METALLURGICAL ACCOUNTING AND CONTROL

Metallurgical Accounting Systems

- Metallurgical accounting is essential for efficient operations.

- Accurate balances are required on daily and monthly basis to *account* for the overall plant inputs and outputs of material.

- Rough accounting on a more frequent basis is used in each section of a plant to *control* the efficiency of the operation and the quality of products.

- Proper accounting depends upon *accurate measurements of mass flow rates* (weighing and volumetric liquid or gas flow measurements) and upon *proper sampling* and analysis (‘assaying’) procedures.

Metallurgical Accounting Systems

- Flow measurements and sampling in particular are very difficult and very rarely entirely satisfactory.

- There are two main methods of accounting:

➢ the ‘retrospective’system
➢ the ‘check-in/check-out’ system

- The *restrospective system* can be used when there is one feed and two products (e.g. concentrate and tailings, or matte and slag, or pregnant solution and leach residue).

Metallurgical Accounting Systems

- Assays are made of the feed and the two products and, if one of the mass flow rates (weights) is known, the other mass flow rates can be calculated from the assays with the '*two-product formula*'.

- The weight chosen should be the most accurate of the three weights.

- It is often the weight of the valuable product, but sometimes it is more convenient to use the weight of the feed.

- The method can be used on a single process unit, or on an entire production section, or on an entire plant.

- In theory, it is an excellent method, but a small error in an assay value results in large errors in the calculated weights, so that the method is normally used for rough accounting only.

Metallurgical Accounting Systems

- Proper metallurgical accounting for an entire plant normally uses the *check-in/check-out system*.

- With this system, all the plant inputs and outputs are weighed and assayed as accurately as possible on a regular basis (e.g. on each shift, or daily).

- Differences between input and output of a particular ‘ingredient’ (e.g. Cu) are assumed to be a ‘change in inventory’.

- Because the composition of the input (feed) fluctuates, the composition of intermediate and final products also changes and inventory changes with time are inevitable.

Metallurgical Accounting Systems

- Shift balances are combined into daily balances and daily balances into ‘to-date’ and so on into monthly balances.

- At intervals (at the month end, or quarterly) a proper check is made of the inventory (material on stockpiles and dumps within the plant, and in the larger items of equipment: bins, storage tanks, thickeners, tankhouses, furnaces, etc.).

- The difference between this measured inventory and the calculated inventory forms an *‘unaccounted loss’ or ‘gain*’.

- This should be small, say, no more than one percent.

- If the unaccounted loss (or gain) is large, an investigation into the cause of the discrepancy is required.

Weighing, Flow Measurements and Sampling

- Weighing is normally quite accurate when a quantity of material can be weighed when at rest (*static weighing*).

- For material that is carried in trucks or rail cars, this can be done on a *weighbridge* (track scale).

- The trucks are weighed when full (gross weight) and when empty (tare weight) and the difference is the nett weight of the material carried.

- This can give quite accurate weights of the main inputs and outputs of the plant (< 0.5 % error)

Weighing, Flow Measurements and Sampling

- Certain types of storage bins and hoppers can be used for static weighing of bulk material, but most ‘in-plant weighing’ is done with belt weighers (weightometers) when the material is being moved on belt conveyors.

- One set of conveyor idlers is mounted on the belt weigher, so that the load on the belt is measured as it moves over the weigher.

- The weigher integrates these loads over time.

- Belt weighing is less accurate than static weighing, but if the weighers are kept clean, errors of no more than 1-2% are possible.

Weighing, Flow Measurements and Sampling

- Normally the ‘dry weight’ of solid material is used in accounting so that the measured weight must be corrected for moisture content.

- The determination of moisture content is very accurate in itself, but large errors are often made by improper sampling of the solids.

- Volumetric flow rates of liquids and slurries can be measured quite accurately by diverting the stream and measuring the time it takes to fill a container of known volume, but this method is rarely practicable.

- Various types of flowmeter can be used on moving streams.

Weighing, Flow Measurements and Sampling

- They are reasonable accurate on homogeneous liquids, but are much less accurate on pulps and on gas flows.

- To determine the mass flow rate of (dry) solids in a pulp stream, the solids concentration in the pulp must be determined, which introduces another error.

Weighing, Flow Measurements and Sampling

- Proper sampling is very important in the mining and chemical industries, and extremely difficult.
- A ‘representative sample’ of a material is a small portion of the material that has exactly the same properties as the ‘bulk’ material so that it can be used to determine those properties.

