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Copper Converter: Basic Research Testing with a Plastic Model Converter and Four Types of Refractories

Arthur C. Bigley Jr.

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- COPPER CONVERTER -
BASIC RESEARCH TESTING
WITH
A PLASTIC MODEL CONVERTER
AND
FOUR TYPES OF REFRACTORIES

by

Arthur C. Bigley Jr.

A Thesis
Submitted to the Department of Metallurgy
in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Metallurgical Engineering

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
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INTRODUCTION

The converting of copper mattes to blister copper by the Bessemer-type process has been employed since the introduction of the Manhes converter in 1880. In 1905 the first basic-lined converter was operated at the Pittsburg and Montana Company's smelter in Butte, Montana. The patent for a basic-lining was obtained by Peirce and Smith in 1909. In 1913 Wheeler and Krejci patented the idea of coating a basic lining with magnetite (1).

Since these above achievements were introduced, there has not been any major change in basic converter practice. Both mechanical tuyere punchers and better flux feeders have been introduced but these innovations are merely servicing the same converter process that has been in use for over 40 years. It is rather surprising that a current standard reference for converting is, "Principles of Copper Smelting", by Peters and published in 1907 (2).

In recent years there has appeared an increasing number of papers on converting operations as related to thermodynamics. This approach is a powerful, potential tool. However, the development of new ideas and changes must rely on accurate basic information.

It is to approach the basic mechanism and reactions of converter operations that this paper is written.
PROBLEM

Converter operators throughout the world are converting copper matte to blister copper. However, an examination of the problems of converting shows an extreme variation in approach and procedure. There seems to be no correlation of basic principles.

The author believes that the most effective approach to better converter operation is by simplifying the various problems involved to their basic elements, namely:

1. Rate and manner of the introduction of air, or enriched air, into the converter.
2. Reaction mechanisms.
3. Lining life.
4. Magnetite content of slag.

The present converter has a basic-lining and apparently requires magnetite to properly maintain this lining. Yet magnetite is an undesirable material in subsequent smelting processes.

Converter efficiency could be improved by faster blowing rates, longer lining life, less magnetite production, faster reaction rates and in fact a whole host of faster and better combinations.

There are probably many basic relationships that determine converter efficiency but this paper will be limited to considering mainly those 4 basic elements noted above.
BASIC RESEARCH TESTING

The project of constructing and testing a model converter was initiated by Mr. Frank H. Day, General Superintendent, Anaconda Reduction Works, who reasoned that the operation of a plastic converter model would provide useful basic information concerning the mechanism of converter operation, especially the effect of air entering the converter from the tuyeres.

Mr. Harold Foard, Assistant Director of Metallurgical Research in charge of Pyrometallurgy, Anaconda Company, initiated the testing of various possible converter refractories.

The initial tests of the above areas of basic investigations have been completed. Results of these tests demonstrate the value of this manner of approach.
A plastic converter model was desired to simulate a standard 13' x 30' Peirce-Smith converter. Considerable calculations were made in attempting to derive a single dimensionless constant as a guide to the model design. However, there was not sufficient information available for an adequate similitude relationship. In order to initiate a reasonably useful model, a scaled down version of the actual converter was designed and the model was constructed with transparent plastic. The completed model measures 4 feet in diameter and has an overall length of 27 inches. Relative locations of the mouth and the tuyeres are identical to those in an actual converter. The model incorporates 2 separate sections, one embodying a single tuyere and the second having 3 tuyeres. Initially, the model was tested with \( \frac{1}{2} \) inch I. D. tuyeres. A detailed sketch of the model and photographs are shown in Figures I and II.

In order to determine the action of matte and slag in the model, water was used to simulate matte while several types of oil were used for slag (3). The oils became finely dispersed in the water during testing and obscured the actions of the model. When small cubes of wood were used the effect of tuyere action was well demonstrated as can be seen in Figures 3 thru 7.
To initiate a series of tests, a set of calculations and accompanying assumptions were made relating the model operation to that of an actual converter. The calculations and assumptions that were made are noted in Appendix A. Photographs of the 5 test series made are in Figures 3 - 7.

In addition to the above pictures, an edited 8 mm color movie film was prepared. This film is available to the various smelter personnel of the Anaconda Company to augment the information in this paper.
MODEL OBSERVATIONS

It should be restated here that water was used to simulate molten matte because of the similarity of their viscosities (3). Oil was originally used to simulate molten slag since the viscosity of castor oil is about the same as that of molten slag (3). However, the intense agitation in the tuyere zone dispersed the oil and obscured observations of the liquid motion in the model. Therefore, small cubes of wood were used to approximate the slag and these proved very useful in determining the circulation in the model. A water-filled plastic ball was used in the test series to show the circulation of the liquid 'matte'.

The liquid 'matte' circulated to some extent whenever air entered the liquid in the model although this circulation increased as the 'slag' cubes were more widely dispersed in the model.

Circulation of liquid 'matte' and 'slag' blocks varies according to conditions set up for each test. This circulation is the most significant result obtained from the tests made. The basic variables of converter operations such as liquid level, tuyere diameter, tuyere inclination, tuyere immersion and air volume all seem to have varying effects on the circulation in the model, as shown in the 5 test series conducted.
In the accompanying photographs the dispersion of the 'slag' cubes was in a counterclockwise pattern. With good circulation the 'slag' is forced down into the bath from the surface area farthest from the tuyere. These cubes then curve toward the tuyere, describing an arc in their return to the surface of the bath. Under optimum circulation the 'slag' describes a circular pattern of over three-fourths of the bath area, as viewed in the photographs.

