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## **Partial Replacement of Coke in Cupola Operation**

**By V. R. Spironello and W. M. Mahan**

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**UNITED STATES DEPARTMENT OF THE INTERIOR**

**Report of Investigations 8488**

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**UNITED STATES DEPARTMENT OF THE INTERIOR**  
**Cecil D. Andrus, Secretary**

**BUREAU OF MINES**  
**Lindsay D. Norman, Director**

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## CONTENTS

|                             | <u>Page</u> |
|-----------------------------|-------------|
| Abstract.....               | 1           |
| Introduction.....           | 1           |
| Materials.....              | 2           |
| Equipment.....              | 4           |
| Procedure.....              | 6           |
| Results and discussion..... | 6           |
| Basic slag practice.....    | 7           |
| High fixed carbon.....      | 7           |
| Medium fixed carbon.....    | 7           |
| Low fixed carbon.....       | 11          |
| Acid slag practice.....     | 12          |
| Strengths of the irons..... | 16          |
| Conclusions.....            | 16          |
| References.....             | 19          |

## ILLUSTRATION

|                                                          |   |
|----------------------------------------------------------|---|
| 1. Cupola in operation, Twin Cities Research Center..... | 5 |
|----------------------------------------------------------|---|

## TABLES

|                                                                                        |    |
|----------------------------------------------------------------------------------------|----|
| 1. Analyses of nonfuel materials used in cupola.....                                   | 3  |
| 2. Analyses of fuels used in cupola.....                                               | 3  |
| 3. Description of cupola charge materials.....                                         | 4  |
| 4. Materials used with 55 pounds of scrap as a standard charge.....                    | 6  |
| 5. Iron resulting from partial replacement of coke under basic slag<br>practice.....   | 8  |
| 6. Basic slags resulting from partial replacement of coke.....                         | 9  |
| 7. Analyses of scrubber and stack waters and solids under basic slag<br>practice.....  | 10 |
| 8. Irons resulting from partial replacement of coke under acid slag<br>practice.....   | 13 |
| 9. Acid slags resulting from partial replacement of coke.....                          | 14 |
| 10. Analyses of scrubber and stack waters and solids under acid slag<br>practice.....  | 15 |
| 11. Tensile and transverse strengths of irons melted under basic slag<br>practice..... | 17 |
| 12. Tensile and transverse strengths of irons melted under acid slag<br>practice.....  | 18 |

# PARTIAL REPLACEMENT OF COKE IN CUPOLA OPERATION

by

V. R. Spironello<sup>1</sup> and W. M. Mahan<sup>2</sup>

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## ABSTRACT

The Bureau of Mines is involved in research directed toward the conservation of important raw materials and the utilization of solid waste. Two of the objectives are to conserve high-quality coking coals used for foundry coke and to utilize waste materials of marginal quality but of high calorific value. These objectives are consistent with Bureau goals. Pilot plant cupola trials were made to evaluate the adequacy of various alternative fuels, and to determine to what extent they could replace the foundry coke in cupola charges. Information was obtained on furnace performance, metal and slag chemistry, environmental questions, and the properties of castings. It was shown that anthracite or bituminous coals can partially replace charge coke up to the 40 pct level. Briquetted materials prepared from fuel fines, and waste products or byproducts of high calorific value, all tend to break down on heating in a cupola so that their use must be restricted to below 20 pct replacement. In cases where pitch-bonded coal fines or petroleum coke were used, carbon pickup by the iron was inadequate for gray iron specifications. Although emphasis during this work was placed on basic slag practice, some acid practice results are included.

## INTRODUCTION

Foundry coke is a premium, high-cost fuel essential for cupola operation. It is produced to close specifications by the carbonization of selected metallurgical coals, anthracite fines, and petroleum coke. A report (3)<sup>3</sup> on the United States foundry coke industry covers the subject of foundry coke in detail. It is used in cupolas to melt ferrous materials to provide hot metal suitable for a variety of cast iron for castings. Although cupolas no longer have a monopoly on providing hot metal for castings, they still melt the most iron (7).

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<sup>1</sup>Metallurgist.

<sup>2</sup>Assistant to the Research Director.

Both authors are with the Twin Cities Research Center, Bureau of Mines, Twin Cities, Minn.

<sup>3</sup>Underlined numbers in parentheses refer to the list of references at the end of this report.

A cupola (2) may be simply described as a vertical shaft furnace into which iron, alloys, and fluxes are charged at the top and molten iron and slag are drawn off at the bottom. The shaft is partially filled with foundry coke to a specified height (coke bed). This is burned by introducing combustion air at several points around the shaft defining one or two horizontal planes. As melting proceeds, the coke in the bed is consumed, and additional coke is charged into the shaft to maintain the height of the bed. Coke provides all the heat required for melting and superheating the iron and for slag formation. It also provides sufficient carbon monoxide in the furnace atmosphere to prevent the oxidation of iron and/or alloying elements. The coke must also support itself and the charge materials physically. Finally, coke provides carbon for carburization of the molten iron so that carbon specifications of the various types of cast iron can be met. The coke preferred by the foundry industry must be high in carbon, low in impurities, and high in strength. Foundry coke has been referred to as a hard-burned, blast-furnace coke (10).

Although the United States has large reserves of premium quality coals for cokemaking, the Interior Department's Bureau of Mines warns (11) of a possible shortage of metallurgical coke by 1985 unless more coke ovens are built to meet anticipated demands. If the pace of rebuilding and/or installing new coke ovens only maintains present capacity, a deficit of 5 to 10 million tons of coke is estimated by 1985. The American Coke and Coal Chemical Association (13) reported that 2,600,000 tons of foundry coke were consumed in 1975, and that consumption was expected to increase. There was an excess of only 500,000 tons of foundry coke between total capacity and expected consumption in 1977. Other factors, such as environmental requirements of powerplants that necessitate the burning of low-sulfur coal and persistent exports of coke, also contribute to the problem, so that foundry men could be faced with a coke shortage.

Considerable interest exists in the foundry and related industries in lowering energy requirements for melting, and in finding suitable alternative fuels (1, 4-5, 8-10, 12). Alleviating potential coke shortages, along with the conservation of coking coals, could be accomplished if a fraction of the coke in cupola operations could be replaced by fuel of lower quality without sacrificing metal quality. This would be consistent with the Bureau of Mines goals of conservation of important raw materials and waste utilization. This research was directed to the effects of coke replacement on furnace performance, metal and slag chemistry, environmental questions, and the properties of castings.

## MATERIALS

Charge materials, other than fuels used in this investigation, are given in table 1 along with the pertinent chemistry. The shredded automobile scrap was obtained from a local dealer and contained small amounts of wire, fabric and other foreign materials. The iron content of this scrap was estimated from this and previous cupola work conducted at the Twin Cities Research Center in Minnesota. The alloying elements silicon and manganese were charged as ferrosilicon and silicomanganese, both commercial products. Limestone and fluorspar were also commercial materials.

TABLE 1. - Analyses of nonfuel materials used in cupola

| Material                      | Constituent, pct   |     |      |    |      |      |                  |     |                                |
|-------------------------------|--------------------|-----|------|----|------|------|------------------|-----|--------------------------------|
|                               | Fe                 | C   | Si   | Mn | CaO  | CaF  | SiO <sub>2</sub> | MgO | Al <sub>2</sub> O <sub>3</sub> |
| Auto scrap <sup>1</sup> ..... | <sup>2</sup> 95-97 | ND  | ND   | ND | ND   | ND   | ND               | ND  | ND                             |
| Ferrosilicon.....             | 50                 | ND  | 48.0 | ND | ND   | ND   | ND               | ND  | ND                             |
| Silicomanganese..             | 14                 | 1.5 | 18.5 | 65 | ND   | ND   | ND               | ND  | ND                             |
| Limestone.....                | ND                 | ND  | ND   | ND | 54.9 | ND   | 0.2              | 0.7 | 0.7                            |
| Fluorspar.....                | ND                 | ND  | ND   | ND | 2.0  | 92.5 | 2.0              | .2  | .5                             |

ND Not determined.

<sup>1</sup>Bulk density 54 pounds per cubic foot.<sup>2</sup>Estimated from this and earlier work.

Proximate and ultimate analyses of all fuels used in this study are given in table 2. Cement-bonded coke breeze was obtained from a manufacturer that operates several sizable foundries. All other fuels were obtained locally.

