CHAPTER II

GENERAL CONSIDERATIONS GOVERNING THE CHOICE OF A METHOD OF STEEL MAKING

The foundry is divided into the following departments, not all of which are included on the premises of every shop, although with the occasional exception of the last, the functions they perform are a necessary part of the production of the castings.

1. Steel making and raw material handling.
2. Pattern making.
3. Sand mixing.
4. Moulding and core making.
5. Casting.
6. Cleaning.
7. Annealing and heat treatment.
8. Finishing, straightening, welding, etc.
9. Laboratories.

In this chapter are set forth the general considerations governing the choice of the steel-making method to be adopted, the processes of steel making available, and the characteristic features of those processes which must be considered in making a choice among them. The processes that can be used are:

1. Crucible.
2. Open-hearth, acid or basic.
3. Bessemer, bottom blown or side blown.
4. Electric.
5. Open-hearth, or Bessemer, and electric.

In the crucible process, puddled iron, or open-hearth scrap low in carbon, is melted in small closed pots with sufficient charcoal or washed metal (iron containing about 3 per cent. of carbon), to produce a steel of the desired carbon content. The pots contain about 100 lb. of metal each, and are heated by coal, coke, gas or oil. The process is one of pure melting, and as no impurities are eliminated from the steel, pure steel is produced only by the use of pure materials. Oxidation of the metal by the gases of the furnace is, however, largely avoided, since the steel is protected from the flame by the pot and its cover.

In the open-hearth process a shallow bath of pig iron and steel scrap is melted down in a large furnace of the bath type, in which the metal is continuously exposed to the oxidizing gases of the furnace, as the flame plays over the metal at all stages of the operation. From a bath comparatively high in silicon, manganese and carbon, these impurities are removed to the desired degree by oxidizing them, both by the action of the oxidizing gases of the furnace, and by that of a slag made oxidizing by additions of iron ore. In the acid process, sulphur and phosphorus are not removed, so that freedom from these harmful impurities is obtained only by using very pure materials. The basis process, on the other hand, does eliminate phosphorus and sulphur, but the slags necessary for this are more oxidizing than those used in the acid process, so that the steel is constantly exposed to severely oxidizing conditions. The open-hearth furnace in foundry work is generally of about 5 to 25 tons capacity.

The Bessemer process, in American practise, removes no phosphorus or sulphur from the steel, as only acid methods are used. By this process, a molten bath of pig iron and scrap high in carbon, silicon and manganese, is converted to nearly pure iron by blowing air through the metal or upon its surface, in a cylindrical vessel containing a narrow deep bath. Carbon, silicon and manganese are oxidized and removed by the oxygen of the air blast, and the composition is then adjusted by proper additions to the molten bath. The conditions in the process are violently oxidizing, especially toward the end of the "blow," when much iron is burned by the air blast. The size of a charge, in foundry work, is from $\frac{1}{2}$ to 3 or 4 tons.

The electric furnace heats a bath of metal by means of the electric arc in a furnace much like an open-hearth furnace, or by means of the resistance of the metal itself to the passage of an electric current through an annular bath of small cross-section. As no oxidizing gases are introduced into the furnace, the metal is not exposed to oxidizing conditions; indeed, by proper manipulation of slag and bath, neutral or even reducing conditions are attained. Not only can carbon, silicon, manganese, phosphorus and sulphur be eliminated from the steel, but the metallic oxides are almost entirely reduced from the steel and slag. In particular, sulphur and oxides are eliminated much more thoroughly than in any other steel-making process.

The electric furnace may be used to both melt and refine the charge, but owing to the high cost of electric melting, and of removing carbon, silicon and manganese while the metal is kept hot by the electric current, it is frequently advisable to use the furnace only as a means of purifying open-hearth or Bessemer metal. Furnaces are built in capacities of from $\frac{1}{2}$ to as high as 25 tons.

