RECENT DEVELOPMENTS IN PRECONCENTRATION USING DENSE MEDIA SEPARATION

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ABSTRACT

Dense medium separation (DMS) is one of several preconcentration methods used for early waste rejection from run of mine ores at relatively coarse particle sizes prior to additional milling and beneficiation. DMS has been used extensively in the coal, diamond and iron ore industries but lab scale and pilot test work has demonstrated successful separation and upgrading of other minerals such as lead, zinc, copper and lithium based ores using DMS. This paper reviews historical dense media systems, results from the pilot scale Condor DMS system as well as associated laboratory heavy liquid separation (HLS) test work.

KEYWORDS

Preconcentration, dense media separation, heavy liquid separation, comminution, copper, lead, lithium, zinc

INTRODUCTION

Interest in preconcentration of run-of-mine material, after minimal attrition and prior to fine comminution, has been increasing over recent years. The advantages of ore preconcentration provide opportunities to not only lower operating costs but also lower capital costs by reducing the size of the downstream beneficiation circuit. In some cases, it may be possible to produce a marketable concentrate directly. The benefits in operating costs arise from reduced mass to the grinding circuit and the downstream beneficiation process. Often, the preconcentrated minerals are of lower hardness than the gangue minerals hence the grinding circuit also benefits from lower energy requirements for equivalent feed mass and significantly reduced wear and media consumption. Preconcentration can also reduce the quantity of problematic minerals reporting to downstream flotation and/or leaching processes. Other benefits include reduced sliming of soft minerals as grinding can be optimized for the target minerals and reduced consumption of water and chemicals.

Preconcentration is achieved by exploiting a variety of differences in mineral properties such as optical characteristics, magnetic susceptibility, density, radioactivity and conductivity. Of these, the most common characteristic utilized for separation is the specific gravity (SG) differences of the minerals through Dense Medium Separation (DMS).

Recently, Met-Solve Laboratories, in conjunction with Sepro Mineral Systems, has conducted a number of pilot scale test programs utilizing the Condor centrifugal, multi-stage, dense media separation system. The mechanical design, operational advantages and findings from pilot plant tests and heavy liquid test results are presented herein. The use of heavy liquid for bench scale simulation and results are also discussed.

Bench Scale Simulation – Heavy Liquid Separation

Although not economically feasible in large scale operations, bench scale heavy liquid separation (HLS) testing is an ideal preliminary step to pilot scale DMS testing.

Past practices of HLS test work utilized heavy organic liquids such as tetrabromothane, diiodomethane, and bromoform (Meyer & Craig, 2010). All three solutions are known to have toxicity issues and require careful handling and extra safety precautions during testing. For this reason, most industries have moved away from using these solutions and are instead utilizing newer tungstate based liquids. The development of these tungstate based solutions such as lithium metatungstate, sodium polytungstate, and lithium heteropolytungstate have made the bench scale testing safer and consequently easier to carry out. The solutions are made of inorganic compounds which dissolve readily in water. They are non-toxic, non-corrosive and reported to be ecologically safe.

Dense Media Separators

Dense media separators can be categorized into two groups (Wills & Napier, 2006): gravitational (static) and centrifugal (dynamic). In gravitational units, the feed and medium are introduced into the vessel and the mixture is gently agitated to maintain a fluidized bed. The less dense minerals are removed by overflow or a paddle, while sink removal varies depending on the vessel. The most common gravitational units include the Wemco cone, Drum, Drewboy and Norwalt (Wills & Napier, 2006).

Centrifugal units utilise high speed and tangential pumping to create a vortex within the vessel. Any mineral with a higher density than the medium will be subject to greater centrifugal forces and be pulled to the outer edge of the vortex, while any lower density mineral will remain at the center of the vortex. The differing minerals are removed through separate discharge lines. There are many different centrifugal vessels in the mining industry; however, the two most common vessels are the Dutch State Mines (DSM) cyclone and the Tri-Flo type multi-stage dense media separator. The Condor is based on the Tri Flo design.

Media

In order to create a stable and efficient suspension of heavy media that can be used in DMS, the solid particles must have specific properties. They must be dense and finely ground to be able to mimic a fluidized bed when agitated. They must be resistant to corrosion and degradation to prevent viscosity increases during operation and they must be easily recoverable from a washing circuit after exiting the vessel (Wills & Napier, 2006).

Currently the most commonly used materials for creating dense medium slurries are ferrosilicon and magnetite. Both materials can produce efficient dense suspensions that can be used in DMS and have the benefit of being easily recoverable by magnetic separation. Ferrosilicon has a higher specific density (6.8 g/cm^3) than magnetite (4.5 g/cm^3) and can therefore produce a higher range of relative medium densities. However, ferrosilicon is more expensive and finds use primarily when the higher separation densities are required.

