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(54) **PROCEDE POUR L'ENRICHISSEMENT DE CONCENTRES DE SULFATES DE NICKEL ET DE MELANGES CORRESPONDANTS IMPROPRES A LA FUSION**

(54) **METHOD FOR BENEFICIATING NICKEL SULFIDE CONCENTRATES AND CORRESPONDING MIXTURES, UNSUITABLE FOR SMELTING**

(57) The present invention relates to a method for beneficiating nickel sulfide concentrates or other corresponding mixtures, unsuitable for smelting, by combining the use of both pyrometallurgical and hydrometallurgical processes, so that there are formed two separate concentrates, the first of which is suited to pyrometallurgical and the second to hydrometallurgical treatment. In the pyrometallurgical concentrate, the valuable metal content increases as a consequence of the treatment, and the Fe/MgO ratio of this concentrate is at least 2.6.

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ABSTRACT OF THE DISCLOSURE

The present invention relates to a method for beneficiating nickel sulfide concentrates or other corresponding mixtures, unsuitable for smelting, by combining the use of both pyrometallurgical and hydrometallurgical processes, so that there are formed two separate concentrates, the first of which is suited to pyrometallurgical and the second to hydrometallurgical treatment. In the pyrometallurgical concentrate, the valuable metal content increases as a consequence of the treatment, and the Fe/MgO ratio of this concentrate is at least 2.6.

The present invention relates to a method for beneficiating nickel sulfide concentrates and corresponding mixtures unsuitable for smelting by combining the use of both pyrometallurgical and hydrometallurgical processes, so that there are formed two concentrates, the first of which is suited to pyrometallurgical and the second to hydrometallurgical treatment.

The amount of such nickel mineralizations that are easily concentrated or processed metallurgically, particularly pyrometallurgically, is decreasing throughout the world. Therefore more and more low-quality mineralizations must be used to recover nickel. In addition to this, several mineralizations are located in areas that are either totally without water or where the water is saline and has a high halogen content.

Problems in concentration due to the presence of difficult gangue minerals are related to the properties of these minerals. Gangue minerals often consist of silicates that cannot be easily treated in a metallurgical process. The geometrically complicated features of gangue minerals consist of many phases containing, in addition to SiO_2, variable amounts of different iron, aluminium, manganese and magnesium compounds, which again are accompanied by a large group of oxides (often magnetite Fe_3O_4), hydroxides, carbonates and sulfates. Various magnesium silicates have been proven to be particularly difficult with respect to process metallurgy.

Minerals are often very soft, electrically strongly charged and particularly easily concentrated together with valuable minerals, owing to textural features and mixed grains with valuable minerals. Accordingly, there has not yet been found conditions where good-quality concentrates for pyrometallurgical processing could be obtained, even if a sufficiently high recovery should be achieved. Intensive flocculation and adsorption with valuable minerals are typical of these minerals, both with dry and wet processing. Moreover, these types of gangues have remarkably high specific areas and often a very high solubility.

Large amounts of concentrates with unsatisfactory qualities to further metallurgical processing are obtained from mineralizations that are not easily concentrated. Problems include high magnesium oxide contents, due to high magnesium oxide contents of the gangue minerals, high halogen contents or low iron contents. Above all, the iron/magnesium oxide ratio is often low because the concentrates contain very little iron sulfides, such as pyrrhotite $Fe_{1-x}S$. Such mineralizations often contain magnetite, sometimes in large quantities. Thus, at the concentration stage, mixed valuable metal-magnetite grains are obtained in the concentrate and the iron content of the concentrate often consists to a remarkable degree in the magnetite of these grains. This leads to difficulties in the pyrometallurgical treatment where, if the MgO content of the slag created in the smelting is over 11%, the viscosity of the slag increases substantially making it difficult to remove the slag from the furnace.

In areas where fresh water is not available, saline ground water must often be used in wet concentration processes. Typically, saline ground water contains high quantities of dissolved salts, particularly chlorine and fluorine, which must be removed by subjecting the concentrates to several successive cleaning and washing stages. Moreover, halogens cause significant corrosion damage particularly to the equipment downstream from the furnaces.