Circulation appears to be caused by three effects. Primarily, the tuyere air flow causes some liquid to flow out across the surface of the bath away from the tuyere and this results in a circulation loop around the periphery of the bath. The second effect is similar to the action of an air-lift pump whereby the air rising to the surface of the bath displaces some liquid and causes circulation. This effect, however, is not as pronounced as the first one mentioned above. The third and lesser effect occurs when the model is positioned for a blow such as that of simulating the end of the copper blow. Here, the angle of incidence of the air stream with the bath surface results in some liquid being ejected from the bath. When this liquid falls back to the bath it causes some minor dispersion of the 'slag' cubes.
Variation of tuyere size, tuyere inclination, tuyere immersion and amount of liquid present, all modified the splattering effect of a tuyere.

Decreasing the tuyere diameter reduced the washing action of the liquid against the model walls above and below the tuyere zone.

A description of each of the 5 test series conducted is presented on the following pages.
SERIES V

Variation of Tuyere Angle (Table III)

In this series a half-inch tuyere was used in demonstrating the effect of 9 and $25\frac{1}{2}$ degree tuyere inclination, measured from the horizontal centerline. The $25\frac{1}{2}$ degree tuyere, tuyere B, simulates the Anaconda tuyere angle whereas the 9 degree tuyere, tuyere C, simulates a horizontal tuyere set slightly below the centerline. Circulation effects are a little better with tuyere B. The upward slope of tuyere C becomes a major factor as the liquid level is lowered. Model observations showed that a converter would receive excessive splashing of liquid on the front portion of the brick above the bath line.
SERIES W

Variation of Tuyere Size (Table IV)

Tuyere A is a 1 inch I. D. tuyere and tuyere B is a \( \frac{3}{4} \) inch I. D. tuyere. Both are delivering the same volume of air to the model. Circulation with tuyere B is much better than tuyere A because of the flow of liquid across the bath surface.

Very noticeable in this test run was the 'washing' effect on the 'lining' above and below the tuyere when using tuyere A. The liquid was not thrown out and away from the model wall, as in the case of tuyere B. The slopping of liquid out of the mouth was increased when using tuyere A. The liquid falling back on the zone of agitation periodically splashed out through the mouth. The air entering tuyere A appeared to surge due to the tendency of the liquid to fall back onto this zone of agitation. With tuyere B this was not noticed since the liquid was thrown out and away in a steady pattern.

When tuyere A was used the liquid falling back onto the zone of air entry washed down past the sides of the tuyere. With tuyere B the area of 'lining' below the tuyere was never washed this way although the increased liquid 'matte' circulation followed the contour of the model around to the tuyere zone.
SERIES X

Variation of Liquid Level (Table V)

Tuyere A was used with various levels of liquid. This series was the same as that with tuyere A in series W but is shown separately, to illustrate the effect of liquid level.

The main difference in this test can be seen in the photographs by comparing the dispersion of the 'slag' blocks for each stage. As the level is lowered, the tuyere attitude reduces the flow effect of the liquid across the bath. The lift effect of the air caused some minor circulation. Wave action can be seen by comparing the liquid level line to a projected horizontal line. The position A-5 corresponds to finishing a copper blow. Circulation at this level is extremely poor due not only to a lack of the above circulation effects but also to the long flat 'shape' of the liquid volume in the model. Circulation here would be extremely poor even if the tuyere attitude were changed.
SERIES Y

Variation of Air Volume (Table VI)

The photographs show that circulation is better with increasing air volume which promotes the flow of liquid across the surface of the bath.

This series was limited by the piping arrangement for the model as initially set up. Therefore, the photograph A-4 represents only 150% of the air volume used in the other test series. Additional tests should be conducted on this particular test series.
SERIES Z

Variation of Tuyere Immersion (Table VII)

In this series the circulation of the 'slag' blocks started to increase with increasing immersion but circulation was disrupted by extreme wave action. Model relationships to a standard converter are not clearly set down by a dimensionless constant so that the author is not sure this wave action demonstrates exactly actual converter conditions. However, the test indicates that at some point of immersion the converter would display similar wave action.
MODEL - CONCLUSIONS

The mechanism of circulation is a factor that must be taken into consideration in converter operational practice. Aside from the question of air efficiency and of optimum air flow, the effect of the entering air on the circulation has been neglected as a point of consideration. This circulation can explain the changing erosion and wear pattern of a converter. Consideration of this circulation may alter some of the basic assumptions previously made in explaining the thermodynamics of copper smelting since the tests show that 'slag' is drawn well down into a circulating liquid matte. Another interesting possibility is presented if one assumes that circulation promotes smoother tuyere action and less tuyere accretion. When blowing copper, for example, the author has seen cases where a longitudinal ridge just below the tuyere line has created extremely difficult if not impossible converter operation due to these tuyere accretions. With good circulation a fresh supply of unreacted liquid is continuously arriving at the tuyere zone whereas without good circulation the tuyere action simply works on the already oxidized molten liquid falling back into the bath. Circulation may also supply unreacted silica flux to this zone of oxidation. Reaction rates would then be dependent on the various conditions of circulation. All these factors demonstrate the possible importance of circulation in a converter.
A second feature of importance is the washing effect on the tuyere lining when using large sized tuyeres as demonstrated in Series W. This washing effect is reduced when the liquid 'matte' is thrown out away from the tuyere zone.

