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A THERMOCHEMICAL MODEL FOR COMPUTER PREDICTION OF CUPOLA PERFORMANCE

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ABSTRACT

Thermochemical equations for the mass and energy balances on a cupola melting furnace have been derived and programmed for the digital computer. The computer model can be used to predict changes in melting rate and coke requirement which would accompany changes in operating conditions and charge analyses. The program is also useful in evaluating the consistency of operating data. Calculations have been carried out to predict the influence of changes in various operating variables on coke consumption and melting rate, including oxygen and natural gas injection in the blast.

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INTRODUCTION

The wide use of the cupola melting furnace has placed it as the number one melting unit of the iron foundry industry. It is an extremely flexible unit in both obtainable product analysis and the ability to operate intermittently or on a continuous basis.

The development of the cupola has received considerable attention in the last decade and several advances have been made, most notably the introduction of hot blast, water cooling the shell, and additional instrumentation. Several other developments appear to be nearing commercial adoption including oxygen and fuel injection in the blast.

The difficulty in obtaining high quality metallurgical coke, the increasing availability of steel scrap at lower costs, the continual demand for maximum production from existing equipment, and increasing requirements for closer metallurgical control have all been factors in the industry move toward development of process improvements and better control. An ever present problem is how to best operate a given cupola with the materials and equipment at hand. The wide variety of scrap materials which are available and the additional variety in metallurgical coke and combustible injectants for fuel addition permit a wide range of operating conditions and charge balances to be used. It is of particular importance in the economical operation of the cupola that these conditions be balanced in such a way that high quality iron is produced at minimum cost.

The subject of this paper is a Thermochemical Model, employing a mass and energy balance for the cupola melting furnace and a kinetic relationship which is based principally on the wind rate, to provide a mathematical description of furnace operation. The model, utilizing prior operating data on a furnace, can be used to predict the coke consumption and melting rate for different operating conditions, including changes in burden, coke analysis, slag practice, blast volume rate, etc., all simultaneously or with each changing individually. These predictions are dependent upon having the general operating conditions of the cupola furnace remain constant. At the outset, it is to be noted that the model does not include the physical aspects of cupola operation which are certainly the limiting ones in terms of wind rate and the form and amounts of many of the materials which may be added. The careful selection of conditions based on what is already known about cupola operation should permit the thermochemical model to be used with discretion and considerable assistance in optimizing cupola performance.

PREVIOUS WORK

The thermochemistry of the cupola melting furnace has been the subject of a number of investigations. Jungbluth and Stockkamp[1] have explored the thermodynamics of reactions involved in cupola melting in some detail. Heat and energy balances on cupola melting furnaces have been presented in several places in the literature including a detailed balance in the AFS book on cupola operation[2]. A recent thermal balance for a 42" diameter cold-blast cupola, which was used as a basis for calculations in this study, was prepared by Subcommittee TS 52 of the Institute of British Foundrymen[3].

Researches on the iron blast furnace published in the last few years have explored the utilization of thermal balances on the furnace for purposes of predicting the changes in coke consumption and production rate associated with changes in operating variables such as coke quality, charge make-up, blast humidity, blast temperature, and other variables which are under control of the furnace operator, including the use of oxygen or fuel injection at the tuyeres. The inter-relationships of operating variables and particularly the influence on fuel consumption and productivity were explored by R. V. Flint[4] who employed a statistical correlation of plant data. An early attempt at relating operating variables to production and coke rate based on material and heat balances was proposed by Marshall[5].

The mass and heat balances and their relationship with blast furnace production rate and coke consumption have been treated in considerable detail by Lander, Meyer and Delve[6,7]. A similar treatment with the addition of heat transfer considerations in the furnace shaft has been proposed by Hodge[8]. In these studies an electronic computer was used because of the length and complexity of the calculations involved.

The approach proposed by Lander _et al._[7] has been modified for application to the cupola furnace, and a series of equations programmed for the IBM 7090 digital computer at the University of Michigan. This computer program provides a method for calculating the changes in cupola melting rate and coke requirement caused by changes in charging or blowing conditions. The program is shown to be capable of predicting furnace behavior on a thermochemical basis and providing a means by which cupola operations can be modified to accomodate changes in practice, to maximize melting rate and minimize coke consumption.

DERIVATION OF THE MODEL

The equations which make up the thermochemical model are based on a material and an energy balance for the cupola melting furnace. The term in the heat balance which is not immediately available from operating data is that of heat losses. The heat losses on a given furnace are evaluated from a selected set of operating data taken in a reference period of operation. By making a material and energy balance on the furnace during this carefully evaluated period of operation, the heat losses for a specific furnace can be determined and utilized in energy balances prepared for prediction of future operating performance, assuming that thermal losses per unit time are constant during continuous operation.

