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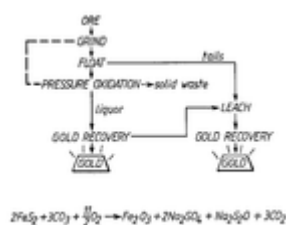


Separation process

Abstract

A process for separating gold or other precious metals from arsenopyrite or pyrite ores. The ore is treated with an alkaline solution under oxygenated conditions to break up the sulphide matrix. The ore is arranged to have an initial base: sulphide sulphur stoichiometry of between 0.6:1 to 1.0:1 to maximise the solubilisation of gold or other precious metals. The metals are then extracted from the resultant solution.

Images (1)



Classifications

[C22B11/04](#) Obtaining noble metals by wet processes

EP0316094A2

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Inventor

[Jonathan Paul Lulham](#)

Current Assignee

Kvaerner Engineering and Construction UK Ltd

Worldwide applications

1987 [GB_1988](#) [EP_ZA_JP_BR](#)

Application EP88310129A events

1987-11-07

Priority to GB8726158

1987-11-07

Priority to GB878726158A

1988-10-27

Application filed by Kvaerner Engineering and Construction UK Ltd, BP PLC

1989-05-17

Publication of EP0316094A2

1990-01-10

Publication of EP0316094A3

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Description

- [0001]

The present invention relates to a process for the separation of gold or other precious metals from ores and associated materials which may be refractory.

- [0002]

It is common for gold or precious metals to be separated from their ores by treatment with cyanide solutions, the metal forming a soluble complex with the cyanide and being subsequently extracted from solution. However, certain gold-bearing ores (referred to generally as 'refractory') are not amenable to cyanidation resulting in low or no gold dissolution. One reason for an ore being refractory is that the gold is occluded within the sulphide matrix and not available for leaching with cyanide. This occurs most frequently with

pyritic and arsenopyritic ores. Furthermore, in some cases cyanidation is a costly technique and not suitable for certain ore types and locations. Also cyanides are highly toxic and their use can cause environmental problems.

- [0003]

The principal cyanide extraction processes for refractory ores are (a) roasting of the ground ore followed by cyanidation and (b) acid pressure leaching of the ore which usually involves treatment of the ground ore with sulphuric acid and oxygen at about 200°C followed by cyanidation of the neutralised residue. The present invention provides an improved precious metal extraction process under alkaline conditions which avoids or reduces some of the disadvantages of the prior art processes such as roasting and cyanidation.

- [0004]

Thus according to the present invention there is provided a process for separating gold or other precious metals from arsenopyrite or pyrite ores and associated materials comprising the steps of (a) treating the ore with an alkaline solution and bubbling an oxygen containing gas through the mixture to break up the sulphide matrix, (b) the ore having an initial base:sulphide sulphur stoichiometry of between 0.6:1 to 1.0:1 so as to maximise the solubilisation of gold or other precious metals, and (c) extracting the gold or other precious metals from the resultant solution. It is desirable that after completion of steps (a) and (b) that the solution has a neutral pH, i.e. about 7.

- [0005]

The alkaline solution may be sodium hydroxide, potassium hydroxide, potassium carbonate, sodium carbonate, ammonium hydroxide or mixtures of the aforesaid compounds. The temperature, pressures and leach times used for the process are dependent on the particular ore being treated. Thus arsenopyritic ores are preferably treated with alkaline solution at 70-90°C and atmospheric pressure for several hours but pyrite ores may require temperatures of up to 150°C and oxygen overpressures of 600kPa though much shorter leach times.

- [0006]

It is possible to treat a refractory ore such as an arsenopyrite ore or pyrite ore with alkaline solution in order to break up the sulphide matrix and release the particulate gold. The gold may then be separated from the residue by cyanidation. However, in the present invention it has been surprisingly found that, under certain conditions of alkaline treatment the released gold rather than forming part of the solid residue tends to be solubilised. In other words by closely controlling the conditions, the gold may be put into an extractable form by use of a one stage process rather than a two stage process i.e. pretreatment to break up the sulphide matrix followed by cyanidation to solubilise the gold.

- [0007]

The invention will now be described by way of example only. The figure shows a schematic diagram of the process according to the invention.

- [0008]

The feed material used in the separation process was a pyritic gold concentrate from a South East Asian mine. The concentrate contained about 45% pyrite and 15.3 grams per tonne of gold. The details of the concentrate are shown in Table 1. The assay and analysis of the sample showed about 45% pyrite with about 50% orthoclase and residue.

- [0009]

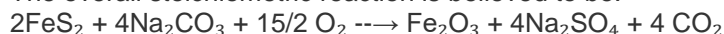
The experiments were carried out in batch mode in a titanium autoclave supplied by Baskerville and Lindsay. The pyritic gold concentrate (50 g) and sodium carbonate solution (500 ml) were added to the autoclave body, the autoclave then being assembled and pressurised. The reactants were then stirred with an impeller and heated to about 150°C. The reactants were sparged with oxygen, the vent system operating continuously at 0.5 litre per minute while maintaining a constant pressure by controlled oxygen flow.

- [0010]

At completion of the leach, the contents of the autoclave were flash discharged. The slurry was filtered and the residue washed with distilled water, the washings being added to the filtrate. The resultant solution was analysed for gold, thiosulphate ion and sulphate ion. The residue was weighed and analysed for total sulphur content. The percentage gold extraction and pyrite decomposition may be calculated by solution and residue analyses.

- [0011]

The overall stoichiometric reaction is believed to be:-



Thus 2 moles of FeS_2 are equivalent to 4 moles of Na_2CO_3 and 1 kg of FeS_2 is equivalent to 1.767 kg of Na_2CO_3 . Thus, 1 tonne of pyritic concentrate (containing 476 kg of FeS_2 - determined by assay) is equivalent to 841 kg of Na_2CO_3 .

- [0012]

The calculated head is the ratio of the total of the weight of gold in solution and weight of gold in solid to the initial weight of solid.

- [0013]

A series of experiments was carried out in which the base stoichiometry was varied for the following baseline conditions, a leach time of 60 minutes, a temperature of 150°C, an oxygen overpressure of 6 bar (equivalent to 600 kPa), (Table 2). Tables 3 to 6 show the varying effects on sulphur conversion and gold dissolution of time, temperature, oxygen overpressure and base stoichiometry.

- [0014]

The gold and/or silver may be extracted from the resultant liquor either by use of a suitable ion exchange resin such as a strong or weak base resin, eg polystyrene or polymethylmethacrylate resins or by addition of zinc powder in the absence of oxygen. Alternative methods of extracting precious metal from the liquor may also be used.

