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Nickel-Cobalt-Copper Proceedings

Dinner Keynote Address

NICKEL-COBALT-COPPER DINNER KEYNOTE ADDRESS

THE PROCESS RESEARCH AND DEVELOPMENT FOR COPPER, NICKEL AND COBALT IN BGRIMM

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ABSTRACT

China is the world largest producer and consumer of copper, nickel and cobalt. Beijing General Research Institute of Mining and Metallurgy (BGRIMM) is one of major research and engineering institutes for nonferrous metallurgy in China. This paper gives a brief introduction about the copper, nickel and cobalt production and the related technologies in China. Some of BGRIMM's process and engineering researches on the hydrometallurgical technologies for copper, nickel and cobalt in the last decade are reviewed. BGRIMM's technologies for complex raw materials include: (1) A lower pressure and temperature leaching technology for an arsenic containing low grade copper and zinc mixed concentrate. At the mild conditions of 105-110°C, $P_{O2} \leq$ 500kPa, almost of all chalcopyrite (> 99%) was completely decomposed while the pyrite was less than 12%. Arsenic entered into the residue as stable $FeAsO_4$; (2) One stage full leaching process for a secondary nickel concentrate containing low copper. Nickel, cobalt and copper were completely leached into the solution with high extraction of 99.70%, 98.6% and 98.5% respectively; (3) Atmospheric leaching process with two or three stages for nickel laterite ores, including limonite and saprolite; (4) A pressure leaching process for a low grade complex concentrate containing cobalt, copper and nickel with low sulfur. Under the conditions of 160-170°C and P_{O2} 300kPa, cobalt, copper and nickel extractions reached more than 98%, 98% and 97%, respectively; (5) SO_2 reductive leaching process and the CO reductive ammonia leaching processes for the extraction of the deep-sea polymetallic nodules and cobalt enriched crusts.

PRODUCTION AND CONSUMPTION OF COPPER, NICKEL AND COBALT IN CHINA

Copper

China is the largest copper producer and consumer in the world. In 2013, China's refined copper production was around 6.2 million tons, of which about 70% was from primary production and 30% was from secondary production. By the end of 2013, China's copper primary smelting capacity reached 4.8 million t/a. All major western smelting technologies, including flash, double flash, Ausmelt/ISA, can be found in China. Between 2007 and 2013, 19 primary smelting projects with 2.6 million t/a capacity were commissioned. In this period, ten copper smelting projects selected western processes, including flash, double flash and ISA/Ausmelt process, and nine projects adopted Chinese invented processes, including side-blown, SKS and Baiyin bath-smelting, etc.

Xiangguang Copper (XGC) is the first Chinese smelter to adopt the double flash process, and it was commissioned in 2007 with the initial smelting capacity of 200kt/a. Its smelting capacity was expanded to 400kt/a by 2010. The second and third Chinese double flash smelters, Tongling Jinguan and Jinchuan Fangchenggang, were commissioned in 2012 and 2013, respectively.

The Chinese improved side-blown smelting process which is a type of bath smelting technology with both side blow system. Compared to other smelting processes, this smelting furnace is more flexible for various raw materials. Concentrates with 8~10 % moisture, fluxes and coal or coke with grain size less than 30 mm can be directly charged into smelting bath. The first Chinese 100kt/yr side blown copper smelter was commissioned at Jinfeng Smelter in May, 2008.

China's SX-EW refined copper production is around 100kt-Cu annually. The traditional L-SX-EW production in China is around 30~40kt per year. Zijin copper is currently the largest traditional SX-EW plant in China, and the SX-EW project at Yunlong copper mine was commissioned at the end of 2013. In China, some gold smelters recovered copper from the roast calcine by SX-EW.

Nickel

China's nickel production was close to 650kt in 2013, of which refined nickel production through the traditional primary smelting-refining process was around 190kt, accounting for 29% China's nickel production. Jinchuan Non-ferrous Metal Corp, is the largest Chinese refined nickel producer, and its refined nickel production in 2013 was around 140kt. Pyro-metallurgical processes such as flash and Ausmelt dominated China's refined nickel production. Refined nickel production from hydrometallurgy processing was around 30kt in 2013.

In 2013, the total nickel laterite ore imports in China was 71 million t, an increase by 10%, of which laterite imports from Indonesia was around 41 million t, while the imports from Philippines was around 29.6 million tons. China's NPI (Nickel Pig Iron) production in 2013 reached 460 kt, accounting for 70% of China's total nickel production. From 2005 nickel price increase and innovation of NPI production supplied a new approach to handle laterite. In 2007 NPI accounted for 39% of Chinese total primary nickel production. The number of NPI producers in China was over 200 at its peak in 2007. With restrictive government policy to cut high energy consumption blast furnace capacity, NPI producers' number decreased. Most new entrants employed the high-efficient RKEF process in order to reduce energy consumption and operation cost as well as to improve product quality.

Cobalt

China's cobalt production was about 38 kt/a in 2013, in which primary cobalt production was around 29kt, while the secondary production was 9kt. Hydrometallurgy processing dominated primary cobalt production in China. With the price fall and slowdown of domestic demand, current capacity utilization rates at some cobalt producers are very low.

