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THE USE OF RADIOISOTOPE TRACERS IN THE METALLURGICAL INDUSTRIES

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ABSTRACT

Radioisotope techniques have been widely used in the metallurgical industries for many years. They have been shown to be very suitable for studying large scale plant and, in many cases, they are the most suitable techniques for such investigations. Applications of radioisotope tracers to some specific metallurgical problems are discussed.

1 INTRODUCTION

The metallurgical industries have made use of radioisotope techniques in production and in research for many years. In the early 1950s when commercial quantities of radioisotopes became available, publications began to appear describing a variety of investigations involving particularly the iron and steel industry.

There had been an early and rapid appreciation of the benefits of using radioisotopes as tracers, and sensitive nucleonic detection equipment that was readily portable and reliable was soon rapidly developed, Because of the relatively high amounts of radioactivity that could be induced in most elements, particularly through neutron irradiation, it was recognised that radioisotopes were ideal tracers for processes involving large (tonne, megalitre, square kilometre) amounts of materials. Further, the fact that the chemistry of the radioisotope of an element is identical to that of a stable isotope for virtually all elements of the periodic table, the important physical and chemical processes for most aspects of the metallurgical cycles could be traced exactly. There was an additional bonus: many of the metallurgically important elements have radioisotopes that emit energetic γ-or X-rays which can penetrate appreciable thicknesses of materials. For the first time what was going on inside a process could be monitored without having to remove samples for analysis, Furthermore, this information was being received and displayed as it happened (i.e. in real time) without the delays formerly caused by the need to send samples away for off-line analysis. The use of radioisotope tracers has been a quantum leap in the technology for both process investigations and research and development.

There are a number of the numerous reported applications of radioisotopes in metallurgy which have common themes which will be covered in this paper:

- 'weighing' of molten metals and other liquids for process and inventory control;
- measurement of mixing times for alloy preparation;
- determination of the distribution of the various sources of an element during the production of a metal;

- determination of flow characteristics and residence times for materials being processed in metallurgical operations.

2 WEIGHING OF MOLTEN METALS AND OTHER LIQUIDS

There are a number of examples of the use of radioisotopes for 'weighing' - the measurement of mercury inventories[1], the measurement of aluminium in electrolytic refining baths[2] and the measurement of slag[3,4], all of which are based on - the isotope dilution technique. In this, a known amount of radioisotope of activity A_0 is thoroughly mixed through the unknown mass of liquid material M_0. Once complete mixing is achieved, a sample of the liquid of mass, m, is removed and its radioactive content α is measured. The relationship between the variables is:

$$\frac{A_o}{M_o} = \frac{\alpha}{m}$$

or

$$M_o = \frac{A_o m}{\alpha}$$

The mass of M_0 can be calculated from the two radioactivity measurements and the mass of a small sample. However, for the measurement to be valid it is important that the radioisotope tracer must be evenly mixed throughout the material. The actual procedures used depend upon the specific system being investigated.

The measurement of the mass of slag in a furnace is often important. Technically it is difficult to get accurate slag weights since many furnaces run the slag directly into a slag pit. Slag can be estimated from material balance calculations based on the materials being put into the furnace. These estimates are generally highly variable from melt to melt and the amount of slag being extracted from the furnace can be very variable.

A range of tracers have been used in the slag studies, the most usual being ^{45}Ca, ^{46}Sc, ^{131}Ba, ^{140}La and ^{160}Tb. Ideally the best tracer is the radioisotope of a slag component, and calcium is a common constituent of normal slags. However, since ^{45}Ca ($t_{1/2}$ 165 days) has a long half life and high radiological toxicity, it is not a desirable tracer for industrial plant studies. Barium has a similar chemistry to calcium and so ^{131}Ba ($t_{1/2}$ 117 days) has been used. Rare earth oxides also have suitable tracing properties and ^{46}Sc ($t_{1/2}$ 83.8 days), ^{140}La ($t_{1/2}$ 40 hours) and ^{160}Tb ($t_{1/2}$ 73 days) have been used.

