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SUBSTITUTES FOR COKING COALS IN IRON-ORE REDUCTION

by

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SUMMARY

From a comparison of modern blast-furnace technology with possible alternatives in the shape of the recently developed iron-making processes it is concluded that the blast furnace will remain the principal source of pig iron for some decades to come, and that metallurgical coke will continue to be required for blast furnaces in amounts equalling - if not exceeding - the present consumption. Owing to the scarcity of good, medium-volatile coking coals research throughout the world is being directed towards the development of processes suitable for making metallurgical coke from other coals (high-volatile coking coals and weakly caking or non-caking coals). Investigations by the Division of Coal Research, C.S.I.R.O., have shown that metallurgical coke of improved strength can be obtained from Australian high-volatile coking coals by blending them with carbonaceous inerts prior to carbonization. Other processes with the same objective include the blending of non-carbonaceous inerts (ferro-coke) with the coking charge, continuous and controlled carbonization of high-volatile coking coals, and the manufacture of formed coke from a wide range of weakly coking or non-coking coals. By the use of formed coke it may prove

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possible to increase the efficiency of blast-furnace operation. In future there will be a variety of coke-making techniques available, and it will be possible to produce coke from almost any (low- or high-rank) coal. In the developing areas of the world the choice will be determined by economic factors.

A review of processes involving the injection of alternative fuels (finely ground coal, oil, coal-oil slurry, natural gas, coke-oven gas) into the blast furnace shows that they are capable not only of reducing the coke consumption per ton of pig iron but also of giving a significant increase in blast-furnace capacity. On economic grounds coal appears to have a more promising future than competitive fuels, and coal injection represents a major advance in blast-furnace technology.

1. INTRODUCTION

(1) In the present century, rapidly increasing demands for steel and a shortage of good coking coals in Europe have stimulated research on raising the efficiency of blast-furnace operation, widening the range of coals suitable for the manufacture of metallurgical coke, and developing new iron-making processes (see Fig.1).

(2) The blast furnace has retained its supremacy, in face of competition from many new iron-making processes, inter alia because of the following inherent advantages:

(A) High thermal efficiency (80-85%).

(B) Quality of pig iron (molten metal, as opposed to the sponge-iron produced by most non-traditional processes).

(C) Continuous improvements in technology (achieved by ore sintering, increased blast temperature and pressure, oxygen enrichment of blast) have led during the past decade to a decrease of the rate of coke consumption from 0.95 to 0.7 ton (19 to 14 cwt) per ton of pig iron (national averages), with a simultaneous increase of 50% in specific iron output.

(D) Further improvements are expected through a wider adoption of fuel-injection techniques (a coke consumption rate as low as 0.3 ton (6 cwt) per ton of pig iron is anticipated).

(E) By making use of recent advances in blast-furnace technology it will be possible to step up the production of iron without building new blast furnaces.

(3) It appears likely that application of the new iron-making processes will be confined to areas where electricity, oil, natural gas, or non-caking coals are abundant and cheap compared with coking coals or where only small amounts of iron are required, which would not justify the construction of large blast furnaces.

(4) World production of steel is increasing at such a rate (5% per annum, on the average) that, even allowing for further reduction in the coke consumption rate, the demand for coke in 20-25 years' time will equal - if not exceed - the present world consumption of 280 million tons per annum.

(5) Using the conventional technique of carbonisation, only the low-medium volatile coals (volatile matter on air-dried basis, 20-30%; B.S. swelling number $\geq$ 4) yield a strong, hard coke suitable for metallurgical use (see Fig.2). Since the reserves of these good coking coals are relatively small (less than 10% of total reserves), attempts are being made in many countries to develop processes for the utilization of high-volatile coking coals and weakly or non-caking coals in the manufacture of metallurgical coke; or, alternatively, to use these coals directly for iron-making without first converting them into metallurgical coke.

(6) Some of the results of this work - obtained in Australia and elsewhere - are described in the present paper. No claim is made to completeness, and in fact rotary-kiln and electric-arc processes (in which coal, coke breeze, and char are used both as reducing agents and as source of energy) are unavoidably excluded.

2. METALLURGICAL COKE FROM HIGH-VOLATILE COKING COALS

(7) Table 1 sets out the main features of processes for making metallurgical coke from coals not normally employed for this purpose, while Table 2 gives the properties of the resulting cokes.

(8) It has been known for more than a century that the coking properties of high-volatile coking coals, which normally yield weak fissured cokes, can be greatly improved by blending the coals with low-volatile carbonaceous additives such as anthracite, coke breeze, low-temperature char (semi-coke), and low-volatile or non-coking coal. Research in this field is being continued in the United Kingdom, United States, Soviet Union, France, Germany, Japan, India, and Australia and recent publications deal with the use of char[1], anthracite fines[2], coke breeze, and blast-furnace flue dust[3].

a. Blending with Carbonaceous Inert Additives

(9) Australia has extensive deposits of high-volatile coking coals in New South Wales and Queensland, and in view of the importance of coke-making for the rapidly growing iron and steel industry the C.S.I.R.O. initiated in 1956 a comprehensive investigation into the carbonization of these coals in blends with carbonaceous inerts. The tests were carried out on 200 lb samples using a technical-scale carbonisation plant. Information was sought on the effect of (1) proportion, size grading, and volatile content of additive; (2) properties of parent coal (volatile content, swelling, fluidity); (3) carbonizing conditions (temperature, bulk density of charge). Detailed results of these investigations have been described in several publications[4-11].

(10) The scope of this paper makes possible only a brief survey of the main results[12], which are shown diagrammatically in Fig.3. While the overall strength of cokes made from high-volatile coals of medium or high fluidity was considerably improved by blending, that of cokes from high-volatile coals of low fluidity and from coals of low-medium volatile content was not.

(11) The following rules have been formulated for the preparation of oven charges to give cokes of improved strength from high-volatile coals:

(A) The <u>inert additive</u> for blending should be suitably chosen in accordance with the coking propensity of the parent coal. (Low-temperature fluidized-bed char (volatile matter 1%) for coals of medium fluidity; high-temperature coke breeze (volatile matter 1-2%) for coals of high fluidity.)

(B) <u>Fine grinding</u> of the additive is essential (between 30 and 120 B.S. mesh, i.e. about 0.5-0.1 mm) to facilitate its incorporation into the coke matrix.

(C) <u>The inert additive, amounting to 10-15% of the total charge</u>, should be thoroughly mixed with the minus 1/8 in. (-3 mm) coal, and the mixture carbonized at a suitable heat-penetration rate (about 0.8 in./hr for blast-furnace coke and about 0.6 in./hr for foundry coke).

(12) Optimum improvements attainable under the above conditions for coke made from New South Wales high-volatile coals of medium fluidity were 8-10 points for 1½ in. shatter index and 1-2 points for 1/4 in. hardness factor.

(13) Among technical and economic advantages of the blend-carbonization process are the following: First, the additive can be made from a wide range of coals using different techniques (fluidized bed, static bed, rotating drum, travelling grate) or even from mineral oil[13,14]. Secondly, if the additive is prepared from a local high-volatile coal, transport costs of low-volatile coal (which could be used as an alternative for blending) may be saved. This is important in countries like Australia, where distances are great. Thirdly, the scale of the blend-carbonization plant can be varied according to requirements - a beehive oven or a by-product type oven can be used, and the process may therefore find useful application in less-developed areas, where the present capacities of the coking and steel industries are small. Finally, the blend-carbonization technique is applicable to all types of high-volatile coking coals, providing the additive is suitably chosen.

(14) Large-scale trials[15] have proved the applicability of the char-blending process to the carbonization of high-volatile New South Wales coals. Future applications will depend on the economics of the process, as well as on the outcome of other investigations designed to obtain improvement of coke strength.

b. Use of Non-carbonaceous Additives

(15) By carbonizing blends of high-volatile coal with iron ore, ferro-coke is produced, in which the iron ore is already partially reduced. Blast-furnace flue dust and iron scrap from foundries have also been used as additives.

(16) The coke product from this process usually has improved shatter strength but is relatively soft, and therefore can be used only in low-shaft furnaces. In an American blast furnace[16] up to 60% of the coke was successfully replaced by ferro-coke (made with 10-20% blast-furnace flue dust). The use of ferro-coke in large-scale cupolas[17] and blast furnaces[18] in Czechoslovakia, Poland, and North Korea is reported to have given improved furnace performance and reductions in cost of iron produced. The introduction of haematite and magnetite (5-10%) and blast-furnace flue dust (10-20%) into carbonizing charges is being studied in the United Kingdom on a pilot-plant scale[19]. Ferro-coke has been made from lignite and iron ores in India[20].