- With a homogeneous material, any portion taken will be a representative sample, but this is not the case with a heterogeneous material, in which the properties are unequally distributed in space.
- In metallurgical plants, the properties of the material to be sampled are not only unequally distributed in space, but also fluctuate with time.

Weighing, Flow Measurements and Sampling

- Hand sampling is done for non-routine investigations, but most routine sampling in plants is done automatically.
- Samples taken at random, without a preconceived plan are called grab samples.

- Samples taken from a moving stream of material should be taken at regular, timed intervals.
- The required size of the sample and the length of intervals can be calculated by using an appropriate ‘sampling theory’.
- A mass of moving loose solids, in particular solids in a pulp, becomes ‘segregated’.

- To minimise the effects of segregation by gravity, samples from moving streams should preferably be take from a vertical stream.

Weighing, Flow Measurements and Sampling

- A good hand sample of material on a conveyor can be taken by stopping the conveyor and removing all the material on the conveyor over a certain length (usually a metre) as sample.

- This is called a ‘belt cut’.

- Samples taken from various places within a stationary quantity of material, or at timed intervals from a moving mass of material, are usually combined into a ‘composite sample’.

- With process streams in plants, these may be ‘shift composites’, ‘daily composites’ etc.

Weighing, Flow Measurements and Sampling

- The larger the increments taken and the shorter the time intervals, the more representative the composite sample becomes, but a large quantity of sample is unpractical.

- ‘Splitting’ of a sample into small ‘sub-samples’ for analysis introduces another error.

- This error is minimised when the sample to be split is made homogeneous (‘homogenised’) by fine grinding and mixing, but this is expensive and time consuming and is not possible for particle-size analysis.

Weighing, Flow Measurements and Sampling

- ‘On-stream analysers’ are automatic samplers that either take a small sample from a process stream continuously, or ‘cut’ the entire stream at short intervals.

- The ‘primary sample’ thus obtained is split to a convenient size and analysed continuously by the machine.

- On-stream analysis of solids is limited to particle-size analysis, but chemical analysis of liquid and gas streams can be done continuously ‘on-stream’.

Monitoring and Control

- To be able to control a process, information (‘feedback’) on the important process parameters is required.
- The collection of such information is called ‘monitoring’ the process.
- Most feedback is obtained with instruments (weighers, flowmeters, samlers, pressure gauges, temperature gauges (thermocouples), pH-meters, etc.).
- Any action taken as a result of this information forms the control of the process.
- Sometimes action is taken automatically because machines and instruments are made to respond to changes in the conditions.
- This is automated control.

Monitoring and Control

- Good instrumentation can make tremendous improvements in the rate of production and the quality of the products, but man remains the most important monitor and controller.

- It is impossible to have instruments on each of the thousands of items of equipment in an industrial plant.

- A plant engineer, who is probably familiar with the plant, will quickly see things that are wrong and will hear unusual sounds and smell unusual smells.