The detailed discussion of these processes is reserved for the following chapters, and here we shall consider them only in the light of their availability for our purposes, as influenced by the considerations governing the choice of a steel-making method, which may be summarized as follows:

A. Market:
1. Class, *i.e.*, alloy steels, very pure ordinary steel, or just plain steel.
2. Variability, *i.e.*, number of kinds of steel.
3. Size of average casting, and of largest and smallest.
4. Intricacy of castings.
5. Price—largely governed by the above 1–2–3–4.
6. Yearly tonnage in sight.

B. Raw material and fuel most available.
C. Capital available.
D. Competition to be faced.
E. Labor available.
F. Intermittent or steady operation.

A1. Quality.—Taking first the quality of the steel produced, the processes may be grouped as follows, in order of decreasing excellence, by which is meant the inherent good quality of the steel itself, unaffected by conditions of casting, or what not.

1. Electric—alone or in connection with Bessemer or open-hearth.
2. Crucible.
3. Acid open-hearth.
4. Basic open-hearth.
5. Bessemer—bottom blown.
6. Bessemer—side blown.

This classification is perhaps open to challenge, and the author is far from believing that it is a hard and fast one, or that it is necessarily correct under any and all circumstances. So much depends upon the raw materials used, the care and skill exercised in handling the work, the degree of refinement to which the different processes are carried, the personal equation of the operating force and the ideal of perfection adhered to by the management and held up to the men for attainment, that the excellence of the steel produced by any one method in a particular shop may be so far above or below the

average for this process as to upset the classification in their case completely. In this discussion, however, are given the reasons for the above classification of the processes, assuming that in every case the maximum possible degree of excellence is kept clearly in mind, worked for, and as nearly as possible attained.

The electric furnace clearly leads, since by electric furnace refining the most injurious impurities found in steel, phosphorus and sulphur, can be removed far more completely than by any other process; and at the same time the steel can be almost perfectly freed from dissolved or suspended oxides. In the electric furnace, and only in this process, it is possible to cover the steel with a slag of almost pure silicate of lime (and in arc furnaces treat this slag with fine coke), and work the steel with ferrosilicon, so that the conditions in steel and slag are strongly reducing, instead of oxidizing as in the other processes, and the last traces of oxides are converted into the metallic form. At the same time the gases which molten steel generally holds in solution are largely eliminated, and a steel is produced that is as nearly pure as we can possibly make it. The ease with which electric furnace steel containing low carbon and only small amounts of silicon and manganese can be poured into small and intricate castings, flowing smoothly like milk, setting perfectly quietly in the sink heads, and producing castings with hardly a trace of blow holes even in the hands of comparatively inexperienced steel makers, is largely due to its great purity.

The crucible process produces excellent steel, the finest that could be made, up to the date of the introduction of the electric furnace. Some authorities may even deny that the electric product excels that of the crucible. The excellencies of crucible steel are due to the protection of the melting and molten steel by the pot and is cover from the oxidizing gases of the furnace, so that after the oxygen of the air in the pot is exhausted by the burning of charcoal used as a source of carbon, or of the carbon, silicon and manganese of the metal, the steel under its layer of slag is exposed to a practically neutral atmosphere. Moreover, silicon added purposely, or absorbed from the clay of the pot, deoxidizes the steel. Thus an excellent product is obtained, even if the raw material is merely steel scrap from the open-hearth process. If the raw material be puddled iron, for reasons which will be set forth at greater length later, a much better steel is the result. But whatever be the raw material, the excellence of the steel is due to the refining in the neutral or slightly reducing atmosphere of the pot, of metal that has previously been subjected to strongly oxidizing conditions, either in the puddling furnace, the open-hearth furnace or the Bessemer vessel.

