Mass balancing for coal processing plant design

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Abstract. With the advent of modern mass balancing programmes, the roots of what makes up these programmes are being lost to all but the developers. This paper draws on the author's experience of designing coal processing plants whilst straddling the transition period of main frame computers using programmes such as Fortran4 and BASIC to PCs using spreadsheets. Their introduction transformed the ways in which mass balancing could be carried out and presented in easy-to-understand tables and graphs, as well as significantly reducing the time and effort involved. Many simple formulas in SI units were developed using Excel to solve the mass and volume flowrates of coal slurries in the numerous pumping and processing circuits of a dense medium plant and downstream processes. They all use the linking concepts of density and % solids and are far simpler than the equivalent formulas in Imperial units or those needed for chemical plants where liquids other than water are used. Their application in mass and water balances of coal processing plants is described using an example of a DMS coal processing cyclone plant.

Key Words: *Mass, Water, Balancing, Equations, DMS, Coal Processing*

1 Introduction

Mass balancing of solids and liquids' circuits is fundamental to the design a of wet minerals processing plant. The calculations are inherently easier than their chemical engineering equivalent as the liquid phase involved is almost always water with a density of 1.0 t/m3 and the processes generally take place at ambient temperature and atmospheric pressure. However, this is not to minimize their complexity, as the nature of the circuits usually consist of solids passing through them which change in their density as they separate into individual minerals, whilst the liquid water phase is often mixed with a second fine solids phase to form a stable "dense medium" in which the separation takes place. As a result, the overall circuit ends up having several recirculating streams, and it is necessary to iterate the initial balance to compute the final mass balance conditions representing a stable process.

Computing the solution to a circuit of this complexity, typically represented by a Dense Medium (DM) cyclone and bath in a single or double separation configuration, generally defied hand calculation methods using personal calculators, let alone slide rules or adding machines prevalent before the 1960s. The method taught to the author on joining Head

Wrightson Process Engineering Ltd. as a Graduate Engineer in 1977, was to compute the minerals solids balance which was relatively simple, followed by a water balance and a dense medium balance. The solids were then added in, displacing some water or dense medium to an overflow launder where all three phases were mixed, such as in the mixing box (wing tank) preceding the DM cyclone.

This reads like a clumsy solution, but if carefully done it worked, and allowed the sizing of the associated pumps, pipes, tanks and distribution boxes common in DM circuits to be calculated with confidence. However, a full understanding of the circuit was lacking and whenever changes took place to the throughput, product yields and size distributions which were common in the initial conceptual studies of any coal or minerals processing plant, it was tedious to have to recalculate the circuit and associated equipment sizes once again.

Attempts to solve the mass balances involved during the 1970s using “mini-computers” equipped with programing languages such as Fortran4 and BASIC were not very successful due to the above factors, and even if a solution could be computed, displaying the results of a processing circuit of a large plant with up to say a hundred different flow-streams in a readable manner, was formidable task in its own right. Easier computational methods and a full understanding of the circuit dynamics remained an elusive goal.

Then with very little fanfare during the mid-1980s, came the solution in the form of Spreadsheets that could be programmed using reliable Personal Computers (PC) such as the IBM PC. The pioneering spreadsheet programmes such as Lotus 1-2-3, were eventually replaced by Microsoft Excel which has since become ubiquitous. It not only allowed the computation of mass balances using iterative functions, but many other common tasks in process engineering such as the depiction of schematic flowsheets; sizing of equipment such as tanks, pipes and launders; their tabulation in mechanical equipment lists; graphical depiction of testwork etc. Mass balancing methodology was transformed and process engineers set about standardizing their methods and the tabulation of the results so that they easily could be inserted into flowsheets and reports.

In the intervening years, it became noticeable to the author that despite the common expertise and use of Excel in mass balancing amoungst minerals processing and chemical engineers, the formulas used have not been widely circulated or publicised. They are taught in-house, and each process engineer often develops his own set. In more sophisticated programmes which incorporate flowsheets and simulations such as Limn [1], the underlying mass balancing equations are hidden, like proprietary equipment sizing programmes for common equipment such as cyclones, pumps, screens, mills and conveyors. In the author’s opinion, it is simply good practice as an engineer to have a thorough understanding of the underlying mathematics in a mass balance, and if they are easily illustrated as in spreadsheets, this also allows detailed investigations into the optimizing of the size of the plant as well as the individual equipment. A mass balance built up by hand often gives a far better understanding of the circulating streams, their critical flowrates and pulp densities, which can be very useful when commissioning and subsequently operating the physical plant.