Domestic cobalt mine production in 2013 was only 1.5kt Co, which was mainly attributed to Jinchuan's nickel-cobalt mine. Cobalt concentrate import in 2013 was 179kt (17kt Co), accounting for 63% of total Co production. China mainly imports Co concentrate and Co containing materials from Africa, including DRC and Zambia.

BGRIMM'S PROCESS AND ENGINEERING RESEARCHES

Lower Pressure and Temperature Leaching Technology

BGRIMM developed a lower pressure and temperature leaching process for an arsenic containing low grade copper and zinc mixed concentrate in 2000(1~3). The process showed the possibility of treating complicated copper concentrates or so-called "dirty concentrates". The ore which contains copper, zinc and arsenic was difficult to separate by flotation. A blended low grade concentrate contained 10.14% Cu, 6.33% Zn, 0.71% As, 33.60% Fe and 40.54% S. The chemical phase analysis of copper is shown in Table 1.

Table 1: Chemical phase analysis of copper

Phase	Oxide	Chalcopyrite	Secondary copper sulfide	Combined copper
Content(%)	0.072	9.43	0.91	0.016
Proportion(%)	0.69	90.43	8.73	0.15

The laboratory and pilot results indicated that the technology achieved an effective leaching of copper and zinc at the mild conditions of 105-110°C, $P_{O2} \leq$ 500kPa. Almost of all chalcopyrite (> 99%) was completely decomposed while the pyrite was less than 12%. Arsenic remained in the leaching residue as the stable $FeAsO_4$ and its concentration in the leaching solution was less than 0.01g/L. More than 96% and 97% for Cu and Zn were leached respectively. The leaching conditions and results are listed in Table 2.

Table 2: Leaching conditions and results

Leaching conditions	Leaching results
Concentrate: Cu 10.14 %, Fe 33.60%, S 40.54%, Zn 6.33%, As 0.71%	E_{Cu}: >95% E_{Zn}: >97% S oxidation ratio: 10~12%
Particle size: P_{90} -0.050mm	Pyrite oxidation ratio: <12%
Pulping L:S: 4~5:1 (L:kg)	Leaching solution: Cu 20g/L, Fe <1.0g/L, As <0.01g/L, H_2SO_4 <10g/L
Temperature: 105~110°C	
Total pressure: 700kPa	Leaching residue ratio: 82~84% of conc.
Oxygen partial pressure(P_{O_2}): 500kPa	Leaching residue: Cu<0.8%, Zn<0.3%, Fe 35%, S 45%
Cl^- concentration: 20~30g/L	
Initial acid concentration: 30g/L	
Retention time: 2.0h	

The flowsheet development was conducted in the pilot tests. Copper cathode was produced by SX-EW. A part of the raffinate was neutralized and precipitated for the recovery of zinc. And zinc cathode could also be produced by SX-EW.

One stage Full Leaching Process for Secondary Nickel Concentrate

The pressure acid leaching (PAL) is one of the major technologies for the refining of nickel precious matte. The traditional PAL process is a high selective leaching of nickel and cobalt to copper and iron, and usually consists of two or three atmospheric leaching stages and two pressure leaching stages(4). But PAL also has very strict limitation of feed materials, which should be either metallic matte or contain higher cuprous sulfide. Jinchuan's nickel refinery adopts the nickel sulfide anode electrolysis process, in which the nickel ion in electrolyte is insufficient due to lower anode efficiency. BGRIMM developed the one stage full leaching process to supply nickel for the refining circuit(5~7). The feed material was the secondary nickel sulfide concentrate from precious matte flotation, which contained 2.65% Cu. The autoclave leaching gained the high extraction, 99.7%, 98.6% and 98.5% for Ni, Co, and Cu respectively. The ratio of leaching residue was only 3~5% and the PGMs were enriched more than 20 times. Compared with the traditional PAL process, BGRIMM's one stage leaching simplified the refining flowsheet and also enhanced the metal direct extraction, so that the capex and opex were lower. In 2002, a commercial demonstration of a leaching plant with 5000tNi/a was put into production. The chemical composition of the secondary nickel concentrate from Jinchuan is given in Table 3. The leaching conditions and results are listed in Table 4.

Table 3: Chemical composition of Jinchuan secondary nickel concentrate

Elements	Ni	Cu	Fe	Co	S	Pb	Zn
Content %	66.27	2.65	2.32	0.85	23.75	0.15	0.05
Elements	Ca	Mg	SiO_2	Al_2O_3	Ag	Pt	Pd
Content %	0.16	0.04	0.26	0.43	30g/t	60g/t	<1g/t

Table 4: PAL conditions and results

Leaching conditions	**Leaching results**
Particle size: P_{90} -0.070mm Pulping L:S: 6:1 (L:kg) Temperature: 160±5°C Total pressure: 1000kPa Oxygen partial pressure(P_{O_2}): 300kPa Final pH value: 1.5~1.8 Retention time: 2.0h	E_{Ni}: 99.72% E_{Cu}: 98.54% E_{Co}: 98.64% Leaching solution: Ni 120g/L, Fe <0.5g/L, Co 2.0g/L, Cu 6.0g/L Leaching residue ratio: 3~5% of feed Leaching residue: Ni 7.0%, Cu 1.0%, Co 0.3%

The copper removal and Ni/Co separation from leaching solution were tested. Under the conditions of 50°C, reaction time 10min, H_2S usage 1.05~1.1 stoichiometry, the remaining copper concentration in the solution was less than 0.001g/L. The CuS residue contained more than 60% Cu and less than 2% Ni(9). Cyanex272 was used for Ni/Co separation(8). After six stages extraction, the Ni/Co separation coefficient reached more than 4000.