- [0015]

Table 2 shows that base stoichiometry has a marked effect on gold extraction. The terminal pH in the autoclave is controlled by base addition at the beginning of the extraction. It is believed that low base concentrations result in oxidation of the thiosulphate ion and the gold thiosulphate complex formed. A base concentration which is too high results in minimal gold dissolution, as the terminal pH is outside the optimum range for gold dissolution by thiosulphate ion.

- [0016]

Table 3 shows the effect of pulp density (weight of solid/[weight of solid + weight of solution] x 100%). Optimum results for gold extraction were obtained at pulp densities greater than 4.

- [0017]

Table 4 shows the effect of oxygen overpressure. Increasing oxygen overpressure marginally tends to increase the gold extraction.

- [0018]

Table 5 shows that at temperatures of greater than 150°C, the gold extraction decreases markedly. This is believed to be caused by gold precipitation from solution due to oxidation of the gold thiosulphate complex and thiosulphate ion.

- [0019]

Table 6 shows the effect of residence time. For residence times of over 70 minutes at 150°C the gold dissolution fell markedly. This is probably caused by oxidation of thiosulphate ion and gold thiosulphate complex.

- [0020]

Table 7 shows a further set of results illustrating the effect of base stoichiometry on gold extraction from a pyritic gold concentrate from a Canadian mine. The concentrate contained about 80.1% pyrite and 8.5 grams per tonne of gold. The conditions for the reactions were similar to the above concentrate and were a leach time of 30 minutes, a temperature of 130°C, and an oxygen overpressure of 8 bar (equivalent to 800 kPa). TABLE 1 GOLD CONCENTRATE By Assay Gold 15.3 g/tonne of concentrate Silver less than 5 g/tonne of concentrate Total Sulphur content 25.4% by weight equivalent to 47.6% pyrite FeS₂. Sulphate ion 0.9% Elemental sulphur less than 0.01% Total carbon less than 0.1% Carbonate ion 0.02% By Atomic Absorption Spectroscopy Fe 20.10% (equivalent to 42.9% pyrite FeS₂), As 0.4%, Si 13.3%, K 4.9%, Al 5.1%. By X-Ray Fluorescence S 23%, Fe 21%, Si 19%, K 8.9%, Al 6.6%, Pb 1.3%, Mg 1.2%, Ti 0.4%, Ca 0.3%, P 0.3%, Mo 0.1%. By X-Ray Diffraction Mainly pyrite and a feldspar (orthoclase) with traces of kaolinite and muscovite.

TABLE 2 Base Stoichiometry kg Na₂CO₃ added/tonne of concentrate kg Na₂CO₃ used/tonne of concentrate Gold Dissolution % Calculated Head g/t % pyrite to Sulphate to Conversion kg thiosulphate produced/tonne concentrate Final
pH 0.700 586 583 20.4 15.1 81.2 8.65 7.4 0.725 607 601 55.7 15.0 82.4 9.68 7.8 0.775 649 6
41 84.3 15.5 86.3 14.1 8.3 0.800 669 644 87.8 14.6 88.7 22.0 10.3 0.825 690 664 89.1 14.8 8
8.1 23.2 10.0 0.850 711 652 64.0 15.0 89.8 19.8 10.2 0.875 732 627 47.7 14.3 88.6 13.4 10.2
0.900 763 642 58.6 14.5 89.1 14.4 10.0 6.0 bar oxygen overpressure 60 mins residence
time 150°C Charge = 50g concentrate + 500ml sodium carbonate solution

TABLE 3 Pulp Density % wt kg Na₂CO₃ used/tonne concentrate Sulphur Conversion % Gold
Dissolution % Calculated Head g/t Av kg thiosulphate produced/tonne
concentrate 2.4 667 84.0 11.0 20.1 1.47 4.8 659 89.1 87.9 16.4 50.8 9.1 644 86.6 87.8 14.6 2
2.0 13.0 604 81.5 85.1 14.9 22.0 Conditions:- 6.0 bar oxygen overpressure 60 mins residence
time 150°C 669 kg sodium carbonate/tonne concentrate Charge = 50g concentrate + 500ml
sodium carbonate solution

TABLE 4 Oxygen Overpressure bar kg Na₂CO₃ used/tonne concentrate Sulphur Conversion
% Gold Dissolution % Calculated Head g/t kg thiosulphate produced/tonne
concentrate 3.0 626 83.2 78.6 16.2 38.1 4.0 641 86.6 85.3 15.8 48.1 5.0 651 86.3 91.1 15.3 3
9.7 6.0 644 86.6 87.8 14.6 22.0 7.0 662 86.6 91.1 15.6 26.6 Conditions:- 150°C 60 mins

residence time 669 kg sodium carbonate/tonne concentrate Charge = 50g concentrate + 500ml sodium carbonate solution

TABLE 5 Temperature °C kg Na₂CO₃ used/tonne concentrate Sulphur Conversion % Gold Dissolution % Calculated Head g/t kg thiosulphate produced/tonne concentrate 135 543 80.8 86.5 15.2 60.8 140 577 85.1 86.3 15.8 59.0 145 635 85.9 87.8 15.7 56.4 150 644 86.6 87.8 14.6 22.0 160 669 87.3 12.4 15.1 1.6 165 669 86.7 2.9 14.0 0.6 Conditions:- 6.0 bar O₂ overpressure 60 mins residence time 669 kg sodium carbonate/tonne concentrate Charge 50g concentrate + 500ml sodium carbonate solution

TABLE 6 Residence Time (Mins) kg Na₂CO₃ used/tonne concentrate Sulphur Conversion % Gold Dissolution % Calculated Head g/t kg thiosulphate produced/tonne concentrate 45 598 80.9 87.2 15.4 49.5 50 624 85.2 87.0 15.2 27.1 55 639 86.6 84.5 14.4 26.8 60 644 86.6 87.8 14.6 22.0 65 662 88.0 85.2 15.6 15.0 70 659 89.5 87.0 14.4 10.8 75 661 88.4 54.6 14.6 7.7 Conditions:- 6.0 bar O₂ overpressure 669 kg sodium carbonate/tonne concentrate 150°C Charge = 50g concentrate + 500ml sodium carbonate solution

TABLE 7 Base Stoichiometry kg.Na₂CO₃/tonne of concentrate Sulphur Conversion % Gold Dissolution % kg/t of thiosulphate formed/tonne of pyrite concentrate Final pH 0.2 288 54.6 13.1 44.5 2.2 0.4 576 73.3 12.0 15.4 2.8 0.5 720 80.0 5.0 13.1 3.0 0.6 864 86.5 74.0 18.3 7.4 0.7 1008 92.8 48.5 38.4 - 0.8 1152 93.8 65.7 16.0 9.6 1.0 1440 85.7 28.8 3.0 9.7

