back

## Steel Revolution

forward

# 1. The Kelly - Bessemer Process

In the fullness of time new insights, inventions, breakthroughs and so on are almost always made by several people independently and usually around the same time. The history of dislocations is just one of many examples. Taking carbon out of cast iron by running air through the liquid is no exception. If one considers reducing the carbon concentration in iron by simply exposing it to air (or steam), including some stirring as in puddling, we have many inventors, the earliest ones being he Chinese more than 2000 years ago. So what's an invention?
Well, it's a matter of taste. If you only accept, for example, iron-making recipes as *true* inventions if:

1. the inventor actually knew that he wanted to take carbon out by reacting it with oxygen to $CO_2$ ,
2. was able to keep the stuff liquid even after the carbon was out.
3. and could process relatively large amounts in reasonable times,

the Chinese and many others do not qualify as *true* inventors. They may just have found a recipe working under some circumstances without having the faintest idea of what was going on. You, being male or female, will find a working recipe for making a baby even if you grew up in a monastery were those things have never been mentioned and where you have never seen a female or male, respectively, after you escaped into the world as a young adult. But you didn't invent the process nor do you know how it works.

- Patent offices actually do not care if you understand exactly how your invention works as long as it works. They do not look at stuff violating basic principles of science, however, and they do appreciate if there is a certain logic to the claim. If you get a patent, you are an inventor.

In the middle of the 19th century it was clear to most everybody that you had to take "dirt", most notably carbon, out of pig iron to produce wrought iron; that the melting point of wrought iron was considerably higher than that of pig iron; and that for making steel you need to have some little carbon in the iron. The "Bessemer process" thus was "in the air", and several people made inventions in the right direction.
**William Kelly** (1811 - 1888), an American Inventor, is nowadays credited with being the first one who conceived running air through molten pig iron. He built a small converter in 1851 for making experiments. That's why we talk about the Kelly - Bessemer process here.

- Kelly started experimenting with his "air-boiling process" in 1847 and built a small converter in 1851 for conducting experiments. His goal was actually to reduce the amount of fuel required for iron and steel making. He had already discovered that, contrary to the expectations of iron workers, the injected air did *not* cool the molten iron but that the temperature actually went up.
  If he understood why this happens, I don't know. Wertime reports that Kelly didn't really understand the chemistry (Kelly did have a college education in metallurgy, though), and not much came out of his work. In particular, he failed to file for a patent early on. Only *after* Bessemer got his patents in England in 1855 - 56, Kelly filed for "Blowing blasts of air, either hot or cold, up and through a mass of liquid iron, the oxygen in the air combining with the carbon in the iron, causing a greatly increased heat and boiling commotion in the fluid mass and decarbonizing and refining the iron." in the USA before Bessemer filed there..
  The unavoidable patent disputes were essentially won by Bessemer; Kelly just received about 5 % of the royalties by steel mills, some of which took licenses from both patents to keep out of trouble. From my experience they probably figured that it is cheaper to pay a few inventors a little instead of many lawyers a lot.

Far more people were involved in suggesting something along the lines of getting air or steam in contact with liquid pig iron to take the carbon out. Suffice it to mention that Bessemer offered one James Nasmyth to pay him one third of the value of his patent to illustrate that ideas and money were around at what is know as "Gründerzeit" (literally: "the Founder Era").

It is one thing to have valid ideas, it is an other thing, entirely, to make them work. Note once more that the primary need for new iron /steel technologies was to *increase the productivity* of all the processes coming *after* pig iron was made. Let's look at a few numbers here:

- A water-power blown blast furnace in the first half of the 18th century easily produced half a ton of pig iron per day, look at the old-fashioned furnace in Schmalkalden to get an idea. Steam-engine blown blast furnaces later in the 19th century went easily up to tens of tons per day. There is a large economy of size for blast furnaces. Make your furnace larger and it produces more iron at lower cost. The maximum size depends essentially only on the air supply you can muster, and that depends on the power you have at your disposal. Water wheels provided for 50 - 100 times more power compared to bellows, and steam engines raised that by another factor of 20 or more.
  Now look at the follow-up processes needed for making steel (and, in a first stage, wrought iron). The numbers given are from Wertime's book:

  - The so-called *natural process* of making steel directly in a modern bloomery gives you around 100 kg or 0.1 ton per day and furnace. If you want more you can't use a bigger bloomery but you need to have more bloomeries. No economy of size.