Though there is evidence tending to show that the metal is freed from oxides to a considerable extent in the puddling furnace, and that the puddled metal is further improved in crucible melting; yet it is impossible to conceive that with the surely moderately reducing conditions in the pot, even puddled metal, much less open-hearth steel, can be freed from oxides to as great an extent as is possible in the electric furnace. We believe that with the greatest care used in both processes, electric steel will excel crucible steel, and that on the average electric steel far outstrips the crucible steel generally made for castings, using open-hearth steel scrap as raw material.

That crucible steel is superior to open-hearth steel is widely accepted, and some of the reasons for that superiority are suggested by the foregoing discussion. In the open-hearth furnace the metal is subjected to strongly oxidizing conditions throughout the process, and the means at the disposal of the steel maker for reducing the oxides of iron absorbed by the steel are insufficient to carry this deoxidation to anything like completion. Hence the quality of the steel produced is inferior to that of crucible or electric furnace steel.

In acid open-hearth practice, no phosphorus and sulphur are removed from the steel, and there is even a slight gain in these impurities, while in the basic furnace the conditions are such that phosphorus and sulphur are largely eliminated; yet more strongly oxidizing slags are used in the basic furnace, and in order to facilitate the removal of phosphorus and sulphur the steel is often refined down to a very low content of carbon, which makes it more easily oxidized, and hence promotes the absorption of oxides. Add to this the fact that very impure grades of scrap are largely used in the basic furnace, and that the deoxidizing additions are generally so used that their effect is much less complete than in acid practice, and we have an array of considerations that point clearly to the superiority of acid over basic open-hearth steel. In some shops it has been found that this superiority can be measured roughly in terms of strength, and that for equal strength basic steel must have 5 "points" more carbon than acid steel.

We now come to the discussion of the excellence of Bessemer steel, and its classification relative to open-hearth. Here the author confesses he is in doubt, and hesitates to classify Bessemer steel as made for castings, below basic open-hearth. After long deliberation, the following discussion appears to him reasonable.

In Bessemer steel making air is blown through a bath of iron containing much carbon, silicon and manganese, or a blast of air is projected strongly upon the surface of such a bath. By the oxidizing action of the air, the carbon, silicon and manganese are converted to CO (gas), and to SiO_2 and MnO, the first escaping, the last two going to form slag. That much iron must at the same time be oxidized where the excess of air is great, especially at the end of the blow when the iron is no longer protected from such oxidation by carbon, silicon and manganese, is axiomatic, and is conclusively proved by the considerable loss of iron in conversion. That the oxidation by the blast is greater than the oxidation in the open-hearth furnace by the gases and the oxidizing slag, is undeniable. At the end of the blow, after the maximum oxidation of iron has taken place, the vessel is at once turned down, containing a steel very rich in oxides and gases (as shown by its "wildness," if we try to pour it at once), and we add ferrosilicon and ferromanganese to reduce the oxides. In the open-hearth process the oxidizing conditions grow less severe as the process proceeds, and we allow the steel to boil for some time, during which it undoubtedly frees itself from part of the oxides absorbed in the earlier stages of the process.

Open-hearth steel is, therefore, purer than converter steel, before the deoxidizing additions are made; and if these additions are used in such a way that their effect is as complete in the one case as in the other, the superiority of the open-hearth steel will be maintained. Since open-hearth steel in foundry work is generally poured into larger ladles than is Bessemer steel, solid additions in the ladle have longer to act, and hence do their work more thoroughly, in open-hearth practice. When the additions are made to the open-hearth furnace, they deoxidize the steel more completely than similar additions made to the Bessemer converter, because they have longer to act. But liquid additions to the Bessemer vessel or ladle probably do their work more thoroughly than solid additions to ladle or furnace. It is, of course, possible to use liquid additions in open-hearth practice, but it is seldom done, and in fact the additions are quite generally made in the ladle. Bessemer foundrymen, on the other hand, usually prefer to make their additions to the vessel, and many of them use melted material.

Open-hearth metal, therefore, can be made superior to Bessemer, but there is no doubt that owing to the more complete deoxidation often attained in Bessemer practice, much of the open-hearth steel poured in foundries is actually inferior to the best Bessemer steel made for similar purposes.