Claims (7)

Hide Dependent

1. A process for separating gold or other precious metals from arsenopyrite or pyrite ores and associated materials comprising the steps of (a) treating the ore with an alkaline solution and bubbling an oxygen containing gas through the mixture to break up the sulphide matrix (b) the ore having an initial base: sulphide sulphur stoichiometry of between 0.6:1 to 1.0:1 so as to maximise the solubilisation of gold or other precious metals and (c) extracting the gold or other precious metals from the resultant solution.
2. A process according to claim 1 in which the alkaline solution is sodium hydroxide, potassium hydroxide, potassium carbonate, sodium carbon, ammonium hydroxide or mixture thereof.
3. A process according to claim 1 or claim 2 in which the temperature of the process is from 70°C to 150°C.
4. A process according to any of the preceding claims in which the resultant solution has a substantially neutral pH.
5. A process according to any of the preceding claims in which the oxygen overpressure is from 0 to 7 bar.
6. A process according to any of the preceding claims in which the initial base:sulphide sulphur stoichiometry is from 0.725 to 0.850.
7. A process according to any of the preceding claims in which the pulp density is greater than 4 wt %.

Patent Citations (4)

Publication number	Priority date	Publication date	Assignee	Title
--------------------	---------------	------------------	----------	-------

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[AT212027B](#) *1959-05-291960-11-25Gerhard Dipl Ing Dr Tech JanggProcess for working up sulphidic ores

Family To Family Citations

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Non-Patent Citations (1)

Title

METALL *

* Cited by examiner, † Cited by third party

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Publication numberPriority datePublication dateAssigneeTitle

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[JP2015214731A](#) *2014-05-122015-12-03住友金属鉱山株式会社Gold recovery method

[JP2019059984A](#) *2017-09-262019-04-18J x 金属株式会社Leaching method of gold and recovery method of gold

Recent studies on germanium-nanomaterials for LIBs anodes

#1 [Vladko Panayotov](#) (BAS: Bulgarian Academy of Sciences)H-Index: 1

#1 [Vladko Panayotov](#)H-Index: 1

Last, [Serhii Chukharev](#)H-Index: 1

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The inherently low capacity of the classically used carbon-based anode is one of the major drawbacks hindering the wide application of lithium ion batteries (LIBs) in electric vehicles. Carbon replacement with materials possessing high theoretical capacity, such as germanium (Ge) represents one of the approaches used for ensuring wider LIBs' implementation. The main disadvantage of the Ge use is its huge volume change during the lithiation / delithiation, causing Ge-based electrodes pulverization...more

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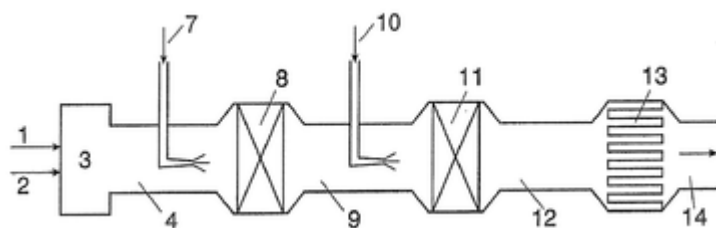
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Method for purification of an exhaust gas from a diesel engine

Abstract

A method for removing impurities in exhaust gas from a diesel engine, where the impurities comprise nitrogen oxides, carbon monoxide, particulate matter and incompletely combusted hydrocarbons. The method comprises the steps of injection of a reductant comprising urea or ammonia into the exhaust gas from the engine, selective catalytic reduction of the nitrogen oxides in the exhaust gas by the reductant, and intermittent injection of a hydrocarbon into this effluent. The succeeding steps are oxidation of carbon monoxide, particulate matter, incompletely combusted hydrocarbons and injected hydrocarbon to carbon dioxide and water, and in selectively oxidising possible excess of reductant to free nitrogen, and finally filtration of the effluent by passing the gas through a catalysed filter. The remaining particulate matter is retained in the filter, and the carbon monoxide, particulate matter and hydrocarbons are oxidised to carbon dioxide and water, and the reductant is selectively oxidised to nitrogen, creating a purified exhaust gas.

Images (1)



Classifications

[F01N3/2066](#) Selective catalytic reduction [SCR]

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US20090260346A1

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Haldor Topsoe AS

Worldwide applications

2009 [EP](#) [US](#) [RU](#) [CN](#)

Application US12/421,947 events

2008-04-22

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Priority to DKPA200800575

2009-04-10

Application filed by Haldor Topsoe AS

2009-04-10

Assigned to HALDOR TOPSOE A/S

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Publication of US20090260346A1

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Description

- [0001]

The invention relates to a method for purification of an exhaust gas from an internal combustion engine.

- [0002]

The invention is specifically directed to cleaning of an exhaust gas from a diesel engine, especially engines in vehicles, which often start with cold engine and cold exhaust gas system.

- [0003]

Processes for purifying exhaust gas are already known. In the process of US 2007/0289289 exhaust gas is purified by catching particles in a filter followed by reduction of nitrogen oxides and thereafter by catalytic oxidation of impurities in the exhaust gas. However, if some nitrogen oxides pass the reducing catalyst, they are oxidised in the subsequent step and

escape to the atmosphere as NO_2 . Further, if excess of a reductant is added, some of it may pass the oxidation catalyst and escape to the atmosphere.

- [0004]

In the process of US 2007/0160508 fuel is injected upstream of a pre-stage oxidation catalyst, in which NO_2 is formed. NO_2 is used in the subsequent filter for oxidising soot particles. Remaining NO_x is reduced by a reductant in the subsequent selective reducing catalyst, before the exhaust gas passes a post-stage oxidation catalyst, which converts CO to CO_2 . In this process four different catalysts are needed.

- [0005]

Gas is led from a combustion engine to a diesel particulate filter in the process disclosed in US 2007/0089403, where the filter is coated with an oxidation/ NO_x storage catalyst. After injection of a reductant the gas passes a hydrolysis catalyst before entering a selective reduction catalyst, after which it passes an ammonia guard catalyst and streams to the atmosphere. This process is a little complicated, the gas to the selective reduction is not sufficiently hot and must pass a hydrolysis catalyst before entering the reduction catalyst, after which an ammonia guard catalyst is needed.