- *Fining* pig iron in a forge gives you around 200 kg or 0.2 tons per day and hearth. No economy of size there.
- *Puddling* needed a skilled puddler and you could have several in parallel at a puddling furnace. Around 500 kg or 0.5 tons could be processed per (rather sophisticated) furnace and day.
- Forget about *cementation* productivity. In tons per day and unit, it is close to zero.

The conclusion is simple: Without **boosting the productivity** of pig iron / steel processing, there would be no (second) **industrial revolution**! It is quite telling in this context that Bessemer's announcements of his invention on August 13, 1856, at the Cheltenham meeting of the British Association, was entitled "The Manufacture of Malleable Iron and Steel Without Fuel".

As already remarked, it is a long way from the idea to run air through *large* quantities of liquid pig iron to a working contraption. Consider just a few points:

- Filling and emptying the converter. After the blast, what you had in there as very hot wrought iron; very hot because the energy source for heating came from its cleaning. When the process was finished, however, it started to cool and there wasn't all the time in the world to get it out before it solidified. You needed a kind of barrel that could be swiveled around.
- The lining of the converter. The thing itself had to be made out of steel. Look at one and try to do make it without iron / steel. Suitable bricks are not enough, you also needed suitable mortar.
- For blowing you needed some tuyeres that survived in molten iron. You also needed some way to keep the molten iron from running out through the tuyeres, which after all, were more or less just holes at the bottom of the container.
- For blowing air through tons of liquid iron you needed a powerful blower. Bellows certainly wouldn't be up to the job.
- You also need an infrastructure, supplying liquid pig iron and moulds for casting the finished stuff into. In other words: you needed substantial amounts of money before you did your first experiment.

Bessemer was aware of all that as the figure in his patent application shows:

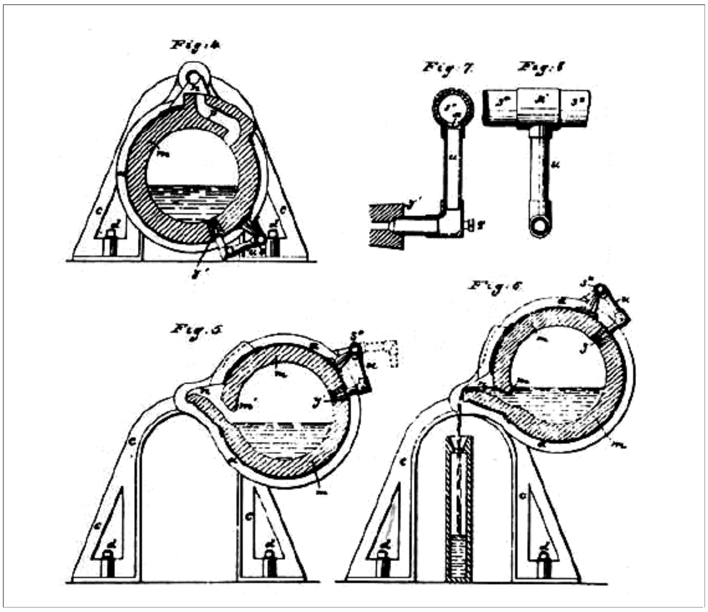
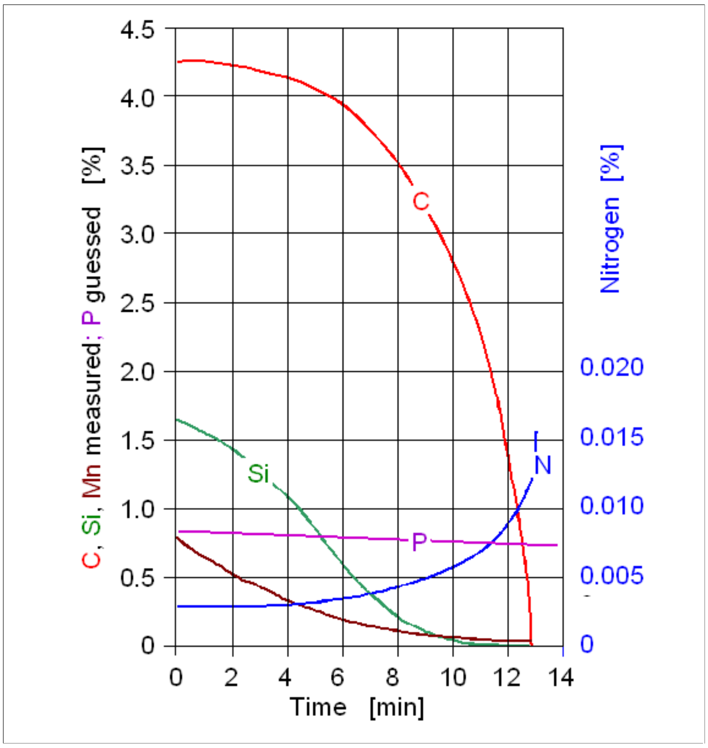