This paper sets out the derivation of basic mass balancing equations from first principles using solids and liquids mass flowrate and density, followed by the most important but easily misunderstood linking formula of % solids (since it can be stated in mass or volume terms), and shows many other formulas relating slurries and solids that can easily be derived. These in turn are used for the creation of individual flow-streams which are linked together to form the mass balance of an entire process plant or circuit. The final computational step of iterating to a final and stable solution is then a mere functional key stroke away.

2 Development of mass balancing formulas

The 1970s in the English-speaking engineering world was a transition time in units when the SI system started to predominate, having been introduced to UK in 1965. The prevailing Imperial units of mass and volume in minerals processing such as the commonly used pounds (lb), short tonnes (2 000 lb), gallons (for liquid measures), cubic feet (for solids) and combined units for volume such as gallons per minute (gpm) and short tonnes per hour for mass flow, were replaced by kilograms (kg), tonnes (1 000 kg), cubic meters (m^3) and combined for volume flow as m^3/h and mass flow such as t/h.

Interchanging mass and volume when the liquid phase is water with a density of 1.000 t/m3 (at 4°C) is inherently simpler than in Imperial units where the density of water is 62.4 lb/ft3 and a gallon of water weighs 9.60 lb (UK, Canada) or 8.00 lb (US). In SI units 1t of water = 1 000 kg and has a volume of 1 m3 whilst a short ton of water has a volume of 239.65 US gallons or 32.04 ft3. Therefore, consequently, formulas linking slurry volumes, density and mass in Imperial units easily become quite complicated, whilst in SI units they remain relatively simple and importantly, free of conversion factors which can lead to computational mistakes.

3 Methodology

Freshly mined solid rock ore normally has zero percent surface moisture unless the seam is saturated. Coals seams can contain moisture according to their Rank and during the mining process, water is often added as a dedusting agent, thus run-of-mine coal will have a degree of surface moisture when presented to the process plant. (Note that the inherent or chemically bound moisture in the coal does not enter the mass balancing equations when just considering the coal preparation plant design).

A typical wet particle is shown in Figure 1, where the entire surface area is covered in a thin film of moisture.

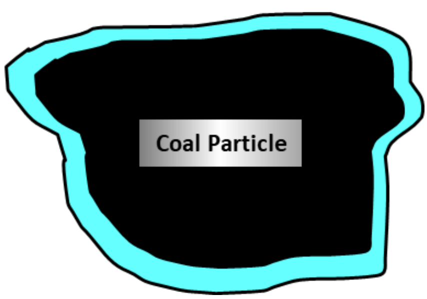

Fig. 1. Coal with surface moisture of ~10%

The opposite situation is when fine coal particles are suspended in water through agitation, illustrated in Figure 2:

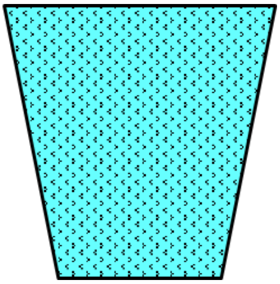

Fig. 2. Coal particles in ~20% solids slurry

The formula for % Solids is the key link between a pure solids or liquid phase and a mixture of the two, generally referred to as a pulp or slurry. It is the most basic derived property of a wet particle or slurry which is fundamental for any mass balancing exercise.

The variables used and their units are given in Table's 1 and 2:

Table 1. Definition of major mass balance variables

Symbol	Description	SI Unit
t	Mass of solids (air dry)	t (tonnes)
V_w	Volume of water	m^3
S_w	% Solids by mass	%
D_s	Density of Solids	t/m^3
D_p	Density of pulp	t/m^3
V_p	Volume of pulp	m^3

Table 2. Definition of minor mass balance variables

Symbol	Description	SI Unit
S_v	% Solids by volume	%
m	% water (moisture) by mass	%
t_w	Mass of water	t
V_s	Volume of solids	m^3

By definition, the % Solids by mass (Sw) can be calculated as:

(mass of particle) / (mass of particle + mass of surface water) x 100

Using the above symbols from Table's 1 and 2, this can be stated as:

$$S_w = 100 \, . \, t / (t + t_w) \tag{1}$$

Substituting Vw for tw since volume of clear water = mass of clear water and manipulating the formula:

$$Sw.t + Sw.Vw = 100.t$$

Re-arranging

$$Sw.Vw = 100.t - t.Sw$$

$$Sw.Vw = t.(100 - Sw)$$

Finally:

$$Vw = t\ .\ (100 - Sw) / Sw \tag{2}$$

This is by far the most important formula in mineral processing mass balances and can be easily manipulated by using the relationship:

$$\%\ Moisture\ (m) = 100 - \%\ Solids\ (Sw) \tag{3}$$

into a second formula:

$$Vw = t\ .\ m / (100 - m) \tag{4}$$

From these two basic formula and the definition of solids density:

$$Ds = t / Vs \tag{5}$$

many others can be derived by simple algebraic manipulation.

The "sister" definition to % Solids by mass is % Solids by volume. This is occasionally used in mass balances:

(volume of particle) / (volume of particle + volume of surface moisture) x 100

$$Sv = 100.\ Vs / (Vs + Vw) \tag{6}$$

Substituting for Vs = t / Ds and manipulating, gives the formula for Sv as stated in Table1:

$$Sv = 100\ .\ t / (t + Vw\ .\ Ds) \tag{7}$$

All the variables in Table 1 can be calculated by formulae using three of the other Table 1 definitions, and sometimes two for simple ones such as solids density from mass and volume. Some are simply the same formula but with the variables stated as mirror images, others require quite extensive algebraic calculations to derive, but all have a place at some point in a mass and water balance.

There are two important groups of formulae frequently used in mass and water balances. Table 3 gives the formulae which use the variables most often associated with building up a basic balance i.e. the solids flowrate t/h and density, and the % Solids of the first slurry encountered in the plant, which is normally the feed to a desliming screen (coal processing) or grinding mill (minerals processing).

Table 3. Mass balance formulas (plant design basics)

Required	Formula	SI Unit	Reference
V_w	$t.(100 - Sw)/Sw$	m^3	(2)
V_w	$Vp - t / Ds$	m^3	(8)
V_p	$Vw + t/Ds$	m^3	(9)
D_p	$(Vw + t)/ Vp$	t/m^3	(10)

Following these simple formulae, the next set of Formulae shown in Table 4, are more complicated and in turn take more algebraic manipulation to derive them.

Table 4: Mass balance formulas (internal slurry circuits)

Required	Formula	SI Unit	Reference
T	*Vp . (Dp – 1). (Ds / (Ds – 1))*	t	(11)
S_w	*100 . t / (t + Vw)*	%	(12)
S_w	*Ds . (Dp – 1) / (Dp . (Ds – 1) .100*	%	(13)
S_w	*100 . t / (t + Vp – t / Ds)*	%	(14)
S_v	*(Dp – 1) / (Ds – 1)*	%	(15)
V_w	*t. (Ds – 1) / (Ds . (Dp -1) -1*	m^3	(16)
D_p	*Ds / (Ds + Sw (1 – Ds) / 100)*	t/m^3	(17)
D_p	*t. (Ds -1) / (Ds . Vp) +1*	t/m^3	(18)
V_p	*t . (1 / Ds + 100 / Sw – 1)*	m^3	(19)
V_p	*100 . t / (t . Sv)*	m^3	(20)

Some formulae have very specialised uses, for example when calculating the amount of desliming water required by the desliming screen for pulping up the feed from raw coal. This is stated as being no more than 7% of the fines solids by volume in the DSM Handbook [2].

$$Vw = t \,.\, (100 - Sv) / (Ds \,.\, Sv) \qquad (21)$$

A common occurrence in coal processing plants is for the solids density to change as the raw coal gets upgraded by a separator such as a DM Cyclone, producing product and discard streams. In this situation it is usual to know what the density of the product will be (or is targeted to be) from washability testwork and separator performance simulation. For the mass balance, the density of the discard dry solids needs to be calculated.

From the basic consideration of a volume balance around a separator such as a DM Cyclone, the separator dry solids feed volume can be calculated as (Feed tf / Density Df) and must equal the dry solids volume of the product and discard streams:

$$tf / Df = (tp / Dp) + (td / Dd) \qquad (22)$$

Where tp and td are the masses of the product and discard with densities Dp, Dd. This formula can then be manipulated to give the dry solids density of the discard (Dd):

$$Dd = td \,.\, (Df \,.\, Dp) / (tf \,.\, Dp - tp \,.\, Df) \qquad (23)$$

There are many other formulae possible, but these are the most useful in constructing mass balances.

