The raw iron produced at New Zealand Steel (NZS) contains approximately 3.3% carbon, and metalloid impurities such as silicon (0.3%), titanium (0.4%) and vanadium (0.5%). These metalloids are removed before converting the iron into steel. Since the vanadium slag by-product is a valuable resource, NZS would like to optimise its recovery.

The vanadium is extracted from the iron by adding oxygen to the liquid iron bath, where it reacts with the vanadium and other elements to form a slag which can be removed from the iron surface.

Oxygen can be added by either blowing gaseous \( O_2 \) into the iron bath, raising the temperature of the bath, or by adding solid millscale \((Fe_2O_3)\) onto the bath surface, which is roughly temperature neutral. Using silicon as an example, the reaction with gaseous \( O_2 \) is:

\[ O_2 + Si = SiO_2 \]

The rate of this reaction at a particular temperature is a constant \( k \), characteristic of the element. The actual form of the temperature dependence of \( k \) is not currently known, but may follow the empirical relation given by the Arrhenius equation. The metalloid/oxygen reaction rates decrease with increasing temperature, making the extraction of the metalloids more favourable at lower temperatures. By contrast, the carbon/oxygen reaction rate increases with temperature, leading to the possibility of a carbon boil, a run-away carbon/oxygen reaction that can happen when the metalloid concentration is low and the temperature is high. The rapid evolution of CO during a carbon boil causes the bath to erupt, damaging the plant equipment. In general, it is desirable to minimise the oxidation of carbon, as it is required for the conversion into steel in the down-stream process.

The reaction produces a certain amount of heat, characteristic of the element, most of which goes into heating the bath, with some lost to the surroundings. The concentration of silicon, \([Si]\), will decrease with time according to an equation which will be something like:

\[ -\frac{d[Si]}{dt} = k [Si]^a [O]^b \]

The values of \( a \) and \( b \) depend on the order of the reaction. For first order reactions, the most common case, both \( a \) and \( b \) will be 1.

A similar equation holds for the reaction of millscale with silicon,

\[ 2Fe_2O_3 + 3Si = 4Fe + 3SiO_2 \]

except that gaseous oxygen is injected at a constant rate \( r \), whereas the millscale is all added in a discrete mass, and the reaction occurs over time as the millscale is stirred into solution.

The concentration of the other elements in the bath, i.e. Ti, Mn, V and C, will have similar forms, leading to a set of coupled differential equations. The problem is to solve the equations for a given batch of iron (i.e. an input weight, temperature and chemical composition), finding an optimal oxygen addition (gaseous \( O_2 \) and/or millscale) that maximises the vanadium oxidised while minimising the carbon loss. The timing of the millscale addition should also be optimised, given that millscale can be added in up to three discrete dumps at any time during the \( O_2 \) injection.

Si can also be added in three discrete dumps during the process, in the form of FeSi. Typically, this is done to prevent carbon boils, which must be avoided at all times.

The plant equipment imposes some physical constraints, such as minimum and maximum millscale and gaseous oxygen additions, maximum oxygen blowing time, and minimum and maximum temperatures during processing.