Having determined the thermal losses on a specific furnace during a reference period of operation, a material and energy balance can then be written for the predicted period of operation. In order to accomplish this, it was necessary to derive, in the form of three simultaneous equations, an energy balance, an oxygen balance, and a carbon balance. These balances are inter-related since the energy balance is based on a material balance which involves both the carbon and oxygen supplied in the charge and blast. The carbon, corrected for solution losses in the metal and any reduction reactions, and oxygen requirements are in turn related to the energy balance since they supply thermal energy to the system. The oxygen and carbon balances are inter-related through the CO/CO_2 ratio in the stack gas. The carbon requirement can then be utilized to predict a coke rate, and the oxygen balance can be related to the blast volume which in turn is proportional to the melting rate as discussed in the following paragraphs.

The Mass Balance

The mass balance is the first step in providing a thermochemical description of the cupola operation. The streams entering the process are the blast, the scrap, the coke, and the flux. The streams leaving the process are the stack gas, the liquid metal and the slag. In order to reduce the material balance to its simplest form and for ease of handling the energy balance, the materials are broken down into element or compound form for each stream. Material flow in the cupola furnace is illustrated schematically in Figure 1. A typical material balance for a cupola reference period of operation is given in Table I.

The Energy Balance

The energy balance for the system can be calculated using thermochemical data for the compounds entering and leaving the process. The total enthalpy balance may be written as $H_{blast} + H_{scrap} + H_{flux} + H_{coke} = H_{top\ gas} + H_{metal} + H_{slag} + H_{losses}$. Each of the enthalpy terms in the equation above can be calculated from a reference temperature and are based on two terms, the energy of reaction to form the compounds in the stream and the sensible heat in the stream relative to the selected base temperature. A summary of the enthalpies of the streams presented in the material balance of Table I are shown in Table II. A heat loss of 458,400 Btu/Net Ton Metal was calculated by the derived model which is in good agreement with the previously calculated value of 447,500 Btu/Net Ton Metal[3].

Melting rate:

Several investigators[9,10] have established that the melting rate is directly proportional to the blast volume entering the cupola. Based

Figure 1. Material Flow in the Cupola Melting Furnace.