THE CONDOR DENSE MEDIA SEPARATOR

The Condor Dense Media Separator has gained interest as an effective and successful preconcentration technology that applies a multi-stage system to improve results for separating near-density materials.

In the Condor DMS unit, the dense media is pumped from the lower end of the cylinder (medium inlet 1 and 2) as shown in Figures 1 and 2. Utilizing gravitational and centrifugal forces, an applied backpressure spirals the media alongside the walls, creating a high pressure vortex that transports the dense media upwards. The medium inlets and sink headers have been placed involutedly to decrease turbulence (Burton et al., 1991). By controlling the pressure and density of the heavy media, the cut point for the Condor unit can be adjusted continuously.

At the top of the unit, feed material is gravity fed through the hopper directly into the vortex of the rotating medium (Wills & Napier, 2006). The floats tube at the bottom of the Condor unit serves as the outlet for float material as well as an opening to create a lower pressure at the center of the vortex. This pressure difference allows lighter material to travel down the internal surface of the media into the core, eventually being drawn out.

The applied back pressure and the density of the heavy media are the main factors for adjusting the cut point. The centrifugal forces created by the vortex transports the sinks (material that is heavier than the cut point) away from the axis and up into the sinks header while the lighter material travels down the vortex and is collected at the bottom.

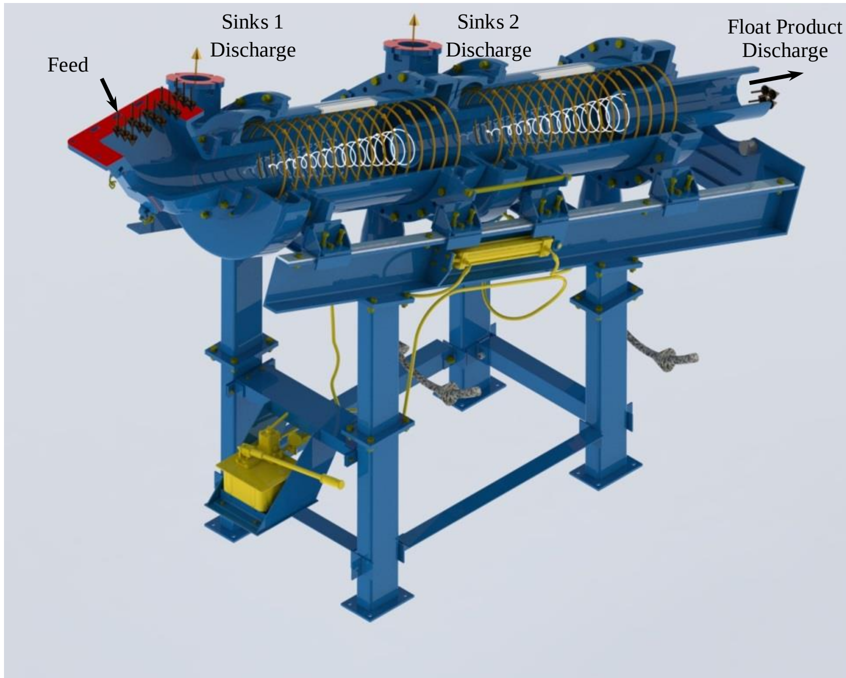

Figure 1 – Internal operations of a 2-stage Condor DMS unit

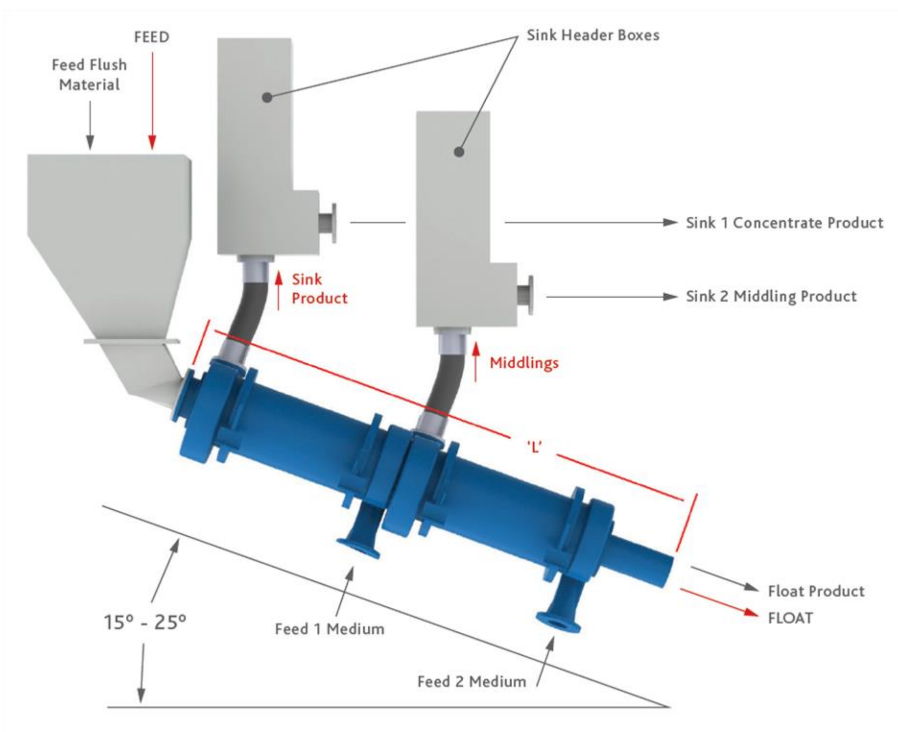

Figure 2 – Condor 2-stage dense media separator

Cyclones vs Condor (Advantages and Disadvantages)

Dense media separators are commonly used for preconcentration of coal and diamonds but less commonly for other mineral systems such as lead and zinc. Due to lower head grades adding to the complexities of the ore, multi-stage dense media separators like the Condor can offer some advantages over the single-stage dense medium cyclones.

The main advantage in using a multi-stage separator is the ability to produce multiple sink products and being able to fix the density cut points of each individual stage. Ores that contain minerals with small density differences can therefore be accurately separated in a single unit. This essentially reduces the need for multiple circuits to a single unit. Alternatively, the device can be operated with both stages having matching separation densities. In this case the two stages can be considered as a cleaner/scavenger system producing a cleaner, higher grade product.

