2015-2016 Spring Semester Material and Energy Balance

Molybdenum

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Content

- Basic Info about Molybdenum
- Production Routes of Molybdenum
- Material & Energy Balance Calculations
 - Mining of Moly Ores
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 - Calcination Process
 - Leaching Process
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 - Ferromolybdenum Production

Molybdenum

- Molybdenum is a refractory metallic element used principally as an alloying agent in cast iron, steel, and superalloys to enhance hardenability, strength, toughness, and wear- and corrosionresistance.
- Moreover, molybdenum finds significant use as a refractory metal in numerous chemical applications, including catalysts, lubricants, and pigments.





PROPERTIES

Atomic Weight:	95.95 g/g atom
Density:	10.22 g/cc
High Melting Temperature	2610°C
Lowest Thermal Expansion	
Coefficient of the Engineering Metals:	4.3 x 10⁵/°C
	4.3 x 10 [.] °C 142 W/m•K at 20°C

PRIMARY CONSUMPTION SECTORS BY END-USE*

Stainless Steels & Super Alloys	30%
Low Alloy Steels	30%
Chemicals & Mo Metal	20%
Tool & High Speed Steels	10%
Foundry	10%
* IMOA estimates	

Source: Molybdenum, 1998, IMOA, webpage.

Molybdenum Minerals and Deposits

- Molybdenum occurs in the earth's crust in an abundance of about 10^{-4} %, mainly as molybdenite (MoS₂). Wulfenite (PbMoO₄), powellite [Ca(Mo,W)O₄], Ferrimolybdite (Fe₂Mo₃O₁₂·8H₂O) are the other significant minerals. There are five genetic types of molybdenum deposits:
 - 1) porphyry deposits in which metallic sulfides are disseminated throughout large volumes of altered and fractured rock,
 - 2) contact-metamorphic zones and bodies in which silicated limestone is adjacent to intrusive granites,

3) quartz veins,

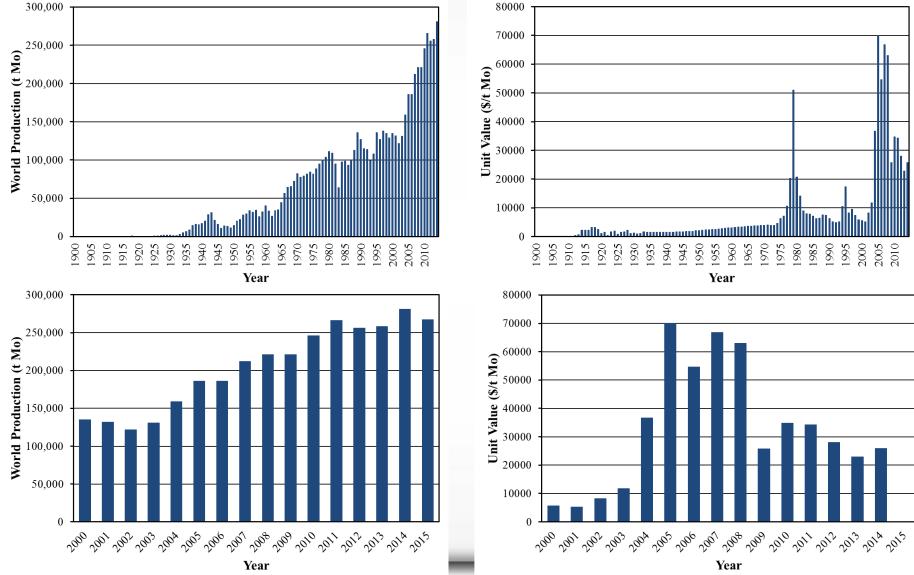
4) pegmatites, and

5) deposits bedded in sedimentary rocks.

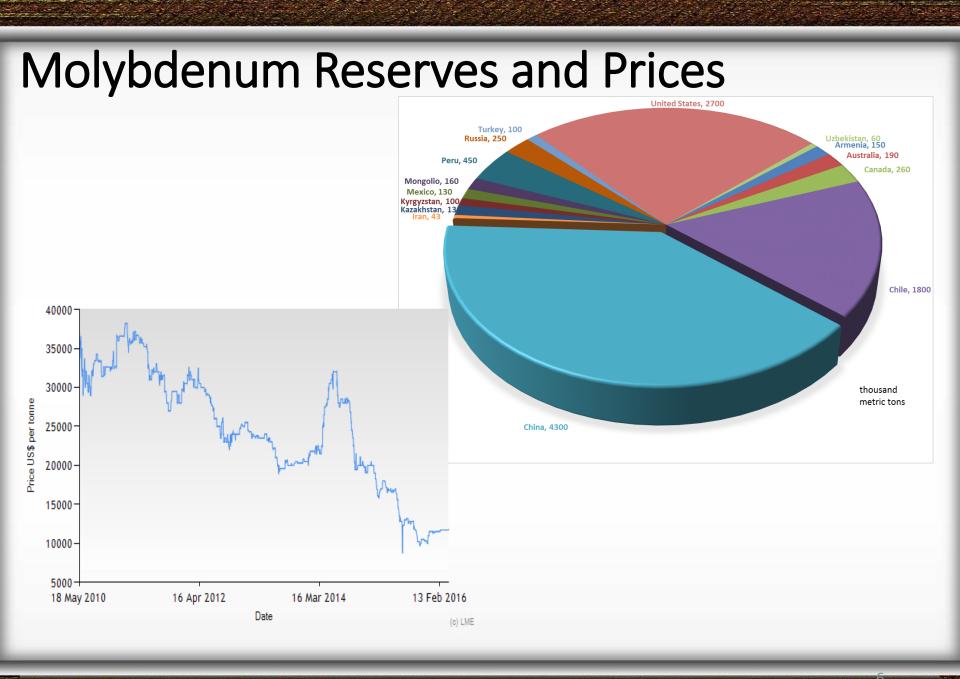
 Average molybdenite concentrations in primary porphyry deposits range from 0.05 to 0.25 %; in secondary copper – molybdenum porphyry deposits molybdenite concentrations are much lower (0.01 – 0.05 %) so that the mineral can only be recovered as a byproduct.

Source: A.R.Burkin, 2005, Molybdenum and Molybdenum compounds, in Ullmann's...

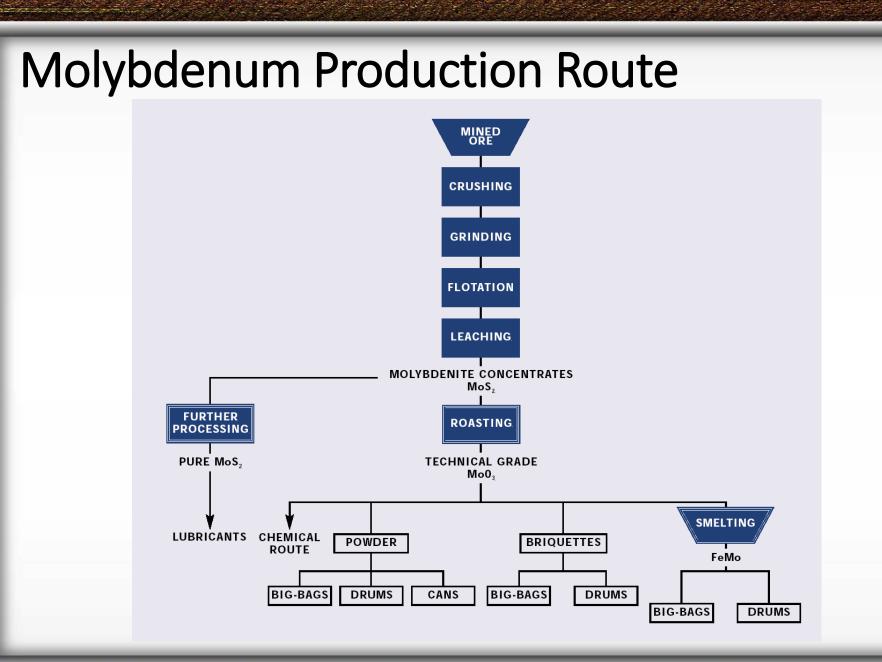
Molybdenum Mine Production and Prices



Source: D.E. Polyak, 2016, Molybdenum Statistics, USGS.

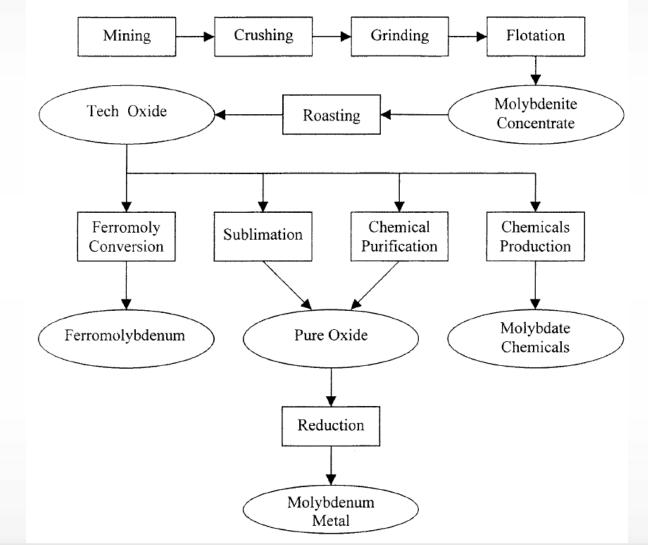


Sources: D.E. Polyak, 2016, Molybdenum Statistics, USGS. LME.com, 2016



Source: Molybdenum, 1998, IMOA, webpage.

Molybdenum Production Route



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Source: M.C. Jha, 2001. Extractive Metallurgy of Molybdenum, TMS2001

M.&E.B. Calculations in Moly Mining

- Molybdenum ore is mined by underground and open-pit methods.
- A typical primary molybdenum ore body contains 0.05 – 0.25% Mo,
- and secondary ore bodies (copper porphyry ores) average 0.3 – 1.6% Cu and 0.01 – 0.05% Mo.