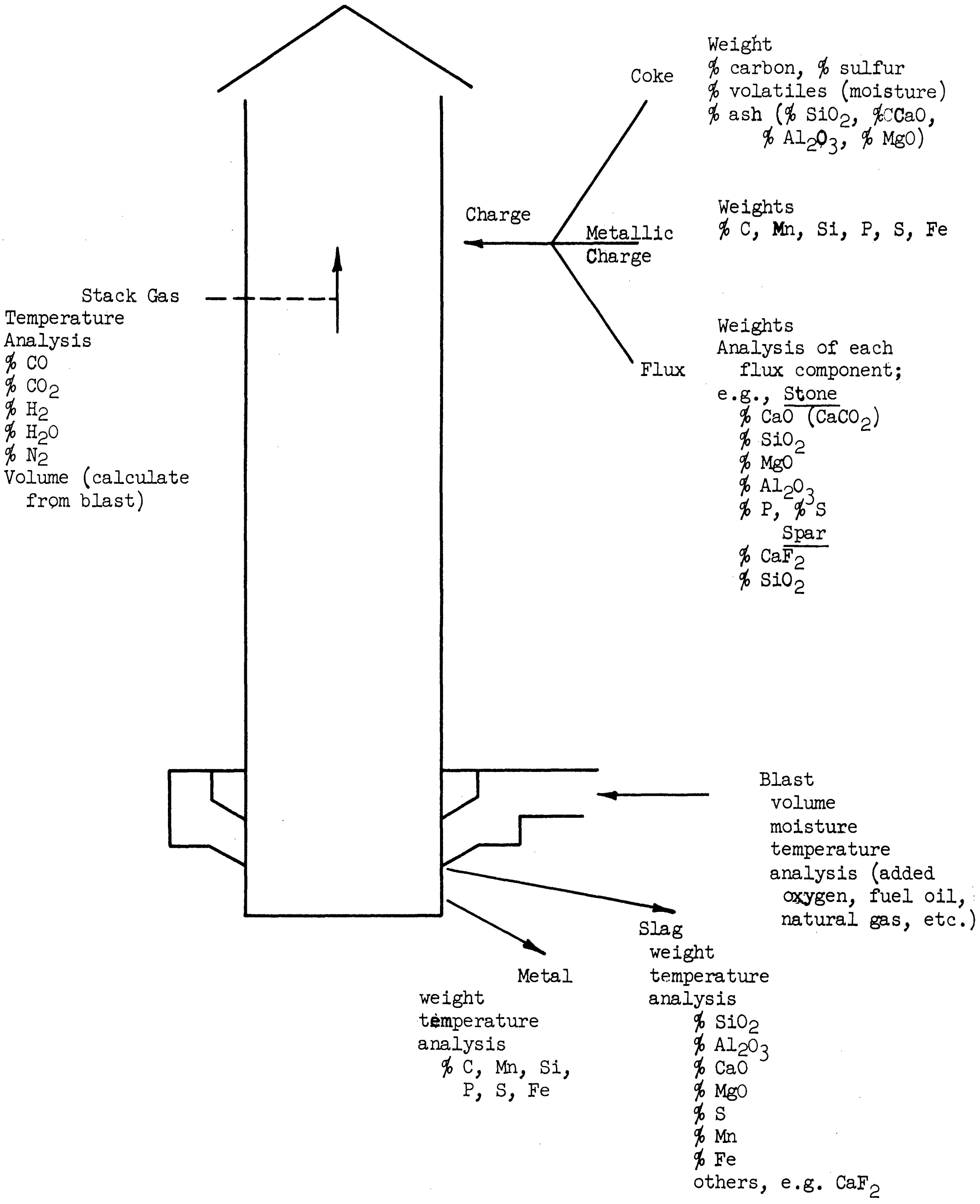

TABLE I

Reference Period Data*

MATERIAL	WEIGHT LB/NET TON MOLTEN METAL	Chemical Analyses in Weight Per Cent										
		SI	S	MN	P	C	FE					
CHARGE												
Hematite Pig	596.85	2.940	-.00	.940	.09	4.00	92.03					
Low P Pig	198.95	2.610	-.00	.800	.24	3.17	93.18					
Return Scrap	795.80	2.000	-.00	.730	.14	3.30	93.83					
Steel Scrap	397.90	.040	-.00	.600	.05	.10	99.21					
Ferromanganese	7.16	-.000	-.00	50.000	-.00	-.00	50.00					
		SIO2	AL203	CAO	MGO	P	FE	FIXED C	S	VOLS	ASH	H20
COKE	265	4.51	2.09	.15	.06	.016	.98	91.25	1.18	.95	7.80	3.00
		SIO2	AL203	CAO	MGO	P	S	CAF2				
FLUX												
Limestone	87	1.81	.12	51.80	1.86	-.000	-.000	-.000				
Lining Loss	55	84.10	15.40	.05	.15	-.000	-.000	-.000				
		SIO2	AL203	CAO	MGO	S	MN	C	FE	CAF2	TEMP	
SLAG	136	48.30	10.96	33.90	.80	-.000	2.47	-.00	2.22	-.00	2642	
		SI	S	MN	P	C	FE	TEMP				
METAL	----	1.79	-.000	.79	.130	3.33	93.96	2642				
		O_2	N_2	H_2O	CO	CO_2	H_2	TEMP	BLAST RATE scfm			
BLAST	----	20.658	77.714	1.627	-----	-----	----	77° F.	3293			
TOP GAS	----	------	70.62	.30	15.04	12.86	1.18	442° F.	----			

*BASED ON MASS BALANCE PRESENTED IN REFERENCE 3

TABLE II

ENERGY BALANCE FOR REFERENCE PERIOD OF OPERATION*
REFERENCE TEMPERATURE 77° F.

	H, Btu/lb Product	lb Product/Ton Metal	H, Btu/Ton Metal
Blast (77°F)			
$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	- 5872	18.67	- 109,630
		H-Blast =	- 109,630
Flux (77°F)			
$CaO + C + O_2 \rightarrow CaCO_3$	- 2467	80.18	- 197,800
$MgO + C + O_2 \rightarrow MgCO_3$	- 2607	3.55	- 9,250
		H-Flux =	- 207,050
Charge (77°F)		loss by oxidation	
$Si(77°F) + O_2(77°F) \rightarrow SiO_2(77°F)$	- 6156	- 6.45	+ 39,700
$Mn(77°F) + \frac{1}{2} O_2(77°F) \rightarrow MnO(77°F)$	- 2335	- 2.70	+ 6,300
$Fe(77°F) + \frac{1}{2} O_2(77°F) \rightarrow FeO(77°F)$	- 1598	- 3.29	+ 5,260
$\underline{C}(77°F) \rightarrow C(77°F)$	+ 1750	56.83	+ 99,450
		H-Charge =	+ 150,710