Another significant advantage that the multi-stage type units provide is the substantial reduction of unit operating costs. Unlike dense medium cyclones, the feed and the media are completely separate before being introduced into the multi-stage vessel. This offers the distinct advantage of having the option to dry feed the ore by gravity. Without having to pump both the ore and the media, pump life and performance is improved and the pump size is significantly reduced.

The Condor unit also provides more reliable and steady operating conditions. Fluctuations in the ore (e.g. grade in the heavy products) are not always considered for preconcentration. Compared to the cyclone which is limited by the crowding effect in the apex, the multi-stage separation in the Condor unit provides larger sinks product capacity.

The primary advantages of using a dense medium cyclone arise when only a single stage separation is required allowing for a simpler circuit and reduced cost (i.e. the dense medium cyclone is generally less expensive).

INDUSTRIAL APPLICATIONS

While dense media separation is used extensively in the coal industry and somewhat commonly in the diamond industry, its use has not been extensively exploited for other mineral systems. The response of upgrading low grade sulfide based nickel ores using dense media cyclones has been reported on samples from Tati Nickel (Denysschen & Wagner, 2009) and the Nkomati Nickel Mine (Pillay et al., 2011). The increase in grades and the potential mass reductions were also discussed briefly. Altun et al. (2013) not only reported the upgrading of mafic ore containing nickel with recoveries up to 97% and mass rejections ranging from 38-53% but also identified the metallurgical benefits that arise from the rejection of magnesium bearing gangue such as talc.

Burton et al. (1991) and Ferrara et al. (1994) present numerous examples of operations and pilot programs utilizing the Tri-Flo preconcentration. The treatise is quite extensive as it covers the response of sulfide materials, tin, fluorspar, barite, bauxite, chromite, lithium, potash, phosphate and nickel laterite ores.

BENCH SCALE AND PILOT CAMPAIGN RESULTS

A series of test programs were performed using a single stage Condor dense media separator in conjunction with bench scale heavy liquid test work. The general approach of the test program as well the types of material tested are enumerated below:

i) A lead and silver bearing sulfide mineralized rock supplied by Benton Resources from their Cape Ray project in southwest Newfoundland. The program consisted of bench scale HLS test work and a pilot Condor DMS test.

ii) A lead ore and a tailings sample supplied by an operating mine (site name is confidential and is labelled as Mine-X in the following sections). The program consisted only of pilot Condor DMS tests on both samples.

iii) A lithium bearing spodumene ore supplied by Nemaska Lithium from their Whabouchi project site in Quebec. The program consisted of bench scale HLS test work and pilot Condor DMS tests.