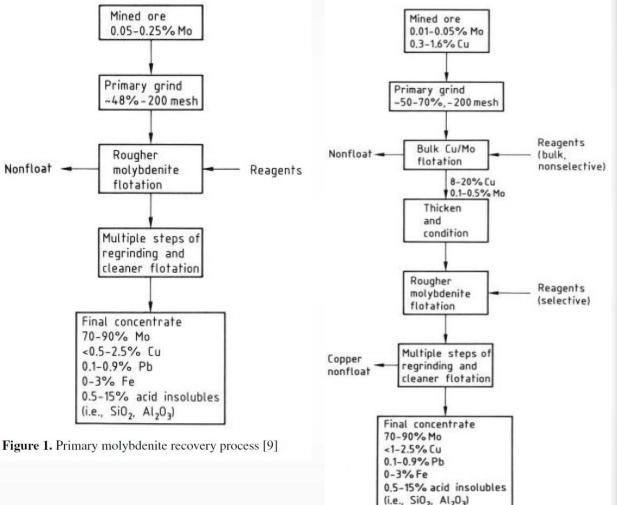


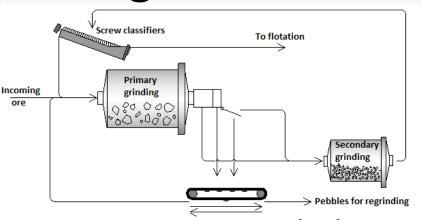
Figure 2. Byproduct copper-molybdenite recovery process [9]

Source: A.R.Burkin, 2005, Molybdenum and Molybdenum compounds, in Ullmann's...

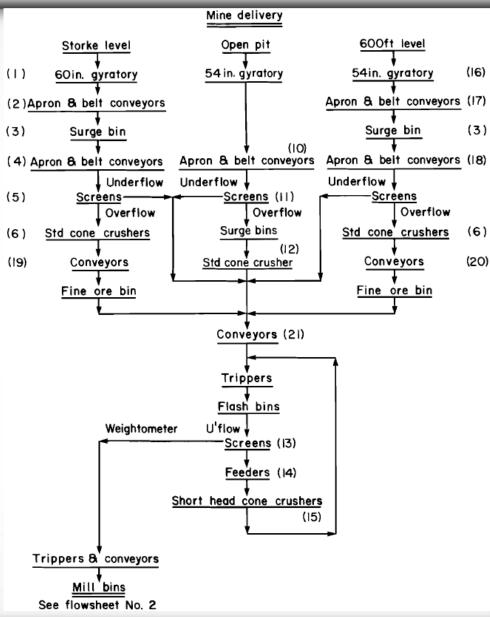
Mining

- Let assume that we have a primary molybdenum ore with the mass composition of 40% quartz (SiO₂), 20% orthoclase (KAlSi₃O₈), 15% plagloclase (NaAlSiO₃O₈), 5% Mica-sericite (Na₂O.K₂O.3Al₂O₃.6SiO₂.2H₂O), 5% Clay (4SiO₂.3MgO.H₂O), 5% Pyrite (FeS₂), 2% Fluorite (CaF₂), 1% Topaz (Al₂SiO₄(F,OH)₂), 0.35% MoS₂, 0.02% Chalcopyrite (CuFeS₂).
- This is an example of Climax-Porphyries deposits. We can design similar mining facility like in Climax Mine, Colorado.

Mining

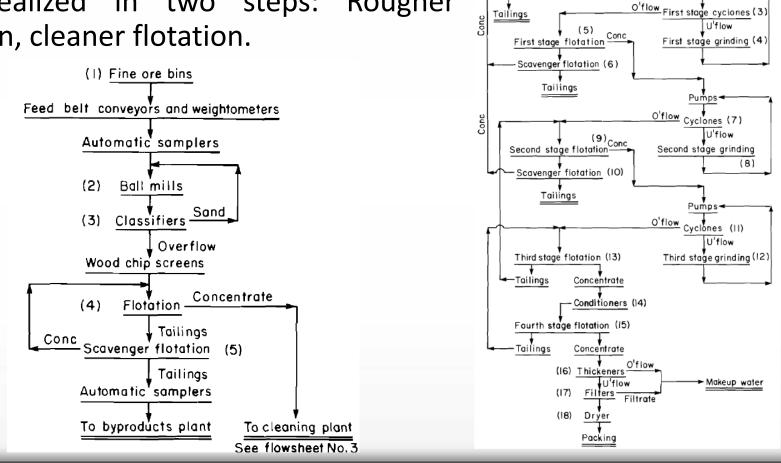


 For mining calculations, energy is required during transportation, milling, grinding, screening, feeding applications. Material balance calculations will be applied in screening and classification sectors.



M.&E.B. Calculations in Moly Flotation

 After grinding, classifier overflow is pumped to flotation step. Froth flotation step realized in two steps: Rougher flotation, cleaner flotation.



Rougher concentrate

Automatic sampler

Pumps

Feed cyclones () U'flow

1Z

O'flow

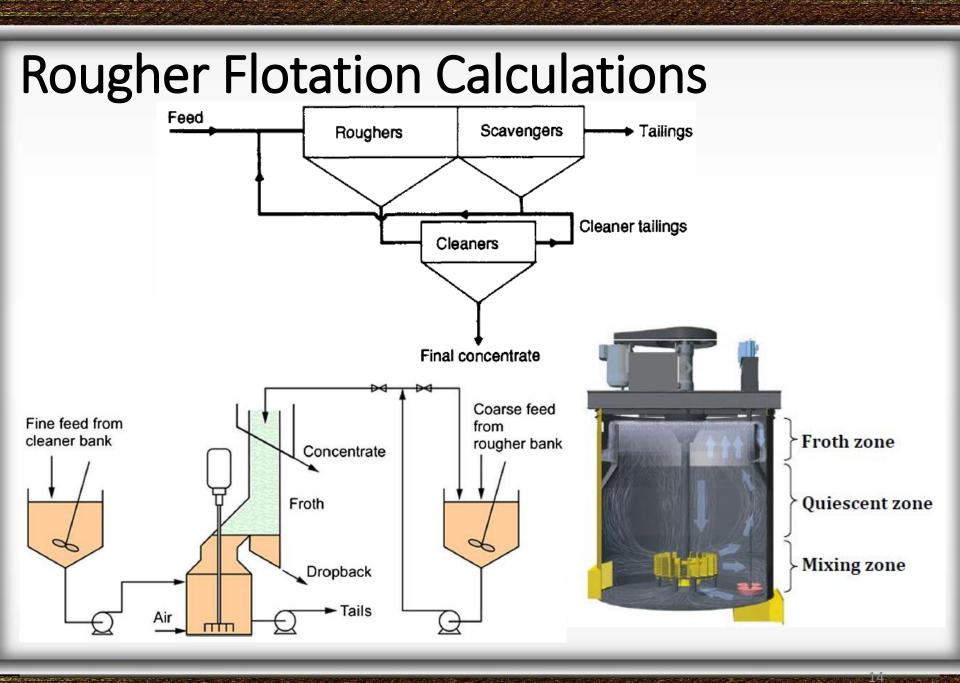
O'flow Thickeners

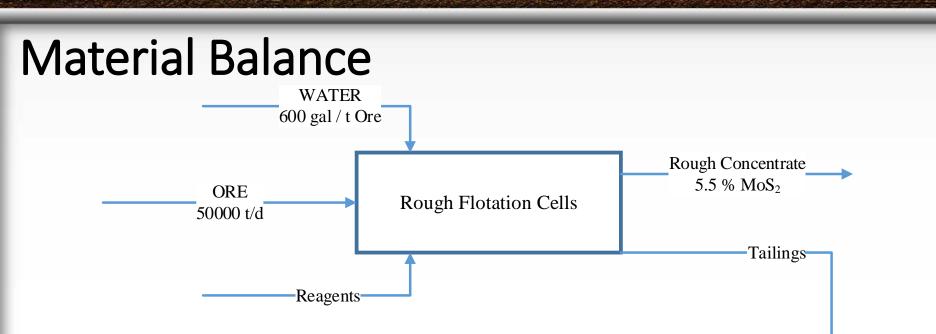
Tailings

Source: JD Vincent and JF Shirley, 1978, Molybdenum,

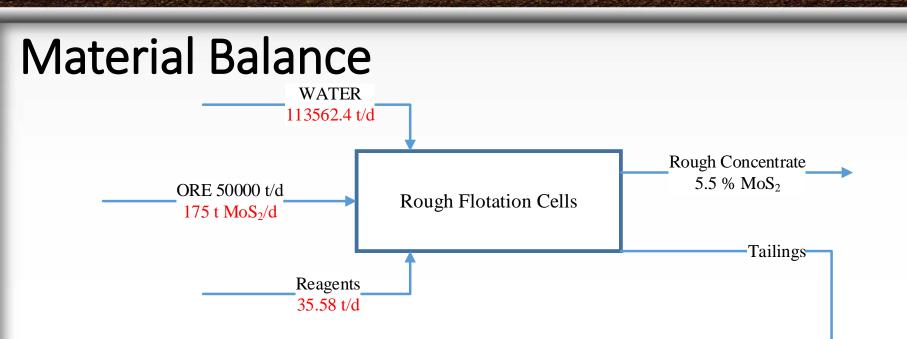
Rougher Flotation Calculations

- We have molybdenum ores with 0.35 wt.% MoS₂, and we have a daily feed of 50,000 tons of ores.
- Water consumption is 600 gallon per ton of feed.
- Flotation reagents are added to the system for per ton of ore as;
 0.035 lb pine oil, 0.67 lb vapor oil, 0.034 lb Syntex, 0.30 lb lime, 0.50 lb sodium silicate, 0.03 lb nokes reagent.
- Rougher concentrate has 5.5 wt.% MoS₂, and overall MoS₂ recovery is 87%.
- The ratio of water in concentration is 350 to 1.
- Rough flotation process takes place 15 minutes for each cell.