The model tests also show that a large tuyere caused more slopping, out of the mouth, than a smaller tuyere. Although the present test series does not specify the related actual tuyere size in a converter it does indicate that larger tuyeres may cause more slopping and result in excessive floor cleanup.
REFRACTORY TESTS

Two series of melting tests were conducted using various combinations of converter slags and matte contained in different types of refractories. The tests were made in a gas-fired muffle furnace.

Mixtures of converter slag with varying amounts of lime and flux ore were smelted in containers made of silica, chrome-magnesite, alumina and chemically-bonded magnesite. Charge materials were all 100% minus 1/4 mesh. Evaluation of the reactions during the tests, was made by visual observation of the contents of the refractory container and of the refractory 'cup' itself. The corrosion and penetration by the slag were especially noted and a small magnet was used to estimate the amount of magnetite present.

Temperature control of the muffle was by manual adjustment according to temperature indicated by a thermocouple. The muffle 'atmosphere' was controlled by gas and air adjustments on the burner. These adjustments were made to maintain an 'atmosphere' as close to neutral as was possible.

Series A

In this series, tests were made with silica scorification dishes and silica crucibles. Assays of the charge components are listed in Table VI. Data and observations are shown in Table VII.
In the initial tests the matte and slag were intimately mixed but the resultant melts indicated excessive oxidation of the exposed matte. The remaining tests were then made with the slag covering the matte.

**Series B**

These tests were conducted with containers of silica, chrome-magnesite, alumina and chemically-bonded magnesite. The silica containers were scorification dishes as used in Series A. The containers of the other three types were made by hollowing out a 'cup' in the center of a standard brick. The charge consisted of 200 grams of matte covered by 250 grams of slag. Assays of the charge components are listed in Table VI. Data and observations are shown in Table VIII.

Several chrome-magnesite 'cups' without charge were tested simultaneously with those containing a charge. This test variation was made after all the initial chrome-magnesite 'cups' containing charge cracked upon cooling.
REFRACTORY TESTS - CONCLUSIONS

Series A

All slags melted in silica scorification dishes produced some magnetite. The slags melted in silica crucibles showed no detectable magnetite content. This indicates the ability of an oxidizing atmosphere over a molten slag and matte to effect chemical reactions.

There was no magnetite in that slag in intimate contact with the silica container. This demonstrates the ability of silica to reduce or control the magnetite content of a slag.

If a silica refractory were to be used in a converter lining, the minimum silica content of the slag must be about 42% and the oxidation reaction would necessarily have to occur where adequate flux ore was present to maintain this 42%. Slags containing 42% silica would be quite viscous for converter operations. The fluidity of these slags could possibly be enhanced by using higher temperatures or various fluxes. These slags would require additional investigations.

Series B

The apparent deterioration of a chrome-magnesite brick by converter slag is an extremely important consideration. Nearly all smelters use a protective coating made of magnetite slag to prolong converter refractory life. Converter refractory bricks commonly spall in normal operation and a protective coating of magnetite slag is used to hold
these spalled bricks in place. If a converter brick could be operated successfully without a coating, magnetite would then become unnecessary and a problem of the past.

Test results indicate that converter slag contributes to an adverse alteration of the chrome-magnesite structure. The converter slags tested apparently created a different lattice structure than that of the original brick. This lattice alteration resulted in sufficient strain to fracture the brick since the bricks with charge cracked while a brick without charge did not crack. Additional tests should be conducted to corroborate the above results.

With the alumina bricks tested, the slags effected complete penetration. This penetration did not appear to corrode or adversely affect the 'cup'. Further tests should be made using alumina bricks saturated with slag. The expansion of these bricks due to the absorption of slag should also be checked.

The chemically - bonded magnesite 'cup' showed little penetration by slags tested. There was no detectable corrosion of this brick in the tests made. The only possible bad feature of these chemically - bonded bricks is in the 'softness' at the melting temperatures used. When using tongs to remove this type of brick from the furnace the sides of the brick were sloughed off when pressure was applied on the tongs.
However, this softness might not be of consequence in a converter lining since the face of the test bricks, where exposed to slag or matte, was quite hard.
SUMMARY

Tests conducted with the plastic model converter showed the following results:

1. Circulation within the liquid bath is an important consideration in converter operation.

2. Circulation is promoted by three mechanisms.
   a) Air entering the converter can induce a flow of liquid across the bath, away from the tuyere.
   b) Air rising through the liquid displaces some liquid upwards.
   c) Liquid ejected above the bath by the tuyere air causes minor circulation upon falling back onto the bath.

3. Circulation varies according to tuyere inclination, tuyere size, liquid volume, air flow rate and tuyere immersion.

4. An intense washing of liquid over the tuyere lining area is reduced by decreasing the tuyere diameter.

5. Splashing of liquid out of the converter mouth is reduced by decreasing the tuyere diameter.

6. Circulation will influence the basic assumptions in thermodynamic calculations for copper converting.

Melting tests with various refractory containers showed the following results:

1. Slag adversely affects chrome-magnesite brick causing fracture.
2. Silica could not be used in a converter lining where the slag contained less than 42% silica.