TABLE 2. - Analyses of fuels used in cupola

|                                            | Constituent, pct |      |      |      |                |          |                |     |                |  |
|--------------------------------------------|------------------|------|------|------|----------------|----------|----------------|-----|----------------|--|
|                                            | Proximate        |      |      |      |                | Ultimate |                |     |                |  |
|                                            | H <sub>2</sub> O | VM   | FC   | Ash  | H <sub>2</sub> | C        | N <sub>2</sub> | S   | O <sub>2</sub> |  |
| HIGH FIXED CARBON                          |                  |      |      |      |                |          |                |     |                |  |
| Foundry coke.....                          | 0.2              | 0.8  | 90.7 | 8.3  | 0.3            | 89.2     | 0.5            | 0.8 | 0.8            |  |
| Petroleum coke (run-of-still)              | .3               | 10.1 | 88.9 | .7   | 3.4            | 87.0     | 1.2            | 5.0 | 2.7            |  |
| Pitch-bonded coal briquets <sup>2</sup> .. | .6               | 17.0 | 81.2 | 1.2  | 4.1            | 86.4     | 1.3            | 4.4 | 2.6            |  |
| Anthracite coal.....                       | 2.0              | 7.0  | 78.2 | 12.8 | 2.2            | 79.6     | .5             | .9  | 4.0            |  |
| MEDIUM FIXED CARBON                        |                  |      |      |      |                |          |                |     |                |  |
| Cement-bonded coke breeze <sup>3</sup> ... | 1.7              | 8.3  | 66.5 | 23.5 | 1.0            | 69.0     | 0.6            | 0.7 | 5.3            |  |
| Charcoal briquets (cooking).. <sup>2</sup> | 4.7              | 19.6 | 62.9 | 12.8 | 2.9            | 70.4     | .5             | .4  | 13.0           |  |
| Bituminous coal.....                       | 2.2              | 36.7 | 54.0 | 7.1  | 5.3            | 75.8     | 1.6            | .9  | 9.3            |  |
| LOW FIXED CARBON                           |                  |      |      |      |                |          |                |     |                |  |
| Chopped rubber tires.....                  | 0.3              | 64.8 | 28.9 | 6.0  | 6.9            | 80.8     | 0.2            | 1.2 | 4.9            |  |
| Wood blocks.....                           | 4.9              | 82.7 | 10.9 | 1.5  | 6.6            | 49.9     | .1             | ND  | 42.0           |  |

ND Not determined.

<sup>1</sup>Analyses on as-used basis.<sup>2</sup>About 2 pct pitch binder.<sup>3</sup>About 8 pct cement binder.

All of the charge materials were sized for use in a pilot cupola. A brief description is given in table 3.

TABLE 3. - Description of cupola charge materials

| <u>Material</u>                               | <u>Description</u>           |
|-----------------------------------------------|------------------------------|
| Auto scrap.....                               | 1- to 4-inch shredded.       |
| Ferrosilicon.....                             | Minus 1 plus 1/4 inch.       |
| Silicomanganese.....                          | Minus 1 plus 1/4 inch.       |
| Limestone.....                                | Minus 1-1/2 plus 1/2 inch.   |
| Fluorspar.....                                | Minus 1 plus 1/2 inch.       |
| Foundry coke.....                             | Minus 1-1/2 plus 3/4 inch.   |
| Petroleum coke (run-of-still).....            | Minus 1-1/2 plus 1 inch.     |
| Pitch-bonded coal briquets <sup>1</sup> ..... | 2- by 2-inch pillows.        |
| Anthracite coal.....                          | Minus 1-1/2 plus 3/4 inch.   |
| Cement-bonded coke breeze <sup>2</sup> .....  | Minus 2 plus 1 inch.         |
| Charcoal briquets (cooking).....              | 2- by 2-inch pillows.        |
| Bituminous coal.....                          | Minus 1-1/2 plus 1 inch.     |
| Chopped rubber tires.....                     | 1- to 3-inch chopped pieces. |
| Wood blocks.....                              | 1- to 2-inch blocks.         |

<sup>1</sup>About 2 pct pitch binder.

<sup>2</sup>About 8 pct cement binder.

Cupola trials were made using either basic or acid slag practice, with either commercial magnesite or fireclay brick linings, respectively. Patching was done using compatible materials.

#### EQUIPMENT

All trials were made in an 18-inch-diameter cupola, figure 1, which type is described in literature (2). It was previously modified by adding 8 feet to the shaft and by enlarging the well in depth and wall thickness to permit additional insulation and the accumulation of about 300 pounds of iron. Combustion air, supplied by a 10-oz turbo blower, was metered by an air-weight controller. Air was preheated in a 136 kw electric stove to 600° F (316° C) and distributed through four tuyeres with a total area of 28 square inches. The four, 3-inch-diameter tuyeres, located 90° apart are 22 inches above the iron taphole.

Exhaust gases at 1,400° F (760° C) to 1,800° F (982° C) were cooled in the spark arrestor hood by means of a water-cooled heat exchanger. Further cooling of the gases was done in the exhaust duct by water sprays before entering the scrubber and fan, prior to exiting through the stack.

The mechanical testing of the as-cast specimens was done on a well-instrumented tensile machine. The machine was adapted to this work through fixtures prepared for holding the specimens, and for eliminating eccentricity.

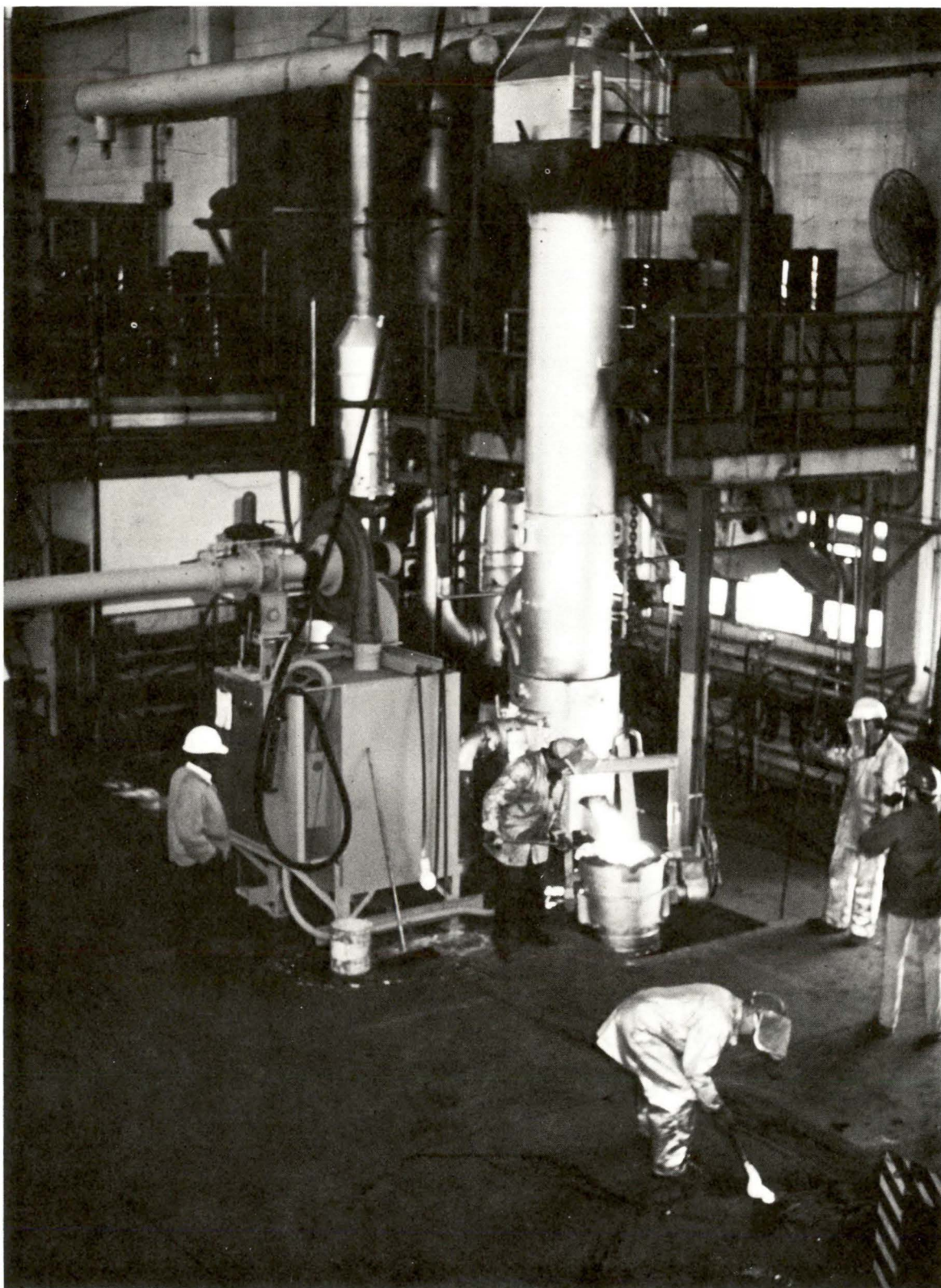


FIGURE 1. - Cupola in operation, Twin Cities Research Center.

