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THE USE OF CHARCOAL IN BLAST FURNACE OPERATIONS

by

The Food and Agriculture Organization of the United Nations
Forestry and Forest Products Division

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Summary

1. The paper brings out the fact that although charcoal has lost much of its importance in pig-iron production there are cases where charcoal is preferred to coke because of its lower cost. Improvements in blast furnace operations and in charcoal production methods have sharply reduced the amount of wood required per unit weight of pig-iron. This has improved the economy of charcoal use and helped in making possible sustained yield forest operations even for relatively large blast furnaces.

2. A favourable characteristic of charcoal is its chemical purity; in particular its low sulphur content. Another important property is compression strength which must be sufficiently high to resist crushing in the furnace. Charcoal from dense woods is generally satisfactory in this respect. Where economic conditions are favourable metallurgical charcoal production should therefore be considered as a possible use for wood from mixed tropical forests from which the dense wood species are generally the least sought after. Clear felling of such forests can be followed by replanting with suitable species of relatively fast growth.

Introduction

3. For a long period in the history of iron production charcoal was the only used fuel and reducing agent. Scarcity of wood in some countries caused the development of coke as an alternative fuel and today coke dominates even in most countries with large forest resources. Coke has become generally thought of as associated with the large, highly productive blast furnaces of today and it is then easy to think of charcoal as less efficient. Although the general trend has been away from charcoal, charcoal blast furnaces are in operation in several countries and there are even plans for expanding some of these operations. Economic conditions vary both between countries and within them and it would therefore be of value to study the cases where charcoal is preferred in order to determine the relevant economic and technical factors. Unfortunately, it has not been possible to make a comprehensive study of the subject but certain data have become available which indicate that technical progress in forestry, charcoal production and blast furnace operations have been of great significance. In his paper Constantine (a) states that "under modern conditions charcoal can be as economic and efficient as coke for smelting iron ore in a standard blast furnace subject only to the provisions of adequate supply of raw materials". At the same time, several of the papers submitted to the present Symposium point out the scarcity and high price of metallurgical coke, which often has to be transported over great distances.

4. About 200 years ago one ton of pig-iron produced in Sweden (b) required

(a) Constantino, A. Charcoal Blast Furnace Operations, Wundowie, W. Australia, Technical Paper, Interregional Symposium on the Application of Modern Technical Practices in the Iron and Steel Industry to Developing Countries. 11-26 Nov. 1

(b) Arpi, G. Den svenska jarnhanteringens träkolsforsorjning 1830-1950, Jernkontor Stockholm 1951 (Summary in English).

over two tons of charcoal, i.e. probably about 18 m^3 of solid wood (softwood). 100 years ago the requirements were less than 1.5 tons of charcoal or 12 m^3 of softwood. Today about 0.7 tons of charcoal (equal to coke) are normally required corresponding to only 5 m^3 of softwood due to higher yields of charcoal. If hardwoods are used this may drop to 3.5 m^3 or even less in the case of very dense wood. Very substantial economies have clearly been achieved in the use of wood and charcoal.

Present Use of Charcoal in Blast furnaces

5. In assessing the value of charcoal in pig-iron production let us first look at some of the operations that are using charcoal today.

i) The Charcoal Iron Industry, Wundowie, West Australia

6. This is an integrated sawmill, charcoal and iron industry described in detail by Constantino (a, para. 3). The principal data can be summarised as follo

7. The forest is of very uniform composition and practically only one eucaly species is used. The forest residues and sawmill residues amount to 70 percent of the growing stock. The forest is managed on a sustained yield basis with a cycle of 100 years. Within a radius of about 40 km (25 miles) there is sufficient wood for 170,000 tons of pig-iron per year and within 65 km (40 miles), which is consid ed the maximum economic transport distance, there is enough for 400,000 tons of pig-iron. The project has been developed in two steps. A pilot plant of 10,000 tons of pig-iron initiated operation in 1948 and was economically self-supporting in 1953. The operation was expanded to 50,000 tons in 1958, is economically succe ful and there are plans for the expansion to 250,000 tons per year.

8. Charcoal is produced in continuous kilns and the yield is 37% of the dry wood. The kilns are integrated with the blast furnace to form a very efficient unit with respect to heat and electric power economy. All operations are highly mechanized, including the forestry operations and the cost of wood prepared for charging to the retorts is less than US$ 4 per ton. The cost of the charcoal is about US$ 20 per ton but is expected to fall to $ 18 with increased volume product

9. The pig-iron is very pure and contains less than 0.015% sulphur and about 0.03% phosphorus and practically no other tramp elements.