(17) Successful tests with ferro-coke pellets in a small experimental blast-furnace in Australia[21] indicated the possibility of developing a burden preparation plant which would combine the functions of coke ovens and sintering units, and which, furthermore, would produce a burden material with a high melting rate.

(18) The addition of manganese ores to Donetz gas-coals has been practised in the Soviet Union[22], while in Romania[23] high-volatile coking coals have been carbonized with lime to reduce the sulphur content of the resulting coke.

c. Continuous and Controlled Carbonization

(19) A better understanding of the mechanism of carbonization, and particularly of the part played by the process of volatile-matter evolution, has led to the development of new techniques for carbonizing high-volatile coals.

(20) In the process developed by Salem-Brosius Inc. and Wise Coal and Coke Co.[24] the coal is carbonized on the rotating hearth of a 10ft diameter furnace, with heat derived from combustion of by-product vapours. Owing to the reduced requirements for coal preparation and labour, operating costs are essentially lower than with other carbonization processes ($1 per ton of coke for single-furnace operation). The capital cost of the plant has been given as $10-12 per ton of annual coke production. In this process a high heating rate is used (1.8 in./hr) and therefore the coke product is small (< 1 in.) and porous. It is mainly suitable for ore-sintering and the production of ferro-alloys. A similar process was developed in the D.I. Mendeleev Institute of Chemical Technology in Moscow[25]. Preheating of the charge to 150-200°C and a long carbonizing time (6-7 hr) made possible the production of metallurgical coke of standard strength from high-volatile coals. The output of the circular oven was 11-13 kg of coke per hour per $1m^2$ of heating surface for an untreated charge, and 18-20 kg/hr for a preheated charge. (The corresponding figure for conventional carbonizing ovens is 7-8 kg/hr.)

(21) In the Newcastle (Australia) works of the Broken Hill Proprietary Company the production of "coked compacts" is being studied[26]. The formed, nearly spherical compacts are produced by binderless briquetting of high-volatile coking coal under 280 kg/cm^2 pressure and are carbonized in a continuous stream of sand (alternatively, haematite fines, sinter fines, or other iron-bearing materials can be used). By means of controlled heating (high heating rate in the first and final stages of carbonization, slow heating in the plastic and semi-coke stage) a strong, non-swollen product is obtained. The coked compacts have been used successfully for the operation of an experimental cold-blast cupola[27]. Smoother operation, better heat transfer, higher metal temperatures, and higher thermal efficiency were obtained than with coke made from the same coal by conventional carbonization techniques. Studies of the high-temperature combustion characteristics of coke compacts are in progress with a view to possible use of the compacts in blast furnaces.

(22) The same company[28] is also investigating continuous coking. The experimental unit involves fluidized-bed preheating of the coal, continuous feeding of preheated coal to the strand, and controlled heating of the coal layer (slow heating between 400 and 550°C, rapid heating in the final stage of carbonization). Coke of considerably improved shatter strength but slightly reduced abrasion hardness can be produced by this technique. Similar processes have been studied during the past few years in the Soviet Union. One of these, the Sapozhnikov process, is described in Section 3b of the present review.

3. METALLURGICAL COKE FROM WEAKLY-CAKING AND NON-CAKING COALS

(23) Apart from high-volatile coking coals, other important raw materials from which strong metallurgical coke cannot be produced by the conventional techniques of carbonization are the weakly caking and non-caking coals (e.g. anthracite, subbituminous coals, brown coal, and lignite). Such coals are, however, used instead of coking coals in many newly developed processes for the manufacture of iron (see Table 1). In all of these, improvement of caking ability is achieved with a binder or by other means (rapid heating, hydrogenation, pressure).

a. Processes Using a Binder

(24) Depending on the volatile content and caking power of the weakly caking coal, carbonization with a binder is either possible directly in a single-stage process, or, alternatively, by means of a combined, two-stage process in which the coal is first partially devolatilized and then briquetted and carbonized.

i. Single-stage processes.

(25) Low-volatile coals ($V_{daf.} < 18\%$) and high-volatile weakly caking coals briquetted with 10–20% of tar, pitch, coking coal, or bitumen, or with a mixture of these, can be carbonized in one step to yield a strong shaped coke. The Otto Company (West Germany) has applied this process successfully to steam coals and anthracitic coals[29] as well as to the fine coals of many developing countries (Korea, Morocco, Peru, Venezuela). The cokes produced cokes suitable for use in foundries (porosity 25–35%) and blast furnaces (porosity 35–45%). A successful blast-furnace trial was carried out with 80 tons of Korean coke in 1961.

(26) The Sojuntan process[13], developed in Japan, enhances the caking capacity of poorly caking or non-caking coals by blending them with a mixture of tar and finely ground non-caking coal (the so-called Sojuntan). If the parent coal has a high volatile content, low-temperature char (semi-coke) is also added to the carbonizing charge. Large-scale trials have established the technical feasibility of the process and any future applications will depend on economic factors (for example, for the process to be competitive the price of local coal must not exceed two-thirds that of imported coal).

(27) Extensive experiments were carried out by the U.S. Bureau of Mines[30] on the production of metallurgical coke from anthracite. Best results were obtained with a ternary blend containing 82% anthrafines, 8% pitch, and 10% bituminous coal. The blend was briquetted under 200 atm pressure and then carbonized at 950°C. The product proved superior, in resistance to impact and abrasion, to premium foundry and blast-furnace cokes.

ii. Two-stage processes

(28) The development of processes for the treatment of high-volatile non-caking coals which have to be partially devolatilized before being briquetted and carbonized, has followed two main patterns. In the first type of process a char is produced from the coal at high temperature and the briquettes made with the ground char are carbonized at a low temperature.

(29) In Western Australia, pilot-scale studies[31] have been carried out in recent years in which the local sub-bituminous coals were carbonized at 800°C in a two-stage circulating-gas retort of the Lurgi Spülgas type. The char was finely ground, and then briquetted under a pressure of 300 kg/cm^2 with the tar and liquor recovered from the carbonization stage. The briquettes were matured at 200°C in flue gas diluted with air, and were then carbonized at 500-600°C in a tunnel oven. The resulting briqcoke product has been tested in small iron foundries and found to compare favourably with imported coke. It has also proved suitable as a locomotive fuel. Detailed data on the economics of the process are not yet available, but its further development would be of importance to Western Australia where the local coal is of the non-caking sub-bituminous type. At present, metallurgical coke for smelting this State's large iron-ore deposits has to be brought from New South Wales, a distance of about 2000 miles.

(30) The IChPW[i] (Poland)[32] and Blum-Nistor (Romania)[33] processes are almost identical. They have been applied not only to sub-bituminous coals but also to brown coals and lignites. The latter had a high ash yield, which was reduced to 10% by washing prior to carbonization. The clean coal was carbonized in a shaft furnace at 850°C. The char was ground to minus 3 mm, and briquetted with pitch or bitumen under a pressure of 300 kg/cm^2. The resulting briquettes were subjected to an oxidation treatment at 250-300°C for 2-4 hr. The strong, shaped coke has been successfully used in foundries but not yet in blast furnaces.

(31) In the other type of two-stage processes, the coal is devolatilized at a low temperature and after char grinding and briquetting the final carbonization is carried out at high temperature. An example is the FMC-coke process[34], developed jointly by the Food Machinery and Chemicals Corporation and the U.S. Steel Corporation. The parent coal (lignite, sub-bituminous coal, or high-volatile bituminous coal) is ground, treated with catalysts, and carbonized at low temperature. The resulting char is calcined and the pitch used for briquetting the char. The briquettes are matured and finally carbonized at a high temperature. Coke produced in the 250-ton/day capacity Kemmerer (Wyoming) plant performed well during the 18-week trial in a small blast furnace. Using self-fluxing sintered iron ore as burden, the rate of coke consumption was 50% (10 cwt/ton) on hot metal. It is claimed that the capital cost of the plant is only 50% of that of a by-product carbonization plant of similar capacity, while operating costs are comparable.

