A PILOT PLANT SCALE INVESTIGATION OF POSSIBILITY OF USING NON-COKING ARMUTÇUK AND AMASRA COALS IN METALLURGICAL COKE PRODUCTION

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ABSTRACT. — In this work, the possibility of utilizing the non-coking Armutçuk and Amasra coals for metallurgical coke production through the Sumi-Coal Improved Briquette Charging Method has been investigated. The successful implementation of the said process would resold in considerable saving in the consumption of coking Zonguldak coal or the high quality imported coals. Results of the research are as below. Both Armutçuk and Amasra coals are suitable for the Sumi-Coal process. As far as the coke size, mechanical strength, density, porosity, reaktivity and chemical analyses are concerned about 25-30 % of Armutçuk or 15-20 % of Amasra coal can be used in the metallurgical coke production by the application of the Sumi-Coal process, without creating by operational difficulties in the blast furnace. The feasibility study of this work is not so simple because of too many unknown factors. However, the feasibility study carried out, under the following condition: Basic data were from actual operating results in Japan. The price estimation of the equipments given by a Japanies expert were based on 1979, prices. The feasibility data were based on 1.5 X 10^6T/y pig iron and 2x10^6T/y crude steel and total coke consumption 1.1 x 10^6T/y. The operation is to be syncronized with that of the charging conveyor to the coal tower of the coke oven. Non-coking coal, as material shall be received in the existing main coal bunker and its size shall be 80 % under 3 mm. All utilities necessary for this plant shall be supplied by Ereğli works. Supply of all the mechanical equipments market flow sheet and corresponding electric and instrumentation equipments at FOB Japan basis. The price of coals and utilities are for Zonguldak coal 14,900 TL/t, Armut-9uk coal 13,200 TL/t and Amasra coal 9,200 TL/t and 25,000 TL/t for pitch. For the imported are 100 $/t coking coal and 70 $/t non-coking coal. From the result of this feasibility study, can be considered the following profit: When the perscentage of Armutçuk coal added to the Zonguldak coal was possible, a saving of 1.0 US $ per ton of coke was predicted when Amasra coal was added to the Zonguldak coal in ratio of 20 %. If both of the coking and non-coking coals were imported a possible saving of 6.0 US $ per ton of the coke produced would be expected.

INTRODUCTION

Coal reserves in the world are presently comprising 10 % anthracide, 20 % coking coal, 40 % non-coking coal and 30 % brown-coal. Among these, mainly coking coals are able to give metallurgical coke. Under these conditions, for upgrading of coking coals or to substitute coking coals by non-coking coals, a considerable amount of research has been carried out as a result, coal pretreatment (Wagener and Ergun, 1978) coal preheating (Wagener et al., 1978; Rhode, 1974; Flockenhaus, 1974) stamped charging (Wagener, 1978; Zielinski, 1972) improved briquette charging (Nacamura, et al., 1977; Sumi-Coal System, 1977) and formed-coke (Wagener and Ergun, 1978; Zielinski, 1972; Nacamura et al., 1977) Sumi-Coal System, (Wagener et al., 1977) processes have been developed (Ahland, et al., 1976).

The only source of coking coal in Turkey is Zonguldak coal and total mineable reserves are around 800 million tons. Taking normal production losses to be 30% and washing efficiency of 60 % as rough fisures, it can be said that 336 million tons are available. If the optimum yearly production is taken as 4.5 million tons the total life of Zonguldak coal basin is estimated as 75 years. In Table 1 the coking coal demand and supply situation in Turkey is shown. As can be seen from Table 1, the coking coal deficit will increase parallel to the planned increase in iron and steel production capacity of Turkey, and even in the case of transfering 60 % of total Zonguldak production to integrated iron and steel plants. Turkey has to pay $ 111 million for the year 1982, and will have to pay $ 819 million for the year 1986 for coking coal, imports.

Table 1 - Coking coal demand and supply in Turkey

Demand (x 10 tons)	1982	1986
ERDEMIR	1.8	3.8
ISDEMIR	2.0	6.0
KARABÜK	1 0	1.0
TOTAL	4.8	10 8
Optimum Saleable Zonguldak Coking Coal production (x 10 tons)	4.5	4.5
Supply (x 10 tons) in the case of transferring 60% of total Zonguldak production to integrated Iron and steel plants.)	Deficit 2.1 2.7	Deficit 9.9 2.7
Present Estimates of Coking Coal Prices ($ / ton)	98	150
Coking Coal imports ($)	205.8×10^6 (10.29×10^9 TL)	1.485×10^9 (74.25×10^9 TL)

The precautions which must be taken urgently can be stated as fallows:

a. The application of sumi-coal system-Improved Briquette Charging process in the short run which may enable a saving of 25-30 % of prime coking coals (Zonguldak or import coals).

b. To establish new iron and steel complexes based on formed-coke which may enable a saving of up to 70 % coking coals.

The present study was undertaken to offer a solution to the metallurgical coke problem of the Turkish Iron and Steel Industry and consists of the investigation of the properties of coke produced on a pilot-scale from Zonguldak, Armutçuk, Amasra or exported same quality coking coals by Sumi-Coal System-Improved Briquette Charging method.

A major determinant in the selection of this process is that it can be applied without altering the present coke factories.

Coal samples and pitch used in this work (Zonguldak, Armut9uk, Amasra) were supplied by the Turkish Coal Enterprices (TKİ). The coal samples were first crushed and prepared in the MTA Institute than were transported to TKİ-Ankara Briquetting plant and six different patterns of briquettes were produced (each pattern almost 1.5 tons). For coking operation a 400 kg. pilot scale test furnace which belongs to Ereğli Iron and Steel Works was used. The furnace had on industrial chamber with and was heated with flue gases.

COKE PRODUCTION TECHNOLOGY

Coke is made by heating pulverized coals in the absence of air for periods of 14 to 19 hours, in long narrow chambers called by-product coke ovens or slot ovens. During heating, coal first softens and melts, simultaneously decomposing, eventually to resolidify into a porous hard solid coke. Because the process covers a wide temperature range, with complex physico-chemical reactions occuring at different coal components, it is useful to consider coal behavior in relation both to its basic components and to temperature.

Basically, coal is composed of reactive and inert components. Reactives and inerts exhibit markedly different behavior during coking. Coal reactives include vitrinite, pseudo-vitrinite, degraninite, and exinite, while the inerts include fusinite, micrinite, scleratite, and mineral matter. In general, the reactive components soften and become quite fluid when heated, exhibiting relatively high reflectivity of light, whereas the inerts do not fuse and are comparatively non reflecting. Reactive components melting during the carbonization process bridges the inert components thus form in strong structure. But in order to obtain high quality coke, these components must exist in the proper proportion in coal. In sufficiency of the inert components decrease the coke strength. Because, gas leaves from the coal structure during the carbonization process and large pores occur, if the amount of the inert component is not sufficient, porous structure causes the mechanical strength of the coke to decrease.

If the amount of the inert components exceed that of the reactive ones, the result is very similar; because there is not sufficient amount of the reactive components to surround the inert components and the mechanical strength of the coke thus obtained is low (Schapiro et al., 1961). The coke-forming stages in a chamber are shown in Figure 1.

During the initial stages of coking, at temperatures below about 300°C, the process is characterized by distillation, where carbon dioxide and water are the predominant gases that evolve from the coal. The mechanism is similar to the progresive elimination of oxygen from vegetable matter that occurs in nature, so that the initial stages of heating can be viewed as a continuation of the coalification process.

At temperatures in the range of 300°C to about 400°C, the reactive components in the coal begin to soften and small gas bubbles start evolving, particularly from the vitrinite fractions. Concurrently, chemical depolymerizatien begins, so that some of the hydrocarbons in coal, including certain aromatic groups, volatilize and evolve as products with low molecular weight. As the temperature increases to some 450°C, the micro bubbles in the coal grow in size, pushing the non fused inert components of the coal into close contact the most fluid components in coal tend to form liquid films that enclose the inerts, to yield a colloidal dispersion of non fusible particles in to fused mass. The extent and temperature range of the softening/melting stage is extremly critical because that stage controls not only depolymerization and subsequent condensation of volatile compounds, but the nature of the bonding between the inert components. Insufficient softening and melting, of the coal can prevent adequate condensation of the low molecular weight gases, leading to a friable and weak coke.