3. The atmosphere over molten slag and matte strongly influences chemical reactions.

4. Alumina bricks may be useful in converter linings.

5. Chemically-bonded magnesite bricks are superior to chrome-magnesite when exposed to molten slags and matte.
Additional test work with the model converter should be done. Variation of the liquid 'matte' density remains to be correlated as well as many other possible features of converter operation. The relation of the model to an actual converter remains ambiguous until a dimensionless constant can be derived.

In refractory testing the possibility of converter slag adversely affecting chrome-magnesite brick should be pursued further. Alumina bricks may possibly afford some answers to refractory problems.
ACKNOWLEDGEMENTS

The material presented in this paper was prepared with the cooperation and helpful advice of Mr. F. L. Holderreed, Director of Research, Anaconda Company, and Mr. C. Arentzen, Assisting Research Engineer, Anaconda Company.

The assistance and cooperation of the various staff members of the Montana School of Mines, especially Professor Ralph I. Smith, are greatly appreciated.
TABLE I. (Series V)

Variation of Tuyere Inclination

<table>
<thead>
<tr>
<th>Volume, air</th>
<th>46.7 CFM at STP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure, header</td>
<td>10 psig</td>
</tr>
<tr>
<td>Liquid, model</td>
<td>Water</td>
</tr>
<tr>
<td>Slag, model</td>
<td>1/2&quot; wood cubes</td>
</tr>
<tr>
<td>Immersion, tuyere</td>
<td>6 inches</td>
</tr>
</tbody>
</table>

**Tuyeres Used**

| Type B | 1/4" I. D. with 25° Inclination |
| Type C | 1/4" I. D. with 9° Inclination |

**Liquid Volumes Used**

<table>
<thead>
<tr>
<th></th>
<th>Model 1/2 full</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stage I (see Appendix A)</td>
</tr>
<tr>
<td>2</td>
<td>Stage II</td>
</tr>
<tr>
<td>3</td>
<td>Stage III</td>
</tr>
<tr>
<td>4</td>
<td>Stage IV</td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

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### TABLE II (Series W)

**Variation of Tuyere Diameter**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume, air</td>
<td>46.7 CFM at STP</td>
</tr>
<tr>
<td>Pressure, header</td>
<td>10 psig</td>
</tr>
<tr>
<td>Liquid, model</td>
<td>Water</td>
</tr>
<tr>
<td>Slag, model</td>
<td>( \frac{1}{2} )&quot; wood cubes</td>
</tr>
<tr>
<td>Immersion, tuyere</td>
<td>6 inches</td>
</tr>
</tbody>
</table>

#### Tuyeres Used

- **Type A** - 1" I.D. tuyere having \( 25\frac{1}{2}^\circ \) Inclination
- **Type B** - \( \frac{1}{2} \)" I.D. tuyere having \( 25\frac{1}{2}^\circ \) Inclination

#### Liquid Volumes Used

1. Model \( \frac{1}{2} \) full
2. Stage I (see Appendix A)
3. Stage II
4. Stage III
5. Stage IV
### TABLE III (Series X)

**Variation of Liquid Volume**

<table>
<thead>
<tr>
<th>Volume, air</th>
<th>46.7 CFM at STP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure, header</td>
<td>10 psig</td>
</tr>
<tr>
<td>Liquid, model</td>
<td>Water</td>
</tr>
<tr>
<td>Slag, model</td>
<td>½&quot; wood cubes</td>
</tr>
<tr>
<td>Immersion, tuyere</td>
<td>6 inches</td>
</tr>
</tbody>
</table>

**Tuveres Used**

Type A - 1" I.D. tuyere having 25½° Inclination

**Liquid Volumes Used**

1 - Model ½ full
2 - Stage I (see Appendix A)
3 - Stage II
4 - Stage III
5 - Stage IV
**TABLE IV (Series Y)**

**Variation of Air Volume**

<table>
<thead>
<tr>
<th>Volume, liquid</th>
<th>Stage I (App. A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid, model</td>
<td>Water</td>
</tr>
<tr>
<td>Slag, model</td>
<td>½&quot; wood cubes</td>
</tr>
<tr>
<td>Immersion, tuyere</td>
<td>6 inches</td>
</tr>
<tr>
<td>Pressure, header</td>
<td>varied</td>
</tr>
</tbody>
</table>

**Tuyere Used**

Type 1" L.D. tuyere having 25½° Inclination

**Air Volumes Used**

1. 50% (of 46.7 CFM at STP)
2. 75%
3. 100%
4. 150%
TABLE V (Series Z)

Variation of Tuyere Immersion

<table>
<thead>
<tr>
<th>Volume, air</th>
<th>46.7 CFM at STP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume, liquid</td>
<td>Stage I (App. A)</td>
</tr>
<tr>
<td>Pressure, header</td>
<td>10 psig</td>
</tr>
<tr>
<td>Liquid, model</td>
<td>Water</td>
</tr>
<tr>
<td>Slag, model</td>
<td>½&quot; wood cubes</td>
</tr>
</tbody>
</table>