Lead Bearing Mineral Sample – Cape Ray Deposit

A sample, supplied by Benton Resources from their Cape Ray project containing lead, copper, silver and gold was subjected to both bench scale HLS test work and pilot scale DMS test work. The sample was crushed to 10 mm followed by fines removal at a particle size of 1.18 mm. The results from the HLS testing demonstrate that 78.4% of the lead was recovered into 7.5% of the feed mass at a specific gravity of 2.85. Recovery increased to 87% when the specific gravity cut point was reduced to 2.75. The mass yield to the sink fraction at this lower cut point is only 12.2% indicating that more than 87% of the mass can be rejected at this coarse crush size.

The lead grade of the heavy sink fraction dropped from 16.4% to 2.41% in the individual fractions with weighted cumulative grade of 11.2% at the lowest cut point.

The results for Cu, Ag and Au show reduced upgrading relative to that of lead. It is likely that these other species are more finely disseminated as well being associated with less dense gangue minerals; this is likely the case for gold.

Table 1 – Bench Scale Heavy Liquid Test Results - Cape Ray Deposit Sample

Specific gravity of fraction	Sink-Float Fraction (Wt %)	Grade		Sink-Float Fraction		Cumulative Distribution	
		Pb (%)	Cu (ppm)	Pb (%)	Cu (%)	Pb (%)	Cu (%)
> 2.85	7.5	16.37	13,862	78.4	56.3	78.4	56.3
2.80/2.85	1.7	3.62	6,138	4.0	5.7	82.4	62.0
2.75/2.80	3.0	2.41	4,787	4.6	7.8	87.0	69.8
> 2.75	**12.2**	**11.16**	**10,552**	**87.0**	**69.8**		
< 2.75	87.8	0.23	638	13.0	30.2	100.0	100.0
Total	**100.0**	**1.57**	**1,852**	**100.0**	**100.0**		

Specific gravity of fraction	Sink-Float Fraction (Wt %)	Grade		Sink-Float Fraction		Cumulative Distribution	
		Au (ppm)	Ag (ppm)	Au (%)	Ag (%)	Au (%)	Ag (%)
> 2.85	7.5	34.15	247.9	35.9	64.5	35.9	64.5
2.80/2.85	1.7	22.87	80.8	5.5	4.8	41.4	69.3
2.75/2.80	3.0	26.34	69.9	11.0	7.3	52.4	76.5
> 2.75	**12.2**	**30.65**	**180.8**	**52.4**	**76.5**		
< 2.75	87.8	3.88	7.7	47.6	23.5	100.0	100.0
Total	**100.0**	**7.16**	**28.9**	**100.0**	**100.0**		

This sample was also subject to separation using the Condor DMS pilot plant at specific gravity cut points of 2.83 and 2.93 at a top particle size of 19.0 mm. The results from the pilot test, presented in Table 2, show a similar response to that of the heavy liquid test work. Note that the material was passed twice through the DMS unit, at identical specific gravity cut points, to scavenge any material that may have short circuited in the first pass.

Table 2 – Condor Pilot Plant Test Results - Cape Ray Deposit Sample (-19 mm , +1.18 mm material)

2-Stage DMS (Rougher-Scav)	Weight (%)	Grade				Distribution (%)			
		Pb (%)	Cu (%)	Au (ppm)	Ag (ppm)	Pb	Cu	Au	Ag
Sinks 1 (SG = 2.93)	6.2	20.0	1.5	37.3	268.0	66.2	45.7	29.6	52.5
Sinks 2 (SG = 2.93)	0.7	9.3	1.1	32.3	168.0	3.3	3.3	2.7	3.5
Total Sinks	**6.8**	**19.0**	**1.5**	**36.8**	**258.4**	**69.5**	**49.0**	**32.3**	**56.0**
Floats	93.2	0.6	0.1	5.7	14.9	30.5	51.0	67.7	44.0
Head	100.0	2.0	0.3	7.8	31.6	100.0	100.0	100.0	100.0

2-Stage DMS (Rougher-Scav)	Weight (%)	Grade (%)				Distribution (%)			
		Pb (%)	Cu (%)	Au (ppm)	Ag (ppm)	Pb	Cu	Au	Ag
Sinks 1 (SG = 2.83)	8.9	15.1	1.4	35.2	234.6	72.7	53.4	38.4	64.1
Sinks 2 (SG = 2.83)	1.8	6.3	0.7	22.6	109.0	6.0	5.3	4.9	5.9
Total Sinks	**10.7**	**13.7**	**1.2**	**33.1**	**213.7**	**78.7**	**58.7**	**43.3**	**70.0**
Floats	89.3	0.4	0.1	5.2	11.0	21.3	41.3	56.7	30.0
Head	100.0	1.9	0.2	8.2	32.7	100.0	100.0	100.0	100.0

The results from both the HLS and DMS are plotted in Figure 3 to present the comparative response of the material from the test work. The slightly lower results from the DMS are most likely due to the coarser particle size distribution of the material in the pilot test program. Generally, the response of the material demonstrates that preconcentration can be effective for the low lead levels present in this material.