After the copper removal and Ni/Co separation, the leaching solution was very pure and very suitable for the production of $NiSO_4$, $Ni(OH)_2$, $NiCO_3$ and Ni_3O_4, etc.

Atmospheric Leaching Process with Two Stages for Nickel Laterite Ores

An atmospheric tank leaching for nickel laterite ores was developed in recent years. It had the advantages of low CAPEX and OPEX, short construction period etc. Two full scale factories produce nickel cathodes from nickel laterite ore in China(10~12).

BGRIMM had conducted many projects of atmospheric tank leaching process. In order to minimize the acid consumption and improve the nickel extraction, two or three stages with primary leaching and secondary leaching were chosen. In the primary leaching stage, the laterite ores with high nickel and low iron content were leached. In the following secondary leaching stage, the ore with high magnesium content was fed. The sulfuric acid was mainly introduced to the primary leaching. The secondary leaching stage also acted as a neutralization and iron precipitation stage. Such a leaching combination can reduce up to 90% of the acid consumption for iron limonite.

For example, a laterite ore sample from the Philippines was sieved by 1mm screen. The oversize portion was fed into the primary leaching and the undersize into the secondary leaching. The conditions and the results of two stage leaching were given in Table 5.

Table 5: Optimum parameters of two stage atmospheric tank leaching

Primary leaching		**Secondary leaching**	
Pulping density:	36%	Pulping density:	36%
Sulfuric acid input:	1 t/t-ore	Sulfuric acid input:	---
Temperature:	95°C	Temperature:	95°C
Retention time:	5.0h	Retention time:	5.0h
E_{Ni}:	>98%	E_{Ni}:	>90%
E_{Fe}:	72%	E_{Fe}:	10%

Pressure Leaching Process for a Low Grade Cobalt Concentrate

BGRIMM developed a pressure leaching process to treat a low grade complex concentrate in 2008(13-15). In the Northeastern China, a low grade deposit contains 0.051%Co, and 0.15% Cu. The flotation tests could only gain a low grade concentrate (Table 6).

Table 6: Chemical composition of the low grade concentrate

Element	Co	Ni	Cu	Fe	S	Zn	Pb	CaO	SiO_2
%	1.18	0.44	3.26	14.23	10.59	0.95	0.93	0.29	42.00
Element	Al_2O_3	MgO	C	As	F	Cl	Au	Ag	
%	11.34	1.63	3.17	0.13	0.012	0.087	0.31g/t	32.25g/t	

The mineralogy study indicated that copper exists mainly as chalcopyrite, cobalt exists as (Co,Fe,Ni)AsS, $(Co,Ni,Fe)_3S_4$ and $(Fe,Co)S_2$, and nickel exists as $(Co,Ni,Fe)_3S_4$. The concentrate contained 10.59% S, which was not enough for an autothermic fluid bed roasting. The pressure leaching test conditions and results are listed in table 7. The proposed principal flowsheet is shown in Figure 1.

Table 7: Pressure leaching conditions and results

Leaching conditions	**Leaching results**
Particle size: P_{90} -0.047mm	E_{Co}: 98%
Pulping density: 20%	E_{Cu}: 98%
Temperature: 160±5°C	E_{Ni}: 97%
Total pressure: 1000kPa	Leaching solution (g/L): Co 2.8, Fe <0.5, Cu 8.5 Ni 1.0
Oxygen partial pressure(P_{O_2}): 300kPa	Leaching residue ratio: 85% of feed
Final pH value: 0.85~0.90	Leaching residue (%): Co 0.02, Cu 0.076, Ni 0.012, S 0.78
Retention time: 3.0h	