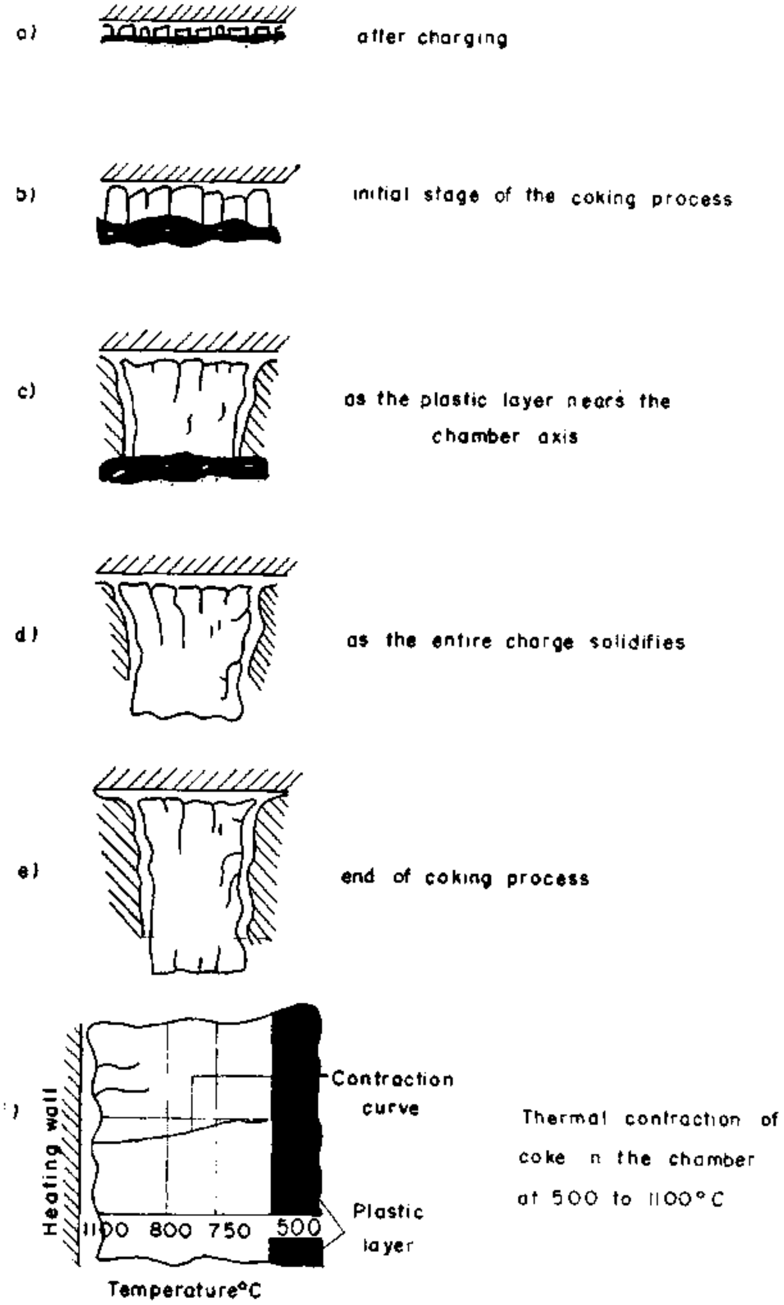

Fig. 1 - Coke-forming stages in a chamber.

Further increases in the temperature of the plastic mass, in the range above 500°-600°C, cause the fused films that enclose the inert grains to solidity into a porous mass of semi-coke. Also during this high temperature (1000°C) stage, as the semi-coke solidifies and contracts, it develops a system of fissures that will subsequently influence coke strength and size distribution (Zielinski, 1972). Another factor causing the formation of fissures in the coke is the coking time. Also high heating rate causes, many small fissures and weak coke to form.

The functions of coke in the blast-furnace operation

It is necessary to mention briefly the role of coke in the blast-furnace. The role of coke in a blast-furnace may be characterized in terms of three fundamental functions, as follows:

a. A calorific function, in which coke reacts with oxygen in the air blast to provide part of the heat required to melt iron and slag, and reduce the burden;

b. A chemical function, in which coke reacts with oxygen and carbondioxide to generate the reducing gases for the process;

c. A mechanical function, in which coke provides a strong, porous and permeable media to support the burden while allowing reducing gases to circulate and distribute evenly through the charge (Nacamura et al., 1977; Dartnell, 1977; Hatano, 1976; Wilkinson, 1964 Coke'in the only solid material at the bosh Nixon and Brooks, 1969; Giedroyc and Mathieson, 1969; Elliot, 1969) and the hearth levels of the blast-furnace.

These three roles place immediately obvious requirements on the properties of coke. As a fuel and a generator of reducing gases, its carbon content should be maximized. As a regenerator of reducing gases it should have an adequate reactivity to carbon dioxide and water vapor, and to provide permeability, it should be charged in a narrow size range and suffer minimal breakdown in its passage to and through the blast-furnace. The produced coke must be mechanically strong under ambient conditions.

With the advent of modern furnace practices, including the use of high blast temperatures as well as auxiliary fuel injection through the tuyeres, the first two functions of coke are becoming progressively less critical. For example, it has been recently estimated that in a modern Japanese blast-furnace, operating with a coke rate of about 440 kg per ton of hot metal and blast temperatures of about 1300°C, over 40 % of the heat in put to the furnace is supplied by the heat content of the air blast. Furthermore, the combustion role of coke poses no constraints since coke arrives at the tuyeres at approximately 1500°C and reacts with the preheated air in preference to any hydrocarbon fuels, being consumed within a few centimeters of the tuyeres. The chemical function of coke may appear to increase in importance as its role as a fuel is minimized, for in modern blast-furnaces the amount of carbon gasified by reaction with oxygen can exeed 50 % of the total carbon in put. But, since part of this carbon is supplied in the form of hydrocarbons injected through the tuyeres, there is potential for reducing the role of coke in its chemical function as will. The importance of this function may be further minimized through injection of reducing gases above the blast-furnace bosh. Thus, the trend in modern practice is away from the traditional roles of coke, but to ward a greater emphasis in its mechanical properties.

The importance of the mechanical properties of coke, particularly its resistance to physical degradation under blast-furnace conditions, can not be overemphasized.

A coke having insufficient mechanical properties can cause:

a. Objectionable amounts of flue dust at the top of the furnace;

b. Uneven distribution of the softening/melting layers in the burden caused by localized zones of low permeability, leading to gas channeling and possibly, flooding problems;

c. Excessive amounts of fine-grained coke in the bosh, preventing the development of a normal raceway profile, aggravating the normal drainage of molten slag and iron, increasing the thermal load on the furnace walls;

d. Poor thermal distribution in the central column of coke, causing lower temperatures in the hearth and leading to potential tapping problems.

Conventional coke production

At present, the coke produced in the iron and steel industry is made of coking coal particles about 80-85 % of which is smaller than 3 mm in diameter or with the addition of maximum 5-10 % of non-coking coals.

Basically the conventional horizontal coke ovens consist of a refractor rectengular chamber heated externally from each wall by gas firing. Chamber width for conventional type, ovens changes from 38 to 50 cm. The chamber has end doors and the coal is charged from the top. At the end of coking period front and back doors are opened and coke is pushed out by means of a ram and is immediately quenched by water sprayed on it. An crucial point in charge preparation is to decide on the composition of the coal mixture. This composition bears essentially upon the structure and properties of coke.

In the Simple Blending Method, main effective parameters on the coke strength are; number of coals in the mixture, mean volatile matter content, size distribution, moisture content and other added materials.

Improved Briquette Charging Method (Sumi-Coal System)

In this method regular coking and non-coking coals are first crushed and mixed with the binder. In the kneader the temperature reached by steam or hot gas injection enables the binder to soften and penatrate into the coal particles and to fully cover them. Then this mixture is fed into the briquetting machine. The seperately manufactured briquettes 30-35 % and the remaining coking coal 65-70 %, after being mixed together are charged into a classical coke oven. Generally, a conventional coke oven is emptied by a pushing machine from machine side, but if 100 % biquette coal is charged and coked in a conventional oven, it is impossible to push it out without damaging oven walls. Therefore it is impossible to charge briquettes into conventional coke ovens more than 35-40 %.

By the use of Improved Briquette Charging Method 20-30 % of the prime coking coal can be substituted by non-coking or weakly-coking hard coals, and the coke obtained which has exactly the same shape and appearance as conventional coke is now 5000 m^3 blast-furnace with success. Process flow-table is shown in Figure 2.

The effect of Improved Briquette Charging on the coke quality

Coke strength can be improved by the Briquette-Blending process for a number of reasons. First, because the coal particles in briquettes are closer together than in coal fines, the coking property of briquette-blended coal is improved, as the shrinkage of coal during the coking process in reduced, the caking action between the particles is intensified, the caking component is increased and the pyrolysis temperature increases. Secondly, the coking properties of briquette-blended charging coal are improved because of the increased bulk density. The coke strength increases with increasing bulk density of coal fines.

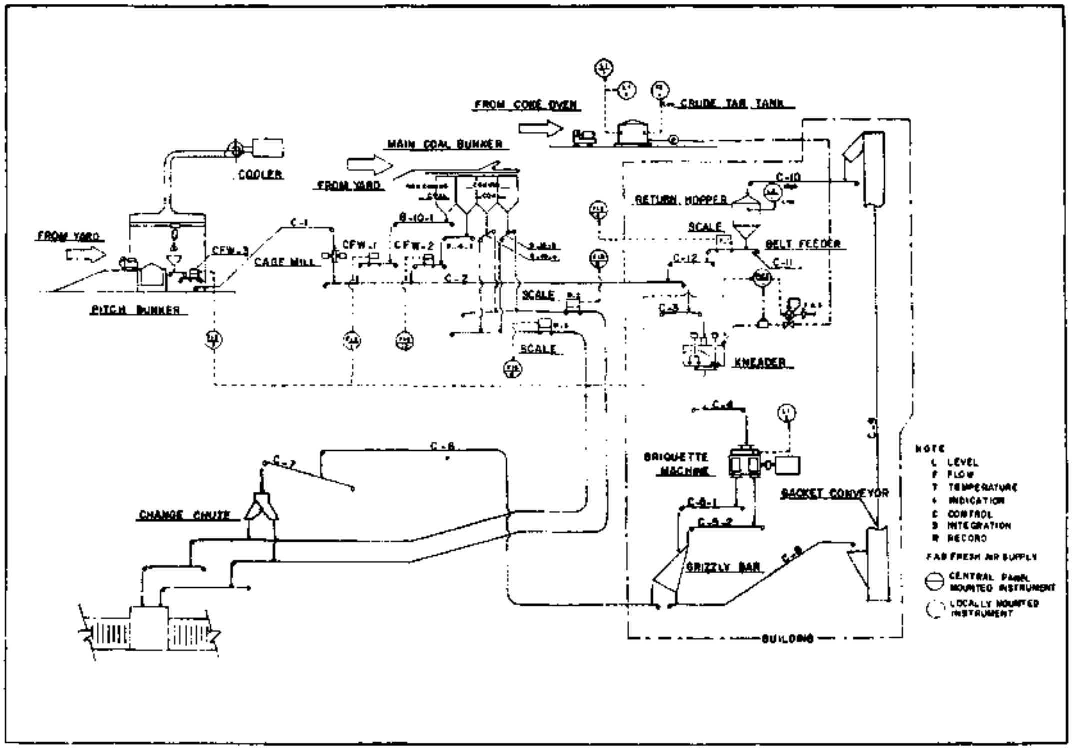

Fig. 2 - Detailed flow sheet diagram of the Sumi-Coal System Improved Briquette Charging Process.