(32) The Otto Company (Western Germany) has announced the construction of a plant of 1 million tons per year capacity for the production of metallurgical coke from South Arcot lignite at Neyveli, India[35,36]. The lignite is devolatilized at low temperature, the resulting char is ground, briquette (with tar or pitch or a mixture of these with coking coal), and the briquettes carbonized at 950°C. In cupola trials with this fuel, 30% reduction in coke consumption and 35% increase in melting capacity was achieved[37] compared with normal foundry coke.

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i Institutu Chemicznej Przerobki Wegla (Institute of Chemical Treatment of Coals).

b. Processes Not Using a Binder

(33) Certain non-caking coals can be converted into shaped strong coke without the use of a binder. Pioneering studies on the carbonization of binderless brown-coal briquettes were undertaken in Germany during the nineteenth century, and after several improvements, among which the briquetting of hard lignites with a ring-roll type press by Herglotz in Czechoslovakia was perhaps the most important, led to the development of the Lurgi-Krupp process[38] in the 1930's. The main steps in this process are flash-drying of the coal with simultaneous reduction of particle size, briquetting in a ring-roll press under high pressure (2000-3000 kg/cm^2), and carbonization to a final temperature of 1000°C. The resulting hard lump-coke is used in low-shaft blast furnaces (Calbe, Elbe), in lime kilns, or in electric furnaces for the production of carbide and phosphorus. Further developments of the process were reported after the Second World War (Rammler and Bilkenroth[39]).

(34) Investigations along similar lines were started in the 1950's in Victoria (Australia), where large reserves of young brown coal, as well as the absence of local supplies of coking coal and the high costs of transporting coke from New South Wales, provided an economic incentive to the production of cheap metallurgical fuel. In the process developed jointly by the University of Melbourne and the Gas and Fuel Corporation of Victoria[40], the brown coal is crushed and briquetted under high pressure. The briquettes are carefully predried and then heated slowly to 900°C (slow "protective" heating gives a stronger product). The coke produced in this way proved to be a satisfactory cupola fuel, when tested in a 24 in. diameter cupola, except that metal temperatures[41] were lower than with ordinary foundry coke.

(35) Another important development in the binderless treatment of weakly caking high-volatile coals, in which the new technique of extrusion briquetting is used, is the Sapoznikov process[42] (Soviet Union, India). In this process finely ground coal is heated in a fluidized-bed carbonizer to just below its softening point and kept at 380-400°C for 1-10 minutes. The resulting char is extruded at 400-450°C under a pressure of 15-16 atm and the green briquettes are carbonized at a heating rate of 5°C/min to 600-750°C. The USSR has a pilot plant of 400 tons/day capacity in operation at Kharkov, and is planning to treat 100 million tons of coal per annum by this process.

(36) Yet another form of binderless briquetting is that developed for non-coking slack coal by the Regional Research Laboratory, Hyderabad, India[43]. The coal is dried, finely ground, and then briquetted at 200-250°C under 200-300 kg/cm² pressure. Maturing of the briquettes in an oxidizing atmosphere at 200°C for 2 hr considerably increased the strength of the coke product obtained on subsequent carbonization at 600 or 900°C.

c. Special Processes

(37) These include a few techniques for the manufacture of metallurgical coke from weakly caking coals. Their commercial development has not yet been undertaken and appears to be less likely than that of other processes previously mentioned. One is hydrogenation under pressure: by this means metallurgical coke can be obtained from non-caking coals[44] and even from lignite[45]. Carbonization under pressure[46] or with high heating rate[47] (up to 150-200°C/min.) has been shown to improve the strength of coke obtainable from weakly-caking coals. Natural gas[48] can be used in the coking of dried pellets made from weakly-caking coals. This technique takes advantage of the cementing effect of the carbon produced by cracking of the natural gas at the carbonizing temperature. In another new technique, developed in India[49], high-temperature chars are briquetted with about 10% of silica-based inorganic binder, maturing of the briquettes for 7-14 days then gives a product suitable for metallurgical use.

4. REDUCTION OF COKE CONSUMPTION IN BLAST FURNACES AND CURVES OF FUEL INJECTION

(38) The efficiency of operation of blast furnaces has recently been improved by injection of alternative fuels in partial replacement of coke[50]. First experiments were carried out in the nineteenth century, but the work was abandoned and it was not until about ten years ago that efforts were renewed and fuel injection was proved to be both technically and economically advantageous.

(39) Results obtained with the injection, into blast furnaces, of finely ground bituminous coal in the United Kingdom[51] with anthracite in the United States[52]; with heavy fuel oil in the UK, USA, Canada, France and Italy[53], with natural gas and coke-oven gas in the USA and the Soviet Union[54], and also with combinations of these fuels, have shown that up to 20-30% of the coke used in the blast furnace can be replaced, with a simultaneous 10-30% increase in iron output. Using oxygen-enriched blast and fuel-oil injection (25% = 5 cwt per ton of hot metal) the coke consumption can be reduced to 30% (6 cwt/ton) of pig-iron output. There is a technical limit, however,

to the extent of replacement of coke by oil or gas. This is determined by two factors: (1) the need for coke to act as a support for the burden and (2) injection of oil or gas requires increase in the blast rate but this, beyond a certain point, may hamper the downward flow of the burden.

(40) In assessing the economics of the use of alternative fuels it has to be taken into consideration that the overall effects of fuel substitutions depend not only on the calorific values involved but also on the reducing efficiency of the various fuels and of their decomposition products. In blast-furnace trials carried out recently in the USA it was confirmed that the attainable savings per ton of hot metal are $1.07 for coal, $0.51 for 60% coal-40% oil slurry, $0.22 for natural gas, and $0.16 for oil[ii]. Similar savings were obtained in recent coal-injection experiments in England. It is therefore clear that in this field coal has advantages over other fuels. It must be admitted, however, that the capital cost of equipment for injecting coal is higher than for fluid fuels. Together with other recent improvements (higher top pressure and blast temperature, beneficiation of the burden, oxygen-enriched blast) the injection of alternative fuels constitutes a major technical advance, representing in some cases an increase of as much as 50% in the capacity of existing blast furnaces. However, these techniques are still in the testing stage and application is confined to the more highly developed industrial areas where large blast furnaces are already in operation.

(41) With cupolas, fuel injection has proved less successful, and in the United Kingdom injection of fuel oil has in fact been discouraged for technical and economic reasons. Recently, however, more promising results were achieved in the Soviet Union and in the United States[55]. In the latter, injection of natural gas is said to have reduced fuel costs by $1.70 per ton of melted iron.

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ii The calculation was based on experimentally established replacement ratios (for coal 1.1, for 60% coal-40% oil slurry 1.0, for oil 0.75, and for natural gas 0.63 lb/lb of coke), a normal coke rate of 1300 lb per ton of hot metal, and a coke replacement of 20%. These values refer to plants on the eastern seaboard of the United States, where fuel prices were recently quoted as: coal, $7 per ton; oil, 8 cents per gal.; natural gas, 50 cents per thousand cu.ft.; and coke $16 per ton.

5. CONCLUSIONS

(42) In spite of the large number of non-traditional iron-making processes developed recently the supremacy of the blast furnace is likely to remain undisputed for some decades to come, and therefore coke will be required in amounts equalling or even exceeding the present consumption.

(43) Results obtained with processes for making good metallurgical coke from high-volatile coking coals, and a review of processes which might be used in the future for producing metallurgical coke from "substitutes" for coking coals (e.g. low- or high-rank, weakly coking and non-coking coals), show that modern techniques make possible the establishment and development of iron- and steel-making industries based on any type of coal which may be economically mined in less developed areas of the world. Proper selection of the coke-making process should ensure the technical feasibility of projected plant in developing countries, and thereafter economic rather than technical considerations will decide its future.

(44) The cokes produced from the "substitutes" are not only of sufficient mechanical strength, but (unlike conventional cokes) can be obtained in any required size and shape. The latter factors exert a strong influence on furnace aerodynamics. In the future, the use of formed coke in preference to conventional coke may well prove advantageous both in blast-furnace and cupola operation.

(45) The process of injection of finely ground coal into the blast furnace, though still in the testing stage, is giving promising results and offers a new outlet for weakly-caking and non-coking coals.

(46) The present rapid rate of progress in blast-furnace technology, and the extension of the range of coals which can be used for coke making, justify confidence in the future of coal in the iron- and steel-making industry.