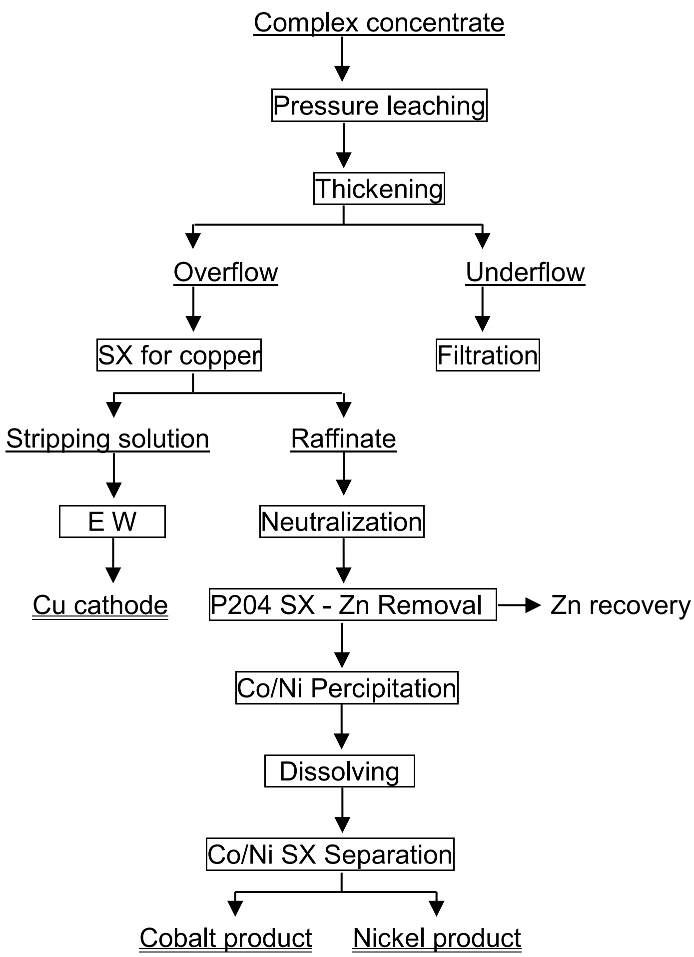

Figure 1: Proposed flowsheet principle for the low grade cobalt

Processes for Deep-Sea Polymetallic Nodules and Cobalt Enriched Crusts

The sea-bed reserves large quantity mineral resources. It contains polymetallic nodules, cobalt-rich crusts, deep-sea phosphorite, polymetallic sulphides and natural gas hydrate. BGRIMM developed the SO_2 reductive leaching process for cobalt-rich crusts and the CO reductive ammonia leaching for polymetallic nodules.

SO_2 reductive leaching process for cobalt-rich crust(16-20)

The chemical composition of cobalt-rich crust is shown in Table 8.

Table 8: Chemical composition of the cobalt-rich crust

Element	Mn	Fe	Co	Ni	Cu	Zn	Mo	CaO	MgO
%	18.91	12.86	0.54	0.36	0.084	0.058	0.042	5.83	1.48
Element	Al_2O_3	SiO_2	TiO_2	Na_2O	K_2O	P	Cl	Pt	REEs
%	1.60	9.04	1.48	1.12	0.48	1.16	0.29	0.18g/t	0.18

The cobalt-rich crusts were firstly crushed and ground to 82% less than 0.074mm. At atmospheric condition, Mn^{4+} in cobalt-rich crusts was reduced into Mn2+ rapidly by SO_2. Due to the dissolution of manganese, the original mineral structure of cobalt-rich crust was decomposed, so that cobalt, nickel and copper were leached into the solution by sulfuric acid. After iron removal by neutralization, solvent extraction was used to recover Cu, Co, Ni and Zn. The principle process flowsheet is shown in Figure 2.

The 10kg/d continuous leaching experiment of cobalt-rich crusts was done. The main parameters and results are shown in Table 9.

Table 9: The leaching conditions and results of SO_2 reductive leaching

Leaching conditions		**Leaching results**	
Particle size:	P_{82} -0.074mm	E_{Co}:	99.3%
Pulping density:	20%	E_{Ni}:	98.3%
Temperature:	Room temperature (25°C)	E_{Cu}:	98.7%
Final pH value:	1.5~2.0	E_{Mn}:	82.4%
Retention time:	30min	E_{Fe}:	<15%
SO_2 consumption: 0.23t/t-crust			
H_2SO_4 consumption: 0.17t/t-crust			

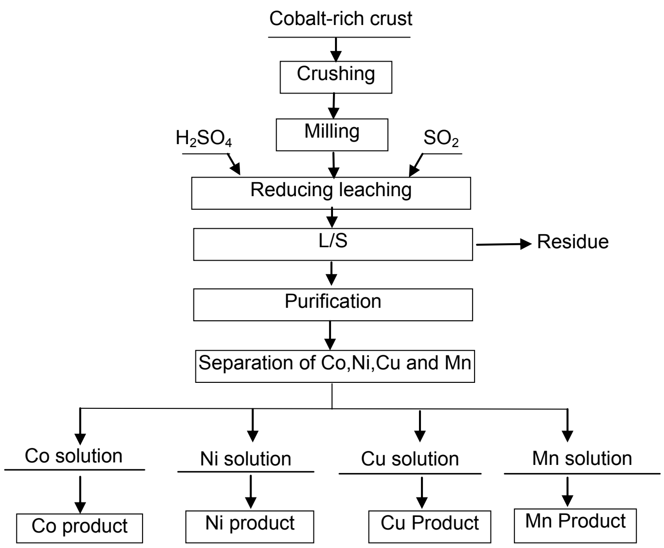

Figure 2: Flowsheet principle for SO_2 reductive leaching for cobalt-rich crusts

Reductive Ammonia Leaching of Polymetallic Nodules [21-27]

The polymetallic nodules have a typical chemical composition in Table 10.