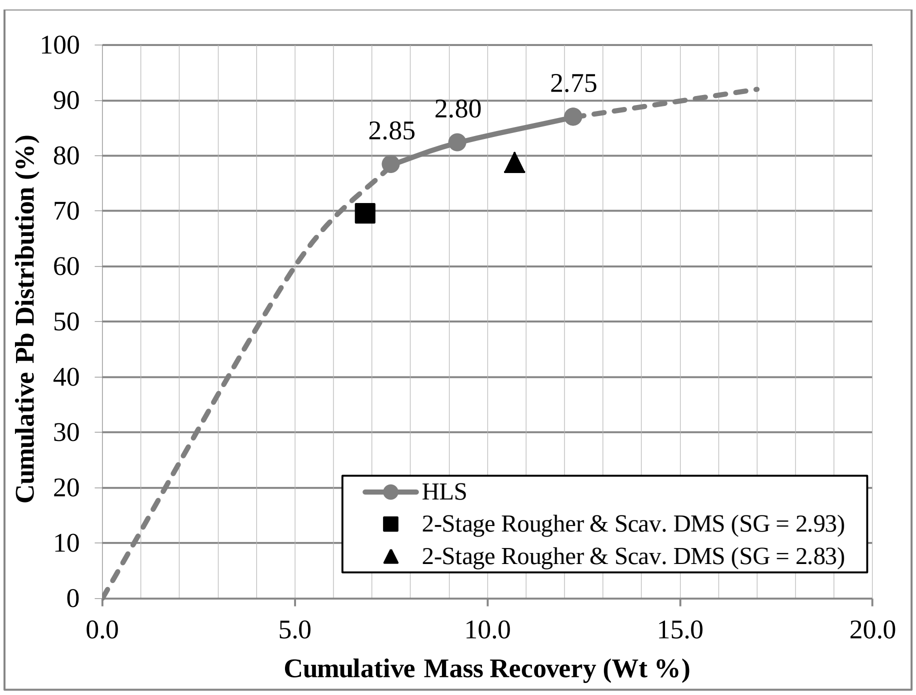

Figure 3 – Lead distribution for dense media separation and heavy liquid separation on the Cape Ray deposit samples

Lead Bearing Ore – Mine-X

A lead ore sample was supplied by an operating mine (Mine-X) to determine the response of the material to dense media separation. The primary objective was to evaluate the potential of preconcentration for the purpose of reducing haulage costs as the mining location was moving increasingly further from the mill. Additional potential benefits include reduced grinding costs and the possibility of re-depositing the waste in the mine as back fill. A potential to locate the DMS circuit underground in the mine was also to be evaluated.

The results, presented in Tables 3 and 4, from the two tests done on the -2.0 and -3.4 mm material demonstrate that over 97% lead recovery was achieved in mass recovery of less than 48%. The results from the slightly finer material (screened at 2.0 mm) were superior: an expected result as there is likely a larger fraction of liberated lead particles present in the finer material.

Table 3 – Condor Pilot Plant Test Results – Mine-X Sample Screened at 3.4 mm

2-Stage DMS	Weight	Grade (%)			Distribution (%)		
(Rougher-Scav)	(%)	Pb	Zn	Cu	Pb	Zn	Cu
Sinks 1 (SG = 2.84)	35.4	5.43	0.25	0.12	95.0	79.0	81.8
Sinks 2 (SG = 2.84)	12.1	0.33	0.07	0.01	2.0	7.4	3.2
Total Sinks	**47.5**	**4.13**	**0.21**	**0.09**	**97.0**	**86.4**	**85.0**
Floats	52.5	0.12	0.03	0.01	3.0	13.6	15.0
Head	100.0	2.02	0.11	0.05	100.0	100.0	100.0

Table 4 – Condor Pilot Plant Test Results – Mine-X Screened at 2.0 mm

2-Stage DMS	Weight	Grade (%)			Distribution (%)		
(Rougher-Scav)	(%)	Pb	Zn	Cu	Pb	Zn	Cu
Sinks 1 (SG = 2.85)	29.9	7.61	0.37	0.12	95.2	77.7	79.5
Sinks 2 (SG = 2.85)	12.2	0.43	0.10	0.03	2.2	8.5	8.3
Total Sinks	**42.0**	**5.53**	**0.29**	**0.10**	**97.4**	**86.2**	**87.7**
Floats	58.0	0.11	0.03	0.01	2.6	13.8	12.3
Head	100.0	2.39	0.14	0.05	100.0	100.0	100.0

Lead Bearing Tailings – Mine-X

Lead bearing tailings dump samples were also supplied by Mine-X to determine the response of the material to dense media separation. The primary objective was to evaluate the potential of recovering lead values as well as to reduce the lead content in the tailings. The results from two different sized materials are presented in Tables 5 and 6. The lead recoveries in the fine sample were higher at 65.6% with a mass yield to the heavy fraction of 13.6% compared to 47.4% recovery in the coarse sample with a mass yield of 5.4%.

