 38.0% in 1983 to 51.9% in 1989, and a large decrease in room heating from 37.5% in 1983 to 25.8% in 1989.

As to the sectoral shares of primary energy in 1995, coal and petroleum are assumed, as shown in Figure 4.2.4, to be roughly the same as those of 1989 given in the 5th Five-Year Plan. On the other hand, if the sectoral shares in lignite is assumed as shown in Figure 4.2.4 considering the said trend and lignite thermal power plants being planned, the requirements of primary energy by sector in 1995 can be forecasted as shown in Table 4.2.6.

Table 4.2.4 Consumption of Primary Energy by Sector (1983)

Unit: equivalent of
1,000 tons of petroleum

	Indus.	Heat	Transp.	Agric.	Power Plants	Gas	Non-energy	Refine. and others	Total
Hardcoal	2,591	40	146	-	273	158	-	-	3,208
Lignite	1,332	2,097	40	-	2,128	-	-	-	5,597
Petroleum Derivatives	4,275	1,814	5,868	1,360	1,990	11	517	979	16,814
Natural Gas	7	-	-	-	-	-	-	-	7
Hydraulic Energy	-	-	-	-	2,839	-	-	-	2,839
Electricity Imports	-	-	-	-	556	-	-	-	556
Wood	-	5,126	-	-	-	-	-	-	5,126
Animal and Veget. Wastes	-	3,574	-	-	-	-	-	-	3,574
Total	8,205	12,651	6,054	1,360	7,786	169	517	979	37,721

Table 4.2.5 Demands for Primary Energy by Sector (1989)

Unit: equivalent of
1,000 tons of petroleum

	Indus.	Heat	Transp.	Agric.	Power Plants	Gas	Non-energy	Refine. and others	Total
Hardcoal	4,518	-	30	-	430	85	-	-	5,063
Lignite	2,306	2,740	50	-	5,504	-	-	-	10,680
Petroleum Derivatives	6,580	2,540	8,320	1,574	2,020	75	1,780	1,200	24,069
Natural Gas	632	-	-	-	-	-	-	-	632
Hydraulic Energy	-	-	-	-	5,800	-	-	-	5,800
Geothermal Energy	-	-	-	-	23	-	-	-	23
Solar Energy	-	2	-	-	-	-	-	-	2
Wood	-	5,344	-	-	-	-	-	-	5,344
Animal and Veget. Wastes	-	3,158	-	-	-	-	-	-	3,158
Total	14,016	13,784	8,400	1,574	13,657	160	1,780	1,200	54,571

Source; 5th Five-Year Development Plan

Table 4.2.6 Demands for Primary Energy by Sectors (anticipated for 1995)

Unit: equivalent of
1,000 tons of petroleum

	Indus.	Heat	Transp.	Agric.	Power Plants	Gas	Non-energy	Refine. and others	Total
Hardcoal	5,812	-	39	-	549	58	-	-	6,458
Lignite	2,752	2,683	69	-	8,255	-	-	-	13,759
Petroleum Derivatives	8,668	3,251	10,526	1,857	2,477	99	2,435	1,645	30,958
Natural Gas	842	-	-	-	-	-	-	-	842
Hydraulic Energy	-	-	-	-	9,744	-	-	-	9,744
Geothermal Energy									
Solar Energy									
Wood	-	5,539	-	-	-	-	-	-	5,339
Animal and Veget. Wastes	-	2,900	-	-	-	-	-	-	2,900
Total	18,074	14,373	10,634	1,857	21,025	157	2,435	1,645	70,200

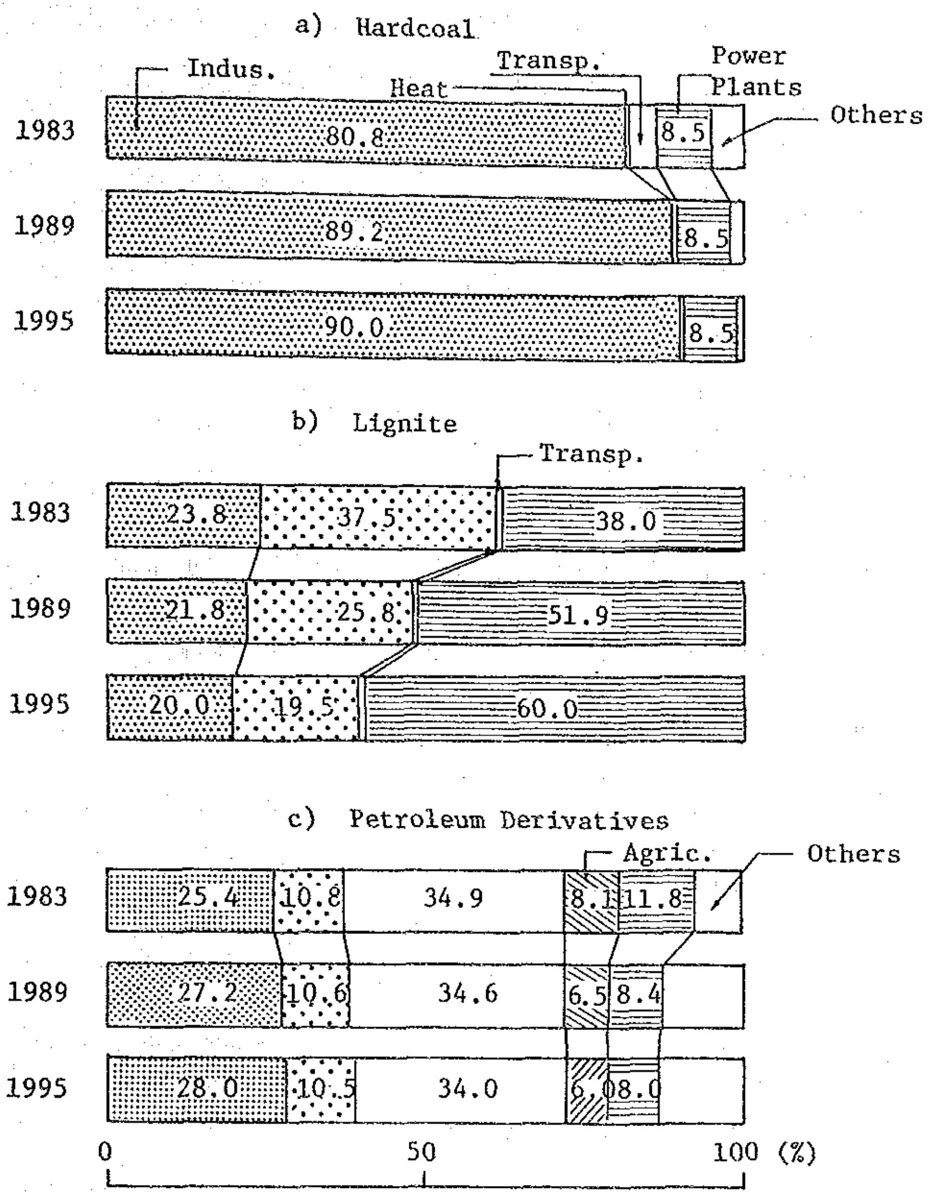


Figure 4.2.4 Trend in Shares of Principal Primary Energy by Sectors

4.2.2 Trend in Demand and Supply of Energy in Ankara City

Energy consumption in Ankara by the kinds of source is shown in Table 4.2.7; and the trend of consumption in Figure 4.2.5. According to the table, the trend of energy consumption in Ankara (1975-1983) shows an annual increase rate of about 10% for solid fuel, and about 5% for gas and electricity. However, practically no increase can be seen at present with regard to liquid fuel.

Table 4.2.7 Consumption of Various Kinds of Energy in Ankara City

Energy	Unit	1970	1975	1980	1981	1982	1983	83/75
1) SOLID FUELS	(x1000 ton) A.G.R.	375.4	514.8	1,024.9	958.6	936.4	1,175.0	10.9%
Lignite	(x1000 ton) A.G.R.	240.1	425.7	952.7	931.7	851.0	1,000.0	11.3%
Coke	(x1000 ton) A.G.R.	128.8	81.8	56.7	12.2	71.8	160.0	8.8%
Briquett	(x1000 ton) A.G.R.	6.5	7.3	15.5	14.7	13.6	15.0	9.4%
2) LIQUID FUELS	(x1000 M ton) A.G.R.		669.6	693.7	661.8	690.3	664.6	0.1%
Fuel Oil	(x1000 M ton) A.G.R.		289.6	260.7	256.8	256.3	226.3	-3.1%
Gasoline	(x1000 M ton) A.G.R.		183.0	189.0	165.0	160.0	155.0	-2.1%
Diesel	(x1000 M ton) A.G.R.		227.0	244.0	240.0	274.0	283.3	2.8%
3) GAS FUELS								
LPG	(x1000 M ton) A.G.R.		39.8	53.7	57.4	63.1	68.0	6.9%
City Gas	($x10^6$ m^3) A.G.R.	56.8	57.7	63.9	67.1	69.7	65.2	1.5%
4) ELECTRICITY	(GWh)							
Electricity	(GWh) A.G.R.	532.2	745.2	1,001.6	972.4	1,030.1	1,092.8	4.9%

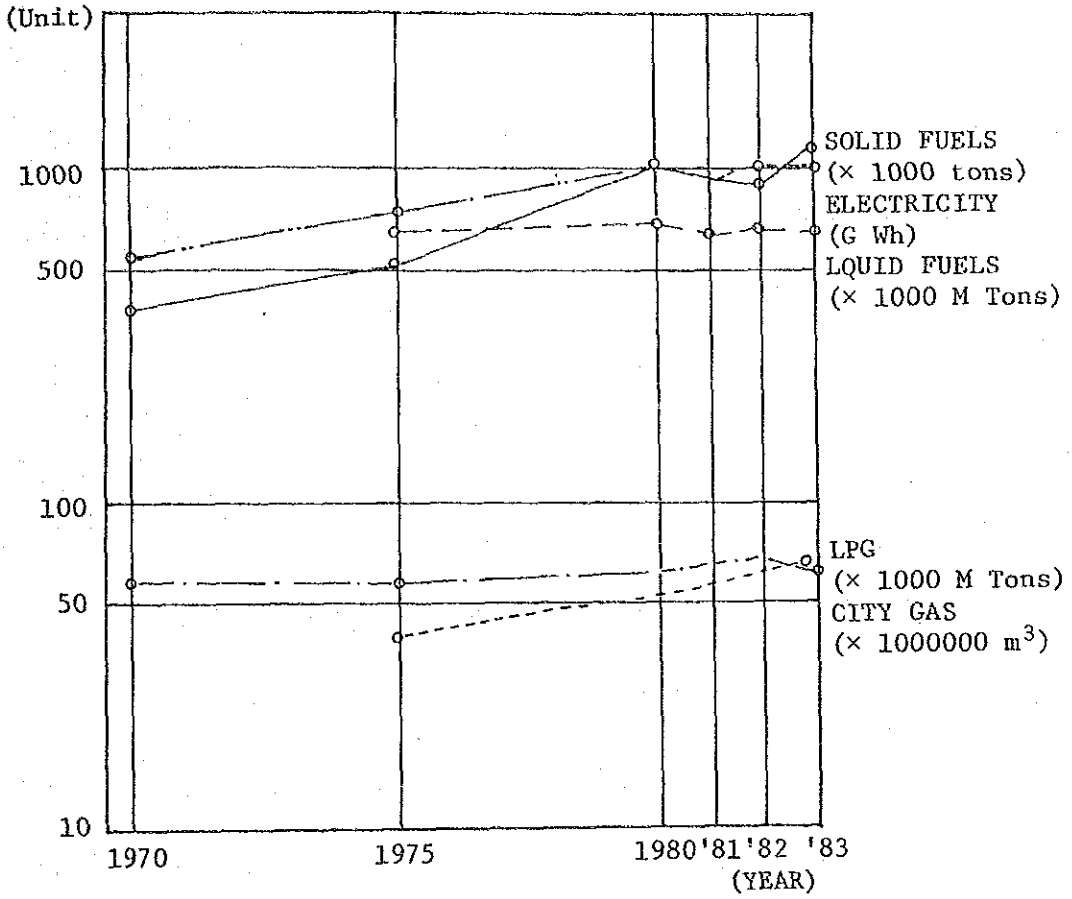
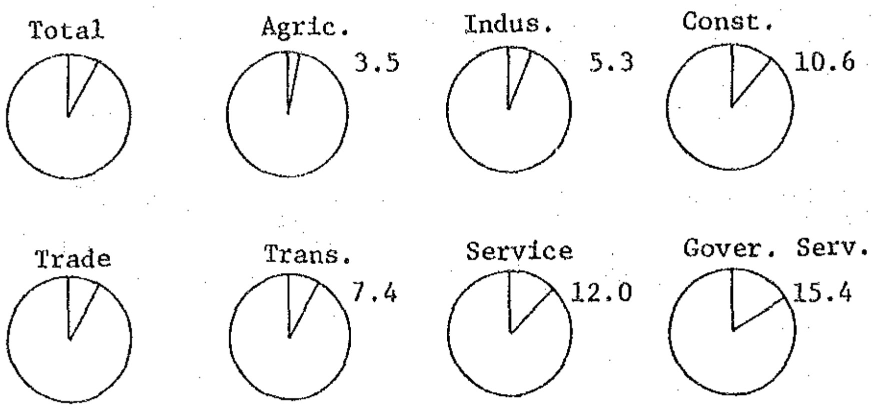


Figure 4.2.5 Trend of Consumption of Various Kinds of Energy in Ankara City

The ratios of GRP (gross regional product) in Ankara Province by sectors are shown in Figure 4.2.6. The figure shows the mean values of the ratio obtained by dividing the GRP by sector in Ankara Province by GDP (gross domestic product) by sector in whole Turkey for the period from 1975 to 1978. The figure shows that the ratio for the governmental service (15.4%), service business (12.0%), and construction business (10.6%) are larger than the ratio of population in Ankara Province against that of whole Turkey (about 6.4%), while ratio for agriculture (3.5%) and industry (5.3%) are smaller.



Note: $\text{Share} = \dfrac{\text{GRP by Sector in Ankara Province}}{\text{GDP by Sector in Turkey}} \times 100(\%)$

Source: Turkey's Gross Domestic Product by Province
1975, 1976, 1977 ve 1978 State Institute of Statistics.

Figure 4.2.6 Ratio of GRP by Sector in Ankara Province

4.2.3 Projection of Energy Demand in Ankara City

(1) General Approach

The demands for various energy in Ankara City in 1995 were estimated in the following manner.

For the primary energy, the consumption was calculated by multiplying the consumption of each primary energy for the whole Turkey in 1983 by the sectoral consumption ratios of each primary energy (of Table 4.2.4), with consideration of GRP ratio by sector in Ankara City (industrial structure of Ankara City was assumed from GRP ratio in Ankara Province by sector in proportion to the population, postulating that the industrial structure will not change in Ankara City). Here livelihood energy consumption was calculated in proportion to the population (the ratio of population in Ankara City against that of whole Turkey). The result of calculation was compared with the actual figures of various primary energy consumed in 1983. This revealed that the amount of lignite used for room heating in 1983 was 0.4 t/person/year in Ankara City, as against 0.17 t/person/year for the whole Turkey, showing more than twice as much consumption as in the whole country. This is considered to be due to the method of room heating as well as the geographical, topographical, and meteorological conditions in Ankara City.

In estimating the demand for energy in the future, the change of industrial structure and the increase of the population in Anakara City are considered to be the main factors.

The urban development plan of Ankara City mentions that a group of small factories in the Ulus area, located in the center of City, will be moved to the OSTIM area near Batikent. This move is in progress at present. There are also development plans for small and medium size factories in the western area of Yenimahalle.

Accordingly, in estimating the demand for energy in 1995, the major conditions will be assumed as follows:

a. The energy demand by the industrial sector remains unchanged in the urban district of Ankara City, increasing only in the suburb.

b. The energy demand in the domestic use is to be calculated by the population ratio (population in Ankara City estimated for 1995 against that for the whole Turkey) and a correction factor (obtained from the actual result in 1983).

(2) Projection of Energy Demand in 1995

i) Demand for Primary Energy

Based on the conditions given above, the demand for primary energy in Ankara City in 1995 was estimated from the demand for each primary energy anticipated in 1995 in the whole Turkey and the energy demand ratio by each sector in 1995 (Table 4.2.6) with the consideration of industrial structure in Ankara City.

ii) Demand for Secondary Energy in 1995

a. Coke and Coke Briquett

The consumption of coke had increased by the average rate of 8.8% per annum from 1975 to 1983, and coke consumption in 1983 was approximately 150,000 ton. But the consumption in 1984 was 120,000 ton; decreased from that in 1983.