- [0006]

US 2006/0107649 discloses an exhaust gas cleaning process, where NO_x is reduced, particles are caught in a filter and CO, hydrocarbons and NO_x are thereafter oxidised. However, no additional heat can be added to the filter to burn off caught soot and particulate matter.

- [0007]

The process of U.S. Pat. No. 6,892,529 comprises hydrogen injection, catalytic oxidation, hydrogen injection, removing particles in a filter, hydrogen injection, urea injection, hydrolysis, selective reduction of NO_x and oxidation of CO and remaining hydrocarbons. A disadvantage of this process is that hydrogen is not easy to handle on board a vehicle.

- [0008]

Exhaust gas is cleaned in two parallel trains in the process disclosed in U.S. Pat. No. 6,823,660. In each train the gas passes an oxidation catalyst, a diesel particulate filter and a selectively reducing catalyst. This process does not supply sufficient heat for regeneration of the filter and control of NO_x reduction.

- [0009]

Reduction and subsequent oxidation of impurities in exhaust gas are comprised in the process of U.S. Pat. No. 5,431,893. Reductant is injected to the exhaust gas upstream of a pyrolysis channel, a mixing channel and a reduction catalyst. The temperature of the oxidation catalyst cannot be adjusted, and particles may block the filter or pass through the filter.

- [0010]

The problem of the known processes is that they are either rather complicated or do not provide a thorough removal of both NO_x , CO, remains of hydrocarbons, particulate matter and soot, especially not just after start of a cold engine.

- [0011]

The problem of known technique is solved by the present invention.

- [0012]

The invention provides a method for removing impurities in exhaust gas from a diesel engine, where the impurities comprise nitrogen oxides, carbon monoxide, particulate matter and incompletely combusted hydrocarbons. The method comprises the steps of injection in excess compared to stoichiometric ratio of a reductant comprising urea or ammonia into the exhaust gas from the engine, selective catalytic reduction of the nitrogen oxides in the exhaust gas by the reductant in the presence of a catalyst active in selective reduction of nitrogen oxides to nitrogen and intermittent injection of a hydrocarbon into this effluent. The succeeding steps are oxidation of carbon monoxide, particulate matter, incompletely combusted hydrocarbons and injected hydrocarbon in the presence of a catalyst active in oxidising carbon monoxide, particulate matter and hydrocarbons, to carbon dioxide and water, and in selectively oxidising possible excess of reductant to free nitrogen, and filtration of the effluent by passing the gas through a catalysed filter, wherein the remaining particulate matter is retained in the filter, and wherein the catalyst is active in oxidising carbon monoxide, particulate matter and hydrocarbons to carbon dioxide and water, and in selectively oxidising reductant to nitrogen creating a purified exhaust gas.

- [0013]

In another embodiment of the invention the method further comprises the step of a pre-oxidation of carbon monoxide, particulate matter, nitrogen oxides and incompletely combusted hydrocarbons in the exhaust gas from the engine in the presence of a catalyst active in oxidising the carbon monoxide, nitrogen oxides, hydrocarbons and particulate matter to carbon dioxide, nitrogen dioxide and water prior to the injection of reductant.

- [0014]

Thereby exhaust gas from a diesel engine is very thoroughly cleaned by a very simple system, also reasonably fast after start of a cold engine.

- [0015]

FIG. 1 is a schematic drawing showing one preferred embodiment of the method of the invention.

- [0016]

FIG. 2 is a schematic drawing showing another preferred embodiment of the method of the invention.

- [0017]

FIG. 3 is a print-out from measurement of pressure drop across diesel particle filter during test.

- [0018]

Diesel engines operate with excess air and their exhaust gasses comprise nitrogen oxides, NO_x, carbon monoxide, CO, particulate matter and incompletely combusted hydrocarbons, which all implement health risk.

- [0019]

The present invention provides a method, wherein nitrogen oxides are catalytically, selectively reduced to free nitrogen. Subsequently CO and incompletely combusted hydrocarbons are oxidised. Finally, particulate matter is caught and remaining CO and incompletely combusted hydrocarbons are oxidised in a filter. These reactions take place in an optimal way, when the exhaust gas and the system are heated up to 250-500° C.

- [0020]

Optionally, the exhaust gas from the diesel engine is passed to a pre-oxidising catalyst, where a considerable part of carbon monoxide, unburned hydrocarbons, particulate matter, and NO_x is oxidised to carbon dioxide, water and NO₂ upstream of the selective, catalytic reduction of NO_x.

- [0021]

In this case the reduction catalyst can be a zeolites catalyst.

- [0022]

The invention is described in more detail by the drawings. FIG. 1 illustrates one preferred embodiment of the invention, where fuel **1** is combusted with air **2** in combustion engine **3**, and the formed exhaust gas **4** is mixed with injected reductant **7**. A preferred reductant is an aqueous solution of urea, which disintegrates to ammonia and carbon dioxide at and above 200° C. This mixed gas flows to a Selective, Catalytic Reduction, SCR, catalyst **8**, which promotes reduction of nitrogen oxides by the reductant, ammonia, resulting in free nitrogen and water.

- [0023]

The catalyst for selective reduction can be a mixture of base metal oxides as the active phase supported on a carrier of one or more metal oxides. The base metals are chosen from vanadium, tungsten, cerium and manganese, and the preferred catalysts are vanadium and tungsten oxide supported on titania or alumina or ceria, or cerium oxide/tungsten oxide supported on titania or alumina, or manganese oxide supported on titania or alumina or ceria. Alternatively, the catalyst for selective reduction can be a zeolite, especially an ion exchanged zeolite supported on an inert substrate, preferably cordierite, and the preferred zeolites is copper and/or iron exchanged beta or ZSM-5 zeolite. The catalyst will typically be in the form of a monolithic structure but can also be in the form of foam or metal mesh.

- [0024]

The reductant might also be ammonia or an aqueous solution of ammonia. The reductant can be added in a slight excess compared to stoichiometric ratio, which ensures a very high degree of conversion of the poisonous nitrogen oxides to free nitrogen.

- [0025]

Hydrocarbon **10** is intermittently injected into SCR effluent **9**, when needed for increasing the temperature. The hydrocarbon can be diesel fuel. This exhaust gas flows to a Diesel Oxidation Catalyst, DOC, **11** where a substantial part of the CO and incompletely combusted hydrocarbons and particulate matter are oxidised to water and carbon dioxide. Excess of ammonia is selectively oxidised to free nitrogen. In this way, the DOC **11** also acts as an ammonia slip guard.