10. The wood used is of very high density and gives hard charcoal with a bulk density of about 300 kg/m^3. This and other factors are the basis for the sta ment in the paper that it is debatable whether there is any limit to the size of charcoal furnaces. The expansion plans call for the building of units of a capa city of 400 tons of iron/day with a 19.5 m (65 ft) working height and a hearth dia meter of 4.5 m (15 ft).

ii) Belgo-Mineira Steel Co., Monlevado, Brazil

11. This company is located on the Brazilian high-plateau in Minas Geraes and there are no local resources of coke. It uses charcoal from 2nd-3rd growth mixed tropical fores. and from plantations of eucalyptus species. At present the plantations only supply 10% of the requirements but the percentage increases every

year and is planned to have reached 100 by 1963, for an iron output of 500,000 tons The total plantation area required for this production volume is 136,000 ha yielding 2.5 million solid m³ per year. Replanting is done after 22 years with intermediate clear-fellings after 8 and 15 years. The average yield is about 20 solid m³/ha, year which is higher than the yield from the natural forest. The species planted yield relatively dense wood. The charcoal from the mixed forest is understood to be quite satisfactory but the density and texture are variable and the plantations yield a more consistently high quality product.

12. The forestry operations are less mechanized than in the previously described operation and charcoal production has so far been in batch kilns built of brick. A continuous kiln is under construction with a capacity of about 60 tons/day. The cost of plantation wood at the charcoal kiln is estimated at US $ 2.5/ton of dry wood. The corresponding cost of the charcoal is about US$ 8/ton whereas charcoal from the native forest, partly purchased, is less expensive.

iii) <u>Other Countries</u>

13. In the USSR an unknown number of charcoal blast furnaces are in operation and Japan produces some 30,000 tons of charcoal iron annually (a, para. 3). In Sweden the use of charcoal has declined mainly because its high cost caused by competition for the raw material from the pulp and paper industries, but as late as 1948 31% of the pig-iron production was made with charcoal (b, para. 4). In Sweden charcoal has been mainly produced from softwoods giving a product with relatively low density whereas in Japan metallurgical charcoal is produced from oak and is of high density.

<u>Technical Properties of Metallurgical Charcoal</u>

14. Two main properties of charcoal of importance in blast furnace operation are compression strength and chemical composition.

15. High compression strength is desirable in order to avoid crushing in the furnace which reduces the possible working height of blast furnaces as well as the specific production per unit of volume. Most metallurgical charcoal produced in the northern hemisphere has been of low density, produced from softwoods or from medium density hardwoods. The charcoal production at Wundowie has quite different characteristics and it is stated (a, para. 3) that with charcoal of comparable quality it is the softening of the iron ore, not the charcoal, that sets the limit of blast furnace height and capacity. In addition the specific output per unit of furnace volume is higher than for soft charcoal.

16. Special testing methods for the compression strength (hardness) of charcoal are used. Some hardness data for different types of charcoal as well as other properties are given in the following table (c).

(c) Forest Experiment Station, Meguro, Charcoal Section <u>Outline of Japanese Charcoal and Charcoal Study</u>, 1960

(1) **Analysis of Charcoal**

Country	Kind of Charcoal	Wood Species	Carbonization Method	Volatile Matter %	Ash %	Moisture %	Hardness 1/	Calorific Value 2/
Japan	black 3/	Quercus glandulifera	Kiln method	6–20	2	6– 8	6–12	7000–76[illegible]
Japan	white	Oak	Kiln method	5	3	8–10	12–20	6800–70[illegible]
U.S.A.	black	Hickory	–	20–30	3	6	18	7500
Mexico	black	–	Miller method	10–30	3	6– 8	–	7200
India	black	–	Cave method	20–30	5–10	6	5–15	7200
Yugoslavia	black	Beech	Kiln method	15–20	3	7– 8	1	7200

1/ Hardness was tested by Miura hardness tester for charcoal
2/ Calorific value calculated from industrial analysis data
3/ The type used for metallurgical purposes in Japan

17. The great range in hardness can be seen from the table. Some hardness data for charcoal from European woods are given in (d) but are not comparable to those contained in the above table.

18. Main factors that influence the density and hardness of charcoal are: wood species, size of the wood as fed to the kiln, and the charcoal production method. Dense wood generally gives dense and hard charcoal and is therefore to be preferred to lighter wood for the production of metallurgical charcoal. It follows that when a mixture of species is used, the hardness of the end product will not be uniform. If the density range is wide, it may be necessary to sort out species of low density in cases where the requirements with respect to hardness are very exacting.

