THE UNIVERSITY OF MICHIGAN

CUPOLA PERFORMANCE: THE POTENTIAL FOR OIL INJECTION

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INTRODUCTION

Fifty years ago Bradley Stoughton presented a summary of his operating experience with the oil-fired cupola.[1] This early exploration provided a clear cut description of some of the limitations imposed on cupola operation with fuel oil injection; the limitations were seen to manifest themselves in a decreasing temperature in the tuyere zone unless the oil was presented to the tuyere zone at high temperatures as a partially or fully combusted fuel-air mixture. Stoughton's study indicated that combustion chambers in or directly behind the tuyere could provide a means for utilization of fuel oil in the cupola.

A number of investigations have been carried out in an attempt to replace all or part of the cupola coke charge with fuel oil.[2-5] It has been observed that the use of oil injection in normal cupola iron melting, because of the endothermic nature of the initial combustion reactions, requires either a hot blast or oxygen enrichment. The utilization of oil alone will decrease the tuyere zone temperature[1,6,7] and results in operating difficulties. However, adoption of hot blast operation and the availability of low cost oxygen can facilitate a satisfactory cupola operation, taking advantage of oil injection.

The challenge of cupola operation with fuel oil injection has been placed before the foundry industry for some time. The purpose of the present study is to describe the operating conditions which can be realized through the use of fuel oil as a cupola injectant, and thereby provide a basis for defining the potential economies associated with fuel oil injection.

THE THERMOCHEMICAL MODEL

Performance of the cupola using oil injection and simultaneous oxygen enrichment with hot blast has been evaluated in a computer study using a previously discussed thermochemical model.[8,9] This model is based on a mass and energy balance for the furnace and employs a kinetic relationship which is based on wind rate.[10] The model utilizes prior furnace performance data to establish a standard reference for the operation of a given furnace and charge. A mass and energy balance is then applied to predict the coke consumption and melting rate under slightly varying operating conditions.

The validity of predictions based on this thermochemical model is dependent upon a fairly constant operating condition for the cupola furnace. In exploring fuel oil injection in the cupola, it must be recognized that these predictions are valid only under conditions which are relatively close to the present operating conditions. Iron melting in the cupola requires that certain physical and chemical limitations be met; the temperature distribution in the tuyere zone and upward into the stack must be within a certain range, and the oxygen potential which the molten metal moves into as it melts and flows downward through the interstices of the coke must be within a certain range. That these conditions are met is assumed in the present computer predictions.

PREDICTED CUPOLA PERFORMANCE

In recognizing the need for a higher tuyere zone temperature with oil injection, a standard cupola practice[11] has been used as a reference operation, and higher blast temperature and oxygen enrichment have been incorporated simultaneously with oil* injection in the calculations.

Coke rate. The predicted coke requirement with fuel oil injection is described in Figure 1. The curves slope downwardly to the right showing that the coke requirement decreases with increasing blast temperature. As the level of oil injection increases, the coke requirement further decreases. Superimposed upon this curve is a furnace operating requirement regarding tuyere zone temperature distribution, and it is expected that the zone of potential cupola operation lies to the lower right of this diagram; i.e., with increasing levels of oil injection, a corresponding increase in blast temperature would be required.

Figure 2 represents predicted coke requirements for various blast temperatures with simultaneous oxygen enrichment. The coke saving with oxygen enrichment alone has been shown to be relatively small,[12-19] and hence the curves are of the same general shape shown in Figure 1. It would be expected, however, that the operating zone for this figure would be in the lower right hand area of the diagram, but not to as great an extent as for Figure 1, since the increase in oxygen level in the blast should provide suitable combustion conditions to handle higher levels of oil injection.

Melting rate. The predicted melting rates at various levels of oil injection are presented in Figure 3. The melting rate increases with increasing blast temperature. Furthermore, the melting rate increases with increased levels of oil injec-

*Bunker C

tion. The acceptable operating conditions would be expected to lie to the upper right of the diagram. It should be noted that these potential increases in melting rate represent a significant increase in production capacity.

