THE ENERGY ECONOMICS OF A NEW ROUTE TO IRON AND ALLOYING METAL POWDERS

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ABSTRACT

The energy costs of existing routes to iron powder are compared with the energy cost of a proposed route, the reduction of molten ferrous chloride with hydrogen at temperatures below the melting point of iron. The theoretical and experimental feasibility has been discussed in a previous paper, and here the energy consumption is shown to be significantly less than the existing processes.

1. INTRODUCTION

It has been recognised for some time that powder metallurgy offers an alternative route for the fabrication of metallic components. However, for compatibility with those fabricated by more conventional means, the powder route must be able to produce components having a good combination of strength, toughness, ductility and reliability at reasonable cost. The fundamental requirements for obtaining these desired mechanical properties in metals are reasonably well understood in terms of the influence of chemical parameters such as density and grain size. Low porosity and fine particle size are particularly desired for good mechanical properties. Previous methods of producing very fine particles have been prohibitively expensive and it is the object of this paper to outline a new route to fine iron powder and to show that, in energy terms, it is not only cheaper than existing routes to conventional iron powder but also has the advantage of being able to use indigenous ores. In addition, at no significant energy difference, the method described here is capable of producing specific alloy compositions for example, a stainless steel powder. The route proposed, in which hydrogen is used to reduce molten ferrous chloride droplets at temperatures below the melting point of iron is discussed from the thermodynamic and kinetic points of view elsewhere in this conference.

Current methods of producing iron powder suitable for powder metallurgy and direct reduction processes which produce an iron sponge, are outlined first with their energy consumptions to provide a background to the proposed route. The energy cost of extracting and transporting iron ore is not included since it is common to all the processes.

2. CURRENT POWDER PRODUCTION METHODS

Any process which starts from refined iron must include the energy cost of producing the iron. From data for the production of rolled coil and using gross energy requirement values for the fuels involved, 27 GJ/tonne of iron is required using the conversion figures given in TABLE 1. (1)(2)

2.1 Powder production from molten iron.

Using molten iron, atomisation and splat cooling techniques producing spherically shaped irregularly sized powders, add on approximately 2 GJ/tonne energy giving a total of 29 GJ/tonne iron powder.

2.2 Powder production by ore reduction.

Reduction of ore to a powder at temperatures below the melting point of iron generally produces a material suitable only as feedstock for steelmaking via open hearth or electric furnaces. Reduction can be accomplished by carbon (Höganäs & Strategic-Udy processes), by hydrogen (Pyron & H-Iron processes), by liquid hydrocarbons (Krupp-Renn & R-N processes) or by carbon monoxide-hydrogen mixtures (Esso-Little, HyL, and Wiberg-Soderfors processes). The energies consumed range from 20 GJ/tonne to 47 GJ/tonne of sponge iron.

2.3 Powder production by electrolytic methods.

These can operate using scrap, sponge iron or even ore as the feedstock. In the last case the overall energy consumption is the lowest at approximately 50 GJ/tonne.

2.4 Powder production by carbonyl decomposition.

Gaseous iron carbonyl is formed from low grade iron powder and carbon monoxide and then cracked at a different temperature and pressure to form a purer iron powder which needs further heat treatment in hydrogen. Although a high quality powder is produced, 40 GJ/tonne is required.

3. PROPOSED PROCESS

To produce iron powder by the direct reduction of ferrous chloride, the iron ore must first be converted to the mixed ferrous and ferric chlorides by treatment with hydrochloric acid.

The relative amounts of ferric and ferrous chloride depend on the ore feedstock. The chlorides are subsequently filtered from the gangue and passed to a crystalliser in which ferric chloride and ferrous chloride are separated. The crystals are then dehydrated and the ferric chloride reduced to ferrous chloride with hydrogen.

The ferrous chloride is then passed to a melting stage from which it is sprayed into a reaction chamber where it meets a flow of hydrogen. The hydrogen is sufficiently hot to maintain the ferrous chloride at the desired reaction temperature. In this chamber, ferrous chloride is reduced to the metal by the hydrogen.

Since the chloride has been sprayed into the reaction chamber below its vaporisation temperature the iron will be formed on the surface of the molten chloride droplet; when reduction is complete, the droplets, it is hoped, will end up as small metal spheres of the order of 1mm diameter composed of micro-particles of the pure metal. (A certain amount of sintering will occur during the reduction process and this will keep the droplets intact.) The product will be collected as a bed of small granules which are composed of very fine iron particles which will need further heat treatment to degass any hydrogen pick-up and to boil off any residual chloride.

During the reduction process, controlled amounts of carbon can be introduced by admixing a small amount of hydrocarbon gas with the hydrogen.