The caking action of coal is closely related to the expansion characteristics of coal. Examination of a change in volume of briquette present in coal fines during carbonization indicated that briquette undergoes rapid increase in porosity from about 300°C and shows a maximum volume expansion at near 400°C. On the other hand, the gas pressure inside the briquette, in the softening and melting zone, who 3 times as large as the maximum inside fine coal particles. The thickness of the softening and melting zone is much larger for briquette than for coal fines. When a mixture of coal fines and briquettes is carbonized in the chamber of a coke oven, the briquette expands with marked evolution of gas during softening and melting, compressing the surrounding coal fines to promote cohesion of the coal particles and the structure becomes more compact, presumably contributing to an increase in coke strength.

The major advantages of Improved Briquette Charging System

a. Weakly-coking coal or noncoking coal can be used in limited amount in the metalurgical coke production by application of Briquette Charging method;

b. Coking process is thermally more efficient;

c. Productivity of coking plant can be mostly increased;

d. Coals of different properties are distributed more homogeneously in the coke-chamber, that's why the mechanical strength of the coke is increased.

EXPERIMENTAL PART

Determination of the physical and chemical properties of coals used in the experiments

Three kinds of coal were used in the experiments. One of them was the Zonguldak coal produced in Zonguldak washery from the run of mine coals of Kozlu and Üzülmez seams. This coal had a particle size of 0-10 mm as produced.

The fallowing tests have been performed on Zonguldak, Armutçuk and Amasra coals.

a. Proximate analyses and total sulfur contents were determined (TSE 690, TSE 711, TSE 330, TSE 363, 1966, 1969)

b. Coking propertly-crucible sweling index (UN Publication-Nr: 1956 I.E. 4)

c. Coking property-dilatometer test (UN Publication-Nr: 1956 I.E. 4)

d. Size analyses of the crushed coals were carried out by using ASTM sieves.

The results of these tests of the coals used in briquetting are shown in Table - 2.

Experimental conditions

For comparison of the results, same mixtures were used for the Improved Briquette Charging Method and for the Simple Blending Method.

Simple Blending experiments. — For simple blending experiments Armutçuk and Zonguldak coals were pulverized such that 85 % passed through 2.8 mm sieve. In this manner the charge pulverization level of coals was kept constant. The charge moisture content also was kept constant at 11 %. After preparation, coal mixture was filled in the charging hopper. The bulk density was 920 kg/m^3.

Improved Briquette Charge experiments.— a. Briquetting of Armutçuk, Amasra and Zonguldak coals with binder: In the present study coal tar pitch obtained from «Ankara Briquetting Plant» was used as binder. It was the fraction with the boiling point above 350°C and had the properties stated below: Moisture 6.0 %, ash 2.8 %, volatile matter 57.32 %, fixed carbon 33.88 %, softening point 79°C, benzene insoluble part 21.5 %, sulfur 0.87 %.

In these experiments since it is not necessary for the strength of briquettes to be high, a wide selection of binder is possible. Any kind of bituminous binders such as coal tar, pitch petroleum pitch, etc., can be used.

Crushed Armutçuk, Amasra, Zonguldak coals and crushed pitch were mixed together at the desired proportions. Briquetting was performed at TKİ-Ankara Briquetting plant. The coal-binder mixture was kneaded at about 80°C and the mixture was briquetted by a roll-press. The percentage of binder in briquettes was taken as 10 %. The composition of briquettes are shown in Table 3.

b. Charge preparation: Calculated amounts of pulverized Zonguldak coal and briquettes were weighed and mixed manually after the necessary water addition for having the fixed charge moisture content of 11 %. The coal and briquette mixture was placed in the charging bin. The bulk density was 995 kg/m^3 (average) for improved briquette charging type experiments.

Carbonization (coking operation). — For coking operation a 400 kg pilot scale test furnace was used. The maximum flue temperature was 1200°C.

Table 2 - Properties of Zonguldak, Armutçuk and Amasra coals used in briquetting

		ZONGULDAK (Air dry)	ARMUTCUK (Air dry)	AMASRA (Air dry)
PROXIMATE ANALYSIS	Moisture %	1.20	2.00	4.80
	Ash %	15.22	14.86	12.74
	VM %	26.40	29.47	33.45
	FC %	56.18	53.67	49.01
	Total Sulfur %	0.36	0.52	0.81
	CSI	7.0	2.5	1.5
DILATOMETER	Softening point °C	380	377	380
	Beginning temp.of dilat°C	414	-	-
	Max dilatation temp.°C	470	-	-
	Contraction %	31.29	20.94	8.13
	Dilatation %	64.14	-	—
	Total Dilatation%	95.43	—	—
	International Classification No	534	711	711
SIZE ANALYSIS	+5.6 mm. %	1.11	1.70	0.51
	-5.6mm. ~ +4.0 mm %	2.26	5.96	2.04
	-4.0mm ~ +2.8 mm %	3.50	46.61	4.50
	-2.8mm. ~ +1.0 mm %	49.12	38.78	52.66
	-1.0mm ~ +0.5mm. %	24.85	2.37	25.70
	-0.5mm ~ +0.212mm%	12.74	3.06	12.59
	-0.212 mm.%	6.12	1.29	1.65

The furnace has a strong steel framework and is thermally insulated by high quality brick. The refractory rectengular chamber has the following dimensions: width 43.2, length 121, heigh 91.4 cm. The oven was heated by an arrangement of flues on each side. The carbonization conditions were controlled as accurately as possible to maintain standard conditions for each experiment, such that oven wall temperature was maintained at 1150°C.

First the empty furnace was heated. The wall temperatures were controlled by means of pyrometer. When they indicated a wall temperature of 1150°C, the filled charging bin was elevated to the top of the furnace and through the top charging hole the coal-briquette mixture was pushed in to the oven by using an iron rod, and the charging hole was closed as quickly as possible.

The carbonization time was fixed at 18 hrs for improved briquette charging type experiments and at 17 hrs for simple blending when the carbonization time, which was fixed according to actual coke plant operational conditions, was completed discharging end door opened and the coke was pulled in to the quenching car. The hot coke was quenched by water spray for preventing from burning.

Experiments performed to determine the quality of the coke samples produced

Sieve Analyses, Tumbling test and Shatter test were applied to the dry cokes according to ASTM (Amarican Society for Testing and Materials) standarts at the same time real and apparend density, porozity, reactivity, chemical analyses and total sulfur determined according to ISO (International Standart Organization). The results of the tests are shown in Table 3.

INTERPRETATION OF THE RESULTS

Charge preparation

In the industrial application of the Improved Briquette Charging Process, it was reported that a briquette addition of 30 % increased the bulk density 8-9 %. In the present study about the same increase in the bulk density was also achived over the Simple Blending case.

The total moisture content of the charge which is a very important carbonization parameter was 11 %. This very high moisture content caused the coke quality to decrease. It is a known fact that the effect of bulk density on coke's physico-mechanical properties is more pronounced if the charge moisture ranged 3-6 %. When moisture content exceeds 9 %, the coke quality is influenced mainly by moisture variations. Since Briquette Charging method improves the coking properties of the charge by improving bulk density, its effect by bulk density increase was obstructed by a very high charge moisture content of 11 %.

Also because of insufficient manual mixing of fine coal and briquettes, filling of charging bin and small charging hole diameter of the furnace, some segregation of briquettes in the chamber was inevitable.

Briquetting operation

The briquettes were manufactured in the TKİ briquetting plant. This plant is usually used for the production of domestic fuel briquettes from coke breeze and pitch as the binder. Therefore this plant was not very suitable to produce briquettes which can be used for metallurgical purposes. For instance this plant had no suitable mixer, the size of the briquette was very big, etc.

Particularly the melting and distribution of binder in briquettes was not satisfactory because the temperature attained in the kneader was not high enough (maximum temperature was only 80°C although it is necessary to work at temperatures at least 15°-25°C higher than the softening temperature of binder). In addition to insufficient heating and insufficient coal moisture removal in the kneader caused the amount of moisture embedded in briquettes and therefore, causing the deterioration of briquette quality and so as the quality of coke obtained. Briquette quality was also badly effected because of long distance transportation to the Ereğli Iron and Steel plant from Ankara TKİ Plant.