**Tuyere Used**

Type A - 1" I. D. tuyere having 25½° Immersion

**Tuyere Immersions**

1 - 2"
2 - 4"
3 - 6"
4 - 8"
5 - 10"
### TABLE VI

Materials Used in Preparing Charges

<table>
<thead>
<tr>
<th>Series A</th>
<th>Converter Slag</th>
<th>Flux Ore</th>
<th>Burned Lime</th>
<th>Reverb Matte</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Fe</td>
<td>48.9</td>
<td>3.4</td>
<td>----</td>
<td>11.6</td>
</tr>
<tr>
<td>% Fe$_3$O$_4$</td>
<td>22.0</td>
<td>----</td>
<td>----</td>
<td>3.5</td>
</tr>
<tr>
<td>% SiO$_2$</td>
<td>27.5</td>
<td>71.0</td>
<td>----</td>
<td>1.2</td>
</tr>
<tr>
<td>% CaO</td>
<td>1.0</td>
<td>1.3</td>
<td>80.0</td>
<td>----</td>
</tr>
<tr>
<td>% Al$_2$O$_3$</td>
<td>0.5</td>
<td>7.0</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>% Cu</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>63.6</td>
</tr>
<tr>
<td>% S</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>20.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Series B</th>
<th>Converter Slag</th>
<th>Flux Ore</th>
<th>Burned Lime</th>
<th>Reverb Matte</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Fe</td>
<td>48.8</td>
<td>3.4</td>
<td>----</td>
<td>11.6</td>
</tr>
<tr>
<td>% Fe$_3$O$_4$</td>
<td>32.8</td>
<td>----</td>
<td>----</td>
<td>3.5</td>
</tr>
<tr>
<td>% SiO$_2$</td>
<td>24.0</td>
<td>71.0</td>
<td>----</td>
<td>1.2</td>
</tr>
<tr>
<td>% CaO</td>
<td>0.4</td>
<td>1.3</td>
<td>80.0</td>
<td>----</td>
</tr>
<tr>
<td>% Al$_2$O$_3$</td>
<td>1.1</td>
<td>7.0</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>% Cu</td>
<td>2.5</td>
<td>----</td>
<td>----</td>
<td>63.6</td>
</tr>
<tr>
<td>% S</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>20.5</td>
</tr>
<tr>
<td>Slag Mix</td>
<td>Matte</td>
<td>Temperature Range in Matte</td>
<td>Corrosion Effect on Matte (°C)</td>
<td>Slag Mix over Matte</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>-----------------------------</td>
<td>-------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>1 93.75 0 6.25 Yes 25.78 5.93 2 2300 Yes - No - - Yes -</td>
<td>2 84.60 9.15 6.25 Yes 29.76 5.97 2 2300 Yes - No - - Yes -</td>
<td>3 72.90 20.85 6.25 Yes 34.85 6.00 2 2300 Yes - No - - Yes -</td>
<td>4 61.00 32.75 6.25 Yes 40.03 6.04 2 2300 Yes - No - - Yes -</td>
<td>5 100.00 0 0 No 27.5 1.00 2 2350 Yes - No - - Yes -</td>
</tr>
</tbody>
</table>

**TABLE VII**

<table>
<thead>
<tr>
<th>Series A</th>
<th>Corrosion Noted</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole in dish</td>
<td>Severe corrosion, some matte oxidized to FeO or FeO&lt;sub&gt;2&lt;/sub&gt;. Slag very magnetic (10)</td>
<td></td>
</tr>
<tr>
<td>Hole in dish</td>
<td>Severe corrosion, some matte to Fe oxide. Slag magnetic (6)</td>
<td></td>
</tr>
<tr>
<td>Some Attack</td>
<td>Some corrosion. Localized penetration areas. Slag magnetic (6-7)</td>
<td></td>
</tr>
<tr>
<td>Some Attack</td>
<td>Shows corrosion and penetration at points into dish. Slag magnetic (6-7)</td>
<td></td>
</tr>
<tr>
<td>Shows</td>
<td>Slag fused in dish but corrosion quite evident.</td>
<td></td>
</tr>
<tr>
<td>Corrosion</td>
<td>Magnetic Slag (6-7)</td>
<td></td>
</tr>
<tr>
<td>Little</td>
<td>Matte oxidized to FeO or FeO&lt;sub&gt;2&lt;/sub&gt;. Slag attacked dish. Slag magnetic (6-7)</td>
<td></td>
</tr>
<tr>
<td>Rinch</td>
<td>Dish was quite thoroughly penetrated by slag.</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks**