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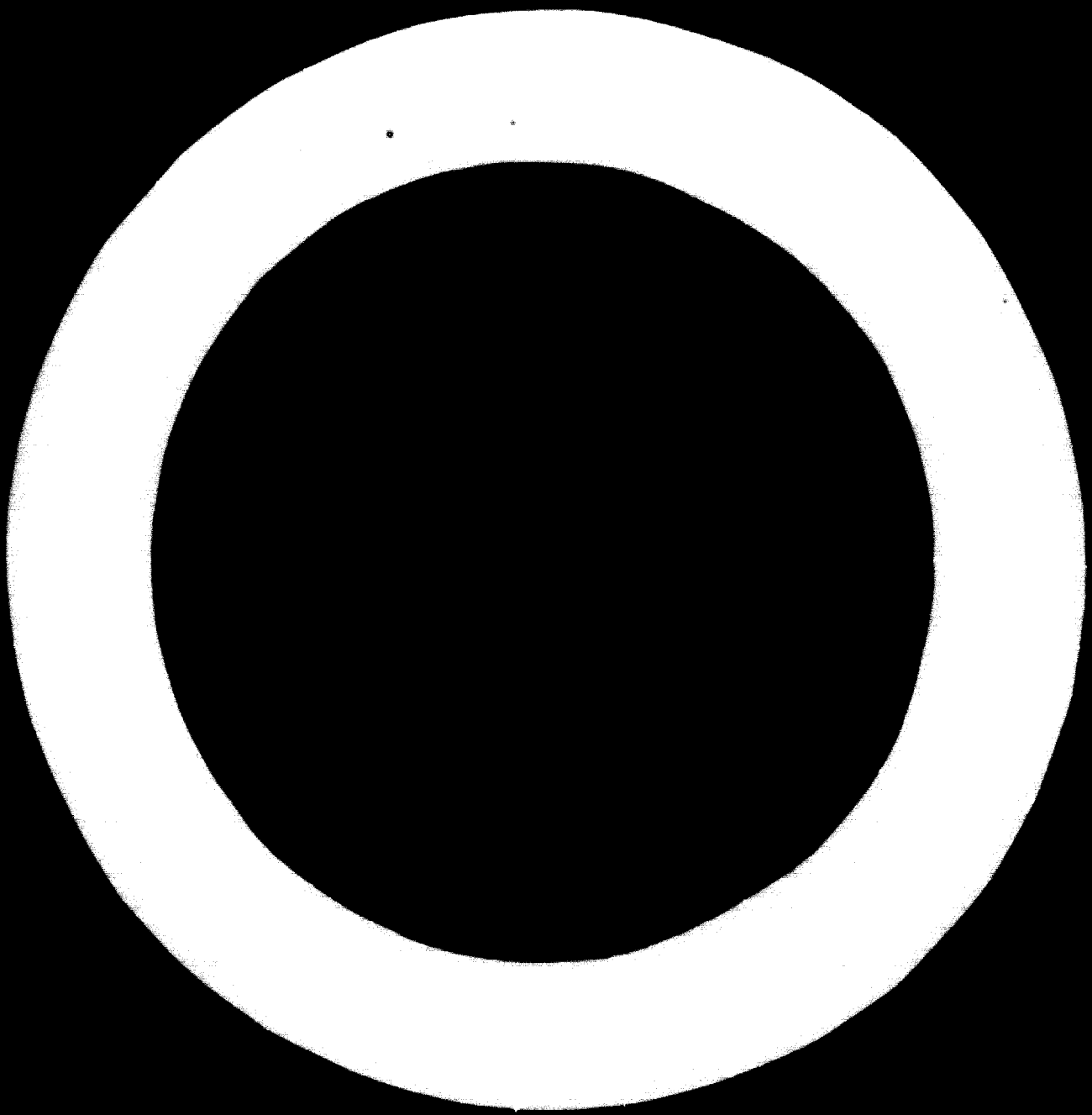
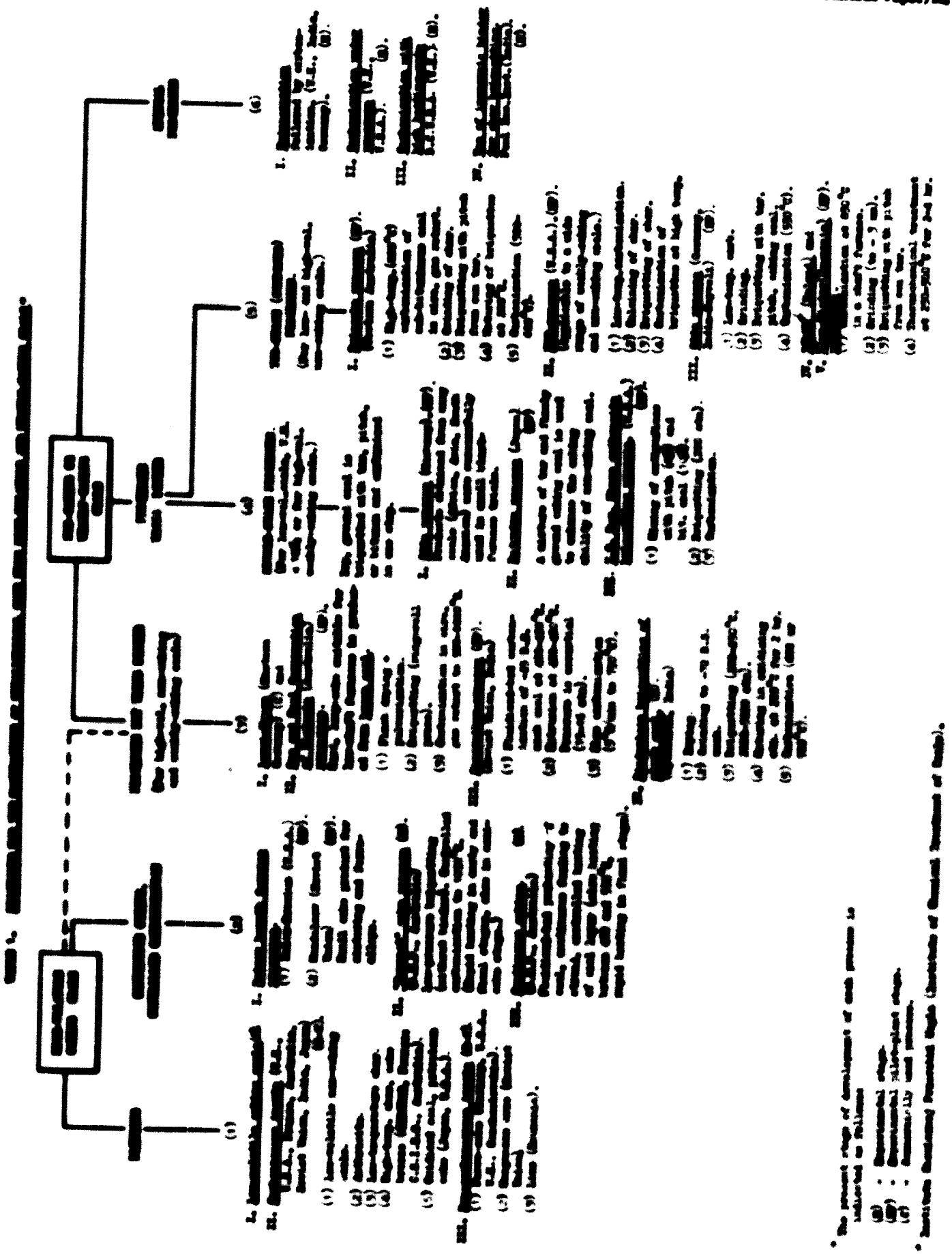