Table 10: Chemical composition of polymetallic nodules

Elements	Ni	Cu	Co	Mo	Zn	Mn	Fe	TiO_2
%	1.20	0.91	0.22	0.05	0.10	22.5	7.80	0.83
Elements	Al_2O_3	CaO	MgO	SiO_2	Na_2O	K_2O	BaO	Be
%	4.42	2.08	2.07	<0.01	4.04	1.98	0.20	<0.01
Elements	Cd	Cr	Li_2O	Sb	Se	Sr	V	Sn
%	0.002	<0.005	0.06	<0.01	<0.01	0.05	0.038	<0.01

Reductive ammonia leaching has the advantages of selective leaching and reagent recycling. Ammonia leaching has two alternatives: roasting-ammonia leaching and direct reductive ammonia leaching. Because of the high moisture (30~40%) of nodules, the energy consumption of roasting process is high. The direct reductive ammonia leaching with CO as reductant should be a good choice. In order to speed up the reduction reaction, it is essential to keep a high copper ion concentration in the leaching slurry, so that much copper has to be recirculated in the leaching circuit. BGRIMM has changed the solution make-up and invented a self-catalysis reductive ammonia leaching process to treat polymetallic nodules, in which copper is not necessary to recirculated. Furthermore, the cobalt extraction increases from about 70% up to 90%. The flowsheet of self-catalysis reductive ammonia leaching is shown in Figure 3.

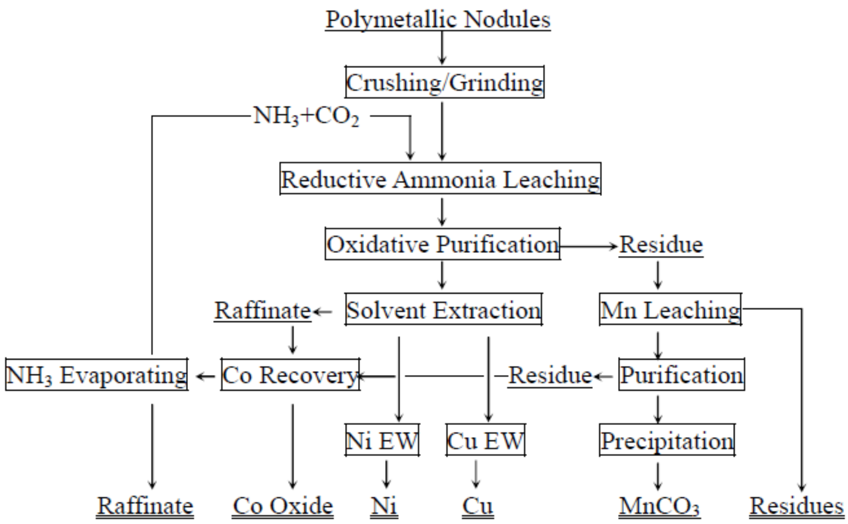

Figure 3: Flowsheet for self-catalysis reductive ammonia leaching

A pilot test with 100kg/d continuous leaching operation was conducted in 2005. A typical leaching solution contained 10-12g/L Cu, 13-15g/L Ni and 2-3g/L Co. The leaching extraction of nickel, copper and cobalt were 98%, 98% and 90% respectively. It was very interested that 96% of the co-existed molybdenum was leached and recovered the ammonia still process, which was to keep water balance.

REFERENCES

1. Wang H. B., Jiang K. X., Qiu D. F. and Lu H. M., “Status of Hydrometallurgical Development on Copper Sulfide Ore”, Nonferrous Metals, 4, 101-104, 2003.

2. Wang H. B., Jiang K. X., Zhang B. S., Wang Y. F., Lin J. S. and Wang C., “A Novel Hydrometallurgical Process with Low Temperature and Pressure for Complicated Copper Concentrate from Xinjiang of China”, Nonferrous Metals, 3, 52-53, 2004.

3. Jiang K. X., “Study on Pressure leaching Technology of Complex Copper Ore”, [R]. Beijing General Research Institute of Mining and Metallurgy(BGRIMM), 2003.

4. Huang Z. H., “Nickel Extraction by Sulfuric Acid Selective Leaching from Metallic Nickel Concentrates”, [R]. Beijing General Research Institute of Mining and Metallurgy, 1991.

5. Jiang K. X., Wang H. B., “A method of nickel extraction by one stage pressure leaching from nickel sulfides”, [P]. Chinese Patent: ZL0112763.9, 2003.

6. Wang H. B., Jiang K. X., Zhang B. S., Liu S. P. and Zhang L., “Study on New Technology of Nickel Concentrate by Acid Pressure Leaching”, Nonferrous Metals(Extractive Metallurgy), 4, 2-4, 2004.

7. Jiang K. X., “One Stage Full Pressure Leaching Technology for Nickel Concentrate of Jinchuan Company”, [R]. Beijing General Research Institute of Mining and Metallurgy, 2001.

8. Wang C.Y., Hu F. C., “Application of Cyanex272 to Co/Ni Separation”, Nonferrous Metals, 3, 1-4, 2001.

9. Jiang K. X., Zhang B. S. and Wang H. B., “Copper Removal by H2S”, [R]. Beijing General Research Institute of Mining and Metallurgy, 2002.

10. Ma B. Z., Yang W. J., Wang C. Y., Yin F. and Chen Y. Q., “Progresses of Hydrometallurgy Processes for Nickel Laterite Ores”, Nonferrous Metals(Extractive Metallurgy), 7, 1-8, 2013.