About 70% of its consumption in 1983 was for room heating, and the use of room heating system with coke is limited to the central area of the Ankara City by the regulations. The population in this area has been decreasing. Accordingly, the demands for coke and coke briquette in the future are considered not to increase. As estimating the demands for coke and coke briquette in 1995, the consumption statistics of 1984 was used.

b. Gasoline

Demand for gasoline in 1995 was estimated based on the anticipated number of cars possessed, as stated in Section 4.1.6, that gives 220,000 cars by the logistic curve. The amount of gasoline was estimated for 160,000 cars among them from the trend of gasoline consumption in the past.

c. Diesel

Demand for diesel in 1995 was estimated in consideration that the 50% of the consumption in 1983 was used for diesel cars, and also the same method of the estimating gasoline was used.

d. LPG, City Gas

Demands for LPG and city gas in 1995 were estimated based on the increasing rates in the past (1975 - 1983); 6.9% for LPG, and 1.5% for city gas, respectively.

e. Electricity

Demand for electric power in 1995 was projected by estimating the amount of electric power generated from the primary energy of 21,025 x 10^3 (equivalent of tons of petroleum) to be used in power plants as shown in Table 4.2.6, at 77,975 GWh, and from the characteristic features of electric power consumption in Ankara City in the whole Turkey in the past.

iii) Projection Results

The estimated demand for each energy in Ankara City obtained by the method described above is shown in Table 4.2.8.

Table 4.2.8 Energy Demand in Ankara City by Sources

Energy	Unit	1983	1975-1982/ 1983	1995	1983-1995
1) Solid Fuels	(x1000 ton)	1,165.0	10.9%	1,407	1.6%
lignite		1,000.0	11.3%	1,270	2.0%
Coke		150.0	8.8%	124	-1.0%
Briquette		15.0	9.4%	13	-1.0%
2) Liquid Fuels	(x1000 m ton)	664.6	-0.1%	928	2.8%
Fuel Oil		226.3	-3.1%	380	4.4%
Gasoline		155.0	-3.1%	208	2.5%
Diesel		283.3	2.8%	340	1.5%
3) Gas Fuels					
LPG	(x1000 m ton)	68.0	6.9%	150	6.9%
City Gas	(x10^6 m^3)	65.2	1.5%	80	1.5%
4) Electricity	(GWh)	1,092.8	4.9%	3,100	9.1%

Note: The demand for lignite for domestic use was estimated based on the figure of 0.47 t/person/year = 0.40 (in 1983) x 0.20/0.17 in Ankara City against 0.2 t/person/year in the whole Turkey. But for the additional increase of population after 1983, effect of thermal insulation for new buildings was taken into consideration, and the figure of 0.33 t/person/year (0.47 x 0.7) was used.

CHAPTER 5 TECHNICAL AND ECONOMIC STUDY OF POLLUTANT SOURCE CONTROL MEASURES

CHAPTER 5 TECHNICAL AND ECONOMIC STUDY OF POLLUTANT SOURCE CONTROL MEASURES

5.1 POSSIBILITY OF SWITCHOVER TO HIGHER QUALITY ENERGY SOURCES

Outline of energy consumption in residences and offices in Ankara by kinds of energy is shown in Table 5.1.1.

Table 5.1.1 Consumption and Cost of Energy Sources for Residences and Offices in Ankara City in the Winter of 1983/84

Energy	Consumption	Price	Average Calorific Value	Unit Price per Calorie (TL/1,000 kcal)
Lignite	1,000,000 ton	14,000 TL/t	4,200 kcal/kg	3.3
Coke	160,000 ton	28,000 TL/t	5,400 kcal/kg	5.2
Coke-Briquette	15,000 ton	25,400 TL/t	5,331 kcal/kg	4.8
Fuel oil	220,000 ton	114,300 TL/m^3	10,500 kcal/kg	11.9
City gas	65,000,000 m^3	75 TL/m^3	3,577 kcal/kg	21.0
Electricity	854 Gwh	33 TL/kwh	860 kcal/kwh	38.4

Note: Specific gravity of the fuel oil was assumed to be 0.916.

The Table 5.1.1 implies that the higher the unit price per calorie, the more convenient for use and cleaner is the energy source. However, lignite and other energy sources of low unit price per calorie that contain high level of sulfur are mainly used for heating offices and private residences. To mitigate the air pollution, authorities proclaimed regulations under which laved lignite with lower sulfur content is to be used in place of ungraded lignite, and fuel oil rather than lignite for new buildings.

Although the administrative decisions were made, the economic situation of Turkey makes it difficult to materialize.

At the supply side, there are problems awaiting for decisions at the national level, such as; 1) a sufficient amount of foreign currency must be reserved for the import of low-sulfur fuels such as oil, natural gas,and high quality coals; 2) even in case of domestically available energy sources, they must be distributed appropriately among industrial and domestic uses; and 3) capital investment must be secured for the construction of power generation plants and gas plants.

At the consumption side, demand for the quality of domestic heating energy is strongly dependent on the household income, although the quantity of heating energy required per household is about the same regardless of income level. It is a common tendency that the demand will shift to fuels of low unit price per calorie when the income is low whereas the demand will shift to high quality energy source of higher unit price when the income is high.

It is considered that the stagnation in the consumption of fuel oil and increase of the lignite consumption observed in the recent years reflect the tendency stated above.

These circumstances notwithstanding, it depends largely on the political decision whether the course of switchover of energy source is to be taken in the light of the protection of public health realizing that the air pollution in Ankara is already at a serious level.

It is easily conceived that the cost for the switchover is high, and difficulty involved is great. However, the switchover to the higher quality energy sources is the essential and most effective means of air pollution control.

Since this subject is strongly related to a political decision, further discussion is not intended in the Study.

5.2 LIGNITE QUALITY IMPROVEMENT

Technique of briquetting, in which lime is added to pulverized coal and the mixture is shaped into proper sizes, has been used as ever in some countries including Japan. When briquette is burned, sulfur in SO_2 gas is fixed into gypsum thereby reducing the emission of SO_2.

However, if this technique is applied to the Turkish lignite as it is, some problems are expected in combustibility and physical strength after the shaping because of the high levels of ash content and relatively low carolific value. Study how to cope with the spontaneous combustion is also necessary because of the high level of volatile matter contained in the lignite.

Therefore, technical and economical study based on the experiment is required in order to apply the techniques of briquetting to the Turkish lignite.

In this Study, the following three methods were studied.

1) Lime used as primal additive, the lignite is shaped into the size of 40-50 mm (hereinafter called as "briquette").

2) Lime added primarily, the lignite is formed in cylindrical shape having air holes (hereinafter called as "rentan").

3) Pulverized wood and lime added primarily, the lignite is shaped into the similar size as in 1) above (hereinafter called as "biocoal").

Results of the study made on these methods are described in the following sub-sections.

5.2.1 Briquette

(1) Effect of Washing in Reducing Sulfur Content

Prior to the briquetting study, washing test was conducted on the ungraded lignite in order to ascertain the sulfur reducing effect of the washing treatment of lignite.

Five kg of ungraded lignite (sulfur content of 2.7%) was crushed into pieces of about 5 cm, and washed. Two specimens were prepared for the determination of total sulfur remained. The results are shown in Table 5.2.1.

Table 5.2.1 Sulfur Reduction Rate by Washing

Specimen	Total sulfur content	Reduction rate
Specimen A	1.89%	31.5%
Specimen B	2.20%	19.3%
Average	2.06%	25.4%

Note: Specimen A was washed for about 30 minutes, and specimen B, was washed in running water for about 3 minutes.

From the results obtained, it is clear that the quality improves by only about 20% under normal conditions of washing.

The lignite presently supplied in Ankara as "laved lignite" contains sulfur by 1.4% in average. It is confirmed later that the "laved lignite" is not produced by simply washing "ungraded lignite" (2.7% S content), but differs in source of origin from that of the ungraded lignite.

(2) Sulfur Fixation by Lime Addition

Eight briquette specimens were prepared by adding lime to the laved(*) and the ungraded lignites by 0-11% in amount.

Two analyzing institutes A and B conducted the analysis of the specimens for sulfur content and obtained the sulfur fixation rate after combustion comparing with the residual sulfur content in ash. The test results are shown in Table 5.2.2.

(*) The "laved lignite" here refers to that supplied in Ankara.

Table 5.2.2 Fixation Rate of Sulfur in Briquette

(Unit: %)

Briquette material	Analyzed by	Lime percentage				
		0	3	5	8	11
Laved lignite	A	-	-	81.8	82.3	80.9
	B	-	78.4	97.4	99.1	-
Ungraded lignite	A	12.3	54.2	67.7	88.4	-
	B	5.5	-	90.0	100.0	-

Note: Institute A used the combustion method specified in the Japan Industrial Standards. Institute B used a portable stove for combustion.

As is clear from Tablle 5.2.2, the sulfur fixation rates were heighest being above 90% on an average when 8% of lime was added.

Further, 10 each of those specimens were extracted and burned in a portable stove to measure the concentration of SO_2 in emissions. The results obtained are shown in Table 5.2.3.

Table 5.2.3 SO_2 Concentration in Exhaust Gas

(Unit: ppm)

Lime percentage / Lignite type	0	3	5	8	11
Lave lignite	-	221	96	65	90
Ungraded lignite	366	335	170	105	-

The SO_2 concentration in exhaust gas was the lowest with 8% of lime added. It reveals further that adding lime more than 8% will no longer improves fixation rate, and besides calorific value will decrease as ash content increases. The subsequent combustion tests, therefore, were carried out on the test briquette with 8% addition of lime.

(3) Briquette Combustion Test Using Stove

Three kinds of briquette with different calorific values produced from ungraded lignite adding 8% of lime were used in the combustion test in stoves.

In the test, measurements were made on flow rate of exhaust gas (with a Pitot-tube flowmeter), temperature of exhaust gas, combustion temperature (with a CA thermocouple), concentration of SO_2 (by neutralization titration), and concentration of dust (with a filter paper). The amounts of SO_2 and dust emission were then calculated. The total sulfur content of specimens had been determined in prior to the test.

There are two methods of determining the fixation rate of sulfur:

a) determination from the difference between the sulfur content of specimen and that in ash

b) determination from the difference between the sulfur content of specimen and that obtained from the amount of exhaust gas and the concentration of SO_2 in the gas.

It is fairly difficult to obtain an accurate value in this type of analysis. There are often disagreements in results between the two methods. In this test, the method b) was adopted.

The results obtained from the combustion test of 3 kinds of briquettes with different calorific values are shown in Table 5.2.4.

Table 5.2.4 Briquette Combustion Test

Kind of Specimen	Specimen weight	Total sulfur weight	Ash weight	Ash content	Maximum combustion temperature	SO_2 emissions	Sulfur fixation rate
Briquette 1	3000g	51.0g	1462g	47.7%	970°C	19.4g	81.0%
	5000	87.2	2252	45.0	1090	78.5	55.0
Briquette 2	4500	86.1	1824	40.5	1140	63.2	63.3
Briquette 3	4885	76.9	1597	32.7	1140	37.7	75.5
	4000	63.0	1258	31.5	1200	19.9	84.2
	3000	58.8	871	29.0	1120	11.7	90.1
	3000 + 2000*	69.0	1705	34.1	1170 1190	26.3	81.0
	4000	66.8	1252	31.3	1142	19.2	85.6
Average	-	-	-	-	-	-	77.0

Notes: Estimated calorific values of the briquette above are as follows.
Briquette 1: approx. 3,700 kcal/kg
Briquette 2: approx. 4,000 kcal/kg
Briquette 3: approx. 5,000 kcal/kg

* The specimen of 3000g was first burned and then 2000g specimen was added in about 1 hour.

The average sulfur fixation rate obtained was 77%.

Taking analytical errors into account, it is considered reasonable to assume the fixation rate being 75%.

(4) Dust Removal Effect of Briquette

The amount of dust emitted by the combustion of each kilogram of fuel was calculated from the results of the flue gas analysis conducted in Ankara and the combustion tests conducted in Japan. The results are shown in Table 5.2.5.

Table 5.2.5 Amounts of Dust Emitted by the Combustion of Lignite and Briquette

Kind of fuel	Test No.	Dust produced form each kilogram of fuel(g)	Average (g)
Laved lignite	1	4.7	4.5
	2	4.2	
Ungraded lignite	3	16.0	16.0
Briquette 1	4	0.6	2.7
	5	2.1	
Briquette 2	6	6.6	
Briquette 3	7	3.7	
	8	1.1	
	9	2.9	
	10	1.6	
Rentan	11	0.1	0.2
	12	0.3	

As shown above, the amount of dust emitted by the combustion of briquette is about 60% of that of the laved lignite (40% reduction) and 17% of that of ungraded lignite (83% reduction). When rentan is burned, dust reduction rates are 96% and 99% in comparison with the laved and the ungraded lignite, respectively.

(5) Shaping Test

Proper material and amount of binder to be mixed with lignite are the key factors to make quality briquettes for handling and flamability. Therefore, a series of tests was conducted for shaping briquette.

i) Starch Binder

Briquette was made from lignite using starch as the binder and shaping them in a roll press and then drying. Hardness was tested by applying load onto the briquette on a weighing machine.

The hardness of the briquette showed between 10 to 20 kg. For a reference, that of anthracite briquette normally ranges from 40 to 50 kg.

ii) Cement Binder

Lignite briquette was shaped by adding about 7% of cement. The hardness of this briquette was measured in the same manner as described above giving the results ranging from 40 to 60 kg. The briquette of this hardness will meet the requirement of practical use.

It is desirable to reduce further the amount of cement in relation to the amount of lime added. The calorific value will be reduced by increasing ash content due to the addition of lime and cement. Therefore, it is advised to add some amount of high calorific coal to improve the calorific value.

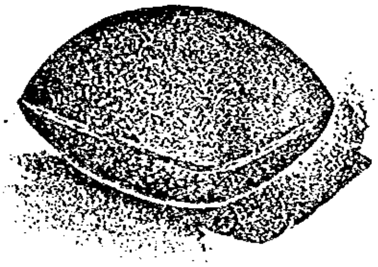
Use of cement as a binder is economically advantageous. And more, the cement-bound briquette has a high degree of waterproofing, and getting wet in rain does not cause serious problem.

iii) Conclusion

The series of tests revealed that briquette shaped with starch as a binder is not of practical use because they are easily broken by mechanical shocks. With economy in mind, as well as durability, use of cement as a binder is considered to be advantageous.

(6) Specifications of Briquette

Shape	Maschec type
Size*	48(L) x 48(W) x 38(H) mm
Weight	approx. 55 g
Hardness	40 to 50 kg



* Briquette can be shaped into various sizes other than that indicated.

(7) Briquette Manufacturing Plant

i) Plant Capacity

Annual consumption of ungraded lignite in Ankara at present is aproximately 800,000 tons. Plant capacity is assumed to be 100,000 tons per year, similar to a typical plant in Japan, for estimating cost of briquette plants.

Production capacity per hour: 15 tons (standard)
Annual operating time: 7,000 hours
Annual production: about 100,000 tons

ii) Raw Lignite

Amount used per hour: 16.3 tons
Amount used per year: 109,000 tons

iii) Product Specifications

See Sec. 5.2.1, (6).

iv) Production Process

The processes of briquette production are described below, referring to the flowchart shown in Figure 5.2.1.

a. Reception of Raw Lignite

Raw lignite is transferred by the shovel loader from the yard to the plant area and placed on the conveyor. After transferred from the conveyor to the trommel, the raw lignite is cleared of foreign matters and charged into the hopper.

The lignite should not be greater than 30 mm in size because of limitations on the battery. If the lignite larger than 30 mm is used, a crusher needs to be installed.
Dressing is required if the raw lignite contains mud, debris, and other foreign matters.

b. Mixing and Crushing

The lignite discharged from the hopper is put into the paddle mixer at a properly adjusted feeding rate. The lignite is mixed with lime which is also supplied into the mixer by a fixed amount.

The lignite-lime mixture is fed to the intermediate hopper. It then enters the crusher at a fixed flow rate and crushed.

The coarsely crushed mixture is fed to the paddle mixer through the trommel and mixed with binder.

c. Milling and Kneading

The mixture from the paddle mixer is transferred to the edge runner mill (or fret mill) through the conveyor system and milled and kneaded.

The milling and keading is the most important process in the briquetting.

d. Shaping

The briquette is shaped by use of three roll presses, each press having a normal capacity of 5 tons per hour.

The flow of mixture is divided into three, each leading to a roll press through the conveyor system.

The mixture is shaped into the Maschec briquette in the roll press.

e. Drying and Cooling

The briquette discharged from the roll press is led to the tunnel dryer and dried.

Hot air from the blast furnace heated by lignite (preferably briquette) is used in the dryer. The air is recycled.

