Oxygen in the Cupola: A Comparison of Enrichment versus Direct Injection

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INTRODUCTION

This report summarizes the results of a continuing program to evaluate the production use of oxygen in the cupola melting operation at Griffin Pipe Products Company, Council Bluffs, Iowa.

BACKGROUND

The use of oxygen in the cupola is not a new concept to the foundry industry. Before 1960, numerous foundries had experimented with and used oxygen on a limited basis for such things as higher tap temperatures, faster temperature recoveries after shutdowns, etc. Oxygen was also used on a limited basis as a means of affording a coke reduction. In a vast majority of these cases, however, oxygen was not economically justified. It must be noted that during this period oxygen was not considered to be the least expensive of the consumables used in a cupola. Coke and scrap were relatively inexpensive, so no real savings could be realized by charge material substitution for the higher cost oxygen. An increasing demand for oxygen by the steel and chemical industry changed this position somewhat.

As bulk quantities of oxygen were becoming available at more attractive pricing, a re-evaluation of oxygen use by the foundry industry became a necessity. During the 1960s, development programs throughout the industry confirmed that cupola oxygen enrichment was economically feasible and that the following general benefits could be realized:

1. increased production
2. decreased cost through increased flexibility in raw material selection
3. increased metal temperature
4. increased carbon pickup
5. greater control of metal chemistry

Griffin Pipe recognized, some nine years ago, that oxygen enrichment could improve economically the cupola melting and pipe casting operation existing at Council Bluffs. An oxygen enrichment system was thus installed in 1971 primarily as a production tool for temperature control during ductile casting periods and intermittent melt rate increases during gray iron production.

From 1971 until 1978, this intermittent use of oxygen for temperature control and production increase proved to be both effective and economical. However, in 1978, a decision by management to produce only ductile pipe placed a burden on the melting operation for higher melt temperatures at a lesser melt rate demand than had been experienced previously. The higher melt temperature demand was successfully met at first by continuously enriching the air blast with 2% oxygen. The blast rate was reduced to offset the lesser melt demand and the added melt rate experienced with a 2% continuous oxygen enrichment blast. Coke and silicon additions were altered to provide the desired base iron chemistries. Thus, the temperature, chemistry and melt rate requirements for the all-ductile operation had now been satisfied. However, higher melt temperatures were desirable, over those obtainable with enrichment, to assist in minimizing those melting problems associated with unscheduled casting machine breakdowns, charging problems, iron transfer problems and scheduled low pipe production. Limited results from past development programs indicated that direct oxygen injection could provide additional benefits over and above that of normal enrichment. Griffin Pipe Products Co. and Union Carbide Corporation, Linde Division, thus embarked on a joint program to investigate the continuous use of high velocity direct injection of oxygen as a means for further improved temperature control.

DISCUSSION

An oxygen enrichment and direct oxygen injection system is presently installed on Griffin Pipe's 96 in. inside diameter, liningless, water-wall cupola. The cupola is equipped with ten 5 in. inside diameter water-cooled cast copper tuyeres. The tuyeres protrude approximately 15-1/2 in. into the coke bed. Blast air is supplied by a blower and hot blast system capable of delivering up to 16,000 standard cubic feet per minute of 540°C (1000°F) preheated air. Oxygen is supplied by a bulk oxygen supply system located on the foundry property. Oxygen is delivered to the foundry by oxygen transport trucks and vaporized and fed to the cupola by way of an in-plant piping system. Figure 1 shows a simple flow scheme of the oxygen control system in which oxygen is manually controlled for blast air enrichment or direct injection through the tuyeres. The oxygen is supplied from liquid storage units (Fig. 2) located adjacent to the foundry. It is vaporized with electric and/or atmospheric vaporizers and delivered by an overhead piping system to the cupola operation where it is properly valved and filtered. The oxygen then passes through a regulator, flow indicator and safety solenoid valves for injection into the main air stream for enrichment or into each tuyere for direct injection. For the direct injection, the oxygen is fed through a ring