- [0026]

The oxidation catalyst is a precious metal(s) catalyst on metal oxide carriers such as aluminium oxide, cerium oxide, zirconium oxide titanium oxide or a zeolite. The requirement to the amount of the noble metal is low. Precious metals are platinum, palladium or rhodium, which are present as mixtures or as single precious elements, where platinum and palladium are the preferred metals, preferably on a titania support.

- [0027]

The precious metals can also be substituted by base metals, typically manganese, copper, cobalt and chromium.

- [0028]

The DOC catalyst will typically be in the form of a monolithic structure, but can also be in the form of foam or metal mesh.

- [0029]

Both the amount of reductant and of hydrocarbon is monitored by the electronic computing unit. This can both be a separate CPU or the CPU of the engine.

- [0030]

The nearly purified exhaust gas **12** flows to a catalysed Diesel Particulate Filter, c-DPF, **13**. Particulate matter is caught in the filter and the catalyst on the surface of the filter promotes the oxidation of the particles as well as the selective oxidation of remaining ammonia, carbon monoxide and hydrocarbons.

- [0031]

The catalyst is a Pt-free coat on the filter, which can be a cordierite filter. The coat is a metal oxide acting as a carrier for a precious metal different from platinum, where the preferred precious metal is palladium. The carrier coat is an oxide of cerium, zirconium, aluminium or titanium, where the preferred oxide is titania.

- [0032]

The amount of hydrocarbons **10** injected up-stream of DOC **11** will influence the temperature not only in the DOC **11**, but also in the c-DPF **13** as well and thereby enhance combustion of collected particles by the increased temperature of c-DPF.

- [0033]

By the exhaust gas cleaning process of the invention, the catalyst **8** for SCR is readily heated by warm exhaust gas coming directly from the engine to the temperature, where urea is disintegrated to ammonia and where nitrogen oxides are reduced.

- [0034]

Further, a very high degree of removal of nitrogen oxides can be obtained, as it is possible to inject excess of urea/ammonia reductant, and without high requirement of accuracy of injected amount, because slip of ammonia is oxidised to nitrogen not only by the DOC **11**, but also by the c-DPF **13**.

- [0035]

Thereby, the content of impurities in the purified exhaust gas stream **14** is extremely low, when it leaves the system. FIG. 2 shows another preferred embodiment of the invention. Fuel **1** is combusted by air **2** in diesel engine **3** and the formed exhaust gas **4** flows to a pre-oxidising catalyst **5**, where a substantial part of CO, NO, particulate matter and remaining HC are oxidised, before this pre-oxidised exhaust gas **6** is mixed with reductant **7** and flows to SCR catalyst **8**, where nitrogen oxides are reduced to free nitrogen. The NO_x free exhaust gas **9** is further cleaned in the same way as in the process described by FIG. 1. With this embodiment it is obtained that the formed nitrogen dioxide supports the selective, catalytic reduction of nitrogen oxides to free nitrogen and that a zeolite catalyst can be used for the SCR reaction.

- [0036]

The pre-oxidising catalyst **5** consists of precious metals on one or more metal oxide carriers as aluminium oxide, cerium oxide, zirconium oxide titanium oxide or a zeolite where the requirement to the amount of the noble metal is low. This catalyst shall have the ability to oxidise NO to NO₂ besides the ability to oxidise carbon monoxide and hydrocarbons to carbon dioxide and water. A preferred catalyst is a mixture of the precious metals platinum and palladium on aluminium oxide/cerium oxide carrier. The precious metals can be mixtures or single precious elements. The precious metals may be substituted by base metals including manganese, copper, cobalt and chromium.

- [0037]

The pre-DOC catalyst will typically be in the form of a monolithic structure but can also be in the form of foam or metal mesh.

- [0038]

The method of the invention is useful for systems for purifying exhaust gas from diesel engines, especially engines installed in cars, vans, vehicles, trains, vessels and power plants.

- [0039]

The performance of a system consisting of SCR+DOC+c-DPF catalysts was evaluated in an Engine test bench on a Scania 12-1 Euro II engine through European transient test cycles, ETC.

- [0040]

The amount of injected urea solution was varied as shown in Table 2, whereas no hydrocarbon was injected upstream of the DOC.

- [0041]

Finally, the exhaust gas was passed through catalysed DPF.

- [0042]

The catalysts used for the evaluation were from current Haldor Topsoe A/S development:

- - DNXV standard SCR catalyst—vanadium based
 - Hi-DOC—Pt/TiO₂ oxidation catalyst
 - BMC-211 coated cordierite DPF

- [0046]

Further specifications of SCR, DOC and DPF are given in Table 1.

- TABLE 1 Catalyst Volume to cylinder Size (litres) ratio Composition DNXV $\varnothing 12.7'' \times 295$ mm 24 2 V₂O₅/WO₃ on SCR TiO₂ DOC $\varnothing 10.5'' \times 100$ mm 5.6 0.46 Pt/TiO₂ DPF $\varnothing 10.5'' \times 12''$ 17 1.42 BMC-211: Pt-free coat on cordierite filter

- [0047]

The measured concentrations of impurities and the temperature in the streams are given in Table 2.

- TABLE 2 Urea CO No_x HC inj CO NO_x HC Max
NH₃ conv conv conv [g] [g/kWh] [g/kWh] [g/kWh] [ppm] [%] [%] [%] Upstream SCR
1 0 3.26 10.14 3.88 0.00 Upstream SCR 2 0 3.82 10.17 4.19 0.00 Downstream
SCR 0 3.16 10.85 0.02 0.00 3 -7 99 Downstream
DOC 0 0.20 10.58 0.03 0.00 94 -4 99 Downstream 0 0.14 9.88 0.00 0.00 96 3 100 Filter
Downstream SCR 586 3.40 4.09 0.02 9.56 -4 60 100 Downstream
SCR 809 3.33 1.85 0.02 17.96 -2 82 100 Downstream
SCR 929 3.41 0.98 0.03 159.00 -5 90 99 Downstream SCR 1
033 3.17 0.52 0.03 392.06 3 95 99 Downstream SCR 1
169 3.39 0.57 0.03 473.00 -4 94 99 Downstream SCR 1
307 3.27 0.40 0.03 643.00 0 96 99 Downstream
DOC 815 0.21 1.82 -0.01 3.29 93 82 100 Downstream 813 0.15 1.71 -0.01 3.44 96 83 100 F
ilter Downstream
DOC 925 0.18 1.26 0.01 3.09 95 88 100 Downstream 902 0.40 1.31 0.01 7.32 88 87 100 Filte
r Downstream DOC 1 041 0.19 1.29 0.01 3.86 94 87 100 Downstream 1
042 0.17 1.24 0.07 4.39 95 88 98 Filter

- [0048]

The efficiency of removal of particulate matter was determined as build-up of pressure drop across the filter and given in FIG. 3.