4. ENERGY REQUIRED BY THE PROCESS

Using the thermodynamic data previously described we see that a molar ratio of 8:1 hydrogen to ferrous chloride gives a 95% efficiency of reduction at about 950K, the melting point of ferrous chloride. With a molar ratio of 8:1, $6\frac{1}{2}$ moles of hydrogen will circulate within the system if the input ore is trivalent and 7 moles if divalent. Let us assume here a mixture of ferrous and ferric chlorides produced by leaching the ore with hydrochloric acid. A possible reaction system is shown in Figure 1. The ore is chlorinated at (A) and crystallised at (B). Energy needs to be supplied at (C) to remove water of crystallisation, for an equal mixture of chlorides this corresponds to 5.2 GJ/ tonne of iron. Reducing the ferric chloride to ferrous chloride consumes 0.009 tonnes of hydrogen, i.e. 1.5 GJ (D). Heating the ferrous chloride and melting it at (E) consumes 1.5 GJ/ tonne iron. Reducing the molten ferrous chloride in the reaction vessel (F) will consume 0.036 tonnes of hydrogen, i.e. 5.8 GJ. The hydrogen can be heated to 1000K by a HTGR (G) which will use 3.0 GJ. To supply the endothermicity of the reaction the hydrogen is further heated to 1300K using either electrical heaters, or an arc heater to heat a fraction of the flow to a high temperature and then admix it with the rest of the hydrogen (H). Since both these techniques are electrical the energy required 1.3 GJ must be converted to a primary energy, i.e. 5.3 GJ. Finally some energy will be required to remove the 5% unreduced ferrous chloride by boiling it out in the powder annealing process (J), if this is accomplished electrically, then 0.6 GJ of primary energy is required. The total energy requirement is thus 23 GJ/tonne of powder. However, no account has yet been made of heat recovery. The unused hydrogen and hydrogen chloride from the reaction vessel carry 3.1 GJ, the ferrous chloride unreduced and boiled off at J carries 0.2 GJ and the water vapour driven off from the crystals has 5.2 GJ. With 80% recovery efficiency, the nett energy for the process becomes 16 GJ/ tonne of iron powder.

Preliminary experiments indicate that the powder is approximately 10μ in size and uniform. A similar energy costing analysis has been performed for nickel and chromium and indicates that stainless steel powders can be produced at a comparable energy cost to current methods for producing high quality iron powders.

5. REFERENCES

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TABLE 1

Coke	32.3 GJ/tonne
Natural Gas	58 GJ/tonne or 1.2 GJ/1000 cu. ft.
Hydrogen	160 GJ/tonne
Electricity	14.3 x 10^{-3} GJ/kWh
Coal	30 GJ/tonne
Therm	0.106 GJ

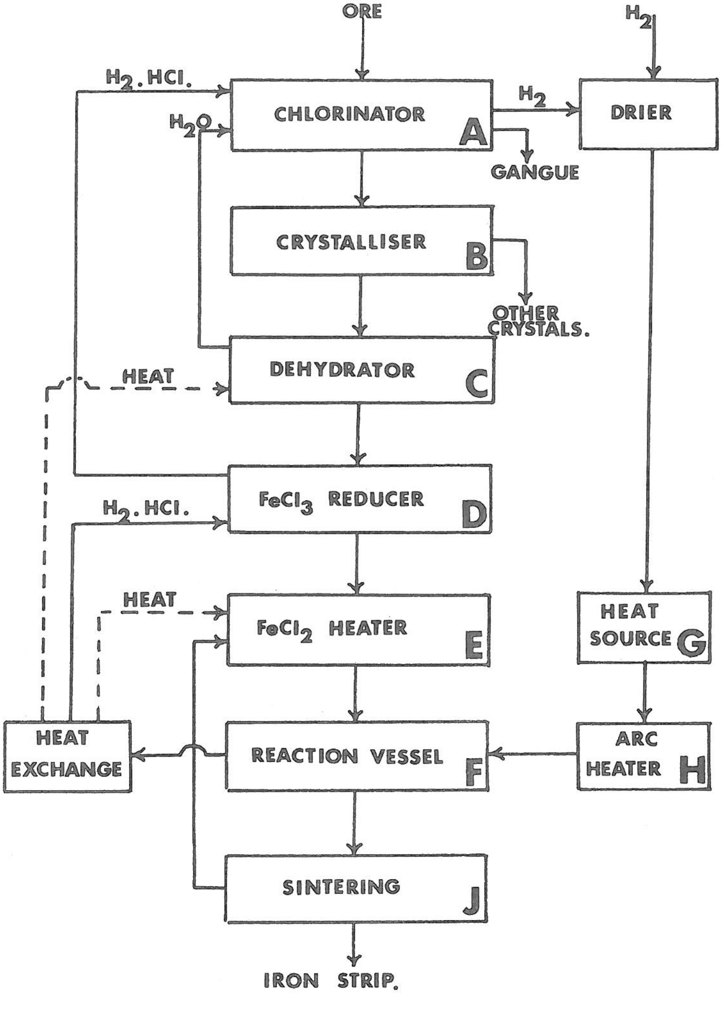

FIG 1 A POSSIBLE FLOW DIAGRAM FOR IRON POWDER PRODUCTION