These formulae were developed for use in spreadsheet mass balances which were introduced into mineral processing plant design around 1985. It is also important to note that they only apply to the SI units as defined above and that the liquid medium is always water with a density of 1.0 t/m3. They do not apply for chemical plants where liquids such as acids, alcohols or salt solutions have densities other than 1.0 t/m3.

4 Mass and water balances in coal processing

Once Spreadsheets such as Lotus 1-2-3, Supercalc and finally Excel became common tools for engineers using Personal Computers, mass balancing soon developed and common structures emerged. The basic format of one row to a flow stream in the sequence of title, formulas for the slurry, liquids and solids and finally any set points soon took hold.

The body of the calculation tables only contains formulas of the type listed above; set point values are listed separately on the right-hand side. These can be altered at will to vary for instance, the incoming flowrate, product yield, feed and product solids densities and pump capacities. The set points also contain calculated values from the mass balance such as the medium-to-coal volume ratio, which is used for sizing and selecting the DM Cyclone from which the rest of the mass and water balance is derived.

The schematic flowsheet can also be very usefully drawn using Excel and an example is shown in Figure 3, while the complete mass balance is given in Figure's 4 - 8 for a typical coal processing flowsheet of a small throughput 100 t/h DM Cyclone plant. Note that the balance assumes a combined floats and sinks Rinse and Drain (R&D) Screen would be used, rather than individual R&D screens as shown in Figure 3 due to the throughput rate.

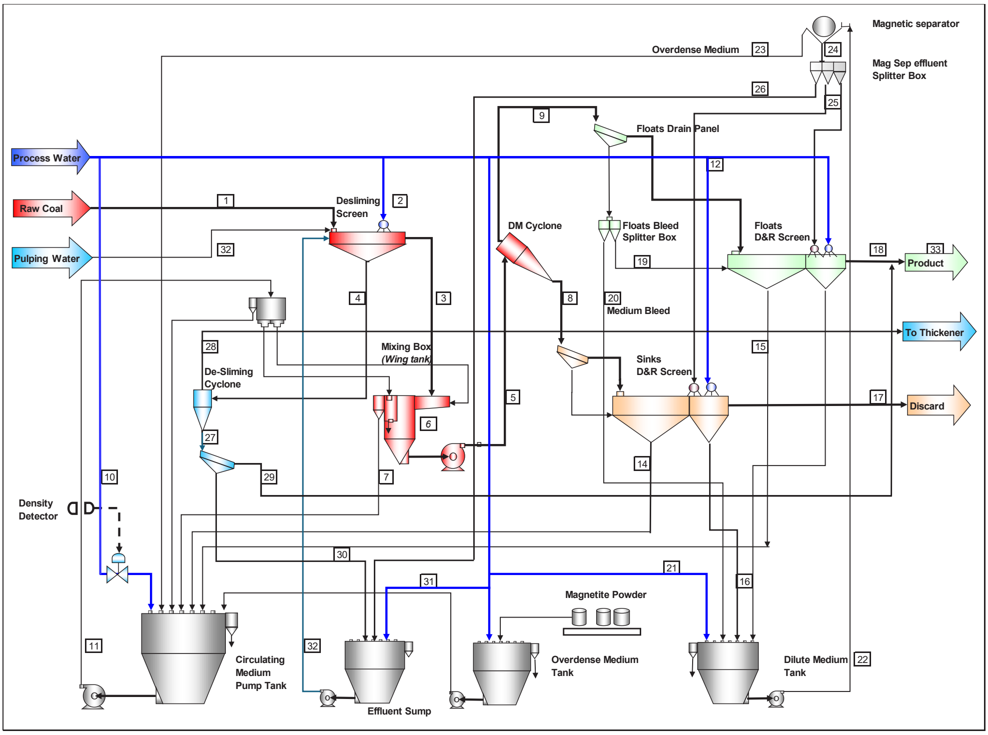

Fig. 3. Schematic flowsheet for a coal processing DM cyclone plant

The mass balance for the circulating medium section of the flowsheet is shown in Figure 4:

COAL PROCESSING DMS CYCLONE PLANT - MASS & WATER BALANCE

SECTION		STREAM	TOTAL SLURRY						ASSUMPTIONS		
			volume	density	% solids	Total	Water	Solids			
			Vp	Dp	Sw	t + Vw	Vw	t			
			m^3/hr	t/m^3	w/w	t/hr	t/hr	t/hr		Set Points	
DESLIMING SCREEN	1	raw coal feed	67.76	1.55	95.00	105.26	5.26	100.00	**Incoming Raw Coal Feed**	**100**	**dry t/hr**
	32	pulping water	210.00	1.00	0.33	210.36	209.67	0.69	Incoming Feed Moisture	5	%
	2	spray water	45.00	1.00	0.00	45.00	45.00		spray water to desliming screen	45	m^3/hr
	3	overflow to mixing box	65.00	1.47	85.00	95.41	14.31	81.10	**Dry Solids density**	**1.60**	**t/m^3**
	4	underflow to desliming cyc.	257.87	1.03	7.39	265.21	245.63	19.59	Screen oversize (+0.5mm)	81.10	t/hr
		check	*- 0.10*			*0.00*	*0.00*	*0.00*	Desliming Screen underflow volume % solids	4.75	%
									moisture of +0.5mm ore diluting the medium	15	% w/w
MIXING BOX	11	medium feed	360.00	1.50	42.34	540.00	311.35	228.65	average particle size	3.85	mm
	3	deslimed feed	65.00	1.47	85.00	95.41	14.31	81.10	Maximum Screen Width Required: desliming (3.6mL)	2.01	m width
	5	pump to cyclone	418.00	1.50	48.86	624.91	319.61	305.30			
	6	medium feed to cyclone	353.00	1.50	42.34	529.50	305.30	224.20	Feed capacity of Multotec max 710 cyclone at 9D	418	m^3/hr
	7	overflow to cm sump	7.00	1.50	42.34	10.50	6.05	4.45	Number of cyclones	1	m^3/hr
		check	*0.00*			*0.00*	*0.00*	*0.00*			
									product yield (50% min; 80% max)	70	%
HM CYCLONE	5	feed	418.00	1.50	48.86	624.91	319.61	305.30	% of medium solids by weight to underflow	40	Multotec
	8	sinks	103.36	1.81	61.05	186.76	72.75	114.01	% of feed medium by volume to underflow	25	Multotec
	9	floats	314.64	1.39	43.66	438.15	246.86	191.29	sinks discard SG (calculated)	2.11	t/m^3
		check	*0.00*			*0.00*	*0.00*	*0.00*	**floats ore SG**	**1.45**	t/m^3
CM SUMP (in)	14	d & r screen sinks medium	88.98	1.77	55.21	157.39	70.49	86.90	Volume sinks to DM cyclone spigot	11.54	m^3
	19	from floats splitter box	186.08	1.38	35.27	257.61	166.74	90.86	Medium to ore ratio (by volume)	5.43	target 4.5
	23	overdense from magsep	33.23	2.10	66.54	69.79	23.35	46.44	**medium density (D50 - density shift of 0.4)**	**1.50**	**t/m^3**
	7	mixing box overflow	7.00	1.50	42.34	10.50	6.05	4.45	**Magnetite dry solids density**	**4.70**	**t/m^3**
	10	water addition	44.71	1.00	0.00	44.71	44.71		Make-up water (manually iterate)	44.71	**t/m^3**
CM SUMP PUMP (out)	11	pump to mixing box	360.00	1.50	42.34	540.00	311.35	228.65	**Correct Medium pump capacity**	**360**	**t/m^3**
		check	*0.00*			*0.00*	*0.00*	*0.00*			
DRAIN AND RINSE SCREEN (floats + sinks)	8	sinks feed	103.36	1.81	61.05	186.76	72.75	114.01			
	9	floats feed	314.64	1.39	43.66	438.15	246.86	191.29			
	25	flood water (mag sep u/f)	61.69	1.00	0.00	61.69	61.69	0.00			
	12	spray water	121.50	1.00	0.00	121.50	121.50		rinsing water to screen	121.50	m^3/hr
	13	spillage pump discharge	15.00	1.00	0.00	15.00	15.00		spillage pump	15	m^3/hr
	14	sinks medium underflow	88.98	1.77	55.21	157.39	70.49	86.90	adhering medium to sinks	117.00	l/ton product
	15	floats medium underflow	265.82	1.38	35.27	368.01	238.21	129.80	adhering medium to floats	170.17	l/ton product
	16	combined dm underflow	196.39	1.03	3.71	202.29	194.79	7.50	product moisture	15	%
	17	sinks discard	15.83	1.81	85.00	28.62	4.29	24.33	Maximum Screen Width Required: sinks (4.8mL)	0.75	m width
	18	floats product	49.17	1.36	85.00	66.79	10.02	56.77	Maximum Screen Width Required: floats (4.8mL)	1.61	m width
		check	*0.00*			*0.00*	*0.00*	*0.00*			

Fig. 4. Initial rows of a coal processing DMS plant mass balance

The construction of the mass balance is started by calculating the volume of water in the incoming raw coal feed from Formula 2: Vw = t . (100 – Sw) / Sw using the set points of raw coal feed (100 t/h) with a surface moisture of 5% which is equivalent to 95% solids.