- [0049]

The allowed values for emissions from trucks in Europe are given in Table 3.

- TABLE 3 European legislation based on the European Transient Cycle (ETC). Euro VI is a proposal of 2007.12.21. All units are in g/kWh Tier Date Test CO NMHC CH₄ NO_x PM Euro
III 2000.10 ETC 5.45 0.78 1.6 5.0 0.16 Euro IV 2005.10 4.0 0.55 1.1 3.5 0.03 Euro
V 2008.10 4.0 0.55 1.1 2.0 0.03 Euro VI 2013.04 4.0 0.16 0.5 0.4 0.01

- [0050]

The test results show clearly that particulate matter is oxidised, as it can be seen in FIG. 3 that the pressure drop across the c-DPF does not increase during operation, as shown.

- [0051]

From Table 2 it is seen that the HC, CO and NO_x conversions are excellent and that the NO_x emission in the outlet exhaust stream **14** is very low. The main reason for the high NO_x conversion is the NH₃/NO_x ratio can be maintained at a high value as the potential NH₃ slip is selectively oxidised both on the DOC **11** and on the catalytic coated filter **13**.

- [0052]

A comparison between the limits of present legislation in Table 3 and test results shows:

- [0053]

The obtained 1.24-1.71 g/kWh NO_x is lower than 2.0 (2008)

- [0054]

The obtained 0.15-0.40 g/kWh CO is lower than 4.0 (2008)

- [0055]

The obtained 0-0.07 g/kWh HC is lower than 1.1 (2008).

- [0056]

The above clearly demonstrates that the legislation is fulfilled.

- [0057]

The engine, which was used for the tests, was an old engine and the emission of impurities was much higher than the emission from modern engines. The purification system of the invention will easily fulfil future Euro VI requirements for limits of emissions from modern vehicles.

Claims (15)

Hide Dependent

1. A method for removing impurities in exhaust gas from a diesel engine, where the impurities comprise nitrogen oxides, carbon monoxide, particulate matter and incompletely combusted hydrocarbons, which method comprises the steps of

- (a) injection in excess compared to stoichiometric ratio of a reductant comprising urea or ammonia into the exhaust gas from the engine;
- (b) reduction of the nitrogen oxides in the exhaust gas by the reductant in the presence of a catalyst active in selective reduction of nitrogen oxides to nitrogen;
- (c) intermittent injection of a hydrocarbon into the effluent from step (b);
- (d) oxidation of carbon monoxide, particulate matter, incompletely combusted hydrocarbons and injected hydrocarbon in the presence of a catalyst active in oxidising carbon monoxide, particulate matter and hydrocarbons, to carbon dioxide and water, and in selectively oxidising excess of reductant to free nitrogen;
- (e) filtration of the effluent from step (d) by passing the gas through a catalysed filter, wherein the remaining particulate matter is retained in the filter, and wherein the catalyst is active in oxidising carbon monoxide, particulate matter and hydrocarbons to carbon dioxide and water, and in selective oxidising reductant to nitrogen, creating a purified exhaust gas; and

(f) withdrawal of the purified exhaust gas.

2. A method according to claim 1, further comprising the step of a pre-oxidation of carbon monoxide, particulate matter, nitrogen oxides and incompletely combusted hydrocarbons in the exhaust gas from the engine in the presence of a catalyst active in oxidising the carbon monoxide, nitrogen oxides, hydrocarbons, and particulate matter to carbon dioxide, nitrogen dioxide and water prior to the step (a).

3. A method according to claim 1, wherein the injected hydrocarbon is diesel fuel.

4. A method according to claim 1, wherein the catalyst for selective reduction is a zeolite or an ion exchanged zeolite on a cordierite catalyst support, or one or more base metal oxides catalyst on a catalyst support of one or more metal oxides, the catalyst having the form of a monolite, a foam or a metal mesh.

5. A method according to claim 1, wherein the oxidation catalyst is one or more precious metals or one or more base metals on a catalyst support of a zeolite or a metal oxide, the catalyst having the form of a monolite, a foam or a metal mesh.

6. A method according to claim 1, wherein the catalyst coated on the filter is a precious metal, but not including platinum, and on a catalyst support of a metal oxide.

7. A method according to claim 2, wherein the preoxidation catalyst is one or more precious metals or one or more base metals on a catalyst support of a zeolite or of an oxide of one or more metals, the catalyst having the form of a monolite, a foam or a metal mesh.

8. A method according to claim 1, wherein the catalyst base metal is one or more of vanadium, tungsten, cerium and manganese, the support metal oxide is titania, alumina and/or ceria and the ion exchanged zeolite is Cu/Fe exchanged β zeolite or ZSM-5 zeolite.

9. A method according to claim 1, wherein the support for the oxidation catalyst is a zeolite, titania, alumina, ceria or zirconia, and wherein the catalyst precious metal is platinum, palladium and/or rhodium and the catalyst base metal is manganese, copper, cobalt and/or chromium.

10. A method according to claim 1, wherein the support for the catalyst is titania, alumina, ceria or zirconia, and the catalyst is palladium.

11. A method according to claim 2, wherein the catalyst support is one or more oxides of aluminium, cerium, zirconium and/or titanium, and the catalyst precious metal is platinum and/or palladium and the catalyst base metal is manganese, copper, cobalt and/or chromium.

12. A method according to claim 1, wherein the catalyst is vanadium/tungsten oxide on a titania support, cerium/tungsten oxide on a titania support or manganese oxide on a titania support.

13. A method according to claim 1, wherein the catalyst is platinum on a titania support or platinum/palladium on a titania support.

14. A method according to claim 1, wherein the catalyst is palladium on a titania support.

15. A method according to claim 2, wherein the catalyst is platinum/palladium on an aluminium/cerium oxide support.

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E3S Web Conf., 2020, **166**, 01008

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Separation process

Abstract

A process for separating gold or other precious metals from arsenopyrite or pyrite ores. The ore is treated with an alkaline solution under oxygenated conditions to break up the sulphide matrix. The ore is arranged to have an initial base: sulphide sulphur stoichiometry of between 0.6:1 to 1.0:1 to maximise the solubilisation of gold or other precious metals. The metals are then extracted from the resultant solution.

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Classifications

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Current Assignee

Kvaerner Engineering and Construction UK Ltd

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Description

- [0001]

The present invention relates to a process for the separation of gold or other precious metals from ores and associated materials which may be refractory.