**Illustration to Bessemer's USA patent applications (identical to the one in the British application)**

Source

Bessemer convinced several steelmakers to invest in his process - and failed miserably at producing good wrought iron or steel! The major problem encountered shows up nicely in the following picture:




**Measured concentration change of some impurities during blasting in the Bessemer process (The phosphorous line is guessed)**

Source; Redrawn from a figure in [Buchwald's second book.]

- Shown is the measured development of the concentration of carbon (C), silicon (Si) and manganese (Mn) in a 25 ton converter during a 12 minute blast. What phosphorous does is not recorded, the line given is my best guess. Note also the increase of the nitrogen concentration, not to mention the oxygen concentration that is not shown.

Bessemer could not get the phosphorous out! Since most iron ore contained phosphorous, most pig iron contained phosphorous, too. While phosphorous-rich iron had been used through the millennia, sometimes conscientiously and sometimes to advantage, its time was over. It was useless.
There were also plenty of other problems. While getting large quantities (phosphorous-free) wrought iron in a short time would have been nice, getting steel would have been even nicer. But that would have necessitated stopping the blowing process at the point where the "right" carbon concentration was reached, let's say 0.7 % as an example. If you look at the red curve above, you realize that this means stopping the process at something like 12 minutes 40 seconds ± 5 seconds. This was obviously impossible!
In the face of all these problems, Bessemer showed his mettle. While he had boasted that "My knowledge of iron metallurgy was at this time very limited, but this was in one sense a great advantage to me, for I had very little to unlearn and so could let my imagination have full scope", he now engaged three chemists / metallurgists (Henry, Riley and Percy) into a task force, charged with solving the problem. Percy was a well-known iron / steel authority; it was he who first suspected that phosphorous was the problem. Bessemer was not very happy with his task force nor were its members with him; note [Percy's quib].

- Nevertheless, the intense work and the interactions with others solved the problem - up to a point. The phosphorous problem, once fully recognized, was simply dealt with by using phosphorous-free pig iron. While that severely limited the Bessemer process, it left enough leeway to allow a major industry to develop. In particular because the "making steel" problem also got solved.

Routines were developed to stop the process just at the right moment - despite the impossibility of that, as I just pointed out above. But it is only impossible if the concentration curve is as given above, not if you manage to make it rather flat around the decisive concentrations. Nothing much came of that, however, since there was a much better way for not only producing good steel but to eliminate other remaining problems in one fell swoop: Pitch in some **spiegeleisen**!

- Spiegeleisen (literally: mirror iron) or ferromanganese is an alloy counted among the cast iron varieties. It contains around 15 % manganese, a little silicon, and quite some carbon besides the iron. It was produced directly from some ores found in Prussia / Germany that consist of iron and manganese carbonates. Why the Germans produced it and what they did with it is not clear to me.
  **Robert Mushet** , who we have encountered before (look it up yourself), was aware of spiegeleisen and its near magical properties at turning "bad" Bessemer iron into good steel. He had filed patents in this direction (and lost them because he couldn't pay the premiums). Mushet well understood the commercial prospects of a redeemed Bessemer process, but Bessemer rejected Mushet's proposal for partnership. Instead he elected to pay Robert Mushet an annual pension of £ 300, a healthy sum that was probably calculated as sufficient to avoid a lawsuit.

Bessemer meanwhile filed more patents, exploiting Mushet's insights.

What is so marvelous about spiegeleisen? Just a few points will tell:

- The manganese takes care of residual sulfur and thus "hot shortness".
- Manganese is a de-oxidizer and "kills" the steel, i.e. takes out the oxygen by forming manganese oxide.
- Manganese oxide helps in slag forming, removing whatever still needed to be removed.
- The carbon in the spiegeleisen makes steel out of the iron.

It was always clear that a working Bessemer process would boost productivity by orders of magnitude, and that's what kept people going. With all the legal and technical back-and forth plus the input of all and sundry who worked with the Bessemer process, it finally emerged as a working process and came of age in the late 1860ties.

---

[1] Philip W. Bishop: The Beginnigs of Cheap Steel", Smithsonian Inst.; Washington 1959; Internt "Projekt Gutenberg"; free access