In Figure 4 the predicted melting rate is shown as a function of blast temperature for various levels of simultaneous oil injection and oxygen enrichment. These curves reflect the marked increases in melting rate associated with oxygen injection.[12-19] The operating zone would again lie to the upper right of this diagram, but not so far as for Figure 3 since higher blast temperatures and increased oxygen enrichment would produce correspondingly higher tuyere zone temperatures. The curves of Figure 4 lie well above the curves of Figure 3, and predict the possibility for a marked increase in melting rate for hot blast operation with simultaneous oxygen enrichment and fuel oil injection.

TUYERE ZONE TEMPERATURE

The distribution of temperature in the tuyere zone is an important operating condition in cupola melting. It is a major factor in determining metal temperature, and also influences the oxygen potential of the gas in the melting zone, thereby influencing the extent of oxidation of the metal. Tuyere zone temperature can be controlled by balancing the blast temperature and fuel or oxygen injection level. The control of tuyere zone temperature based on adiabatic flame temperature for combustion of the blast with the hot coke has met with success in iron blast furnace operation[20,21] and offers a useful means for effecting cupola blast control.[9,22] A previously described computer calculation of adiabatic flame temperature[22] has been carried out for fuel oil injection with simultaneous oxygen enrichment over a range of blast temperatures. The results of these calculations are shown in Figure 5.

The injection of fuel oil at the tuyeres decreases the melting zone temperature because of the endothermic decomposition of the oil, and maintenance of the desired temperature distribution therefore requires either oxygen injection or an increased blast temperature. The results presented in Figure 5 are based on an assumed coke temperature and combustion to CO and H_2. The flame temperatures are calculated based on adiabatic conditions. Although these calculated values are not the actual values reached during operation, they should prove useful for comparing changes in blast conditions.

Operating experience has shown that the combustion of oil does not take place as rapidly as in the case of gaseous fuel injection. Consequently, the use of a special burner to insure combustion of the injected oil may be required. Recent development work has led to improved burner designs of the oxy-fuel type, which operate efficiently with oil injection.

USE OF BURNERS

The early experience of Stoughton[1] demonstrated the necessity for precombustion of injected oil. Recent development of oxy-fuel furners[23,24] offers a means for accomplishing simultaneous oxygen enrichment and oil injection. These burners offer a very efficient means for mixing fuel and oxidizer in a combustion chamber of simple construction. The detonation and turbulent conditions in the combustion chamber provide for effective mixing and the discharge of the combustion products at high velocity. The jet exiting from the combustion chamber could be directed into the cupola bed or into the blast, and then into the furnace in an indirect manner. A reasonably wide range of air/fuel ratios can be reached using these burners.

CONCLUSION

Oil injection in the cupola can be achieved in a variety of ways, most of which permit precombustion to occur to various degrees, and allow the injected combustion products to enter the furnace at any desired temperature and over a range of compositions. The injection of oil precombusted to a desired composition and raised to a suitable temperature should permit efficient cupola operation, putting the furnace performance outlined in the foregoing sections within reach by using straightforward modifications of present equipment. The determining factor in the use of oil injection will be set by fuel costs, including the price of oil relative to coke, natural gas, and other supplementary fuels.

SUMMARY

1. Fuel oil represents a potential blast injectant for the cupola which could reduce coke requirements and increase melting rates.

2. The use of oil injection requires either oxygen enrichment or hot blast for successful cupola operation, as well as equipment for insuring proper combustion of the injected oil.