	H, Btu/lb Product	lb Product/Ton Metal	H, Btu/Ton Metal
Stack gas (442°F)			
$C(77°F) + \frac{1}{2} O_2(77°F) \rightarrow CO(442°F)$	- 1605	295	- 473,475
$C(77°F) + O_2(77°F) \rightarrow CO_2(442°F)$	- 3763	397	- 1,493,910
$H_2(77°F) \rightarrow H_2(442°F)$	+ 1271	1.68	+ 2,135
$H_2(77°F) + \frac{1}{2} O_2(77°F) \rightarrow H_2O(442°F)$	- 5608	3.63	- 20,360
$N_2(77°F) \rightarrow N_2(442°F)$	+ 91	1385	+ 126,035
		H-Stack gas =	-1,859,575
Slag (2642°F)			
Slag (77°F) → Slag (2642°F)	+ 822	136	+ 111,790
$CaO + SiO_2 \rightarrow CaO \cdot SiO_2(77°F)$	- 330	82.8	- 27,320
$2MgO + SiO_2 \rightarrow 2MgO \cdot SiO_2(77°F)$	- 194	3.22	- 624
$CaO + \frac{1}{2} S_2(g) \rightarrow CaS + \frac{1}{2} O_2(77°F)$	+ 915	6.81	+ 6,230
		H-Slag =	+ 90,076
Metal (2642°F)			
$Fe(77°F) \rightarrow Fe(2642°F)$	+ 549	1879	+ 1,031,571
$Si(77°F) \rightarrow \underline{Si}(2642°F)$	- 587	35.7	- 20,956
$P(77°F) \rightarrow \underline{P}(2642°F)$	- 2606	2.6	- 6,776
$Mn(77°F) \rightarrow \underline{Mn}(2642°F)$	+ 582	15.8	+ 9,116
$C(77°F) \rightarrow \underline{C}(2642°F)$	+ 1987	66.5	+ 132,135
		H-Metal =	+ 1,145,090

Heat Loss (by difference) = 458,439 Btu/Net Ton Metal

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* based on Table I

on this assumption the melting rate referred to the same blast volume rate on a dry basis as in the reference period under a new set of operating conditions can be predicted by the relationship:

$$\text{Melting Rate} = \frac{(\text{NBL}^*)(X^*_{N_2})}{(\text{NBL})(X_{N_2})} \quad (\text{MR})$$

where NBL is the volume of blast per pound of iron during the prediction period and X_{N_2} is the volume per cent nitrogen in the blast during the prediction period. NBL^* is the volume of blast per pound of iron during the reference period and $X^*_{N_2}$ is the volume per cent nitrogen in the blast during the reference period. MR is the melting rate during the reference period.

Coke Consumption:

The coke requirement in pounds of coke per ton of metal produced can be calculated using the relationship:

$$\text{Coke Consumption} = (2000) \left[\frac{\%\text{Fe(metal)}}{\%\text{C(coke)}}\right] \quad (\text{LBC})$$

where % Fe(iron) is the per cent Fe in the metal during the period of prediction. % C(coke) is the per cent carbon in the coke during the period of prediction. LBC is pounds of carbon per pound of iron required from the coke during the period of prediction.

REQUIREMENTS FOR USE OF MODEL

The requirement that the mass and energy balance on the furnace be complete presents the cupola operator with the rather stringent requirement of providing a reliable set of data regarding the compositions, temperatures, and amounts of material going into and coming out of the furnace. Material flow through the cupola melting furnace and the variables relating to each stream which must be measured if the mass-energy balance is to be accurately closed are schematically shown in Figure 1. These streams are:

1. Blast
    - a. Temperature (particularly for the hot blast cupola)
    - b. Humidity
    - c. Volume, SCFM
2. Charge Materials - Weights and Analyses
    - a. Coke Weight; Composition (carbon, volatiles, and the analysis of oxides present in the ash including silica, alumina, calcia, and magnesia)
    - b. Metallic Charge

      Weight

      Analysis; carbon, manganese, silicon, phosphorus, and sulfur.
    - c. Flux

      Weight and analysis of each component
3. Stack gas
    - a. Temperature
    - b. Per cent CO, CO_2, H_2, H_2O, N_2
    - c. Volume (can be computed from blast rate)
4. Slag
    - a. Weight
    - b. Temperature
    - c. Analysis; silica, alumina, calcia, magnesia, P_2O_5, Mn, Fe
5. Metal
    - a. Weight
    - b. Temperature
    - c. Analysis; carbon, manganese, silicon, phosphorus, and sulfur

The thermochemical model is relatively complete in the reactions considered, although there are a number of possible slag reactions which are not taken into account. In utilizing the reference period calculation to establish the heat loss, it should be noted that this term contains in addition to the heat loss through the walls of the furnace, the sum of all errors in operating data and in the thermochemical data used to prepare the model. The use of the model to evaluate the furnace performance under a different set of operating conditions is such that the error in the heat loss term does not markedly affect the results of the calculations. No appreciable error arises because the model treats only differences between the furnace performance for the predicted and the reference period conditions. Since the errors in the heat loss term are common to both cases, they tend to cancel out.

The evaluation of changes in performance of a furnace requires that operating conditions during the period of prediction be known. Consequently, the accuracy of the predicted furnace performance depends on the accuracy with which the new operating conditions can be correctly estimated. One such variable which is particularly sensitive in the thermochemical model as presented here is the CO/CO_2 ratio in the stack gas. The change in the CO/CO_2 ratio which would result with a change in operating practice will have to be estimated from similiar furnaces operating under the conditions of the prediction period. An error of 0.1 in the CO/CO_2 ratio would result in an error in the coke requirement of 8.5 lbs./net ton of metal produced.* Furthermore, the changes in blast volume rate which could accompany a variation in charging practice will

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* based on Table I

have to be estimated from experience on other furnaces.