The results from these tests demonstrate that waste rock or stockpiled run-of-mine waste can potentially be pre-concentrated for feed to a milling or processing operation. Depending on the quantity of stockpile, an economic assessment can be made for processing these types of materials.

Table 5 – Condor Pilot Plant Test Results – Mine-X Tailings Coarse Sample

2-Stage DMS (Rougher-Scav)	Weight (%)	Grade			Distribution		
		Pb (ppm)	Zn (%)	Cu (ppm)	Pb	Zn	Cu
Sinks 1 (SG = 2.82)	3.4	3,103	3.6	596	43.1	30.7	45.6
Sinks 2 (SG = 2.82)	2.0	512	1.2	77	4.3	6.4	3.6
Total Sinks	**5.4**	**2,123**	**2.7**	**400**	**47.4**	**37.1**	**49.2**
Floats	94.6	135	0.3	24	52.6	62.9	50.8
Head	100.0	242	0.4	44	100.0	100.0	100.0

Table 6 – Condor Pilot Plant Test Results – Mine-X Tailings Fine Sample

2-Stage DMS (Rougher-Scav)	Weight (%)	Grade			Distribution		
		Pb (ppm)	Zn (%)	Cu (ppm)	Pb	Zn	Cu
Sinks 1 (SG = 2.82)	7.0	11,507	4.6	107	57.0	43.2	27.3
Sinks 2 (SG = 2.82)	6.6	1,846	1.0	37	8.6	9.1	8.8
Total Sinks	**13.6**	**6,836**	**2.9**	**73**	**65.6**	**52.3**	**36.1**
Floats	86.4	564	0.4	20	34.4	47.7	63.9
Head	100.0	1,417	0.8	28	100.0	100.0	100.0

Lithium Bearing (Spodumene) Ore

A lithium bearing sample was provided by Nemaska Lithium Inc. to examine whether it would be economically viable to use DMS as a preconcentration method to separate lithium oxide (Li_2O) from other gangue material.

The material treated was sized on site at 9.5mm x 0.5mm. No other sample preparation was done on the sample in the laboratory except for drying and splitting the samples.

Heavy liquid separation test work was done with specific gravities of the heavy liquid ranging from 2.65 – 3.00. The results presented in Table 7 show that 90.6% of the lithium oxide can be recovered in 37.2% of the mass at a specific gravity of 2.72.

Table 7 – Nemaska HLS Mass Balance

Specific Gravity of Fraction	Sink-Float Fraction (Wt.%)	Grade (% Li_2O)	Sink-Float Fraction (% Li_2O)	Cumulative Distribution (% Li_2O)
> 3.00	9.4	7.07	35.9	35.9
2.93/3.00	5.5	5.54	16.3	52.2
2.86/2.93	5.9	4.61	14.7	66.9
2.79/2.86	7.8	3.36	14.1	81.0
2.72/2.79	8.6	2.07	9.6	90.6
2.65/2.72	15.6	0.74	6.2	96.8
< 2.65	47.1	0.12	3.2	100.0
Total	**100.0**	**1.86**	**100.0**	

For the pilot test work the material was processed through the Sepro Condor separator in stages. The test was done in two stages with a separation SG of 2.97 in the first stage followed by processing the floats from stage one at a separation SG of 2.69.

The results show that 90% of the lithium oxide was recovered in 44.8% of the mass with an average sinks product grade of 3.4% Li_2O (combined sink 1 and sink 2 product). The objective was to generate a product grade of at least a 5.8% Li_2O in the first sink product. The final floats fraction contained only 10% of the Li_2O in 55.2% of the mass at a relatively low grade of 0.3% Li_2O. The 5.8% Li2O sink product can be further upgraded to 6.1% Li_2O by magnetic separation in order to obtain the high quality concentrate. This reduced mass and higher grade product allows for a much smaller downstream processing plant used produce high quality lithium compound such as $LiOH*H_2O$ and Li_2CO_3.