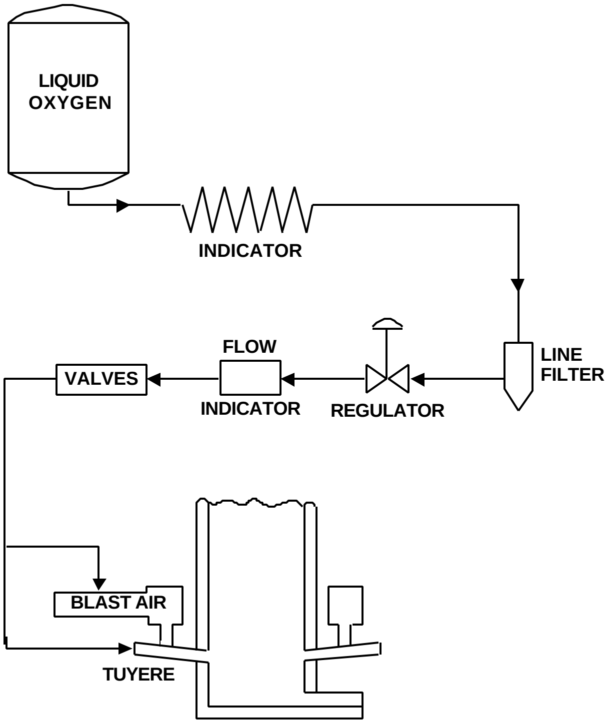

Figure 1. Oxygen Flow Schematic.

manifold to instrumentation at and into each tuyere (Fig. 3). Note that the tuyere injector releases the oxygen in the center of the tuyere within approximately 3 in. of the coke interface (Fig. 4). To minimize the effects of high temperature on the nose of the tuyere injector during the wind-off, oxygen-off mode, a small flow of nitrogen is automatically purged through each injector.

Spout temperature measurements are monitored and recorded on a strip chart recorder. The temperatures are time-oriented, thus providing an accurate correlation between temperatures and other recorded melt data.

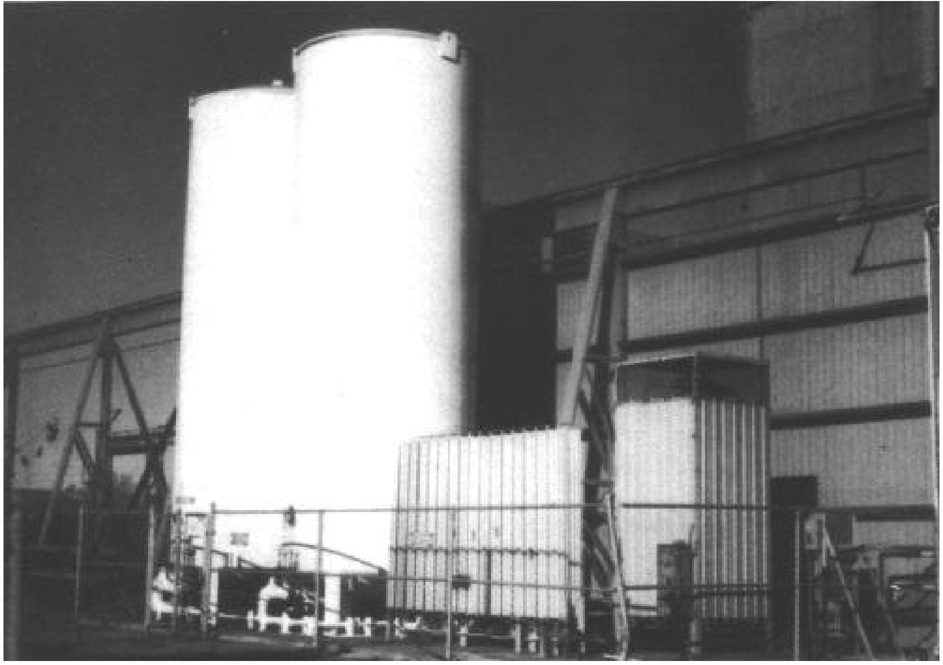

Figure 3. Cupola with tuyere injectors.

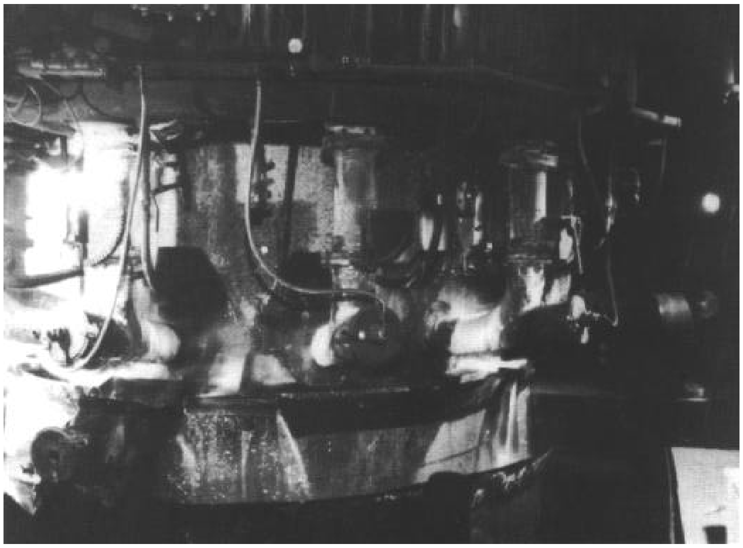

Figure 2. Liquid oxygen storage units.