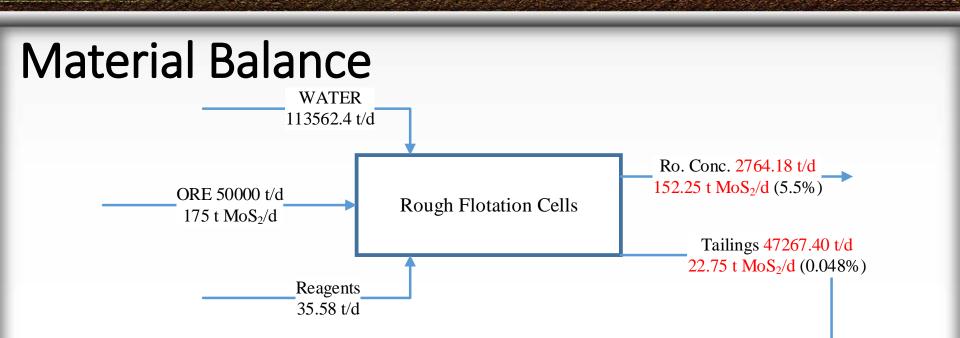


- 50000 t/d ores contain 50000x0.35% = 175 t MoS₂/d
- 50000 t/d ores require; v_{water}=50000x600 =3x10⁷gal=113562.4 m³
- d_{water}=1000kg/m³ so m_{water}=113562.4 t/d
- Amount of reagents are; 0.79 t/d pine oil, 15.20 t/d vapor oil, 0.77 t/d Syntex, 6.80 t/d CaO, 11.34 t/d Na₂SiO₃, 0.68 t/d Na₃PS₂O₂. Total 35.58 t/d reagents.



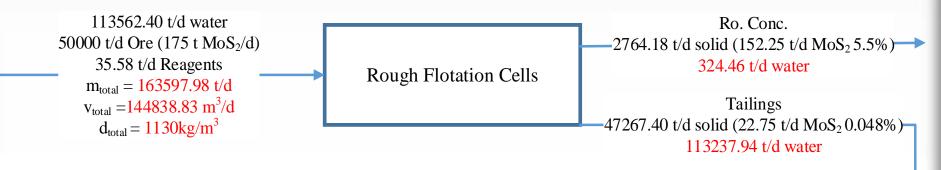
- Flotation process has 87% efficiency. So,
- 175x0.87=152.25 t MoS₂/d recovered into concentrate
- 175-152.25=22.75 t MoS₂/d go into tailings.
- Concentration has 5.5 wt.% MoS₂. So;
- m_{conc.}=152.25/(5.5%)=2768.18 t/d
- m_{tail.}=50035.58-2768.18=47267.40 t/d (0.048 % MoS₂)

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- Amount of water is 113562.4 t/d. Concentration has 350 to 1 ratio.
 So,
- m_{water in conc.} = 113562.4/350=324.46 t/d
- m_{water in tail.}=113237.94 t/d
- Total weight of the raw material = 163597.98 t/d
- Total volume of the raw materials = 144838.83 m³/d (calculated from density values of raw material)

Material Balance



- Total volume of the raw material is 144838.83 m³/d. Flotation time is 15 min. So, in a single day (24x60)/15=96 cycle applied.
- 144838.83 / 96 = 1508.73 m³ per flotation cycle. We need at least 1600 m³ total flotation capacity plant.

Energy Balance

- There is no heating and cooling require for this process, and there is no reaction. We need energy during flotation and pumping.
- Let's select flotation cell from Outokumpu TankCell. We need at least 1600 m³ total flotation capacity plant.
- For OK-100-TC type flotation cell (with 100 m³ volume) a 110 kW capacity motor is used.
- In 16 cells, 110x16x24=42240 kWh energy consumed per day for rough flotation.

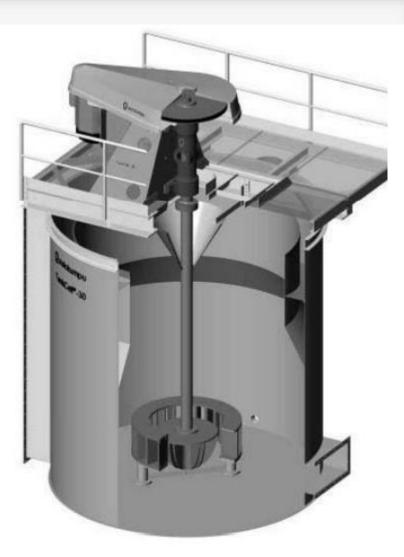


A schematic diagram of Outokumpu TankCell

Source: B.K. Gorain, 2000. Flotation Cell Design: Application of Fundamental Principles

Energy Balance

- We also require energy for hydrodynamic process. For 87% Mo recovery, we obtain
 - 0.84 kW/m³ specific power for pumping,
 - 195 m³/min pumping rate,
 - 34.0 m³/min airflow.
- 1600m³x0.84x24=32256 kWh energy
- 34x24x60=48960m³ air consumed.
- Total 32256+42240=74496kWh energy consumed per day for rough flotation

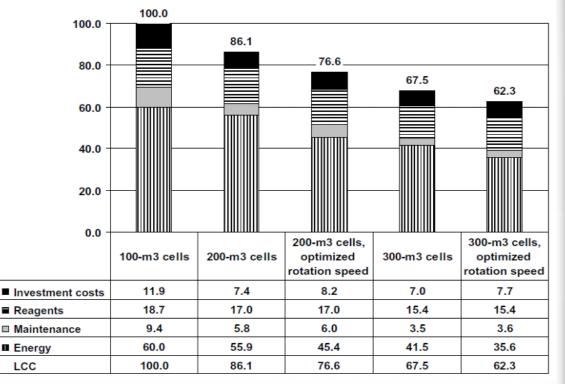


A schematic diagram of Outokumpu TankCell

Source: D.Lenindski, 2011, Effective use of energy in the flotation process

Energy Balance

- This is a comparison of
 - 18 cells of 100 m³ in two lines of nine cells.
 - 9 cells of 200 m³ in a single line.
 - 9 cells of 200 m³ in a single line, fitted with variable speed drive mechanisms.
 - 6 cells of 300 m³ in a single line.
 - 6 cells of 300 m³ in a single line, fitted with variable speed drive mechanisms.



- If we use 300m³ rather than 100m³ cell, we could save;
- 74496x(60-41.5)/60=22969.9 kWh per day

Cleaner Flotation Calculations Copper-Moly Conc **Rougher Feed** Banks Conc **Final Cu** Conc 1st Cleaner 6' Column Cell 2nd 2nd Cleane Cleaner 3rd в A Cleaner Tails Moly Final Moly Thickene Conc

Similar calculations can be also made for cleaner flotation step.

Source: R.Rogers, 2010, Design, installation and operation of Pinto Valley moly flotation.

Cleaner Flotation Calculations

Mass balance of the new moly plant configuration.							
	Solids Water, GPM			GPM	Pulp		
Stream	%		%	Drip			
	MoS ₂	DTPD	Solids	pan	Launder	GPM	
	-						
Ro feed	1.6	953.7	26.0			489.6	
Ro tails	0.4	883.1	27.1			430.4	
Ro conc	17.4	70.7	17.7		15	57.5	
First cleaner							
Feed (6' col.)	15.2	102.1	12.0			283.4	
First cleaner							
Tail (6' col.)	9.0	62.0	14.0	10		212.6	
First cleaner							
Con(6' col.)	25.0	39.5	10.0		10	70.8	
Second cleaner							
Feed (30" col.)	34.7	72.1	8.0			111.3	
Second cleaner							
Tail (30" col.)	9.0	31.4	6.5	10		78.7	
Second cleaner			10.0		10		
Con (30" col.)	60.0	40.6	18.0		10	32.9	
Third cleaner			40 -	-		00.4	
Tail (20" col.)	50.0	34.9	16.5	5		20.4	
Third cleaner	00.0		05.0		-	10 5	
Final con (20" col.)	90.0	5.7	35.0		5	12.5	
Scavenger cail	6.0	50.7	4.0	10		100.4	
(30" col.)	0.0	53.7	4.0	10		160.4	
Scavenger	05.0	0.0	2		10	co o	
con (30' col.)	25.0	9.6	3		10	62.2	



Design parameters of the flotation columns.

Flotation column parameter	Scavenger	Second cleaner	Third cleaner
Height (h), ft	32	32	25
Diameter (d), in.	30	30	20
h/d, ft/ft	12	12	15
Flow feed, gpm	220	120	35
Nitrogen, scfm	10	10	5
Nitrogen, psi	50	50	50
hold up, %	15	15	12
Feed superficial velocity, cm/s	1.5	1.5	1.2
Water superficial velocity, cm/s	0.122	0.122	0.108
Froth depth, in.	12	12	9

Source: R.Rogers, 2010, Design, installation and operation of Pinto Valley moly flotation.

Cleaner Flotation Calculations





- Molybdenite ore with 0,05 0,25 % Mo milled and grinded to 74 μ m.
- Gravitation, agitating with water, collecter oil and other chemicals.
- Flotation with kerosene, stove oil, light oil, pine oil, Syntex VB (sulfated monoglyceride of coconut oil) and lime or soda ash for alkalinity for pH 8,5. Sodium silicate is used to disperse slimes.
- 70-90 % MoS₂ with 0,5-2,5 % Cu, 0,1-0,9 % Pb, 0-3 % Fe.

Source: A.R.Burkin, 2005, Molybdenum and Molybdenum compounds, in Ullmann's...

Roasting of Molybdenum Concentrate

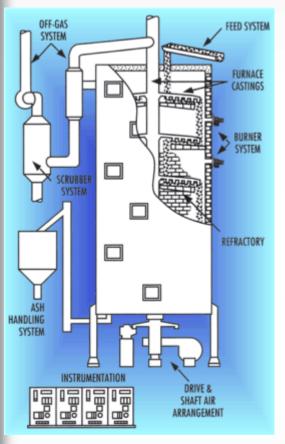
- Molybdenite concentrates are convened to technical grade oxide, which is the starting material for a variety of products for the metallurgical and chemical industries.
- The roasted concentrate is discharged from the furnace and either marketed as technical grade oxide or subjected to additional conversion operations to remove impurities.