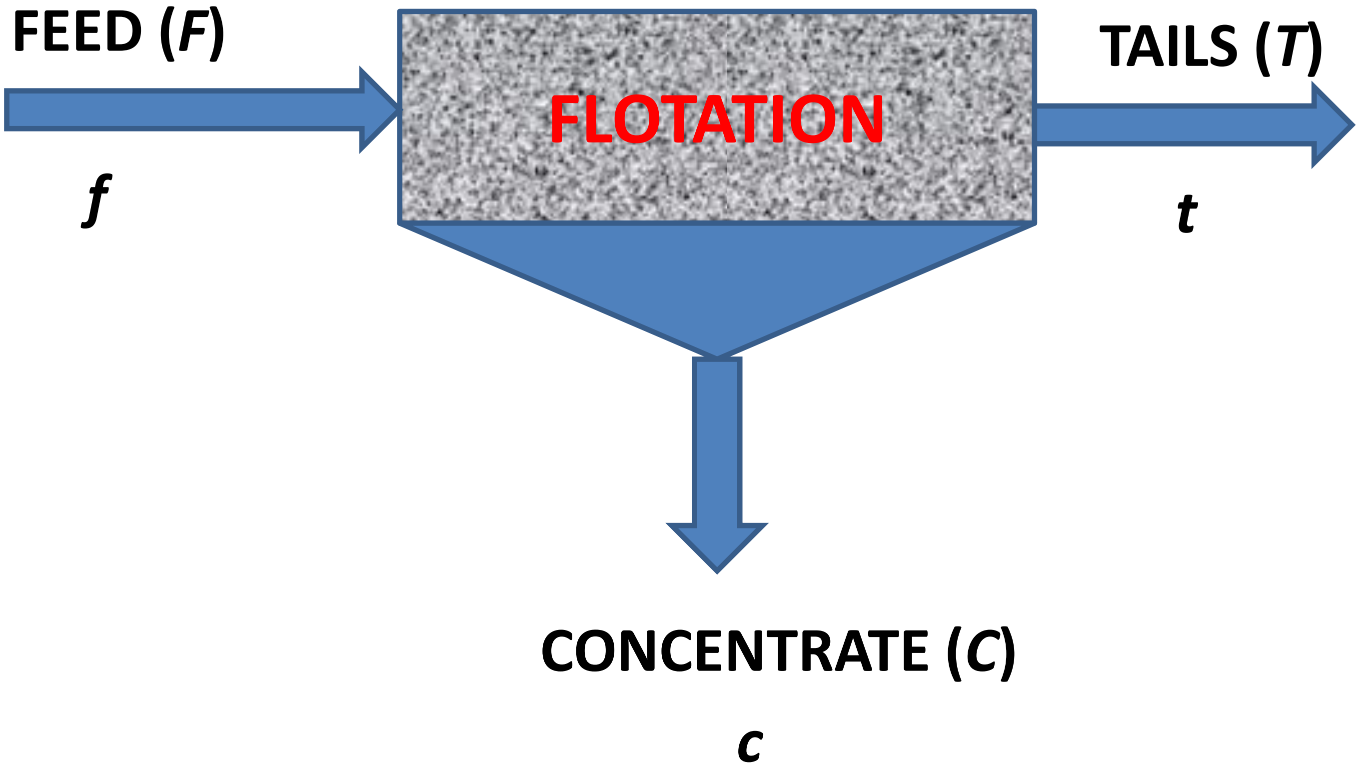
- He can feel it when a bearing is overheating and when a cyclone overflow is too coarse

Mass Balancing Methods

- In order to assess plant performance, and to control the operation using the evaluated results, it is necessary to account for the products in terms of material and contained component weights.

- Mass balancing is particularly important in accounting for valuable mineral or metal distributions, and the two-product formula is of great use in this respect.

- If the weights of the feed, concentrate and tailings are ***F***, ***C*** and ***T*** respectively, and their corresponding assays ***f***, ***c*** and ***t***, then



FEED (F)

f

FLOTATION

TAILS (T)

t

CONCENTRATE (C)

c

Mass Balancing Methods

mass balance $$F = C + T \qquad (1)$$

i.e. material input = material output

and

Ingredient balance $$Ff = Cc + Tt \qquad (2)$$

F, ***C*** and ***T*** are the mass flow rates (e.g. Tonnes per hour) of the feed and the two products (e.g. concentrate and tailings) and ***f***, ***c*** and ***t*** are the percentages of a particular ‘ingredient’ in these process streams (e.g. % Cu), and we may assume that there is no ‘inventory change’ (no build-up of material in the process unit).

Mass Balancing Methods

If we want to eliminate, say, T, we multiply equation 1 by t:

$$F\,t = C\,t + T\,t \qquad (3)$$

Subtracting equation (3) from equation (2), we have:

$$F\,(f - t) = C\,(c - t) \qquad (4)$$

If C and the three 'analyses' (f, c and t) are known, F can be calculated, and then T can be calculated.

Mass Balancing Methods

In the case of mineral concentration processes, the two-product formula is often used to calculate the recovery of certain ingredients:

recovery from feed to concentrate:

$$\text{Recovery} = \frac{Cc}{Ff} = \frac{(f - t)c}{(c - t)f} \times 100\,\% \qquad (5)$$

$$\text{ratio of concentration}: \frac{F}{C} = \frac{(c - t)}{(f - t)} \qquad (6)$$

Mass Balancing Methods

- As values of recovery, ratio of concentration (F/C) and enrichment ratio (***c/f***) can be determined from the assay results alone, the two-product formula method is often used to provide information for plant control, although this will be retrospective, dependent on the time taken to receive and process the assay results.

- Direct control can be achieved by the use of on-stream analysis systems, where values of ***c***, ***f*** and ***t*** can be continuously computed to provide up-to-date values of metallurgical performance.

Mass Balancing Methods

Example 1

The feed to a flotation plant assays 0.8% copper. The concentrate produced assays 25% Cu, and the tailings 0.15% Cu. Calculate the recovery of copper to the concentrate, the ratio of concentration, and the enrichment ratio.

