

Separation and recovery of Bi from CuSO₄-solution

1. Perspective

Glencore Nikkelverk AS ("Nikkelverk") is wholly owned by Glencore PLC, a diversified resource company with activities within the whole value chain in different industries like minerals, metals, energy and grains, from mines through concentrators, smelters, refineries, marketing and sales to end users.

Nikkelverk belongs to Glencore's nickel division, where activities also cover the whole value chain from mine to refinery and sales. Nikkelverk as a refinery represents the last link in this chain, where concentrates are refined to finished, marketable nickel and copper metals, as well as a range of other byproducts that originates in the often "complex" nickel ores.

In the nickel mining industry, the resources are of two different types:

- Sulphidic ores
- Oxidic ores (socalled "laterite ores")

Nikkelverk was designed to refine concentrates from mines containing nickel sulphide ores, ores that are complex and contain a range of valuable minerals and metals of economic value, as well as numerous elements and compounds that are not economic to recover. In this context, these are often termed "impurities" as they have to be separated and removed from the process stream containing the valuables in order to prevent them from contaminating the finished products. This is one of the main tasks of a metal refinery, and will be of focus in this project.

Copper as the main "by-product" from Nikkelverk, originates from mixed nickel-copper sulphide ores, a common source for production of refined nickel. As both copper and nickel are contained in the same feed material, the copper circuit (separated from the nickel circuit) and copper electrolyte sees the same impurity elements, in different quantities though.

This project will focus on the element bismuth (Bi), and its separation and removal from copper sulphate (CuSO₄) solutions.

2. Operative conditions

In Nikkelverk's flowsheet, Bi as well as a number of other impurities reports to the process solution in the main copper circuit and the accumulation of Bi is controlled by a process which bleeds a continuous but limited quantity. Maximum daily production of copper in the tankhouse is 110 tonnes, and this requires a continuous flow (24/7) of pregnant leach solution ("PLS") of ca. 100m³/h, from which Bi is removed.

3. Chemical elements, compositions and other conditions

The PLS consist of the following main ions and species: Cu(2+), Ni(2+), Co(2+), Fe(2+), Fe(3+), As(3+), Bi(3+), Te(4+), Te(6+), H₂SO₄, SO₄(2-), all as dissolved species.

<u>Element</u>	<u>Typical ranges (g/l)</u>
Cu(2+)	60-120
Ni(2+)	15-25
Co(2+)	2-5
Fe(2+,3+)	0.5-1.0
As(3+)	0.3-0.6
Bi(3+)	0.2-0.6
Te(4+,6+)	0.2-0.6
H ₂ SO ₄	20-100
SO ₄ (2-)	balance
Temperature	50-70°C
Pressure	atmospheric

Remark: The large range for Cu and H₂SO₄ reflects the fact that several different solutions from the copper circuit may be candidates for Bi-removal, and the range reflects the electrolysis process the PLS goes through.

4. Design specifications

Industrial constraints for Bi.

Target concentration: 0.5-1 g/l Bi in PLS,

Target level of removal: >50% of Bi removed, preferably >90%

5. Literature

Nikkelverk R&D department has focused on optimizing current technology.

6. Analytical methods

Methods chosen may vary, depending on the specific laboratory's instrumentation. Below are listed methods used at Nikkelverk analytical laboratory:

1. ICP-OES

7. Other

If interesting technologies for Bi-removal are identified, Bi removal and recovery from NiCl₂-solutions may also be investigated.

Separation and recovery of As from CuSO₄-solution

1. Perspective

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Nikkelverk belongs to Glencore's nickel division, where activities also cover the whole value chain from mine to refinery and sales. Nikkelverk as a refinery represents the last link in this chain, where concentrates are refined to finished, marketable nickel and copper metals, as well as a range of other byproducts that originates in the often "complex" nickel ores.

In the nickel mining industry, the resources are of two different types:

- Sulphidic ores
- Oxidic ores (so-called "laterite ores")

Nikkelverk was designed to refine concentrates from mines containing nickel sulphide ores, ores that are complex and contain a range of valuable minerals and metals of economic value, as well as numerous elements and compounds that are not economic to recover. In this context, these are often termed "impurities" as they have to be separated and removed from the process stream containing the valuables in order to prevent them from contaminating the finished products. This is one of the main tasks of a metal refinery, and will be of focus in this project.

