Title: ENCAPSULATED SOLID FUEL FOR MINERAL MELTING FURNACES

Abstract: The present invention relates to a novel encapsulated solid fuel particularly useful for cupola and blast furnaces for, e.g. mineral and metal ore melting. The present invention also relates to the preparation of such an encapsulated solid fuel and to the use of the encapsulated solid fuel in a mineral melting furnace process. More particularly, the invention relates to an encapsulated solid fuel, said fuel comprising a core portion comprising at least 50% by volume of one or more carbonaceous fuel material(s) (e.g. coke, PET coke, charcoal, anthracite, bituminous coal, lower rank coals, waste material, and biofuels), and a shell portion comprising at least 60% by volume of one or more mineral material(s) (e.g. olivine, basalt, diabase, gabbro, slag, limestone, waste stone wool, fly-ash, sand and cement).
ENCAPSULATED SOLID FUEL FOR MINERAL MELTING FURNACES

FIELD OF THE INVENTION

The present invention relates to a novel encapsulated solid fuel particularly useful for cupola and blast furnaces for, e.g. mineral and metal ore melting. The present invention also relates to the preparation of such an encapsulated solid fuel and to the use of the encapsulated solid fuel in a mineral melting furnace process.

BACKGROUND OF THE INVENTION

The production of stone wool and, e.g., iron ore are important industrial processes. The mineral melting in the production process for stone wool is typically conducted in a so-called cupola furnace in which the raw materials, e.g. coke (or another carbonaceous fuel material) and mineral materials (such as rocks (e.g. of basalt, diabase, gabbro), briquettes (e.g. of olivine, basalt, diabase, gabbro), slag, limestone, waste stone wool, etc.), are charged to the upper part of the furnace. Air is blasted through a number of nozzles near the bottom of the cupola. Most of the coke combusts at a very high temperature in the lower region just above the nozzles. The hot flue gas from the combustion containing carbon dioxide and water vapour flows up through the cupola and leaves the top at a significantly reduced temperature of perhaps 100-200°C. The upward flowing flue gas transfers its energy to the down flowing raw materials that melt and to the coke. The raw materials melt in the region above the nozzles. The melt runs to the bottom of the cupola furnace and is collected in a melt bath located below the nozzles. The molten mineral material is found in the lower region of the furnace, and coke is found in a region just above the lower region.

Other industrial processes also involve a similar type of furnace and also require a carbonaceous fuel material as an energy source.

A problem realised in conventional cupola furnaces is that a considerable amount of the fuel, i.e. coke or other carbonaceous fuel material is partly pyrolysed or gasified with carbon dioxide or water vapour in the upper part of the furnace. Hereby a significant fraction of the energy is lost from the cupola furnace and a significant amount of potential problematic emissions from the furnace, i.e. CO (carbon monoxide), C\textsubscript{x}H\textsubscript{y} (hydrocarbons), nitrogen containing and/or sulphur containing species are formed.
Another, more practical, problem is that a particular type of coke (not too reactive and physically stable) is required for optimal processing in a cupola furnace. Sources of such coke qualities are not unlimited, and the market price is presently relatively high.

SE 450,579 A discloses ore smelting furnace supplementary fuel in the form of a briquette comprising coal or coke, a hydraulic binder, and a filler.

BRIEF DESCRIPTION OF THE INVENTION

The present invention provides an elegant solution to the above problems by means of the encapsulated solid fuel defined herein.

One aspect of the present invention relates to an encapsulated solid fuel, said fuel comprising a core portion comprising at least 50% by volume of one or more carbonaceous fuel material(s), and a shell portion comprising at least 60% by volume of one or more mineral material(s).

Another aspect of the present invention relates to a process for the preparation of a melt of a mineral material in a furnace, said process comprising the step of charging one or more carbonaceous fuel material(s) and one or more mineral material(s) to said furnace, and combusting said carbonaceous fuel material(s) in said furnace, wherein at least a part of said carbonaceous fuel material(s) and said mineral material(s) are charged to the furnace in the form of the encapsulated solid fuel defined herein.