The concentration of ores is generally carried out by concentration methods known to those skilled in the art, by using either dry or wet processes. Normally, with mineralogically distinctive ores, after a number of cleaning stages, the concentrates are well-suited for smelting. Such high-grade and/or mineralogically good-quality ores are those which do not contain, or contain to a slight extent only, problematic gangue minerals, such as magnesium silicates, hydroxides and/or hydroxyhalides. The iron/magnesium oxide ratio does not cause problems with these high-grade and good quality ores.

When the valuable minerals of an ore deposit are present in finely disseminated and intergrown form, it is often very difficult to achieve a good quality concentrate with an economically satisfactory recovery. In order to obtain a good (high-grade) concentrate, the degree of liberation of minerals after grinding must be high, which often requires a very fine grind. However, the concentrate is often suitable for smelting if the ore deposit contains other sulfidic minerals rich in iron, such as pyrrhotite, and if these sulfidic minerals are recovered in the concentrate. The nature of silicates contained in an ore deposit may also be such that they are not easily recovered in a concentrate, or that they can be depressed at the cleaning stages.

When an ore deposit contains silicates, particularly magnesium silicates, such as talc and serpentinite minerals, that are easily concentrated into the concentrate, it is often very difficult to obtain concentrates with a sufficient quality for pyrometallurgical treatment, i.e. concentrates with a sufficiently low MgO content. Various silicates may cause similar problems with volcanitic ores (e.g. Kambalda, Australia).

According to the present invention, there is provided a method for beneficiating nickel sulfide concentrate, or other nickel-containing concentrate, unsuitable for smelting, comprising the steps of separating the nickel concentrate into a first and a second separate concentrate, the first concentrate having a higher valuable metal content and the second concentrate having a lower valuable metal content, adjusting the Fe/MgO ratio of the first concentrate with the higher valuable metal content to be at least 2.6, and treating such first concentrate pyrometallurgically, and treating the second concentrate, which has the lower valuable metal content and has a high MgO content, hydrometallurgically.

The present invention relates to a method for economically and technically utilizing a concentrate, that is otherwise unsuitable or poorly suited for smelting, to the full extent by separating it into two separate concentrates. The separation of the concentrate can be carried out by means of either wet or dry concentration.

A suitable wet concentration method can be, for example, a thorough selective flotation, constituting several intermediate product grindings and classifications as well as cleaning stages. Suitable dry methods include, for example, various grinding and classification methods and magnetic separations often connected thereto, as well as various methods based on specific weight and electrostatic methods. Grinding methods include grinding in a ball mill or a vibrating mill, or jet mill grinding. In the treatment of the complicated materials, there is now found a narrow particle size region and conditions which can be utilized in order to make processing possible.

A first concentrate is formed wherein the amount of harmful gangue minerals and particularly harmful magnesium silicates is so low, that the concentrate is suited to pyrometallurgical treatment. The iron/magnesium oxide ratio of the concentrate is greater than 2.6, and its valuable metal content is significantly greater than that of the second concentrate produced in the method. The limit of the Fe/MgO ratio is the lower limit of the pyrometallurgically treatable concentrate; obviously the higher the ratio, the better the prospects for processing.

The iron/magnesium oxide ratio of the concentrate can also be defined so that the MgO content of the slag produced in the pyrometallurgical treatment is less than 11%. If the MgO content of the slag is higher, the viscosity of the slag is increased so that it is difficult to remove the slag from the furnace at the temperature of the pyrometallurgical treatment of nickel. An increase in the temperature improves the fluidity of the slag, but it is not technically and economically beneficial. The nickel concentrate produced according to this method is advantageously treated in a flash smelting furnace.

The second concentrate to be produced has a lower valuable metal content than the first concentrate and it contains more gangue minerals and silicates, such as magnesium silicate, that are particularly harmful with respect to smelting. The second concentrate, which is poorer in valuable metal content, can be treated hydrometallurgically, and an economically profitable process can be achieved.