Copper as the main "by-product" from Nikkelverk, originates from mixed nickel-copper sulphide ores, a common source for production of refined nickel. As both copper and nickel are contained in the same feed material, the copper circuit (separated from the nickel circuit) and copper electrolyte sees the same impurity elements, in different quantities though.

This project will focus on the element Arsenic (As), and its separation and removal from copper sulphate (CuSO₄) solutions.

2. Operative conditions

In Nikkelverk's flowsheet, As as well as a number of other impurities reports to the process solution in the main copper circuit and the accumulation of As is controlled by a process which bleeds a continuous but limited quantity. Maximum daily production of copper in the tankhouse is 110 tonnes, and this requires a continuous flow (24/7) of pregnant leach solution ("PLS") of ca. 100m³/h, from which As is removed.

3. Chemical elements, compositions and other conditions

The PLS consist of the following main ions and species: Cu(2+), Ni(2+), Co(2+), Fe(2+), Fe(3+), As(3+), Bi(3+), Te(4+), Te(6+), H₂SO₄, SO₄(2-), all as dissolved species.

<u>Element</u>	<u>Typical ranges (g/l)</u>
Cu(2+)	60-120
Ni(2+)	15-25
Co(2+)	2-5
Fe(2+,3+)	0.5-1.0
As(3+)	0.3-0.6
Bi(3+)	0.2-0.6
Te(4+,6+)	0.2-0.6
H2SO4	20-100
SO4(2-)	balance
Temperature	50-70°C
Pressure	atmospheric

Remark: The large range for Cu and H2SO4 reflects the fact that several different solutions from the copper circuit may be candidates for As-removal, and the range reflects the electrolysis process the PLS goes through.

4. Design specifications

Industrial constraints for As.

Target concentration: 0.5-1 g/l As in the PLS,

Target level of removal: >50% of As removed, preferably >90%

5. Literature

Nikkelverk R&D department has focused on optimizing current technology.

6. Analytical methods

Methods chosen may vary, depending on the specific laboratory's instrumentation. Below are listed methods used for As at Nikkelverk analytical laboratory:

1. ICP-OES

7. Other

If interesting technologies for As-removal are identified, As removal and recovery from NiCl2-solutions may also be investigated.

Separation and recovery of Pt, Ru and Rh from CuSO₄-solution

1. Perspective

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In the nickel mining industry, the resources are of two different types:

- Sulphidic ores
- Oxidic ores (socalled "laterite ores")

Nikkelverk was designed to refine concentrates from mines containing nickel sulphide ores, ores that are complex and contain a range of valuable minerals and metals of economic value, as well as numerous elements and compounds that are not economic to recover. In this context, these are often termed "impurities" as they have to be separated and removed from the process stream containing the valuables in order to prevent them from contaminating the finished products. This is one of the main tasks of a metal refinery, and will be of focus in this project.

Copper as the main "by-product" from Nikkelverk, originates from mixed nickel-copper sulphide ores, a common source for production of refined nickel. As both copper and nickel are contained in the same feed material, the copper circuit (separated from the nickel circuit) and copper electrolyte sees the same impurity elements, in different quantities though.

This project will focus on the elements Platinum (Pt), Ruthenium (Ru) and Rhodium (Rh), and its separation and removal from copper sulphate (CuSO₄) solutions.

2. Operative conditions

In Nikkelverk's flowsheet, Pt, Ru, Rh as well as a number of other impurities reports to the process solution in the main copper circuit and these three elements mainly report to the copper cathode produced in the electrowinning process ("tankhouse"). Maximum daily production of copper in the tankhouse is 110 tonnes, and this requires a continuous flow (24/7) of pregnant leach solution ("PLS") of ca. 100m³/h.

3. Chemical elements, compositions and other conditions

The PLS consist of the following main ions and species: Cu(2+), Ni(2+), Co(2+), Fe(2+), Fe(3+), As(3+), Bi(3+), Te(4+), Te(6+), H₂SO₄, SO₄(2-), all as dissolved species.

<u>Element</u>	<u>Typical ranges (g/l)</u>
Cu(2+)	100-120
Ni(2+)	15-25
Co(2+)	2-5
Fe(2+,3+)	0.5-1.0
As(3+)	0.3-0.6
Bi(3+)	0.2-0.6
Te(4+,6+)	0.2-0.6
H ₂ SO ₄	20-30
SO ₄ (2-)	balance
Temperature	50-70°C
Pressure	atmospheric

4. Design specifications

Industrial constraints for Pt, Ru and Rh.