Solution

- The concentrator recovery (***equation 5***) is:

$$= \frac{(0.8 - 0.15)\,25}{(25 - 0.15)\,0.8} \times 100\,\% = 81.7\,\%$$

- The ratio of concentration (***equation 6***) is:

$$= \frac{25 - 0.15}{0.8 - 0.15} = 38.2$$

Mass Balancing Methods

Solution

- The enrichment ratio (c/f) is: = 25 / 0.8 = 31.3

Mass Balancing Methods

The Use of Size Analysis in Mass Balancing

- Many unit process machines, such as hydrocyclones and certain gravity separators, produce a good degree of particle size separation, and size analysis data can often be effectively used in the two-product formula.

Example 2

- In the circuit shown in Fig. 2, the rod mill is fed at the rate of 20 t/h of dry solids (density 2900 kg/m^3). The cyclone feed contains 35% solids by weight, and size analyses on the rod mill discharge, ball mill discharge and cyclone feed gave:

Rod mill discharge	26.9% +250 μm
Ball mill discharge	4.9 % + 250 μm
Cyclone feed	13.8% + 250 μm

Calculate the volumetric flow rate of feed to the cyclone.

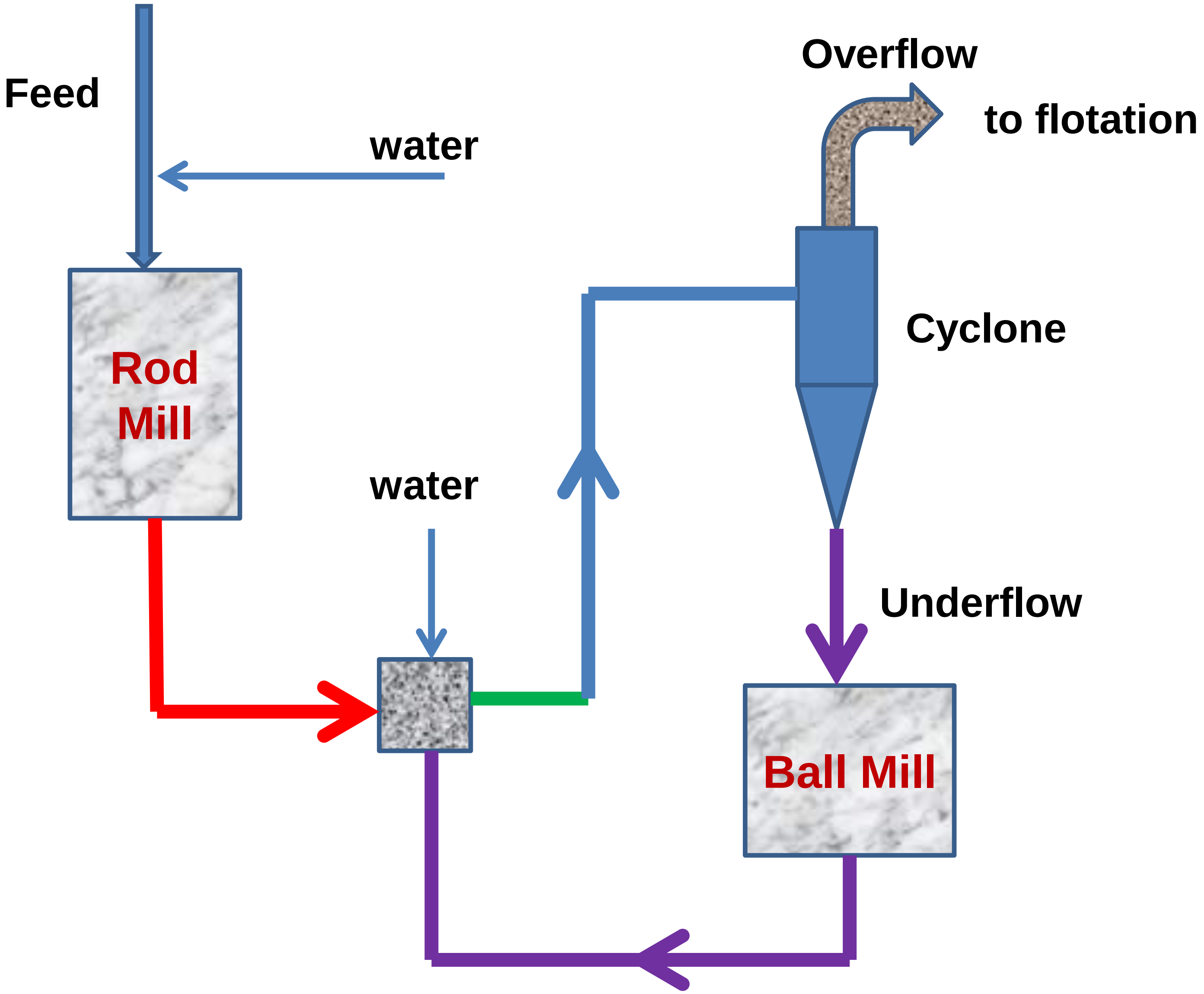


Figure 2: Rod Mill – Ball Mill – Cyclone Circuit

Solution

A material balance on the cyclone feed junction gives: *F = 20 + B*

where F = cyclone feed, and B = ball mill discharge.

Therefore *F = 20 + (F – 20)*, and a balance of +250 μm material gives:

13.8F = (26.9 x 20) + (F –20) x 4.9

from which F = 49.4 t/h

Volumetric flowrate of solids = 49.4 x 1000 / 2900 = **17.0 m^3 / h**

Volumetric flowrate of water = 49.4 x 65 / 35 = **91.7 m^3/h**

Therefore, flowrate of feed to cyclone = 17.0 + 91.7 = **108.7 m^3/h**

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

- Water plays a very important role in mineral processing operations.
- Not only is it used as a transportation medium for the solids in the circuit, but it is also the medium in which most of the mineral separations take place.
- Individual processes require different optimum water contents. Ball mills, for instance, rarely operate below about 65% solids by weight, and the discharge may need diluting before being fed to hydrocyclones.
- Most flotation operations are performed at between 25 – 40% solids by weight, and some gravity concentration devices such as Reichert cones operate most efficiently on slurries containing 55 – 70% solids.
- A mineral processing plant is a large consumer of water.

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

- In a plant treating 10 000 tonnes per day of ore, about 20 m^3/min of water is required, which is expensive if some form of conservation is not practised.
- If the slurry must be dewatered before feeding to a unit process, then the water should be used to dilute the feed as required elsewhere in the circuit.