The dried briquette is then led to the conveyor-type refrigerator to be cooled for the final process of production.

f. Storage of Product and Shipping

The finished briquette is carried by the conveyor to the warehouse for storage.

The product is transported by truck in bulk or in the package bags to consumers.

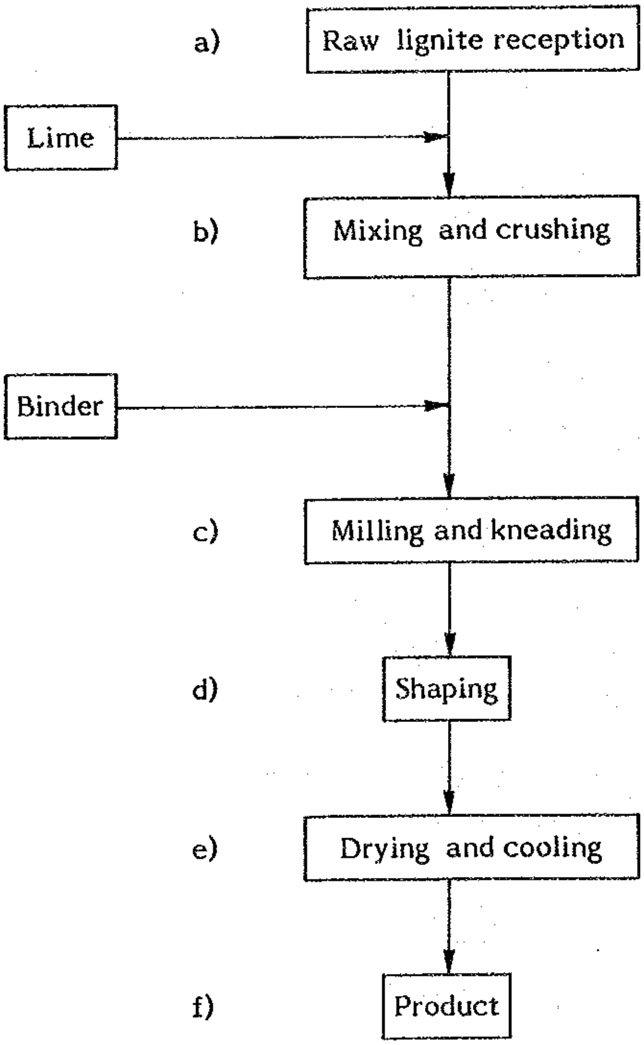


Figure 5.2.1 Briquette Production Process

v) Law Materials and Utilities Consumption
(per ton of product)

a. Raw material

Ungraded lignite: 1.09 tons

b. Auxiliary materials

Slaked lime:	20 kg
Cement:	80 kg
Water:	150 liter

c. Utilities

Power:	35 kWh
Lignite fuel:	90 kg

Note: The figures shown above are approximate values and subject to change depending on the results of detailed study.

(8) Cost Estimation

i) Plant Cost

The plant costs are broken down as follows.

• 100,000 tons/year plant cost (including 2 year spare parts, marine transportation, and insurance)	1 set	1,220,000,000 yen
• Inland transportation (in Turkey)	1 set	12,000,000 yen
• On-site construction	1 set	190,000,000 yen
• Transportation and overhead costs required in the construction period (including interest)	1 set	60,000,000 yen
• Construction of factory shed, warehouse,office, and other buildings	1 set	203,000,000 yen
• Auxiliary facilities	1 set	421,250,000 yen
	Subtotal	2,106,250,000 yen

- Options

- Coal crusher (including marine transportation and insurance)	1 set	213,000,000 yen
Inland transportation (in Turkey)	1 set	5,000,000 yen
- Container bag (1.5 m^3 x 4,000) (including marine transportation and insurance)	1 set	252,000,000 yen
Inland transportation (in Turkey)	1 set	2,300,000 yen
	Subtotal	472,300,000 yen
	Grand total	2,578,550,000 yen (5,414,955,000 TL)

ii) Unit Production Cost (per ton)

• Plant depreciation (period, 10 years; interest, 8%) 2,324 + 1,859 (interest) =	4,183 yen (8,784 TL)
• Labor cost	200 yen (420 TL)
• Repairs (3% of plant cost)	571 yen (1,200 TL)
• Transportation container depreciation (period, 5 years; interest, 8%)	672 yen (1,411 TL)
• Materials and utilities	
Raw material	1.09 tons x 4,333 yen = 4,723 yen (65% of Ankara retail price)
Lime	20 kg x 14 yen/kg = 280 yen
Cement	80 kg x 8 yen/kg = 640 yen
Power	35 kWh x 15 yen/kW = 530 yen
Fuel lignite	90 kg x 4,333 yen/ton = 390 yen
	6,563 yen (13,782 TL)
Total Cost/ton	12,189 yen (25,596 TL)

As shown above, the lignite briquette cost per ton is about 26,000 TL including the comparatively high initial investment cost required in the first year. When high-quality coal and other similar materials are blended to increase the calorific value, the cost will be 10 to 20% higher than otherwise.

5.2.2 Rentan

The process of making rentan is similar to that of briquette; adding lime and binder to raw material. As shown in Sec. 5.2.1 the best ratio of addition of liime is 8%. Dustproof effect of rentan was already shown. In this sub-section, description will be made on the desulfurizing effect of rentan, rentan stove, specifications of rentan, rentan manufacturing plant, and rentan manufacturing cost.

(1) Rentan Combustion Test Using a Stove

Ungraded lignite crushed and mixed with 8% of lime was shaped into rentan measuring 206 mm in diameter and 157.5 mm in height. The specimens thus made were brought to the same combustion test as done for briquette. The test results obtained are shown in Table 5.2.6.

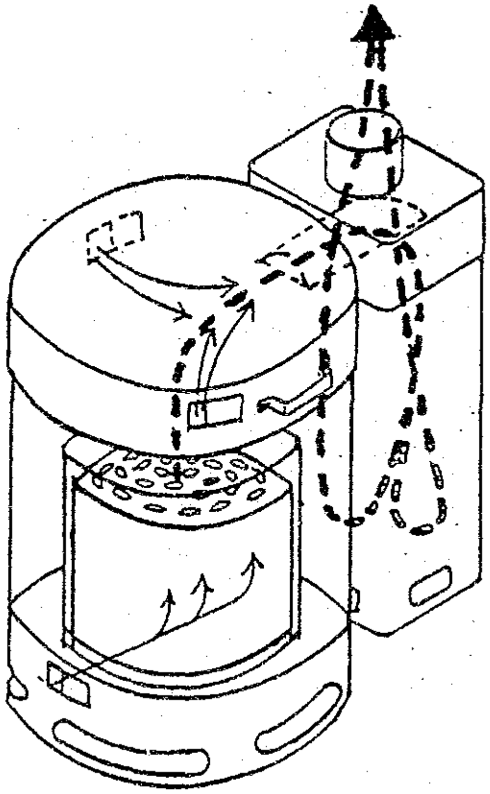
Table 5.2.6 Results of Rentan Combustion Test

Specimen	Specimen weight	Total sulfur weight	Ash weight	Ash content	Maximum combustion temperature	SO_2 emission	Sulfur fixation rate
Rentan 1	5076g	114g	1458g	28.7%	1040°C	24.1g	89.4%
Rentan 2	5105	115	1217	23.8%	1090	45.3	80.3
Average	-	-	-	-	-	-	84.9

As shown above, an average sulfur fixation rate was about 85%.

(2) Stove for Rentan

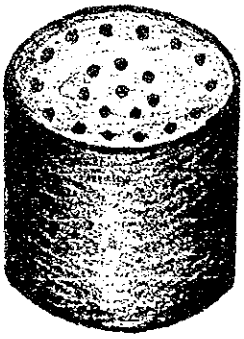
For the burning of rentan made of lignite with high content of volatile matter, the stove should have a secondary combustion chamber for the efficient heat radiation (refer to Sec. 5.3.1, (2)). A new stove for lignite rentan designed based on a Japanese-made stove, as described in Sec.5.3.1, gives excellent burning conditions resulting in a long heat retention time with high surface temperatured (see the Figure below).



The main part of the stove consists of steel plate and partly of cast iron and refractory materials. The surface is coated with a paint which withstands 800°C. If locally manufactured in Turkey, the stoves will be made available for 35,000 to 40,000 TL.

(3) Specifications of Rentan

Shape	number of holes, 25; diameter of hole, 15 mm
Size	206(diam.) x 257.5(H) mm
Weight	approx. 5 kg



(4) Rentan Manufacturing Plant

i) Plant Capacity

a. Production capacity per hour: 12 tons (standard)
b. Annual operating time: 7,000 hours
c. Annual production: approx. 84,000 tons

ii) Raw Lignite

a. Amount used per hour: 13tons
b. Amount used per year: 91,000 tons

iii) Product Specifications

See Sec. 5.2.2, (3).

iv) Production Process

The processes of rentan production are explained below, referring to the flowchart shown in Figure 5.2.2.

a. Reception of Raw Material

Raw lignite should not be larger than 50 mm in size. If larger lignite is used, a crusher needs to be installed. Dressing is required when mud, debris, or other foreign matters are contained in the material.

b. Blending

The crushed lignite is charged into the taper screw blender and blended with water, lime, and cement.

c. Milling and Mixing

The blended material is charged into the fret mill, mixed, and milled.

d. Kneading

The mixture is charged into a double horizontal kneader in which it is mixed with water. Afterwards, it is sufficiently mixed through further addition of water in the horizontal and vertical kneaders.

e. Shaping

The kneaded mixture is fed to a 10-case rotary press and shaped into rentan.

f. Drying

The shaped rentan can be dried under the sun to make the finished product.

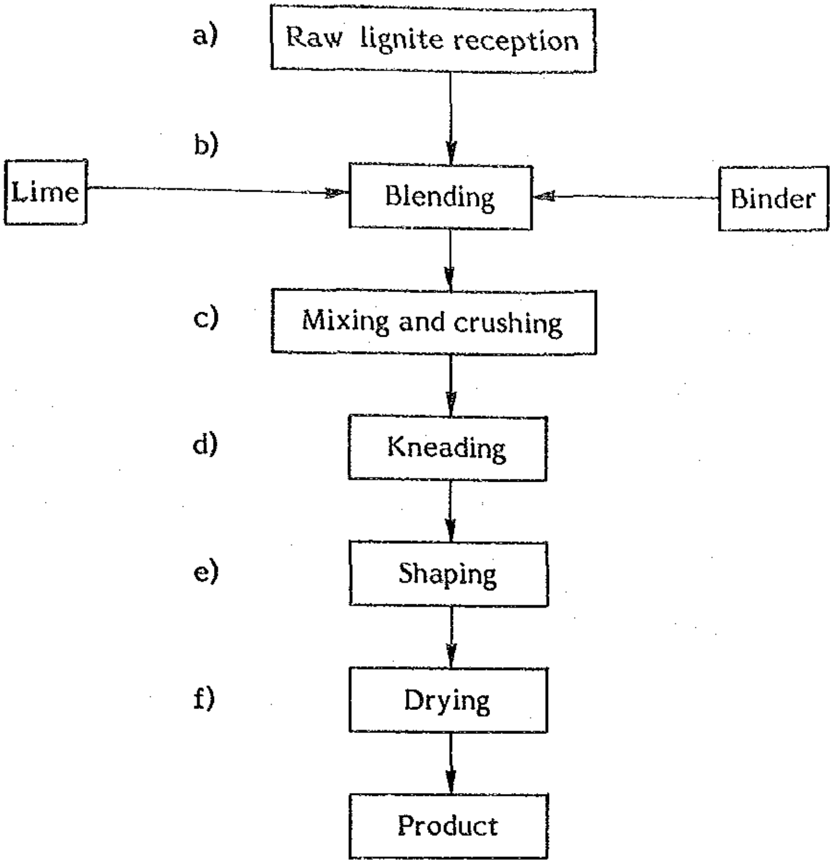


Figure 5.2.2 Rentan Production Process

v) Consumption of Raw Material and Utilities (per ton of product)

a. Raw material

Ungraded lignite: 1.09 tons

b. Auxiliary materials

Slaked lime: 30 kg
Cement: 70 kg
Water: 150 lit

c. Utilities

Power: 25 kWh

Note: The figures shown above are approximate values and subject to change depending on the results of detailed study.

(5) Cost Estimation

i) Plant Cost

The plant costs are shown below.

• 84,000-ton/year plant (including 2-year spare parts, marine transportation, and insurance)	1 set	450,000,000 yen
• Inland transportation (in Turkey)	1 set	7,500,000 yen
• On-site construction	1 set	105,000,000 yen
• Materials locally purchased	1 set	16,000,000 yen
• Transportation and overhead cost required in the construction period (including interest)	1 set	25,000,000 yen
• Construction of factory shed, warehouse,office, and other buildings	1 set	130,000,000 yen
• Auxiliary facilities	1 set	183,375,000 yen
	Total	916,875,000 yen (1,925,437,500 TL)

ii) Unit Production Cost (per ton)

• Plant depreciation (period, 10 years; interest, 8%)	1,091 yen + 873 yen (interest) = 1,964 yen(4,124 TL)
• Labor cost	600 yen (1,260 TL)
• Repairs (3% of plant cost)	220 yen (462 TL)
• Materials, utilities, and other raw material	1.09 tons x 4,333 yen/kg = 4,723 yen (65% of Ankara retail price)
Lime	30 kg x 14 yen/kg = 420 yen
Cement	70 kg x 8 yen/kg = 560 yen
Power	25 kWh x 15 yen/kW = 375 yen
Packaging paper	20 sheets x 60 yen/shee = 1,200 yen
	7,278 yen (15,284 TL)
Total Cost/ton	10,062 yen (21,130 TL)

As shown above, the cost of rentan is estimated at about 21,000 - 22,000 TL per ton.

5.2.3 Biocoal

(1) General Features of Biocoal

Biocoal is a kind of briquette made in combination of advantages of wood (low ash content, low nitrogen content, small amount of smoke emitted, and high combustibility), and of coal (high-calorie). The biocoal gives extended time of combustion, quick ignition, and appropriate calorific value. Many kinds of coals can be mixed with various kinds of wooden materials, such as sawdust, bark, and scrapped members of building. Three kinds of methods are generally adopted in briquetting: compression, addition of binder, and heating (at 60 to 80°C) under high pressure. Because biocoal is produced by means of compression, the product retain intrinsic characteristics of materials. Specifically, fluidic characteristics of wooden materials enhance the performance of biocoal; lignin hemicellulose constituting wooden structure softens at relatively low temperatures, and lignin particularly displays its adhesiveness property above the softening temperature. The wooden materials therefore provide the product with excellent effect of binder as well as the characteristics as a fuel.

For the sake of sulfur reduction, it is necessary to add lime as is required for briquette and rentan. But since the addition of cement as the binder is not required, reduction in the calorific value is minimized.

(2) Sulfur Reduction Effect

Sulfur reduction rate of lignite in relation to rate of lime added was already shown in Table 5.2.2.

The combustion tests in stove were carried out using the biocoal made on an experimental basis (mixing ratio for lignite, wood fluor, and lime is 71 : 24 : 5).

From the results of the test (under the normal burning temperature), it was confirmed that the sulfur fixing rate is approximately 75%.

(3) Compressive Strengh and Waterproofing of Biocoal

To check the compressive strength and waterproofing of biocoal, several kinds of test were made using the biocoal made of Turkish lignite, Japanese wood, and lime (with mixing ratio same as above).

Generally, the coal-wood pellet increases its hardness with increasing amount of wooden material or their increasing fineness. For this reason, lignite was crushed into pieces of diameter below 1 mm. Wood flour with the particle size greater than 1 mm constituted 5% of all the wood and the remaining bulk of flour had the sizes ranging from 0.3 to 0.6 mm. (The lignite used in the test had a moisture content of 14.7% and the wood flour 10.0%.)

The tests were also made on the specimens of different mixing ratio of lime including of no lime added.

The results of the series of the tests are as follows.

a. The strength of biocoal increases with increasing pressure for shaping.

b. The biocoal made by adding slaked lime showed a higher strength compared with the biocoal made without adding lime.

c. The larger the amount of wooden materials added, the higher the compressive strength of biocoal becomes. The strength of specimens containing wood by 50% was 1.5 - 2.0 times that of specimens containing wood by 20% under the condition of relative humidity being 42% at the room temperature. This means that addition of wooden materials undoubtedly increases the compressive strength of biocoal. A strength between 100 and 300 kg/cm^2 was obtained with 15 to 25% addition of wooden materials. At a high relative humidity (93%), strength of the lignite-wood biocoal greatly decreased due to its hydroscopicity. When the biocoal is to be protected against moisture, waterproof container or other suitable means should be used in transportation.