Target concentration: For Pt, Ru, Rh - to be determined

Target level of removal: For Pt, Ru, Rh - to be determined

5. Literature

6. Analytical methods

Methods chosen may vary, depending on the specific laboratory's instrumentation. Below are listed methods used for As at Nikkelverk analytical laboratory:

1. Complex, needs development

7. Other

Separation and recovery of Zn from NiCl₂-solution

1. Perspective

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In the nickel mining industry, the resources are of two different types:

- Sulphidic ores
- Oxidic ores (socalled "laterite ores")

Nikkelverk was designed to refine concentrates from mines containing nickel sulphide ores, ores that are complex and contain a range of valuable minerals and metals of economic value, as well as numerous elements and compounds that are not economic to recover. In this context, these are often termed "impurities" as they have to be separated and removed from the process stream containing the valuables in order to prevent them from contaminating the finished products. This is one of the main tasks of a metal refinery, and will be of focus in this project.

The nickel industry is in a slow, but fundamental change, converting its main sources of nickel from mines producing sulphide ores to mines producing oxide ores.

This necessitates a number of changes and improvements in the value chains in order to be able to produce the product qualities the market demands. This requires both new investments and new technology, and the last issue is of interest here.

More specifically for this project is the chemical composition, and the differences from its traditional sources, from which it currently bases its operation on. Even though there are many similarities between concentrates originating from sulphidic and lateritic ores, a few stands out and is of importance to Nikkelverk and the possibility to refine concentrates from lateritic mines.

Three of the element impurities in the laterite concentrates are in quantities that limits Nikkelverk's capacity to treat these concentrates, and as usual in these kinds of industries, economy of scale is important to keep unit costs low. Nikkelverk sees it necessary to limit or eliminate these constraints in order to gain the scale to compete in this market.

The three impurity elements of interest are;

- zinc (Zn),
- magnesium (Mg) and
- manganese (Mn),

contained in concentrates typically termed “Mixed Hydroxide Precipitates” (“MHP”).

Main components in MHP could be:

<u>Element</u>	<u>Typical ranges (% by weight, dry matter)</u>
Ni(2+)	30-45
Co(2+)	<3
Mn(2+)	2-4
Zn(2+)	<1.5
Mg(2+)	0.5-3.0
SO ₄ (2-)	10-15
OH(-)	balance

This project will focus on the element zinc (Zn), and its separation and removal from nickel chloride (NiCl₂) solutions.

2. Operative conditions

In Nikkelverk’s flowsheet, these elements would report to the process solution in the main nickel circuit, where most of the impurities are removed before a pure nickel electrolyte is produced to feed the nickel electrolysis process (“Ni tankhouse”). Today, maximum daily production of nickel in the tankhouse is 270 tonnes, and this requires a continuous flow (24/7) of pregnant leach solution (“PLS”) of ca. 60m³/h.

3. Chemical elements, compositions and other conditions

The PLS consist of the following main ions and species: Ni(2+), Co(2+), Fe(2+), Fe(3+), Pb(2+), Mn(2+), Zn(2+), Mg(2+), Na(+), SO₄(2-) and Cl(-), all in dissolved states.

<u>Element</u>	<u>Typical ranges (g/l)</u>
Ni(2+)	200-220
Co(2+)	10-13
Fe(2+,3+)	0.1-0.2
Pb(2+)	0.1-0.2
Mn(2+)	0.05-0.1
Zn(2+)	0.01-0.05
Mg(2+)	0.5-1.0
Na(+)	4-6
SO ₄ (2-)	20-25
Cl(-)	balance
Temperature	28-35°C

Pressure atmospheric

4. Design specifications

Industrial constraints for Zn.