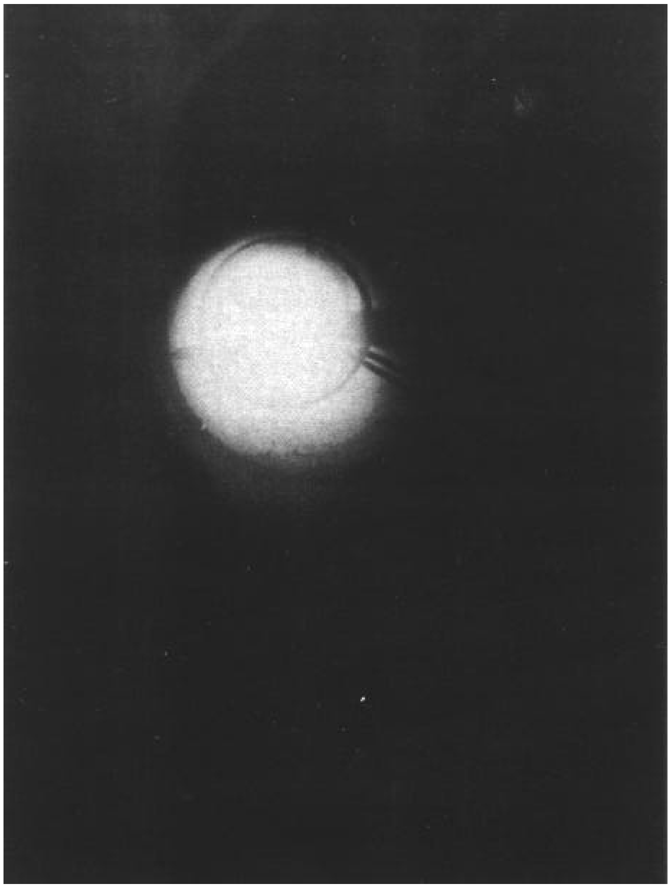

Figure 4. Oxygen injector in tuyere.

RESULTS

The various process methods of cupola oxygen use at Griffin Pipe over the last nine years offer a unique opportunity of reviewing and comparing the results obtained. For comparison purposes, the process methods can be divided into the following four categories:

1. 2% oxygen enriched blast, intermittent (used from 1971 until January, 1978)
2. 2% oxygen enriched blast, continuous (used from January 1978 through October, 1978)
3. direct oxygen injection, 5 tuyeres, 2% enrichment equivalent flow rate (every other tuyere) (used from November, 1978 through August, 1979)
4. direct oxygen injection, 10 tuyeres, 2% enrichment equivalent flow rate (all tuyeres) (used from September, 1979 to present).

The recorded data, when compared against these four oxygen process variables, revealed the following observations:

1. An increase in spout temperature was obtained with direct injected oxygen over normal oxygen enrichment. Figure 5 shows that a 42-56°C (75-100°F) increase was obtained. It is postulated that the more concentrated oxygen levels that exist at the tuyere-coke interface and the high velocity of the oxygen at each tuyere account for this increase. The higher temperatures obtained with the 10-tuyere injection method resulted from a more balanced

penetration of the oxygen. In each case, the existing oxygen velocity was about the same.

All temperatures shown here are the average of all the temperatures recorded as part of the normal data-taking process.

2. A coke reduction was realized with each oxygen process change, as shown in Fig. 6. Direct injected oxygen resulted in approximately an 18-20% coke reduction. A small additional reduction (2%) was realized with the 10-tuyere method but, because the resulting higher temperatures could be used effectively, no real effort was made toward additional coke reduction. However, it is estimated that an additional 5% coke reduction will be realized as time progresses. The increased spout temperatures obtained and the resulting carbon pickup dictated this substantial reduction in coke in order to maintain the desired base iron chemical analysis, which in this case consisted of: carbon, 3.55%; silicon, 1.65%; manganese, 0.33%; sulfur, 0.14%; and phosphorus, 0.09%.