- [0002]

It is common for gold or precious metals to be separated from their ores by treatment with cyanide solutions, the metal forming a soluble complex with the cyanide and being

subsequently extracted from solution. However, certain gold-bearing ores (referred to generally as 'refractory') are not amenable to cyanidation resulting in low or no gold dissolution. One reason for an ore being refractory is that the gold is occluded within the sulphide matrix and not available for leaching with cyanide. This occurs most frequently with pyritic and arsenopyritic ores. Furthermore, in some cases cyanidation is a costly technique and not suitable for certain ore types and locations. Also cyanides are highly toxic and their use can cause environmental problems.

- [0003]

The principal cyanide extraction processes for refractory ores are (a) roasting of the ground ore followed by cyanidation and (b) acid pressure leaching of the ore which usually involves treatment of the ground ore with sulphuric acid and oxygen at about 200°C followed by cyanidation of the neutralised residue. The present invention provides an improved precious metal extraction process under alkaline conditions which avoids or reduces some of the disadvantages of the prior art processes such as roasting and cyanidation.

- [0004]

Thus according to the present invention there is provided a process for separating gold or other precious metals from arsenopyrite or pyrite ores and associated materials comprising the steps of (a) treating the ore with an alkaline solution and bubbling an oxygen containing gas through the mixture to break up the sulphide matrix, (b) the ore having an initial base:sulphide sulphur stoichiometry of between 0.6:1 to 1.0:1 so as to maximise the solubilisation of gold or other precious metals, and (c) extracting the gold or other precious metals from the resultant solution. It is desirable that after completion of steps (a) and (b) that the solution has a neutral pH, i.e. about 7.

- [0005]

The alkaline solution may be sodium hydroxide, potassium hydroxide, potassium carbonate, sodium carbonate, ammonium hydroxide or mixtures of the aforesaid compounds. The temperature, pressures and leach times used for the process are dependent on the particular ore being treated. Thus arsenopyritic ores are preferably treated with alkaline solution at 70-90°C and atmospheric pressure for several hours but pyrite ores may require temperatures of up to 150°C and oxygen overpressures of 600kPa though much shorter leach times.

- [0006]

It is possible to treat a refractory ore such as an arsenopyrite ore or pyrite ore with alkaline solution in order to break up the sulphide matrix and release the particulate gold. The gold may then be separated from the residue by cyanidation. However, in the present invention it has been surprisingly found that, under certain conditions of alkaline treatment the released gold rather than forming part of the solid residue tends to be solubilised. In other words by closely controlling the conditions, the gold may be put into an extractable form by use of a one stage process rather than a two stage process i.e. pretreatment to break up the sulphide matrix followed by cyanidation to solubilise the gold.

- [0007]

The invention will now be described by way of example only. The figure shows a schematic diagram of the process according to the invention.

- [0008]

The feed material used in the separation process was a pyritic gold concentrate from a South East Asian mine. The concentrate contained about 45% pyrite and 15.3 grams per tonne of

gold. The details of the concentrate are shown in Table 1. The assay and analysis of the sample showed about 45% pyrite with about 50% orthoclase and residue.

- [0009]

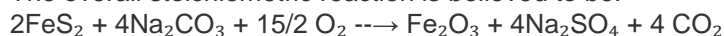
The experiments were carried out in batch mode in a titanium autoclave supplied by Baskerville and Lindsay. The pyritic gold concentrate (50 g) and sodium carbonate solution (500 ml) were added to the autoclave body, the autoclave then being assembled and pressurised. The reactants were then stirred with an impeller and heated to about 150°C. The reactants were sparged with oxygen, the vent system operating continuously at 0.5 litre per minute while maintaining a constant pressure by controlled oxygen flow.

- [0010]

At completion of the leach, the contents of the autoclave were flash discharged. The slurry was filtered and the residue washed with distilled water, the washings being added to the filtrate. The resultant solution was analysed for gold, thiosulphate ion and sulphate ion. The residue was weighed and analysed for total sulphur content. The percentage gold extraction and pyrite decomposition may be calculated by solution and residue analyses.

- [0011]

The overall stoichiometric reaction is believed to be:-



Thus 2 moles of FeS_2 are equivalent to 4 moles of Na_2CO_3 and 1 kg of FeS_2 is equivalent to 1.767 kg of Na_2CO_3 . Thus, 1 tonne of pyritic concentrate (containing 476 kg of FeS_2 - determined by assay) is equivalent to 841 kg of Na_2CO_3 .

- [0012]

The calculated head is the ratio of the total of the weight of gold in solution and weight of gold in solid to the initial weight of solid.

- [0013]

A series of experiments was carried out in which the base stoichiometry was varied for the following baseline conditions, a leach time of 60 minutes, a temperature of 150°C, an oxygen overpressure of 6 bar (equivalent to 600 kPa), (Table 2). Tables 3 to 6 show the varying effects on sulphur conversion and gold dissolution of time, temperature, oxygen overpressure and base stoichiometry.

- [0014]

The gold and/or silver may be extracted from the resultant liquor either by use of a suitable ion exchange resin such as a strong or weak base resin, eg polystyrene or polymethylmethacrylate resins or by addition of zinc powder in the absence of oxygen. Alternative methods of extracting precious metal from the liquor may also be used.

- [0015]

Table 2 shows that base stoichiometry has a marked effect on gold extraction. The terminal pH in the autoclave is controlled by base addition at the beginning of the extraction. It is believed that low base concentrations result in oxidation of the thiosulphate ion and the gold thiosulphate complex formed. A base concentration which is too high results in minimal gold dissolution, as the terminal pH is outside the optimum range for gold dissolution by thiosulphate ion.

- [0016]

Table 3 shows the effect of pulp density (weight of solid/[weight of solid + weight of solution] x 100%). Optimum results for gold extraction were obtained at pulp densities greater than 4.

- [0017]

Table 4 shows the effect of oxygen overpressure. Increasing oxygen overpressure marginally tends to increase the gold extraction.

- [0018]

Table 5 shows that at temperatures of greater than 150°C, the gold extraction decreases markedly. This is believed to be caused by gold precipitation from solution due to oxidation of the gold thiosulphate complex and thiosulphate ion.

- [0019]

Table 6 shows the effect of residence time. For residence times of over 70 minutes at 150°C the gold dissolution fell markedly. This is probably caused by oxidation of thiosulphate ion and gold thiosulphate complex.

