(54) Title: METHOD OF RECOVERING A METAL FROM A MIXTURE

(57) Abstract: The invention relates to a method of recovering a metal from a mixture comprising more than one metal. According to the invention, the method comprises the steps of (a) melting the mixture to produce a melt; (b) passing the melt over a cooled surface, causing the metal to be recovered to crystallise out on the cooled surface and a desired metal-depleted melt is discharged from the cooled surface.
Method of recovering a metal from a mixture

The present invention relates to a method of recovering a metal from a mixture comprising more than one metal.

The recovery of a desired metal from a mixture of metals, such as scrap, often results in the desired recovered metal being contaminated with other metals present in the original mixture of metals. That is to say, the metal lattice of the desired metal is contaminated. It is not uncommon for this contamination to be worse than that of an original scrap particle of the metal to be recovered.

The object of the present invention is to provide a method of effectively recovering a metal from a mixture of more than one metal.

To this end the method according to the invention is characterised in that the method comprises the steps of

a) melting the mixture to produce a melt;
b) passing the melt over a cooled surface, causing the metal to be recovered to crystallise out on the cooled surface and a desired metal-depleted melt is discharged from the cooled surface.

It has been found that by maintaining the cooled surface at a suitable, easily determined temperature, the metal to be recovered crystallises on the cooled surface and forms a crystalline layer thereon. The desired metal-depleted melt flows off this surface. The material crystallised on the surface has a high purity, and is deficient in other metals polluting the desired metal. The cooled surface is for example a plate, and cooling may occur both by feeding a cooling medium through ducts in the plate, and by means of a gas that is contacted with the plate. The plate may oscillate or rotate, but even a non-moving plate works excellently. The desired metal-depleted melt may, if the same still comprises an interesting amount of metal to be recovered, be subjected again to the treatment described at b). The definition of metal as used in the present application includes, apart from the elements generally known as metals also elements having semiconductor properties, such as silicon. The recovery of the metal to be recovered results in a melt enriched with one
or several other metals, which may also be useful. Although this invention is described by way of the crystallisation of a desired metal on a cooled surface, it is obvious to the person skilled in the art, that it may equally well be the melt discharged from the cooled surface that one wishes to recover. That is to say the metal to be recovered is a metal whose separation from the mixture is desired and the melt deficient in this metal is the desired product. This falls completely within the scope of the present invention. What becomes deposited on a cooled surface depends on the composition of the mixture, more particularly the melt thereof, and more specifically still, the phase-diagram of the melt. The actual deposited material is determined, apart from by the phase-diagram, also by other parameters known from the literature (Burton, W.K. et al, J. Chem. Phys. 21, pp. 1987-1990 (1953)).

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k = \frac{k_0}{k_0 + (1-k_0) \exp \left( -\frac{f\delta}{D} \right)}
\]

\(k_0\) = the best possible partition coefficient with the extremely slow growth of a single crystal
\(k\) = actual partition coefficient with practical crystallisation speed
\(f\) = crystallisation speed
\(\delta\) = thickness of the boundary-layer, where atom diffusion takes place
\(D\) = atomic diffusion coefficient of the component (metal to be recovered) in the fluid boundary layer.

In contrast to several other methods known in the art, the present invention does not rely on the formation of (metal)crystals in solution (e.g. the melt).

In practice this will suffice the ordinary person skilled in the art to determine and optimise without problems the suitable operational conditions for the melt at hand, requiring no further explanation.
In an area different to that of the present invention, namely the separation and purification of organic compounds, US 3,621,664 relates to a method for fractional crystallisation. The possibility has been reported of using a melt instead of a solution.

For passing the melt over the cooled surface and discharging the recoverable metal-depleted smelt, the cooled surface is preferably disposed at an angle to the horizontal.

Allowing the melt to thus flow over the cooled surface provides non-laminar, i.e. turbulent flow, with the result that recoverable metal can reach the cooled surface due to flow (and hence not only diffusion), allowing it to crystallise there.

The angle may be chosen from a wide range and is, for example, between 0.1 and 30°C to the vertical.

Preferably the angle is between 2°C and 12°C to the vertical.

Thus excellent turbulent flow of the melt over the cooled surface can be achieved.

The crystalline metal layer deposited on the cooled surface may comprise cavities containing recoverable metal-depleted melt. After discharging the recoverable metal-depleted melt from the cooled surface on which metal is deposited, the metal surface is, in accordance with a preferred embodiment, heated to just below the melting temperature of the crystallised recoverable metal, and a further amount of recoverable metal-depleted melt is discharged from the heated surface.

In this way the recoverable metal-depleted melt "sweats out" of the metal layer deposited on the cooled surface and the material sweated out is discharged over the heated surface.

According to a preferred embodiment, the metal surface is heated by passing melt over it, and contaminations are discharged from the metal surface by the melt.

Here, either a hotter melt is conducted over the cooled surface or if a melt that has not been heated is conducted over the surface, cooling of the cooled surface is re-
duced or even stopped. A combination of both measures is also possible.

The crystallised material may be removed from the cooled surface in various ways, for example, by means of mechanical techniques such as grinding. However, according to a preferred embodiment, the surface is heated to at least the melting temperature of the recoverable crystallised metal, for the removal of the recoverable metal from the metal surface. The molten recoverable metal may then simply be collected. Optionally the recoverable metal may be molten anew and further purified with the aid the method according to the invention.