(4) Biocoal Manufacturing Plant

i) Plant Capacity

The plant capacity is assumed to be 100,000 tons/year as it was for the briquette plant.

a.	Production capacity per hour:	15 tons (standard)
b.	Annual operating time:	7,000 hours
c.	Annual production:	100,000 tons

ii) Lignite and Wooden Materials

a. Amount used per hour

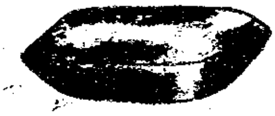
11.7 tons (lignite)
3.6 tons (wooden materials)

b. Amount used per year

82,000 tons (lignite)
25,200 tons (wooden materials)

iii) Product Specifications

Shape	almond type
Size	37(L) x 22(W) x 13(H) mm
Weight	8 g
Hardness	120 kg



Note: Further study is recommended on the specifications of biocoal for practical use.

iv) Production Process

The outline of biocoal production process is shown in Figure 5.2.3.

a. Materials

Sizes of raw lignite and wooden materials should not be greater than 40 mm and 200 mm, respectively. Lignite containing stones, mud, debris, and other foreign matters should be removed. Generally, coals with non or low caking power, low ash content, and high calorific value are desirable in producing high-grade biocoal. The quality of biocoal produced from the low-grade coal can be improved by the addition of oil-coke and other suitable materials. Wooden materials that can be used include chips produced in the woodworking industry, scrapped building materials, and scrap wood in forests. However, materials should have a grain size equivalent to that of sawdust.

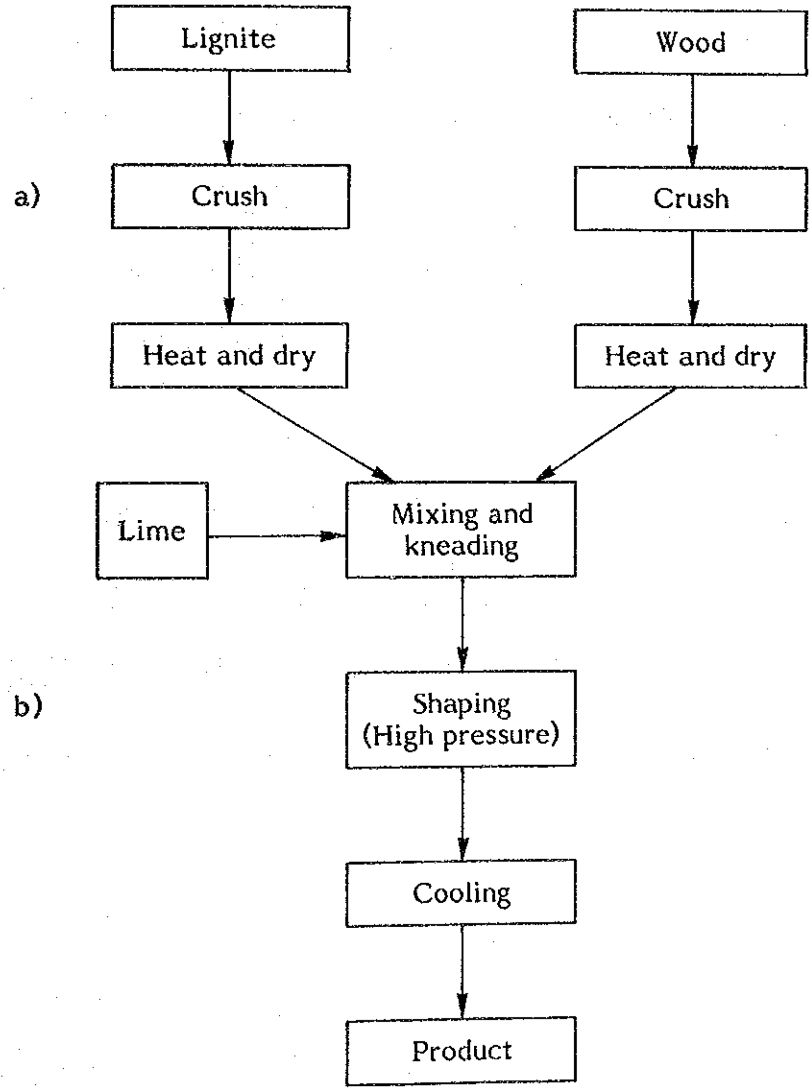


Figure 5.2.3 Biocoal Production Process

b. Mixing, Crushing, and Shaping

Raw materials are adjusted for proper level of moisture and grain size, and mixed with the ratio of 72% lignite, 23% wooden material, and 5% lime. The mixture is heated at 60 to 80°C and then fed immediately into the roll which has pockets of specified shape and size. Biocoal is continuously produced by the two rolls under the high pressure (3 to 5 tons/cm^2).

v) Raw Materials and Utilities Consumption (per ton of product)

a. Materials

Ungraded lignite:	0.78 ton
Wooden materials:	0.24 ton

b. Auxiliary materials

Slaked lime:	50 kg
Water:	1 m^3

c. Utilities

Power:	61 kWh
Lignite fuel:	40 kg

Note: The figures shown above are approximate values and subject to change depending on the results of detailed study.

(5) Cost Estimation

i) Plant Cost

The plant costs are as follows.

• 100,000-ton/year plant (including costs of 2-year spare parts, marine transportation, and insurance)	1 set	1,190,000,000 yen
• Inland transportation (in Turkey)	1 set	12,000,000 yen
• On-site construction	1 set	180,000,000 yen
• Materials and equipment locally purchased	1 set	80,000,000 yen
• Transportation and overhead cost required in the construction period (including interest)	1 set	64,000,000 yen
• Construction of factory shed, warehouse, office, and others	1 set	152,000,000 yen
• Auxiliary facilities	1 set	419,500,000 yen
	Subtotal	2,097,500,000 yen
• Options		
- Container bags (1.5 m^3 x 4,000) (including costs of marine transportation and insurance)	1 set	252,000,000 yen
- Inland transportation (in Turkey)	1 set	2,300,000 yen
	Subtotal	254,300,000 yen
Grand total		2,351,800,000 yen (4,938,780,000 TL)

ii) Unit Production Cost (per ton)

- Plant depreciation
  (period, 10 years; interest, 8%)
  2,097 yen + 1,677 yen (interest) = 3,774 yen
  (7,925 TL)

• Labor cost	200 yen	(420 TL)
• Repairs (3% of plant cost)	503 yen	(1,057 TL)

• Transportation container depreciation (period, 5 years; interest, 8%)	672 yen	(1,411 TL)
• Materials and utilities		
Lignite	0.78 ton x 4,333 yen = 3,380 yen (65% of Ankara retail price)	
Wooden materials	0.24 ton x 8,570 yen = 2,057 yen (average estimate of scraps)	
Lime	50 kg x 14 yen/kg = 700 yen	
Power	61 kWh x 15 yen/kW = 915 yen	
Fuel lignite	40 kg x 4,333 yen/ton = 173 yen	
	7,225 yen	(15,173 TL)
Total Cost/ton	12,374 yen	(25,985 TL)

As shown above, the lignite biocoal cost per ton is estimated at about 26,000 TL including the comparatively high initial investment cost required in the first year.

5.2.4 Comparison of the Improvement Techniques

(1) Comparison of Characteristics

The briquette, rentan, and biocoal are compared in Table 5.2.7 with respect to property, combustion characteristics, contribution to air pollution, storage life, and other factors.

Table 5.2.7 Comparison of Characteristics of Briquette, Rentan, and Biocoal

	Briquette	Rentan	Biocoal
Ash content	D	D	B
Moisture content	C	C	B
Calorific value	D	D	C
Ignitability	C	C	A
Combustibility	C	B	A
Heat Retention Time	B	A	C
Rise in water temperature	C	C	A
Klinker generation	C	C	B
Amount of dust emitted	C	B	B
Sulfur fixation	B	A	B
Compressive strength	B	B	A
Water-resistance	C	C	D
Compatibility with burner	B	D	B
Cost	B	A	B

Note:
A: very good
B: good
C: fair
D: not good

(2) Economic Comparison

According to the questionnaire made in January 1985, each household possessed of stove in Ankara consumes 2.3 tons of lignite and 1 ton of firewood on an average during the heating season. Since lignite and firewood are priced at 14,000 TL and 30,000 TL per ton, respectively, the heating cost during the season including the depreciation of the conventional stove (about 4,000 TL annually) is;

2.3 x 14,000 + 1 x 30,000 + 4,000 = 66,200 TL

The necessary amounts of fuels are estimated and economical features of the three fuels are compared. The briquette and biocoal are assumed to be burned in a conventional lignite stove or in a new stove which is equipped with a radiator offering high combustion efficiency. Rentan is assumed to be burned in a rentan stove equivalent to that designed in Japan. In the economic estimation, the amount of firewood used is taken into account.

i) Briquette

The retail price of the briquette is assumed to be 30,000 TL/t.

a. When Burned in a Conventional Stove

An increase in combustion efficiency by the use of briquette can be estimated at about 10% because the calorific value decreased by the addition of lime and cement is presumably compensated by the removal of stones, mud, debris, and other unwanted substances in the manufacturing process, and the uniformity in size contributes to the efficient combustion. When the amount consumed is considered to be 2.1 tons for the briquette and halved or 0.5 ton for firewood, heating cost per household per season will be as follows:

2.1 x 30,000 + 0.5 x 30,000 + 4,000 = 82,000 TL.

This result indicates that the rate of increase in cost is 23.9%.

b. When Burned in a New Stove Offering High Heat Radiation and Combustion Efficiency

The depreciation cost of the new stove is considered to be 3,000 TL higher than that of the conventional stove. But since a 17% decrease in fuel cost is considered below the level referred to above, the heating cost will be as follows:

(2.1 x 0.83) x 30,000 + 0.5 x 30,000 + 7,000 = 74,290 TL

The heating cost increases by 12.2%.

ii) Rentan

The retail price of the rentan is assumed to be 25,000 TL.
Depreciation cost of rentan stove is estimated to be 8,000 TL per year assuming the price of the stove being 40,000 TL and the depreciatin period being 5 years. On the assumption that two of 5-kg rentan are used per day, the amount used in one heating season is 1.6 tons. (*)

(*) Calorific value of a 5 kg - rentan made from Turkish lignite is 22,500 kcal (4500 kcal/kg). Heat retention time of the piece is 7 hours giving a constant heat emission of about 3200 kcal/h preventing wasteful combustion. Burning two pieces of the rentan per day will suffice the heating requirement of an average household.

The firewood which is used in igniting the upper surface of rentan is considered to be only about 0.2 ton because the rentan has air holes which are helpful in improving ignitability.

The heating cost will be as follows:

$$1.6 \times 25{,}000 + 0.2 \times 30{,}000 + 8{,}000 = 54{,}000 \text{ TL}$$

The heating cost decreases by 18.4%.

iii) Biocoal

The retail price of the biocoal is assumed to be 30,000 TL/t.

a. When Burned in a Conventional Stove

As compared with the lignite, total of about 5% of increase in calorific value is expected even in the presence of 5% lime added because of about 25% addition of dry wood flour (4,000 kcal/kg) and the effect of dressing. In addition, the improvement in combustion efficiency is anticipated by 15% due to the uniform size of biocoal. In total, the fuel consumption as compared with the lignite will be reduced by 15%. The consumption of biocoal, therefore, will be 1.95 ton per household per season. About 10% of the amount of firewood presently consumed well suffices the purpose because the biocoal provides excellent ignitability and flammability. (In the combustion test conducted by the Study Team, the fuel was ignited only with a rolled newspaper.)

Consequently, the heating cost will be as follows:

1.95 x 30,000 + 0.1 x 30,000 + 4,000 = 65,500 TL

The cost will be decreased by 1.1%.

b. When Burned in a New Stove with High Combustion Efficiency

Since 17% decrease in fuel cost is attainable, and the depreciation cost of the stove is estimated at 7,000 TL, the heating cost will be as follows:

(1.95 x 0.83) x 30,000 + 0.1 x 30,000 + 7,000 = 58,555 TL

The heating cost will be decreased by 11.5%.

iv) Summary

The heating costs described above are summarized in Table 5.2.8 in comparison with the cost of using ungraded lignite.

Table 5.2.8 Heating Cost and SO_2 Emission as Compared with the Use of Ungraded Lignite

	Briquette	Rentan	Biocoal
Increase in heating cost per household	a) +23.9% b) +12.2%	-18.4%	a) -1.1% b) -11.5%
Rate of SO_2 reduction	a) 77.2% b) 81.1%	86.1%	a) 79% b) 82.4%

Notes: a) denotes the rates obtained from conventional stove.
b) denotes the rates obtained from a new stove with high combustion efficiency.

As is clear from Table 5.2.8, rentan is most advantageous in cost. The citizens of Ankara, however, are quite unfamiliar with the handling of rentan, and rentan cannot be used in the boiler.

A problem of vulnerability to water common to the three can be solved by using waterproof containers or bags which are also useful in storage. Rentan should be packed by 40 to 50 kg groups if they are transported by trucks with tarpaulin and stored in a simple outdoor warehouse. Under any circumstances, briquette, rentan, and bicoal should not be left outdoors.

5.2.5 Environmental Consideration

At the sites of the manufacturing plant of briquette, rentan, and biocoal, a sufficient consideration should be given to the environment against the scattering of coal dust. The surrounding area must be afforested to minimize the adverse effects of coal dust, noise, and others. The plant should be most desirably built far away from densely populated districts. In the plant, particular attention must be paid to the working environment; there is need of making it mandatory to install dust collectors, wear dustproof mask, and take other necessary precautions to protect the health of workers.

5.3 IMPROVEMENT OF COMBUSTION AND HEATING APPARATUS AND COMBUSTION METHODS

5.3.1 Types of Stove and Methods of Combustion

(1) Stove for Lignite and Stove for Coke

Two types of stoves are available in Ankara: one for coke and the other for lignite.

The coke stove of either round or square type used in Ankara is said to be capable of burning a solid fuel which have a calorific value of up to 8,000 kcal/kg. The combustion efficiency is claimed to be 70%. The majority of stoves are of the mannual-feeding type. No stove is installed with a stoker. Coke does not require drying and gasification in combustion process because it does not contain volatile matter. If lignite is burned in this stove as is done in some cases in Ankara, dust and soot will be emitted in large amount because the upper section of the stove absorbs the heat of hot air and lowers temperature. Therefore, part of volatile matter is unburned and emitted as smoke. It should be brought home to the people not to use the coke stove for burning lignite with high content of volatile matter. If lignite is to be burned, the stove should be replaced with the one designed for lignite burning.

The cylindrical lignite stove equipped with a bucket having a grate in the bottom is most widely used. Lignite is placed in the bucket and firewood is put on the top of the lignite for ignition. The average calorific value of the fuel is designed to be 4,000 kcal/kg and the stove combustion efficiency is calculated at 60 to 70%. A new cylindrical stove having a small secondary combustion chamber has been recently on the market. The combustion efficiency obtained from this stove is said to be as high as 75 to 80%. If the material of bucket is changed from cast-iron to steel plate and both the primary and secondary airs are properly adjusted, the combustion efficiency will be further improved.

(2) Difference in Performance by Stove Materials and Types

The types of stove should be selected according to the fuel used. When low-grade coals of high volatile matter content, such as lignite, are to be used, the selection of type of stove is difficult to make. It is common practice to burn firewood in a steel-plate stove. If firewood is burned in the cast-iron stove having a grate, the heat produced will be halved and the fuel consumption will more than double.

A series of tests were conducted to examine combustion efficiency between a Turkish-made bucket type stove for lignite and a Japanese-made bucket-type stove which is entirely made of steel plate having a radiation box. The tests were conducted at MTA and in Tokyo. In the tests, two lumps of lignite each weighing 6.5 kg having a calorific value of 5,500 kcal/kg were burned in those stoves.

Results of the tests are shown in Table 5.3.1.

Table 5.3.1 Comparison of Stove Performance

Item	Unit	Japanese-made	Turkish-made
Average surface temperature	°C	427	368
Difference from room temperature	deg	392	340
Surface area *1	m^2	0.770	0.97
Exhaust gas temperature	°C	201	198
CO_2 in exhaust gas	%	8.7	6.0
Heat retention time *2	min	250	195

*1 The bottom area is excluded in either case.

*2 The heat retention time refers to the duration in which the stove maintains warmth or continues its performance in terms of stove surface temperature and exhaust gas temperature (Stove surface and exhaust gas temperatures higher than 300°C and 170°C, respectively, are set as criteria).

As shown in Table 5.3.1, the Japanese-made steel-plate stove maintains warmth for about 55 minutes or 28% longer than that of the Turkish-made stove when a 6.5 kg lump of lignite is burned. This result indicates that the heat retention time of this stove is 28% longer than that of the Turkish stove. The concentration of CO_2 in the gas emitted from the Japanese-made stove is slightly lower than that of the Turkish-made stove.