Target concentration: up to 5 g/l Zn in PLS,

Target level of removal: To <0.03 g/l Zn, preferably <0.01 g/l Zn in purified PLS

5. Literature

Nikkelverk R&D department has carried out a number of studies on new technology of the removal of Zn from PLS, including:

1. Liquid-liquid extraction (SX): applying commercially available tertiary and quarternary amine extractants
2. Liquid-solid extraction: (IX): applying commercially available strong-base resins (quarternary amines)

6. Analytical methods

Methods chosen may vary, depending on the specific laboratory's instrumentation. Below are listed methods used at Nikkelverk analytical laboratory:

1. AA for higher Zn-concentrations
2. ICP-OES for lower Zn-concentrations

7. Other

Separation and recovery of Mn from NiCl₂-solution

1. Perspective

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In the nickel mining industry, the resources are of two different types:

- Sulphidic ores
- Oxidic ores (socalled "laterite ores")

Nikkelverk was designed to refine concentrates from mines containing nickel sulphide ores, ores that are complex and contain a range of valuable minerals and metals of economic value, as well as numerous elements and compounds that are not economic to recover. In this context, these are often termed "impurities" as they have to be separated and removed from the process stream containing the valuables in order to prevent them from contaminating the finished products. This is one of the main tasks of a metal refinery, and will be of focus in this project.

The nickel industry is in a slow, but fundamental change, converting its main sources of nickel from mines producing sulphide ores to mines producing oxide ores.

This necessitates a number of changes and improvements in the value chains in order to be able to produce the product qualities the market demands. This requires both new investments and new technology, and the last issue is of interest here.

More specifically for this project is the chemical composition, and the differences from its traditional sources, from which it currently bases its operation on. Even though there are many similarities between concentrates originating from sulphidic and lateritic ores, a few stands out and is of importance to Nikkelverk and the possibility to refine concentrates from lateritic mines.

Three of the element impurities in the laterite concentrates are in quantities that limits Nikkelverk's capacity to treat these concentrates, and as usual in these kinds of industries, economy of scale is important to keep unit costs low. Nikkelverk sees it necessary to limit or eliminate these constraints in order to gain the scale to compete in this market.

The three impurity elements of interest are;

- zinc (Zn),
- magnesium (Mg) and

- manganese (Mn),

contained in concentrates typically termed “Mixed Hydroxide Precipitates” (“MHP”).

Main components in MHP could be:

<u>Element</u>	<u>Typical ranges (% by weight, dry matter)</u>
Ni(2+)	30-45
Co(2+)	<3
Mn(2+)	2-4
Zn(2+)	<1.5
Mg(2+)	0.5-3.0
SO ₄ (2-)	10-15
OH(-)	balance

This project will focus on the element manganese (Mn), and its separation and removal from nickel chloride (NiCl₂) solutions.

2. Operative conditions

In Nikkelverk’s flowsheet, these elements would report to the process solution in the main nickel circuit, where most of the impurities are removed before a pure nickel electrolyte is produced to feed the nickel electrolysis process (“Ni tankhouse”). Today, maximum daily production of nickel in the tankhouse is 270 tonnes, and this requires a continuous flow (24/7) of pregnant leach solution (“PLS”) of ca. 60m³/h.

3. Chemical elements, compositions and other conditions

The PLS consist of the following main ions and species: Ni(2+), Co(2+), Fe(2+), Fe(3+), Pb(2+), Mn(2+), Zn(2+), Mg(2+), Na(+), SO₄(2-) and Cl(-), all in dissolved states.

<u>Element</u>	<u>Typical ranges (g/l)</u>
Ni(2+)	200-220
Co(2+)	0.1-13
Fe(2+,3+)	0.1-0.2
Pb(2+)	0.1-0.2
Mn(2+)	0.05-0.1
Zn(2+)	0.01-0.05
Mg(2+)	0.5-1.0
Na(+)	4-6
SO ₄ (2-)	20-25
Cl(-)	balance
Temperature	28-35°C
Pressure	atmospheric

4. Design specifications

Industrial constraints for Mn.

Target concentration: up to ca. 1 g/l Mn in PLS,

Target level of removal: To <0.1 g/l Mn, preferably <0.01 g/l Mn in purified NiCl₂-solution

5. Literature

Nikkelverk R&D department has carried out a number of studies on optimizing existing technology of the removal of Mn from PLS.

6. Analytical methods

Methods chosen may vary, depending on the specific laboratory's instrumentation. Below are listed methods used at Nikkelverk analytical laboratory:

1. ICP for higher Mn-concentrations
2. AA for lower Mn-concentrations

7. Other

Separation and recovery of Mg from NiCl₂-solution

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In the nickel mining industry, the resources are of two different types:

- Sulphidic ores
- Oxidic ores (socalled "laterite ores")

Nikkelverk was designed to refine concentrates from mines containing nickel sulphide ores, ores that are complex and contain a range of valuable minerals and metals of economic value, as well as numerous elements and compounds that are not economic to recover. In this context, these are often termed "impurities" as they have to be separated and removed from the process stream containing the valuables in order to prevent them from contaminating the finished products. This is one of the main tasks of a metal refinery, and will be of focus in this project.

