Management Science

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

Letter to the Editor—A Note on the Economics of Metallurgical Coke Production

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A Note on the Economics of Metallurgical Coke Production

A process analysis model of the U. S. steel industry recently presented by Tsao and Day [4], while accurate in almost every other aspect, is in error in the treatment of coking coal production. This note attempts to remedy this deficiency and presents a corrected matrix for this stage of production.

Coking is a destructive distillation process in which mineral coals are subjected to high temperatures in order to reduce their volatile matter content. Since carbonization drives off most of the volatile content, the coke yield per ton of coal charged is primarily determined by it. However, blending of coals with different volatile contents will also affect the physical qualities of the coke and the yield of coking byproducts (gas, tar, ammonium sulphate, ammonia liquor, light oil). The remaining residue, called metallurgical coke, is a chemical compound containing 85–90 per cent fixed carbon, and ash, sulphur, phosphorus, and other substances [6, p. 99]. Coke is primarily used as a fuel and as a source of carbon in the blast furnace production of pig iron.

There are two alternative processes for the production of coke, the bee-hive oven process and the slot or byproduct oven process. The basic technical difference is that air is admitted to the beehive oven chambers for the purpose of burning the volatile products (and some coke) distilled from the coal to generate heat for further distillation; while in the byproduct process, air is excluded and the necessary heat is supplied from external combustion of some of the gas recovered in the coking process.

The major advantages of the byproduct process are [7, p. 207]: (1) many types of low quality coal, not suitable for use in the beehive ovens, can be utilized in byproduct ovens by blending with other coals; (2) the byproduct oven permits the full recovery and use or sale of the gas and coal chemicals released from the coal; (3) the byproduct process allows greater control over the conditions of carbonization; and (4) the byproduct process obtains higher yields and produces a more uniform coke. Thus, despite considerably higher capital costs, the byproduct process accounts for over 98 per cent of annual metallurgical coke production in the United States. Existing beehive capacity in the steel industry (1960, 877,000 net tons; 1970, less than 100,000 net tons) is mainly of a standby nature and is used to satisfy peak demands.

Not all coals possess the coking (agglomerating) property to the same degree and, in order to make a satisfactory coke, a careful selection of coals is necessary. The most

TABLE 1

Revised Technology Matrix, Stage I (coking)

Constraint	Unit	Beehive Oven	Byproduct Oven	Byproduct Oven
		x_1	x_2	x_3
1. High and medium-volatile coal	N.T.	1.652[a]	1.142[a, b]	1.470[a, b]
2. Low-volatile coal	N.T.		0.286[a, b]	
4. Beehive oven capacity	N.T.	1.000		
5. Byproduct oven cap.	N.T.		1.000	1.000
6. Coke balance	N.T.	−1.000	−1.000	−1.000
24. Electric power	1000 kwh		0.015[c]	0.015[c]
66. Fuel consumption	M. Btu		3.230[d]	3.230[d]
67. Recoverable byproduct fuel or waste heat	M. Btu		−12.960[d]	−12.960[d]
68. Labor	man hr.	0.682[a]	0.724[a]	0.724[a]

[a] U.S. Bureau of Mines, *Minerals Yearbook*, Washington, 1955–1966 editions.

[b] C. L. Trozzo, "The Technical Efficiency of the Location of Integrated Blast Furnace Capacity," unpublished Ph.D. dissertation, Harvard University, 1966, pp. 454–462 and 615–636.

[c] *Watkins Cyclopedia of the Steel Industry*, 11th ed., Pittsburgh, 1967, p. 426.

[d] U.S. Steel Corp., *The Making, Shaping and Treating of Steel*, 8th ed., Pittsburgh, 1967, p. 99.

common method of selection is by measuring the relative amounts of fixed carbon, ash and volatile matter in the coal. This is called a proximate analysis [6, p. 72] and coals are then ranked according to their relative volatile matter content [6, p. 74]: (1) high-volatile bituminous, 31–69 per cent; (2) medium-volatile bituminous, 22–31 per cent; (3) low-volatile bituminous, 14–22 per cent; and, (4) anthracite and semi-anthracite, 2–14 per cent.

Essentially all coking coals are from the bituminous category.[1] Since in the majority of cases, a single coal will not give the desired quality of coke, it is necessary to mix or blend coals. Common blending practices are 80 per cent high-volatile coal and 20 per cent low-volatile coal[2] or 65 per cent high-volatile coal combined with varying proportions of medium and low-volatile coal [8, p. 33]. In 1962, 65.6 per cent of the coals received by coke oven operators were high-volatile bituminous compared to 12.7 per cent medium-volatile bituminous coal, and 20.0 per cent low-volatile bituminous [2, Table A-12, p. 61]. The relative amounts of each coal used have been remarkably stable since 1941 indicating stability in the underlying technological and economic relationships.

The desirability of blending explains why states such as Alabama, which produce substantial quantities of coal for coking purposes, still find it necessary and economical to import coal from Pennsylvania and West Virginia (the only important sources of low-volatile coal). In distant steel plants, such as Colorado, Utah and California, the use of large amounts of low-volatile coal is not economical and coke yields are relatively low as a result [8, p. 33].

[1] Tsao and Day [4, p. B-590] classify coking coals as bituminous and subbituminous. It is not clear from their paper exactly how these categories are defined but subbituminous coals do not possess the agglomerating property necessary for coke production by conventional processes [5, p. 4] [8, p. 33].

[2] Low-volatile coals also improve the physical properties of the coke, particularly strength and size, with a resulting increase in yield [8, p. 30]. The expansionary property of this coal rank limits its amount in the oven change to between 10 and 30 per cent.

A suggested revision of the Tsao-Day technology matrix for coking coal is given in Table 1.[3] In addition, the authors specify that lignite coal is used in the direct reduction process for making steel. The direct reduction process is still in the development stage, there were over 240 patented processes in 1951 [1, p. 28], so characterization of a standard fuel for use as a reducing agent seems highly uncertain. Rather than lignite, more readily available fuels such as coke, coke fines (breeze), or other bituminous coal fines are likely to be used in the initial commercial applications (see [6, Chapter 13], [1, p. 29]).

Process analysis models are often an artful blend of economics and engineering. Engineering estimates of input-output coefficients are widely scattered and difficult to obtain. The investigator should, however, reject the single activity representation of the production process where this disregards the essential economics of the situation.

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Reply to Nelson's Comments

Nelson is quite right in saying that the typical byproduct oven uses bituminous coals of various volatile content. Subbituminous coals are not used. The appropriate heading for the second constraint in our model should therefore read "low rank bituminous coals," where "low rank" refers to a proximate analysis of less than 69 per cent of dry fixed carbon and more than 31 per cent of dry volatile matter in the coal. (For a detailed classification of coals by rank, see [48, p. 74] in our paper.) We have checked our work sheets and found that the input coefficient a_{23} was indeed intended to represent the per unit input requirement on this class of low rank bituminous coals. Our apologies to our readers for the incorrect use of the word "subbituminous" in this context.

Regarding Nelson's suggested coefficients, we only wish to refer our readers to the comments we made in §3 of our paper (p. B-606, first paragraph). We think it is obvious to our readers that, in view of the multitude of production methods used in the

[3] A more complete treatment of the problem would necessitate solution of a large scale coal blending linear programming model. For some initial work on this problem, see Trozzo [3].