Various types of stoves were tested to know their heat retention time, using the stoves made in Japan.

The results are shown Table 5.3.2.

Table 5.3.2 Difference in Heat Retention Time by Types of Stove

Stove type	Fuel	Amount of fuel used (kg)	Heat retention time	
			Total (min)	Per kg (min/kg)
Stoker-type with a secondary combustion chamber	Lignite	6.5	245	38
	"	12.38	492	40
Bucket-type with a secondary combustion chamber	"	6.5	240	37
	"	5.7	215	38
	Briquette	5.16	176	34
Mannual-feeding coke stove without secondary combustion chamber	Lignite	5.23	95	18
	"	3.00	40	13
	Briquette	4.88	130	29
	"	5.00	155	33

Note: All the stoves are Japanese-made.

When ungraded lignite was burned (with 5,000 to 5,400 kcal/kg), the stove equipped with the secondary combustion chamber maintained heat for 34 - 40 minutes per kg of lignite while the mannual-feeding coke stove maintained only for 13 to 18 minutes. The reason for this large difference in heat retention time is considered to be due to the presence or absence of the secondary combustion chamber for the combustion of volatile matter and the difference in the structure of the stoves.

(3) Stove and Draft

Even high-grade coal poorly burns when sufficient means are not provided for draft and air supply. Supply of too large an amount of air causes the fuel to burn wastefully. If the firewood stove is equipped with a grate, two times the necessary amount of firewood will be burned because air is supplied at too high a flow-rate. When fine coal is to be burned, the draft air appropriate for lump coal does not lead to complete combustion because of insufficient air draft. As far as lump coal is concerned, the amount of air required for combustion varies with the kind of coal. Necessary amount of air also varies largely at the onset and at the last stage of combustion because the coal is converted to coke at the last stage.

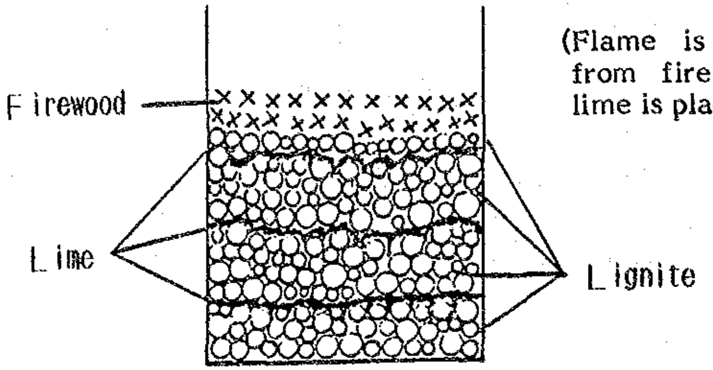
The air draft is properly controlled by handling a damper installed on the chimney. Generally, breadth and height of the chimney are selected according to the maximum necessary flow of air. As coal is changed into coke in combustion process, less air is required. If the air supply remains the same after volatile matter has burned, it will result in wasteful consumption of fuel because the heat produced is carried away with the execessive air flow. By properly adjsting the damper, which can be easily installed on the chimney, fuel saving will be achieved by about 20% because the damper serves to enlarge the space of the stove. Without the damper, the stove cannot be controlled to attain to an appropriate state of combustion.

(4) Simple Desulfurization in Stove

The desulfurization test was conducted by burning the lignite-lime mixture in a stove. It proved this relatively simple method of combustion is effective in reducing the emission of SO_2. The process of this method is described below.

a. Appropriate amount of lignite and 3 to 4% of lime are put alternatively in the bucket-type lignite stove (the desulfurization effect is insufficient in the use of coke stove) so that 3 layers of these substances are formed like a sandwitch. Firewood is placed atop the contents. Each lignite layer should be 10 to

15 cm thick when 10 kg of lignite is burned. Each lime layer should be formed with two cupfuls of lime (about 150 cc) scattered evenly in between the lignite layers.



(Flame is slow in spreading from firewood to coal when lime is placed atop.)

b. When flame spreads from firewood to lignite, minimize the flow rate of the primary air from the bottom so that the secondary burning of volatile matter is accelerated by the secondary air supplied through the top cover of the stove. Close the stove-damper to introduce the gas into the secondary combustion chamber. Adjust the chimney damper according to the outdoor temperature (keep the damper open about two thirds) so that the gas is led to the secondary combustion chamber.

c. When coal changes into coke and starts burning in a bluish white flame indicating the end of the combustion of volatile matter, stop the supply of secondary air and burn the coke by slightly opening the primary air inlet at the bottom.

d. Discard the ash after the combustion and repeat the steps a to c for a new burning.

The desulfurization efficiency attained by this method varies naturally with sulfur content of lignite. A 6.5 kg lump of ungraded lignite (5,500 kcal/kg) with 3.3% sulfur content was burned in the test conducted at MTA. As shown in Table 5.3.3, the desulfurization rate ranged from 45 to 50%.

Table 5.3.3 Desulfurization Rate of Ungraded Lignite Burned with Lime

Test No.	Lime added (%)	Amount of sulfur emitted (g)	Temperature of exhaust gas (°C)	Chemical composition of exhaust gas (%)			Desulfurization rate (%)
				CO_2	O_2	CO	
1	0	220.1	204	7.0	11.0	0.3	-
	3	110.1	191	5.0	11.0	0.4	50
2	0	215.2	207	8.8	10.0	0.2	-
	3	118.8	195	8.6	10.3	0.1	45

In other tests, the mixture of laved lignite of 1.49% sulfur content (5,400 kcal/kg) with 3% lime, and the briquette made by adding cement by 7% were burned. The desulfurization rate was then found to be between 56 and 58.7% as shown in Table 5.3.4.

Table 5.3.4 Desulfurization Rate of Laved Lignite Burned with Lime

Stove	Fuel	Amount of fuel used (kg)	Amount of sulfur emissions (g)	Desulfurization rate (%)
Stoker -type	Lignite	6.5	42.3	56.3
Bucket -type	Lignite	6.5	40.0	58.7
	Briquette	5.16	31.1	56.0

From these tests, it was found that warmth is retained when the lignite stove equipped with the secondary combustion chamber is used, and that a desulfurization rate of 45 to 60% is attained by addition of 3% of lime. However, addition of more than 5% of lime or large amount of lime placed between firewood and lignite will cause poor flamability.

(5) Conclusions

It is not very easy to achieve desulfurization in the process of burning without sacrificing performance of stove and heat efficiency, although the principle of stove combustion may appear to be very simple. There is a need of familiarizing the citizens with the best method of burning fuel and appealing them the significance of lime mixing through the TV, radio, and other media. It is also recommended that round teams be organized to provide the citizens with necessary instructions.

It is expected that the amount of sulfur emitted to the atmosphere will be decreased by about 60% if the fuel consumption rate is reduced through the use of the steel-plate stove having a secondary combustion chamber and radiation box and, at the same time, the lime-mixing combustion in stove is adopted for desulfurization. If the steel-plate stove of the type mentioned above achieves saving in fuel consumption by 20%, 571,300 tons/yr of lignite currently consumed in the lignite stove in Ankara will be decreased by 114,260 tons/yr. This means that 1.6 billion TL is annually saved assuming the price of lignite being 14,000 TL/ton.

According to the results of the questionnaire conducted in January 1985, the amount of lignite consumed in stoves is about 2.3 tons per household per year. Even with 3% addition of lime, the fuel cost saving per household per year will be as follows:

(2.3 tons x 0.2 x 14,000 TL) - (2.3 tons x 0.03 x 30,000 TL) = 4,300 TL.

On the other hand, an increase of 10,000 to 15,000 TL in the cost of a stove, even if locally assembled, may be unavoidable because of addition of such parts as a radiation box and regulators, which finely regulate airs flowing through the primary and the secondary air inlets. Although the decrease in the cost reaches only 1,300 to 2,300 TL a year, when the depreciation of the stove is taken into cosideration, the reduction of the SO_2 emission from the stove will be as high as 60%.

5.3.2 Maintenance of Boilers and Improvement of Combustion Method

(1) Boilers Used in Ankara

The questionnaire in December 1984 and the flue gas analysin in February 1985 revealed that the boilers used in Ankara are divided into lignite and oil-fired types. The former are mostly semicylindrical fire tube boilers and the latter are cylindrical or semicylindrical fire tube boilers equipped with a pressure spray burner or rotary burner. The boilers with a small program-controlled automatic burner were not found although such boilers have rapidly come into use in Japan these years. The reasons for this situation may be due to lack of suitable space of a boiler room, high cost required in building brick furnace, and prohibitive price of small, modern, fully automatic boilers.

Most of the boilers in Ankara are low-cost fire tube type because of a limited height of the boiler room. They are installed in the basement room in a set of two or three units. It seems that the increased load in the winter is coped with by using all of these boilers each having a heating surface between 30 and 60 m^2. In the early spring and the late autumn, it seems that space heating is done by operating one of these boilers and hot water supply is done by the use of anoter boiler with a capacity of less than 30 m^2 probably by economic consideration.

In Turkey, the heat transmission rate per unit area of the heating surface is designed to be 6,000 kcal/h·m^2 for hot-water boilers for space heating. Therefore, the heat transmission rate of the boiler having heating surface of 50 m^2 is 300,000 kcal/h. The flowrate of hot water circulating in this boiler system is calculated to be 1.5 m^3/h on the assumption that the difference in water temperature between the inlet and the outlet is 20°C (60°C at the inlet and 80°C at the outlet). Generally, the efficiency of a semicylindrical boiler in the combustion of lignite is assumes to be 65%. When the calorific value of the lignite is assumed to be 4,200 kcal/kg, the amount of the fuel required per hour is 110 kg for boilers having a heating surface area of 50 m^2 and 66 kg for the 30 m^2 boilers. The standard grate area is 1.86 m^2 for the 50 m^2 boiler, and 1.14 m^2 for the 30 m^2 boiler.

In the case of boilers having a secondary combustion chamber, grate area is smaller than those indicated above by 30% on the average. For oil-fired boilers having a large combustion chamber, it is said that about 80% of combustion efficiency is attained by reducing the grate area by piling up bricks and installing a fire bridge behind the grate.

Recently in some countries, a programmed 2 to 3-stage combustion method, in which the hot air is forced into the combustion chamber, has been employed. Also in Turkey, the boilers with 2-stage combustion have recently been on the market. Efforts are being made to increase the combustion efficiency of boilers to 70 to 80%.

(2) Air Consumption in Combustion

The results of the analysis of the flue gas (February 1985) and the combustion test of boilers for hot water supply (August 1985) are shown in Table 5.3.5.

Table 5.3.5 Results of Flue Gas Analysis and Combustion Test

Season	Fuel	Chemical composition of flue gas (%)				Air ratio	SO_2 content (ppm)	Remarks
		CO_2	O_2	CO	N_2			
Winter	Oil	6.2	12.3	0	81.5	2.76	220	Mean value of 6 measurements
Summer	"	9.7	7.6	0	82.8	1.57	410	
Winter	Laved lignite	4.7	15.3	0	80.0	3.56	330	
Summer	"	2.0	17.8	0.1	80.1	9.4	300	
Winter	Ungraded lignite	5.0	14.9	0	80.1	3.44	970	Mean value of 6 measurements
Summer	"	4.6	14.9	0.5	80.1	5.0	620	

As shown above, the boiler combustion is generally characterized by the presence of excess air except in the case of the oil fired boiler used for hot water supply in summer. This feature is markedly noticed in the laved lignite fired boilers. The probable cause of such combustion is a short supply of fuel compared to the grate area and air leak from damaged area around the ash outlet.

An increasing number of Turkish combustion engineers and boiler manufacturers have advocated the installation of complete combustion system by the forced draft of secondary air supply when lignite containing a lot of volatile matter is used. Necessity for this system is evident. However, the on-site investigation by the Study Team showed that air is far from being in short supply but, in many instances, on the contrary, the lignite is burned in excessive amount of air. For this reason, it is considered necessary to properly adjust the primary and secondary air inlets, to prevent the air leakage by reparing damaged areas, and to control the damper. As instructed in the boiler textbook provided by the Turkish Government, intaking excess air leads to wasteful burning of fuel because much of the heat produced is allowed to escape. When excessively small amount of fuel compared to the combustion capacity is fed into the boiler, much of the heat is lost by large amount of air admitted through the exposed grate areas around lignite and the layer of ash located in the back, leading to incomplete combustion, or "choking" as occurs in stoves.

(3) Improvement in Boiler Efficiency by Damper Adjustment

In the desulfurization test conducted at MTA on August 2 with lime spraying, investigation was made on changes in flue gas, combustion efficiency, and other factors to see the effect of adjusting the damper attached in the middle of the flue. As shown in Table 5.3.6, a 43 kg of lignite was fed each hour in Test No. 3-1. In Test No. 3-2, 2.1% lime was sprayed against lignite fed in 43 kg each hour. In Test No. 3-3, 8 kg of coal per 15 minutes amounting to 32 kg per hour was fed, with the flue damper closed by one-third. The temperature of the flue gas increased from 190 to 220°C by the use of the damper and simultaneously the combustion efficiency increased to 87%. As compared with the results of Test No. 3-2, the fuel economy improved by about 10%. The investigation in February on the conditions of flue gas revealed that in most cases, lignite was burned with an excess supply of air in the lignite fired boilers, thus leading to the waste of the fuel.

In winter, the atmospheric temperature falls as low as -25°C and strong cold north winds often blow. Under such conditions, the waste of fuel is accelerated by enhanced function of the chimney. If such is the case, the damper at the outlet should be adjusted to prevent wastful combustion with an excess supply of air.

(4) Fuel Saving by Flue Cleaning and Proper Fuel Feeding

A series of combustion tests was carried out at MTA as mentioned above on July 22 and 23 and August 2. The purposes were to obtain the basic data concerning fuel saving by improving combustion methods and equipment to calculate a boiler combustion efficiency, and to study desulfurization effect brought about by addition of lime.

The first test was made on July 22 following the MTA's conventional method (43 kg of lignite fed every hour). In the second test carried out on July 23, the fire tube and the flue were cleaned and frequency of fuel feeding was increased (3 to 4 times per hour). The total amount of fuel fed per hour was, however, decreased to see the effect of fuel saving.

The desulfurization test was also conducted by mixing the fuel with lime. On August 2, lime was sprayed to the fuel to see the desulfurization effect. The processing will be discussed in Sec. 5.4.1 (3) and reference will be made to the flue gas desulfurization test conducted in Ankara. The data obtained by Olzat on the chemical composition of exhaust gas, air ratio, and combustion efficiency of boilers are shown in Table 5.3.6.

Table 5.3.6 Results of Combustion Efficiency Test (at MTA)

Test No.	Date	Amount of coal fed/hour	Fire tube and flue cleanig	Other conditions	Chemical composition (%) of exhaust gas (average in stationary state)				Air ratio	Boiler efficiency (%)
					CO_2	O_2	CO	N_2		
1	7/22	43kg x 1 time	before		12.4	5.3	0.4	82.0	1.34	65
2	7/23	10kg x 3 times	after		7.6	11.6	0	80.8	2.31	84
3-1	8/2	43kg x 1 time	after		7.6	12.1	0.1	80.2	2.32	83
3-2		43kg x 1 time	after	Lime Spray	9.7	8.3	0.1	81.9	1.62	78
3-3		8kg x 4 times	after	Close damper 1/3	10.5	7.8	0.1	81.6	1.56	87

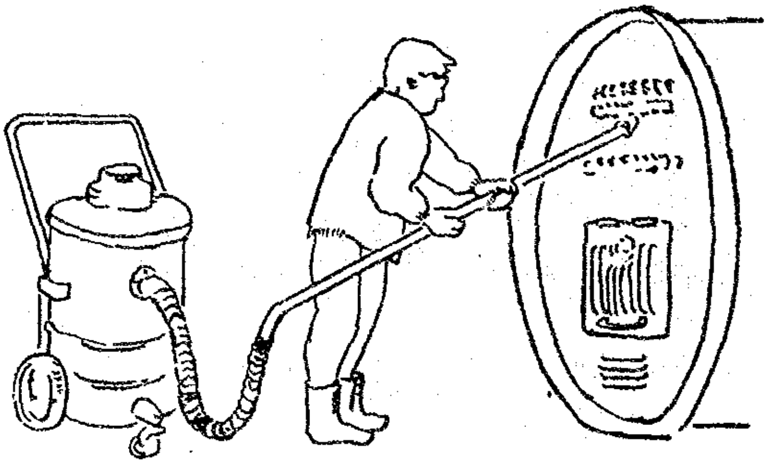
The combustion efficiency was measured much higher in the second test (July 23) than in the first test (July 22). There are two reasons attributed the result: 1) the fire tube and flue were cleaned, and 2) fuel saving achieved by the frequent fuel feeding; 30.9 kg/h (10.3 kg x 3 times) and 27.03 kg/h (8 kg x 3 times $+\alpha$) as contrasted with 43 kg/h fed at once in the first test. The reduction in the fuel consumption by this feeding method was 23% in comparison with the first test on July 22. This was achieved because of the improvement in the combustion efficiency (from 65% to 84%). This fact proves that not only an economical effect is brought about but also a substantial reduction in SO_2 emission by 23% is possible by the new method. This method may play an important role in air pollution control project in Ankara.