## PROCEDURE

The cupola was preheated, then coke was charged for further preheating and to establish the coke bed. The fuels used to partially replace foundry coke were not added to the starting coke bed. The height of the coke bed was set at 30 inches above the tuyeres. Six charges containing a total of 330 pounds of scrap were charged for each tap, and seven taps were made for each trial. The cupola was operated with one charge at a time above the coke bed. Under both basic and acid slag practice, most trials were made using a fixed-carbon basis for replacing the foundry coke in the charge, although some were made on a weight basis. The materials shown in table 4 were added with each 55 pounds of scrap as a standard charge. The charging sequence was scrap, additives, then coke.

TABLE 4. - Materials used with 55 pounds of scrap as a standard charge

| Material                           | Weight, pounds |      |
|------------------------------------|----------------|------|
|                                    | Basic          | Acid |
| Fuel fixed carbon <sup>1</sup> ... | 9.1            | 9.1  |
| Ferrosilicon.....                  | 3.0            | 3.0  |
| Silicomanganese.....               | .5             | .5   |
| Limestone.....                     | 2.5            | 1.65 |
| Fluorspar.....                     | .5             | .5   |

<sup>1</sup>5.5 to 1 scrap to coke ratio.

Iron was tapped into a ladle and pigged in sand. Analytical and chill control samples of iron were taken from the casting ladle. Slag samples were always taken from the slag stream (back slagging cupola). Temperatures were taken optically on the stream. Taps 3, 4, 5, and 6 were considered representative of steady-state conditions. Following each trial, the cupola bottom was dropped and the hot coke of the bed was quenched and discarded. The procedure was identical for both basic or acid slag practice.

All trials were made using 700 cfm air preheated to 600° F (316° C). Each series was made with the alloying additions and fluxes at constant levels. Test castings were poured in green sand molds from steady-state taps 3, 4, 5, and 6, providing one tensile and one transverse bar from each tap (ASTM Specification A48). Water samples containing particulates were taken during steady-state operation from the scrubber discharge and from the base of the exhaust stack as condensate.

## RESULTS AND DISCUSSION

Several materials believed suitable as alternatives for foundry charge coke were evaluated in cupola operation. This was done using either basic or acid slag practice, with basic practice receiving major consideration. For each practice, a baseline trial was made for comparison using all foundry coke. Results are discussed under each practice with the fuels arranged in three groups according to fixed-carbon content. The strengths of the irons are covered separately.

### Basic Slag Practice

The iron and slags resulting from partial replacement of foundry coke in the charges are listed in tables 5 and 6. Slag basicities ranged from about 1.03 to about 1.52. Table 7 gives analyses from samples of scrubber and stack waters and solids. Discussions of results must be referred to the information contained in all three tables. The tables include the replacement fuels used, their levels, and the basis of replacement. The fuels are listed arbitrarily in three groups in descending order of their fixed-carbon contents. Discussions include such factors as availability of materials, furnace size, economics, and judgment.

### High Fixed Carbon

Anthracite coal provided satisfactory cupola performance at the 40 pct level of replacement. No adverse effects were evident in metal and slag behavior or analyses, and the scrubber solids analyses were comparable to those obtained using all foundry coke. The behavior of anthracite coal in sizes appropriate for larger cupolas would be important (10). It is possible that decrepitation of this fuel in larger units could cause problems. The problems that could arise from fuel breakdown in a cupola are discussed later.

Pitch-bonded coal briquets, produced commercially for home and industrial heating (5), were evaluated at the 20 and 40 pct levels of replacement. The irons produced were not acceptable as gray iron, but could be considered in the white/malleable grades, particularly for heavy sections. Carbon pickup was inadequate and the sulfur content too high for gray iron. At the 40 pct level of replacement acceptable transverse bar castings could not be poured (cold shut). Some sparking was evident under the hood, and the opacity of the off-gases was higher than any of the trials. This condition was confirmed as shown in table 7 under scrubber solids and in their carbon contents. In this case the pitch binder softened and melted without time for coking. The volatiles and coal particles were carried out of the furnace contributing to both the opacity of the gases, and the high carbon contents of the scrubber solids. If this material was coked prior to use in a cupola, success would probably be assured. A product similar to formed coke (4) would result, but then economics would be an important factor.

Irons similar to those resulting from the use of pitch-bonded coal were obtained using run-of-still (uncalcined) petroleum coke at 20 and 40 pct level of replacement. Furnace conditions were also similar due to fuel breakdown. The iron carbon content was low and the sulfur high. Transverse bar castings could not be poured from iron at the 40 pct level of replacement. Synthetic coke has been made in the past from petroleum coke of low sulfur (10), bonded with pitch and carbonized.

### Medium Fixed Carbon

Bituminous coal was found to be satisfactory at the 40 pct level of replacement. The observations and comments made under anthracite coal would also apply to this coal. Although the volatile matter in coal of this grade is considerably higher than that of anthracite, no ill effects were observed.

TABLE 5. - Irons resulting from partial replacement of coke under basic slag practice

(FC = fixed carbon; wt = weight - replacement : coke)

| Replacement                                   | Chemical analyses <sup>1</sup> , pct |      |       |      |      |      |      |       | Cast iron           |       |                           |                    |
|-----------------------------------------------|--------------------------------------|------|-------|------|------|------|------|-------|---------------------|-------|---------------------------|--------------------|
| Fuel : Level : Basis                          | C                                    | Si   | S     | P    | Mn   | Al   | Cu   | Sn    | Tapping temperature |       | Melting rate <sup>2</sup> |                    |
|                                               |                                      |      |       |      |      |      |      |       | ° F                 | ° C   | Lb/min                    | Index <sup>3</sup> |
| HIGH FIXED CARBON                             |                                      |      |       |      |      |      |      |       |                     |       |                           |                    |
| None : 100 pct foundry coke.....              | 3.50                                 | 1.80 | 0.054 | 0.01 | 0.71 | 0.02 | 0.19 | 0.024 | 2,710               | 1,488 | 25.1                      | 1.02               |
| Petroleum coke <sup>4</sup> : 20 pct : FC...  | 2.80                                 | 2.10 | .14   | .01  | .70  | ND   | .26  | ND    | 2,520               | 1,382 | 22.4                      | .93                |
| : 40 pct : FC...                              | 2.52                                 | 2.10 | .19   | .01  | .68  | .02  | .24  | .012  | 2,590               | 1,421 | 23.9                      | 1.01               |
| Pitch-bonded coal <sup>5</sup> : 20 pct : FC  | 2.80                                 | 1.80 | .13   | .01  | .70  | ND   | .26  | .013  | 2,690               | 1,477 | 24.8                      | 1.04               |
| : 40 pct : FC                                 | 2.50                                 | 2.10 | .16   | .01  | .67  | ND   | .31  | .011  | 2,650               | 1,454 | 27.4                      | .99                |
| Anthracite coal : 40 pct : FC...              | 3.70                                 | 2.20 | .050  | .02  | .87  | .02  | .30  | .015  | 2,610               | 1,432 | 23.9                      | 1.05               |
| MEDIUM FIXED CARBON                           |                                      |      |       |      |      |      |      |       |                     |       |                           |                    |
| Cemented breeze <sup>6</sup> : 10 pct : FC..  | 3.10                                 | 2.30 | 0.064 | 0.01 | 0.74 | 0.02 | 0.29 | 0.013 | 2,560               | 1,404 | 29.4                      | 1.06               |
| : 20 pct : FC..                               | 3.00                                 | 2.20 | .066  | .01  | .76  | .02  | .29  | .012  | 2,520               | 1,382 | 29.1                      | 1.05               |
| : 40 pct : FC..                               | 3.00                                 | 2.20 | .080  | .01  | .74  | .02  | .28  | .012  | 2,520               | 1,382 | 30.2                      | 1.05               |
| Charcoal briquets : 20 pct : FC.              | 3.10                                 | 2.10 | .081  | .01  | .73  | ND   | .21  | .010  | 2,710               | 1,488 | 23.3                      | 1.04               |
| Bituminous coal : 40 pct : FC...              | 3.50                                 | 2.10 | .050  | .02  | .87  | .01  | .18  | .009  | 2,610               | 1,432 | 23.8                      | 1.05               |
| LOW FIXED CARBON                              |                                      |      |       |      |      |      |      |       |                     |       |                           |                    |
| Chopped tires : 10 pct : 1:1 wt.              | 3.49                                 | 2.01 | 0.063 | 0.01 | 0.66 | 0.02 | 0.20 | 0.024 | 2,680               | 1,471 | 22.2                      | 1.08               |
| : 20 pct : 1:1 wt.                            | 3.25                                 | 1.97 | .063  | .01  | .64  | .02  | .16  | .024  | 2,610               | 1,432 | 23.6                      | .97                |
| : 20 pct : 5.4 wt.                            | 3.23                                 | 1.53 | .078  | ND   | .74  | ND   | .14  | .013  | 2,680               | 1,471 | 29.0                      | .95                |
| : 20 pct : 3:2 wt.                            | 3.27                                 | 1.90 | .083  | .01  | .73  | .02  | .23  | .023  | 2,640               | 1,449 | 27.7                      | 1.07               |
| : 20 pct : FC.....                            | 3.40                                 | 2.00 | .095  | .02  | .84  | .02  | .17  | .013  | 2,620               | 1,438 | 24.6                      | 1.02               |
| Wood blocks : 5 pounds added <sup>7</sup> ... | 3.10                                 | 2.20 | .082  | .01  | .70  | ND   | .22  | ND    | 2,720               | 1,493 | 23.7                      | 1.03               |