That bottom-blown Bessemer steel should be ranked above side-blown may surprise many readers, since it would seem at first glance that air blown through the metal must oxidize more iron than air blown upon the surface of the metal. However, partly because the higher temperature of side-blown steel promotes oxidation of the iron and absorption of the oxide by the steel, partly because in the bottom-blown vessel, the iron oxide formed is largely reduced again by the carbon of the overlying bath, actually the loss of iron is considerably greater in the side-blown vessel than in the bottom-blown. It would appear, therefore, that the metal must be less pure where the greatest oxidation has occurred and the greatest opportunity given for absorption of the oxide, and that other things being equal the superior position should be assigned to bottom-blown steel. The side-blown vessel, it should be said, is almost exclusively used in the steel foundry, and in numerous shops steel of very high grade is produced.

Before leaving the subject of the quality of the steel produced by the different processes, it is well to add that there are few castings used in this country to-day that call for steel of any grade higher than crucible steel made from open-hearth scrap, and that the choice of a process is largely governed by other considerations than the quality of the steel produced. Well-designed steel castings, made by any of the old processes carefully conducted, when free from flaws and blow holes and properly annealed or heat treated are excellently adapted to the uses to which they are put and will show by tests that they possess strength and ductility far beyond what they ever will be called upon to exhibit. That there is a market to-day for crucible castings made from high-grade puddled iron or for electric furnace castings, with regard to quality alone, is open to serious question, and the foundryman who makes them will certainly find it difficult to market his goods simply because of the inherent excellence of the steel from which they are poured.

A2. Variability of Product.—This demands flexibility in the steel-making process. By this is meant the ability to produce readily steels of widely differing analyses to take care of orders for small lots of steel of special composition. Such orders form a very inconsiderable proportion of the steel foundry business, and in almost no case

can be counted upon as a steady source of income-producing work. As in some special cases this may be a consideration worth taking into account, it must be touched on briefly here.

In order of decreasing flexibility, the processes are:

1. Crucible.
2. Electric.
3. Bessemer.
4. Open-hearth.

The flexibility is, of course, determined by the weight of metal in each lot melted and by the difficulty of dividing a lot into parts. On the score of weight of lots, the flexibility is therefore in the order of capacity; but the capacity in the case of crucible melting is not that of the whole furnace, but that of a pot. In crucible melting, of course, each pot is a law unto itself, so that within limits as many different steels may be melted at once as there are pots in the furnace. Indeed, as we shall see, the difficulty in crucible work is just the other way around, and great efforts must be made to produce uniform steel. There are certain sorts of steel, such as very low carbon, that are hard to produce from crucibles, but the process is out and away the most flexible.

The contents of an electric furnace may be brought to a certain composition, enough steel of this sort poured off for the purposes in hand, and the composition of the bath then changed to suit other requirements. It is easy to see that only the small furnace lends itself to such treatment, as the expense of so handling 10 or 15 tons would be prohibitive. Or, we may produce steels of different compositions from a uniform bath by making our additions in the ladle. There are two objections to this method, which are first, that it sacrifices the benefit of thoroughly mixing our steel in the furnace, and second, that it is difficult to weigh accurately the amount of steel poured out, and so to secure correct composition.

In Bessemer work, after the steel is blown no further heat is added to it, and it begins to cool as soon as the vessel is turned down. Therefore, the only method of making different compositions of steel from one heat is to do the mixing in the ladle. The same considerations apply to this as to doing the same thing with an electric furnace, and in practice the method is rather unsatisfactory. The chief difficulty is the slag, which, if fluid, cannot be held back in pouring, and makes it practically impossible to pour the proper quantity of metal into each ladle. As the metal cools quite rapidly, it must be handled without much delay. For this reason, not over two kinds of steel can be made from one heat. The Bessemer process is, therefore, less flexible than the electric.