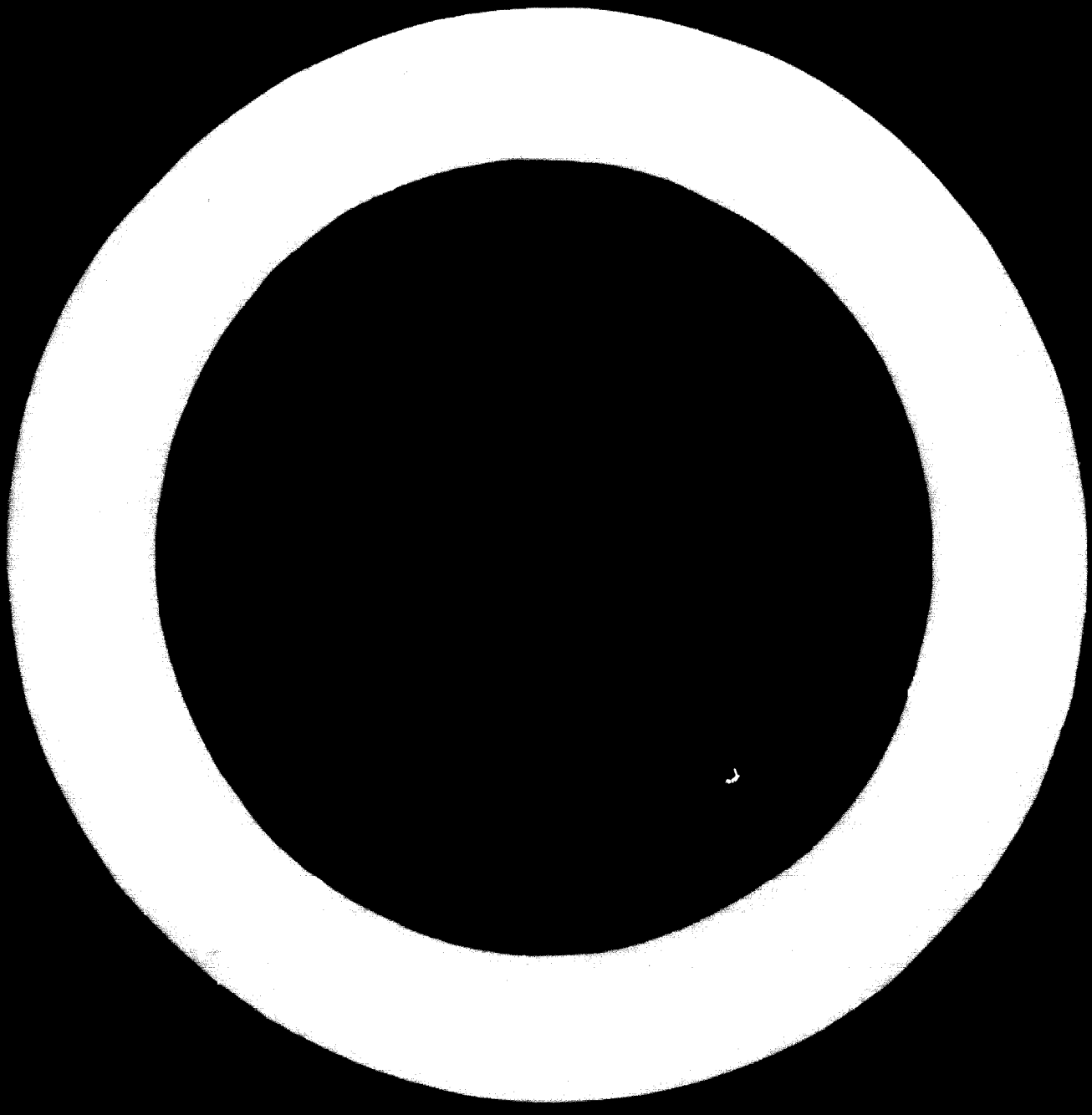
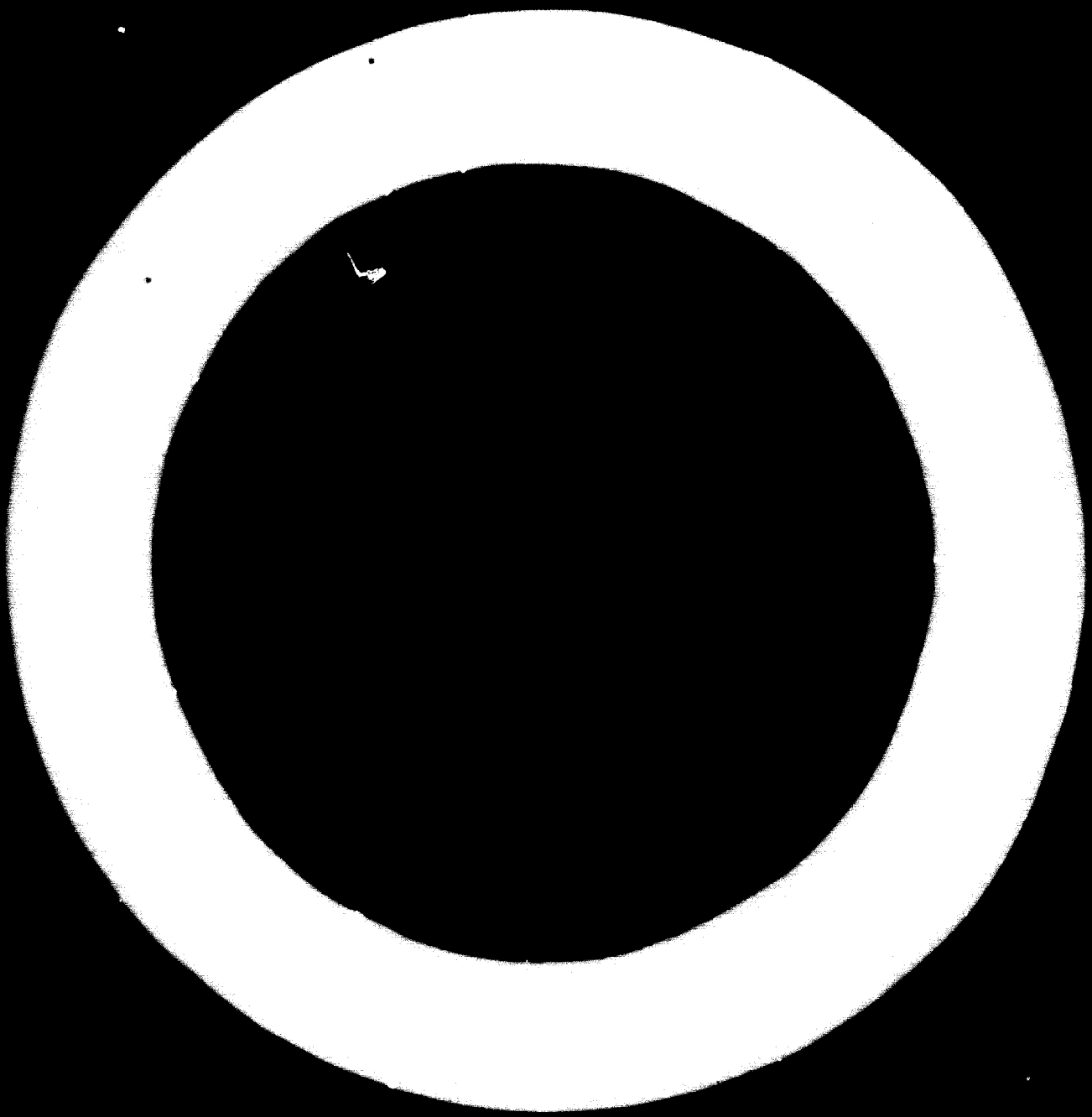


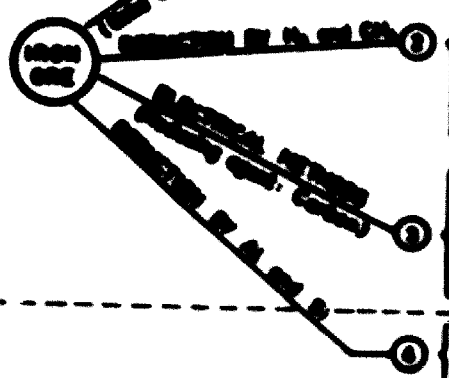
TABLE 2. [illegible]