Although the method according to the invention can be used for numerous metals, the metal to be recovered is preferably chosen from aluminium, magnesium, tin, lead, silicon, germanium and gallium.

It will generally be preferred to carry out the method according to the invention under an inert atmosphere. It is especially preferred to work in low-oxygen conditions and preferably in the absence of oxygen. The inert atmosphere preferably provided by a noble gas, such as argon.

When conducting the melt over a cooled surface, the film thickness is for an optimal turbulence chosen such that the Reynolds number $\text{Re}$ is at least 300, and preferably at least 500. The film thickness is preferably chosen such that the Reynolds number has a value between 700 and 1300.

The Reynolds number is defined as

$$\text{Re} = \frac{\rho \bar{v} \delta}{\eta}$$

wherein

$\rho$ is the density of the melt conducted over the cooled surface;

$\delta$ is the thickness of the film;

$\eta$ is the dynamic viscosity of the melt conducted over the cooled surface; and

$\bar{v}$ is the mean flow velocity of the film.

Values for the above mentioned parameters are ei-
and Physics, CRC Press), or maybe determined by the ordinary person skilled in the art (see Fulford, Advances in Chemical Engineering, volume 5 (1964), Academic Press, New York). A suitable film thickness for aluminium is less than 1 mm, preferably less than 0.7 mm, in particular approximately 0.5 mm.

The invention will now be elucidated by way of a drawing, wherein,

Fig. 1 is a schematic illustration of an apparatus suitable for the application of the method according to the invention; and

Fig. 2 is a side view of the apparatus shown in fig. 1.

The apparatus depicted in fig. 1 comprises a vat 1 for a melt, which is, for example, a melt of aluminium metal-containing scrap. The melt has a temperature of 5°C above the point at which solidification of aluminium takes place. Via a discharge opening of the vat 1, the melt is conducted under the influence of gravitation, over a substantially vertically disposed cooling element 2. Aluminium from the melt is deposited on the cooling element 2, and the aluminium-depleted melt is collected in a receptacle 3. The aluminium-depleted melt collected in the receptacle 3 may again be conducted over the cooling element 2 (or another not shown cooling element 2').

To remove any metal-depleted melt in pores in the layer of aluminium deposited on the cooling element 2, the cooling element 2 can be heated, after the passing of the melt over the cooling element 2 has stopped, to a temperature below the melting point of the deposited aluminium. To harvest the deposited aluminium, the layer of deposited aluminium is heated to above its melting point, and then molten desired aluminium is collected. If desired, the purification process as described above is repeated.

In the embodiment illustrated in fig. 2, the cooling element 2 is provided with fins 4, which contribute to the dissipation of solidification heat.

The material used for the cooling element 2 depends on the operational temperatures, which in turn will be deter-
mined by the temperature of the melt and the material being deposited. Obviously, the material should be able to conduct heat well, and have a melting point that is above that of the melt. For this embodiment, a copper cooling element 2 is contemplated, said copper cooling element being covered with an alumina coating, or other ceramic coating, which helps to prevent exchange of metals between the cooling element and the deposited layer (if any). If deemed necessary, the cooling element 2 may have a rough surface, helping to prevent that the aluminium deposited to slide off. The ordinary person skilled in the art can use his or her general expertise to select a proper material for working with the melt at hand.
CLAIMS

1. Method of recovering a metal from a mixture comprising more than one metal, characterized in that the method comprises the steps of
   a) melting the mixture to produce a melt;
   b) passing the melt over a cooled surface, causing the metal to be recovered to crystallise out on the cooled surface and a desired metal-depleted melt is discharged from the cooled surface.

2. Method according to claim 1, characterized in that for passing the melt over the cooled surface and discharging the recoverable metal-depleted smelt, the cooled surface is disposed at an angle to the horizontal.

3. Method according to claim 2, characterized in that the angle is between 2°C and 12°C to the vertical.

4. Method according to any of the preceding claims characterized in that after discharging the recoverable metal-depleted melt from the cooled surface on which metal is deposited, the metal surface is heated to just below the melting temperature of the crystallised recoverable metal, and a further amount of recoverable metal-depleted melt is discharged from the heated surface.

5. Method according to claim 4, characterized in that the metal surface is heated by passing melt over it, and contaminations are discharged from the metal surface by the melt.

6. Method according to any of the preceding claims, characterized in that the surface is heated to at least the melting temperature of the recoverable crystallised metal, for the removal of the recoverable metal from the metal surface. The molten recoverable metal may then simply be collected. Optionally the recoverable metal may be molten anew and further purified with the aid the method according to the invention.

7. Method according to any of the preceding claims, characterized in that the metal to be recovered is chosen
from aluminium, magnesium, tin, lead, silicon, germanium and gallium.

8. Method according to any of the preceding claims, characterized in that the method is carried out under an inert atmosphere.

9. Method according to any of the preceding claims, characterized in that when conducting the melt over a cooled surface, the film thickness is for an optimal turbulence chosen such that the Reynolds number $Re$ is at least 300, and preferably at least 500.

10. Method according to any of the preceding claims, characterized in that the film thickness is chosen such that the Reynolds number has a value between 700 and 1300.