In open-hearth work, it is almost out of the question to make more than one kind of steel at a time. The furnaces being of large capacity it is not commercially practicable to make different compositions successively in the furnace; and the steel rushes so rapidly from fixed furnaces that even with a bifurcated spout the accurate proportioning of steel to each of two ladles is extremely difficult. Should the furnaces be tilting, not fixed, more can be done in this line, but even then we have the slag to hamper us and very little flexibility is practicable. To transfer steel of low carbon from one ladle to another of smaller capacity and so produce two steels at one tap is somtimes practicable, but the limit of such procedure is soon reached by the cooling of the steel.

A3-4. Size and Intricacy.—The processes in order of decreasing suitability for pouring small and intricate work can be tabulated as follows:

1. Crucible.
2. Electric.
3. Side blown Bessemer.
4. Bottom blown Bessemer.
5. Acid open-hearth.
6. Basic open-hearth.

This classification is a difficult one to fix arbitrarily, since there are many factors in the problem to be taken into consideration, which in particular cases may shift the relative positions of the processes.

To take a single instance, electric steel, owing to its great purity and freedom from gas, and to the high temperature at which it may be poured, is eminently suited to pouring castings of the very lightest weight and of very thin section. Many excellent castings that have been regularly poured of electric steel would be almost impossible to produce by the older processes. Should the electric furnace that is being used be of small size, therefore, especially if the steel is taken from the furnace in small ladles or shanks, the electric furnace may well handle work that even the crucible foundryman would hesitate to tackle.

On the other hand, the crucible process is pre-eminently one of small units. The average pot contains from 90 to 100 lb. of steel, and it has never proved economical to melt in larger crucibles. The steel can be made exceedingly hot, fluid, and free from gas, runs well

in very light sections, and is kept hot by the hot pot, a very poor conductor of heat and so shaped as to present a very small surface of liquid steel compared to its mass. When the practice of pouring from the pots is followed, the steel can be brought to the moulds very hot, and all poured before it has an opportunity to chill. It would have to be a very small electric furnace indeed that would make it economical to shank off the steel in such very small lots that it would all be poured in light castings at the maximum temperature, and if the steel be poured directly from a large ladle it is impossible to do good work with very small castings, besides which the steel in the ladle would soon chill, at the very slow rate at which it would be disposed of. To "shank" from the large ladle manifestly would not bring the steel, especially that from the last of the ladle, to the moulds at as high a temperature as that of the pots kept hot in the crucible furnace until wanted. Lastly, the cost factor enters into this question very strongly, since the smaller electric furnaces cost very much more to operate per ton of steel than the large ones, the cost increasing in inverse ratio to the size. Hence to pour exclusively light work, using a number of small electric furnaces, considerably increases the cost of the steel in the ladle over what is possible with furnaces of 5 to 10 tons. In the crucible process, on the other hand, the unit of weight per pot is fixed and does not enter into the problem of cost of steel which is determined by the size and style of furnace used. The cost per pound of steel decreases with the increase in number of pots melted per day, and the process is as well suited to a large production of very light work as to a small tonnage. The leading position is, therefore, given to the crucible process, with the qualifying statement that other considerations may in particular cases put the electric furnace in the lead.

Again, the advocates of the small Bessemer converter, especially of the side-blown vessel of about 2 tons capacity, point out that their process is in many ways excellently adapted to the production of the very lightest work. The temperature of the metal can be made very high, the total tonnage of steel to be disposed of per blow is low, and by keeping the steel hot in the vessel and pouring from shanks, or pouring from a ladle with a number of shanks, extremely light castings can be poured. To this we may answer that as compared with the electric or crucible furnace of equal daily tonnage, the steel will undoubtedly chill faster in the unfired, although hot, vessel or ladle, than in the furnace, so that the last of the heat will often be colder in Bessemer practice than in the other processes, in spite of its initial extreme heat. Coupled with this is the fact that Bessemer steel is necessarily very full of oxides and gases, and hence "wild," when the vessel is turned down, and the time allowed for the action of the deoxidizers being short, the steel is never as pure, gas free and smooth flowing as crucible or electric steel. We are compelled, therefore, to conclude that in its nature the Bessemer process is less suitable to the production of a large tonnage of very light work than either the crucible or the electric process.