Typical concentrations in the analysis range of molybdenite concentrates are:

A typical analysis range of commercially available technical grade molybdic oxide is:

Total molybdenum Sulfur Acid insol. Lead Tin Zinc Bismuth Phosphorus Iron Copper Oil Water	$\begin{array}{r rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$MoS_2 + \frac{7}{2}O_2 \rightarrow MoO_3 + 2SO_2.$	Molybdenum Sulfur Insolubles Iron Copper CaO ZnO	$\begin{array}{r} & Wt \ \% \\ \hline 56 & -62 \\ 0.02 \ - \ 0.25 \\ 5.00 \ -11.00 \\ 0.50 \ - \ 1.00 \\ 0.015 \ - \ 1.00 \\ 0.05 \ - \ 0.20 \\ 0.10 \ - \ 0.20 \end{array}$
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Roasting of Molybdenum Concentrate



 $2MoS_2 + 7O_2 \rightarrow 2MoO_3 + 4SO_2$ $MoS_2 + 6MoO_3 \rightarrow 7MoO_2 + 2SO_2$ $2MoO_2 + O_2 \rightarrow 2MoO_3$



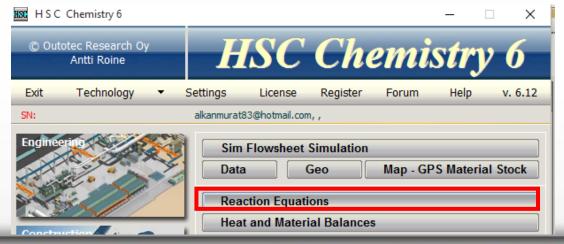
- Molybdenite is converted to technical-grade MoO₃ by roasting it in air in a multiple hearth furnace of the Nichols-Herreshoff design.
- Upper hearth temp 600-700°C, the hearth temperatures are controlled 600-650 °C by addition of excess hot air or water sprey cooling.
- Technical-grade MoO_3 typically contains 85-90% MoO_3 , the balance being silica with some Fe_2O_3 and Al_2O_3 .

Source: A.R.Burkin, 2005, Molybdenum and Molybdenum compounds, in Ullmann's...

Calcination takes place due to three reactions.

 $2 \text{ MoS}_{2} + 7 \text{ O}_{2} = 2 \text{ MoO}_{3} + 4 \text{ SO}_{2}$ $\text{MoS}_{2} + 3 \text{ O}_{2} = \text{MoO}_{2} + 2 \text{ SO}_{2}$ $2 \text{ MoO}_{2} + \text{ O}_{2} = 2 \text{ MoO}_{3}$

- To decide which one is favorable, we need to plot Gibbs Free Energy Changing vs Temperature diagram (Ellingham).
- We can use "Reaction Equation" Module of HSC for obtaining data.



Source: A.R.Burkin, 2005, Molybdenum and Molybdenum compounds, in Ullmann's...

ISC Reaction Equations			– 🗆 X						
Reaction Equation or Chemical Formula:									
2MoO2 + O2(g) = 2MoO3									
Temperature:	From To Step Temperature: 100 1000.000 50.000 C								
Temperature Units:	Energy Units:	Format of Results:	Settings:						
Celsius	Calories kcal	Normal	Collect to Sheet						
C Kelvins	 Joules kJ ○ Wats Wh 	 Show Transitions Criss-Cobble 							
	Me	nu							
Help	File Open HSC 2 File	Balance Equation	Browse Database						
Exit	File Open	1	Calculate						

3 – Balance the equation

4 – Press Calculate for calculating 1- Writing the equation

!!! Attention !!!

If the phase is gaseous form write (g)

If the phase is liquid form write (I)

If the phase is in aqueous form write (aq)

2 – Temperature range and step

You can select temperature and energy unit from here

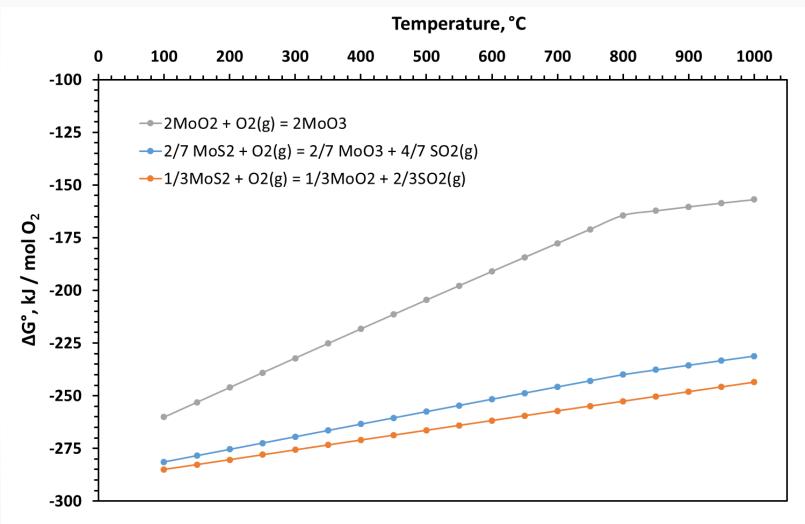
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🚾 Results - 🗆 X File Edit Format Help								
	T	Ср	H	s	G	Reference		
1	2MoO2 + O2(g) =			1	Ī			
2	T	deltaH	deltaS	deltaG	К	Log(K)		
3	С	kJ	J/K	kJ				
4	100.000	-312.890	-141.309	-260.160	2.637E+036	36.421		
5	150.000	-312.638	-140.676	-253.111	1.767E+031	31.247		
6	200.000	-312.395	-140.133	-246.091	1.480E+027	27.170		
7	250.000	-312.130	-139.601	-239.098	7.500E+023	23.875		
8	300.000	-311.826	-139.046	-232.132	1.437E+021	21.157		
9	350.000	-311.471	-138.452	-225.194	7.553E+018	18.878		
10	400.000	-311.057	-137.814	-218.287	8.708E+016	16.940		
11	450.000	-310.580	-137.132	-211.413	1.871E+015	15.272		
12	500.000	-310.037	-136.407	-204.575	6.643E+013	13.822		
13	550.000	-309.427	-135.642	-197.773	3.558E+012	12.551		
14	600.000	-308.749	-134.843	-191.011	2.678E+011	11.428		
15	650.000	-308.004	-134.013	-184.289	2.682E+010	10.429		
16	700.000	-307.193	-133.158	-177.610	3.421E+009	9.534		
17	750.000	-306.318	-132.281	-170.974	5.363E+008	8.729		
18	800.000	-305.381	-131.388	-164.382	1.004E+008	8.002		
19	850.000	-205.466	-38.494	-162.231	3.512E+007	7.546		
20	900.000	-203.013	-36.357	-160.361	1.383E+007	7.141		
21	950.000	-200.687	-34.415	-158.593	5.933E+006	6.773		
22	1000.000	-198.490	-32.654	-156.917	2.745E+006	6.438		
23								
24	Formula	FM	Conc.	Amount	Amount	Volume		
25		g/mol	wt-%	mol	g	l or ml		
26	MoO2	127.939	88.885	2.000	255.878	39.548 ml		
27	O2(g)	31.999	11.115	1.000	31.999	22.414 1		
28		g/mol	wt-%	mol	g	l or ml		
29	MoO3	143.938	100.000	2.000	287.876	61.355 ml		
30							-	
	Exit Help	Prin	t Cl	ear C	Copy All C	opy Save	•	

 Results give us Enthalpy, Entropy, and Free Energy Changing at the selected temperatures.

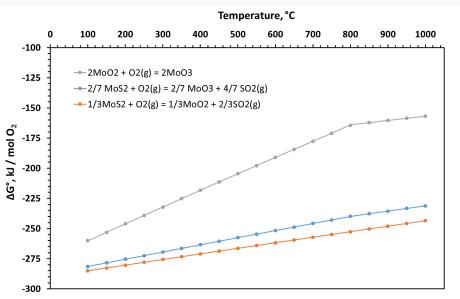
• Also K (equilibrium constant) values are also available in the results.

Source: HSC Chemistry

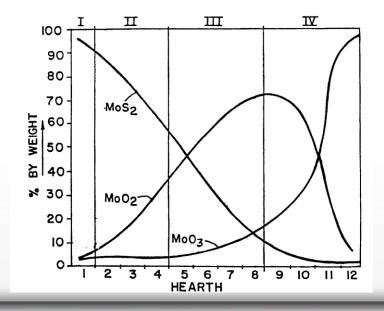


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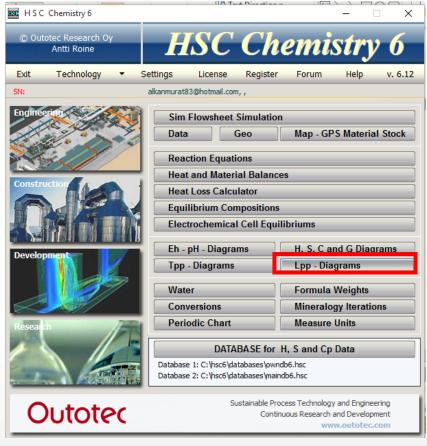
Source: HSC Chemistry



- Because of this reason, multiple hearth furnace (12-16 hearth) is commonly used for calcination of molybdenite concentration.
- The lowest energy obtaining reaction is the most favorable ones. So, MoO₂ formation reaction is firstly occurred. After consumption of all MoS₂ phase, MoO₃ formation reaction can be started.



 In Sulphur containing systems, we can also use Kellogg Diagrams. To plot Kellogg Diagram (Mo-O-S Stability diagram) we can use "LPP-Diagrams" module in HSC.