In Japan, boiler tube cleaning is mechanized to mitigate the work of boiler operators. The cleaners now available in Japan are mainly moter-driven and powerful vacuum cleaner. A vacuum cleaner priced at about 570,000 TL is not considered costly if it is jointly purchased by 3 to 5 apartments. One of the presumably efficient ways of flue cleaning is to establish a privately-run business for this job and offer services to each apartment periodically.

The boiler which burns low-grade fuels containing high levels of voltile matter and ash such as lignite should, in principle, be cleaned every day.

One of the ways for mitigating the toil of boiler operators is to install a stoker by which fuel is automatically and continuously fed.

Stokers are of several kinds, such as conveyor type, stepping type, chain grading type. Some horizontal grates are equipped with a simple shovel type stoker at the fuel inlet. An investigation should be made as to which stoker is most suitable for burning the lignite which is low in calory and contains much impurities. The stoker is helpful in lessening the work load of boiler operators and in shutting out the cold air to enter the boiler through the fuel inlet.



(5) Removal of Impurities from Boiler Water

The data collected by the Ankara Waterworks Department on the quality of city water indicate that the total dissolved solids of the water amount to 140 to 650 mg/l, suggesting that the water is not suitable for the use in boilers.

The Study Team investigated the adverse effect of the use of the water in boilers. The photos were taken of inside walls of boilers by use of a fiberscope, to check the effect of boiler cleaning agent on descaling. Analysis was also made on raw water and blown water to investigate scaling conditions in relation to water quality.

The frequency of water-blowing was also checked on several boilers. As a result, it was found that only one boiler was blown once at an interval of 15 to 30 days and that there were 9 boilers that were never so treated after the installation. There was one boiler which was provided with a raw water softening unit against scaling. This unit however, was remained unused because of being out of order.

Photos of inner wall of the boiler showed no signs that blowing or cleaning was ever done.

The results of the analyses of raw and blown waters are shown in Table 5.3.7

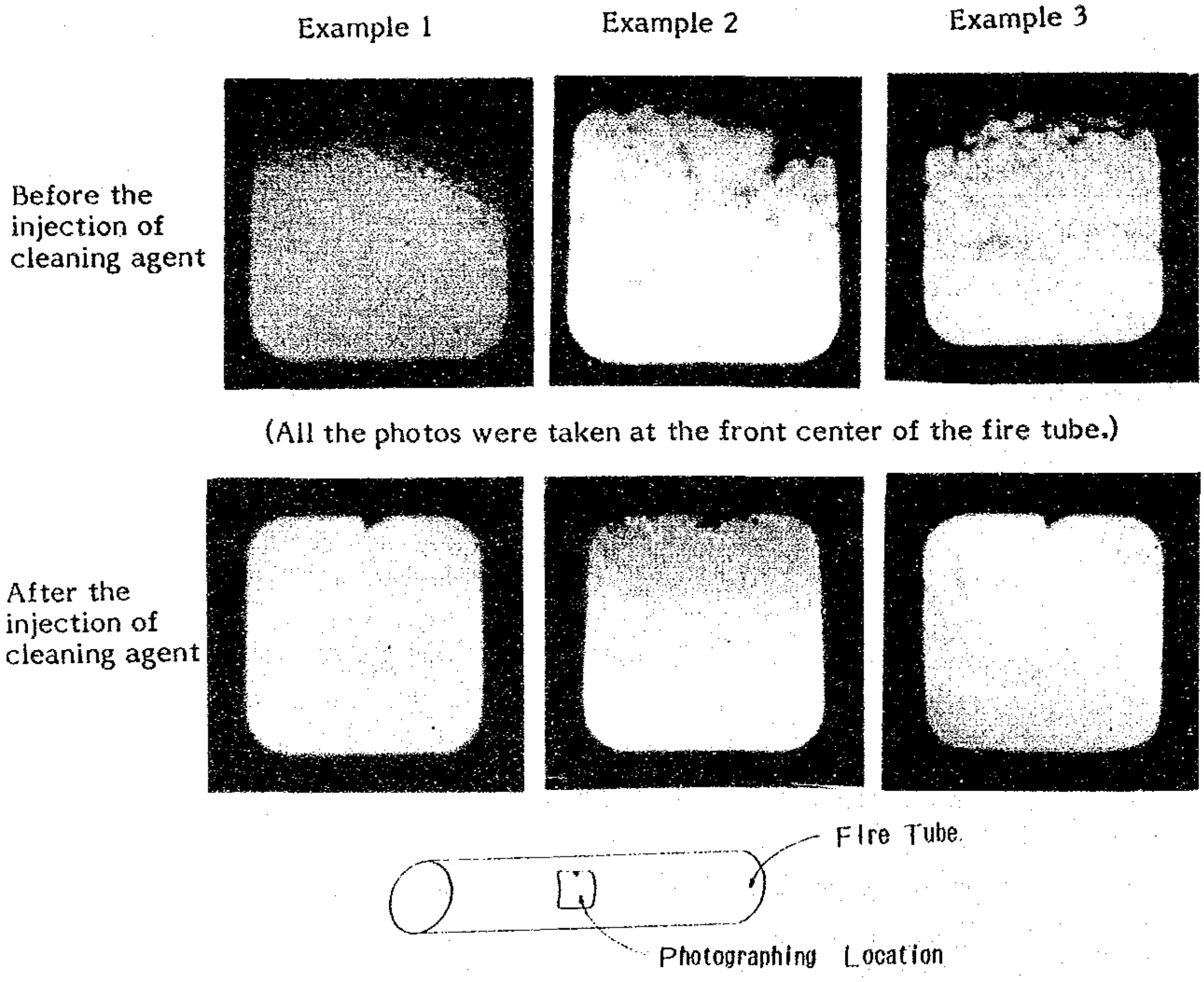
Table 5.3.7 Analyses of Raw and Blown Water

Item	Survey spot / Kind of water	Pembe Kosk		Hava Sok		Cinnha Cad.		Kuleli Sok
		Raw water	Blown water	Raw water	Blown water	Raw water	Blown water	Raw water
Hydrogen ion				6.8	7.0	6.8	7.8	-
Total hardness as $CaCO_3$ (mg/l)		150		134	48	136	37	260
M-alkalinity (mg/l)		100		120	66	123	87	181
Turbidity (mg/l)			7	1	13	1	3	-
Conductivity (µv/cm)			710	310	210	320	270	-
Total iron (mg/l)		< 1	< 1	< 1	< 1	< 1	< 1	< 1
Remarks	Boiler type	Lignite fired		Lignite fired		Heavy oil		-
	Water softening unit	Equipped but unused		Not equipped		Not equipped		-
	Heating surface area	$60m^2$		$30m^2$				

Note: The blown water at Hava Sok contained sludge at first. The data above are of the water after sludge was removed.

As is clear from the Table 5.3.7, the raw waters show higher values both in total hardness and M-alkalinity than the blown waters. This indicates that carbonate in the water deposits on inner wall surfaces as the boiler is heated, and as a result the hardness of the water has decreased. The hardness greatly varies with the geological features. As far as the water used in Ankara is concerned, the raw boiler water or city water shows a high degree of hardness.

The water hardness is generally expressed in mg/l as $CaCO_3$ converting the amount of calcium and magnesium ions. The substances which constitute water hardness are main causes of scale and sludge. An increase in the hardness can cause a decrease in thermal conductivity and eventual corrosion. A thick scale is apt to prevent smooth circulation of boiler water. And it leads to lowering the boiler performance. In order to cope up with this trouble, periodical descaling with a boiler cleaning agent should be done at least once a year. It is advised that a raw water softning unit be installed to eliminate the water hardening substances after the cleaning. Descaling a boiler (including hot water supply pipes and radiaters) will have an effect of improving combustion efficiency by 20 to 30%. Photos below taken by the use of a fiberscope, show inside a boiler before and 7 to 10 days after the injection of cleaning agent.



(All the photos were taken at the front center of the fire tube.)

Figure 5.3.1 Photographs Inside Boiler Smoke-Tubes

The cleaning agents are generally divided into two kinds; slow acting high molecular organic acids, salts, and enzyms, and quick acting organic acids, such as ferric citrate, sulfamic acid, and their salts.

The use of chelate compounds, such as EDTA, NTA, citrates, and gluoconates are recommended in the calcium-rich city water in Ankara, because these compounds impedes the precipitation of Mg and Ca ions as insoluble substances. To prevent scaling of such insoluble substances, reagents promoting protective colloidal action and emulsion dispersion are recommended.

Importance of descaling is not pointed out in the combustion regulations and textbooks for boiler operators in Turkey. Wider publicity is required to enlighten the citizens on the importance of descaling through the mass media, such as radio and TV.

5.3.3 Energy Saving in Hot-Water Central Heating System

(1) Hot-Water Heating System in Ankara

Hot-water heating systems employing a radiator is classified into (i) the conventional type in which the water temperature is maintained at constant while flow rate of hot water supplied into radiators are varied, and (ii) the type in which the hot water temperature is varied while the flow rate is maintained constant. The former is called the variable flowrate and constant temperature type and the latter the constant flowrate and variable temperature type.

Almost all the hot-water heating systems currently adopted in Ankara belong to the type (i). However, the radiator valves are not operated for regulating the flow rate in the individual residences, thus resulting in wastful energy consumption (See Figure 5.3.2).

In house heating, energy is further wasted by heating all the rooms including bathroom and toilette and even rooms where no one is using by circulating hot water through the radiator.

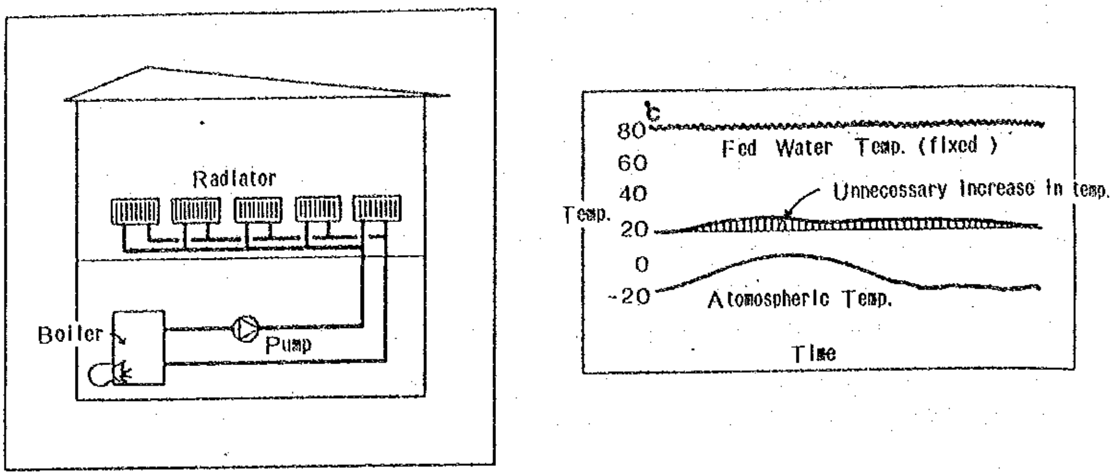


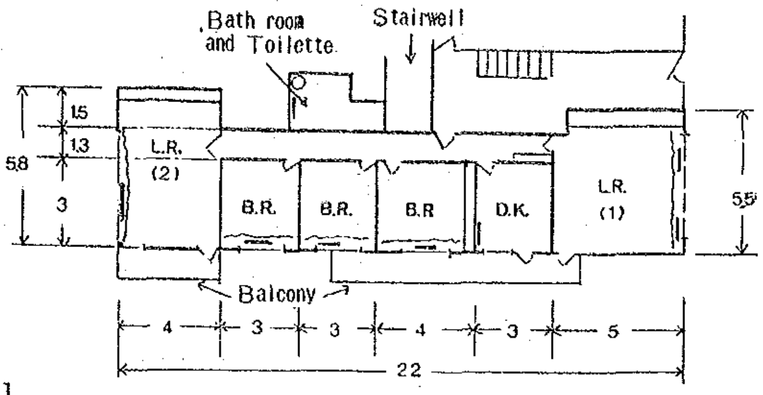
Figure 5.3.2 Present Central Heating System in Ankara

(2) Energy Saving Effect by Variable Flowrate/Constant Temperature System

Comparison of energy consumption between the two cases is made in the following. Case 1: A residence is wholly heated. Case 2: Only the rooms necessary for heating are heated.

According to the results of the questionnaire, the average floor area of the residences heated by lignite boilers is 118 m^2. The floor area of the apartment house in which the survey team stayed is 112 m^2. The layout is considered to be common in the City. Therefore it is used as a model in the calculation. (See Figure 5.3.3)

The answers to the questionnaires and the data in the past indicate that 85% of the annual lignite consumption is used for boilers during the heating season. The amount of lignite annually consumed for this purpose by each household is about 6 tons. Much of the heat thus produced is lost through windows and other openings, ventilation, heat loss in combustion, and other factors. In the calculation, the temperature of the rooms being used is set at 18°C and that of the unused rooms is set at 12°C on the assumption that the proportional control system valve which functions to maintain the room temperature at the fixed level by changing the flow rate of hot water according to the room temperature is attached to the radiator installed in each room.



[Place]
Çankaya, Gaziosmanpasa
[Floor Areas (Approximate)]
Whole residence: 112 m²
Living room (1) + Dining Kitchen: 36.5 m²
Bed room : 30 m²

〰 : Curtain
▬ : Radiator   Unit : meter

Figure 5.3.3 Layout of the Sample Apartment

These rooms may be used at different time zones. A total floor area of 36.5 m^2 (living room (1) and dining kitchen) is assumed to be continuously heated at 18°C and the rest of the area is assumed to be maintained at 12°C. The amount of lignite used for hot-water supply during the period other than heating season is estimated at about 15% of the total consumption (according to T.K.I.). Lignite consumption for hot-water supply in the heating season is also assumed to be about 15% because the period is as short as about 5 months. Thus the amount of lignite consumed for heating purposes is calculated at 5.1 tons which account for 85% of 6 tons. When all the area is constantly kept at 18°C, the amount of lignite used to raise each degree centigrade per square meter of the area is given as follows;

$$\frac{5.1}{(18 - 3.24) \times 112} = 0.00309 \text{ (t)}$$

The value 3.24 represents the average atmospheric temperature over 45 years during the heating season (November to March) in Ankara.

The amount of lignite required to keep the living room and dining kitchen at 18°C is given by;

$$(18 - 3.24) \times 36.5 \times 0.00309 = 1.66 \text{ t}$$

When other rooms are to be maintained at 12°C, the amount of lignite to be consumed is calculated as follows;

$$(12 - 3.24) \times 75.5 \times 0.00309 = 2.04 \text{ t}$$

Thus, the amount of lignite burned in each heating season will be 1.66 t + 2.04 t = 3.7 t. Compared with the case where all the area is maintained at 18°C, the selective heating will save the fuel by 27.5%.

The economy resulting from this energy saving is further elaborated below.

The lignite consumption for boilers in Ankara in the winter of 1984/85 amounted to about 630,000 tons. In the residences excluding the governmental and business offices, 544,000 tons of lignite were consumed. Accordingly, 462,400 tons of lignite which accounts for 85% of the total consumption was used for heating purposes except for hot-water supply necessary during the heating season. It is possible to reduce the amount, by 27.5%, so 127,000 tons of lignite will be saved. Since the current retail price of lignite is 14,000 TL/t, the cost saved will reach 1,778,000 TL (846,700,000 yen) in each heating season.

The same can be said about the oil boilers for heating. The total amount of oil consumed for heating is 220,000 tons. The results of the on-site questionnaire revealed that about one-third the amount is for heating governmental and other offices, and about 146,600 tons of the oil is consumed in residences. If the rate of energy saving is assumed to be the same as the case of lignite, the oil conserved will amount to 34,260 tons excluding the oil for hot water supply. This will result in the saving of 4,166,000,000 TL (1,984,000,000 yen) in each heating season as the oil is now priced at 121,596 TL/t. From the above description, the economic benefit obtained from the combined savings in lignite and fuel oil amounts to as high as 5,944,000,000 TL (2,830,000,000 yen) per season.