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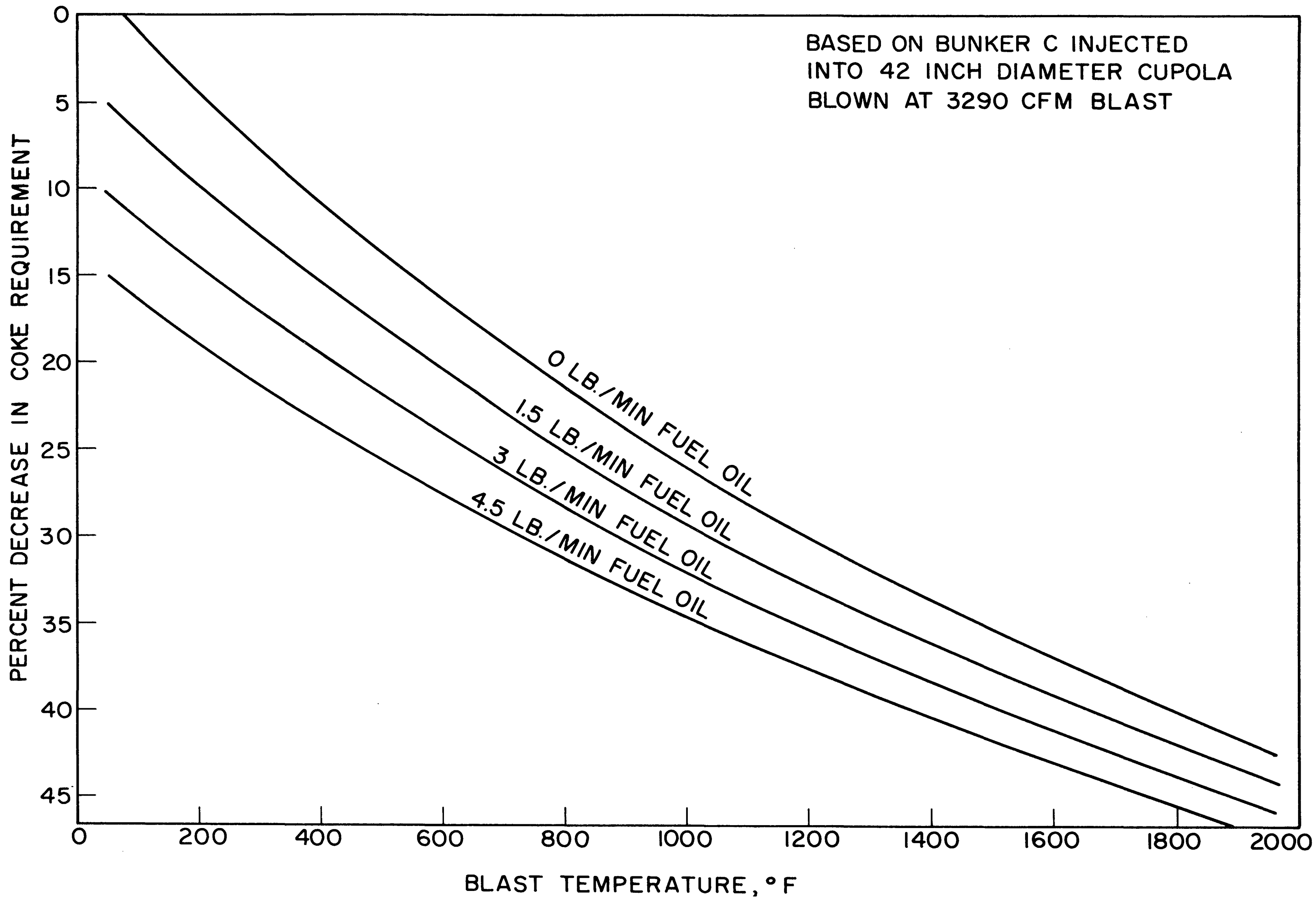

Figure 1. Calculated Effect of Fuel Oil Injection on Coke Requirement.