Table 3 - Physical and chemical properties of coke samples

Run No*	Briquette * (%)	Fine coal (%)	Blending ratio of Coals and binder in briquette (% Original moist basis)				Overal Composition (%) (dry basis)				Change VM daf Content (%)	Dry Coke yield (%)	COKE PROPERTIES										
			Zonguldak	Armutçuk	Amasra	Binder	Zonguldak	Armutçuk	Amasra	Binder			VM (%)	FC (%)	Ash (%)	Sulfur (%)	Coke Strength				Apparent Density (g/cm³)	Porosity (%)	Reactivity (%Wt loss)
																	Experimental		Corrected				
																	T_{25}	T_6	T_{25}	T_6			
																	Drum Test						
1	21.44	78.56	20	70	–	10	82.88	15	–	2.12	33.25	72.7	0.86	80.14	19.00	0.56	49.1	70.6	53.1	75.6	1.02	49.3	33.96
2	28.58	71.42	20	70	–	10	77.18	20	–	2.82	33.18	80.8	0.81	81.89	17.29	0.62	47.8	70.8	51.8	75.8	0.98	51.4	37.13
3	31.24	68.76	10	80	–	10	71.91	25	–	3.09	33.65	83.9	0.62	82.69	16.69	0.61	46.9	65.5	50.9	70.5	0.97	51.6	39.03
4	37.49	62.51	10	80	–	10	66.29	30	–	3.70	34.60	78.5	0.80	80.35	18.86	0.60	44.1	64.1	48.1	69.1	1.00	49.8	44.93
5	–	100	–	–	–	–	85	15	–	–	32.66	77.8	0.85	79.31	19.85	0.56	46.7	62.7	50.7	67.7	0.97	52.6	38.14
6	–	100	–	–	–	–	80	20	–	–	32.52	75.6	1.01	79.99	19.01	0.52	45.3	59.7	49.3	64.7	0.98	51.5	44.20
7	–	100	–	–	–	–	75	25	–	–	32.43	75.8	0.80	79.40	19.80	0.57	42.2	54.4	46.2	59.1	1.05	48.7	45.05
8	25.33	74.67	30	–	60	10	82.45	–	15	2.55	33.16	74.9	0.61	80.05	19.35	0.60	45.6	58.0	49.6	63.0	1.07	47.4	35.18
9	33.77	66.23	30	–	60	10	76.61	–	20	3.39	33.84	78.5	1.02	80.60	18.39	0.71	45.8	61.8	49.8	66.8	0.97	51.7	40.10
10	36.04	63.96	20	–	70	10	71.37	–	25	3.63	34.55	77.5	1.13	80.08	18.79	0.50	43.8	58.0	47.8	63.0	0.95	52.1	43.20

The briquette size was quite large (55 gm) resultingly contributing to non-uniform distribution in the charge. In the commercial realization of the process they will be smaller in order to have better distribution, in other words in the case of using smaller briquettes, the number of briquettes in volumetric samples taken from different parts of the charge will not fluctuate appreciably. Also large size caused the number of cracks to increase. Half sized briquettes, weight 20-30 gm is desirable.

Oven operation and coking

Because of insufficient bulk density calculation facilities the coking time in the Improved Briquette Charging experiments was roughly estimated as 18 hrs. Which was taken as 17 hrs in Simple Blending type experiments. Therefore the relation of true bulk density, carbonization time and coke quality couldn't be established as required. As there was not a thermocouple placed at the center of the furnace, chamber and coke center temperatures couldn't be measured. But the control of temperature in the axial plane of coke at height in cm, above sole is very important and this would give us a better figure resembling the real carbonization conditions.

During the Improved Briquette Charging type experiments, one chamber wall was not heated enough. Because of non-uniform heating the coke cake centerline shifted from mid position (Photo 1, 2), resultingly lovering the physicomechanical properties of coke samples taken from left back, upper surface and in front of the discharging door sides of the coke cake. In other words, the faster movement of plastic layer from the right-wall, than that from the left, caused non-uniform coke quality in the furnace.

Coke size

For any given blend the carbonizing time is the greatest single factor influencing the coke size, although the initial coke size is greatly affected by crushing of coke during the discharge.

During the discharge, the coke cake as it leaves the oven mouth, must be fissured at the coke cake centerline in the middle position, the largest pieces of coke being about half the oven width. But in the present study in most of the experiments the coke cake had been fissured, because of non-uniform heating. As a result many fluctuations in the coke size distribution were observed.

Apparent and real density

The most important factor affecting the apparent and the real density measurements is samplig because of the non-uniformity of samples prepared as a representative of the coke of a specific overall composition and type of the experiment.

As can be seen from Figure 3 and 4 the apparent density decreases with the increasing Armut9uk percentage in the charge for the Improved Briquette Charging type experiments, as expected. But the opposite behavior in the case of the Simple Blending is not to be expected. The expected trend of apparent density decrase with the increasing Amasra percentage was also observed in the case of Amasra coal addition by the Improved Briquette Charging.

Porosity

When the porosity of cokes obtained is platted against Armutçuk and Amasra percentages added to charge as shown in Figures 4,5 and 6 it can be seen that the porosity of coke for the Improved Briquette Charging experiments increases with increasing Armutçuk and Amasra percentages.

The decrease of porosity with increasing Armutçuk percentage in the charge by simple blending is contradictory and unexpected behavior.

The desired porosity is 42-52 % for a commercial coke (Graham, 1969). Therefore porosity values of 51.6 % and 49,8 % for 25 % and 30 % Armutçuk addition and 47.4 % and 51.7 % values for 15 % and 20 % Amasra addition are very cloase to acceptable limits and creates no problem.

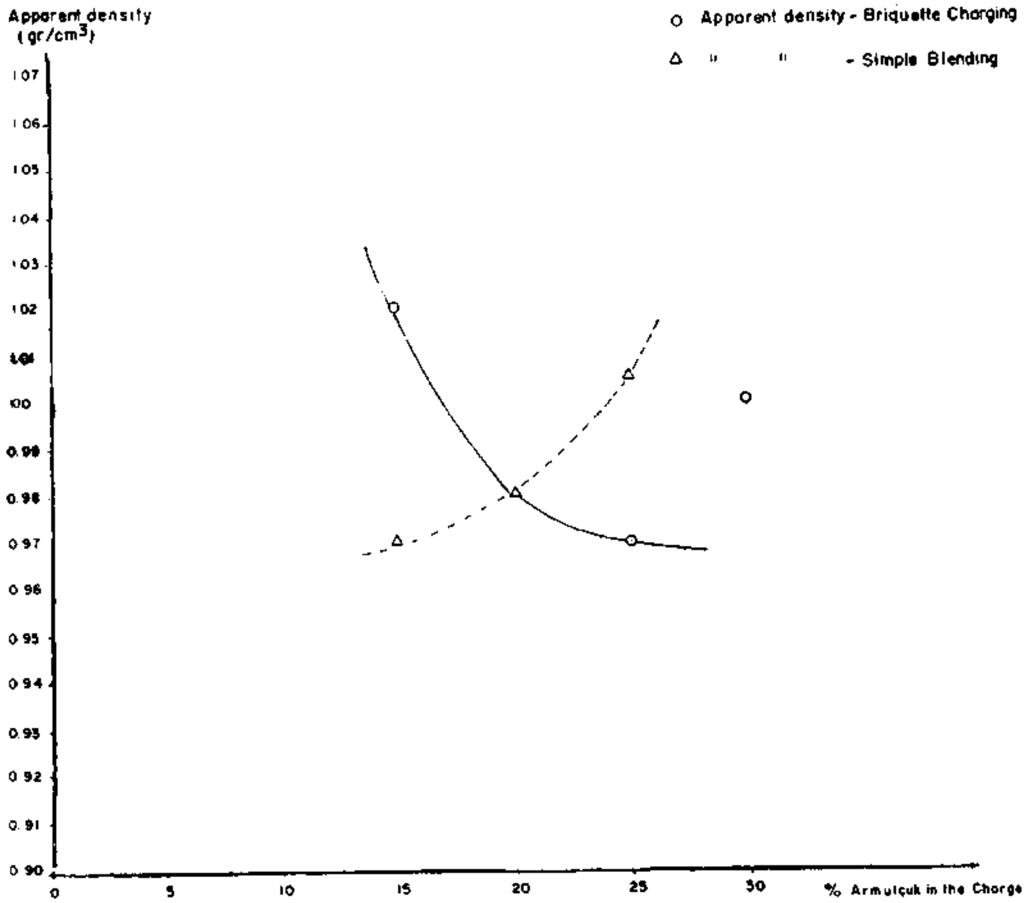

Fig. 3 - Effect of Armutçuk coal percentage in the charge on apparent density of coke.

Chemical analyses of coke samples

a. Moisture. — Coke moisture is an extremely important parameter in blast-furnace performance and its variation can prove harmful costwise. If the moisture varies, the carbon content varies, 3 % change in moisture is equivalent to 0.40-0.45 cwt coke/ton iron, which would require a 100°C change in blast temperature to correct (Nixon and Brooks, 1969). When the coke is charged with a high moisture of say 8 %, this often implies that the coke is truly saturated. Some moisture can be entrapped in the center core of the coke pieces and then in the lower regions of the furnace, coke breakdown can occur by the sudden release of the entrapped moisture, which is not desired (TSE 363, 1966). The moisture content must not exceed 3 % and a mean of 2 % is desired. In the present study the moisture contents of the cokes obtained from the small furnace were normally higher than that of commercial cokes because of a different way of quenching.

b. Ash. — Ash is undesirable because it is inert and therefore reduces the carbon content, also ash must be melted and this requires additional limestone because of its acidic character. This will result in extra slag, necessitating higher coke consumption and restriction of output (Nixon and Brooks, 1969). The ash content should not exceed 8 %, with a +- 1.7 % variation.