Knowing the volume of water, the total incoming mass can be calculated as water + coal solids, and finally the volume and density of the pulp or slurry from Formulas 9 and 10.

A important check that the overall incoming flows balance with the outgoing flows is generally given at the bottom of the spreadsheet as shown in Figure 5:

SECTION		STREAM	TOTAL SLURRY						ASSUMPTIONS		
			volume	density	% solids	Total	Water	Solids			
			Vp	Dp	Sw	t + Vw	Vw	t			
			m^3/hr	t/m^3	w/w	t/hr	t/hr	t/hr		Set Points	
IN STREAMS	1	feed to desliming screen	67.76	1.55	95.00	105.26	5.26	100.00			
	2	desliming spray water	45.00			45.00	45.00				
	12	rinsing screen spray water	121.50	1.00	0.00	121.50	121.50	0.00			
	13	spillage pump	15.00	1.00	0.00	15.00	15.00	0.00			
	10	cm sump water addition	44.71	1.00	0.00	44.71	44.71	0.00			
	21	dm sump water addition	3.87	1.00	0.00	3.87	3.87	0.00			
	31	effluent sump water	4.95			4.95	4.95	0.00			
		TOTAL	302.79			340.29	240.29	100.00			
	34	Total Process Water Requi	235.02				235.02		at 2.5 Bar		
OUT STREAMS	17	sinks discard	15.83	1.81	85.00	28.62	4.29	24.33			
	28	desliming cyclone o/f	226.80	1.00	2.59	226.94	221.06	5.88	mag losses	3.48	kg/hr
	33	combined product to stock	60.26	1.41	82.38	84.73	14.93	69.80	to mix (per 7 day week, 90% availability)	527	kg/week
		TOTAL	302.89			340.29	240.29	100.00			
		check	*- 0.10*			*0.00*	*0.00*	*0.00*			

Fig. 5. Overall process plant mass balance check

This overall check is supplemented by checks around each process piece of equipment. These are shown as the small "check" line beneath the complete equipment balance as shown in Figure 6:

SECTION		STREAM	TOTAL SLURRY						ASSUMPTIONS		
			volume	density	% solids	Total	Water	Solids			
			Vp	Dp	Sw	t + Vw	Vw	t			
			m^3/hr	t/m^3	w/w	t/hr	t/hr	t/hr		Set Points	
DRAIN AND RINSE SCREEN	8	sinks feed	103.36	1.81	61.05	186.76	72.75	114.01			
(floats + sinks)	9	floats feed	314.64	1.39	43.66	438.15	246.86	191.29			
	25	flood water (mag sep u/f)	61.69	1.00	0.00	61.69	61.69	0.00			
	12	spray water	121.50	1.00	0.00	121.50	121.50		rinsing water to screen	121.50	m^3/hr
	13	spillage pump discharge	15.00	1.00	0.00	15.00	15.00		spillage pump	15	m^3/hr
	14	sinks medium underflow	88.98	1.77	55.21	157.39	70.49	86.90	adhering medium to sinks	117.00	l/ton product
	15	floats medium underflow	265.82	1.38	35.27	368.01	238.21	129.80	adhering medium to floats	170.17	l/ton product
	16	combined dm underflow	196.39	1.03	3.71	202.29	194.79	7.50	product moisture	15	%
	17	sinks discard	15.83	1.81	85.00	28.62	4.29	24.33	Maximum Screen Width Required	0.75	m width
	18	floats product	49.17	1.36	85.00	66.79	10.02	56.77	Maximum Screen Width Required	1.61	m width
		check	*0.00*			*0.00*	*0.00*	*0.00*			
FLOATS MEDIUM	15	floats medium underflow	265.82	1.38	35.27	368.01	238.21	129.80			
SPLITTER BOX	19	split to cm sump	186.08	1.38	35.27	257.61	166.74	90.86	Volume % Split to correct medium sump	70	%
	20	split to dm sump	79.75	1.38	35.27	110.40	71.46	38.94			
		check	*0.00*			*0.00*	*0.00*	*0.00*			

Fig. 6. Individual equipment incoming and outgoing mass balance checks

Sometimes it is necessary to do a volume balance as well as a mass balance on the solids to eliminate computing errors, which often arise due to not recognising when solids densities have changed (reference Formulas 22 and 23).