ISC Phase Stability Diagram

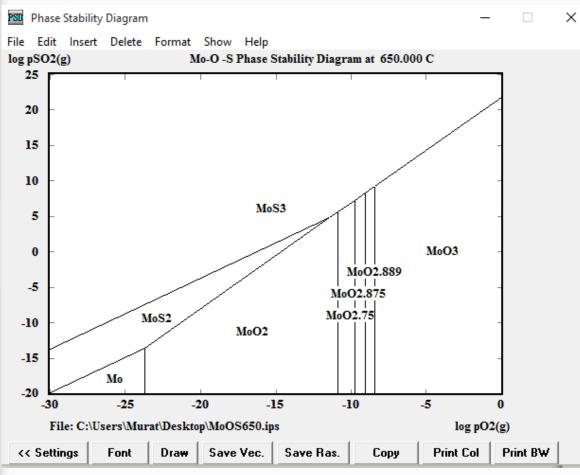
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Authors: W Russell, N Shah, A Fine, A Morris, D Murphy and A Roine

Select 3 Elements	Select Species	AII	Select X - axis		Select Y - a	xis
Ac Cu Lu Re Y	Mo	~	Mo(g)	~	03(g)	~
Ag Dy Mg Rh Yb	Mo2		Mo2(g)		S(g)	
Al Er Min Rin Zin	MoO2		MoO(g)		S2(g)	
Am Es <u>Mo Ru</u> Zr	Mo02.75		MoO2(g)		S3(g)	
Ar Eu N S	Mo02.875		MoO3(g)		S4(g)	
As F Na Sb	MoO2.889		Mo206(g)		S5(g)	
At Fe Nb Sc	MoO3		Mo309(g)		S6(g)	
Au Fm Nd Se	Mo4011		Mo4012(g)		S7(g)	
B Fr Ne Si	Mo9026		Mo5015(g)		S8(g)	
Ba Ga Ni Sm	MoS2		MoS(g)		30(y)	
Be Gd Np Sn	MoS3	_	MoS2(g)		SO2(g)	
Bi Ge 🚺 Sr	Mo2S3		0(9)	7-	ooclo.o.oaidi	
Bk H Os Ta	02(0.01bar)		02(g)		SO2(0.05barg)	
Br He P Tb	02(0.05bar)		02(0.01barg) 02(0.055)		SO2(0.1barg)	
C Hf Pa Tc Ca Hg Pb Te	02(0.1bar)		02(0.05barg)		SO2(0.5barg)	
Ca Hg Pb Te Cd Ho Pd Th	02(0.5bar) 02(100bar)		02(0.1barg) 02(0.5barg)		SO2(10barg)	
Cel Pm Ti	02(10bar)		02(0.50arg) 02(10barg)		SO2(1barg) SO2(20barg)	
Cf In Po TI	02(1bar)		02(1barg)		SO2(30barg)	
CI IN POTT	02(200bar)		02(10arg) 02(20barg)		SO2(40barg)	
Cm K Pt U	02(20bar)		02(30barg)		SO2(50barg)	
Co Kr Pu V	02(300bar)		02(40barg)		SO2(5barg)	
Cr La Ra W	02(30bar)		02(45barg)		SO2(60barg)	
Cs Li Rb Xe	02(400bar)		02(5barg)		SO2(70barg)	
1	02(40bar)		03(g)		SO3(g)	
OK	02(45bar)	\mathbf{v}	S(g)	¥ .	\$20(d)	\sim
Liquids Temperature: 650 C						
Exit Help File Oper C:\Users\Murat\Desktop\MoOS650.ips File Save PSD						

1- Select the elements (Mo, O, S) then click OK 2- Select the species appeared in the diagram 3- Select the axises. X-axis O₂ partial pressure Y-axis SO₂ partial pressure 4- Select the temperature 5- Save file to a folder 6- Click PSD to plot diagram



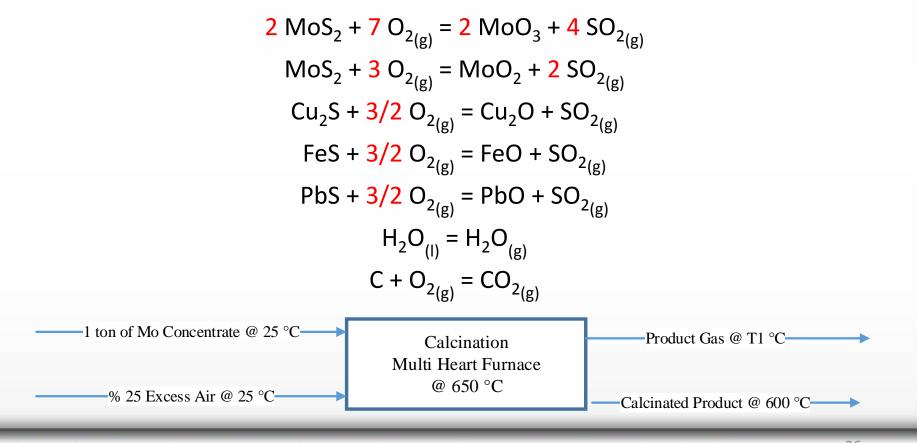
- As we can see from the figure, MoO₂ will be formed firstly for producing MoO₃.
 MoO_{2.75}, MoO_{2.875}, MoO_{2.889} phases can be occurred during the reaction.
- For final product formation we need to calculate partial pressure of gases.

Material Balance

- Let consider that we have 1 ton of concentrate with: 51.0 % Mo, 34.56 % S, 1.2 % Cu, 0.2 % Fe, 0.4 % Pb, 1.1 % SiO₂ by mass. Rest are water-moisture (11.34%) and oil (0.2 %).
- In concentrate, there are MoS₂, Cu₂S, FeS, PbS, SiO₂, H₂O, C compounds. Total:
- 850.9 kg MoS_2 = 5.316 kmol
- $15.0 \text{ kg Cu}_2\text{S} = 0.094 \text{ kmol}$
- 3.1 kg FeS = 0.035 kmol
- 4.6 kg PbS = 0.019 kmol
- $12.0 \text{ kg SiO}_2 = 0.200 \text{ kmol}$
- 113.4 kg H_2O = 6.300 kmol
- 2.0 kg Oil (C) = 0.166 kmol

Material Balance

- We have 1 ton of concentrate, reacted at 650 °C, with 99.5% reaction efficiency (for MoS_2). MoO_3 to MoO_2 conversion is 90 %.
- We use 25% excess air for calcinations. The reactions are:



30



Material Balance

- For 99.5% reaction efficiency: 5.316 x 99.5% = 5.289 kmol MoS₂ will react. 5.316 5.289 = 0.027 kmol MoS₂ unreacted.
- For 90% MoO3 conversion: 5.289 x 90% = 4.760 kmol MoS₂ will react into MoO₃. 5.289 – 4.760 = 0.529 kmol MoS₂ will react into MoO₂.

 $2 \text{ MoS}_2 + 7 \text{ O}_{2(g)} = 2 \text{ MoO}_3 + 4 \text{ SO}_{2(g)}$ 4.760 kmol MoS₂ require 4.760 x 7 / 2 = 16.66 kmol O₂ 4.760 kmol MoO₃ and 9.520 kmol SO₂ formed

 $MoS_2 + 3 O_{2(g)} = MoO_2 + 2 SO_{2(g)}$ 0.529 kmol MoS₂ require 0.529 x 3 = 1.587 kmol O₂ 0.529 kmol MoO₂ and 1.058 kmol SO₂ formed



Material Balance

 $Cu_2S + 3/2 O_{2(g)} = Cu_2O + SO_{2(g)}$ $0.094 \text{ kmol } \text{Cu}_2\text{S} + 0.141 \text{ kmol } \text{O}_2 = 0.094 \text{ kmol } \text{Cu}_2\text{O} + 0.094 \text{ kmol } \text{SO}_2$ $FeS + 3/2 O_{2(g)} = FeO + SO_{2(g)}$ $0.035 \text{ kmol FeS} + 0.053 \text{ kmol O}_2 = 0.035 \text{ kmol FeO} + 0.035 \text{ kmol SO}_2$ $PbS + 3/2 O_{2(g)} = PbO + SO_{2(g)}$ $0.019 \text{ kmol PbS} + 0.0,029 \text{ kmol O}_{2} = 0.019 \text{ kmol PbO} + 0.019 \text{ kmol SO}_{2}$ $H_2O_{(1)} = H_2O_{(g)}$ $6.300 \text{ kmol H}_2\text{O} = 6.300 \text{ kmol H}_2\text{O}$ $C + O_{2(g)} = CO_{2(g)}$ $0.166 \text{ kmol C} + 0.166 \text{ kmol O}_2 = 0.166 \text{ CO}_2$ Total O₂ require = 18.636 kmol (100% stoichiometric) with 25% excess $18.636 + (18.636 \times 25\%) = 23.295 \text{ kmol } O_2$



Material Balance

Total N₂ require = 23.295 x 0.79 / 0.21 = 87.634 kmol N₂

Total SO₂ produced = 10.726 kmol

Total input:

5.316 kmol MoS₂ + 0.094 kmol Cu₂S + 0.035 kmol FeS +

 $0.019 \text{ kmol PbS} + 0.200 \text{ kmol SiO}_2 + 6.300 \text{ kmol H}_2\text{O} + 0.166 \text{ kmol C}$

+ 23.295 kmol O_2 + 87.634 kmol N_2

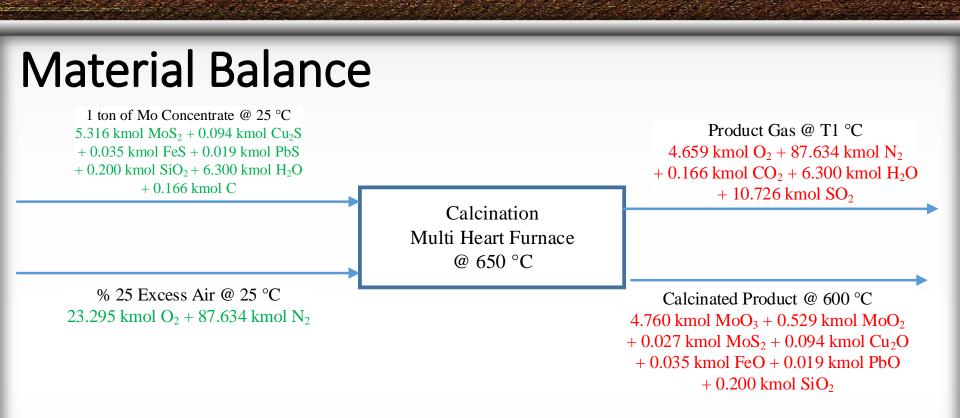
Total output:

 $4.760 \text{ kmol MoO}_3 + 0.529 \text{ kmol MoO}_2 + 0.027 \text{ kmol MoS}_2$

+ 0.094 kmol Cu₂O + 0.035 kmol FeO + 0.019 kmol PbO

+ 0.200 kmol SiO₂ + 4.659 kmol O₂ + 87.634 kmol N₂ + 0.166 kmol CO₂ + 6.300 kmol H₂O + 10.726 kmol SO₂