- [0020]

Table 7 shows a further set of results illustrating the effect of base stoichiometry on gold extraction from a pyritic gold concentrate from a Canadian mine. The concentrate contained about 80.1% pyrite and 8.5 grams per tonne of gold. The conditions for the reactions were similar to the above concentrate and were a leach time of 30 minutes, a temperature of 130°C, and an oxygen overpressure of 8 bar (equivalent to 800 kPa). TABLE 1 GOLD CONCENTRATE By Assay Gold 15.3 g/tonne of concentrate Silver less than 5 g/tonne of concentrate Total Sulphur content 25.4% by weight equivalent to 47.6% pyrite FeS₂. Sulphate ion 0.9% Elemental sulphur less than 0.01% Total carbon less than 0.1% Carbonate ion 0.02% By Atomic Absorption Spectroscopy Fe 20.10% (equivalent to 42.9% pyrite FeS₂), As 0.4%, Si 13.3%, K 4.9%, Al 5.1%. By X-Ray Fluorescence S 23%, Fe 21%, Si 19%, K 8.9%, Al 6.6%, Pb 1.3%, Mg 1.2%, Ti 0.4%, Ca 0.3%, P 0.3%, Mo 0.1%. By X-Ray Diffraction Mainly pyrite and a feldspar (orthoclase) with traces of kaolinite and muscovite.

TABLE 2 Base Stoichiometry kg Na₂CO₃ added/tonne of concentrate kg Na₂CO₃ used/tonne of concentrate Gold Dissolution % Calculated Head g/t % pyrite to Sulphate to Conversion kg thiosulphate produced/tonne concentrate Final
pH 0.700 586 583 20.4 15.1 81.2 8.65 7.4 0.725 607 601 55.7 15.0 82.4 9.68 7.8 0.775 649 6
41 84.3 15.5 86.3 14.1 8.3 0.800 669 644 87.8 14.6 88.7 22.0 10.3 0.825 690 664 89.1 14.8 8
8.1 23.2 10.0 0.850 711 652 64.0 15.0 89.8 19.8 10.2 0.875 732 627 47.7 14.3 88.6 13.4 10.2
0.900 763 642 58.6 14.5 89.1 14.4 10.0 6.0 bar oxygen overpressure 60 mins residence
time 150°C Charge = 50g concentrate + 500ml sodium carbonate solution

TABLE 3 Pulp Density % wt kg Na₂CO₃ used/tonne concentrate Sulphur Conversion % Gold
Dissolution % Calculated Head g/t Av kg thiosulphate produced/tonne
concentrate 2.4 667 84.0 11.0 20.1 1.47 4.8 659 89.1 87.9 16.4 50.8 9.1 644 86.6 87.8 14.6 2
2.0 13.0 604 81.5 85.1 14.9 22.0 Conditions:- 6.0 bar oxygen overpressure 60 mins residence
time 150°C 669 kg sodium carbonate/tonne concentrate Charge = 50g concentrate + 500ml
sodium carbonate solution

TABLE 4 Oxygen Overpressure bar kg Na₂CO₃ used/tonne concentrate Sulphur Conversion % Gold Dissolution % Calculated Head g/t kg thiosulphate produced/tonne concentrate 3.0 626 83.2 78.6 16.2 38.1 4.0 641 86.6 85.3 15.8 48.1 5.0 651 86.3 91.1 15.3 3 9.7 6.0 644 86.6 87.8 14.6 22.0 7.0 662 86.6 91.1 15.6 26.6 Conditions:- 150°C 60 mins residence time 669 kg sodium carbonate/tonne concentrate Charge = 50g concentrate + 500ml sodium carbonate solution

TABLE 5 Temperature °C kg Na₂CO₃ used/tonne concentrate Sulphur Conversion % Gold Dissolution % Calculated Head g/t kg thiosulphate produced/tonne concentrate 135 543 80.8 86.5 15.2 60.8 140 577 85.1 86.3 15.8 59.0 145 635 85.9 87.8 15.7 56.4 150 644 86.6 87.8 14.6 22.0 160 669 87.3 12.4 15.1 1.6 165 669 86.7 2.9 14.0 0.6 Con ditions:- 6.0 bar O₂ overpressure 60 mins residence time 669 kg sodium carbonate/tonne concentrate Charge 50g concentrate + 500ml sodium carbonate solution

TABLE 6 Residence Time (Mins) kg Na₂CO₃ used/tonne concentrate Sulphur Conversion % Gold Dissolution % Calculated Head g/t kg thiosulphate produced/tonne concentrate 45 598 80.9 87.2 15.4 49.5 50 624 85.2 87.0 15.2 27.1 55 639 86.6 84.5 14.4 26. 8 60 644 86.6 87.8 14.6 22.0 65 662 88.0 85.2 15.6 15.0 70 659 89.5 87.0 14.4 10.8 75 661 8 8.4 54.6 14.6 7.7 Conditions:- 6.0 bar O₂ overpressure 669 kg sodium carbonate/tonne concentrate 150°C Charge = 50g concentrate + 500ml sodium carbonate solution

TABLE 7 Base Stoichiometry kg.Na₂CO₃/tonne of concentrate Sulphur Conversion % Gold Dissolution % kg/t of thiosulphate formed/tonne of pyrite concentrate Final pH 0.2 288 54.6 13.1 44.5 2.2 0.4 576 73.3 12.0 15.4 2.8 0.5 720 80.0 5.0 13.1 3.0 0.6 864 8 6.5 74.0 18.3 7.4 0.7 1008 92.8 48.5 38.4 - 0.8 1152 93.8 65.7 16.0 9.6 1.0 1440 85.7 28.8 3. 0 9.7

Claims (7)

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1. A process for separating gold or other precious metals from arsenopyrite or pyrite ores and associated materials comprising the steps of (a) treating the ore with an alkaline solution and bubbling an oxygen containing gas through the mixture to break up the sulphide matrix (b) the ore having an initial base: sulphide sulphur stoichiometry of between 0.6:1 to 1.0:1 so as to maximise the solubilisation of gold or other precious metals and (c) extracting the gold or other precious metals from the resultant solution.
2. A process according to claim 1 in which the alkaline solution is sodium hydroxide, potassium hydroxide, potassium carbonate, sodium carbon, ammonium hydroxide or mixture thereof.
3. A process according to claim 1 or claim 2 in which the temperature of the process is from 70°C to 150°C.
4. A process according to any of the preceding claims in which the resultant solution has a substantially neutral pH.
5. A process according to any of the preceding claims in which the oxygen overpressure is from 0 to 7 bar.
6. A process according to any of the preceding claims in which the initial base:sulphide sulphur stoichiometry is from 0.725 to 0.850.
7. A process according to any of the preceding claims in which the pulp density is greater than 4 wt %.

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