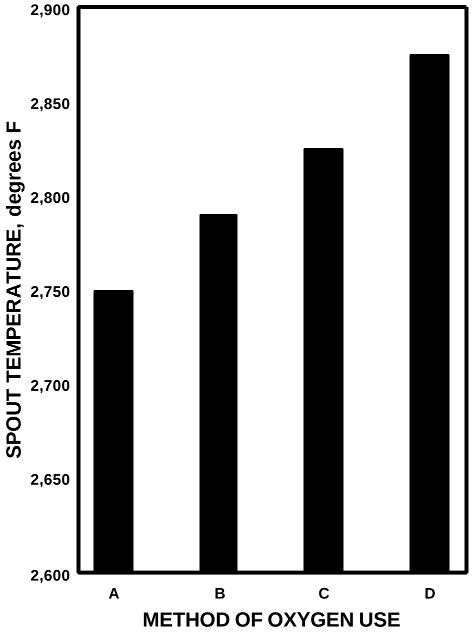

Figure 5. Temperature vs. method of oxygen use.

3. Oxygen consumption per ton of iron melted has not significantly changed, as shown in Fig. 7. The intermittent operation is shown for information purposes and would, of course, indicate less oxygen because it was not used continuously. The important consideration is that the chart implies that the increased temperatures and coke reductions were obtained at no appreciable increase in cost, which is the case. Care was exercised, in each case, to maintain the same oxygen flow to the system so that a decent comparison could be made.

4. The substantial coke reductions with direct injection resulted in melt rates far in excess of those required. The wind rate was thus reduced by some 20% to maintain the normal required melt rate. Figure 8 indicates this change. In the past, these low wind rates over a prolonged period of time resulted in less than favorable penetration conditions with predicted losses in temperatures and carbons. The addition of high velocity direct injection appears to promote better penetration at these low wind

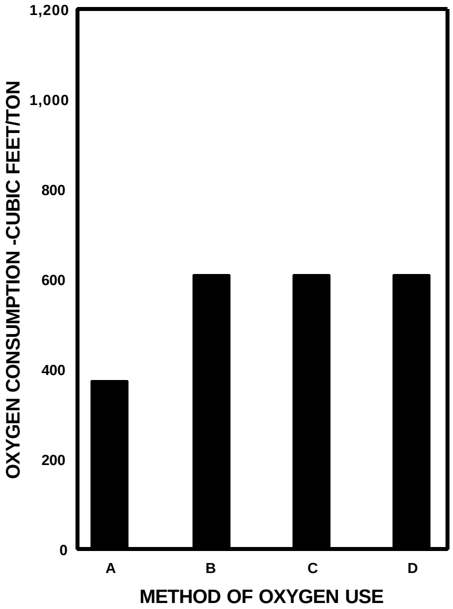

Figure 6. Percent coke vs. method of oxygen use.

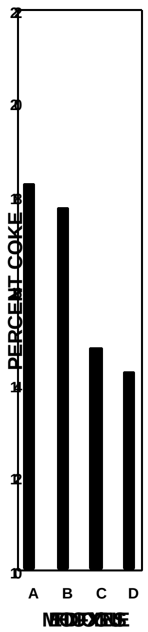

Figure 7. Oxygen consumption vs. method of oxygen use.

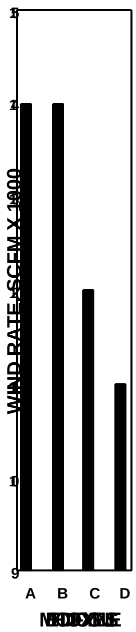

Figure 8. Wind rate vs. oxygen use.

rates and the normal problems at these levels have not been observed.

SUMMARY

In summary, continuous direct oxygen injection, when compared to continuous oxygen enrichment, has proven to be both a useful and economic addition to ductile iron melting and casting. A review of the benefits are as follows:

1. decreased coke consumption/ton of iron melted
2. increased metal temperature
3. increased carbon pickup (allowing less coke)
4. greater control of metal chemistry at low wind rates
5. beneficial results obtained at no increase in oxygen consumption/ton of iron melted
6. stack emissions are presumed to be reduced because of the reduction in blast air

The authors have attempted to present the practical results that were obtained from a program designed to aid them in their own particular melting operation. No attempt has been made to explain theoretically the reasons for some of the results. This will be accomplished during a continuing program to further improve the melting operation.