ND Not determined.

<sup>1</sup>Average of steady-state taps, not weighted.

<sup>2</sup>Steady-state conditions.

<sup>3</sup>Pounds cast iron ÷ pounds scrap, on overall basis.

<sup>4</sup>Run-of-still.

<sup>5</sup>About 2 pct pitch binder.

<sup>6</sup>About 8 pct cement binder.

<sup>7</sup>In addition to normal charge coke.

TABLE 6. - Basic slags resulting from partial replacement of coke

(FC = fixed carbon; wt = weight - replacement : coke)

| Replacement                                      | Chemical analyses, pct |      |      |                  |                                |     |     |                  | Slag                    |                     |
|--------------------------------------------------|------------------------|------|------|------------------|--------------------------------|-----|-----|------------------|-------------------------|---------------------|
| Fuel : Level : Basis                             | Fe                     | CaO  | MgO  | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | Mn  | S   | F                | Basicity <sup>1 2</sup> | Volume <sup>3</sup> |
| HIGH FIXED CARBON                                |                        |      |      |                  |                                |     |     |                  |                         |                     |
| None : 100 pct foundry coke.....                 | 0.6                    | 37.8 | 19.5 | 31.7             | 6.8                            | 1.4 | 0.9 | 1.3              | 1.49                    | 0.066               |
| Petroleum coke <sup>4</sup> : 20 pct : FC.....   | ND                     | 38.1 | 15.9 | 30.2             | 10.4                           | 3.0 | 1.4 | ( <sup>5</sup> ) | 1.33                    | .052                |
| : 40 pct : FC.....                               | 1.3                    | 34.7 | 19.3 | 30.3             | 8.2                            | 3.0 | 2.0 | ( <sup>5</sup> ) | 1.40                    | .044                |
| Pitch-bonded coal <sup>6</sup> : 20 pct : FC.... | 1.4                    | 38.8 | 14.4 | 30.1             | 9.0                            | 2.6 | 1.3 | .6               | 1.27                    | .071                |
| : 40 pct : FC....                                | 2.6                    | 37.3 | 13.5 | 29.5             | 7.9                            | 3.4 | 1.1 | .7               | 1.36                    | .043                |
| Anthracite coal : 40 pct : FC.....               | .8                     | 41.8 | 16.3 | 26.3             | 10.8                           | 1.6 | 1.5 | 2.4              | 1.50                    | .042                |
| MEDIUM FIXED CARBON                              |                        |      |      |                  |                                |     |     |                  |                         |                     |
| Cemented breeze <sup>7</sup> : 10 pct : FC.....  | 0.8                    | 33.6 | 18.1 | 31.4             | 11.6                           | 2.1 | 0.7 | ND               | 1.20                    | 0.051               |
| : 20 pct : FC.....                               | 1.2                    | 33.8 | 19.6 | 31.0             | 8.9                            | 2.6 | .7  | ND               | 1.29                    | .045                |
| : 40 pct : FC.....                               | 1.3                    | 31.1 | 15.2 | 33.0             | 12.2                           | 2.7 | .6  | ND               | 1.03                    | .059                |
| Charcoal briquets : 20 pct : FC....              | .4                     | 39.1 | 15.3 | 29.1             | 10.8                           | 1.7 | 1.5 | ND               | 1.34                    | .065                |
| Bituminous coal : 40 pct : FC.....               | .5                     | 41.9 | 14.7 | 30.0             | 9.4                            | 1.1 | 1.4 | 2.4              | 1.44                    | .047                |
| LOW FIXED CARBON                                 |                        |      |      |                  |                                |     |     |                  |                         |                     |
| Chopped tires : 10 pct : 1:1 wt....              | 0.7                    | 38.1 | 17.4 | 31.5             | 8.3                            | 2.4 | 0.9 | 0.9              | 1.40                    | 0.065               |
| : 20 pct : 1:1 wt....                            | 1.6                    | 38.8 | 16.4 | 29.5             | 6.8                            | 2.4 | .7  | 1.0              | 1.52                    | .072                |
| : 20 pct : 5:4 wt....                            | 1.5                    | 38.4 | 12.2 | 34.5             | 8.5                            | 2.2 | .6  | 1.6              | 1.18                    | .088                |
| : 20 pct : 3:2 wt....                            | 1.4                    | 38.6 | 10.6 | 36.2             | 8.8                            | 1.6 | .5  | 1.1              | 1.10                    | .074                |
| : 20 pct : FC.....                               | .7                     | 42.0 | 11.4 | 31.7             | 8.2                            | 1.3 | 1.0 | 1.9              | 1.34                    | .061                |
| Wood blocks : 5 pounds added <sup>8</sup> .....  | .9                     | 36.1 | 15.3 | 28.8             | 13.4                           | 2.2 | .9  | ND               | 1.21                    | .035                |

ND Not determined.

<sup>1</sup>Average of steady-state taps, not weighted.<sup>2</sup>Basicity = pct (CaO + MgO) ÷ pct (SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub>).<sup>3</sup>Pounds slag ÷ pounds iron, on overall basis.<sup>4</sup>Run-of-still.<sup>5</sup>No fluorspar used.<sup>6</sup>About 2 pct pitch binder.<sup>7</sup>About 8 pct pitch binder.<sup>8</sup>In addition to normal charge coke.