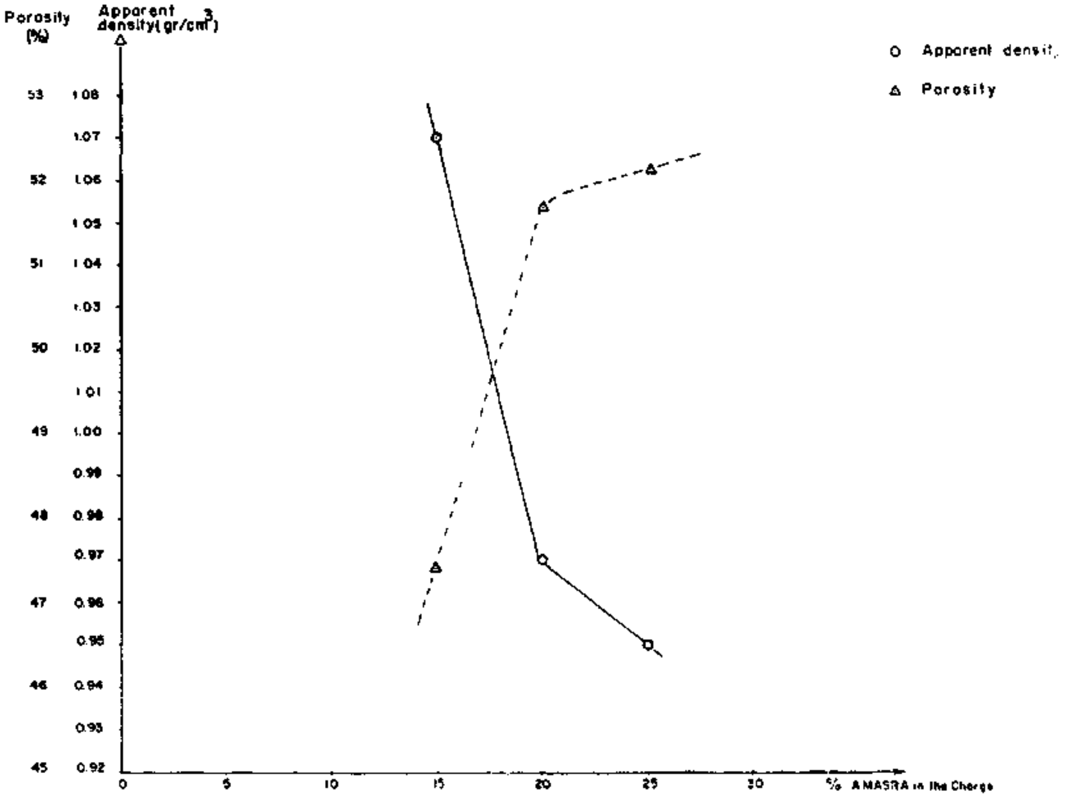

Fig. 4 - Effect of Amasra coal percentage in the charge on apparent density and porosity of coke.

Generally in Turkey, the ash contents of cokes used in iron and steel complexes are quite high (around 15-19 %). The examination of ash contents of coke samples for all experiments (Table 3) shows that the addition of the Armutçuk and the Amasra coals to the Zonguldak coal doesn't create any problem as far as ash content is concerned.

c. Volatile matter. — The increase in volatile matter content of the coke is not desired, because the rate coke consumption to increase. The amount of volatile matter in coke is related to the degres of carbonization. Normally the carbonization degres achieved in large industrial ovens is higher than that achieved in semi-industrial scale ovens. The produced cokes volatile matter contents are in the acceptable limits (0.75- 2 %) (Graham, 1969).

d. Fixed carbon. — According to the blast-furnace coke spesifications (Graham, 1969) the fixed carbon content of a blast-furnace coke should be 85-90 % . The fixed carbon contents of the coke samples obtained in the present study are very similar to carbon content of the industrial coke sample of the Ereğli Iron and Steel plant (about 80 %).

e. Sulfur content. — According to blast-furnace coke specification (Graham, 1969), the sulfur content should not exceed 0.6 % with a variation of +- 0.17. Sulfur content of the coke directly affects the quality of the iron. The steel produced becomes hot short, and brittle because of the presence of sulfur. In the present study addition of relatively higher sulfur containing younger Armutçuk and Amasra coals caus no serious increase in the sulfur content of the coke and as can be seen from Table 3, it remains in the allowable limits,

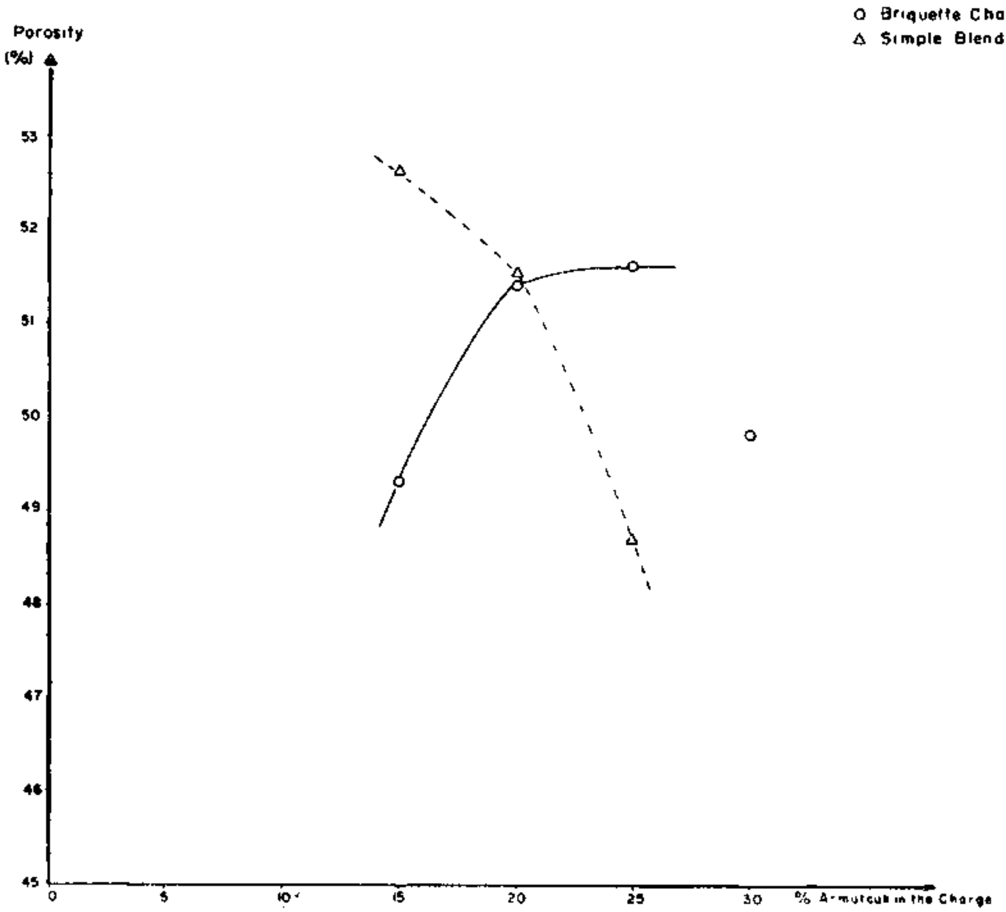

Fig. 5 - Effect of Armutçuk coal percentage in the charge on porosity of coke.

Coke mechanical strength

In the present study, the increased percentage of Armutçuk and Amasra coals in the charge makes the coke produced more heterogeneous and the ability of coke to suffer degradation in blast-furnace operation starts to lessen. Because, the Armutçuk-Zonguldak and the Amasra-Zonguldak sections of obtained cokes will exhibit extensive fissuring (causing internal stresses, and finally breakdown of coke) due to the heating in blast-furnace operation to the temperatures (up to 1400°-1600°C) higher than those at which the coke was initially carbonized.

Therefore the resistance to abrasion and breakdown under ambient conditions must be the main measure in assessing the quality of the coke.

T_{25} index gives a measure of stability and indicates the size of fissures in the coke. T_6 index (the rate of abrasion) is largely independent of the features of the coke-handling system and changes which may occur in the amount of breakage occuring in bunkers. The abrasion index would therefore be valid for cokes of different initial size and would be roughly the same, whether from the coke sampled at ovens or at the furnace skip. Also it was recognized that a high resistance to abrasion is a very desirable property of the, blast-furnace coke.

As can be seen from the examination of Figure 7, the rate of decrease of both T_{25} and T_6 index for Simple Blending case is much higher compared to the Improved Briquette Charging case.