A still further aspect of the present invention relates to an encapsulated solid fuel, said fuel comprising a core portion comprising at least 50% by volume of one or more carbonaceous fuel material(s), and a shell portion comprising at least 60% by volume of one or more metals and/or metal oxides.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates an overall process for production of stone wool products, and Figure 2 illustrates a cupola furnace in the production of stone wool products (both from “Mathematical Modelling of a Cupola Furnace” by Rasmus Leth-Miller, Ph.D. Thesis, DTU, Lyngby, Denmark.)
Figure 3 illustrates a cross-sectional view of various embodiments of the encapsulated solid fuel according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

One aspect of the present invention relates to an encapsulated solid fuel, said fuel comprising a core portion comprising at least 50% by volume of one or more carbonaceous fuel material(s), and a shell portion comprising at least 60% by volume of one or more mineral material(s).

When used herein, the term "% by volume" is based on the total volume of the solids in the core and in the shell, respectively. The shell (and the core) may have a certain porosity, but the void space represented by pores, canals, etc. will – of course - not contribute to the total volume of the solids. Thus, a shell layer exclusively consisting of waste mineral wool will consist of “100% by volume of waste mineral wool” regardless of the porosity of this shell layer.

The encapsulated solid fuel is particularly useful for industrial processes wherein the main energy source is carbonaceous fuel materials. Examples of such processes are, e.g., mineral melting processes (e.g. stone wool production) and metal ore melting processes. In general, the fuels of the present invention are particularly useful for processes relying on cupola and blast furnaces.

A main feature of the fuel is that the one or more carbonaceous fuel materials are encapsulated in such a manner that the conversion (combustion, gasification, pyrolysis) thereof will be delayed, and so that – when referring to a cupola furnace – the carbonaceous fuel materials will undergo conversion (combustion, gasification, pyrolysis) further down in the furnace compared to conventional carbonaceous fuel materials. Thus, the encapsulated solid fuel can be seen as a fuel which has an exterior shell providing thermal insulation for the carbonaceous fuel material(s) and/or diffusion limitations for reactive gases such as oxygen, carbon dioxide, water vapor, etc. The fuel may also comprise other reactants useful or necessary for the above-mentioned industrial processes.

The fuel can also be used in moving bed reactors for indirectly feeding of reactants in different positions of the reactor – even though only one physical location for the loading of raw materials is used.
Encapsulated solid fuel

The fuel defined herein has a core portion comprising as predominant constituents (i.e. at least 50% by volume) one or more carbonaceous fuel material(s), and a shell portion comprising as predominant constituent(s) (i.e. at least 60% by volume) one or more mineral materials.

The volume ratio between the core and the shell is sometimes given by the overall ratio between the mineral material(s) and the carbonaceous fuel material(s) required for a given process. In most instances, however, the volume fraction of the shell is typically in the range 5-99%, such as 15-98%, e.g. 25-97%, of the total volume of the fuel.

The fuel typically has an average size of 0.1-500 mm, such as 1-500 mm, or 10 mm-500 mm, or 10 mm-350 mm, or 20 mm-350 mm, or 20 mm-300 mm, or 20 mm-250 mm. The actual size of the fuel is typically defined by the overall dimensions and process parameters of the process in which the fuel is used. Typically, the dimensions of the fuel are such that it allows the mineral material melt to pass through the interstices.

Thus, the thickness of the shell portion is on average in the range of 0.01-200 mm, such as 5-200 mm, or 30-200 mm, or 30-100 mm. It is advantageous that the shell portion of the fuel has a somewhat even thickness so that the insulating/diffusion protection properties upon use can be maintained for a fairly well-defined time, and so that the carbonaceous fuel material(s) is/are not rendered accessible before the fuel reaches a predetermined location in the furnace.

The core

The core portion comprises at least 50% by volume, more typically at least 60% by volume, or at least 75% by volume, such as at least 85% by volume, or at least 95% by volume, or even 100% by volume, of the carbonaceous fuel material(s). Most available carbonaceous fuel materials include minor amounts of ash components, and such ash components are considered as an integral part of the carbonaceous fuel materials when considering the volume fraction of carbonaceous fuel material(s) in the core portion.