TABLE 7. - Analyses<sup>1</sup> of scrubber and stack waters and solids under basic slag practice

(FC = fixed carbon; wt = weight - replacement : coke)

| Replacement                                    | Sampling<br>location   | Waters <sup>2</sup> |       |                   | Solids,<br>g/l | Chemical analyses of solids, pct |      |     |                                |                |     |      |     |      |     |                 |
|------------------------------------------------|------------------------|---------------------|-------|-------------------|----------------|----------------------------------|------|-----|--------------------------------|----------------|-----|------|-----|------|-----|-----------------|
| Fuel : Level : Basis                           |                        | pH                  | ppm F | NaOH <sup>3</sup> |                | Fe                               | CaO  | MgO | Al <sub>2</sub> O <sub>3</sub> | C <sup>4</sup> | Mn  | Cu   | Pb  | Zn   | Sn  | F               |
| HIGH FIXED CARBON                              |                        |                     |       |                   |                |                                  |      |     |                                |                |     |      |     |      |     |                 |
| None : 100 pct foundry coke.....               | Scrubber <sup>5</sup>  | 3.6                 | 319   | 44.7              | 1.6            | 10.6                             | 14.1 | 0.8 | 2.0                            | 33.6           | 1.2 | ND   | 0.8 | 1.0  | 1.9 | 13.2            |
|                                                | Stack <sup>6</sup> ... | 4.0                 | 20    | ND                | 4.2            | 13.7                             | 6.2  | 2.6 | 4.3                            | 11.0           | 2.4 | ND   | 3.7 | 7.8  | 2.6 | 12.0            |
| Petroleum coke <sup>7</sup> : 20 pct : FC....  | Scrubber.              | 6.7                 | ND    | 50.7              | 7.0            | 13.2                             | 2.0  | 3.8 | 2.4                            | 52.4           | .5  | ND   | .5  | 4.7  | 0.2 | <sup>8</sup> ND |
|                                                | Stack....              | 3.2                 | ND    | ND                | 3.0            | 24.9                             | .9   | 1.9 | 1.2                            | 3.4            | 2.7 | ND   | 2.4 | 8.4  | .3  | ND              |
| : 40 pct : FC....                              | Scrubber.              | 6.7                 | ND    | 52.1              | 8.1            | 17.3                             | 1.9  | 3.1 | 2.3                            | 48.6           | .6  | ND   | .7  | 5.8  | .2  | <sup>8</sup> ND |
|                                                | Stack....              | 3.7                 | ND    | ND                | 4.2            | 29.0                             | .7   | 1.9 | 2.0                            | 3.0            | 2.0 | ND   | 2.6 | 5.7  | .2  | ND              |
| Pitch-bonded coal <sup>9</sup> : 20 pct : FC.  | Scrubber.              | 4.1                 | 425   | 65.0              | 15.4           | 5.6                              | 6.8  | 2.1 | 1.8                            | 52.2           | .1  | 0.07 | .2  | .6   | .2  | 5.3             |
|                                                | Stack....              | 4.0                 | 220   | ND                | 1.5            | 24.0                             | 2.4  | 1.3 | 2.7                            | 8.3            | 2.3 | .19  | 3.9 | 10.6 | .6  | 5.3             |
| : 40 pct : FC.                                 | Scrubber.              | 4.0                 | 475   | 64.0              | 17.8           | 5.8                              | 5.1  | 1.9 | 1.2                            | 55.8           | .1  | .08  | .2  | .8   | .2  | 4.0             |
|                                                | Stack....              | 4.5                 | 275   | ND                | 10.0           | 26.1                             | 2.9  | 1.4 | 2.5                            | ND             | 1.4 | .29  | 8.1 | 11.7 | .8  | 2.7             |
| Anthracite coal : 40 pct : FC....              | Scrubber.              | 4.4                 | 280   | 34.3              | 4.6            | 10.9                             | 16.9 | 3.2 | 3.4                            | 31.9           | .4  | .07  | .6  | 2.2  | .2  | 9.6             |
|                                                | Stack....              | 4.4                 | 195   | ND                | 3.8            | 18.8                             | 3.3  | 2.9 | 3.8                            | 2.5            | 3.0 | .08  | 2.5 | 9.4  | .6  | 1.6             |
| MEDIUM FIXED CARBON                            |                        |                     |       |                   |                |                                  |      |     |                                |                |     |      |     |      |     |                 |
| Cemented breeze <sup>10</sup> : 10 pct : FC..  | Scrubber.              | 7.4                 | ND    | ND                | 11.8           | 12.8                             | 2.8  | ND  | ND                             | 46.8           | ND  | 0.10 | 0.5 | 2.8  | 0.1 | 0.2             |
|                                                | Stack....              | NS                  | ND    | ND                | 8.8            | 13.6                             | 4.1  | ND  | ND                             | 41.7           | 0.3 | .11  | .6  | 4.9  | .2  | .1              |
| : 20 pct : FC..                                | Scrubber.              | 6.6                 | ND    | ND                | 8.8            | 13.6                             | 4.1  | ND  | ND                             | 41.7           | 0.3 | .11  | .6  | 4.9  | .2  | .1              |
|                                                | Stack....              | NS                  | ND    | ND                | 12.7           | 5.9                              | 2.2  | ND  | ND                             | 51.2           | ND  | .11  | .6  | 4.3  | .2  | .1              |
| : 40 pct : FC..                                | Scrubber.              | 8.1                 | ND    | ND                | 12.7           | 5.9                              | 2.2  | ND  | ND                             | 51.2           | ND  | .11  | .6  | 4.3  | .2  | .1              |
|                                                | Stack....              | NS                  | ND    | ND                | 12.7           | 5.9                              | 2.2  | ND  | ND                             | 51.2           | ND  | .11  | .6  | 4.3  | .2  | .1              |
| Charcoal briquets : 20 pct : FC..              | Scrubber.              | 4.5                 | 253   | 57.5              | 7.7            | 5.9                              | 5.7  | 2.7 | 2.7                            | 45.3           | .2  | .30  | .2  | .9   | .2  | 5.1             |
|                                                | Stack....              | 3.8                 | 236   | ND                | 2.0            | 18.9                             | 1.6  | 2.5 | 4.0                            | 6.6            | 2.4 | .10  | 1.5 | 5.8  | .3  | 5.6             |
| Bituminous coal : 40 pct : FC....              | Scrubber.              | 4.6                 | 301   | 31.5              | 4.3            | 7.3                              | 13.9 | 4.0 | 2.7                            | 36.1           | .3  | .07  | .3  | 1.8  | .2  | 1.8             |
|                                                | Stack....              | 4.5                 | 258   | ND                | 3.6            | 16.9                             | 3.1  | 2.3 | 5.2                            | 4.1            | 3.1 | .10  | 2.0 | 10.0 | .6  | 2.3             |
| LOW FIXED CARBON                               |                        |                     |       |                   |                |                                  |      |     |                                |                |     |      |     |      |     |                 |
| Chopped tires : 10 pct : 1:1 wt..              | Scrubber.              | 3.5                 | 508   | 38.1              | 3.4            | 6.1                              | 11.4 | 0.7 | 1.5                            | 52.4           | 0.3 | 0.12 | 0.8 | 1.7  | 0.3 | 10.9            |
|                                                | Stack....              | 5.6                 | 1,775 | ND                | 8.4            | 12.1                             | 4.5  | 2.4 | 3.1                            | 24.4           | 2.1 | .18  | 4.1 | 8.5  | 1.0 | 9.4             |
| : 20 pct : 1:1 wt..                            | Scrubber.              | 3.9                 | 467   | 40.7              | 5.0            | 3.1                              | 8.3  | .4  | 1.1                            | 69.0           | .3  | .09  | .4  | 1.7  | .3  | 7.3             |
|                                                | Stack....              | 4.8                 | 3,260 | ND                | 7.1            | 12.0                             | 2.9  | 1.0 | 1.8                            | 44.9           | 1.2 | .22  | 2.9 | 5.1  | .6  | 7.2             |
| : 20 pct : 5:4 wt..                            | Scrubber.              | 4.1                 | 295   | 66.8              | 11.8           | 10.0                             | 4.7  | .9  | 1.6                            | 59.8           | .2  | .05  | .2  | 1.7  | .2  | 3.7             |
|                                                | Stack....              | NS                  | ND    | ND                | 7.3            | 3.8                              | 7.6  | .7  | 1.0                            | 68.5           | .2  | .13  | .2  | 1.0  | .1  | 5.3             |
| : 20 pct : 3:2 wt..                            | Scrubber.              | 3.9                 | 370   | 50.3              | 7.3            | 3.8                              | 7.6  | .7  | 1.0                            | 68.5           | .2  | .13  | .2  | 1.0  | .1  | 5.3             |
|                                                | Stack....              | 4.8                 | 410   | ND                | 2.1            | 13.5                             | 2.4  | 2.1 | 2.8                            | 25.3           | 1.5 | .35  | 2.5 | 7.9  | .5  | 6.5             |
| : 20 pct : FC.....                             | Scrubber.              | 5.1                 | 155   | 62.4              | 8.3            | 5.4                              | 14.1 | 3.5 | 2.1                            | 61.7           | .2  | .05  | .4  | .3   | .1  | 2.0             |
|                                                | Stack....              | 4.3                 | 95    | ND                | 3.0            | 17.4                             | 5.2  | 2.3 | 3.3                            | 27.9           | .9  | .08  | .3  | 2.2  | .8  | 2.9             |
| Wood blocks : 5 pounds added <sup>11</sup> ... | Scrubber.              | 6.6                 | ND    | 15.5              | 6.8            | 11.2                             | 1.7  | 4.1 | 2.3                            | 25.6           | .4  | ND   | .4  | 4.1  | .2  | ND              |
|                                                | Stack....              | 6.1                 | ND    | ND                | 2.1            | 34.1                             | .8   | 1.3 | .8                             | 3.1            | 1.0 | ND   | 1.0 | 4.6  | .2  | ND              |

ND Not determined.