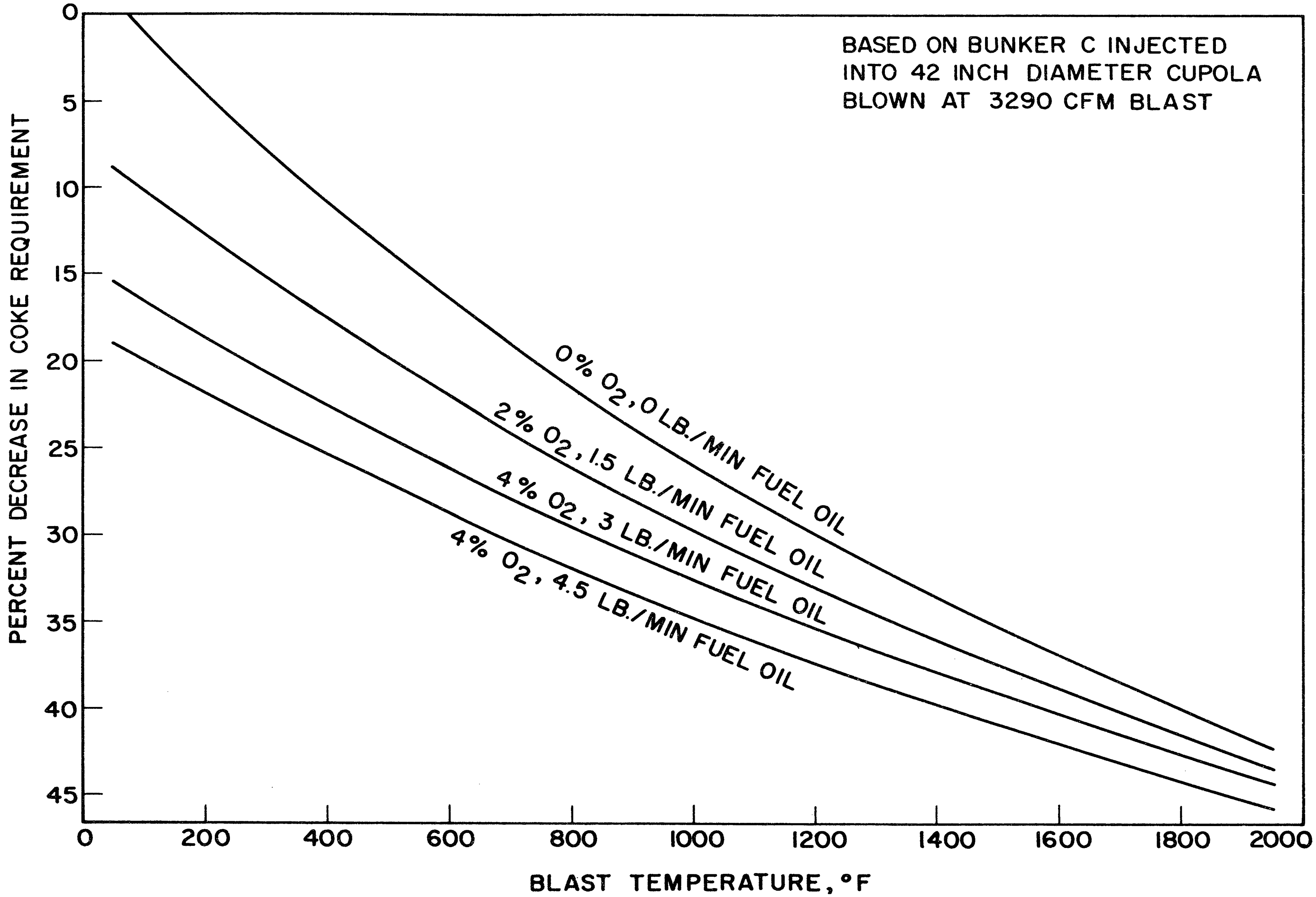

Figure 2. Calculated Effect of Simultaneous Oxygen Enrichment and Fuel Oil Injection on Coke Requirement.