The one or more carbonaceous fuel material(s) can be selected from a wide range of materials useful for similar purposes. Illustrative examples are, e.g., those selected from coke, PETcoke, charcoal, anthracite, bituminous coal, lower rank coals, waste material, and biofuels, in particular selected from coke. It is noted that the range of carbonaceous fuel
materials is somewhat broader that conventional fuel materials for similar industrial processes, e.g. mineral melting and metal ore melting, in that it is not required that the carbonaceous fuel materials have the same high quality with respect to chemical characteristics and size distribution. Thus, carbonaceous fuel materials of a lower quality may be used because the materials are encapsulated so that conversion (combustion, gasification, pyrolysis) thereof will be somewhat delayed and because the size distribution determined by the encapsulation process (and not by the parent carbonaceous fuel material particles).

The shell

The shell comprises at least 60% by volume of mineral material(s). The mineral material(s) of the shell can be selected among the materials conventionally used in briquettes for the mineral melting process, among high-melting or lower melting cements, metals of different kinds etc. Furthermore the inner part of the shell can be a material with a lower heat transfer coefficient. In this way the encapsulated solid fuel can be formulated to pyrolyse (for volatile-containing fuels) or to be liberated for combustion/gasification in different positions in the furnace depending on where the melting will occur. This introduces a significant flexibility for the selection of fuel, for the design of the process and for the control of the process.

Illustrative examples of mineral materials to be used as shell materials are olivine, basalt, diabase, gabbro, slag, limestone, waste stone wool, fly-ash, sand, and cement.

At least one mineral material must be included, however in a preferred embodiment, at least two different mineral materials are included.

For fuels containing significant amounts of volatiles, a certain porosity of the shell is most often required, either as a few larger pores (see, e.g., Figure 3B) or as a more distributed porosity (see, e.g., Figure 3C). For such fuels, insulation by, e.g., a layer of stone wool or other material with a low heat transfer coefficient may be advantageous (see, e.g., Figures 3D and 3F where the wavy lines illustrate a material with a low heat transfer coefficient). Such a layer will be considered a part of the shell.

Thus in one embodiment, the shell is porous, thereby allowing gasses (pyrolysis) from the carbonaceous fuel material to escape while maintaining the structural integrity of the encapsulating mineral material. The shell preferably has a porosity of up to 20%. If the shell comprises a mineral wool layer, however, the overall porosity of the shell may even be higher than 20%.
In one embodiment, the shell comprises an inner shell layer comprising at least 25% by volume of mineral wool, e.g. waste mineral wool (see, e.g., Figures 3D and 3F where the areas with wavy lines illustrate the waste mineral wool). It should be noted that the porosity of such an inner layer of mineral wool may be fairly high, depending on the compression of such an inner layer upon manufacture of the encapsulated solid fuel.

In one preferred embodiment of the encapsulated solid fuel according to the invention, the core portion comprises at least 85% of coke, and the shell portion having a maximum porosity of 20%, the average block size being in the range of 30–250 mm, and the shell layer volume fraction being 25-97%.

In one embodiment, the shell also comprises an inner shell layer comprising a reagent, e.g. urea or the like, which can liberate reactants, e.g. ammonia, at a suitable temperature (typically 600-1000°C) so as to reduce the NOx release from a furnace.

**Structure of the encapsulated solid fuel**

In general terms, the fuel comprises a core portion and a shell portion. In many instances, it may be somewhat difficult to recognize a stringent border between the core portion and the shell portion, because the materials in a border zone may be mixed. For the purpose of the present description with claims, however, the core can be defined as fictitious “body” within the fuel which has approximately the same shape as the fuel itself and which comprises at least 50% by volume of carbonaceous fuel material(s). This is illustrated in Figure 3E wherein the dashed circle illustrates the fictitious border between the core and the shell.

Figures 3A-3H illustrate various embodiments of the encapsulated solid fuels of the invention. It should be understood that the fuel may have form of a briquette, a tablet, an elongated member, a substantially spherical object, a rod, a cylinder, etc. For the purpose of illustrating the principles behind the construction of the fuels, Figures 3A-3H illustrate a substantially spherical encapsulated solid fuel. For practical reasons with respect to production, the encapsulated solid fuel is preferably in the form of a briquette or a tablet.