19. Among the chemical properties of charcoal for pig-iron production the vola[tile] content and the ash content are the most important. In modern retorts the carbon and volatile content can be satisfactorily controlled and should not present difficulties even if the wood is not of uniform composition.

20. The charcoal retains all the ash content of the wood which varies considerably according to species. The total ash content should be as low as possible. A figure of 0.24 percent has been indicated as excellent and an upper limit of 1.5 percent has been given (d, para. 17). At Wundowie the ash content is very low, 0.25 percent. Apart from total ash, the amounts of phosphorus and sulphur are of

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(d) Food and Agriculture Organization of the United Nations: *Charcoal from Portab[le] Kilns and Fixed Installations*, Rome 1956 major interest. The content of sulphur is generally very low making charcoal suit for the production of iron of high purity with respect to sulphur. Phosphorus is variable within wide limits not only between species but also within a tree and wi the soil composition. Swedish hardwoods were found to contain four times as much phosphorus as the softwoods; bark contains much more than wood and splintwood more than heartwood. However, even in hardwoods the content of phosphorus is generally low enough for the production of pig-iron of high purity. Typical data for the phosphorus content of Swedish charcoal are about 0.01 percent for softwood charcoal and about 0.04 for hardwood charcoal (birch, alder, aspen), (c). Data for the phosphorus and sulphur content of charcoal pig-iron from Wundowie (a, para. 3) are given as 0.03 percent and 0.015 percent, respectively.

21. There is considerable variation in the ash content of tropical hardwoods, some of these having high silica content. The ash content will no doubt require attention in any new project to utilize mixed tropical woods although this aspect has not been reported as causing difficulties in the use of Brazilian woods.

22. Of other analytical data the moisture content is of importance to smooth furnace operations. Charcoal should therefore be suitably protected against moistu

__Availability of Wood__

23. As mentioned initially, local shortage of wood was the main reason for developing coke for pig-iron production. Although the lower wood consumption per ton of iron brought about by technical improvements has helped to reduce the wood requirements for an iron operation, the larger output of many modern furnaces has worked in the other direction. In order to obtain a picture of the wood consumption, the forest area required and the corresponding transport distance for a pig-iron operation, the following table has been prepared.

(c) Bergstrom, H. __Kolning i ugn__, Jernkontoret, Uppsala 1947 (in Swedish)

(2) **Wood Requirements, Forest Area and Transport Distance for Pig-iron Operations of Various Size**

Size, tons of pig-iron per year	Wood requirement		Yield of charcoal wood from forest, m^3 per ha, year					
			5 m^3/ha, year		10 m^3/ha, year		20 m^3/ha, year	
	thousand m tons/ year	thousand solid m^3 per year	Forest area required, ha	Maximum transport distance km	Forest area required, ha	Maximum transport distance km.	Forest area required, ha	Maximum transport distance km.
20,000	40	70	14,000	12	7,000	8	3,500	6
50,000	100	170	34,000	18	17,000	13	8,500	9
00,000	200	340	70,000	26	35,000	18	17,000	13
00,000	400	700	140,000	36	70,000	26	35,000	18
00,000	600	1,000	200,000	44	100,000	31	50,000	22
00,000	1,000	1,700	340,000	57	170,000	40	85,000	29

__Note__ The following assumptions have been made.

Charcoal consumption 0.7 tons/ton charcoal yield 35%; wood density 0.6 g/m^3; one third of the land area around the plant available for timber supply

24. A wide range of plant sizes has been included in the table. It is noted that with respect to wood requirement pig-iron and chemical pulp production are very similar with a consumption of close to 2 tons per ton of end product. From a forestry standpoint already the 300,000 ton project is a very large one, there are not many pulp mills with a larger wood intake. The economic size of pig-iron operations will be discussed during the present symposium. The data presented for Monlevade (p, para.3 mention the economic results and expectations at 50,000 and 300,000 tons per year respectively. Under the assumptions made in the table above, a 50,000-ton plant would need an operating radius of about 18 km at the lowest of the yields assumed. At 300,000 tons per year a minimum yield of 6-7 m^3 per ha, year would be required to keep within the present operating distance contemplated at Monlevade, i.e. 40 km. A yield of this magnitude should normally be possible to reach in locations with sub-tropical or tropical climate and adequate rainfall. It should be noted that the average yield assumed in the planting programme at Monlevade is above 20 m^3/ha, year.