Table 8 – Nemaska 2-Stage DMS Mass Balance

2-Stage DMS	Weight (%)	Grade (% Li_2O)	Distribution (% Li_2O)
Sinks 1 (SG = 2.97)	10.9	5.9	37.6
Sinks 2 (SG = 2.69)	33.9	2.6	52.4
Total Sinks	**44.8**	**3.4**	**90.0**
Floats	55.2	0.3	10.0
Head	100.0	1.7	100.0

For the following test, a three stage process was used. The first two stages were operated at the same density (SG = 3.00) to simulate the operation as a rougher-scavenger system. Again, the objective was to achieve a sinks grade of at least 5.8% Li_2O in the first and second sinks products. The results presented in Table 9 show that 33.3% of the lithium product was recovered at a grade of 6.1% Li_2O in only 9.5% of the mass. The third stage was operated at a density of 2.87 to generate a high grade middlings product with the option of combining the dense product from the third stage to the sinks 1 and sinks 2 products. Combining these products generated an overall grade of 5.2% Li_2O at an overall recovery of 66.8%. The final floats material still contained 33.2% of the Li_2O at a grade of 0.7%. This test demonstrated that in order to increase recovery, a lower final stage specific gravity would be required. A third test was carried out with a lower final specific gravity cut point.

Table 9 – Nemaska 3-Stage DMS Mass Balance (Rougher & Scav)

3-Stage DMS	Weight (%)	Grade (% Li_2O)	Distribution (% Li_2O)
Sinks 1 (SG = 3.00)	6.8	6.2	24.2
Sinks 2 (SG = 3.00)	2.7	5.9	9.0
Sinks 1 + Sinks 2	**9.5**	**6.1**	**33.3**
Sinks 3 (SG = 2.87)	12.9	4.5	33.5
Total Sinks	**22.4**	**5.2**	**66.8**
Floats	77.6	0.7	33.2
Head	100.0	1.7	100.0

The objective of the third test on this material was to generate a high grade product (at least 5.8% Li_2O) in sinks 1. The second stage was used as an intermediate stage to provide the flexibility of combining with sinks 1 to increase the mass in the primary sink product, without decreasing the grade to below 5.8% Li_2O. Alternatively, the sinks 2 material could potentially be used to increase the grade of the middlings product that is being generated in sinks 3.

The results from this 3-stage test, presented in Table 10, show that 89.3% of the Li_2O was recovered in 43% of the mass with an overall grade of 3.5% Li_2O. Only 10.7% of the Li_2O remained in the final floats product at a grade of 0.3%. The requirement to achieve a primary product exceeding 5.8% grade was also achieved.

Table 10 – Nemaska 3-Stage DMS Mass Balance

3-Stage DMS	Weight (%)	Grade (% Li_2O)	Distribution (% Li_2O)
Sinks 1 (SG = 2.94)	9.7	5.9	33.5
Sinks 2 (SG = 2.86)	13.4	4.3	34.1
Sinks 3 (SG = 2.70)	19.9	1.9	21.8
Total Sinks	**43.0**	**3.5**	**89.3**
Floats	57.0	0.3	10.7
Head	100.0	1.7	100.0

The cumulative Li_2O recovery as function of mass recovery is plotted on the graph presented in Figure 4 for both the pilot plant test work and the HLS test work. The HLS results represent a near prefect separation of the ore. It is impressive to see is that there is very little difference between HLS test and the pilot plant tests. There is only 2 – 3% inefficiency in the separation of the pilot plant when compared to the HLS tests.