Type of coke	Raw material	Country	Ref. no. in Table 1	Shatter index[a]			Hardness[b]		Micum indices				Crushing strength kg/cm²	Appt. sp. gr.
				2 in.	1½ in.	½ in.	1 in. shrk.	½ in. hemi-sphs.	M40	M10	I20	I40		
Requirements for high-quality coke			-	-	95	-	60–65	65–72	-	80–85	-	6–7	-	-
Oven coke (B.S.F., Brownside)	High-volatile coking coals	N.S.W., Australia	-	-	74	95.0	98	68	-	65–80	-	12–14	-	-
Blend-coke with char (C.S.I.R.O.)	High-volatile coking coals	N.S.W., Australia	(1)	-	89	-	-	78 (B.S.)	-	-	-	-	-	0.98–0.99
Coke from experimental continuous coking	High-volatile coking coals	N.S.W., Australia	(2)	65	88	96.6	55–60	60–63	37	83	94	5.5	-	-
Furnace coke (Philadelphia)	Med.-volatile coking coals	U.S.A.	-	-	-	92.5	55	64	-	-	-	-	-	-
Foundry coke (Philadelphia)	Med.-volatile coking coals	U.S.A.	-	-	-	97.9	52	54	-	-	-	-	average 140–280	0.95
Foundry coke (Hoppers)	Med.-volatile coking coals	U.S.A.	-	-	-	-	56	66	-	-	-	-		
Anthracite briquetted coke (Bur. Mines)	Anthracite	U.S.A.	(4)	-	-	-	67	67	-	-	-	-	-	1.29
FMC - coke	Various low-rank coals	U.S.A.	(5)	-	92	-	-	-	-	-	-	-	210–600	1.00–1.05
Briquette	Sub-bituminous coals	Western Australia	(5)	96–99	-	-	-	67–74	-	-	-	-	140–200	1.05–1.15
Formed coke (ROMP-process)	Weakly-coking high-vol. coals	Poland	(5)	-	-	-	-	-	-	80	-	10	-	-
Lignite coke (Neyveli)	Lignite	India	(5)	-	-	-	-	-	-	-	-	-	210	-
Brown-coal coke	Brown coals	Victoria, Australia	(5)	-	80	-	-	-	-	-	-	-	175	-
Coke from Sapozhnikov process	High-vol. weakly-coking coals	Soviet Union	(5)	-	-	95.8	-	-	-	-	-	-	-	-
Coke from non-coking sleek coal (hot briquetting)	Non-coking coals	India	(3)	-	-	-	-	-	-	-	-	-	150	-
Coke from high-temp. char with inorganic binders	Low-rank, high-volatile coals	India	(6)	-	-	87–97	-	-	-	-	-	-	-	-

[a] A.S.T.M. or British Standard (the two standards are the same).

[b] A.S.T.M. except where otherwise stated.





[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Lump ore + good metall. coke	Molten iron	4,000 - 7,000	[illegible]
Krupp-Renn	Low-grade siliceous ore	Nodules	8,400	[illegible]
[illegible]	Ore fines of any grade	Sponge iron	7,000	[illegible]
[illegible]	High-grade conc. ore + fine coke		5,500	[illegible]
Flame-smelting (D.I.S.R.A.)	Fine ore + pulv. coal + O_2	Molten iron	8,000 - 9,000	[illegible]
Gallusser (Lungi)	Pelleted ore concentrate	Sponge iron	2,000	[illegible]
Esso Research-Little	High-grade fine ore		4,000	[illegible]
Kyl (Kapalata i Lasica)	High-grade lump ore		5,400	[illegible]
Norwegian Hydrogen	Lump ore or pellets		4,000	[illegible]
[illegible]	High-grade fine ore (conc.)		4,000	[illegible]
[illegible]	High-grade fine ore (conc.)		[illegible]	-
[illegible]	Pellets of high-grade concentrate	Sponge iron	2,000	[illegible]
[illegible]	Lump ore	Molten iron	5,000	[illegible]
[illegible]	Fine ore + fine coal		5,000	[illegible]
[illegible]	Pelletized ore + fine coke		5,000	[illegible]
[illegible]	Iron ore - Si-Al-Ti-Fe alloy	Al-Fe alloy	-	-
[illegible]	Ferrosilicon + ore (Fe_2Si)	Ferro-nickel	-	-

BASIC REACTIONS OF [illegible] PROCESSES (1), (2), and (3)

Use of energy alone: $Fe_2O_3 + 2Fe + 1\frac{1}{2}O_2 + 197$ kcal

Reaction with carbon: $Fe_2O_3 + 1\frac{1}{2}C + 2Fe + 1\frac{1}{2}CO_2 + 55.0$ kcal

Reaction with hydrogen: $Fe_2O_3 + 3H_2 + 2Fe + 3H_2O + 26.0$ kcal

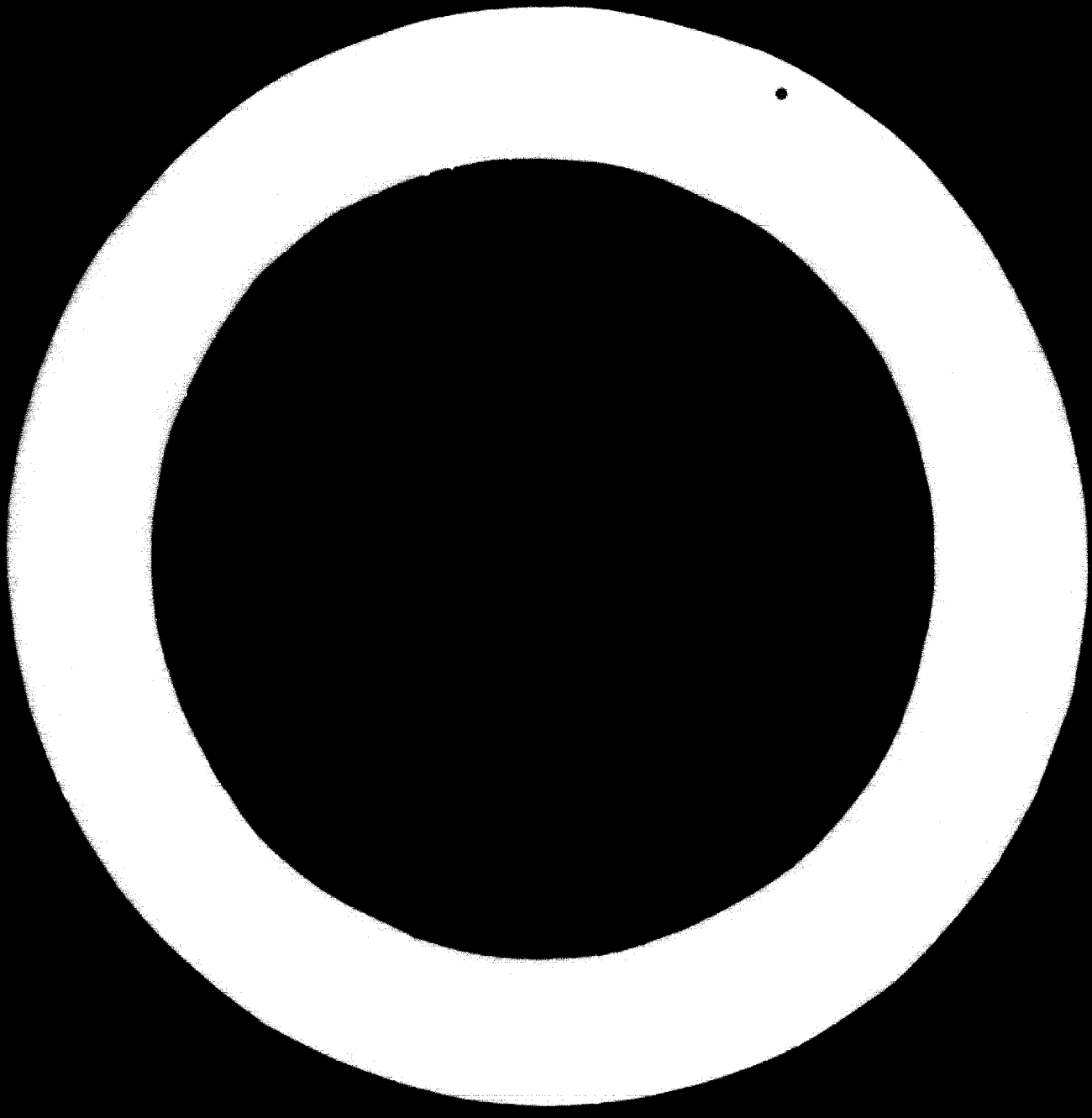
Reaction with methane: $Fe_2O_3 + \frac{3}{2}CH_4 + 2Fe + \frac{3}{2}CO_2 + 1\frac{1}{2}H_2O + 55.2$ kcal

BASIC REACTIONS OF [illegible] PROCESSES (4)

Use of metals as reducing agents: $Fe_2O_3 + 2Al + 2Fe + Al_2O_3 + 209$ kcal

$Fe_2O_3 + 1\frac{1}{2}Si + 2Fe + 1\frac{1}{2}SiO_2 + 118$ kcal

FIG. 1.- [illegible]