11. Jiang K. X., “A Method of Nickel Extraction from Laterite”, [P]. Chinese Patent: CN101619400, 2010.

12. Liu S. P., “Atmospheric Tank Leaching for Nickel Laterite from Philippines”, [R]. Beijing General Research Institute of Mining and Metallurgy, 2012.

13. Huang S., Zhang L., Wang H. B. and Feng Y. P., “Research on the Pressure Leaching of Complex Cobalt Sulfide Ore”, Nonferrous Metals(Extractive Metallurgy), 1, 2-4, 2010.

14. Jiang K. X., “A Method of Cobalt Extraction from Copper-Cobalt Sulfide Ore”, [P]. Chinese Patent: CN101705371A, 2010.

15. Zhang L., “Pressure Leaching for Low Grade Complex Copper-Cobalt Concentrate”, [R]. Beijing General Research Institute of Mining and Metallurgy, 2007.

16. Jiang X. X., Wang S. D. and Yin C. Q., “Study of Sulfuric Acid Leaching on Ocean Cobalt-Rich Crust Using Sulfur Dioxide as Reductant”, Nonferrous Metals(Extractive Metallurgy), 3, 2-5, 2002.

17. Fan Y. Q., Jiang X. X., Wang S. D. and Jiang K. X., “Extractive Separation of Cobalt and Nickel in Leaching Solution of Oceanic Cobalt Crust with N235”, Nonferrous Metals, 3, 70-72, 2006.

18. Wang S. D., Jiang X. X., Jiang K. X. and Fan Y. Q., “Study on Sulfurized Residue from Cobalt-Rich Crust by Acid Leaching under Pressure”, Nonferrous Metals(Extractive Metallurgy), 1, 17-19, 2006.

19. Jiang X. X., Yin C. Q. and Wang S. D., “Recovering Co, Ni, Cu and Mn from Ocean Cobalt-Rich Crust by Acid Leaching and Solvent Extraction”, Mining & Metallurgy, 1, 67-70, 2002.

20. Jiang X. X., Wang S. D. and Yin C. Q., “Leaching of Cobalt-Rich Crust with Sulfuric Aid in Normal Temperature and Pressure”, Nonferrous Metals(Extractive Metallurgy), 3, 2-5, 2002.

21. Jiang X. X., Jiang K. X. and Wang S. D., “A Method of Ammonia Leaching for Mixing Deep-Sea Polymetallic Nodules and Cobalt-Rich Crusts”, [P]. Chinese Patent: ZL200510134513.2.

22. Jiang K. X., Jiang X. X., Feng L. Y., Jiang W., Wang S. D., Zhao L. and Fan Y. Q., “Study on Self-Catalysis Reduction Leaching of Ocean Co-Mn Polymetallic Ores in Ammonia Solution”.

23. Jiang K. X., Jiang X. X. and Wang S. D., " Study on Ammonia Leaching of Ocean Polymetallic Nodules Using Carbon Monoxide as Reducing Agent", The Proceedings of the Sixth ISOPE Ocean Mining Symposium, Changsha, China, 218-222, 2005.

24. Jiang X. X., Jiang K. X. and Wang S. D., "A Method of Self-Catalysis Reduction Ammonia Leaching for Deep-Sea Polymetallic Nodules", [P]. Chinese Patent: ZL200510134512.8.

25. Jiang X. X., Yin C. Q., Zhou B. Y., "Extraction of Nickel, Cobalt and Copper from Ocean Polymetallic Nodules by Catalytic Reduction Ammonia Leaching", Nonferrous Metals, 3, 46-51, 2007.

26. Jiang W., Jiang X. X., Jiang K. X., "Study on treatment of Ammonia-Nitrogen Waste by Manganese Nodules", China Resources Comprehensive Utilization, 3, 16-18, 2010.

27. Jiang K. X., Jiang X. X. and Feng L. Y., "Study on Self-Catalysis Reduction Leaching of Ocean Co-Mn Polymetallic Ores in Ammonia Solution", The Tenth ISOPE Ocean Mining and Gas Hydrates Symposium, Poland, 167-173, 2013.

conference. The amenability test results for these tests are summarized below. All tests were conducted in site water (~100,000 ppm TDS), at pH 3.5, on as received concentrate (approx. grind size of 80% passing 150µm) with no nutrients added. These tests examined the leaching behaviour of the ore at a range of pulp densities.