Figure 3A illustrates the most simplified embodiment of the invention, wherein the core (including carbonaceous fuel material(s) as one large particle or as a briquette of smaller particles) (black) is positioned slightly ex-centric to the shell material (including mineral material(s)) (fine mesh).
Figures 3B and 3C illustrate an embodiment based on the embodiment in Figure 3A, but where the shell has a few larger pores (Figure 3B) or many smaller pores distributed in the structure (Figure 3C).

Figures 3D, 3F and 3G illustrate embodiments where the shell consists of two and three layers.

In Figure 3F, the fuel consists of the outer shell (fine mesh) which comprises the mineral material and an inner shell (wavy lines) consisting of a different mineral material, e.g. a mineral material with a lower heat transfer coefficient. In Figure 3G, the core consists of a mixture of the carbonaceous fuel material and a mineral material, e.g. waste stone wool.

In Figure 3D, the embodiment of Figure 3F is extended with an intermediate layer (coarse mesh), e.g. illustrating certain reactants useful for the industrial process. It should be noted that the reactants may also be present in the outer layer.

The shell of the fuel may also have several layers which gradually will be rendered accessible during the transfer through the bed, as illustrated in Figure 3D. The outer layer could, e.g., be a porous layer, the intermediate layer could be composed of a mineral part and a solid reactant which can be catalytically active for converting gaseous species (e.g. by oxidation) or it can be a solid reactant which could react directly with species in the gas or which could be decomposed to gaseous reactant. An example could be urea in particulate form which typically decomposes to NH₃ and HNCO and which can act as effective NO-reductants in the gas phase in the temperature region between 600–1050°C. The outer layer thickness and heat conductivity should in this case be formulated so the urea decomposition starts around a gas temperature of 800-1000°C. Hereby reactants can be made available at different positions in the reactor.

Figure 3E illustrate an embodiment where the core (defined by the dashed circle) consists of a mixture of a carbonaceous fuel material(s) and a mineral material (illustrated as a number of smaller particles of carbonaceous fuel material(s)), however where the carbonaceous fuel material(s) constitute(s) at least 50% by volume.

Figure 3H illustrates an embodiment where the core portion has included therein a reactant (coarse mesh) for the industrial process.

The fuel particle(s) may be encapsulated by an isolating material, e.g. stone wool or the like, in order to reduce the heating rate of the fuel particle in the furnace (see, e.g., Figures 3D,
3F or 3G) or the core may be composed of a briquette composed of a smaller fuel particles in a high temperature resistant and strong briquette.

**Preparation of the encapsulated solid fuel**

The production of the encapsulated solid fuel depends on the characteristics of the fuel (volatile content, ash content and composition, heating value, physical strength of the solid structure, the particle size or size distribution) and the process in which it will be used.

An encapsulated low volatile single coke particle (as conventional coke for mineral melting processes) can be produced by encapsulating the shell comprising cement and sand. The composition of the shell layer should preferably take into account the strength requirement.

For smaller particles of conventional low-volatile coke, an inner core composed of the smaller coke particles distributed in a cement/sand mixture. For high-volatile fuel materials, the core is preferably covered by a shell layer of a mineral material with low thermal conductivity, and (preferably) subsequently with another shell layer.

The encapsulated solid fuels can, e.g., be prepared by sequential application of conventional techniques for the preparation of briquettes. An example hereof is provided in Example 1. Generally, moulding techniques can be applied and it is suggested that the core portion is prepared in a first step, whereafter the final fuel is prepared by placing the core portion in a larger mould also comprising the material for the shell portion. With reference to the Figures 3A-3H, such a process may include 2-4 steps. Alternatively, the moulding may be realized in one step wherein the various constituents (mineral materials and carbonaceous fuel materials) are arranged in a mould by sequentially adding the mineral materials, the carbonaceous fuel materials and, finally, further mineral materials in such a manner that the carbonaceous materials are encapsulated by the mineral materials after pressing/moulding.