- Very Little Corrosion: Not too badly pitted, but some nothching. Slag Magnetic (6-5)
- Some Little Corrosion: Minor pitting of dish at places. Slag Magnetic (6-4)
- Very Little Corrosion: Very little pitting of dish. Slag in Magnetic (6-4)
- Some Corrosion: Dish showed slag penetration and cooled slag - Dish hard Interlocked. Slag Magnetic (6-5)
- Some Corrosion: Some slag penetration. Slag Magnetic (5-6)
- Very Minor Corrosion: Some minor penetration of slags into dish. Slag Magnetic (2-3)
- Very Little Corrosion: Some penetration of slags into dish. Slag Magnetic (2)
- Hole in dish | Severe penetration throughout. |
- Small Corrosion: Some pitting or penetration into dish. Slag Magnetic (3)
- Some Corrosion: Some penetration of orphicle, non-magnetic slags. |
- Very Little | Little if any penetration. Some matte oxidized. |
- Corrosion | Non-Magnetic Slags. |
- Hole in Crucible | Severe pitting. No Magnetic pull from slags. |
<table>
<thead>
<tr>
<th>Sample No</th>
<th>% Conduit Clad</th>
<th>% Alumina Clay</th>
<th>% Chamotte Clay</th>
<th>Matte Mixed 1 to 1 with undissolved Alkali</th>
<th>SiO₂ to Steel</th>
<th>Temperature Range in Steel F (°C)</th>
<th>Black Matter in Matte</th>
<th>Black Matter over Matte</th>
<th>Black Matter over Matte only</th>
<th>Black Matter over Matte only</th>
<th>Black Matter only</th>
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<th>Remarks</th>
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<tbody>
<tr>
<td>20</td>
<td>4.60</td>
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<td>6.25</td>
<td>No</td>
<td>29.76</td>
<td>6.97</td>
<td>24</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Hole in Crucible</td>
<td>Severe penetration, Non-Magnetic slag.</td>
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<tr>
<td>21</td>
<td>72.90</td>
<td>20.85</td>
<td>6.25</td>
<td>No</td>
<td>34.85</td>
<td>6.00</td>
<td>24</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>-</td>
<td>None</td>
<td>Practically no penetration, Non-Magnetic slag.</td>
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<tr>
<td>22</td>
<td>61.00</td>
<td>32.75</td>
<td>6.25</td>
<td>No</td>
<td>40.03</td>
<td>6.04</td>
<td>24</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>-</td>
<td>Little Corrosion</td>
<td>Minor penetration of crucible, Non-Magnetic slag.</td>
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<tr>
<td>23</td>
<td>63.18</td>
<td>31.87</td>
<td>4.95</td>
<td>No</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Very minor penetration of crucible, Non-Magnetic slag.</td>
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<td>24</td>
<td>63.18</td>
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<td>4.95</td>
<td>No</td>
<td>40.0</td>
<td>5.0</td>
<td>24</td>
<td>Yes</td>
<td>No</td>
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<td>36.45</td>
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<td>5.0</td>
<td>24</td>
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<td>Yes</td>
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<td>4.91</td>
<td>No</td>
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<td>5.0</td>
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<td>No penetration of crucible - Non-Magnetic Slag.</td>
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<td>4.91</td>
<td>No</td>
<td>44.0</td>
<td>5.0</td>
<td>24</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<td>14</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-</td>
<td>None</td>
<td>Penetration of some points in crucible, Non-Magnetic slag.</td>
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<td>67.75</td>
<td>27.28</td>
<td>4.97</td>
<td>No</td>
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<td>14</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Thru the Crucible</td>
<td>Severe penetration, Non-Magnetic slag. 180.5g matte button.</td>
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<td>Theoretical % CaO</td>
<td>Slag in Matte</td>
<td>Temperature of Slag in Matte (°C)</td>
<td>Spontaneous Dickite Use</td>
<td>Occur Use</td>
<td>Slag Matte Mix</td>
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<td>5</td>
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<td>No</td>
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<td>5</td>
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<td>No</td>
<td>42.0</td>
<td>5.0</td>
<td>5</td>
<td>2400</td>
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<td>Run No.</td>
<td>Type Refractory</td>
<td>% Aluminum Oxide</td>
<td>% OF in burden mix</td>
<td>Theoretical % SiO2 in slag</td>
<td>Theoretical % CaO in slag</td>
<td>Hours in matte</td>
<td>Temperature of matte</td>
<td>20s % matte and 20s % slag</td>
<td>Slag mix</td>
<td>Observations</td>
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<td>1</td>
<td>SiO2</td>
<td>94.92</td>
<td>0</td>
<td>5.08</td>
<td>22.78</td>
<td>4.44</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Dish burned thru near matte-slag interface. Magnetic slag over matte, non-magnetic slag near dish.</td>
<td></td>
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<td>2</td>
<td>Kronag</td>
<td>94.92</td>
<td>0</td>
<td>5.08</td>
<td>22.78</td>
<td>4.44</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Brick cracked and all liquid entered cracks. Magnetic slag in crust remaining in “cup” and very little in slag penetrating brick. Much slag penetration into brick before cracked.</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>MgO</td>
<td>94.92</td>
<td>0</td>
<td>5.08</td>
<td>22.78</td>
<td>4.44</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Some penetration where heat cracks but not normal penetration of slag into brick. No magnetic slag near brick, some magnetic in crust.</td>
<td></td>
<td></td>
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<td>Al2O3</td>
<td>94.92</td>
<td>0</td>
<td>5.08</td>
<td>22.78</td>
<td>4.44</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Practically all slag soaked up by brick but not matte. Brick not cracked. No magnetic slag absorbed by brick but some in “crust” over matte.</td>
<td></td>
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<td>SiO2</td>
<td>86.05</td>
<td>8.9</td>
<td>5.05</td>
<td>26.96</td>
<td>4.48</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Dish burned thru at slag-matte interface. Similar to Run # 3.</td>
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<td>86.05</td>
<td>8.9</td>
<td>5.05</td>
<td>26.96</td>
<td>4.48</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Brick cracked. Quite a bit of slag penetration into brick. Slag magnetic at face of “cup” but not near penetrated into brick.</td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>MgO</td>
<td>86.05</td>
<td>8.9</td>
<td>5.05</td>
<td>26.96</td>
<td>4.48</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Brick not cracked. Some little penetration by slag but not by matte. Slag was magnetic over matte and little magnetic roll at brick-slag face.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>Al2O3</td>