NS Not sampled.

<sup>1</sup>Representative of steady-state conditions.<sup>2</sup>Water flow through scrubber at 20-30 l/min, pH = 7.<sup>3</sup>Titration to pH 7 with ml 0.307 N NaOH per liter scrubber water.<sup>4</sup>Accuracy  $\pm$  5 pct relative.<sup>5</sup>Sampled at scrubber discharge.<sup>6</sup>Sampled at base of stack.<sup>7</sup>Run-of-still.<sup>8</sup>No fluorspar used.<sup>9</sup>About 2 pct pitch binder.<sup>10</sup>About 8 pct cement binder.<sup>11</sup>In addition to normal charge coke.

The bonding together of fine coke particles would appear to be an acceptable solution to the problem of utilizing the fines (1-inch by down) screened from coke for large cupolas. Using cement as a binder, shapes can be produced in sizes suitable for commercial furnaces. Cement-bonded coke breeze was evaluated at the 10, 20, and 40 pct levels in the pilot cupola. The material seemed to be satisfactory at the 10 pct level of replacement. The higher levels, however, resulted in erratic chills, increased sparking at the spark-arrestor hood, a slight decrease in carbon pickup by the iron and increased air back pressure on the furnace. The 20 and 40 pct levels also showed more fine fuel particles in the coke bed removed (or dropped) from the cupola at the termination of the trial. Tapping temperature of the iron decreased slightly, another sign of a tight furnace. A tight furnace has restricted air flow causing an increase in back pressure, which could also lead to channeling. Additional evidence of fuel degradation was found in the analyses of solids from the discharge of the scrubber. Table 7 shows higher than normal carbon contents in the sludge. The three levels of replacement used showed increases of at least 30 to 40 pct as compared to all foundry coke, and the hard coals. Comparing only the 40 pct levels shows an increase in carbon of about 60 pct, however. Aside from furnacing problems, if fuel efficiency is considered, then economics would be important. Apparently, the high temperature of cupola operation caused the binder to break down at all levels of replacement. It would appear that such a material should not be used above the 10 pct level because of the problems outlined, and only then with economic justification.

One trial was made using a 20 pct replacement of coke with charcoal briquets on a fixed-carbon basis. There were no serious problems, although some signs of fuel breakdown were evident. Some sparking was observed under the hood of the furnace. The scrubber solids were about 30 pct higher in carbon than when all coke was used. The use of this and similar materials would probably depend on economic and size considerations.

#### Low Fixed Carbon

Experiences of others concerning the use of scrap rubber tires in commercial cupolas were received informally during this work. By-and-large results of others were in agreement with the findings of this study. Scrap rubber tires contain a variety of potentially valuable products (14), and they might well be used to that end. The physical form and calorific value (about 13,000 Btu per pound) of tires suggest, however, that their use in cupolas would be reasonable. Several trials were made to evaluate this material as shown in tables 5, 6, and 7. The following discussion covers results as well as some observations.

In using rubber tires, several trials were made at levels of coke replacement below those on a fixed-carbon basis because of uncertainties regarding the effectiveness of volatile constituents. The use of one or two coke blanks (extra charge coke) per run to maintain the level of the bed became necessary. Carbon pickup by the iron was satisfactory as was the tapping temperature. The sulfur content of the iron compared to all foundry coke increased about 20 to 90 pct, depending on the level of replacement. Sulfurs were still below

0.10 pct, a maximum content considered for most gray iron applications. Higher sulfurs could be controlled by external desulfurization, however, when necessary.

Considerable sparking was observed under the cupola hood (truly an umbrella of sparks) when scrap rubber was used at any level of replacement. This resulted from decrepitation of the rubber under forced burning. Small particles of rubber and/or carbon black filler which are liberated, in the cupola shaft, are ignited under the hood. The characteristic odor of burning rubber was evident around the furnace and downwind of the exhaust stack. A replacement ratio of 3 to 1 rubber for coke is required for fixed-carbon equivalency, and this creates a bulk handling problem even at the 20 pct replacement level. The carbon contained in the scrubber solids increased by a factor of about 2 as compared to all coke with or without the coals used, depending on the level and basis for replacement.

Although rubber can be used to partially replace charge coke in a cupola, its use would be restricted to units with wet scrubbers. On operating days with unfavorable wind directions, its use would be unwise. Moreover, additional personnel would be required to handle the rubber bulk charge.

Wood blocks were charged to the furnace in addition to the normal charge coke in order to observe general behavior. The thinking is that the high levels of volatiles can be contributed to scrap preheating and that the resulting charcoal will maintain the porosity of the coke bed. This latter thought would be important when combinations of fuels are used, particularly those that tend to decrepitate. In plants where waste cupola heat, in one or more forms, is used for space heating or for preheating cupola combustion air, the energy available in waste wood can be put to good use. Under cupola operating conditions, the wood was forced to burn quickly. In so doing, large sparks were liberated which were evident under the hood. Further evaluation of wood was terminated due to the abnormally large sparks and the hazard they represented using the existing exhaust system.

#### Acid Slag Practice

The use of acid cupola practice in the foundry industry is not as widespread as basic practice, but some sizable plants still employ it. Therefore, only a few trials were made for comparative purposes. The information obtained from this work is contained in tables 8, 9, and 10. Slag basicities ranged from about 0.40 to 0.62. The chemistry of the iron is normal for acid practice. There were no adverse effects of using partial replacement of foundry coke under acid practice, and the comments made under basic slag practice would apply.

Both anthracite and bituminous coal were satisfactory in the pilot cupola. As in basic practice, a trial made under acid practice at less than fixed-carbon level required extra charge coke to maintain the level of the bed. Sparking under the cupola hood was again evident with the use of tires or charcoal briquets. The carbon content of the scrubber sludge was increased with their use.

TABLE 8. - Irons resulting from partial replacement of coke under acid slag practice

(FC = fixed carbon; wt = weight - replacement : coke)

| Replacement<br>Fuel : Level : Basis   | Chemical analyses <sup>1</sup> , pct |      |       |       |      |       |      |       | Cast iron           |       |                           |                    |
|---------------------------------------|--------------------------------------|------|-------|-------|------|-------|------|-------|---------------------|-------|---------------------------|--------------------|
|                                       | C                                    | Si   | S     | P     | Mn   | Al    | Cu   | Sn    | Tapping temperature |       | Melting rate <sup>2</sup> |                    |
|                                       |                                      |      |       |       |      |       |      |       | ° F                 | ° C   | Lb/min                    | Index <sup>3</sup> |
| HIGH FIXED CARBON                     |                                      |      |       |       |      |       |      |       |                     |       |                           |                    |
| None : 100 pct foundry coke.....      | 3.20                                 | 1.83 | 0.087 | 0.06  | 0.67 | 0.02  | 0.15 | 0.011 | 2,730               | 1,499 | 29.5                      | 1.02               |
| Anthracite coal : 20 pct : FC.....    | 3.43                                 | 2.10 | .098  | ND    | .70  | .02   | .16  | .012  | 2,750               | 1,510 | 29.9                      | 1.06               |
| : 40 pct : FC.....                    | 3.40                                 | 2.10 | .078  | ND    | .78  | ND    | .20  | .012  | 2,700               | 1,482 | 27.0                      | 1.06               |
| MEDIUM FIXED CARBON                   |                                      |      |       |       |      |       |      |       |                     |       |                           |                    |
| Charcoal briquets : 20 pct : FC.....  | 3.20                                 | 1.88 | 0.098 | 0.035 | 0.81 | 0.02  | 0.13 | 0.01  | 2,710               | 1,488 | 26.5                      | 1.06               |
| Bituminous coal : 20 pct : 1:1 wt.... | 3.30                                 | 1.93 | .095  | ND    | .69  | .025  | .15  | .019  | 2,710               | 1,488 | 30.5                      | 1.07               |
| : 20 pct : FC.....                    | 3.60                                 | 2.10 | .083  | ND    | .78  | .02   | .23  | .016  | 2,660               | 1,460 | 24.6                      | 1.07               |
| : 40 pct : FC.....                    | 3.30                                 | 2.00 | .11   | .05   | .76  | .02   | .21  | .014  | 2,670               | 1,466 | 22.8                      | 1.06               |
| LOW FIXED CARBON                      |                                      |      |       |       |      |       |      |       |                     |       |                           |                    |
| Chopped tires : 20 pct : FC.....      | 3.20                                 | 2.30 | 0.11  | 0.06  | 0.76 | 0.016 | 0.25 | 0.016 | 2,680               | 1,471 | 24.3                      | 1.06               |

ND Not determined.