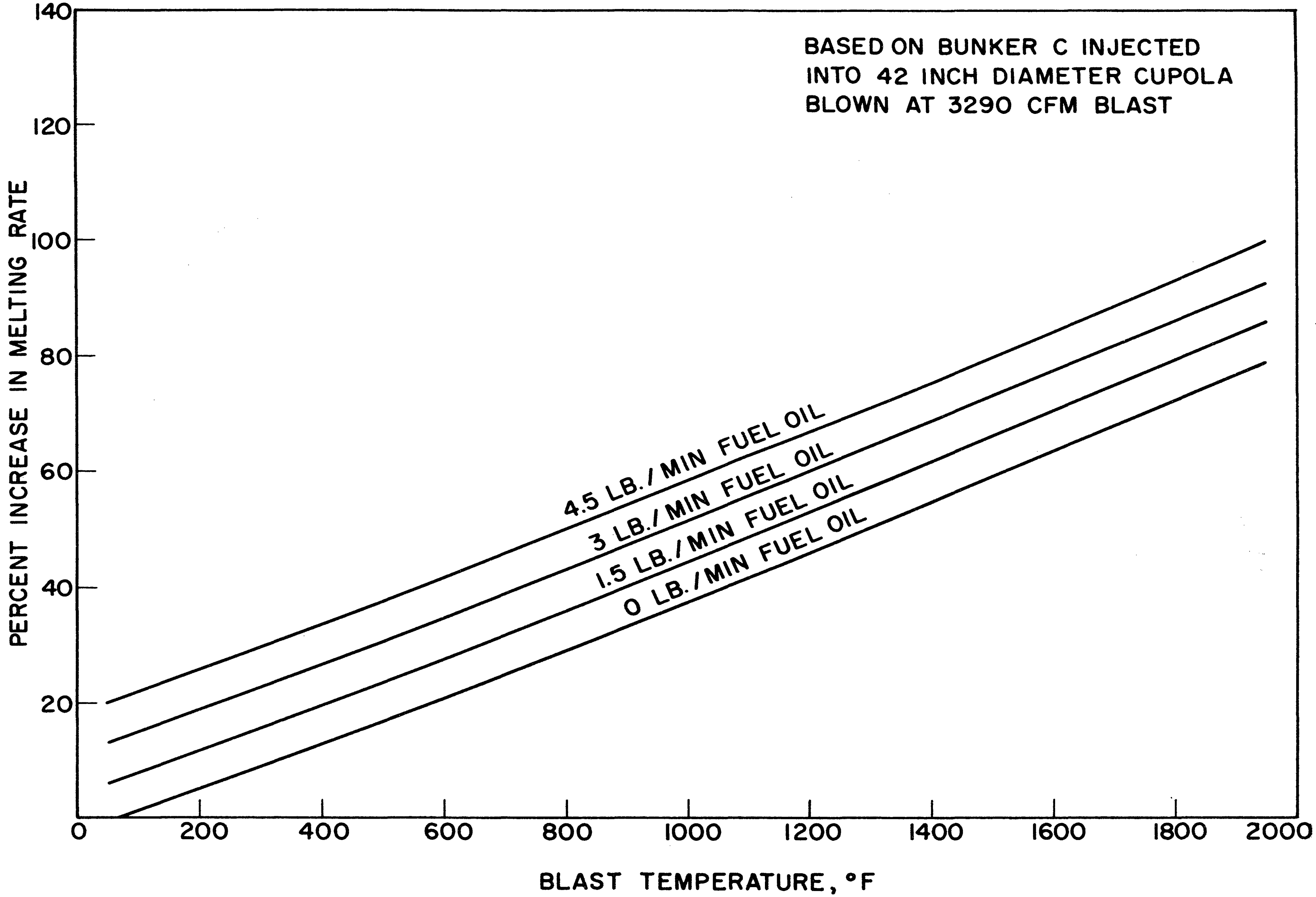

Figure 3. Calculated Effect of Fuel Oil Injection on Melting Rate.