25. Wood in sufficient quantity and for sustained yield operations should thoro-

fore be available or possible to produce in many locations even for relatively large pig-iron operations. Today wood from mixed tropical forests and from plantations of fast growing species for wood production are sources that may be most generally available for charcoal pig-iron production. In particular, opportunities may be at hand in some instances for the clear-cutting of tropical or sub-tropical mixed forests for which there is little use at present except for a few species, often representing only a small fraction of the standing volume. In view of the technical requirements it might be necessary to reject certain species because of low density or high ash content. The area would then be replanted with high-yielding suitable species so that eventually the mill would switch over to using plantation wood. Another possibility is natural regeneration with suppression of undesirable species but this alternative is likely to be less attractive, as plantations will yield a more uniform product and offer better opportunities for the mechanization of operations.

26. There are also a few cases where wood is available at little or no stumpage value, e.g. rubber and wattle plantations. For rubber plantations estimates have been made (f) about the amount of wood available on a sustained basis in Thailand. The data indicate that after allowing for the need of rubber wood for smoking the rubber (1.3 m^3/ha, year) approximately 4 m^3 per ha and year could be obtained for industrial purposes. In wattle plantations which may yield 5 to 10 m^3 of wood per ha and year, there is often little use for the wood which may even be left behind after the bark has been removed for tannin extraction.

Cost of Wood and Charcoal

27. A natural upper limit for the cost of charcoal in pig-iron operations will be set by the price of metallurgical coke. When taking the price of coke as a basis for comparison, it is assumed that coke and charcoal are approximately equal with respect to the quantity required. It is further assumed that the charcoal produced is of such quality that its performance in the blast furnace is similar to that of coke. Even so a charcoal operation will require more capital both for charcoal production and for the development of the forest and its exploitation. In case the charcoal is of lower quality this will have to be compensated by lower cost otherwise the cost of the pig-iron will be higher than if coke were used.

28. Several of the papers presented to the Symposium mention the scarcity of coke which enters into international trade and is often transported over long distances. In (g) the price of coke at plants on the eastern seaboard of the U.S.A. is given as US$ 16 per ton. The cost of charcoal given above for the Brazilian operation is well below this figure. Even in the Australian example it is obvious that transport costs would bring coke above the cost of locally produced charcoal.

29. It can, however, be argued that a maximum allowable cost of charcoal wood of about 5-6 US$ per ton is a very low figure. It may be compared with approximately $ 15 per ton of coniferous pulpwood in Europe and about half this cost for broad-leaved pulpwood in the U.S.A. In 1953 studies were made on pulpmill projects based on tropical species in Amapa in the Amazon area of Brazil and in Yucatan (h). The

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(f) UN/FAO, Pulp and Paper Prospects in Asia and the Far East, Vol. II, Bangkok 1962
(g) Brown, H.H. Substitutes for Coking Coals in Iron Ore Reduction
(h) UN/FAO, Pulp and Paper Prospects in Latin America. New York, 1955

ost of fuelwood was shown to increase somewhat with the size of the operation but as given as about US$ 4.7 and 2.3 respectively at 200,000 tons per year.

30. It will obviously take efficient organization and careful planning even under favourable conditions to reach the low cost required but the Australian example cited shows that the required cost level can be reached even where labour costs are high.

Conclusions

31. On the basis of information on experience recently gained on the use of charcoal in blast furnace operation the following conclusions appear justified.

i) Pig-iron production with charcoal in blast furnaces requires approximately the same amount as coke, 0.7 tons/ton. This corresponds to about 2 tons of dry wood per ton or iron. In view of the fact that pig-iron production generally is conducted in comparatively large units, it follows that forestry operations to supply charcoal for blast furnaces must normally be of a size comparable to pulp mill projects.

ii) Charcoal from dense woods performs as well as coke in blast furnaces and can be used in units up to at least 400 t/day capacity. Softer charcoal reduces the maximum size of a unit as well as the capacity of a furnace of a given size.

iii) It is possible, in certain locations, to produce charcoal at a cost Comparable to or lower than that of metallurgical coke. This requires a large, well organized forestry operation, mechanized according to local conditions as well as the use of continuous charcoal retorts.

iv) The large volume of wood required on a sustained yield basis to serve a pig-iron operation as well as the requirements with respect to the cost of the wood and charcoal produced and the quality of the product considerably limit the number of locations where conditions are deemed favourable.

v) Such conditions could be at hand in areas where high yield tree species can be grown, where the population pressure is low and where transport costs offer a natural protection against competition from coke.

vi) The forestry operation could be developed by gradually converting natural forests of mixed species into plantations of uniform composition. This offers one of the few possibilities for the large-scale utilization of mixed hardwood species including the very dense woods.

22.3. 74