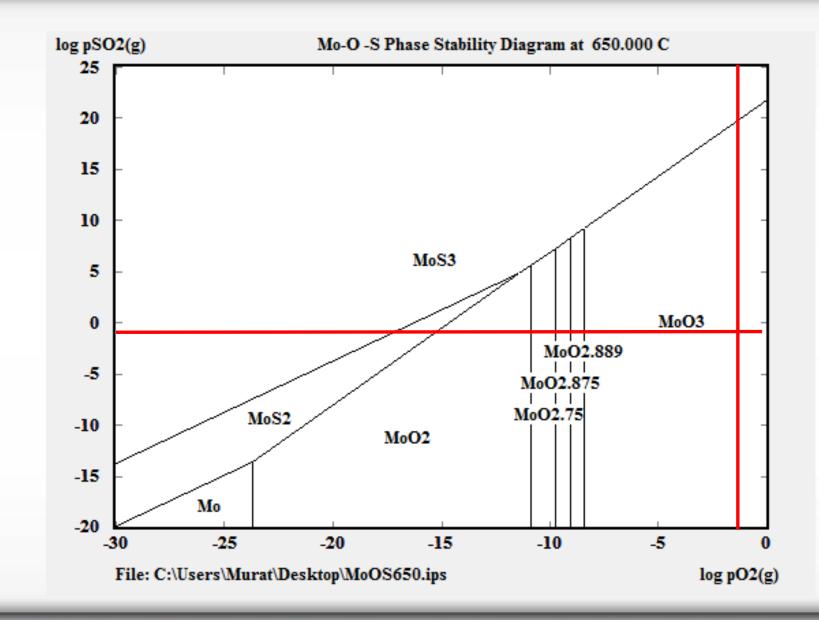




Product gas has 4.26 % O₂, 80.04 % N₂, 9.80 % SO₂, 5.75 % H₂O, 0.15 % CO₂ log p_{O_2} = - 1.37 log p_{SO_2} = - 1.01

40



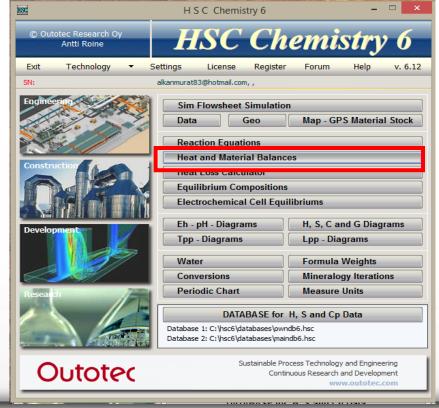


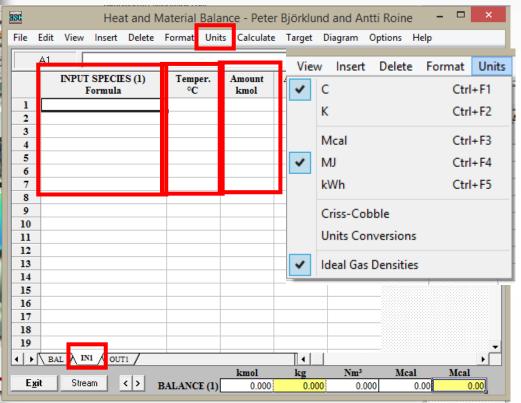
41

Source: HSC Chemistry

 Our raw materials and air have entered the calcination furnace at 25 °C temperature. So Firstly, we use energy to heat up the raw materials at the reaction temperature (650 °C). For calculating energy requirement, we can use "Heat and Material Balance"

module of HSC.





• In this module:

1- Firstly we choose our units by clicking Unit tab.

2- In 'In1' window, we can write the formula, amount and temperature of raw materials.

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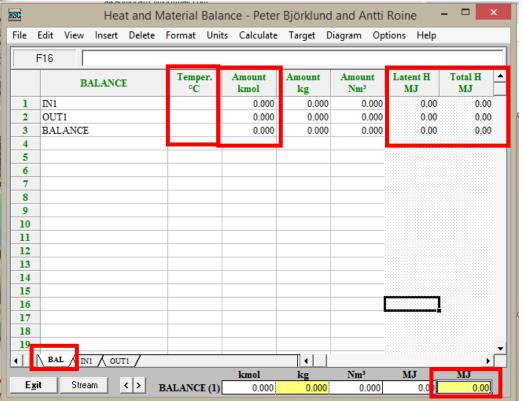
HSC	Heat and M		ince - Peter	r Björklund	and Antti	Roine	- 🗆 🗙
File	Edit View Insert Delete						
	A1						
┢	OUTPUT SPECIES (1) Formula	Temper. °C	Amount kmol	Amount kg	Amount Nm ³	Latent H MJ	Total H 🔺 MJ
1							
2							
3							
4							
5							
7							
8							
9							
10							
11							
12							
13							
15							
16							
17							
18							
19							
	BAL ANI OUTI		kmol	1	Nm ³	MJ	MJ
E,	xit Stream <> B	ALANCE (1)		kg 0.000	0.000	MJ 0.00	0.00

• In this module:

1- Firstly we choose our units by clicking Unit tab.

2- In 'In1' window, we can write the formula, amount and temperature of raw materials.

3- In 'Out1' window, we can write the formula, amount and temperature of products.



• In this module:

1- Firstly we choose our units by clicking Unit tab.

2- In 'In1' window, we can write the formula, amount and temperature of raw materials.

3- In 'Out1' window, we can write the formula, amount and temperature of products.

4- In 'Bal' window, we can see amount, temperature and energy values of Input, Output and Balance states.

HSC	Heat and M	aterial Bala	nce - Peter	Björklund	and Antti	Roine	- 🗆 🗙
<u>F</u> ile	<u>E</u> dit <u>V</u> iew <u>I</u> nsert <u>D</u> elete	<u>F</u> ormat <u>U</u> nit	s <u>C</u> alculate	<u>T</u> arget D <u>i</u>	iagram <u>O</u> pt	tions <u>H</u> elp	
	A12						
	INPUT SPECIES (1) Formula	Temper. °C	Amount kmol	Amount kg	Amount Nm ³	Latent H MJ	Total H 🔺 MJ
1	MoS2	25.000	5.316	850.879	0.168	0.00	-1467.98
2	Cu2S	25.000	0.094	14.960	0.003	0.00	-7.47
3	FeS	25.000	0.035	3.077	0.001	0.00	-3.56
4	PbS	25.000	0.019	4.546	0.001	0.00	-1.87
5	SiO2	25.000	0.200	12.017	0.005	0.00	-182.17
6	H2O	25.000	6.300	113.496	0.124	0.00	-1800.73
7	С	25.000	0.166	1.994	0.001 0.0		0.00
8	O2(g)	25.000	23.295	745.412	522.125	0.00	0.00
9	N2(g)	25.000	87.634	2454.926	1964.193	0.00	0.00
10							
11							
12		l					
13							
14							
15							
16							
17							
18							
19							<u> </u>
	BAL NI OUTI / Ini-%	0ut1-% /		•			•
E	xit Stream < > 12		kmol	kg	Nm ³	MJ	MJ
	<u>kit</u> Stream <> B	ALANCE (1)	0.000	0.000	141.082	2536.10	2813.32

Our Input temperature is 25 °C

!!! Attention !!!
Do not forget to write (g) for all gaseous phases

Let apply for our example. Total input: 5.316 kmol MoS₂ 0.094 kmol Cu₂S 0.035 kmol FeS 0.019 kmol PbS 0.200 kmol SiO_2 6.300 kmol H₂O 0.166 kmol C 23.295 kmol O₂ 87.634 kmol N₂

46

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HSC													
<u>F</u> ile	<u>E</u> dit <u>V</u> iew <u>I</u> nsert <u>D</u> elete <u>F</u>	ormat <u>U</u> nits	<u>C</u> alculate	<u>T</u> arget D <u>i</u>	agram <u>O</u> pt	tions <u>H</u> elp							
	E14		_										
	OUTPUT SPECIES (1) Formula	Temper. °C	Amount kmol	Amount kg	Amount Nm ³	Latent H MJ	Total H ▲ MJ						
1	MoS2	650.000	5.316	850.879	0.168	245.19	-1222.79						
2	Cu2S	650.000	0.094	14.960	0.003	5.7 6	-1.72						
3	FeS	650.000	0.035	3.077	0.001	1.50	-2.06						
4	PbS	650.000	0.019	4.546	0.001	0.62	-1.24						
5	SiO2	650.000	0.200	12.017	0.005	8.03	-174.15						
6	H2O(g)	650.000	6.300	113.496	141.206	144.27	-1379.23						
7	C	650.000	0.166	1.994	0.001	1.69	1.69						
8	O2(g)	650.000	23.295	745.412	522.125	466.85	466.85						
9	N2(g)	650.000	87.634	2454.926	1964.193	1662.21	1662.21						
10													
11													
12													
13													
14													
15													
16													
17													
18													
19							-						
4 >	BAL N1 OUT1 In1-%	Out1-% /		•									
		_	kmol	kg	Nm ³	MJ	MJ						
<u> </u>	git Stream <> BA	LANCE (1)	0.000	0.000	0.000	2536.10	2536.10						

Our Input temperature is 650 °C

!!! Attention !!!
Do not forget to write (g) for all gaseous phases

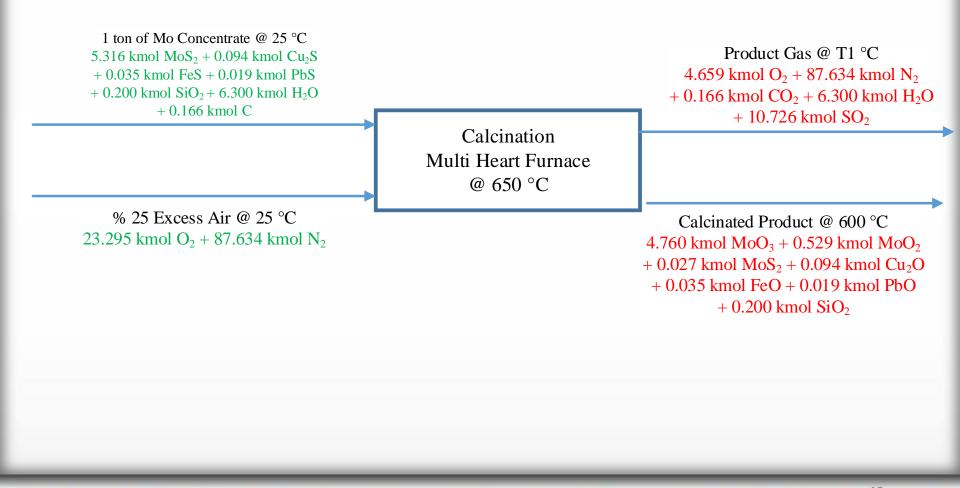
Let apply for our example. Total input: 5.316 kmol MoS₂ 0.094 kmol Cu₂S 0.035 kmol FeS 0.019 kmol PbS 0.200 kmol SiO_2 6.300 kmol H₂O 0.166 kmol C 23.295 kmol O₂ 87.634 kmol N₂