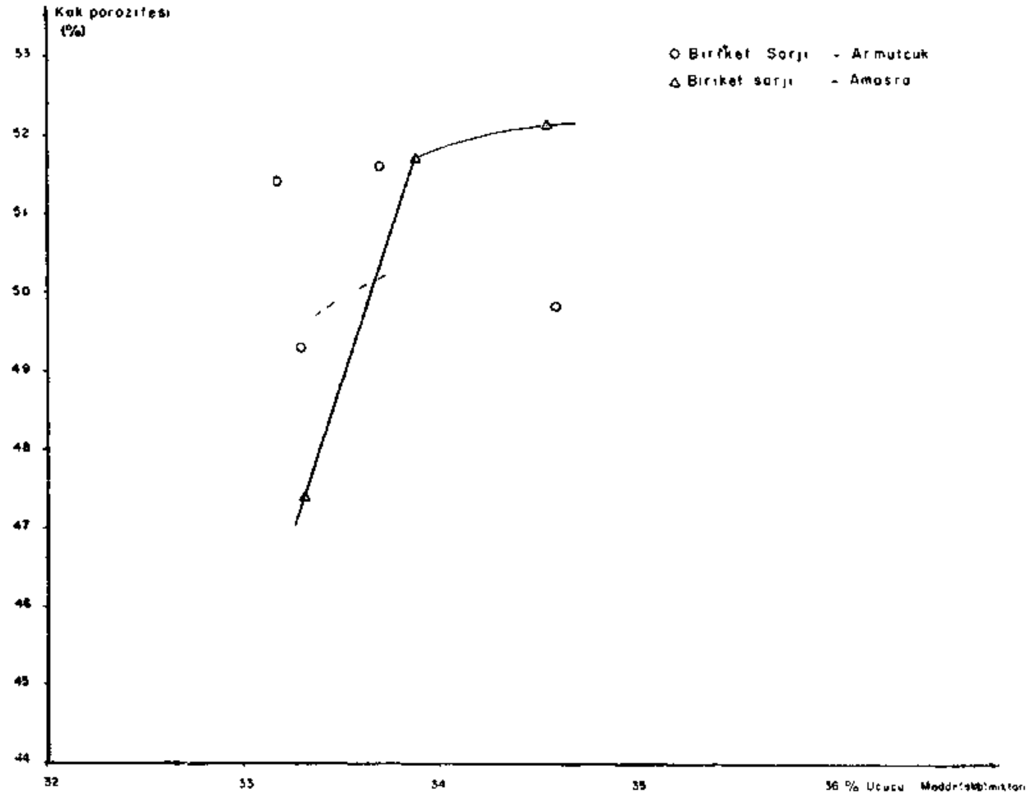

Fig. 6 - Effect of charge volatile matter (dry, ash free) content on coke porosity.

Figures 7 and 8 are drawn according to the previous experiences of the Ereğli Coke plant staff by adding 4 points to T_{25} and *5* points to T_6, because of the better operational conditions (oven charging, heating, quenching, etc.) in commercial coke batteries compared to small scale test oven.

Therefore if a T_{25} value of 50.5 is taken as the minimum permissible figure and a horizontal straightline parallel to x-axis is drawn to the right starting from the point 50.5 and crossing the two T_{25} curves (Fig. 7), it can be said that around 16 % of Armutçuk coal addition by simple blending and around 26 % of Armutçuk coal addition by the Improved Briquette Charging seems possible.

At this point it is necessary to clarify that, in the present study the test furnace capacity was only 400 kg. Therefore the chance of obtaining a uniform charge blend and a moderate quality coke was increased. But in the actual industrial practice (commercial coke ovens) a remarkable decrease in the coke quality with increasing percentages of non-coking coal in the charge was observed with the application of simple blending method even if satisfactory results were obtained from 250 or 400 kg capacity test ovens for the same blend. This situation is also valid for Erdemir that a T_{25} value of 50.7 in the 400 kg test oven and a T_{25} value of 45.6 in the commercial ovens was observed for the same blend (15 % Armutçuk and 85 % Zonguldak) when Simple Blending method was applied. Therefore 16 % Armutçuk addition (in other words exceeding 10 %) by simple blending method without lowering the coke quality below permissible limits, seems rather optimistic.

No such problem is valid in the case of the Improved Briquette Charging Method and the conclusions arrived at according to the results of the small scale test ovens doesn't deviate appreciably when compared to industrial results.

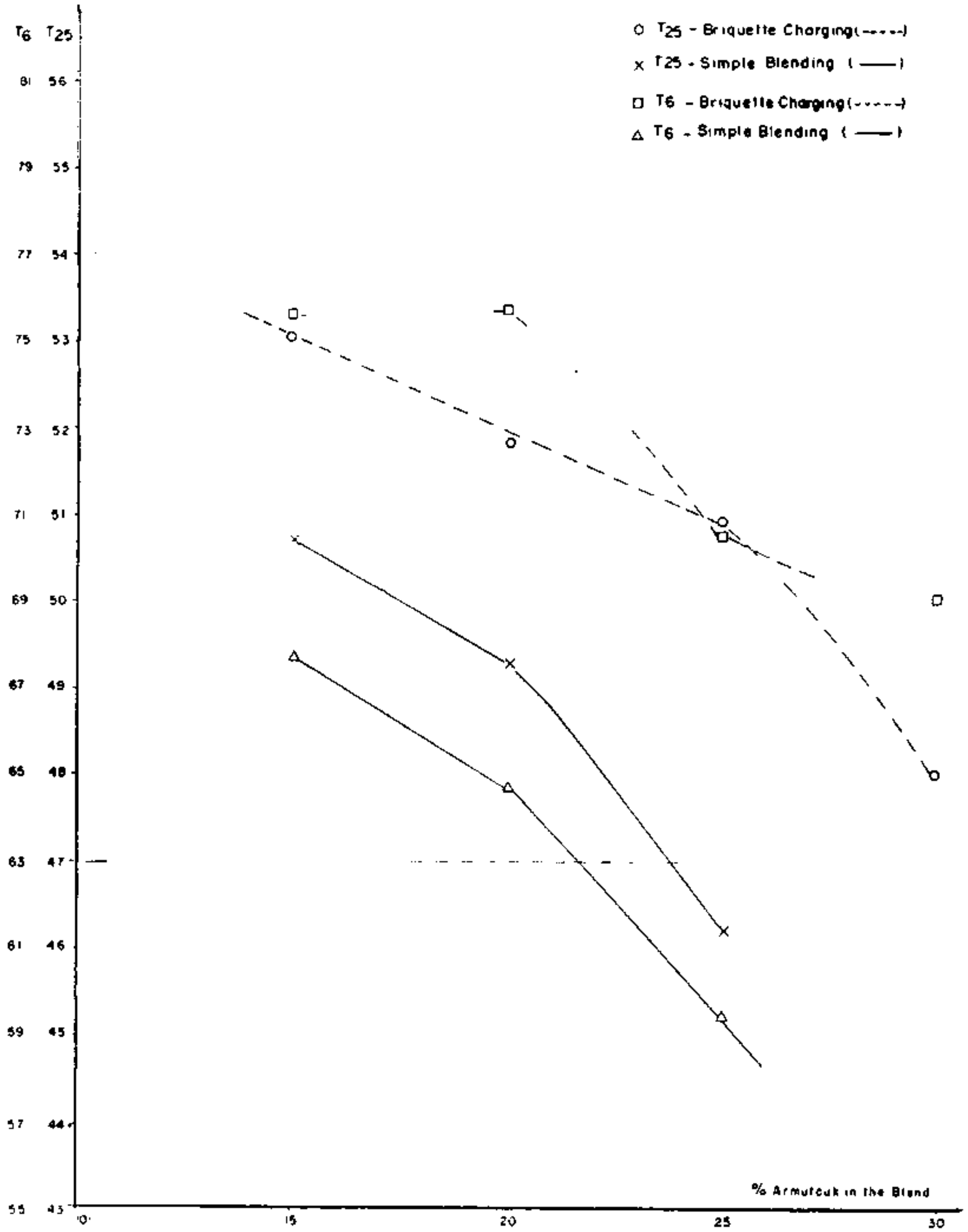

Fig. 7 - Effect of Armutçuk coal percentage on T_{25} and T_6 values of coke samples for simple blending and improved briquette charging experiments.

Examination of Figure 8 shows that the usage of Amasra coal up to 15-20 % in the metallurgical coke production by the application of the Improved Briquette Charging method seems possible.

As can be seen from Figure 9 the addition of Armutçuk to the blend by Simple Blending Method inevitably causes the amount of coke breeze produced to increase compared to that produced in the