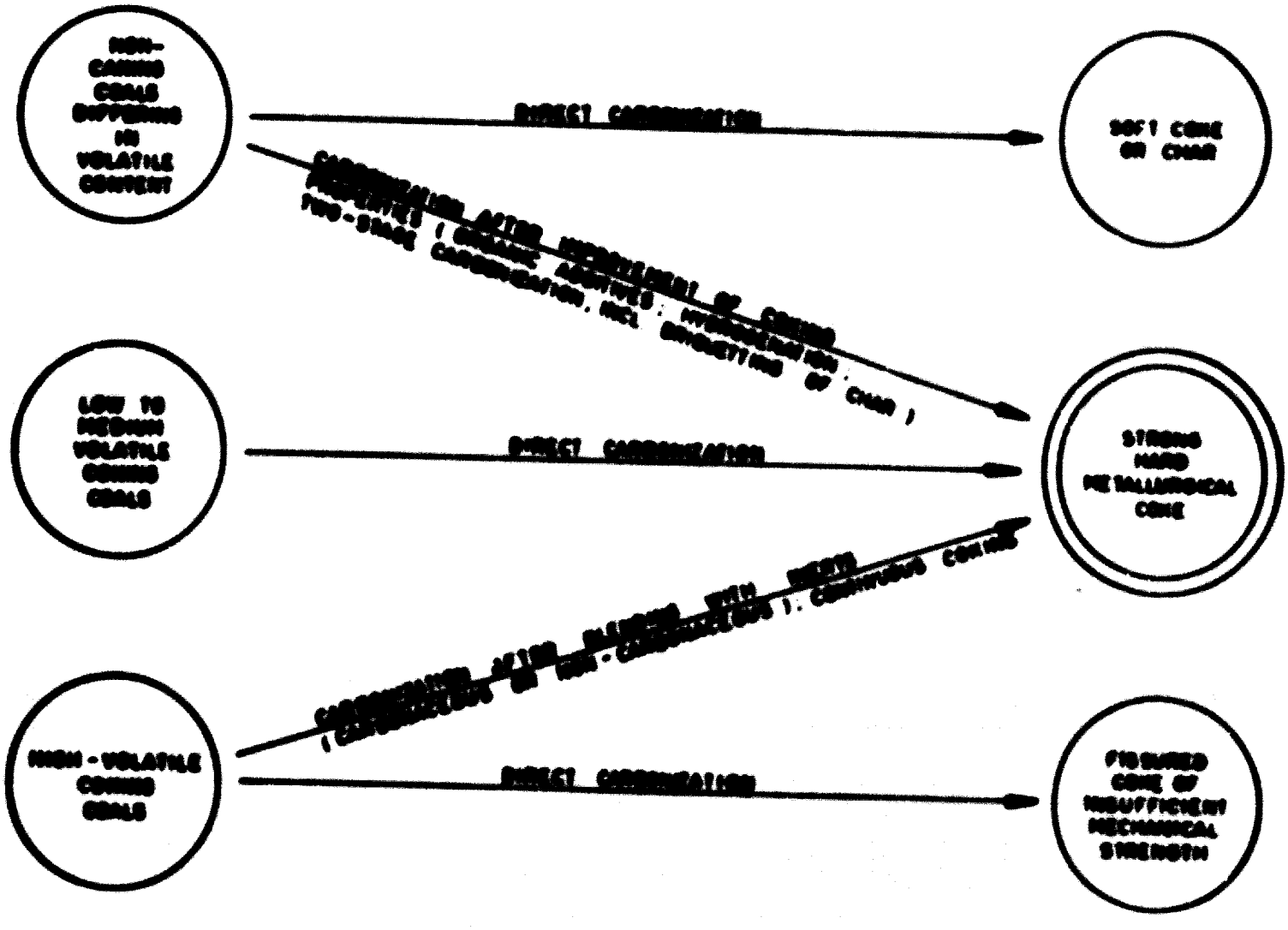
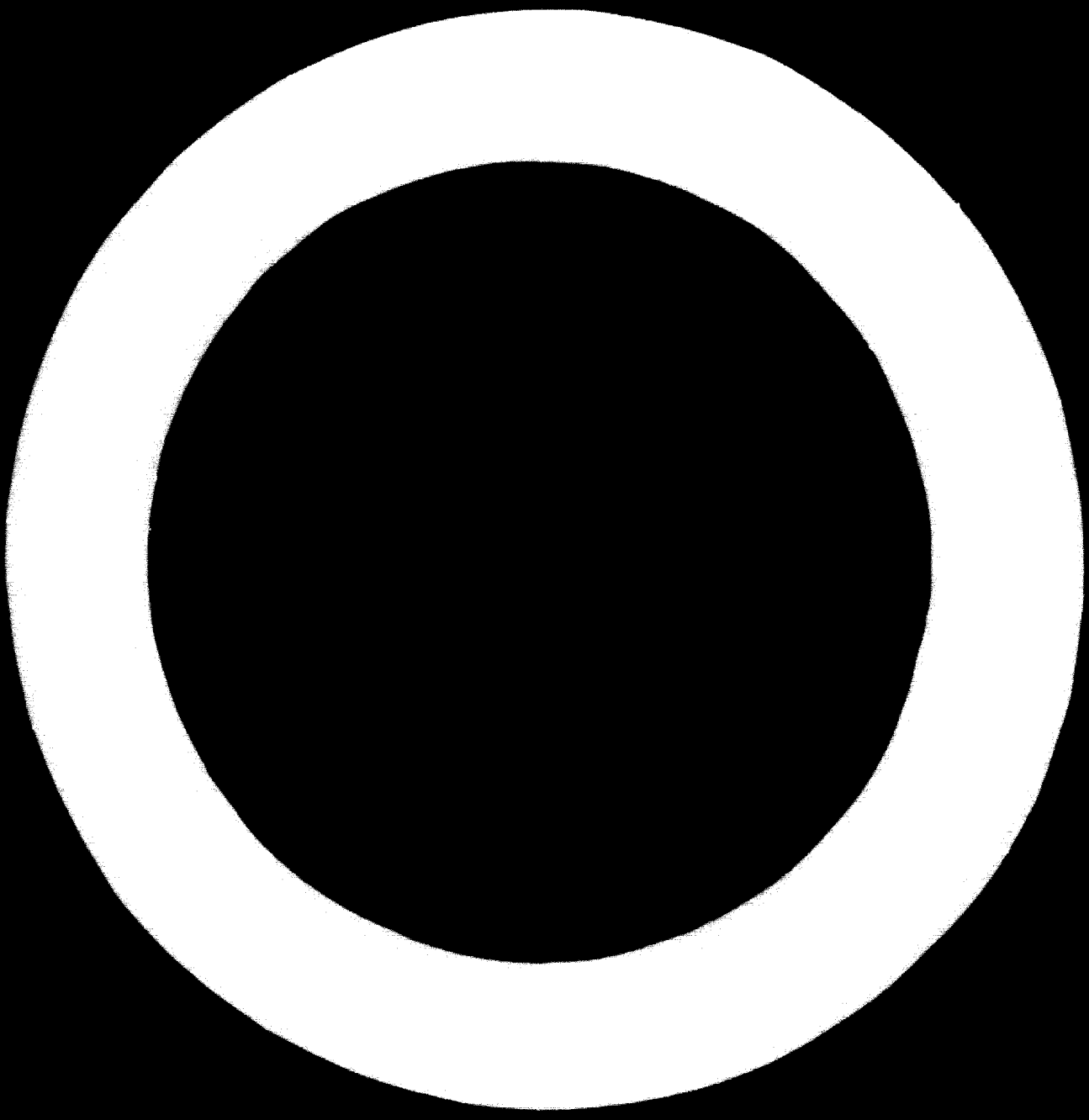