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HSC			Hea		/aterial	Balar	nce - Peter	r Biörklund	d and Antti	Roine	- 🗆 🗙
<u>F</u> ile	Edit	View						-	D <u>i</u> agram <u>O</u> p		
	_		-	_	-	_	_	- /			1
	C10										
		B	ALANC	E	Temp °C	er.	Amount kmol	Amount kg	Amount Nm ³	Latent H MJ	Total H MJ
1	IN1						123.059	4201.307	2486.620	0.0	-3463.78
2	OU.	Γ1					123.059	4201.307	2627.701	2536.1	-650.45
3	BAI	ANCE					0.000	0.000	141.082	2536.1 <mark>0</mark>	2813.32
4											
5											
6	_										
7	_										
8	_										
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15	-										
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19											_
	BA	L	1 / o u	[1] / Ini-	% 🔨 Out1-	%/		•			ان ا
		7 (, , , ,			kmol	kg	Nm ³	MJ	MJ
E	<u>x</u> it	Strea	m	< >	BALANC	E (1)	0.000	0.000		2536.10	2813.32
-		· · · · · · · · · · · · · · · · · · ·				(-)L	,			8.	

In Balance, we can see that we need 2813.32 MJ energy for 1 ton of concentrate to heat up from 25°C to 650°C • Let apply for our example. Total input: 5.316 kmol MoS₂ 0.094 kmol Cu₂S 0.035 kmol FeS 0.019 kmol PbS 0.200 kmol SiO_2 6.300 kmol H₂O 0.166 kmol C 23.295 kmol O₂ 87.634 kmol N₂

Energy balance for the reaction





Energy balance for the reaction

07				aikanin	iurai A Su	onnai ro	um					
	HSC			Heat	and N	Aaterial	Balan	nce - Peter	Björklund	and Antti	Roine	- 🗆 🗙
	<u>F</u> ile	<u>E</u> dit	<u>V</u> iew	<u>I</u> nsert	<u>D</u> elete	<u>F</u> ormat	<u>U</u> nits	<u>C</u> alculate	<u>T</u> arget D	<u>i</u> agram <u>O</u> pt	tions <u>H</u> elp	
		C15										
1 ton of Mo Concentrate @ 25 °C $5.316 \text{ kmol MoS}_2 + 0.094 \text{ kmol Cu}_2\text{S}$]		SPECIE: ormula	š (1)	Temp °C		Amount kmol	Amount kg	Amount Nm ³	Latent H MJ	Total H 🔺 MJ
+ 0.035 kmol FeS + 0.019 kmol PbS	1	MoS	2			650	0.000	5.316	850.879	0.168	245.19	-1222.79
+ 0.200 kmol SiO ₂ + 6.300 kmol H ₂ O	2	Cu28	5			650	0.000	0.094	14.960	0.003	5.76	-1.72
+ 0.166 kmol C	3	FeS				650	0.000	0.035	3.077	0.001	1.50	-2.06
+ 0.100 KIII0I C	4	PbS				650	0.000	0.019	4.546	0.001	0.62	-1.24
	5	SiO2					0.000	0.200	12.017	0.005	8.03	-174.15
	6	H2O	(g)				0.000	6.300	113.496	141.206	144.27	-1379.23
	7	С					0.000	0.166	1.994	0.001	1.69	1.69
	8	02(g					0.000	23.295	745.412	522.125	466.85	466.85
	9	N2(g)			650	0.000	87.634	2454.926	1964.193	1662.21	1662.21
% 25 Excess Air @ 25 °C	10	_										
	11	-										
23.295 kmol O_2 + 87.634 kmol N_2	12											
	13											
	14	-										
	16	-										
	10	-										
	18											
	19											
		N PAT			1				•			▼
		I \ BAL	· ∧ •	- / 001				kmol	kg	Nm ³	MJ	MJ
	E	git	Strea	m 🖌 🗸		BALANC	Em	-7.910	-0.032	-173.583	-208.88	-5869.22
						Difficience.	- (1)	-7.210	-0.032	-175.565	-200.00	

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• Energy balance for the reaction

	aikanmuratxsii						-
HSC	Heat and M	Aaterial Bala	nce - Peter	Björklund	and Antti	Roine	- • ×
<u>F</u> ile	<u>E</u> dit <u>V</u> iew <u>I</u> nsert <u>D</u> elete	<u>F</u> ormat <u>U</u> nit	s <u>C</u> alculate	<u>T</u> arget D	<u>i</u> agram <u>O</u> pt	tions <u>H</u> elp	
	D15						
<u> </u>	OUTPUT SPECIES (1) Formula	Temper. °C	Amount kmol	Amount kg	Amount Nm ³	Latent H MJ	Total H 🔺 MJ
1	MoO3	600.000	4.760	685.146	0.146	248.88	-3295.41
2	MoO2	600.000	0.529	67.680	0.010	21.58	-289.42
3	MoS2	600.000	0.027	4.322	0.001	1.14	-6.32
4	Cu2O	600.000	0.094	13.451	0.002	3.91	-12.12
5	FeO	600.000	0.035	2.515	0.000	1.10	-8.26
6	РЬО	600.000	0.019	4.241	0.000	0.56	-3.58
7	SiO2	600.000	0.200	12.017	0.005	7.35	-174.83
8	O2(g)	600.000	4.659	149.082	104.425	85.37	85.37
9	N2(g)	600.000	87.634	2454.926	1964.193	1521.65	1521.65
10	CO2(g)	600.000	0.166	7.306	3.721	4.42	-60.90
11	H2O(g)	600.000	6.300	113.496	141.206	131.65	-1391.85
12	SO2(g)	600.000	10.726	687.095	240.408	299.61	-2884.00
13							
14							
15	.			l			
10							
17							
18							
19							
•	BAL (INI) OUTI			•			
			kmol	kg	Nm ³	MJ	MJ
E	xit Stream < >	BALANCE (1)	-7.910	-0.032	-173.583	-208.88	-5869.22

 $\begin{array}{c} \mbox{Product Gas @ T1 °C} \\ 4.659 \ \mbox{kmol O}_2 + 87.634 \ \mbox{kmol N}_2 \\ + \ 0.166 \ \mbox{kmol CO}_2 + 6.300 \ \mbox{kmol H}_2 O \\ + \ 10.726 \ \mbox{kmol SO}_2 \end{array}$

 $\begin{array}{c} \mbox{Calcinated Product @ 600 °C} \\ 4.760 \mbox{ kmol MoO}_3 + 0.529 \mbox{ kmol MoO}_2 \\ + 0.027 \mbox{ kmol MoS}_2 + 0.094 \mbox{ kmol Cu}_2 O \\ + 0.035 \mbox{ kmol FeO} + 0.019 \mbox{ kmol PbO} \\ + 0.200 \mbox{ kmol SiO}_2 \end{array}$



 In balance we have 0.032 kg lost in products. To find the problem Click Calculate Tab and choose Element Balance

HSC	Heat and Ma		nce - Peter	· Björklund	and Antti	Roine	- 🗆 🗙	ert	De	elete <u>F</u>	ormat	<u>U</u> nits	<u>C</u> alculate		
<u>F</u> ile	<u>E</u> dit <u>V</u> iew <u>Insert</u> <u>D</u> elete <u>I</u>	<u>F</u> ormat <u>U</u> nit	; <u>C</u> alculate	[arget Dj	<u>i</u> agram <u>O</u> pt	tions <u>H</u> elp		5		ReCalc			F2		
	D3 =D2-D1									Elemen	nt Bal 😠	SC		Element Balance	_ 🗆 🗙
	BALANCE	Temper. °C	Amount kmol	Amount kg	Amount Nm ³	Latent H MJ	Total H MJ			Tempe					
1	IN1		123.059	4201.307	2627.701	2536.10	-650.45			Stream		c	kmol 0.166	kmol 0.166	kmol 0.000
2	OUT1		115.149	4201.275	2454.118	2327.21	-6519.67	-		Stream		Cu	0.188	0.188	0.000
3	BALANCE		-7.910	-0.032	-173.583	-208.88	-5869.22			Total B		Fe	0.035	0.035	0.000
4												н	12.600	12.600	0.000
5										Mol. W	/eign	Мо	5.316	5.316	0.000
6										Enthalp	ov fo	N	175.268	175.268	0.000
7								1				0	53.290	53.288	-0.002
9												Pb	0.019	0.019	0.000
10												S	10.780	10.780	0.000
11												Si	0.200	0.200	0.000
12															
13													kg	kg	kg
14												с	1.994	1.994	0.000
15												Cu	11.947	11.947	0.000
16												Fe	1.955	1.955	0.000
17												Н	12.700	12.700	0.000
18												Mo	510.017	510.017	0.000
19												N	2454.926	2454.926	0.000
• •	BAL NI OUTI			•			•					0 Pb	852.608	852.576 3.937	-0.032
			kmol	kg	Nm ³	MJ	MJ					PD S	345.607	345.607	0.000
E;	kit Stream < > BA	ALANCE (1)	-7.910	-0.032	-173.583	-208.88	-5869.22					S Si	5.617	5.617	0.000
		~ ~ ~							c				5.617	5.617	0.000

• There is 0.002 kmol O absence in final products. It can be negligible.

Source: ...