<sup>1</sup>Average of steady-state taps, not weighted.<sup>2</sup>Steady-state conditions.<sup>3</sup>Pounds cast iron ÷ pounds scrap, on overall basis.

TABLE 9. - Acid slags resulting from partial replacement of coke

(FC = fixed carbon; wt = weight - replacement : coke)

| Replacement                            | Chemical analyses <sup>1</sup> , pct |      |     |                  |                                |     |     |     | Slag                  |                     |
|----------------------------------------|--------------------------------------|------|-----|------------------|--------------------------------|-----|-----|-----|-----------------------|---------------------|
| Fuel : Level : Basis                   | Fe                                   | CaO  | MgO | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | Mn  | S   | F   | Basicity <sup>2</sup> | Volume <sup>3</sup> |
| HIGH FIXED CARBON                      |                                      |      |     |                  |                                |     |     |     |                       |                     |
| None : 100 pct foundry coke.....       | 2.6                                  | 25.1 | 1.0 | 35.3             | 28.8                           | 2.9 | 0.2 | 0.9 | 0.43                  | 0.071               |
| Anthracite coal : 20 pct : FC.....     | 1.1                                  | 29.4 | 1.1 | 28.0             | 35.8                           | 1.7 | .4  | 1.0 | .47                   | .048                |
| : 40 pct : FC.....                     | 1.9                                  | 28.4 | .7  | 28.4             | 32.9                           | 1.2 | .5  | 1.4 | .48                   | .080                |
| MEDIUM FIXED CARBON                    |                                      |      |     |                  |                                |     |     |     |                       |                     |
| Charcoal briquets : 20 pct : FC.....   | 1.6                                  | 34.6 | 1.2 | 30.7             | 27.6                           | 2.0 | 0.5 | 1.1 | 0.62                  | 0.060               |
| Bituminous coal : 20 pct : 1:1 wt..... | 1.8                                  | 28.8 | .4  | 30.6             | 32.8                           | 2.3 | .3  | 1.1 | .46                   | .065                |
| : 20 pct : FC.....                     | 1.0                                  | 28.7 | .7  | 24.9             | 36.5                           | .9  | .6  | 1.4 | .48                   | .035                |
| : 40 pct : FC.....                     | 2.8                                  | 24.4 | .9  | 30.1             | 33.2                           | 2.0 | .4  | .8  | .40                   | .040                |
| LOW FIXED CARBON                       |                                      |      |     |                  |                                |     |     |     |                       |                     |
| Chopped tires : 20 pct : FC.....       | 1.2                                  | 31.0 | 0.8 | 25.8             | 22.3                           | 1.7 | 0.6 | 2.2 | 0.57                  | 0.056               |

<sup>1</sup>Average of steady-state taps, not weighted.<sup>2</sup>Basicity = pct (CaO + MgO) ÷ pct (SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub>).<sup>3</sup>Pounds slag ÷ pounds iron, on overall basis.

TABLE 10. - Analyses<sup>1</sup> of scrubber and stack waters and solids under acid slag practice

(FC = fixed carbon; wt = weight - replacement : coke)

| Replacement<br>Fuel : Level : Basis                                                                                          | Sampling<br>location              | Waters <sup>2</sup> |       |                   | Solids,<br>g/l | Chemical analyses of solids, pct |      |      |                                |                |      |      |     |     |     |      |     |
|------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|---------------------|-------|-------------------|----------------|----------------------------------|------|------|--------------------------------|----------------|------|------|-----|-----|-----|------|-----|
|                                                                                                                              |                                   | pH                  | ppm F | NaOH <sup>3</sup> |                | Fe                               | CaO  | MgO  | Al <sub>2</sub> O <sub>3</sub> | C <sup>4</sup> | Mn   | Cu   | Pb  | Zn  | Sn  | F    |     |
| HIGH FIXED CARBON                                                                                                            |                                   |                     |       |                   |                |                                  |      |      |                                |                |      |      |     |     |     |      |     |
| None : 100 pct foundry coke.....                                                                                             | Scrubber <sup>5</sup>             | 3.7                 | 502   | 76.9              | 4.1            | 13.9                             | 6.2  | 0.7  | 2.7                            | 37.2           | 0.4  | 0.14 | 0.3 | 0.5 | 0.2 | 4.6  |     |
|                                                                                                                              | Stack <sup>6</sup> ...            | 4.5                 | 1,500 | ND                | 1.4            | 11.8                             | 3.8  | 3.2  | 5.1                            | 3.1            | 3.2  | .16  | 4.1 | 9.5 | .7  | 6.1  |     |
|                                                                                                                              | Anthracite coal : 20 pct : FC.... | Scrubber.           | 4.2   | 605               | 90.0           | 4.1                              | 11.0 | 11.3 | .5                             | 3.0            | 36.3 | .6   | .08 | .2  | .6  | .7   | 7.5 |
|                                                                                                                              |                                   | Stack....           | 5.1   | 568               | ND             | 1.8                              | 8.3  | 3.1  | 1.2                            | 4.7            | 2.0  | 3.4  | .09 | .3  | 7.0 | 3.9  | 3.7 |
|                                                                                                                              | : 40 pct : FC....                 | Scrubber.           | 3.7   | 398               | 70.0           | 5.6                              | 8.2  | 9.2  | .4                             | 2.5            | 33.0 | .2   | .05 | .3  | 1.2 | .1   | 6.2 |
|                                                                                                                              | Stack....                         | 3.8                 | 830   | ND                | 3.7            | 13.4                             | 2.4  | .9   | 6.1                            | 2.4            | 2.9  | .09  | 2.4 | 1.2 | .5  | 1.2  |     |
| MEDIUM FIXED CARBON                                                                                                          |                                   |                     |       |                   |                |                                  |      |      |                                |                |      |      |     |     |     |      |     |
| Charcoal briquets : 20 pct : FC..<br><br>Bituminous coal : 20 pct : 1:1 wt<br><br>: 20 pct : FC....<br><br>: 40 pct : FC.... | Scrubber.                         | 4.0                 | 488   | 75.0              | 9.1            | 10.7                             | 8.7  | 0.4  | 2.1                            | 48.5           | 0.2  | 0.04 | 0.6 | 0.9 | 0.2 | 6.7  |     |
|                                                                                                                              | Stack....                         | 4.6                 | 1,280 | ND                | 1.3            | 13.9                             | 2.3  | 1.4  | 3.3                            | 7.2            | 3.0  | .16  | 6.9 | 5.5 | .4  | 5.1  |     |
|                                                                                                                              | Scrubber.                         | 3.3                 | 520   | 80.5              | 3.7            | 14.8                             | 10.6 | 10.4 | 2.1                            | 36.0           | .2   | .09  | .7  | .7  | .2  | 8.1  |     |
|                                                                                                                              | Stack....                         | 4.5                 | 900   | ND                | 1.4            | 14.2                             | 3.1  | 1.0  | 4.8                            | 5.8            | 3.3  | .16  | .9  | 8.6 | .5  | 5.4  |     |
|                                                                                                                              | Scrubber.                         | 4.1                 | 390   | 82.5              | 3.6            | 13.9                             | 15.3 | .5   | 3.9                            | 28.1           | .5   | .07  | .6  | .2  | .2  | 12.4 |     |
|                                                                                                                              | Stack....                         | 4.2                 | 293   | ND                | 4.4            | 12.8                             | 3.2  | 1.2  | 6.7                            | 1.5            | 2.8  | .10  | 1.7 | .6  | .6  | 1.7  |     |
|                                                                                                                              | Scrubber.                         | 3.4                 | 528   | 78.0              | 3.6            | 6.6                              | 18.5 | .1   | 4.1                            | 33.8           | .2   | .05  | .1  | 1.1 | .2  | 11.9 |     |
|                                                                                                                              | Stack....                         | 4.0                 | 560   | ND                | 4.0            | 14.6                             | 4.1  | .5   | 5.9                            | 5.3            | 3.1  | .07  | 1.9 | 7.4 | 1.0 | 3.1  |     |
| LOW FIXED CARBON                                                                                                             |                                   |                     |       |                   |                |                                  |      |      |                                |                |      |      |     |     |     |      |     |
| Chopped tires : 20 pct : FC.....                                                                                             | Scrubber.                         | 4.3                 | 285   | 51.0              | 18.1           | 3.6                              | 5.3  | 0.6  | 2.0                            | 54.0           | 0.4  | 0.07 | 0.6 | 1.7 | 0.1 | 3.9  |     |
|                                                                                                                              | Stack....                         | 4.0                 | 513   | ND                | 5.2            | 9.5                              | 3.0  | 1.1  | 4.5                            | 20.0           | 2.6  | .12  | .4  | 8.2 | .6  | 2.3  |     |

ND Not determined.