By concentrating the finely separated silicate material contained in the original composite concentrate to a significant degree into the hydrometallurgical concentrate, it is possible to produce a concentrate which is suitable to pyrometallurgical smelting, has a higher valuable metal content and a lower content of magnesium silicates that are harmful for the smelting of the concentrate.

Owing to finely separated silicate impurities, the hydrometallurgical concentrate has a significantly finer particle size than the coarser pyrometallurgical concentrate. However, the fine particle size distribution is an advantage with respect to hydrometallurgical leaching. Furthermore, a significant proportion of the halogen is contained in the hydrometallurgically treatable concentrate, which is advantageous for the pyrometallurgical processing.

The concentrate that is prepared for hydrometallurgical treatment and has a high MgO content, is first conducted into pressure leaching carried out with oxygen. Valuable metals (nickel, cobalt and copper) are leached into a sulfate form and the iron is precipitated. The sulfate solution is cleaned, for example, by means of suitable extraction stages. When the valuable metals other than nickel are removed from the solution, the recovery of nickel from the solution can be carried out either electrolytically or by reduction.

The following Examples illustrate the invention. Example 1 describes dry concentration and Example 2 describes wet concentration.

Example 1

The nickel concentrates used were of the serpentinite and pyroaurate type containing magnesium silicates. These concentrates were extremely difficult to concentrate, soft, electrically charged and had a high specific area. The object was to achieve, according to the invention, two separate concentrates, the first of which is suited to pyrometallurgical and the second to hydrometallurgical treatment.

The initial treatment of nickel ore was carried out in conventional fashion by using thorough selective flotation. In addition to the rougher flotation, several cleaning flotations were performed with depressant chemicals. The object was to decrease, with conventional methods, the amount of the magnesium silicates and halogens easily flotated into the concentrate to be as low as possible. The analysis of the obtained concentrate is shown in Table 1. The concentrate was subjected to washing and filtration to improve the quality thereof. Table 1 also illustrates the composition of the concentrate after washing.

TABLE 1

Concentrate Analysis

Component	Quantity before washing	Quantity after washing
	% by weight	% by weight
Ni	18.2	15.8
Fe	30.5	28.5
MgO	8.9	7.1
Fe/MgO	3.43	4.01
S	29.3	26.5
SiO_2	6.7	6.5
F	11.3	20.4
Cl	0.56	0.12

Table 1 illustrates that the valuable metal, iron and MgO content decreased during washing and filtration. The Fe/MgO ratio increased as a result of the washing and filtration and consequently the pyrometallurgical processing characteristics of the concentrate was improved. Table 1 also shows that the concentrate contains only a small amount of chlorine which is advantageous for pyro-metallurgical treatment.

The washed and filtered concentrate was further treated by separating it into two separate concentrates. The separation was carried out by grinding and classification with an Alpine jet mill. The PY concentrate was coarser, which is suitable for pyrometallurgical treatment, and had a sufficiently high Fe/MgO ratio, and a high valuable metal content. The second HY concentrate had a finer particle distribution and a lower valuable metal content. The second concentrate was suitable for hydro-metallurgical treatment. Table 2 shows that the coarser product is more suitable for pyrometallurgical concentration than the original concentrate represented in Table 1. The contents are given in percentages by weight. Table 3 shows the fineness of the same products.

The tables below show that both of these products (the HY and PY concentrates), obtained from the original concentrate, can be utilized in a technically and economically sensible way. In addition to this, Table 2 shows (in percentages of quantity) that the proportion of the coarser product (PY) and finer product (HY) can be easily adapted, for instance according to the requirements of a particular pyrometallurgical treatment. Thus the proportions of the new products obtained from the original concentrate can also be defined in a desired fashion.

While the decreased content of silicates, calculated as SiO_2 content, is unfavourable with respect to pyrometallurgical processing of the product, it is easy to add silicates, such as sand, to the pyrometallurgical process. Moreover, the amount of soft magnesium silicates, and particularly magnesium, is also decreased when the amount of silicates in a pyrometallurgical process is decreased.