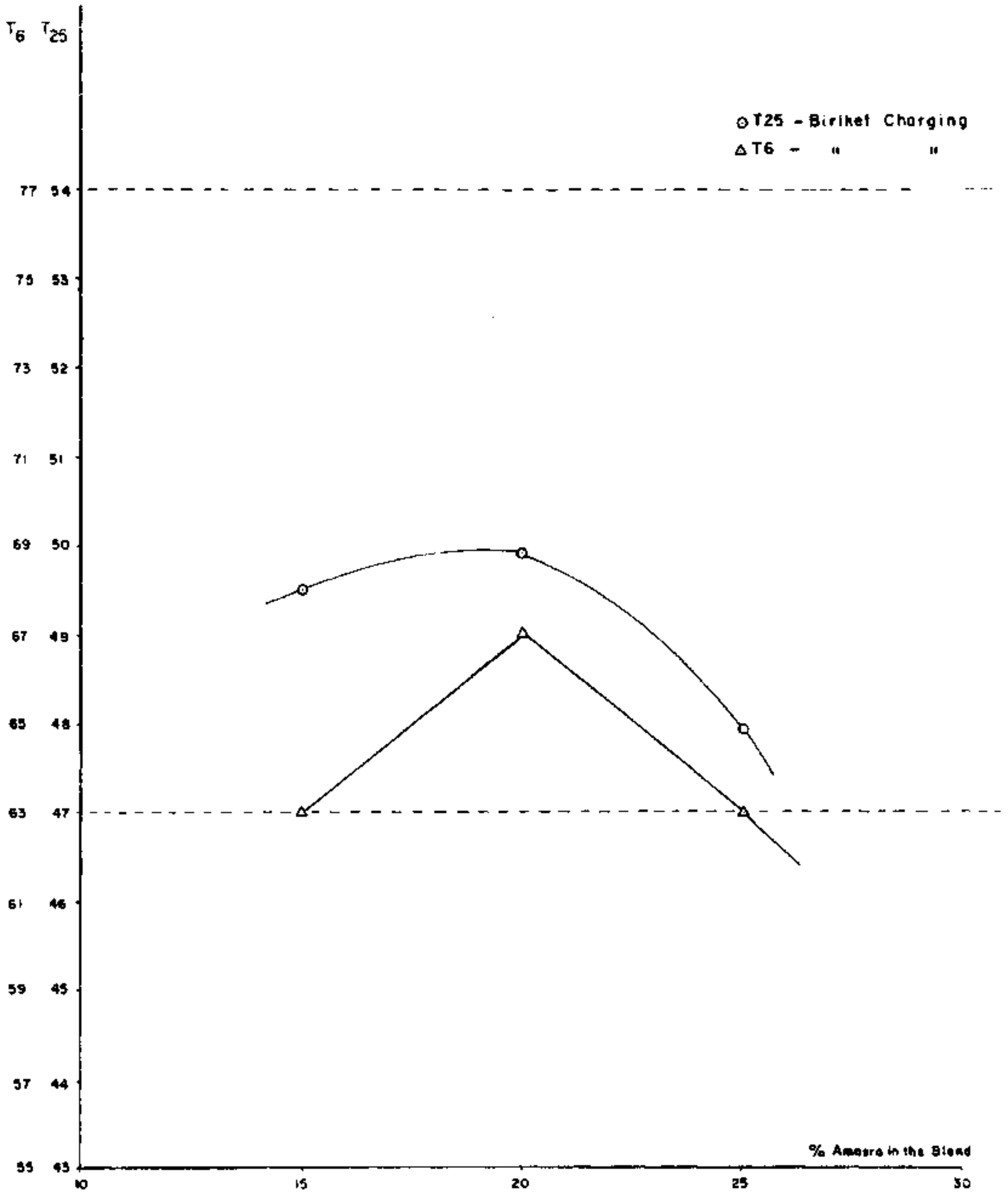

Fig. 8 - **Effect of Amasra coal percentage on T_{25} and T_6 values of coke samples for improved briquette charging experiments.**

improved briquette charging method, even if the discharged coke has not being subjected to normal mechanical shocks (falling down from 3-5 m of height during discharge, etc). The breeze percentage (-25.4 mm) of 5% in the case of Simple Blending decreases to 3.9 % (22 % decrease) in the case of the Improved Briquette Charging when 20 % Armutçuk was added to the charge. This decrease is 15 % (from 6 % to 5.1 %) when 25 % Armutçuk was added to the charge.

The major aim of the Improved Briquette Charging is to obtain the maximum coke yield by using around 25-30 % Armut9uk coal or 15-20 % Amasra coal in other words to produce maximum possible amount of coke containing around 25-30 % Armutçuk or 15-20 % Amasra coke which can be charged to blast-furnace, without creating any difficulties in its operation.

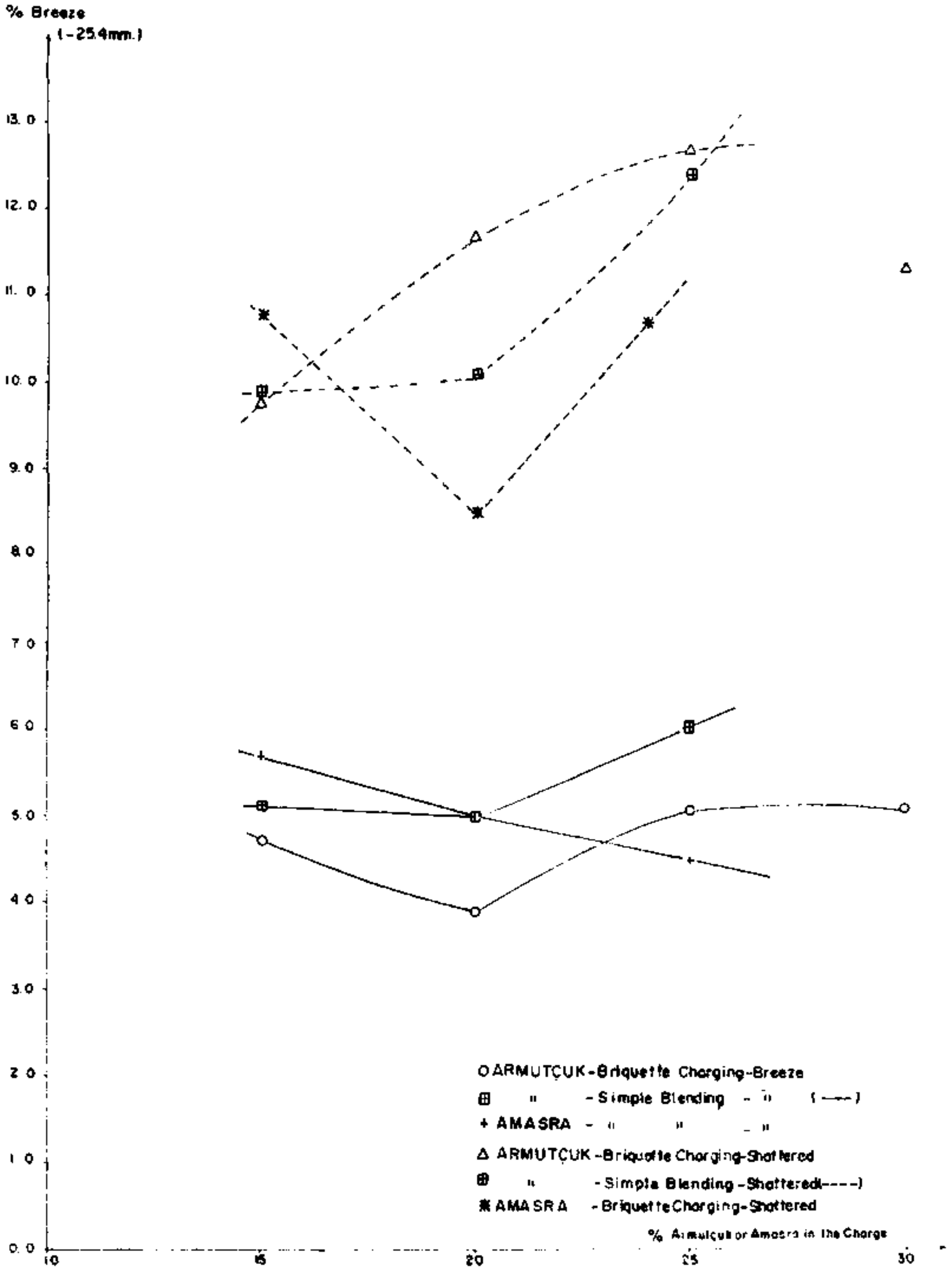

Fig. 9 - Effect of Armutçuk and Amaşra coal percentages in the charge on breeze content of the discharged and shattered coke

Also the effect of charge volatile matter (dry ash free) contents (Table 3) on the T_{25} and T_6 indexes of the respective cokes produced, can be seen from the Figure 10. Examination of this figure shows that the increase in volatile matter (d.a.f) content in the charge has a remarkable influence an the coke strength and lowers T_{25} and T_6 indexes sharply. The adverse effect of volatile matter (d.a.f) content of the charge on T_{25} and T_6 indexes can be lowered by the Improved Briquette Charging method.