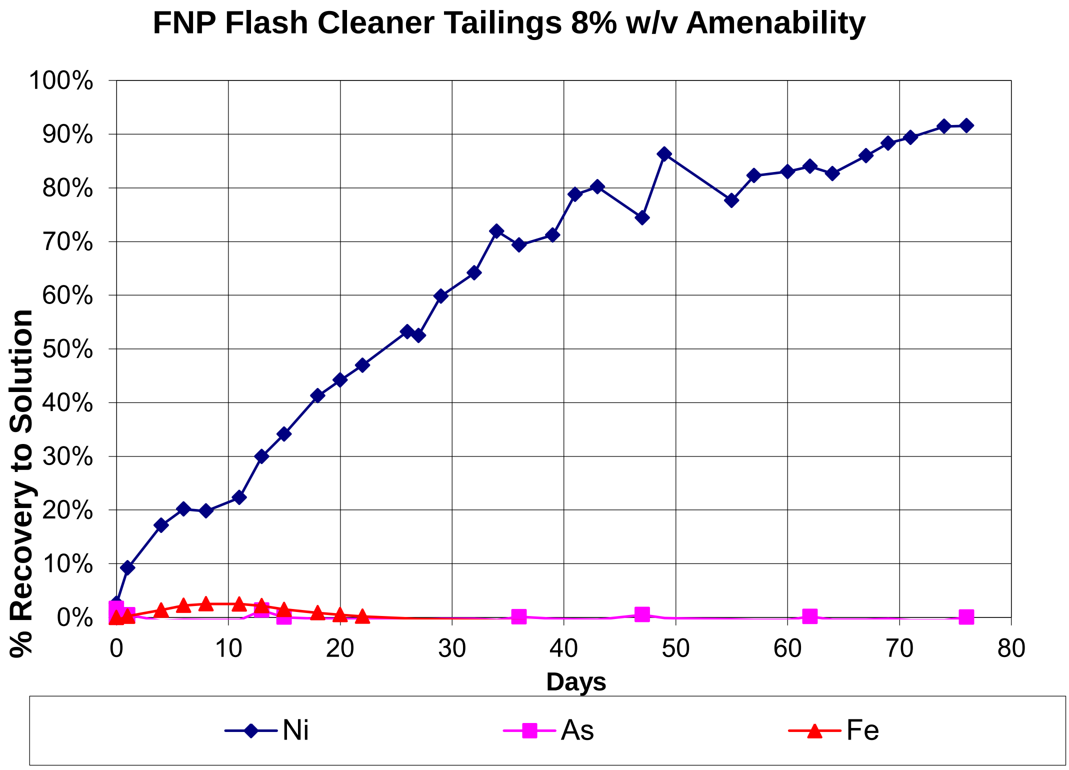

Figure 5: FNP Flash Cleaner Tailings 8% w/v Amenability

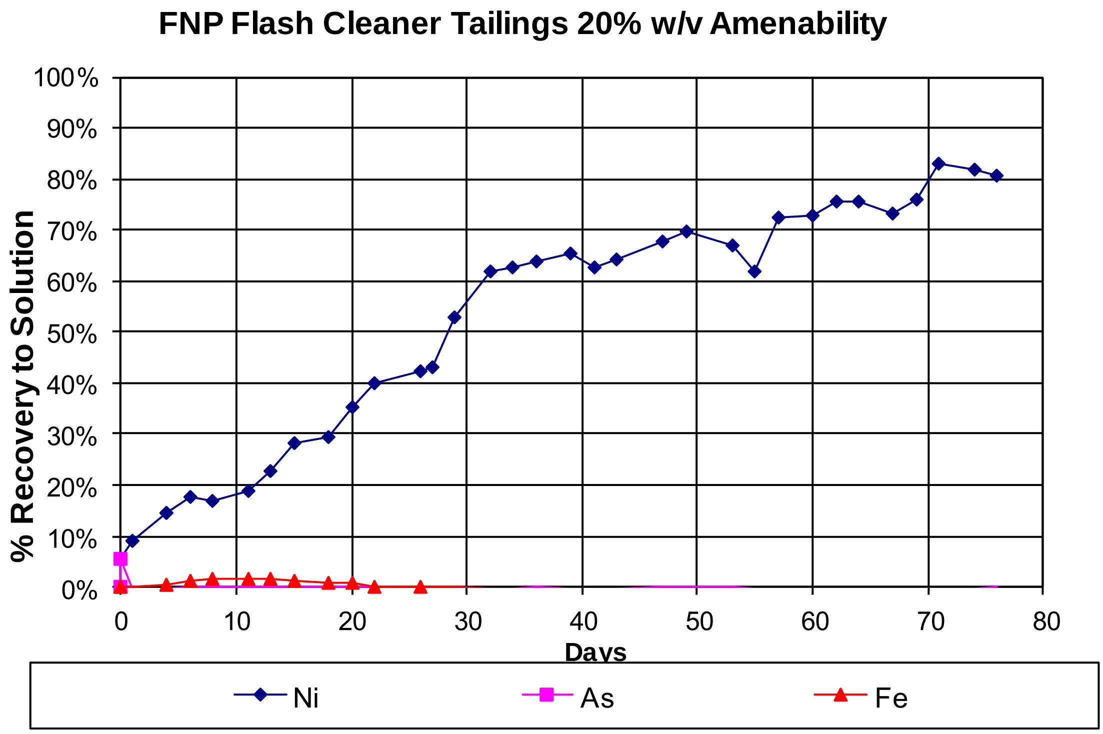

Figure 6: FNP Flash Cleaner Tailings 20% w/v Amenability

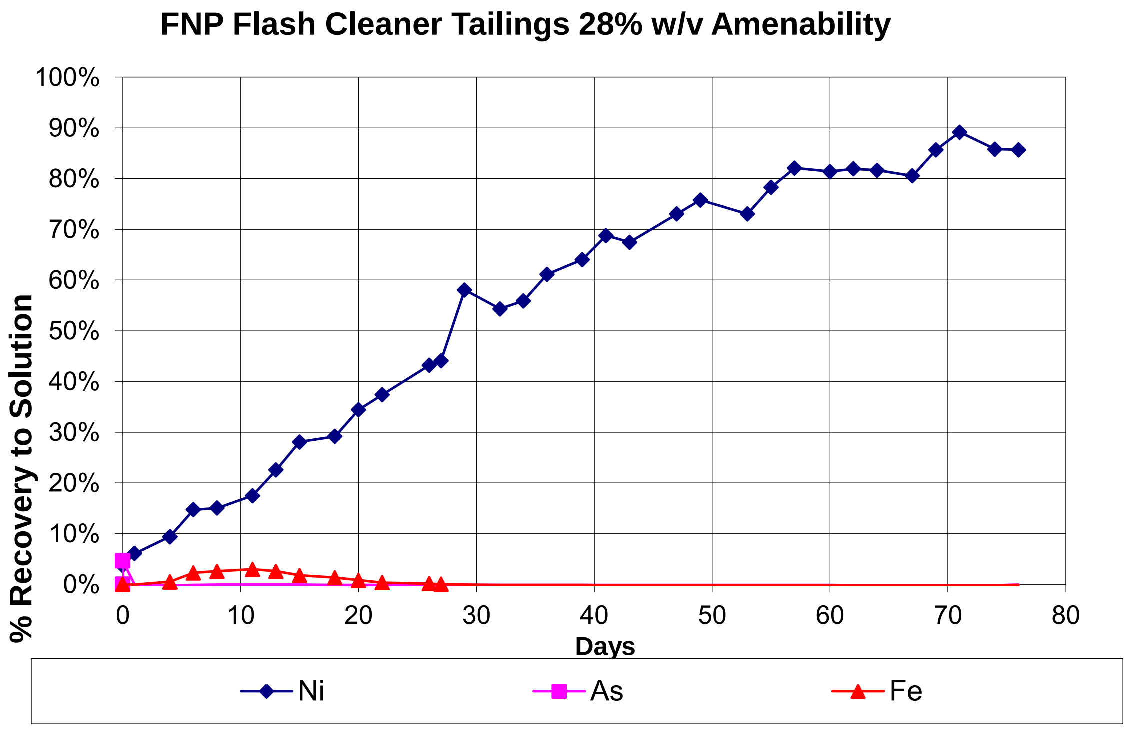

Figure 7: FNP Flash Cleaner Tailings 28% w/v Amenability

SCOPING STUDY OUTCOMES

In 2013, a scoping study of the BioHeap® integration into the Cosmic Boy concentrator was undertaken by a Perth engineering firm. The study focussed on the Spotted Quoll option due to the results of the previous test work program, and the high nickel grade of the stream.

A number of downstream recovery options for the bioleached nickel were also examined. The results of the study indicated that sulphide precipitation is a preferred option that that is compatible with existing offtake arrangements for Western Areas concentrate. This processing route allows Western Areas to blend the bioleached product with concentrate prior to shipment.

The outcome of the scoping study indicated an IRR of 61% (8% discount rate) using Western Areas internal nickel price and exchange rate estimates. To check robustness, a pessimistic case was run using a nickel price of US$7/lb and a US$:AUD$ of parity gave an estimated IRR of 43% (8% discount rate).

The plant footprint was expected to be approximately 1000m^2 and can fit in a previously cleared area currently being used for equipment laydown, potentially simplifying the environmental process.

The positive results of the scoping study has allowed the project to proceed to a feasibility study examining options to optimize the current flotation circuit and integrate a BioHeap® tank leach into the current circuit. The feasibility study and continuous testwork program was initiated in January 2014 and is currently in progress.

CURRENT STATUS