TABLE 2

Test	1		2		3		4		5		6	
	HY	PY	HY	PY	HY	PY	HY	PY	HY	PY	HY	PY
% of quantity	59.6	40.4	45.4	54.6	34.7	65.3	31.9	68.1	20.3	79.7	12.8	87.2
Ni												
% of content	14.6	15.0	14.5	15.3	13.8	15.5	13.8	15.3	12.9	15.4	11.6	15.4
% of recovery	58.9	41.1	44.0	56.0	32.1	67.9	29.7	70.3	17.6	82.4	10.0	90.0
MgO												
% of content	6.8	6.3	7.1	6.1	7.3	6.1	7.5	6.0	8.3	5.9	8.7	6.2
% of recovery	61.4	38.6	49.2	50.8	38.9	61.1	36.9	63.1	26.4	73.6	17.1	82.9
Fe												
% of content	24.0	25.9	24.2	27.0	23.1	26.9	23.0	27.3	20.5	26.7	19.3	26.3
% of recovery	57.7	42.3	42.7	57.3	31.4	68.6	28.3	71.7	16.4	83.6	9.8	90.2
Fe/MgO	3.53	4.11	3.41	4.43	3.16	4.41	3.06	4.55	2.47	4.53	2.22	4.24
SiO_2												
% of content	6.2	5.7	6.3	5.5	6.6	5.7	6.6	5.6	6.9	5.8	7.2	5.7
% of recovery	61.6	38.4	48.8	51.2	38.1	61.9	35.5	64.5	23.3	76.7	15.7	84.3
S												
% of content	22.0	24.8	22.2	25.2	22.2	25.7	21.1	25.2	19.5	26.1	18.6	25.3
% of recovery	56.7	43.3	42.3	57.7	31.5	68.5	28.1	71.9	16.0	84.0	9.8	90.2
Cl												
% of content	0.083	0.083	0.1	0.082	0.11	0.083	0.13	0.083	0.14	0.084	0.16	0.086
% of recovery	59.6	40.4	50.3	49.7	41.4	58.6	42.3	57.7	29.8	70.2	21.5	78.5
F												
Content - ppm	30.5	30.0	27.0	23.0	22.0	22.0	21.5	27.0	21.5	20.5	34.5	36.5
% of recovery	60.0	40.0	49.4	50.6	34.7	65.3	27.1	72.7	21.1	78.9	12.4	87.6
Specific area m^2/g	1.50	0.97	1.44	0.96	1.73	0.93	1.70	1.04	1.82	0.88	2.08	0.99

HY = product for hydrometallurgical treatment
PY = product for pyrometallurgical treatment

TABLE 3

Results for Fineness

Test	1		2		3		4		5		6	
Fineness (μm)	HY	PY	HY	PY	HY	PY	HY	PY	HY	PY	HY	PY
d10	2.52	5.03	1.85	5.20	1.28	6.38	1.22	7.15	0.97	6.86	0.87	6.11
d50	14.02	20.21	10.94	21.44	7.83	22.25	7.09	21.56	4.54	20.40	3.48	19.21
d90	33.00	38.59	28.89	38.18	21.42	41.70	21.75	40.90	11.75	39.25	10.34	38.38

dx = x(μm) passing percentage
d10 = 10% of the particles have a diameter smaller than the given μm-value
d50 = 50% of the particles have a diameter smaller than the given μm-value
d90 = 90% of the particles have a diameter smaller than the given μm-value

In the above Tables, it is clearly shown that, when the proportion of the finer product (HY) for hydrometallurgical treatment is decreased, the valuable metal content (Ni) is also decreased, as well as the iron and sulfur content. The magnesium oxide (MgO), silicon oxide and chlorine contents increase. It is further seen from the Tables that the specific area increases and fineness decreased. The decrease in fineness was due to the changes of the material proportions between the hydrometallurgical and pyrometallurgical product. In the classification, the quantity of the product for pyrometallurgical treatment increased, and at the same time some fine material was transferred into this section.

The coarser product for pyrometallurgical treatment behaved in an opposite fashion. The Fe/MgO ratio that is important for the pyrometallurgical treatment consistently decreased for the hydrometallurgically treatable product, and increased for the pyrometallurgically treatable coarser product. Thus the choice between the two metallurgical process alternatives for the concentrate is simple and depends on the requirements set for the particular metallurgical treatment.