Consequently, in prediction of furnace performance it is necessary that many of the variables be estimated from previous experience. Several investigations have been carried out in an effort to evaluate the influence of operating conditions on cupola furnace performance. The work of Patterson and Neumann[9] has shown that the combustion ratio $r_{(comb)} = (CO_2/(CO_2 + CO))$ depends on the temperature, the coke charge, the coke quality, and the blast volume. Evans et al.[11] has reported on the influence of the blast volume on combustion ratio, as have Neumann and Patterson[12] in a more recent work. It may be possible through studies of this type to predict a priori what the specific operating conditions will be under the changes brought about during the prediction period. Meanwhile, however, it will be necessary to estimate the relationships from current practice.

APPLICATIONS OF THE THERMOCHEMICAL MODEL

The thermochemical model may be applied to a number of cupola problems. It is particularly useful in evaluating the effect of changes in some of the operating variables on cupola performance. For example, the effect of modifications in blast temperature and composition, and changes in charge balances and slag basicity ratio can be evaluated for a given furnace.

The model is an especially powerful means for interpreting data reported on operating test runs. When carrying out a test on a production furnace, it is impossible to maintain all operating conditions constant. However, the model can be used to evaluate the separate effect of each particular variable, provided all of the changes in operating conditions have been measured and utilized in the thermochemical calculations. The model is a direct and convenient means for assuring consistency in data reported on production tests.

The model may be used in studies on production planning. If an increase in iron production is required from a cupola or a group of cupolas, the cost involved in obtaining the desired production rate can be assessed for various combinations of blast and/or charge modifications. The predicted performances of the furnace under various operating conditions can provide information for cost comparisons. The changes in metal costs resulting from the use of various charge mixes can be evaluated using linear programming techniques as proposed by Bailey[13]. It should be possible to incorporate the thermochemical model with a linear program involving restrictions on the quality requirements, operating costs, and charge costs to optimize a cupola operation involving, for example, several furnaces or even a group of furnaces at different locations.

The thermochemical model should find considerable use in furthering studies of cupola theory. It would not only assure consistent material and energy balances but could serve as a guideline for areas of cupola operation to be investigated. It could provide a basis for further theoretical work on the thermochemistry of cupola operation, and serve as a useful tool in planning experimental work.

PREDICTIONS OF FURNACE PERFORMANCE

To illustrate the use of the thermochemical model, several calculations were carried out on the IBM 7090 computer. These calculations are based on the data presented in Table I for an acid-lined 42-inch cupola. In order to carry out these calculations, several assumptions were made regarding the predicted period of operation. These assumptions, which might be improved by considering prior operating experience with the furnace, include:

1. No change in chemistry of metal produced.
2. Slag basicity constant-measured as: $\frac{\% \mathrm{CaO} + \% \mathrm{MgO}}{\% \mathrm{SiO_2} + \% \mathrm{Al_2O_3}}$
3. Constant CO/CO_2 and H_2/H_2O ratios in stack gas.
4. No change in temperature of exiting streams: metal, slag, and stack gas.
5. Constant blast volume rate.
6. Constant heat loss per unit time.

Model Coefficients

The thermochemical model was used to estimate the change in coke requirement caused by changes in certain operating variables. The results of these calculations are summarized in Table III. These coefficients are based on precise thermochemical data and should apply with reasonable accuracy to acid cupola operations in general. It should be noted, however, that the calculations are based on a specific coke and metallic charge analysis. Furthermore, the predictions are based on the forementioned assumptions and might require slight revision with changes in operating conditions. These results are an indication of the potential of the thermochemical model in predicting furnace performance and analyzing cupola operation.

Coke Quality

The calculation of a predicted period of operation in which coke with a lower fixed carbon content was substituted is summarized

TABLE III

EFFECT OF OPERATING VARIABLES ON CUPOLA COKE REQUIREMENT AS CALCULATED BY THE THERMOCHEMICAL MODEL

CHANGE IN VARIABLE	CHANGE IN COKE REQUIREMENT* lb/Net Ton Metal
Increase in slag volume of 100 lb/NT Metal	+ 30
Increase in steel scrap in charge (substituted for pig iron) of 100 lb/NT Metal	+ 11
Increase in blast moisture from 5.5 to 6.5 gr/ft^3	+ 3
Increase in blast temperature of 100° F.	- 10
Injection of 1% oxygen in blast	- 6
Injection of 1% natural gas in blast	- 8

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* based on coke containing 91.25% fixed carbon

in Table IV. A decrease in fixed carbon content from 91.25 to 88.23 would yield an estimated increase of 9 lb/N.T. Metal based on a constant carbon requirement. The additional increase to 10.9 lb/N.T. Metal is necessitated by the increase in slag volume of 7.7 lb/N.T. Metal which also includes a 3.2 lb/N.T. Metal increase in the limestone charged. The predicted melting rate decreased by 0.6%.