The remainder of the mass balance, the Dilute Medium Circuit is given in Figure 7:

SECTION		STREAM	TOTAL SLURRY						ASSUMPTIONS		
			volume	density	% solids	Total	Water	Solids			
			Vp	Dp	Sw	t + Vw	Vw	t			
			m^3/hr	t/m^3	w/w	t/hr	t/hr	t/hr		Set Points	
DM SUMP	16	combined dm underflow	196.39	1.03	3.71	202.29	194.79	7.50			
	20	floats medium bleed	79.75	1.38	35.27	110.40	71.46	38.94			
	21	water addition	3.87	1.00		3.87	3.87				
	22	pump to magsep	280.00	1.13	14.67	316.56	270.12	46.44	**Densifier Cyclone Feed Pump**	**280**	**m^3/hr**
		check	*0.00*			*0.00*	*0.00*	*0.00*			
MAGSEP	22	dm pump feed	280.00	1.13	14.67	316.56	270.12	46.44	Feed Concentration (g magnetite/litre)	166	g/l
	23	mag concentrate	33.23	2.10	66.54	69.79	23.35	46.44	**magsep concentrate sg**	**2.1**	**t/m^3**
	24	mag effluent	246.77	1.00	0.00	246.77	246.77	0.00	% Recovery (from Magnapower graph)	99.99	%
		check	*0.00*			*0.00*	*0.00*	*0.00*	Effluent Concentration	0.02	g/l
									magsep width for 912mm diam chosen	1.8	m
MAGSEP U/F SPLITTER BOX	24	magsep effluent feed	246.77	1.00	0.00	246.77	246.77	0.00			
	25	split to flood water	61.69	1.00	0.00	61.69	61.69	0.00	% of mag sep u/f used as flood water	25	%
	26	split to effluent sump	185.08	1.00	0.00	185.08	185.08	0.00			
		check	*0.00*			*0.00*	*0.00*	*0.00*			
DE-SLIMING CYCLONE	4	feed from desliming scree	257.87	1.03	7.39	265.21	245.63	19.59			
	27	underflow	31.06	1.23	35.83	38.27	24.56	13.71	volume of water split to overflow %	90	Multotec
	28	overflow	226.80	1.00	2.59	226.94	221.06	5.88	mass of solids split to underflow %	70	Multotec
		check	*0.00*			*0.00*	*0.00*	*0.00*			
DE-WATERING SCREEN	27	cyclone underflow feed	31.06	1.23	35.83	38.27	24.56	13.71			
	29	screen product (-1+0.3)mr	11.09	1.62	72.62	17.94	4.91	13.03	volume of water split to overflow %	80	%
	30	screen underflow	19.98	1.02	3.37	20.34	19.65	0.69	screen %recovery	95	%
		check	*0.00*			*0.00*	*0.00*	*0.00*			
EFFLUENT SUMP	26	balance of mag sep u/f	185.08	1.00	0.00	185.08	185.08	0.00	magsep loading (volume)	155.6	$m^3/hr/m$ width
	30	dewatering screen u/f	19.98	1.02	3.37	20.34	19.65	0.69	magsep loading (solids)	25.8	t/hr/m Magnetite
	31	water addition	4.95	1.00		4.95	4.95				
	32	pump to desliming screen	210.00	1.00	0.33	210.36	209.67	0.69	**Effluent Pump pumping capacity**	**210**	**m^3/hr**
		check	*0.00*			*0.00*	*0.00*	*0.00*			
COMBINED PRODUCT	18	floats product	49.17	1.36	85.00	66.79	10.02	56.77			
	29	dewatering screen product	11.09	1.62	72.62	17.94	4.91	13.03			
	33	combined product to stock	60.26	1.41	82.38	84.73	14.93	69.80			
		check	*0.00*			*0.00*	*0.00*	*0.00*			

Fig. 7. Dilute medium circuit

This mass balance is fully contained by one Worksheet in the Excel spreadsheet. Other sections of the plant such as the fine coal and slimes processing sections would be developed on an adjacent Worksheet with the incoming flows linked to the DMS worksheet. In this way, the mass and water balance for a large coal processing plant consisting of for example, double stage DM Cyclone circuits followed by fine coal Spirals and Slimes flotation circuits, producing overall primary and middlings products can be constructed.