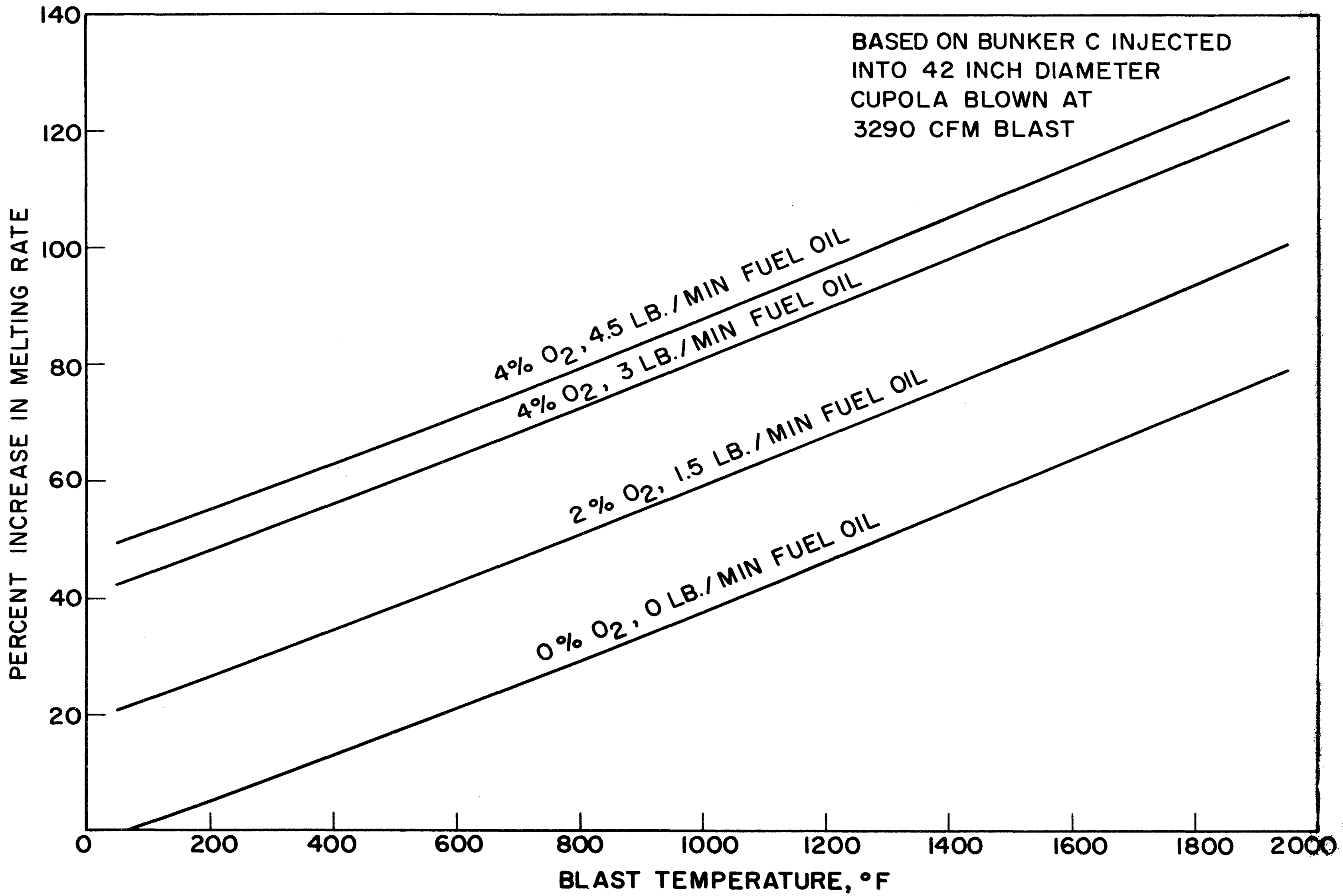

Figure 4. Calculated Effect of Simultaneous Oxygen Enrichment and Fuel Oil Injection on Melting Rate.