Phase 1 of the feasibility study has been completed, recommending specific modifications to the flotation circuit to improve operational efficiencies and to better prepare the bioleach feed streams. The pilot plant is currently being prepared for a series of tests that will operate continuously to gather data to support the engineering design and to provide samples for downstream processing study and for vendor testing requirements.

CONCLUSIONS

The predominant method of processing nickel sulphide ores is through flotation(2), smelting and refining to produce nickel metal for use in stainless steel production. While this process is effective it is somewhat sensitive to impurities, most notably magnesia(3) and arsenic. For concentrators treating ores that contain such impurities there is normally a nickel loss associated with rejecting these elements from the final product, and in some cases the levels of impurities can affect revenues and even project viability.

Using the BioHeap® technology, Western Areas have been examining flow sheet options for treating some of these streams by removal of the impurities through bioleaching and recovering of the nickel as a sulphide precipitate with an aim to increase overall grade and recovery for the concentrator.

Scoping study results of such a plant at Western Areas' Cosmic Boy nickel concentrator predicted an IRR of 61% prompting further investigations through a feasibility study. This feasibility study is currently in progress.

REFERENCES

1. Western Areas Ltd, *Activity Report for the period ending 31 March 2014*. 2014, Western Areas Ltd: Perth, Australia.

2. The Urals Metallurgical Group. *Nickel Ore Processing*. 2014 [cited 2014 21/5/14]; Available from: http://www.highmetals.com/en/technology_nickel-ore-copper-nickel-sulfide-nickel-oxide.htm.

3. Jones, D.L., et al., *Unlocking Disseminated Nickel Sulphides Using the CESL Nickel Process.* 2010.