In the following, the negative aspect of the new heating method is discussed in connection with the investment for the necessary equipment. In 1985, lignite is used for the boilers in about 90,000 households and fuel oil is used for the same purpose in about 70,000 households, totaling 160,000 households in Ankara (estimated from the results of questionnaire). If the valve which automatically controls the hot-water flow rate according to the temperature is installed to radiators (8 on average in each household), the initial investment required will be:

160,000 x 8 x 29,000 TL = 37,632,000,000 TL (17,920,000,000 TL).

The benefit obtained from the fuel savings referred to above is almost offset only by the depreciation cost.

However, amount of SO_2 emission can be reduced by about 20% because of the reduction in fuel consumption (including the use in governmental and business officed).

(3) Energy Saving by Constant Flowrate/Variable Temperature System

The amount of heat transferred from the radiator varies in proporation to the difference between the hot water temperature in the radiator and the room temperature. When the hot water temperature is lowered, the amount of radiant heat decreases, avoiding the trouble of actuating the valve, and enabling a relatively efficient heating. This way of heating is called the constant flowrate and variable temperature system (see Figure 5.3.4).

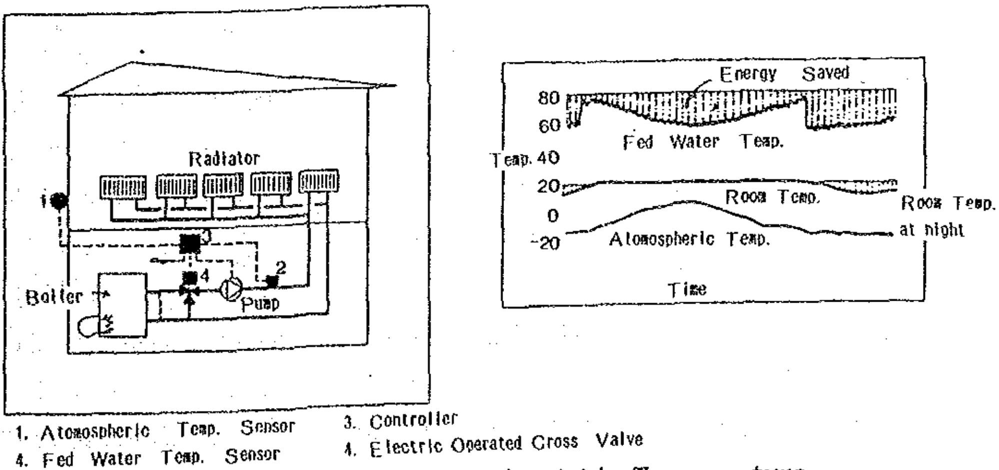


Figure 5.3.4 Constant Flowrate/Variable Temperature Central Heating System

The room temperature varies in proportion to the outside air temperature. The room temperature decreases with the decrease in outside air temperature because the amount of heat escaping outside increases. In such a condition, the amount of heat emitted from the radiator must be increased to maintain the constant room temperature. When the heating method of constant flowrate and variable temperature is used, the room temperature is maintained constant by raising the temperature of hot water flowing to the radiator and, when the outside air temperature rises, by lowering the hot water temerature. By making the atmospheric compensation under the program control through the provision of a sensor which detects the outside air temperature, the hot-water temperature is prevented from excessively falling or rising. ("Atmospheric compensation" means the adjustment of hot-water temperature so that the room temperature is kept at a constant level.) The hot-water boiler is thus economically operated without wasting the fuel.

The boiler operation can be automatically controlled by the use of timers to switch the designated room temperatures by day and night. The heating system can be started automatically when necessary and stopped when unnecessary. When the controller which performs the function mentioned above is provided, the water temperature is controlled as illustrated in Figure 5.3.4. An electrically operated cross valve can also be installed in order not to return the water from the radiator to the boiler but to send it back to the radiator. If all the aforementioned measures are applied, it is highly possible to attain the saving of about 25% in the fuel cost.

The discussion given above is entirely based on the premise that a radiator gives more than 90% of its performance efficiency. Many complaints about the heating system were heard when the Study Team questioned the citizen. Common complaints were "The room is not heated even when the boiler is in operation. When I opened the valve, hot water does not run well." In fact, only a little amount of hot water was obtained even with the valve fully opened in the 4-storied apartment house located in the Cankaya ward in which the Study Team stayed during the winter. The room temperature reached 13 to 14°C at best when the hot water temperature in the boiler was

80°C. The probable causes of these problems are; 1) capacity of the hot-water pump is insufficient; 2) pipes are clogged by scale or rust; and 3) the raditor does not satisfactorily function due to hardened scale or sediments inside. This assumption was verified by the fact that the room temperature on the first floor rose above 22°C and the residents complained about the over-heated room temperature. In such a situation, it is recommended that a quick-acting cleaning agent or a pipe cleaner be injected into the heating system to thoroughly clean inside the pipes and the radiators.

The number of boilers used in Ankara is estimated at about 16,000 on the basis of data collected from the questionnaire surveys. To install heat controllers to all of them, it requires an investment totaling about 16,800,000,000 TL (8,000,000,000 yen), [about 1,050,000 TL (500,000 yen) for each boiler] including the installation cost. If a saving of 20% is possible in fuel cost as in the above case, the cost saved in consumption of both lignite and fuel oil during each heating season will amount to 5,943,000,000 TL (2,830,000,000 yen). On the other hand, the total cost incurred in the installation of the device is 3,794,700,000 TL (1,807,000,000 yen) [annual depreciation cost (7 years) + interest (8%) + repairing cost (3%)]. The balance between the two totals, 2,100,000,000 TL (1,000,000,000 yen) is the cost saved.

This heating system is considered to be far advantageous compared to the automatic valve controller that should be installed on each radiator to regulate the hot-water flow rate according to the prevailing temperature.

A more economical heating method is to control the hot-water temperature by a program-controlled atmospheric compensation controller, attached to the oil boiler burner. Unlike the conventional heating system in which only the hot-water temperature is controlled, this advanced system enables a greater energy saving because the turn-on and -off takes place less frequently. Under this method, an electrically controlled cross valve becomes unnecessary. This means that required installation cost per boiler is reduced to about 840,000 TL (400,000 yen). So the initial investment amounts to

4,452,000,000 TL (2,120,000,000 yen). However the cost saved in fuel consumption is 4,815,201,600 TL (2,292,953,142 yen) (39,600 tons x 121,596 TL) because 20% of 198,000 tons of oil (excluding 22,000 tons used for hot water supply in residences) can be saved. If the two figures compared, the expenditures for installation of the new device can be recouped only in the initial year. At the same time, SO_2 emissions are reduced by 20% (about 173 tons).

5.3.4 Promotion of Energy Saving Action

The following steps are recommended as an action program for energy saving.

i) Make appeal to the public for the importance of energy saving and its effectiveness in fighting air pollution, showing figures to emphasize the economic benefit to be derived.

ii) Urge the people to check the working conditions of radiator ahead of the heating season; to check the capcity of hot water pump; to check if there is clogging in pipes, valves, radiators, and other components caused by scale, iron rust, or deposits of foreign matter; to be sure to inject the cleaning agent into the heating system to clean the inside once a year for better thermal radiation. (Since the radiator is not in use in summer and water stays still for that period, sedimentation of foreign matters can often cause problems.)

iii) Heat only the rooms in use. Partially close the radiator valve to reduce the hot water flow rate when the room is empty. (Do not completely close the valve, or the water may be frozen or foreign matter may deposit in the radiator.)

(Mark the radiator valve to show the flow rate, large or small, at a glance. Such marks are helpful in controlling the heating depending on the situation of the rooms; the residents are in or out, heating is required or not, and day or night.)

iv) Install a new type radiator valve which automatically controls the hot-water flow rate according to the prevailing temperature (8 to

28°C) in each house, or install a controller of the constant flowrate and variable temperature type to each boiler so that the atmospheric compensation can be made by the boiler itself.

[The radiator valve for automatic hot-water temperature control according to the prevailing temperature, costs about 29,500 TL (14,000 yen) including the installation cost. On the other hand, the constant flowrate and variable temperature system controller which offers atmospheric compensation and is equipped with an electrically operated cross valve costs about 1,050,000 TL (500,000 yen).]

v) It seems that the citizens of Ankara have begun to recognize the waste of fuels incurred in the operation of boilers for hot water supply. And conversion is being made from large water boilers to small water heaters. It is desired that the large boilers for this purpose be switched to the smaller water heaters.

5.3.5 Training of Boiler Operators

The Ankara Provincial Decree No. 3 promulgated on November 30, 1984 was introduced on the official Turkish gazette published on the December 7, 1984. In this decree, it is ordered that special measures be taken to mitigate the air pollution in Ankara during the winter of 1984/85.

One clause in the decree touches upon problems of combustion. It deals with boiler operators and their employers as described in Section 3.2.1, and is reproduced below.

i) Works to be Done by Boiler Operators

a. Combustion shall be made by suitable method for the type of boiler, and a boiler diaries shall be kept. Boiler rooms shall be kept clean, and all the necessary tools shall be properly maintained so that they can be used any time.

b. Flues shall be cleaned twice a week for lignite boilers and once a week for oil boilers.

c. Any failure found in the boiler system shall be immediately informed to the manager to be repaired promptly.

d. Windows of the boiler room shall be kept open.

ii) Responsibilities of Managers of Official Buildings and Apartment Buildings and Their Employers

a. Works of boiler operators in the boiler room shall be supervised and inspected once a week.

b. Necessary measures shall be taken against the failure of the boiler system.

c. Fine paid due to the fault of boiler operators or managers shall not be added to the management cost of the apartment.

d. Cleaning of building stack made twice per year shall be confirmed and documented. The document shall be submitted to TKI at the time of delivery of fuel.

On August 11, 1983, i.e., 16 months before the issuance of this decree, the Environment Law (Law No. 7872) came into effect. The Law containg 56 articles deals with the protection of health and the prevention of environmental pollution to which the government and the citizens are duly bound to give ample attention. Punitive provisions, obligations, and fiduciary relations concerning this duty are prescribed, and various regulations pertaining to the pollution are stipulated. Despite all the legal measures mentioned above, environmental problems have not been overcome.

TKI has been giving an administrative guidance to boiler operators since 1960 as to the handling of boilers for house heating. Since 1972, the Ministry of Energy and Natural Resources has been giving the training, and since 1976 the Ministry of Education has joined in this undertaking. This educational course lasts 24 days and the classes totals 48 hours. Beginning with the causes of air pollution and adverse effects of the pollution on the human health, detailed description is given in a textbook. The textbook covers boiler handling and firing, maintenance of boilers, chimneys, and other components, as well as other precautions.

The textbook states as follows;

"The pollutants contained in the foul air gradually affect the human body, deprive it of resistance to diseases, and eventually lead to death. The primary concern should be paid to the fact that children are quickly affected by the pollution. As has been described, it is clear that the chief cause of the air pollution in Ankara is the exhaust gas emitted from heating facilities. For this reason, the best solutions to the problem are the installation of district heating system and the increasing use of harmless fuels, such as city gas, coke, and anthracite, that contain a relatively small percentage of pollutants. Under the current circumstance in Turkey, however, those solutions are difficult to reach in a short period of time. The most practicable measure will be probably to reduce the exhaust gas by complete combustion, and decrease fuel consumption."

The author of the textbook evidently tries to point out the fact that incomplete combustion or excess air combustion leads to poor thermal efficiency, to wasteful use of energy resources, and to aggaravation of air pollution. The booklet gives an extensive technical guidance on the combustion of lignite and the stove firing. The author goes so far as to stating in other papers that powdered lignite should be formed into briquette with 2 to 3% addition of lime and that this briquette should be cut into cubes of 5 cm square and dried for 1 to 2 days in summer before use. The author proposes to stop supply of low-grade lignite, removal of stones, earth, and mud from the lignite, separation of powdered lignite for briquetting, and revision of combustion hours. The author also points out the necessity of changing the boiler ignition time. Most of boilers are now ignited at 5 or 6 o'clock in the morning, and this practice, he points out, is causing the problem. In conclusion, the author stresses the importance of the educating boiler operators because the success in both fuel saving and mitigation of the air pollution depends largely on proper combustion which is possibly performed by well-trained operators.

In the investigation of the stationary pollutant sources and checking the data obtained through the questionnaire at boiler rooms of apartment houses, the Study Team found that many instructions written in the textbook and regulations were not strictly observed by those concerned. In many places, they witnessed fire tubes soiled with soot, clogged chimneys, foul boiler water, large amount of scale deposits, and other undesirable conditions. For this reason, it seems mandatory to rigidly enforce the regulations, make a surprise inspection of the boiler room, request boiler operators to show the license, give more detailed administrative guidance, and revise some of the regulations. Under the circumstances, the training of boiler operators is considered indispensable. Other than boiler operation, many boiler operators are engaged in miscellaneous jobs, such as residential cleaning, repairs, and food shopping by orders of residents.

Under the present circumstances, it is very difficult to achieve energy saving by training only boiler operators.

It is therefore necessary to educate all those who are responsible for maintenance of boilers, buildings, and apartment houses to make them realize the significance of observing the regulations, practicing energy saving methods, and the benefits derived as a consequence of such efforts. The lectures on those subjects should be given to groups from district to district during the non-heating season. Hand-to-hand technical training should also be given to participants.

It is also pointed out that efforts must be steadily and systematically made in the long-term perspective under the administrative guidance to effectively carry out the trainning program.

Boiler manufacturers are said to number more than 1,000 in Turkey. This means that there are probably a great deal of engineering personnel with much knowledge on the combustion technology in those companies and related organizations. It is then recommended that a boiler maintenance enterprise be established with the backing of such personnel to carry out maintenance works of boilers: fire tube cleaning in winter, and boiler descaling in summer. Creation of this kind of enterprise is considered to be one of the most promising solutions to the current problem.

5.4 INTRODUTION OF SMOKE AND SOOT REMOVAL DEVICES

5.4.1 Methods of Flue Gas Desulfurization and Applicability in Ankara

The methods of flue gas desulfurization is broadly classified into two categories, the dry-type and the wet-type. The methods of dry-type are shown in Table 5.4.1 and the methods of wet-type are shown in Table 5.4.2.

Table 5.4.1 Methods of Dry-Type Desulfurization

Method		Description
Pneumatic Tube Method	Alkaline Earth Metal Injection Method	Substances such as $CaCO_3$, $MgCO_3$, $Ca(OH)_2$ are injected into combustion chamber to convert SO_2 to $CaSO_4$.
	Aklaline Metal Addition Method	Substances such as Na_2CO_3, $Na_2O{\cdot}Al_2O_3$ are added to flue gas to convert SO_2 into Na_2SO_4 by reduction method.
	Maganese Oxide Addition Method	$MnOx{\cdot}nH_2O$ is added to flue gas so that SO_2 is converted to $MnSO_4$ in the reaction. $MnSO_4$ is reacted with ammonium. Thus Manganese Oxide is retrieved and SO_2 is converted to Ammonium Sulfate.
Fixed and Mobile Bed Method	Activated Carbon Adsorption Method	Activated Carbon is used as a fixed or mobile bed where SO_2 is adsorbed and converted to sulfate. Desorption is made by laving or high temperature inactive gas.
Fixed and Mobile Bed Method	Contact Catalytic Oxidation Method	By direct oxidation through a fixed catalytic bed, SO_2 is converted to sulfuric acid. SO_3 thus made is, in some cases, reacted with ammonium to produce ammonium sulfate.
	Direct Reduction Method	In the presence of H_2S or CO, SO_2 is directly oxidized into S.

(to be continued)

Table 5.4.1 (continued)

Method		Description
Other Methods	Carbonate Solution Method	Carbonate solution of Li, Na, K is reacted with SO_2 and sulfite is produced. The solution is retrieved and reduced.
	Electron Beam Irradiation Method	After precooling of flue gas to about 70°C, a small amount of ammonium is added. Electron beam is irradiated into this mixture. With the high oxidization effect of the beam, SO_2 and NOx in the flue gas is converted to H_2SO_4 and HNO_3 molecules which are further reacted with surrounding ammonium and converted to fine particle mixture of ammonium sulfate and ammonium nitrate.