Once mass and water balances were firmly established for coal and water, it was a short but quite complicated step in Dense Medium circuits to also incorporate magnetite or Ferrosilicon (FeSi) in heavy mineral DM circuits, as a second solid making up the liquid separating medium. Extra columns were added which are illustrated below around the Mixing Box, DM Cyclone and CM Sump where the medium is introduced into the circuit.

This development was very useful in predicting and highlighting the magnetite or FeSi losses around the circuit (as shown in Figure 6). The extra columns are shown in Figure 8, around the DM cyclone section where the magnetite medium is first encountered.

SECTION		STREAM	TOTAL SLURRY								ASSUMPTIONS		
			volume	density	% solids	Total	Water	Solids	Coal	Magnetite			
			Vp	Dp	Sw	t + Vw	Vw	t	tc	tm			
			m^3/hr	t/m^3	w/w	t/hr	t/hr	t/hr	t/hr	t/hr		Set Points	
											moisture of +0.5mm ore diluting the medi	15	% w/w
MIXING BOX	11	medium feed	360.00	1.50	42.34	540.00	311.35	228.65	0.00	228.65	average particle size	3.85	mm
	3	deslimed feed	65.00	1.47	85.00	95.41	14.31	81.10	81.10		Maximum Screen Width Required: deslim	2.01	m width
	5	pump to cyclone	418.00	1.50	48.86	624.91	319.61	305.30	81.10	224.20			
	6	medium feed to cyclone	353.00	1.50	42.34	529.50	305.30	224.20		224.20	Feed capacity of Multotec max 710 cyclo	418	m^3/hr
	7	overflow to cm sump	7.00	1.50	42.34	10.50	6.05	4.45		4.45	Number of cyclones	1	m^3/hr
		check	*0.00*			*0.00*	*0.00*	*0.00*	*0.00*	*0.00*			
											product yield (50% min; 80% max)	70	%
HM CYCLONE	5	feed	418.00	1.50	48.86	624.91	319.61	305.30	81.10	224.20	% of medium solids by weight to underflo	40	Multotec
	8	sinks	103.36	1.81	61.05	186.76	72.75	114.01	24.33	89.68	% of feed medium by volume to underflov	25	Multotec
	9	floats	314.64	1.39	43.66	438.15	246.86	191.29	56.77	134.52	sinks discard SG (calculated)	2.11	t/m^3
		check	*0.00*			*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	**floats ore SG**	**1.45**	t/m^3
CM SUMP (in)	14	d & r screen sinks medium	88.98	1.77	55.21	157.39	70.49	86.90	0.00	86.90	Volume sinks to DM cyclone spigot	11.54	m^3
	19	from floats splitter box	186.08	1.38	35.27	257.61	166.74	90.86	0.00	90.86	Medium to ore ratio (by volume)	5.43	target 4.5
	23	overdense from magsep	33.23	2.10	66.54	69.79	23.35	46.44	0.00	46.44	**medium density (D50 - density shift of (**	**1.50**	**t/m^3**
	7	mixing box overflow	7.00	1.50	42.34	10.50	6.05	4.45	0.00	4.45	**Magnetite dry solids density**	**4.70**	**t/m^3**
	10	water addition	44.71	1.00	0.00	44.71	44.71				Make-up water (manually iterate)	44.71	**t/m^3**
CM SUMP PUMP (out)	11	pump to mixing box	360.00	1.50	42.34	540.00	311.35	228.65		228.65	**Correct Medium pump capacity**	**360**	**t/m^3**
		check	*0.00*			*0.00*	*0.00*	*0.00*	*0.00*	*0.00*			

Fig. 8. Full coal, magnetite and water balance around the DM cyclones

5 Conclusions

The introduction of Spreadsheets revolutionized the way mass balances were constructed in coal and minerals processing plants. They allowed complex flowsheets to be modelled using numerous specific and relatively simple mass balance equations. These are at the heart of any minerals processing plant design, once the incoming flowrate has been determined from the mine plan, and testwork has established the separating conditions for the plant.

References

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