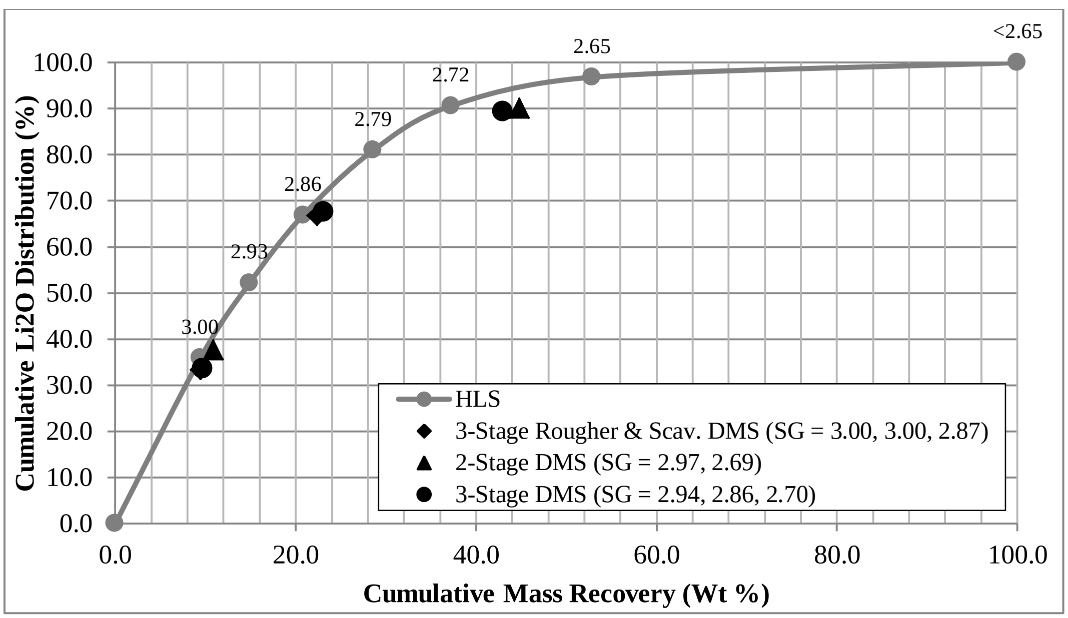

Figure 4 – Lithium distribution for dense media separation and heavy liquid separation on Nemaska samples.

From Figure 5 one can see that the separation data that was produced from all three tests was very consistent and generated good repeatability.

Based on these results, Nemaska has determined that it can process more than two thirds of its ore by DMS only to obtain high quality concentrate with grades exceeding 6% Li_2O at relatively low cost. Additionally, because ~8-10% of the Nemaska concentrate is magnetic gangue, it can be upgraded and part of sinks 2 can be split and added to the concentrate making recovery as 6% concentrate containing ~39-40% of the Li. The middlings, containing ~50% of the Li, will have a grade of 2.7% Li_2O and can be used as an enriched feed for flotation in their downstream processing plant.

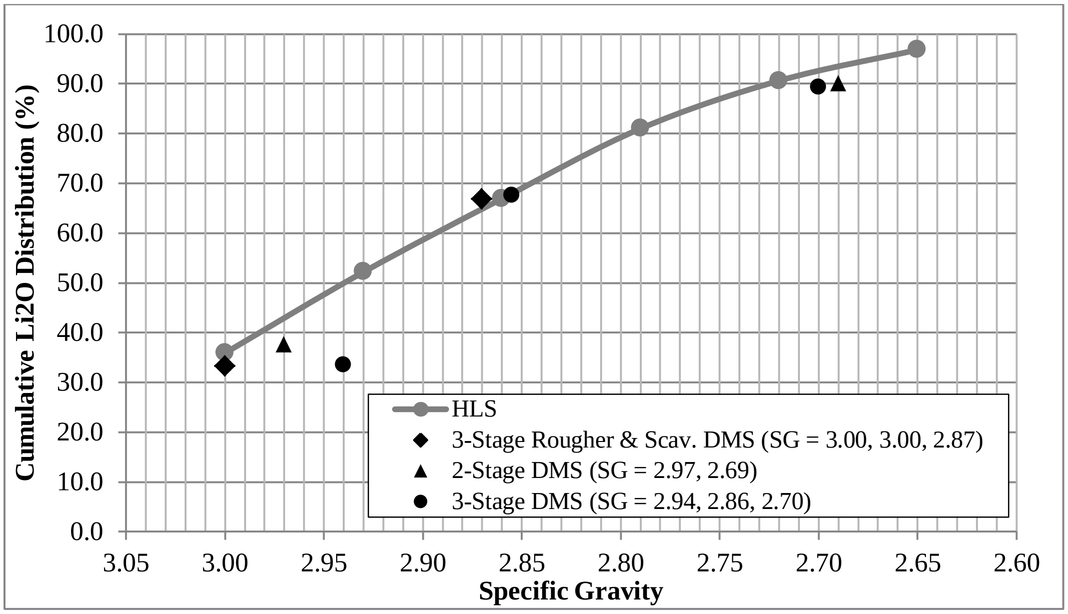

Figure 5 – Lithium distribution for dense media separation and heavy liquid separation on Nemaska samples.

SUMMARY

Preconcentration using dense medium separation has been used extensively in the coal and diamond industries however its use for upgrading other mineral systems has been less common. Examples from historical work on dense medium separation for various mineral systems were reviewed and there was a precedent found for application in base metals and industrial minerals.

The test work completed on lead based ores, a lead bearing run of mine reject and lithium bearing spodumene ore demonstrated the efficacy of DMS as a preconcentration process. Its versatility was also noted through the ability to achieve targeted grade and recovery response based on the profile generated through bench scale heavy liquid test work.

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