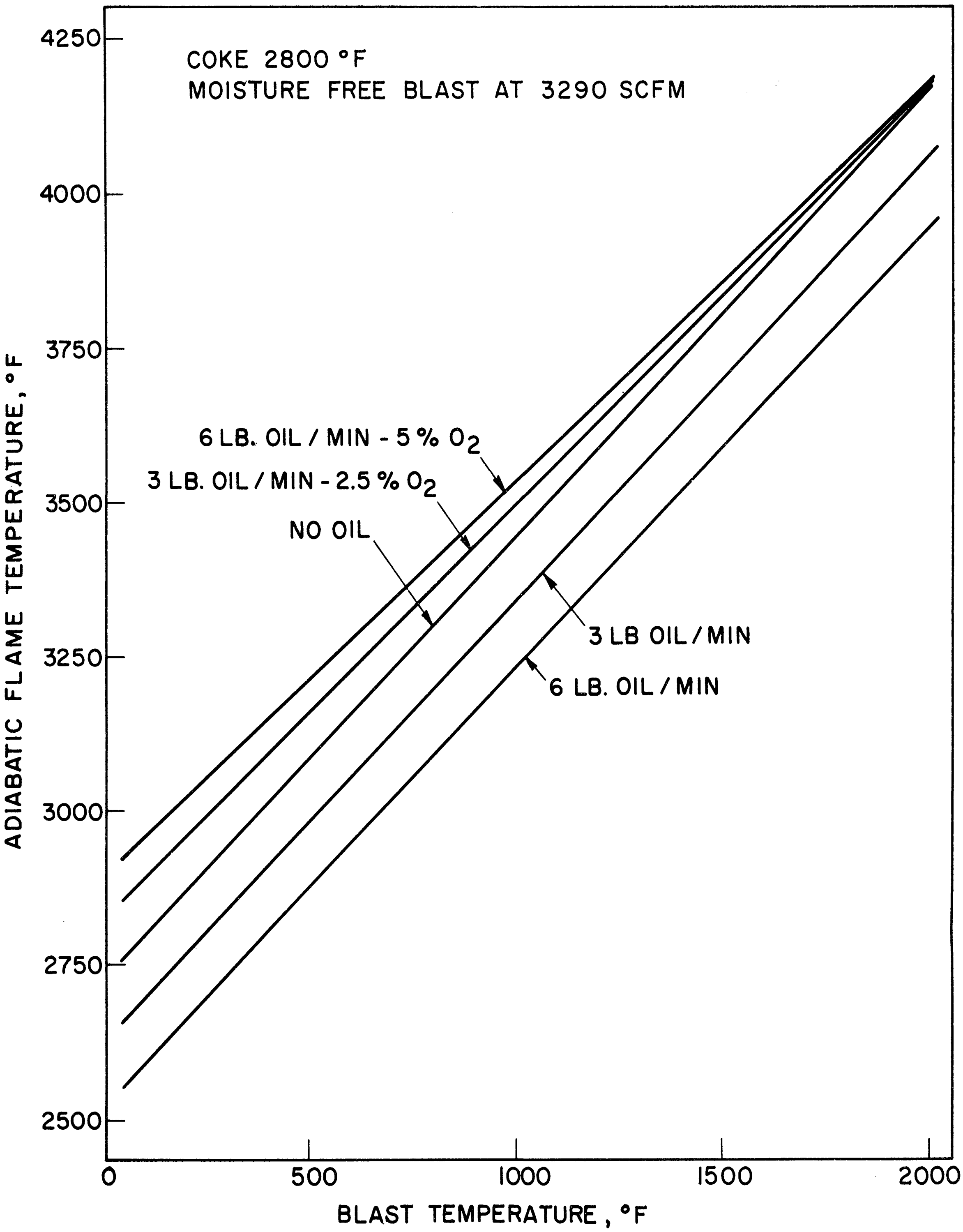

Figure 5. Calculated Adiabatic Flame Temperature in Tuyere Zone of Cupola for Various Levels of Blast Enrichment.