The outer layer of the shell may be provided in such a manner that pores will occur in the final product, or porosity may be obtained by including low-melting or sublimating constituents in the shell layer, whereby the fuel will become porous by heating in the upper part of a furnace.
Use of the encapsulated solid fuel

As it will be understood, the encapsulated solid fuel is very useful for mineral melting processes, in particular stone wool production processes, and particular processes utilizing a cupola furnace.

Thus, a further aspect of the present invention relates to a process for the preparation of a melt of a mineral material in a furnace, said process comprising the step of charging one or more carbonaceous fuel material(s) and one or more mineral material(s) to said furnace, and combusting said carbonaceous fuel material(s) in said furnace, wherein at least a part of said carbonaceous fuel material(s) and said mineral material(s) are charged to the furnace in the form of the encapsulated solid fuel defined herein. It is furthermore believed that it is advantageous if at least 50% of the carbonaceous fuel material(s) is/are provided in the form of the encapsulated solid fuel. With reference to Figure 2, the encapsulated solid fuel of the invention is loaded via the raw material inlet. Thus, the furnace is preferably a cupola furnace.

In a conventional cupola furnace (e.g. as illustrated in Figure 2), air (oxygen) is blasted through a number of nozzles near the bottom of the cupola, i.e. air is lead into the furnace at one specified zone near the bottom of the cupola furnace.

It is believed that it in some instances may be advantageous to feed air to the furnace within two or more separate zones, instead of within a single zone as illustrated in Figure 2.

According to this improvement in combination with the novel encapsulated solid fuel, it is possible to utilize the upper part of the furnace for burn-up of gasses which would otherwise cause environmental problems, e.g. CO (carbon monoxide), \( \text{C}_x\text{H}_y \) (hydrocarbons), nitrogen containing and/or sulphur containing species. Thus, it is believed that by feeding air into one or more separate zones apart from the zone in the bottom of the furnace, and in particular above the zone in the bottom of the furnace (e.g. in the preheating zone, cf. Figure 2), a more efficient overall process may be realized.

It is also believe that it in some instances may be advantageous to feed gaseous and/or liquid reactants to the furnace within one or more separate zones. Such gaseous and/or liquid reactants may be added in order to reduce the emission of harmful components. Examples of such reactants are gaseous ammonia (\( \text{NH}_3 \)), liquid solutions of urea (\( \text{NH}_2\text{H}_2\text{CO} \)), amines, other nitrogen containing species, and the like, which may be added in order to facilitate the selective thermal reduction of \( \text{NO}_x \) and \( \text{SO}_x \) and other sulphur containing species, which may be added in order to improve burn-out of \( \text{CO} \), hydrocarbons, etc. Thus, it is believed that by feeding gaseous and/or liquid reactants to one or more separate zones (e.g. in the
preheating zone, cf. Figure 2), a more efficient overall process can be realized. The reactants may originate from waste-streams from other parts of the mineral product production process, e.g. from exhaust gasses from curing processes, etc.

Alternative encapsulated solid fuels

An alternative aspect of the invention relates to an encapsulated solid fuel, said fuel comprising a core portion comprising at least 50% by volume of one or more carbonaceous fuel material(s), and a shell portion comprising at least 60% by volume of one or more metals and/or metal oxides. It is envisaged that such fuels may be useful for metal production processes, e.g. steel production processes. The conditions with respect to the shell, the core, and the general structure follow that described hereinabove.

EXAMPLES

Example 1 - Preparation of encapsulated solid fuel

The core of the encapsulated solid fuel is prepared by preparing a briquette consisting of 65% coke and 35% of mineral materials. The mixture is pressed into a briquette (100 x 50 x 50 mm) using a standard tool for forming briquettes. The encapsulated solid fuel is prepared by placing the core in a (larger) tool for forming briquettes together with a mixture of mineral materials. The fuel has a size of 200 x 100 x 100 mm.

Example 2 - Characterization of encapsulated solid fuel

The characterisation of the encapsulated solid fuel can be performed in a thermogravimetric analyser, e.g. a STA (Simultaneous Thermal Analyser), where the volatile content, the temperature of volatilisation, the reactivity of the char and the melting characteristics of the ash can be detected. The measurement can be performed in a well-defined atmosphere which should be chosen according to the process where the fuel is to be used, e.g. a mineral melting process.