Table 5.4.2 Methods of Wet Type Desulfurization

Method		Description
Solution Absorption Method	Caustic Soda Method	Caustic Soda and SO_2 is reacted and converted to sodium sulfite or sodium sulfate.
	Sodium Sufite Method	Principally, this method is the same with the Caustic Soda Method. Na of sodium sulfite is reacted with SO_2 and converted to sodium hydro sulfite which is reduced to sodium sulfite and SO_2 is retrieved by heating. In some cases by adding alkaline to sodium hydro sulfite, sodium sulfite is obtained. Or by adding lime gypsum is obtained.
	Ammonium Method	Diluted ammonium and SO_2 are reacted and converted to sodium sulfite, sodium hydro sulfite, and sulfuric acid. These are consequently made into ammonium sulfate or gypsum.
	Dilute Sulfuric Acid Method	SO_2 is absorbed into water containing catalyst and converted to sulfuric acid. By adding lime, gypsum is produced.
	Sodium Hydrochlorite Method	SO_2 is oxidized by sodium hypochlorite and converted into sulfuric acid and sodium chloride. By adding lime to the former, gypsum is obtained. By electrolysis, sodium hypochlorite is retrieved.
Slurry Absorption Method	Lime Method	Lime stone and slaked lime are reacted with SO_2 and converted to sulfurous acid calcium. Gypsum can also be obtained by air oxidation.

(to be continued)

Table 5.4.2 (continued)

Method		Description
	Magnesium Hydroxide Method	Magnesium hydroxide and SO_2 are reacted and converted to magnesium sulfuric acid. By pyrolysis it is separated as magnesia and SO_2. Pyrolysis can also be made after Sulfite is obtained.
Other Method	Wet-Type Activated Carbon Adsorption Method	When the effluent is passing through the fixed bed of activated carbon, water is sprayed, and sulfuric acid is produced. Gypsum can also be produced. Activated carbon can be used as slurry.

Among the dry type desulfurization methods the method under which powdered $CaCO_3$ or $Ca(OH_2)$ is injected into the combustion chamber in the boiler is convenient, because the boiler itself functions as a desulfurizer saving the cost of auxiliary equipments and the absorbent can be obtained in low cost. This method is considered to be most effective way of flue gas desulfurization for the heating boilers in Ankara, and will be described in detail under the following headline.

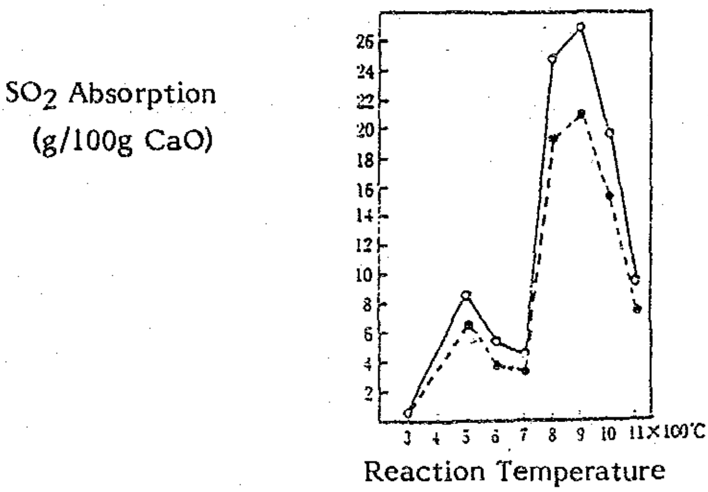
The methods of wet type are widely used in Japan where water is abundant. But in case of Ankara City where water supply is frequently stopped, this type is hard to adopt at present. The description of this type will be made for the possible adoption in the suburban factories and offices where water supply is more abundant.

5.4.2 Desulfurization by Alkaline Earth Metal Injection Method

(1) Basic Test on Reaction

The basic test on the reaction of SO_2 with the fixed layer of lime particles was conducted as follows:

A mixture of gases (SO_2: 0.2%, CO_2: 12%, O_2: 3%, H_2O: 13%, N2: remnants) was blown at a volumetric velocity of 3,000 per hour into the fixed layer of lime stones calcinated at 1,000°C. The amount of SO_2 absorbed at temperatures between 300 and 1,100°C is shown in Figure 5.4.1.



○ Calculated from gas.

● Calculated from analysis of absorbent. Diameter of samples was 1-2mm. SO_2 absorption indicated is the absorbed quantity by the time when the concentration of SO_2 at the outlet was reduced to the half of that at the inlet.

Figure 5.4.1 Reaction Temperature and Amount of SO_2 Absorbed

The optimum temperature is about 900°C. Desulfurization rate decreases drastically below 800°C and reaches its lowest at 700°C.

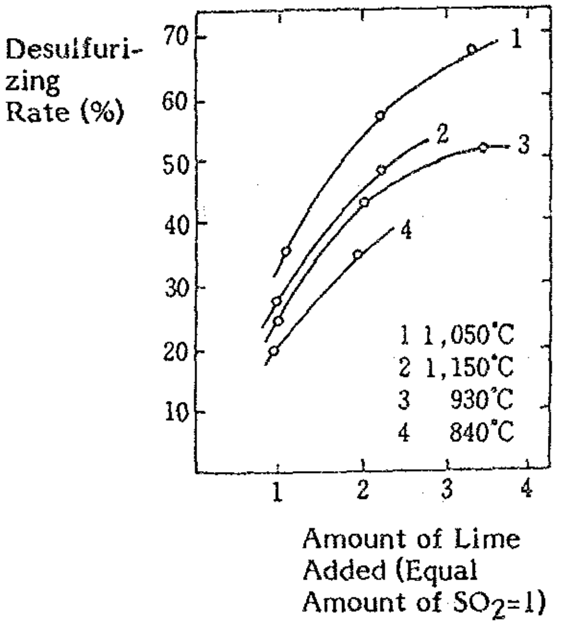
Table 5.4.3 shows the compositions of compounds produced in the process. This indicates that $CaCO_3$ is formed mostly between 600-700°C and very small amount of $CaSO_4$ is formed in this temperature range.

Table 5.4.3 Composition of Products

Reaction Temperature	300	500	600	700	800	900	1,000	1,100
$CaSO_4$(%)	1.6	11.4	5.7	6.1	34.4	36.4	29.5	17.7
$CaCO_3$(%)	24.0	54.5	70.3	73.9	0	0	0.6	0.5
CaO (%)	74.4	34.1	20.0	2.0	65.6	63.6	69.9	81.8

(2) Slaked Lime Injection into a Boiler combustion Chamber

The test results are shown in Figure 5.4.2 and Figure 5.4.3. The former indicates the data obtained from the experiment on the test plant and the latter from the on-site experiment boiler with an evaporative capacity of 54 ton/h (in Japan), respectively. The both Figures show the relativity of the amount of lime injected, the gas temperature at the point of injection, and the desulfurizing rate.



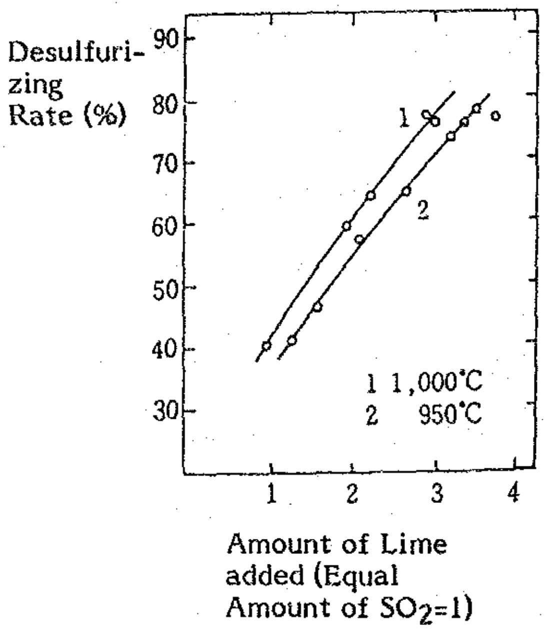


Figure 5.4.2 Relation between Amount of Lime Added and Desulfurization Rate (Test Plant)

Figure 5.4.3 Relation between Amount of Lime Added and Desulfurization Rate (Practical Plant)

From Figure 5.4.2, 1,050^{o}C is the optimum temperature at the point of injection. To generate reaction at temperatures between 800-900^{o}C in the process of the flue gas being carried past and gradually cooled, the temperature at the injection point should be higher than reaction temperatures.

(3) On-Site Desulfurizing Test in Ankara

A series of desulfurizing tests was conducted as a team work of the Turkish engineers and the Japanese Study Team in July and August, 1985 at MTA in the presence of the staff of GDE. The test was made upon the Tuncbilec lignite actually used in Ankara City. It included the mixed combustion of lime and lignite in which slaked lime was attached to lignite surface by use of water, and the injection of slaked lime into the combustion chamber of a boiler. The desulfurizing test is described in the following, while the combustion test method and other matters were already discussed in the Section 5.3.

i) Desulfurization Test on Stoves

The test was conducted on the stove which is generally used in Ankara for lignite burning. Lignite and slaked lime (3%) were fed into the stove in sandwitch-like three layers. Desulfurizing rate of 50% was attained as compared to otherwise. (See 5.3.1, (4) Simple Desulfurization Method for Stoves.)

ii) Desulfurization Test on Boilers by Mixed Combustion

On July 22, lignite was burnt in a boiler with a heating surface area of 25m^{2} in the Turkish manner without slaked lime. On July 23, lignite combustion was made with 4.5% addition of slaked lime. The results are shown in Table 5.4.4.

a. Without Lime Addition

After ignition by wooden chips, fuel feeding was made several times at proper intervals until combustion became normal. Then 43 kg of lignite was fed every one hour for three times.

Table 5.4.4 Results of Desulfurization Test on Boilers

Method	Lignite Feeding Rate (kg/h)	Time Period (hour: min)	Sulfur Emission			Combustion Temperature	Flame Temperature
			Per Period (g)	Per Hour (g/h)	Per Hour Average (g/h)		
Without Lime	43	14:40 - 15:07	576	427	425	1105	770
		15:07 - 15:34	278				
		15:34 - 15:58	398	424		998	852
		15:58 - 16:24	495			1151	519
		16:24 - 16:38	336			1166	
With Lime (4.5%)	30	12:46 - 13:04	385	279	290		
		13:04 - 13:25	207				
		13:25 - 13:44	257			1071	755
		13:44 - 14:08	367	336			
		14:08 - 14:26	374				
		14:26 - 14:44	258				
		14:44 - 15:02	283	258		1190	
		15:02 - 15:26	238				
		15:26 - 15:47	252				

b. With 4.5% Addition of Lime

As with a., after combustion was attained, a total of 43 kg of lignite was fed for three times for the first one hour. (In this case 10.75 kg was fed at each feeding.) For the following two hours, 7 kg of lignite was fed for 7 times.

The lignite in this test was left untouched for a night before use after lime had been applied to its surface by 4.5% by use of water. The test was conducted after the flue and smoke stacks were cleaned. The removal rate of SO_2 is shown below.

$$\text{Rate of } SO_2 \text{ removal} = \frac{425 - 290}{425} \times 100 = 32\ (\%)$$

Rough calculation of the amount of fuel reduced as a result of cleaning flues and stacks and changing feeding method is shown below.

$$\text{Fuel reduction} = \overset{\text{without lime}}{(43\ \text{kg} \times 3\ \text{hr})} - \overset{\text{with lime}}{[\,(10.75\ \text{kg} \times 3\ \text{times})}$$
$$+ (8.06\ \text{kg} \times 7\ \text{times})\,] = 40.3\ (\text{kg})$$

$$\text{Percent reduction} = \frac{40.3}{(43 \times 3)} \times 100 = 31\ (\%)$$

As shown above emission of SO_2 was reduced by 32% as compared with the experiment of the previous day. However, amount of the fuel burnt was also reduced by 31% due to cleaning of flues and stacks, and frequent feeding method. This led to the conclusion that the mixed combustion with lime had no effect at all in desulfurization in case of boilers whose combustion temperature is high. The reason for this is assumed to be as follows.

The combustion temperature is as high as 1,100 - 1,200°C and the temperature shows its highest on the lignite surface where lime is attached. Furthermore, lime is not uniformly mixed like briquette.

As a result, contact surface of lime with SO_2 is much smaller, causing difficulty in SO_2 fixation.

In case of briquette when used for boilers in large amount, the combustion temperature may become as high as 1,100 -1,200°C. However, a large temperature gradient exists inside the briquette when burned and inner combustion temperature is considerably lower than that of outside. In addition, lime is uniformly mixed, resulting in larger contact surface with SO_2 and better fixation rate. However, in case briquette is employed as a major means of SO_2 fixation for boilers, re-investigation into SO_2 fixation rate should be made by feeding a large amount of briquette in varying fire thickness.

In the case of stoves, desulfurizing rate of 50% was obtained only by adding lime. The reason is assumed as follows.

Combustion temperature in stoves is about 800°C, much lower than that of boilers. This temperature is within the optimum range of SO_2 fixation (800 - 900°C). And because lignite and lime were fed in sandwitch-like three layers, contact surface of SO_2 with lime is considerably large. As a result, even when combustion of coke with a high temperature occurs in the lower part and $CaSO_4$ is re-decomposed, SO_2 tends to be fixed by passing through the second and third lime layers.

iii) Desulfurizing Test by Lime Injection on Pembe Kosk Boiler

The Study Team also conducted a series of lime injection tests in which lime is injected into the combustion chamber with secondary air to cause desulfurization in the flue, in order to confirm the desulfurizing effect of lime injection into a boiler. The first test was carried out in Pembe on July 24.

It was during a summer vacation when the test was conducted on Pembe Kosk boiler. Because most of the apartment residents were on leave, demand for hot water was less than usual. Consequently the amount of fuel used was smaller than usual.

Out of 40 kg of fuel in total, 20 kg was fed at first. Then 10 kg was fed twice. During the normal combustion condition, desulfurization rate was measured for the cases of with and without lime injection. Results of these tests are shown in Table 5.4.5. It should be noted that the test was conducted under the condition in which air flow was overcharged thus CO_2 concentration was low, as the amount of fuel burned was too little compared to the grate area.

Table 5.4.5 Result of Desulfurization Test by Lime Injection on Pembe Kosk Boiler

Test No.	Lime injection	Exhaust gas flowrate (m^3/h)	SO_2 conc. (ppm)	Sulfur emission (g/h)	Sulfur fixation rate (%)	Lime injection (g/h)
1	with	386	151	93	39	about 1600
	without	479	202	153		--
2	with	397	211	133	50	about 1600
	without	396	104	66		--

From the results of this test, the average desulfurization rate was found to be 45%.

iv) Desulfurization Test by Lime Injection in MTA Boiler

The desulfurization test by lime injection method was conducted on the MTA's boiler with 25 m^2 heating surface area.

The test was carried out in close cooperation between the Study Team and the Turkish side.

Measurement was made on two types of combustion; (1) with lime, and (2) without lime. Desulfurizing rate was checked by measuring the sulfur emission in the effluent.

Results of this test is shown in Table 5.4.6.

Table 5.4.6 Result of Desulfurization Test by Lime Injection on MTA Boiler

Test Number	Lime injection	Exhaust gas flowrate (m^3/h)	SO$_2$ conc. (ppm)	Sulfur emission (g/h)	Sulfur fixation rate (%)	Lime injection (g/h)	Lignite feeding (kg/h)
1	without	477.5	1250	854			43
	with	400	1181	677	20.7	1820	43
2	without	463	974	542			32
	with	390	777	433	20.1	2460	32

As shown above, the desulfurizing rate of 20% was obtained. These rather poor result is considered to be attributed to the fact that a make shift injection equipment made up of laboratory glass wares and a SO$_2$ sampling pump were used, and therefore, lime was not injected evenly, particularly to the rear part of the combustion chamber.

v) Economic Evaluation of Desulfurization by Lime Injection

An average of 90 tons of lignite is burned per one building or apartment for one heating season in Ankara City. Based on the above fact, additional cost per building for desulfurization is estimated as follows:

Facilities

1)	Hopper and nozzle unit for lime injection (with installation cost)	¥ 100,000
2)	Forcible draft cylone for absorbent and dust collection with a set of auxiliary equipment (S-TEN-1 acid proof)	¥ 900,000
	Total	¥ 1,000,000 (2,100,000TL)

Operating Cost

3)	Electricity (3.7 Kw x 11h x 160 days x 44 TL)	286,530TL
4)	Absorbent (5 kg x 11h x 160 days x 30 TL)	264,000TL
	Total	550,530TL

5)	Depreciation, etc., Depreciation of 1) and 2) (5 years), repairs (10%), interest rate (8%)	
	Total	800,000

Even though the total of annual expenditure amounts to nearly 1,350,000 TL, this system is economical compared with other methods. In addition, most of the facilities can be locally produced. When operated properly, more economical operation would be possible as the operation may not be required at the time of rainfall and strong winds.

However, even with highly reactive absorbent, the maximum desulfurizing rate is 50%. Tarry substances abundantly contained in the Tancbilec lignite act as adhesive and cause absorbent to adhere to the flue, resulting in prevention of heat transmission and