Oxygen Enrichment

Calculations of predicted cupola performance with oxygen enrichment were carried out using the thermochemical model. For 2% oxygen enrichment, the computer model predicts a 4.4% decrease in coke requirement and a 14.7% increase in melting rate. In Table V, these results are compared with actual plant and laboratory tests[14, 15, 16].

The predicted and experimental values can be considered to be in qualitative agreement. The accuracy of the thermochemical model is limited in this case since these calculations were based on the data of Table I using the forementioned assumptions. Some modification of these predictions should be made since oxygen injection studies have shown that an increase in metal temperature, and an increase in carbon and silicon content are realized[17]. The experimental data of Table V are also of limited accuracy, however, since it is difficult to separate the true change in coke requirement and melting rate caused by oxygen enrichment when a number of other variables are simultaneously varying. It is in this latter respect that the thermochemical model has a considerable advantage, and that the usefulness of utilizing the model in conjuntion with test programs is clearly shown.

TABLE IV

Predicted Change in Coke Requirement for a Specific Change in Coke Analysis

Coke Analysis	Standard Operation (Table I)	Predicted Operation
Fixed Carbon	91.25	88.23
Ash	7.80	10.65
Volatiles	0.95	1.12
H_2O	3.00	3.00
SiO_2	4.51	5.12
Al_2O_3	2.09	2.89
CaO	0.15	0.45
MgO	0.06	0.11
P	0.016	0.015
Fe	0.98	1.01
S	1.18	1.11
Predicted Coke Rate lb /N.T. metal	265	275.9
Melting Rate N.T. Metal / HR	6.425	6.39
Slag Volume lb/N.T. Metal	136	143.7 /
Flux Rate lb/N.T. Metal	87	90.2

TABLE V

Comparison of Changes in Coke Requirement and Melting Rate Predicted by Thermochemical Model with Experimental Data

Source	% Oxygen Enrichment	Per cent Decrease in Coke Requirement	Per cent Increase in Melting Rate
Thermochemical Model	2	4.4	14.7
Sub-committe TS43[14]	2	13.2	--
Wick[15]	3.5	--	10
Danis[16]	2.5 - 3.0	--	25

Natural Gas Injection

The operating conditions which are attainable using natural gas injection are presently of considerable interest. Natural gas represents a potential replacement for part of the scarce high-quality metallurgical coke, at a possible economic advantage. Plant trials on natural gas injection can be checked for consistency in reported test data using the thermochemical model. Full-scale tests will also permit an evaluation of the prediction accuracy of the model.

In predicting furnace performance with natural gas injection, consideration must be given to the attainable operating conditions such as blast volume rate, top gas analysis, and any increases in blast temperature necessary to provide smooth operation at higher injection rates. However, the model permits a wide range of possible operating conditions to be evaluated. Thus a qualitative insight can be gained into the relative importance of various operating variables on furnace performance, even before the precise conditions attainable with fuel injection are known. This is illustrated in the results presented in Figures 2 and 3 which summarize calculations of coke requirements and melting rates at two levels of blast temperature and two levels of natural gas injection over a wide range of H_2/H_2O ratios in the stack gas. The CO/CO_2 ratio was held constant at 1.17 in order to illustrate the effects of the H_2/H_2O ratio alone. The coke rate is found to decrease and the melting rate to increase at lower H_2/H_2O ratios. This results from the increase in thermal energy and consequent decrease in coke and blast requirement resulting from a higher H_2O content in the stack gas.

The major conclusion which can be reached regarding these calculations is that significant decreases in coke rate and increases in