The nickel industry is in a slow, but fundamental change, converting its main sources of nickel from mines producing sulphide ores to mines producing oxide ores.

This necessitates a number of changes and improvements in the value chains in order to be able to produce the product qualities the market demands. This requires both new investments and new technology, and the last issue is of interest here.

More specifically for this project is the chemical composition, and the differences from its traditional sources, from which it currently bases its operation on. Even though there are many similarities between concentrates originating from sulphidic and lateritic ores, a few stands out and is of importance to Nikkelverk and the possibility to refine concentrates from lateritic mines.

Three of the element impurities in the laterite concentrates are in quantities that limits Nikkelverk's capacity to treat these concentrates, and as usual in these kinds of industries, economy of scale is important to keep unit costs low. Nikkelverk sees it necessary to limit or eliminate these constraints in order to gain the scale to compete in this market.

The three impurity elements of interest are;

- zinc (Zn),
- magnesium (Mg) and

- manganese (Mn),

contained in concentrates typically termed “Mixed Hydroxide Precipitates” (“MHP”).

Main components in MHP could be:

<u>Element</u>	<u>Typical ranges (% by weight, dry matter)</u>
Ni(2+)	30-45
Co(2+)	<3
Mn(2+)	2-4
Zn(2+)	<1.5
Mg(2+)	0.5-3.0
SO ₄ (2-)	10-15
OH(-)	balance

This project will focus on the element magnesium (Mg), and its separation and removal from nickel chloride (NiCl₂) solutions.

2. Operative conditions

In Nikkelverk’s flowsheet, these elements would report to the process solution in the main nickel circuit, where most of the impurities are removed before a pure nickel electrolyte is produced to feed the nickel electrolysis process (“Ni tankhouse”). Today, maximum daily production of nickel in the tankhouse is 270 tonnes, and this requires a continuous flow (24/7) of pregnant leach solution (“PLS”) of ca. 60m³/h. For Mg as an impurity, there are other solutions for removal, namely nickel electrolyte (or “spent electrolyte”), a solution that makes up the main circulation in the nickel electrowinning plant (“nickel tankhouse”).

3. Chemical elements, compositions and other conditions

The PLS consist of the following main ions and species: Ni(2+), Co(2+), Fe(2+), Fe(3+), Pb(2+), Mn(2+), Zn(2+), Mg(2+), Na(+), SO₄(2-) and Cl(-), all in dissolved states.

<u>Element</u>	<u>Typical ranges (g/l)</u>
Ni(2+)	200-220
Co(2+)	0.1-13
Fe(2+,3+)	0.1-0.2
Pb(2+)	0.1-0.2
Mn(2+)	0.05-0.1
Zn(2+)	0.01-0.05
Mg(2+)	0.5-1.0
Na(+)	4-6
SO ₄ (2-)	20-25
Cl(-)	balance
Temperature	28-35°C
Pressure	atmospheric

The nickel electrolyte or spent electrolyte (“electrolyte”) consist of the following main ions and species: Ni(2+), Mg(2+), Na(+), SO₄(2-) and Cl(-), all in dissolved states.

<u>Element</u>	<u>Typical ranges (g/l)</u>
Ni(2+)	35-60
Mg(2+)	0.5-1.0
Na(+)	4-6
SO ₄ (2-)	20-25
Cl(-)	balance
Temperature	55-60°C
Pressure	atmospheric

4. Design specifications

Industrial constraints for Mg.

Target concentration: up to ca. 5 g/l Mg in PLS and electrolyte,

Target level of removal: To <1 g/l Mg, preferably <0.1 g/l Mg in purified NiCl₂-solutions

5. Literature

Nikkelverk R&D department has carried out a number of studies on optimizing existing technology of the removal of Mg from various solutions.

6. Analytical methods

Methods chosen may vary, depending on the specific laboratory’s instrumentation. Below are listed methods used at Nikkelverk analytical laboratory:

1. ICP for all Mg-concentrations

7. Other