The change from charcoal to coke in iron smelting
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Abstract

From the two bases of 19th century American experience with alternate blast furnace fuels and of modern knowledge of combustion, it is possible to construct with some confidence the changes that occurred when Abraham Darby in 1709 first operated an iron blast furnace on coke instead of charcoal as fuel. Production rate would have fallen by more than one third, nearly 80 percent more air would be required per ton of iron made, and the tapped iron would be at higher temperature, be more fluid, and would make machinable thin-sectioned gray iron castings. The need for more air proved to be a serious problem, which was solved finally by the use of steam power. The coke smelted iron made possible the castings that were essential for the construction of the new steam engines that were being developed, and there was a symbiosis that was productive but that took 40 to 50 years to mature. The new coke pig iron was not popular at the finery because the softer iron took longer to fine and had higher losses, but the correction for this was worked out and from the 1750s onward, charcoal furnaces were steadily and increasingly rapidly converted to coke fuel.

When charcoal is replaced by coke in a blast furnace, several considerable changes take place in the furnace operating parameters because of the quite different combustion characteristics of the fuels. These have been largely forgotten since the few charcoal furnaces still operating do not customarily change fuel. However change back and forth between charcoal and coke in the same furnace was a common practice in the eastern United States in the late 19th century, and was well recorded. This information combined with modern knowledge of solid fuels and their combustion makes it possible to reconstruct with some confidence the consequences of such changes in fuel.

This can be useful in the study of historical events which occurred when few technical records were kept, and applies particularly to the original use of coke to replace charcoal in the blast furnace, by Abraham Darby in 1709. Few details of operating procedures or experiments were then recorded or at least survive, but reconstruction of what necessarily happened and had to be dealt with should be instructive, and can possibly help to explain the slow progress from initial use of coke to more general use 50 years later.

The procedure here will be to establish the kinds and extent of operational change produced by the change from charcoal to coke, for which an excursion into the physics and chemistry of combustion in fuel beds will be necessary. It will then be established what a normal charcoal fueled operation would likely have been in Darby’s furnace in 1709, and on this basis to then show what changes the operation of the same furnace on coke would produce. The changes can then be compared to what actually happened as shown by the surviving record. The subsequent progress to general acceptance of coke smelting can then be examined, and comment made on further development of furnace design. The historical record is based principally on Raistrick1 and Mott2.

Combustion of Charcoal and of Coke in Packed Beds

A blast furnace is basically a device for oxidizing carbon in lump form as a packed bed, the conditions of combustion depending on the physical and chemical properties of the fuel, and the reduction of metal oxides being ancillary. In modern blast furnaces with high air preheat temperatures and high tuyere velocities a tunnel or raceway is formed at the nose of each tuyere and combustion takes place within the raceway very largely to carbon monoxide and nitrogen. However with ambient temperature air and lower blowing rates such as were used up until the first quarter of the 19th century, raceways are not formed and the sequence of combustion events is extended physically into the fuel bed.

In such circumstances combustion is characterized by a very high temperature zone of oxidizing gas close to the tuyere nose (a few lump diameters distance), followed by a considerably longer zone of gas of decreasing temperature and increasing carbon monoxide content as the initially high carbon dioxide content is reduced by surrounding fuel. The length of these zones and the rate of reduction of carbon dioxide are strongly affected by the chemical reactivity and the lump size (surface area) of the type of carbon being burned. This process has been extensively explored by Hiles and Mott4.

Charcoal is a highly reactive form of carbon, in the order of ten times that of coke, and initial combustion with cold blast is to 10 to 12 percent carbon dioxide, which creates an adiabatic flame temperature of about 1,920°C within a few cm. of air entry. This carbon dioxide is then rapidly reduced to carbon monoxide by passage through more fuel, the reduction being complete typically within 40 to 60 cm. of air entry at the tuyere velocities used in early 18th century furnaces. However with coke which is much less reactive, the maximum initial carbon dioxide on combustion is about 17 percent, which creates an AFT of about 2,070°C, and