The way of introducing tracer(s) into the furnace is usually either by preabsorption of tracer solution on fluorspar balls, or encapsulation of tracer powder in metal with or without addition of fluorspar.

Slag is very viscous and good mixing may be difficult, especially where the volume or area of slag is large. It is necessary to take several samples over the whole material and average them to get the best possible estimate of slag weight.

3 MIXING TIME MEASUREMENTS

Mixing Times in Ladles

Blast furnace iron contains traces of sulphur, phosphorus, silicon and other elements. The molten iron from the blast furnaces is usually transported in refractory-lined ladles to the steel works where it is stored in large refractory-lined reservoirs known as 'hot metal mixers'. Such storage helps to smooth out variations in the properties of the molten iron. In general, no external mixing is undertaken in the hot metal mixers and the iron is kept molten through good heat insulation. There are usually gas flames at the entry and exit of the mixer.

The isotope dilution technique has been used to study the mixing efficiency of the hot metal mixer[5]. The tracer ^{59}Fe is added to a ladle being used to charge the mixer. Samples from the mixer are taken periodically and the specific activity of the samples compared to the calculated specific activity based on the known amounts of iron present. The theory regarding the determining of mixer efficiency has been dealt with by Guizerix[6].

4 DETERMINATION OF THE DISTRIBUTION OF THE VARIOUS SOURCES OF AN ELEMENT DURING THE PRODUCTION OF A METAL

Elements in the Metal

The levels of the various elements present greatly affects the quality of steel but maintaining consistent chemical compositions in the various feed materials used to make the steel is difficult. Chemical and statistical analyses cannot answer questions on the amounts and rates of transfer of the various elements between the various furnace components and the final steel product. Tracer investigations are a means of solving these problems so that the elemental balance in the process can be determined.

Each of the raw materials going into the process has to be labelled with the radioisotope of the element under investigation, e.g. sulphur, phosphorus, chromium[7]. The tracer levels in the slag, the metal inclusions in the slag, the gases and the bulk steel are made and the material distributions obtained from the balance of the tracer.

Studies of this kind have had valuable inputs into the production efficiency and the quality of steel.

Non-Metallic Inclusions

Tracer techniques have been used in a number of countries in order to determine the origin of non-metallic inclusions in steel[4,8,9]. Non-metallic inclusions in steel cause problems, particularly when the steel has been either hot-or cold-rolled. The inclusions, which show up as surface defects, are usually pure silica or mixtures of metal silicates from a variety of possible sources:

- furnace brickwork
- tapping hole brickwork

The tracers for the slag phase are usually ^{140}La or ^{46}Sc, while those for the metal are usually ^{60}Co or ^{198}Au. The tracers, which are encapsulated in steel or iron, are usually introduced into the furnace through the tuyeres via either manual or pneumatic injection.

Samples of iron and of slag from the exit streams of the furnace are taken and counted. The flow characteristics of the regions of the furnace near each tuyere are then characterised and compared to investigate whether there are blockages to flow paths in the hearth. The residence time for the tracers can also be calculated.

Flow Studies in Nickel Electrolytic Refinery

The flow and mixing behaviour of an electrolyte during electrolysis is important for the efficiency of the process. In a study of a nickel refinery[11] the movement of the electrolyte was followed using ^{24}Na and ^{82}Br.

Circulation times for the electrolyte were determined using the peak-to-peak technique, and residence times in purifying vessels were measured by means of detectors attached to outlet pipes. Such measurements showed up variations in electrolyte injection rates and also confirmed that the cathode chamber design results in homogeneous mixing.

The use of radioisotope tracers for evaluation of process parameters has been reviewed[12,13].

6 CONCLUSIONS

Radioisotope techniques have been shown to be important for investigation of the complex processes that are part of metallurgical industries. They are well suited to large-scale industry because even at very low levels, radioisotopes can be readily detected. The flexibility and subtlety of these techniques allow cost-effective investigations to be readily undertaken that cannot be done using other technologies.

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