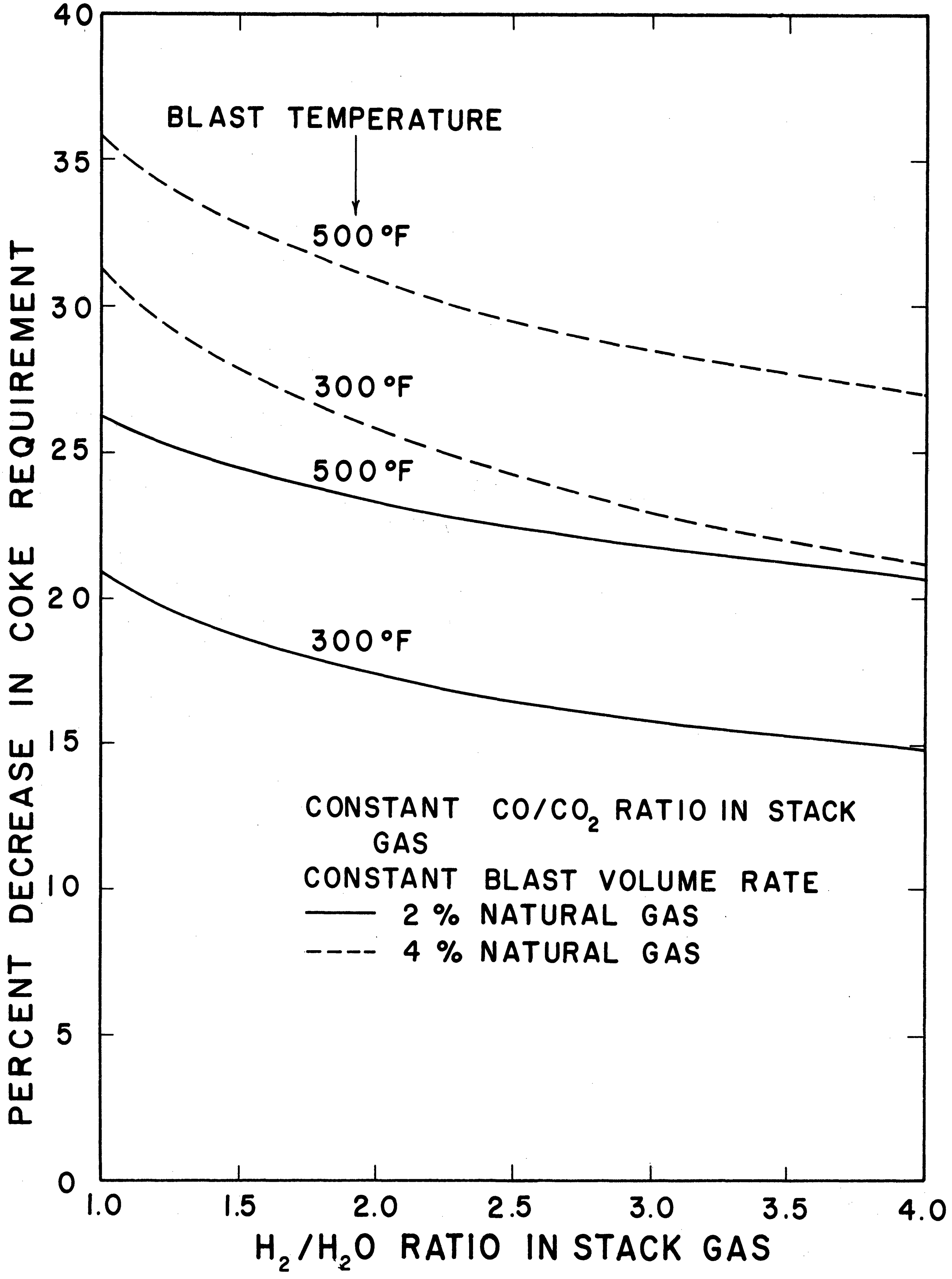

Figure 2. Calculated Effect of Natural Gas Injection on Cupola Coke Requirements.