The side-blown Bessemer vessel as a general rule produces much hotter steel than the bottom-blown, and hence can be used for the manufacture of lighter castings. The higher temperature of the metal is perhaps offset to a certain extent by its greater sluggishness, due to the larger amount of oxides absorbed. This, however, is not proven, and is suggested as a possibility rather than stated as a fact. In some shops, where the bottom-blown vessel is run by men of exceptional skill and experience, it has been successfully used for extremely light work. As commonly handled, however, the side-blown vessel does better work on light castings than the bottom-blown.

The open-hearth furnace is not at all suited to light work. This is due to the generally large tonnage produced at a heat, and to the fact that the whole heat is from the necessities of the case commonly poured at once. Both of these factors militate against the pouring of large numbers of small castings, since the steel would be seriously chilled before all of it could be run into light work. The use of nozzles to pour with, and the necessarily large and violently flowing stream involved, prevents the proper pouring of small castings. Moreover, the steel is not so hot as that produced by the other processes and is less pure and well killed than crucible or electric steel. For castings averaging over 50 or 100 lb., on the other hand, the open-hearth furnace is the most suitable of the processes, especially as this heavy work commonly requires only a good average grade of steel and there is no incentive to the use of higher grade materials.

That basic open-hearth steel is less well killed, more oxidized, and contains more gas, and is therefore "wilder" and more difficult to pour into light work than acid open-hearth steel, is in the opinion of the author widely accepted, and certainly is in line with theoretical considerations of the case.

Recently a special design of small open-hearth furnace (W. M. Carr's combined furnace and ladle), has come into notice, and exceedingly good work has been done with these furnaces in pouring

very pure metal into light castings. We doubt, however, if there is sufficient evidence at this time of the economy of these furnaces on light work to justify a rearrangement of this classification in the case of the open-hearth furnace.

A5. Price of Castings.—The price paid for castings of a given sort of steel is largely governed by the size and intricacy of the castings, since this involves the amount of moulding and core making time spent upon the mould per pound of casting, the difficulty of securing good castings, etc. Though special prices are paid for alloy steels, that of ordinary carbon steel castings does not at present depend upon quality as such. The desideratum is a casting as free as possible from blow holes, cracks and flaws and other defects, of a steel well enough made and annealed to pass the usual specifications. Since the tests commonly specified are intended to exclude only badly made and annealed steels, they are comparatively easy to pass with steel made by any of the commercial processes. With a comparatively few exceptions, therefore, superior quality, whether due to the steel-making methods used, or to the heat treatment put upon the steel, will not ensure higher prices and the more costly processes should be adopted only when they are absolutely needed to produce sound castings from the patterns to be handled. It should be remembered, however, that the cost of the steel is not the only factor in the cost of the castings.

The processes are grouped as follows, in order of increasing cost of steel, the estimates being based upon prices of raw materials in the Philadelphia market as given in the *Iron Age* for Nov. 27, 1913.

1. Basic open hearth.
2. Acid open hearth.
3. Bottom-blown Bessemer.
4. Basic open-hearth and electric furnace.
5. Side-blown Bessemer.
6. Electric furnace.
7. Gas crucible furnace, 30 pot.
8. Crucible furnace, coal holes or oil melting.

The variations in the price of raw material, fuel, power, etc., from time to time and from place to place, and the effect of fluctuating output, make these figures of value chiefly to illustrate the factors governing the costs of production. Some of the estimates, for instance that for the electric furnace, are considerably higher than many that have been published. In figuring these costs, an effort has been made to adhere as closely as possible to the conditions of