FIG. 2 - SUITABILITY OF COALS FOR COKE MAKING



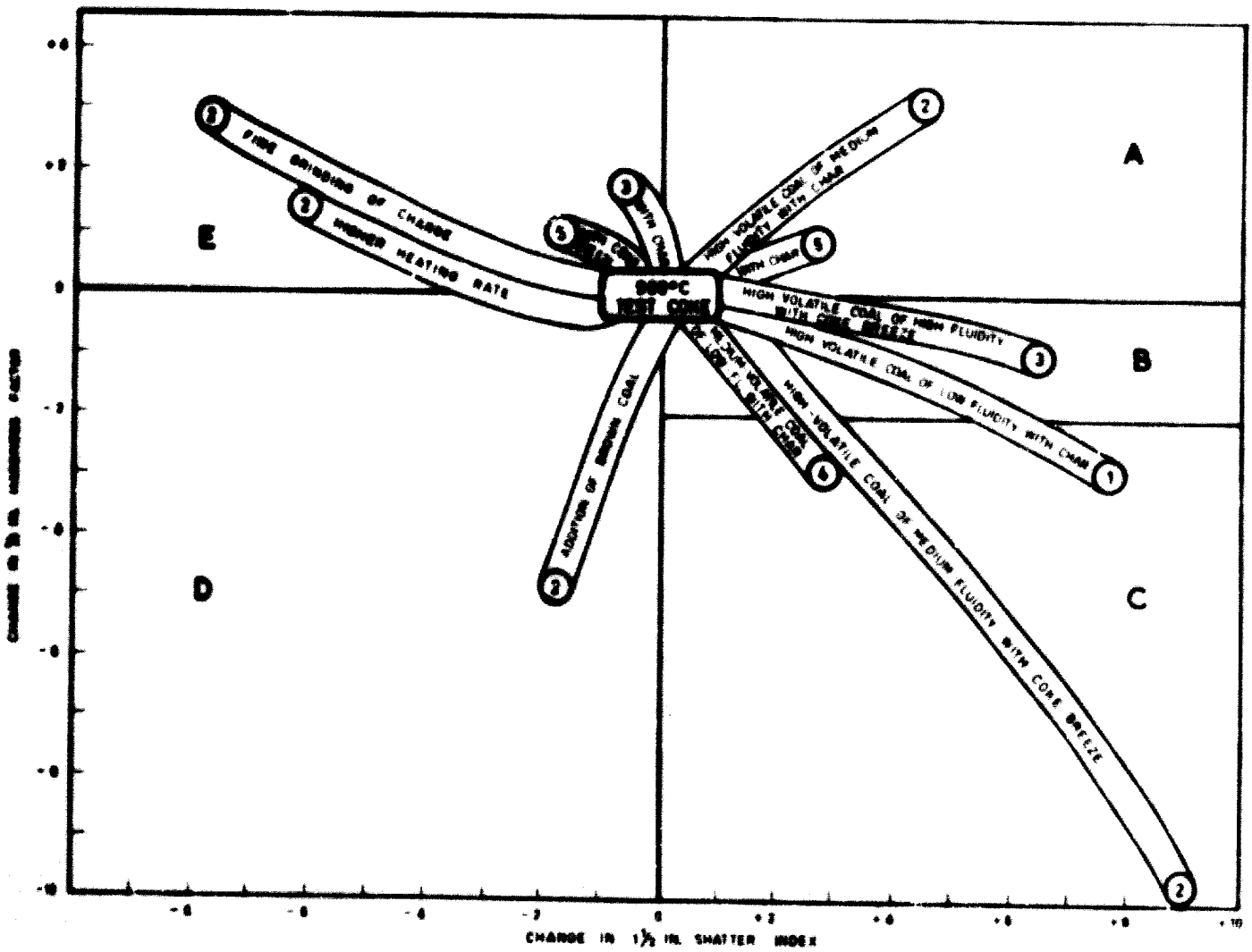


FIG 3- RELATIVE CHANGES IN STRENGTH OF COKE PRODUCED FROM VARIOUS BLENDS[12]

THE NUMBER OF THE COAL IS SHOWN AGAINST LINES INDICATING VARIATION OF COKE STRENGTH

A. IMPROVEMENT IN BOTH SHATTER STRENGTH AND HARDNESS
B. IMPROVEMENT OF SHATTER STRENGTH WITHOUT CONSIDERABLE LOSS IN HARDNESS
C. IMPROVEMENT OF SHATTER STRENGTH WITH CONSIDERABLE LOSS IN HARDNESS
D. DETERIORATION OF BOTH SHATTER STRENGTH AND HARDNESS
E. IMPROVEMENT OF HARDNESS WITH LOSS IN SHATTER STRENGTH

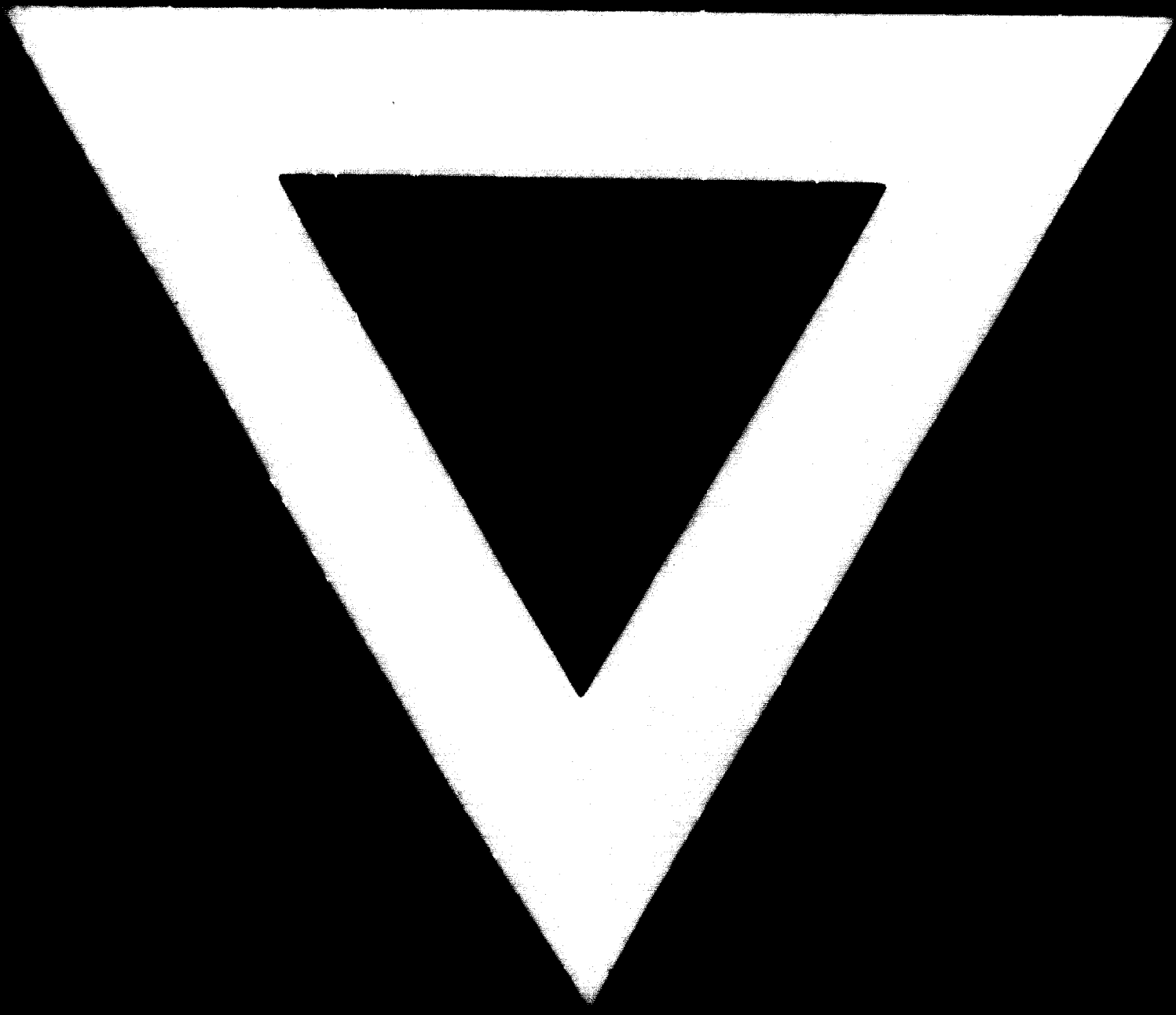
THE TABLE BELOW SHOWS PROPERTIES OF THE UNBLENDED COALS AND THE STRENGTHS OF COKES OBTAINED FROM THEM

COAL			COKE	
No.	V.M. (a.d.)	GIESELER FLUIDITY DIAL DIV. /MIN	1½ IN.* SHATTER IND.	⅛ IN. HARDN. FACTOR*
1	30·0	10	79	76
2	31·5	210	81	76
3	31·0	5000	80	76
4	29·0	400	80	69
5	28·3	8300	81	76

* B.S. STANDARD

MAIN ADDITIVES

No.		V.M. (a.d.)
1	LOW-TEMPERATURE, FLUIDIZED BED CHAR (600-650°C) FROM HIGH-VOL. COAL	15·0
2	HIGH TEMPERATURE (900°C) STATIC BED COKE BREEZE	1·0



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