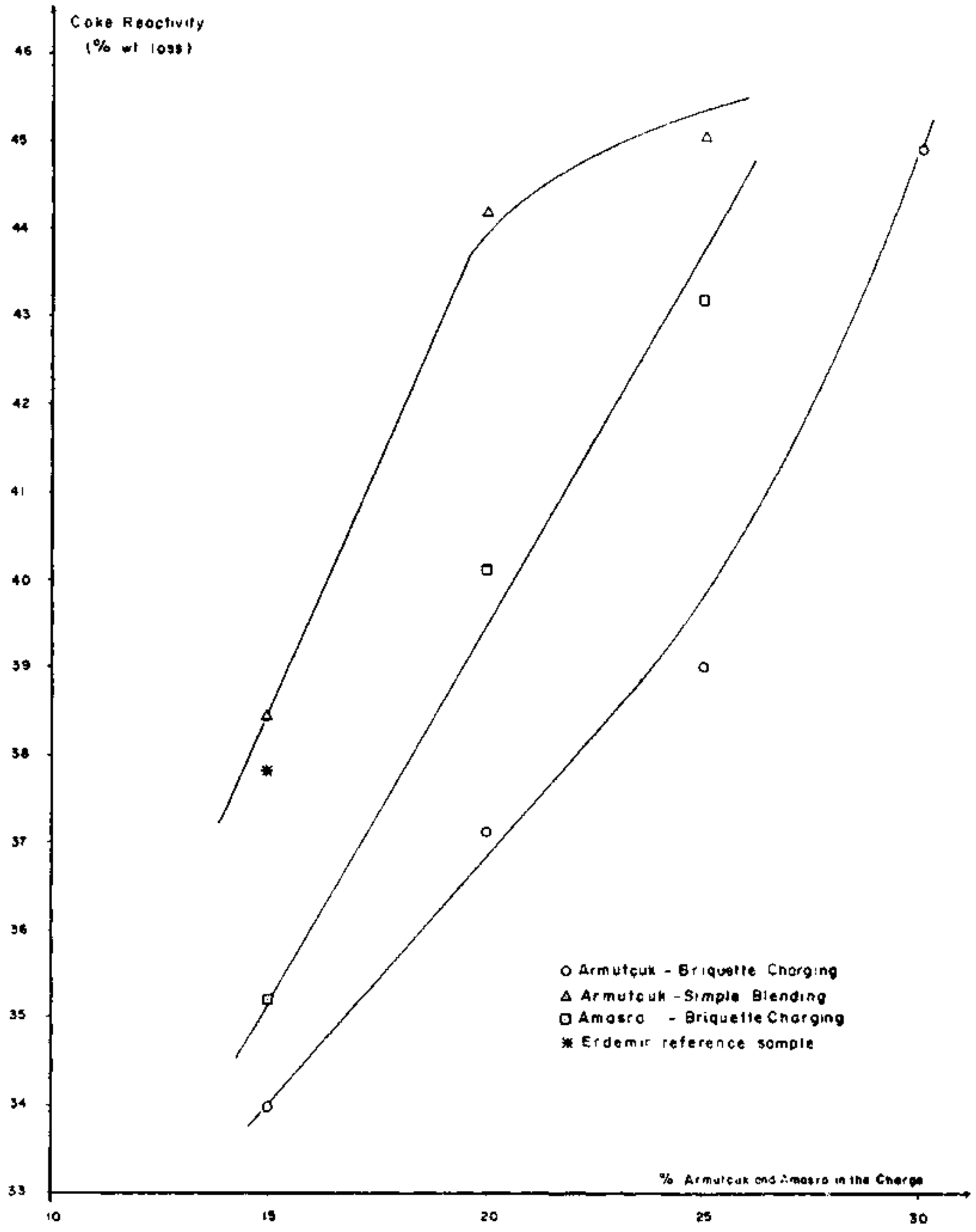

Fig. 10 - Effect of charge volatile matter (dry, ash free) content on T_{25} and T_6 values of coke samples.

Coke reactivity

Figure 11 shows that the addition of Armutçuk or Amasra coal to the blend increases the reactivity of the coke obtained, as expected. Because the addition of younger Armutçuk or Amasra coal increases the porosity and internal surface area of the coke (because of pores having small wall thickness) and also the coke structure becomes less highly ordered. As can be seen from the examination of the Figure 11 reactivity values of the cokes obtained for the same Armutçuk percentage in the charge by Simple Blending Method are much more higher than that obtained by the application of the Improved Briquette Charging Method. The reactivity value for a commercial coke is reported as 25-35 % and a maximum of 40-42 % is accepted.

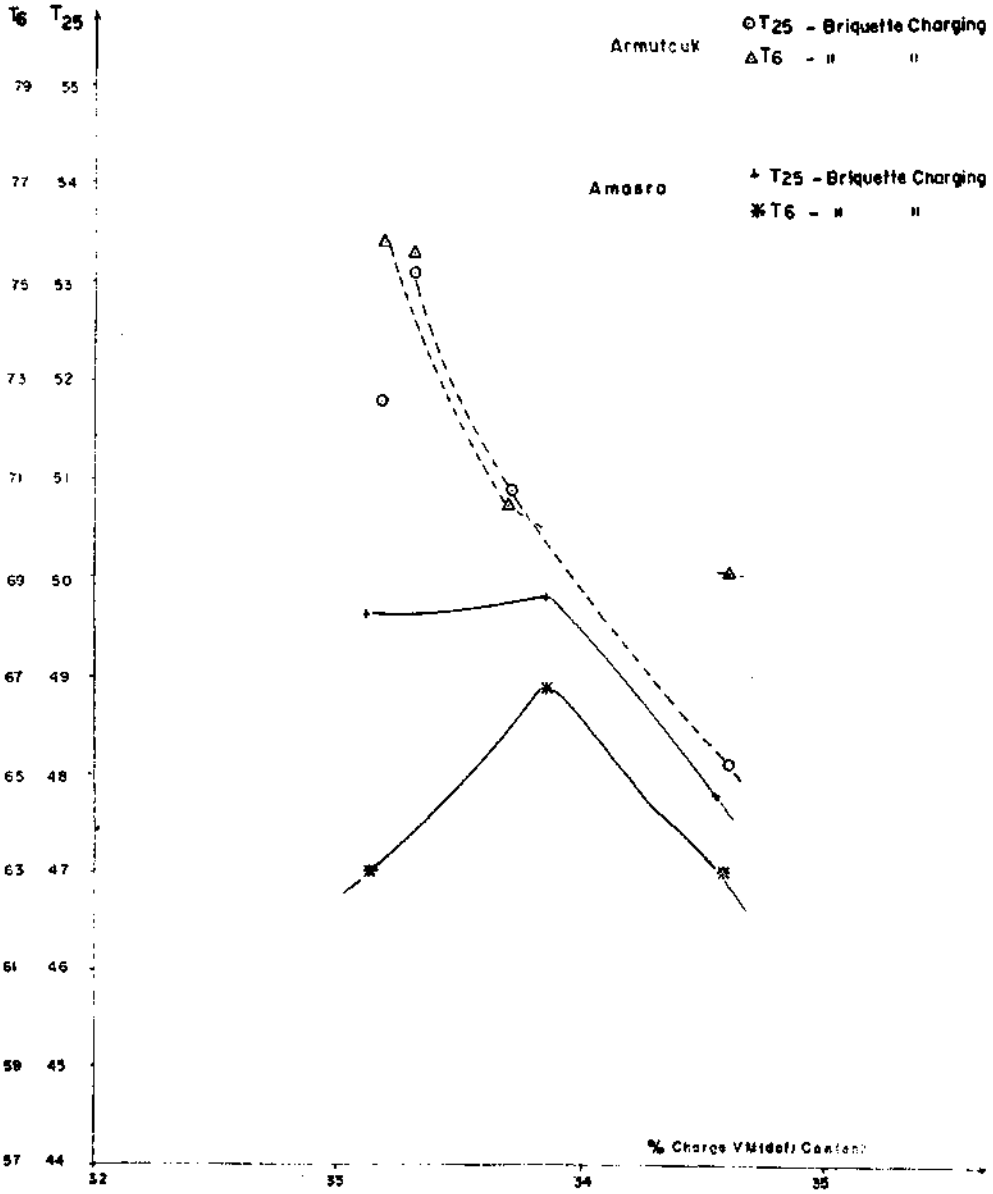

Fig. 11 - Effect of Armutçuk and Amasra percentage in the charge on coke reactivity.

It can be seen that the maximum limit of 42 % reactivity gives us a maximum Armutçuk coal addition of 27-28 % and a maximum Amasra coal addition of 23 % by the application of the Improved Briquette Charging process. These values are about the same as the maximum allowable valves calculated by the evaluation of coke mechanical strength valves.

CONCLUSIONS

a. Both Armut9uk and Amasra coals are suitable for the Sumi-Coal System-Improved Briquette Charging Process.

b. As for as the coke size, mechanical strength, density, porosity, reactivity and chemical analyses are concerned about 25-30 % of Armut9uk coal and 15-20 % of Amasra coal can be used in the metallurgical coke production by the application of the Sumi-Coal-Improved Briquette Charging Process, without creating any operational difficulties in the blast furnace.

c. Results of our feasibility studies can be summarized as follows: when the percentage of the Armutçuk coal added to the Zonguldak coal was 25 % a saving of $ 1.0 U.S. per ton of coke was possible, a saving of $ 3.0 U.S. per ton of coke was predicted when Amasra coal was added at the Zonguldak coal in ratio of 20 %. If both the coking and the non-coking coals were imported a possible saving of $ 6.0 U.S. per ton of the coke produced would be expected.

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Photo 1 - Discharging of the coked mixture from the oven.

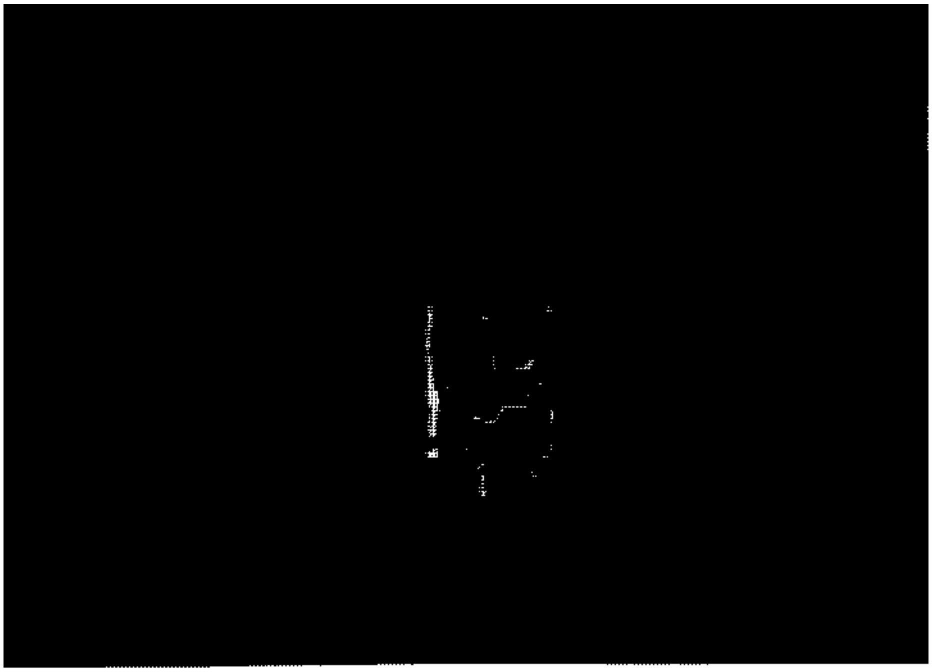

Photo 2 - Shifting of the center-line of the coke cake from the mid position.

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