<sup>1</sup>Representative of steady-state conditions.<sup>2</sup>Water flow through scrubber at 20-30 l/min, pH = 7.<sup>3</sup>Titration of pH 7 with ml 0.307 N NaOH per liter scrubber water.<sup>4</sup>Accuracy  $\pm$  5 pct relative.<sup>5</sup>Sampled at scrubber discharge.<sup>6</sup>Sampled at base of stack.

### Strengths of the Irons

The mechanical tests made on the castings poured for this purpose provided the information in tables 11 and 12 for basic and acid practice, respectively. All testing was done on irons in the as-cast condition. Adverse effects of using alternative fuels were not apparent. All of the irons were Class 30 or better. In two trials, under basic practice using pitch-bonded coal or petroleum coke at the 40 pct level of replacement, acceptable transverse bar castings could not be poured.

### CONCLUSIONS

Based on the information contained in this report, it is concluded that:

1. A pilot plant cupola can be used to generate comparative information on the effects of partially replacing foundry charge coke with alternative fuels.
2. Anthracite or bituminous coal can replace up to 40 pct of the charge coke in a pilot plant without adverse effects on performance or products.
3. Cement bonded coke breeze can replace about 10 pct of the charge coke. Although fuel decrepitation occurs, the effects at this level are insignificant.
4. Scrap rubber tires can replace up to 20 pct of the charge coke. Problems or conditions unique to the use of tires would require special consideration, however.
5. Charcoal briquets can replace up to 20 pct of the charge coke. Questions about availability and economics must be considered.
6. Pitch-bonded coal or uncalcined petroleum coke behave similarly at the 20 and 40 pct levels of replacement. At either level they are not satisfactory for melting gray iron. These levels can be used for replacement in the melting of white/malleable iron grades.
7. Wood blocks charged in addition to the normal charge coke were detrimental to cupola operation because of large sparks. They could provide useful effects in the melting process, however.
8. All of the formed fuels, waste products, or byproducts evaluated broke down in various ways so that their use at high levels of replacement is not advisable in cupola operation.
9. No adverse effects of using alternative fuels were found in the tensile or transverse strengths of the iron castings produced.

TABLE 11. - Tensile and transverse strengths of irons melted under basic slag practice

(FC = fixed carbon; wt = weight - replacement : coke; CNA = castings not acceptable)

| Replacement                                       | Tensile strength, <sup>1</sup><br>psi | Transverse strength <sup>1 2</sup> |                  | Iron,<br>pct, CE <sup>3</sup> |
|---------------------------------------------------|---------------------------------------|------------------------------------|------------------|-------------------------------|
| Fuel : Level : Basis                              |                                       | Pounds                             | Deflection, inch |                               |
| HIGH FIXED CARBON                                 |                                       |                                    |                  |                               |
| None : 100 pct foundry coke.....                  | 35,200                                | 3,500                              | 0.135            | 4.10                          |
| Petroleum coke <sup>4</sup> : 20 pct : FC.....    | 50,200                                | 4,510                              | .137             | 3.50                          |
| : 40 pct : FC.....                                | 47,700                                | CNA                                | ND               | 3.22                          |
| Pitch-bonded coal <sup>5</sup> : 20 pct : FC..... | 38,100                                | 4,780                              | .150             | 3.40                          |
| : 40 pct : FC.....                                | 41,300                                | CNA                                | ND               | 3.20                          |
| Anthracite coal : 40 pct : FC.....                | 34,100                                | 3,060                              | .165             | 4.44                          |
| MEDIUM FIXED CARBON                               |                                       |                                    |                  |                               |
| Cemented breeze <sup>6</sup> : 10 pct : FC.....   | 43,700                                | 4,040                              | 0.151            | 3.87                          |
| : 20 pct : FC.....                                | 39,100                                | 4,260                              | .123             | 3.73                          |
| : 40 pct : FC.....                                | 44,100                                | 4,390                              | .139             | 3.73                          |
| Charcoal briquets : 20 pct : FC.....              | 39,400                                | 4,420                              | .186             | 3.80                          |
| Bituminous coal : 40 pct : FC.....                | 30,600                                | 3,050                              | .160             | 4.20                          |
| LOW FIXED CARBON                                  |                                       |                                    |                  |                               |
| Chopped tires : 10 pct : 1:1 wt.....              | 35,700                                | 3,830                              | 0.138            | 4.16                          |
| : 20 pct : 1:1 wt.....                            | 37,100                                | 3,860                              | .143             | 3.91                          |
| : 20 pct : 5:4 wt.....                            | 36,300                                | 3,520                              | .151             | 3.74                          |
| : 20 pct : 3:2 wt.....                            | 37,200                                | 4,250                              | .147             | 3.90                          |
| : 20 pct : FC.....                                | 32,700                                | 3,340                              | .163             | 4.07                          |
| Wood blocks : 5 pounds added <sup>7</sup> .....   | 42,200                                | 4,610                              | .193             | 3.83                          |

ND Not determined.

<sup>1</sup>Average of 4 specimens from steady-state taps.<sup>2</sup>Bar of 1.2 inches diameter.<sup>3</sup>Pct carbon equivalent = pct total carbon +  $\frac{\text{pct (Si + P)}}{3}$ , P estimated where applicable.<sup>4</sup>Run-of-still.<sup>5</sup>About 2 pct pitch binder.<sup>6</sup>About 8 pct cement binder.<sup>7</sup>In addition to normal charge coke.

TABLE 12. - Tensile and transverse strengths of irons melted under acid practice

(FC = fixed carbon; wt = weight - replacement : coke)

| Replacement                            | Tensile strength, <sup>1</sup><br>psi | Transverse strength <sup>1 2</sup> |                  | Iron,<br>pct, CE <sup>3</sup> |
|----------------------------------------|---------------------------------------|------------------------------------|------------------|-------------------------------|
| Fuel : Level : Basis                   |                                       | Pounds                             | Deflection, inch |                               |
| HIGH FIXED CARBON                      |                                       |                                    |                  |                               |
| None : 100 pct foundry coke.....       | 36,900                                | 3,640                              | 0.169            | 3.82                          |
| Anthracite coal : 20 pct : FC.....     | 34,200                                | 3,490                              | .155             | 4.15                          |
| : 40 pct : FC.....                     | 31,600                                | 3,410                              | .181             | 4.12                          |
| MEDIUM FIXED CARBON                    |                                       |                                    |                  |                               |
| Charcoal briquets : 20 pct : FC.....   | 34,300                                | 4,090                              | 0.168            | 3.84                          |
| Bituminous coal : 20 pct : 1:1 wt..... | 44,100                                | 3,530                              | .173             | 3.96                          |
| : 20 pct : FC.....                     | 30,500                                | 3,380                              | .160             | 4.32                          |
| : 40 pct : FC.....                     | 40,100                                | 4,110                              | .171             | 3.98                          |
| LOW FIXED CARBON                       |                                       |                                    |                  |                               |
| Chopped tires : 20 pct : FC.....       | 41,100                                | 3,740                              | 0.140            | 3.99                          |

<sup>1</sup>Average of 4 specimens from steady-state taps.<sup>2</sup>Bar of 1.2 inches diameter.<sup>3</sup>Pct carbon equivalent = pct total carbon +  $\frac{\text{pct (Si + P)}}{3}$ , P estimated where applicable.

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