Example 2

Example 2 describes how the concentrate is separated for pyrometallurgical and hydrometallurgical treatment by means of wet concentration.

The washed and filtered concentrate (Table 1) was treated further by separating it into two separate concentrates. The separation was carried out by means of intensively magnetic Carpco separation. The concentrate was elutriated into water and dispersed with sodium silicate (Na_2SiO_3) or water-glass at a rate of 2.2 kg/h. The matrix was a Jones Matrix with an aperture of 1.5 mm. The currents used were 0.6 A, 1.2 A, 3.5 A and 5.6 A. The results are shown in Table 4.

TABLE 4

Fraction	M1	M2	M3	M4	EM
Current	0.6A	1.2A	3.5A	5.6A	-
% of quantity	35.9	12.3	13.3	5.8	32.8
Cumulative % of quantity	-	48.2	61.5	67.3	100
Ni					
% of content	13.4	17.7	20.2	21.5	14.4
Cumulative % of content	-	14.5	15.7	16.2	15.6
% of recovery	30.8	14.0	17.2	8.0	30.1
Cumulative % of recovery	-	44.7	61.9	69.9	100
MgO					
% of content	4.6	5.2	6.2	8.8	8.8
Cumulative % of content	-	4.7	4.9	5.0	6.2
% of recovery	26.5	10.2	11.5	5.7	46.0
Cumulative % of recovery	-	36.7	48.3	54.0	100
Fe					
% of Content	37.3	30.8	29.7	27.9	26.9
Cumulative % of content	-	35.6	34.4	33.8	31.5
% of recovery	42.4	12.0	12.5	5.1	27.8
Cumulative % of recovery	-	54.5	67.0	72.1	100
Fe/MgO					
Fe/MgO	8.11	5.92	4.79	3.17	3.06
Fe/MgO, cumulative	-	7.57	7.02	6.76	5.08
Fe_3O_4					
% of content	17.3	2.8	1.6	1.4	1.3
Cumulative % of content	-	13.6	11.0	10.2	7.2
% of recovery	85.4	4.7	2.9	1.1	5.8
Cumulative % of recovery	-	90.1	93.0	94.2	100

M1...M4 = magnetic fractions
EM = non-magnetic fraction

The Fe_3O_4 content (magnetite) of Table 4 describes the amount of ferromagnetic material in the sample, defined by a Satmagan-analyzer (Saturation Magnetization Analyzer).

The proportion of magnetic material increased with increased current strength. The valuable metal content (Ni) and its recovery to magnetic fractions also increased in a cumulative fashion. The magnesium oxide content (MgO) increased slightly along with an increase in the strength of the magnetic field, but it remained clearly below the content of the non-magnetic fraction. Iron was accumulated in intensively magnetic fractions. The iron/magnesium oxide ratio was naturally decreased when the quantity of magnetically separated material increased, but the difference over the non-magnetic fraction is clear. The value of the cumulative Fe/MgO ratio is 6.76, corresponding to a ratio of 3.06 in the non-magnetic fraction. The magnetite content (Fe_3O_4) distinctly shows that almost all of the ferromagnetic material was transferred to the magnetic fractions.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method for beneficiating nickel sulfide concentrate, or other nickel-containing concentrate, unsuitable for smelting, comprising the steps of separating the nickel concentrate into a first and a second separate concentrate, the first concentrate having a higher valuable metal content and the second concentrate having a lower valuable metal content, adjusting the Fe/MgO ratio of the first concentrate with the higher valuable metal content to be at least 2.6, and treating such first concentrate pyrometallurgically, and treating the second concentrate, which has the lower valuable metal content and has a high MgO content, hydrometallurgically.

2. A method according to claim 1, wherein the nickel concentrate is separated into the first and second concentrates by means of wet concentration.

3. A method according to claim 1, wherein the nickel concentrate is separated into the first and second concentrates by means of dry concentration.

4. A method according to claim 1, 2 or 3, wherein the MgO content of a slag formed from the first pyrometallurgically treatable concentrate is not more than 11%.

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