<td>86.05</td>
<td>8.9</td>
<td>5.05</td>
<td>26.96</td>
<td>4.48</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Brick OK. Slag penetrated deep into brick under slag-brick interface but no penetration under matte. Matte oxidized to rash after slag absorbed by brick.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>9</td>
<td>SiO2</td>
<td>74.61</td>
<td>20.39</td>
<td>5.0</td>
<td>32.32</td>
<td>4.56</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Some reaction of slag and dish. Slag very glassy. Magnetic content of slag quite low. Matte-slag interface very close and compact.</td>
<td></td>
<td></td>
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<tr>
<td>10</td>
<td>Kronag</td>
<td>74.61</td>
<td>20.39</td>
<td>5.0</td>
<td>32.32</td>
<td>4.56</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Brick cracked. Grain structure of brick appears altered where penetrated by slag. No slag or matte left in cone. Penetration under slag layer.</td>
<td></td>
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<tr>
<td>11</td>
<td>MgO</td>
<td>74.61</td>
<td>20.39</td>
<td>5.0</td>
<td>32.32</td>
<td>4.56</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Brick OK. Some slag penetration into brick but no matte penetration. Some magnetic slag in crust but none in slag where absorbed by brick.</td>
<td></td>
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<td>12</td>
<td>Al2O3</td>
<td>74.61</td>
<td>20.39</td>
<td>5.0</td>
<td>32.32</td>
<td>4.56</td>
<td>2 hrs.</td>
<td>2300</td>
<td>Yes</td>
<td>Brick OK. Very deep penetration under slag-brick interface. None under matte-brick interface. Matte oxidized to rash when slagorporated by brick.</td>
<td></td>
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<tr>
<td>13</td>
<td>SiO2</td>
<td>67.75</td>
<td>27.28</td>
<td>4.97</td>
<td>35.63</td>
<td>4.60</td>
<td>2 hrs.</td>
<td>2350</td>
<td>Yes</td>
<td>Some reaction with dish. Slag formed into cap over matte. Shows gas evolution from matte-slag interface. Slag magnetic in “cup”. Some 0 at edges of “cup”.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>14</td>
<td>Kronag</td>
<td>67.75</td>
<td>27.28</td>
<td>4.97</td>
<td>35.63</td>
<td>4.60</td>
<td>2 hrs.</td>
<td>2350</td>
<td>Yes</td>
<td>Brick cracked. No liquid left in “cup”. Some magnetite where slag absorbed by brick. Brick grains appear altered.</td>
<td></td>
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<td>15</td>
<td>MgO</td>
<td>67.75</td>
<td>27.28</td>
<td>4.97</td>
<td>35.63</td>
<td>4.60</td>
<td>k hrs.</td>
<td>2350</td>
<td>Yes</td>
<td>Brick 0. Some minor penetration of slag into brick. Magnetic slag in cap over matte. Gas evolution from matte to push up slag cap over this area. On top edges of cap.</td>
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<td></td>
<td></td>
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<tr>
<td>Sample</td>
<td>Type Refractory Used</td>
<td>C.S CONTENT: SiO2</td>
<td>Al2O3 Con</td>
<td>% Alumina Loss</td>
<td>% SiO2 in Brick Change</td>
<td>% CaO in Slag Change</td>
<td>Temp in Degrees</td>
<td>Martin Top</td>
<td>200g Matte and 250g Slag Mix</td>
<td>Remarks</td>
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<td>4.97</td>
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<td>2 hrs.</td>
<td>2350</td>
<td>Yes</td>
<td>Brick OK. Some mushy slag remained in cup. Much penetration of slag into brick but not matte. Magnetic slag in crumb.</td>
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<td>63.18</td>
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<td>4.95</td>
<td>37.79</td>
<td>4.62</td>
<td>2 hrs.</td>
<td>2350</td>
<td>Yes</td>
<td>Dish not badly attacked by slag. Gas evolution from matte area to form slag cap. Some slagotty on underside of slag cap. Some Cu at edges of slag cap.</td>
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<td>63.18</td>
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<td>4.95</td>
<td>37.79</td>
<td>4.62</td>
<td>2 hrs.</td>
<td>2350</td>
<td>Yes</td>
<td>Brick cracked. Much penetration of liquid into brick. Some magnetic content in slag crust and within brick.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>MgO</td>
<td>63.18</td>
<td>31.87</td>
<td>4.95</td>
<td>37.79</td>
<td>4.62</td>
<td>2 hrs.</td>
<td>2350</td>
<td>Yes</td>
<td>Brick showed minor cracking. Cracks appeared to be from thermal shock and not slag. Effect since there was only minor slag penetration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Al2O3</td>
<td>63.18</td>
<td>31.87</td>
<td>4.95</td>
<td>37.79</td>
<td>4.62</td>
<td>2 hrs.</td>
<td>2350</td>
<td>Yes (1)</td>
<td>Brick broke apart when pulled from furnace. Slag penetration throughout brick but not matte. No magnetic slag found. Heating cycle probably too fast.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>SiO2</td>
<td>58.62</td>
<td>36.45</td>
<td>4.93</td>
<td>39.95</td>
<td>4.64</td>
<td>2 hrs.</td>
<td>2350</td>
<td>Yes (1)</td>
<td>Dish good. Large cap over matte where gas evolved. Copper button where matte should be. Slag cap magnetic. Slag over Cu button extremely brown to copper color.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Kromag</td>
<td>58.62</td>
<td>36.45</td>
<td>4.93</td>
<td>39.95</td>
<td>4.64</td>
<td>2 hrs.</td>
<td>2350</td>
<td>Yes (1)</td>
<td>Brick cracked. Slag charge heavy. Much slag penetration. Some Cu where matte button is. Some yellow 'sulfur' color on underside of slag cap. Some magnetic slag.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>MgO</td>
<td>58.62</td>
<td>36.45</td>
<td>4.93</td>
<td>39.95</td>
<td>4.64</td>
<td>2 hrs.</td>
<td>2350</td>
<td>Yes (1)</td>
<td>Very little slag penetration. Matte appears to be regal. Gas evolution due to shaped slag cap. Slag cap magnetic. Some cracks in brick where no slag penetration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Al2O3</td>
<td>58.62</td>
<td>36.45</td>
<td>4.93</td>
<td>39.95</td>
<td>4.64</td>
<td>2 hrs.</td>
<td>2350</td>
<td>Yes (1)</td>
<td>Charge quite heavy. Left some silicious ore as sinter. Slag penetration into brick but no matte. Shows slag cap and silica tenacious islands of slag on regal metal.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Kromag</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>26.0</td>
<td>0.4</td>
<td>2 x 2</td>
<td>2350</td>
<td>No</td>
<td>Brick did not crack after first run but after second run the brick cracked. Showed penetration about 3/4 to 5/8&quot; concentric ring below cup. Crack showed at edge of this penetration line, and uneaten brick. Examination shows possible alteration of brick in this zone.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Kromag</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 x 2</td>
<td>2350</td>
<td></td>
<td>This brick was not filled with any charge and received actually 3 heatings and coolings. Brick did not crack.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Footnotes:

(1) Required 2 runs since muffle secondary air port on first run was too small. Another run was made on the partially fused charges.
APPENDIX A

Calculations for Model Tests

February, 1960 converter operating data from the Anaconda Reduction Works is used as a basis for calculations.

PLANT OPERATIONS

1. Charge 4 ladles of matte (Stage I)
2. Skim slag and charge 2 ladles of matte (Stage II)
3. Skim slag and blow white metal (Stage III)
4. Finish copper blow (Stage IV)

Matte was 55% Cu, volumes of flux and floor cleanings are neglected.

Copper loss via slag is neglected.

Specific Gravity Matte - 4.6
Specific Gravity White Metal - 5.2
Specific Gravity Copper - 7.78

Calculated Volumes

Stage I

4 ladles matte @ 20 T/l - 558 cu. ft.

Stage II

6 ladles matte @ 20 T/l - 619 cu. ft.

Stage III

White metal from 6 ladles matte - 510 cu. ft.
Stage IV

Copper from 6 ladles matte - 272 cu. ft.

Cross section area of P. S. 13 ft. x 30 ft.

Converter with all 18 inch brick - 78.4 sq. ft.

48 tuyeres are at 6 inch centers and typical tuyere section volume - 39.2 cu. ft.

Inside length converter - 25.3 ft.

Total converter volume - 1983.5 cu. ft.

The ratio of typical tuyere section volume per total volume - 1.976 %

Stage I

558 cu. ft. at 1.976 % is 11.03 cu. ft. and bath depth is 3 ft. 4 in.

Stage II

619 cu. ft. at 1.976 % is 12.2 cu. ft. and bath depth is 3 ft. 6 in.

Stage III

510 cu. ft. at 1.976 % is 10.08 cu. ft. and bath depth is 3 ft. 3 in.

Stage IV

272 cu. ft. at 1.976 % is 5.37 cu. ft. and bath depth is 1 ft. 11 in.

Average air rate was 18,000 CFM. This provides 290 CFM at S.T.P. per tuyere.
Model and converter were compared on an area to area ratio of 6.3 sq. ft. to 39.2 sq. ft. or 16.1%. Model tuyere zone width was assumed as 6 inch and air rates were based on the ratio of air volume to liquid volume in an effective tuyere zone. Therefore, average model air flow was 46.7 CFM at S.T.P. per tuyere.

Average converter air velocities through the tuyere are 173.5 ft/sec assuming 1-7/8 in. opening for 2 inch tuyere with air pressure at tuyere at 12.3 psig and temperature of air at 100°F.

Assuming a tuyere immersion of 12 inches the air velocity through the tuyere would be about 190 ft/sec.

Air velocity in the ½ inch tuyere of the model at 6 inch immersion is about 430 ft/sec. For the 1 inch tuyere air velocity would be 105 ft/sec.

Only these 2 tuyere sizes were used because of time limitations.

Model volumes were based on 16.1% ratio of model vs converter cross sectional area and tuyere immersion for standard test runs was 6 inches. Related model volumes are listed for single tuyere section only:

Stage I
1103 cu. ft. at 16.1% is 1.78 cu. ft. and bath depth is 1 ft. 3-5/8 in.
Stage II
12.2 cu. ft. at 16.1% is 1.97 cu. ft. and bath depth is 1 ft. 4-3/4 in.
Stage III

10.08 cu. ft. at 16.1 % is 1.62 cu. ft. and bath depth is 1 ft. 2-5/8 in.

Stage IV

5.37 cu. ft. at 16.1 % is 0.87 cu. ft. and bath depth is 0 ft. 9-2/5 in.

There are undoubtedly a great number of ratios and relationships that should be included in these calculations. However, for the present test series the common denominator was the necessity to start some place. After the results of these tests are correlated and examined then additional series can be scheduled to optimum advantage. Future tests should attempt to derive a dimensionless constant that will relate the model tests to definite converter conditions.

The three-tuyere section of the model was not used for this series but later tests should make use of this portion when further model studies are made.
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