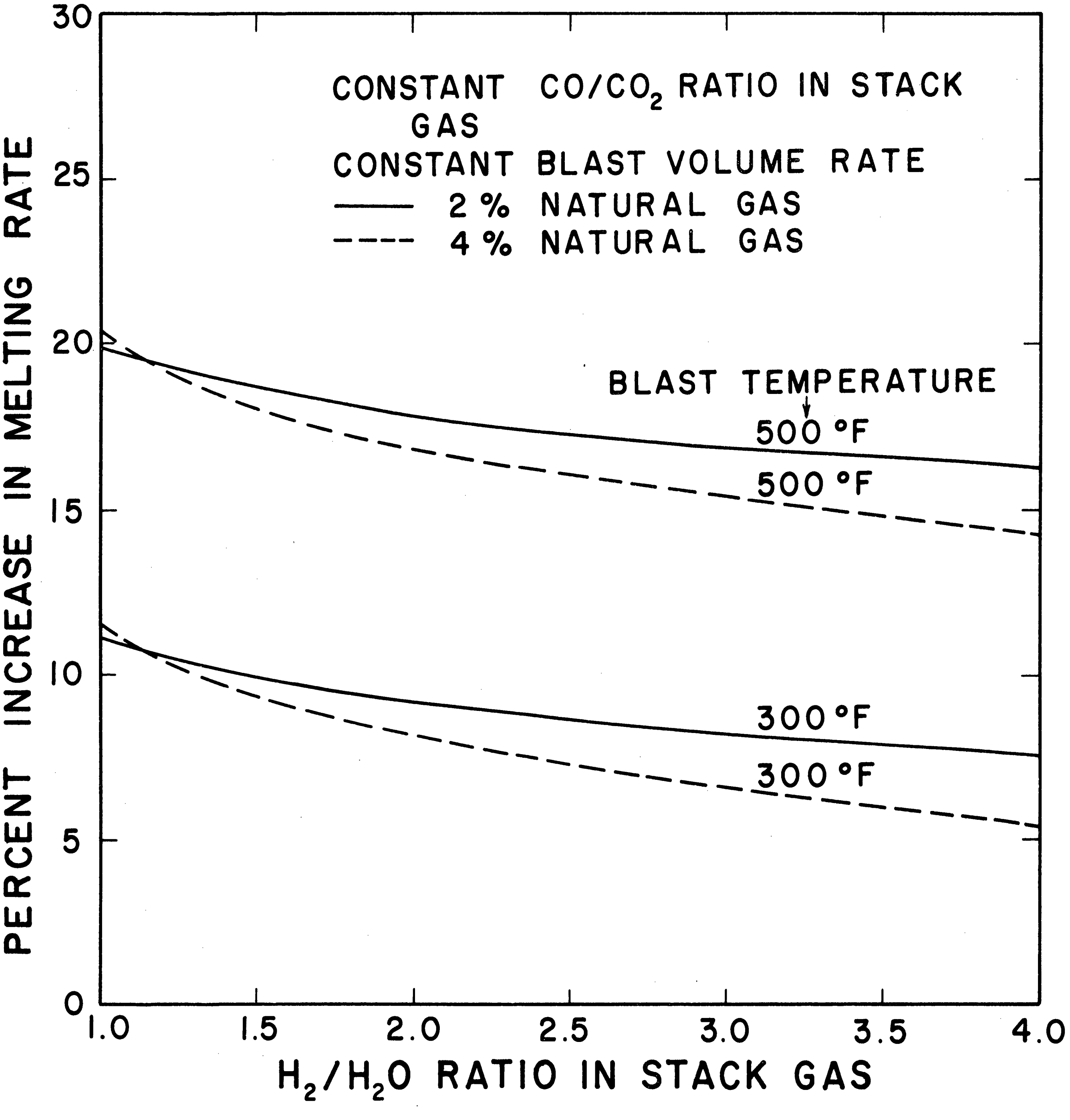

Figure 3. Calculated Effect of Natural Gas Injection on Cupola Melting Rate.

melting rate can be attained with increasing blast temperature. However, increasing rates of natural gas injection do not appreciably change the melting rate, but do result in coke savings.

These predictions are useful guidelines in indicating the furnace performance which might be expected with natural gas injection. It is necessary that actual operating data be generated with natural gas trials to provide a basis for accurately predicting cupola performance utilizing natural gas injection.

PRESENT POTENTIAL

Even more important for immediate application of this model, one should consider the rather limited knowledge that presently exists regarding cupola operations. Despite the fact that the furnace is a simple shaft in geometry and involves only melting, and combustion reactions, the physical and kinetic inter-relationships are not well understood. The advanced instrumentation which is presently available to the foundry industry today, such as high speed analytical equipment, weighing equipment of sufficient precision and durability to operate under hot, dust-laden conditions, precision temperature-recording devices, and gas analyzing equipment for operating on a continuous basis, will permit the collection of data of sufficient accuracy and completeness to provide good reference period data for a thermochemical model. In order to fully understand the dynamics and the inter-relationships between temperature, chemistry, and controllable operating variables, it is necessary that the material and energy flow through the system be known. It would seem apparent that being able to accurately describe the cupola operation in terms of material and heat balances on a continuous basis would be a firm foundation upon which correlation of operating variables could be based. The thermochemical model provides a step toward commercial realization of the full potential of the cupola melting furnace.

The fact that the thermochemical model, and perhaps one even more complete than that which has been described in this paper, involves many calculations is of little consequence in today's world of high speed computing equipment. The computation for a reference period involving a complete material and energy balance on a cupola furnace which would require six to eight man-hours has been carried out on a routine basis using the IBM 7090 computer in 3.7 seconds per operating condition. Even with a smaller and less expensive machine, it would be possible to perform heat and energy balances under operating conditions on a repeating schedule. This type of precise information on a continuous basis would be invaluable for studies of cupola operation.

SUMMARY

A thermochemical model for use in predicting cupola furnace performance under various operating conditions has been described. The model, based on material and energy balances, has been programmed for the IBM 7090 digital computer and utilized in evaluating changes in coke requirement and melting rate which would accompany various changes in operating variables. The changes in coke requirement with changes in slag volume, substitution of scrap for pig iron, change in coke quality and changes in blast moisture and temperature were estimated. Predicted decreases in coke requirement and increases in melting rate with oxygen enrichment of the cupola blast were shown to qualitatively agree with experimental values. Improvements in cupola performance with natural gas injection and increasing blast temperature have been predicted.

Limitations of the model in terms of the necessity of knowing attainable operating conditions and estimating operating variables during prediction periods of operation were discussed. Applications of the model in research and development were cited including evaluation of the influence of changes in operating variables on furnace performance, checking of operational test data, assistance in production planning, and uses in further studies of cupola operation.

ACKNOWLEDGEMENT

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