- In balance, 5869.22 MJ energy are generated during the reaction.
- This is an exothermic reaction

ISC		Hea	it and N	laterial Bala	nce - Peter	r Björklund	and Antti	Roine		<
<u>F</u> ile	<u>E</u> dit <u>V</u> iew	Insert	<u>D</u> elete	<u>Format</u> <u>Unit</u>	s <u>C</u> alculate	<u>T</u> arget D	<u>i</u> agram <u>O</u> pt	tions <u>H</u> elp		
	G3 =	G2-G1								
	B	ALANCI	E	Temper. °C	Amount kmol	Amount kg	Amount Nm ³	Latent H MJ	Total H MJ	1
1	IN1				123.059	4201.307	2627.701	2536.10	-650.45	
2	OUT1				115.149	4201.275	2454.118	2327.21	-6519.67	
3	BALANCE				-7.910	-0.032	-173.583	-208.88	-5869.22	
4										-
- 5										
6										
7										
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9										
10	_									
11 12										
12	-									
13										
15										
16										
17										
18										
19										-
• •	BAL	i ∕ om	[1] ∕ In1-9	% / Out1-% /					Þ	ŕ
					kmol	kg	Nm ³	MJ	MJ	
E;	xit Strea	m	< >]	BALANCE (1)	-7.910	-0.032	-173.583	-208.88	-5869.22	

Source: ...

- During the heating, we require 2813.32 MJ per ton Concentrate.
- And during the reaction we produce 5869.22 MJ per ton Concentrate.
- We can use these excess energy for heating the raw materials. And we have 3055.9 MJ per ton excess heat.

- These 3055.9 MJ/t concentrate heat (energy) may be transferred by the off-gas. So, these excess heat will raise the off-gas outlet temperature from 600 °C to T °C.
- To find the maximum temperature of the off-gas in an adiabatic conditions; we will use

$$Q = \Delta H_{rxn}^{\circ} = H_{T_2} - H_{T_1} = \int_{T_1}^{T_2} C_p \times dT$$

• For finding Cp values we can use "Database" module of HSC.

$$C_{p,m} = a + b T + c T^2 + d T^3$$



HSC	H S C Chemistry 6	- 🗆 🗙									
© Outotec Research Oy Antti Roine	HSC Ch	emistry 6									
Exit Technology 🔻 S	Settings License Register	Forum Help v. 6.12									
SN:	alkanmurat83@hotmail.com, ,										
Engineering	Sim Flowsheet Simulatio Data Geo Reaction Equations Heat and Material Balance Heat Loss Calculator	Map - GPS Material Stock									
	Equilibrium Compositions Electrochemical Cell Equilibriums										
Development	Eh - pH - Diagrams Tpp - Diagrams	H, S, C and G Diagrams									
	Water	Formula Weights									
	Conversions	Mineralogy Iterations									
Research	Periodic Chart	Measure Units									
		H, S and Cp Data									
	Database 1: C: \hsc6\databases\own Database 2: C: \hsc6\databases\mai										
Outotec		ocess Technology and Engineering nuous Research and Development									

HS	HSC - DATABASE – 🗆 🗙
	HSC Database Main Menu
	© Outotec Research Oy, Pori, Finland, Antti Roine
	Find Species with given Elements
	Find Species with the same Stoichiometry
	Find Species with Key Word
[List Names
	List Formulae
	Database Editor with Diagrams
	Database Editor (Spreadsheet)
	Fit Cp Data for Database
	Convert Data to HSC Format
Ì	Convert old Databases to new Format
[Select Active Databases
	Exit References Help

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HSC								Data	abase	9					-		×
ТА	٦	Ple	ase se	elect I	Eleme	nts:		٨	All mus	st exis	it 🗆						8A
н	2A	ΟΝ	ICI	ΗS								3A	44	54	64	7A	He
Li	Be	ĺ										В	С	N	0	F	Ne
Na	Mg	3B	4 B	5B	6B	7B	8B	8B	8B	1B	2B	AI	Si	Р	S	CI	Ar
к	Ca	Sc	Ti	۷	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	Т	Xe
Cs	Ba	La	Hf	Ta	w	Re	Os	Ir	Pt	Au	Hg	TI	Pb	Bi	Ро	At	Rn
Fr	Ra	Ac															
			Ce	Pr	Nd	Pm	Sm	Eu	Gd	ть	Dy	Ho	Er	Tm	Yb	Lu	
			Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	101			
Sea	rch M	ode:					Tr	itium l	H		~	Press	sure =	1 bar			
	iases ias lo			Cond Liqui	ensea ds		-	lueou: 1ueou:				Orga	nic (>	2 C).	Carbo	n Limi	ts:
	Gas lons Liquids Aqueous neutral Exit Help Maximum number 4000 OK																

Then we click OK for the next step

Source: ...

- Firstly, we select the elements that considered.
- We are looking for gaseous and solid phases so, we select Gases and Condensed mode at 1 bar atmospheric pressure
- If we have Gas ions or liquids or aqueous ions, we also select these mode too.
- If we studied under pressure different than 1 bar we won't select 1 bar pressure.

 The program listed all the compounds available. If we click one of them we'll find its thermodynamical values.

Main	Database Path: C	™ MainDB File ▼	Key Formula:	CO2(g)	ep to C:\HS	C6\Databas	ses\MainDB	6.HSC			_ [
Own Database:	Main		MainDB	1.	2.	3.	4.	5.	6.	7.	8.	
	2472 0	CNI(g)	Formula	CO2(g)	CO2(g)	CO2(g)	CO2(g)	CO2(g)				
	2477 C		Structural Formula									
	2481 C 2486 C		Chemical Name	Carbon dioxide	Carbon dioxide	Carbon dioxide	Carbon dioxide	Carbon dioxide				
	2565 C	CNN(g)	Common Name									
	4671 C 4677 C		CAN	124-38-9	124-38-9	124-38-9	124-38-9	124-38-9				
	4677 0		Mol. Weight	44.01	44.01	44.01	44.01	44.01				
	4686 C		Molting p K	216.58	216.58	216.58	216.58	216.58	•			
	4951 C		Boiling p. K	194.75	194.75	194.75	194.75	194.75				
	4961 C	C2NO(g)	T1 K	50.00	298.15	900.00	2700.00	7600.00				
	4963 C	C2NO(g)	T2 K	298.15	900.00	2700.00	7600.00	10000.00				
	4972 C 4977 C	C2NO(g) C2NO(g)	State	g	g	g	g	g				
	18679 (C3N20(0PDNg)	H kJ/mol	-393.505	0.000	0.000	0.000	0.000				
	18686 (C3N2O(OPDNg)	S J/(mol*K)	213.769	0.000	0.000	0.000	0.000				
	18690 (C3N2O(OPDNg) C3N2O(OPDNg)	A J/(mol*K)	22.226	29.314	54.435	76.000	-85.588				
	18693 (C3N20(0PDNg)	В	56.200	39.970	5.116	-5.214	24.518				
	18698 (CNO(-a)	С	0.105	-2.484	-43.578	-350.714	14014.292				
	18705 (CNS(-a) CNS(-a)	D	-22.518	-14.783	-0.806	0.640	-0.905				
	18724 (Density g/l	1.931	0.000	0.000	0.000	0.000				
	18731	CO(g)	Color RGB	Colorless 16	0.000	0.000	0.000	0.000				
	18736 (CO(g)	Solubility	0.000	0.000	0.000	0.000	0.000				
	18750	CO(g) CO(a)	Reference	Barin 93, Frenk	Glushko 04 T -	Clushing 04 Ta	Clushing 04 Ta	Clushies 04. Tax	4-1+ 00			
	19015	CO(a)	Class	1	1							
		CO2(g)	OwnDB	1.	2			T .	m ² .	1 3	8.	
Contraction of the Contract of	-	CO2(g) CO2(g)	Formula		C	n m =	$\mathbf{a} + \mathbf{b}$	T + c	1~+	d		
		CO2(g)	Structural Formula		-	p,m			-			
		CO2(g)	Chemical Name									
		C02(a) C02(a)	Common Name									•
		Exit Print S P	C Cal O J	Remove	Insert	Find	1					

Source: ...

• Or we can easily use HSC Heat and Material Module

HSC			eat and M	aterial Bala	nce - Pete	r Björklund	and Antti	Roine	- 🗆 🗙	HSC		Heat and M						- 🗆 🗙	
<u>File Edit View Insert D</u> elete <u>F</u> ormat <u>U</u> nits <u>C</u> alculate <u>T</u> arget Dia								agram <u>O</u> ptions <u>H</u> elp				<u>V</u> iew <u>I</u> nsert <u>D</u> elete	<u>F</u> ormat <u>U</u> nit	<u>C</u> alculate	arget D	<u>i</u> agram <u>O</u> pt	tions <u>H</u> elp		
	F13			-							B6		•						1
	IN	PUT SPEC Formu		Temper. °C	Amount kmol	Amount kg	Amount Nm ³	Latent H MJ	Total H 🔺 MJ		0	UTPUT SPECIES (1) Formula	Temper. °C	Amount kmol	Amount kg	Amount Nm ³	Latent H MJ	Total H MJ	•
1 2	O2(g)			600.000 600.000	4.659 87.634	149.082 2454.926	104.425 1964.193	85.37 1521.65	85.37 1521.65		O2(g) N2(g)		600.000 600.000	4.659 87.634	149.082 2454.926	104.425 1964.193	85.37 1521.65	85.37 1521.65	
3	N2(g) CO2(g)			600.000	0.166	7.306	3.721	4.42	-60,90		CO2(s		600.000	0.166	7.306	3.721	4.42	-60.90	
4	H2O(g			600.000	6.300	113.496	141.206	131.65	-1391.85		H2O(w/	600.000	6.300	113.496	141.206	131.65	-1391.85	
5	SO2(g)			600.000	10.726	687.095	240.408	299.6	-2884.00	5	SO2(s		600.000	10.726	687.095	240.408	299.61	-2884.00	
6									3055.90	6									
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E	rit	Stream	ReCa	alc		F2	Nm ³	MJ	MJ	1	.	- 1 1 1		kmol	kg	Nm ³	MJ 0.00	MJ	
Lak		oucan	Flem	ent Balan	e	F3	0.000	0.00	-3055.90		HSC	Tempera	ture Bala	ance	×	0.000		-3055.90	
												Temperature of							
			Tem	perature Balance		F4	Ļ												
			Stream Co		ositions	F5	-					(when Heat Balance = 0)							
			Total Balance				-												
			Mol. Weight			ł													
			Enthalpy for Species						<u><u> </u></u>										
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