By using a STA, the material for the different layers of the shell can be characterised with respect to melting characteristics.
Example 3 – Stone wool production utilizing the encapsulated solid fuel

An encapsulated solid fuel prepared according to Example 1 can be used in the stone wool production process illustrated in Figure 1. The fuel is provided to the furnace via the raw material inlet (see Figure 2).
CLAIMS

1. An encapsulated solid fuel, said fuel comprising a core portion comprising at least 50% by volume of one or more carbonaceous fuel material(s), and a shell portion comprising at least 60% by volume of one or more mineral material(s).

5. The fuel according to claim 1, wherein the volume fraction of the shell is in the range 5-99%, such as 15-98%, e.g. 25-97%, of the total volume of the fuel.

3. The fuel according to any one of the preceding claims, which has an average size of 0.1-500 mm, such as 1-500 mm, or 10 mm-500 mm, or 10 mm-350 mm, or 20 mm-350 mm, or 20 mm-300 mm, or 20 mm-250 mm.

10. The fuel according to any one of the preceding claims, wherein the thickness of the shell portion is on average in the range of 0.01-200 mm, such as 5-200 mm, or 30-200 mm, or 30-100 mm.

5. The fuel according to any one of the preceding claims, wherein the carbonaceous fuel material(s) is/are selected from coke, PETcoke, charcoal, anthracite, bituminous coal, lower rank coals, waste material, and biofuels, in particular selected from coke.

6. The fuel according to any one of the preceding claims, wherein the core portion comprises at least 60% by volume, or at least 75% by volume, such as at least 85% by volume, or at least 95% by volume, or even 100% by volume, of the carbonaceous fuel material(s).

20. The fuel according to any one of the preceding claims, wherein the shell layer is porous.

8. The fuel according to any one of the preceding claims, wherein the shell layer comprises at least one mineral material selected from olivine, basalt, diabase, gabbro, slag, limestone, waste stone wool, fly-ash, sand, and cement.

25. The fuel according to claim 8, wherein the shell layer comprises at least two different mineral materials.

10. The fuel according to any one of the preceding claims, wherein the shell layer comprises a shell layer comprising at least 25% by volume of mineral wool.
11. The fuel according to any one of the preceding claims, wherein the core portion comprises at least 85% of coke, and the shell portion having a maximum porosity of 20%, the average block size being in the range of 30–250 mm, and the shell layer volume fraction being 25-97%.

12. A process for the preparation of a melt of a mineral material in a furnace, said process comprising the step of charging one or more carbonaceous fuel material(s) and one or more mineral material(s) to said furnace, and combusting said carbonaceous fuel material(s) in said furnace, wherein at least a part of said carbonaceous fuel material(s) and said mineral material(s) are charged to the furnace in the form of the encapsulated solid fuel defined in any one of the claim 1-11.

13. The process according to claim 12, wherein at least 50% of the carbonaceous fuel material(s) is/are provided in the form of the encapsulated solid fuel.

14. The process according to any one of the claims 12-13, wherein the furnace is a cupola furnace.

15. The process according to any one of the claims 12-14, wherein air is fed to the furnace within two or more separate zones.

16. The process according to any one of the claims 12-15, wherein gaseous and/or liquid reactants are fed to the furnace within one or more separate zones.
Fig. 3
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

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According to International Patent Classification (IPC) or to both national classification and IPC.

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols):

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched.

**Electronic database consulted during the international search (name of database and, where practical, search terms used)**

EPO-Internal, COMPENDEX, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
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<td>X</td>
<td>FR 2 330 769 A (AIR INDUSTRIE) 3 June 1977 (1977-06-03) page 1, lines 5-8,19-28 page 3, lines 21-23</td>
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**Further documents are listed in the continuation of box C.**

**Patent family members are listed in annex.**

**Date of the actual completion of the international search**

9 November 2005

**Date of mailing of the international search report**

17/11/2005

**Name and mailing address of the ISA**

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**Authorized officer**

Bertin-van Bommel, S
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<td>US 4 504 274 A (ANDERSON ET AL) 12 March 1985 (1985-03-12) column 4, lines 14-21</td>
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