- For optimum performance, therefore, there is a water requirement, which produces optimum slurry composition in all parts of the circuit.
- The two-product formula is of great use in assessing water balances.

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

- Consider a hydrocyclone fed with slurry containing ***f*** % solids by weight, and producing two products – an underflow containing ***u*** % solids, and an overflow containing ***v*** % solids.

- If the weight of solids per unit time in the feed, underflow and overflow are ***F***, ***U*** and ***V*** respectively, then providing the cyclone is operating under equilibrium conditions:

$$F = U + V \qquad (7)$$

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

- The dilution ratio of the feed slurry **= (100 – f) / f = f ’**
- Similarly, the dilution ratio of the underflow = **(100 - u) / u = u’** and dilution ratio of overflow **= (100 – v) / v = v’**
- Since the weight of water entering the cyclone must equal the weight leaving in the two products, the water balance is:

$$Ff' = Uu' + Vv' \qquad (8)$$

Combining equations 7 and 8:

$$U / F = (f' - v') / (u' - v') \qquad (9)$$

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

Example 3

A cyclone is fed at the rate of 20 t/h of dry solids. The cyclone feed contains 30% solids, the underflow 50% solids, and the overflow 15% solids by weight. Calculate the tonnage of solids per hour in the underflow.

Solution

Dilution ratio of feed slurry = 70/30 = 2.33

Dilution ratio of underflow = 50/50 = 1.00

Dilution ration of overflow = 85/15 = 5.67

A material balance on the cyclone gives:

$$20 = U + V$$

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

where

U = tonnes of dry solids per hour in underflow

V = tonnes of dry solids per hour in overflow

Since the weight of water entering the cyclone equals the weight of water leaving:

$$20 \times 2.33 = 1.00U + 5.67V$$

or

$$46.6 = U + 5.67(20 - U)$$

- which gives U = **14.3 t/h**

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

Example 4

The flowsheet shown in Fig. 3 illustrates a conventional closed circuit grinding operation. The cyclone overflow line is instrumented with a magnetic flowmeter and a nuclear density gauge, and the mass of dry ore fed to flotation is 25 t/h. The feed from the fine ore bins is sampled, and is found to contain 5% moisture.

The cyclone feed contains 33% solids, the cyclone underflow 65% solids, and the overflow 15% solids.

Calculate the circulating load on the circuit and the amount of water required to dilute the ball mill discharge.

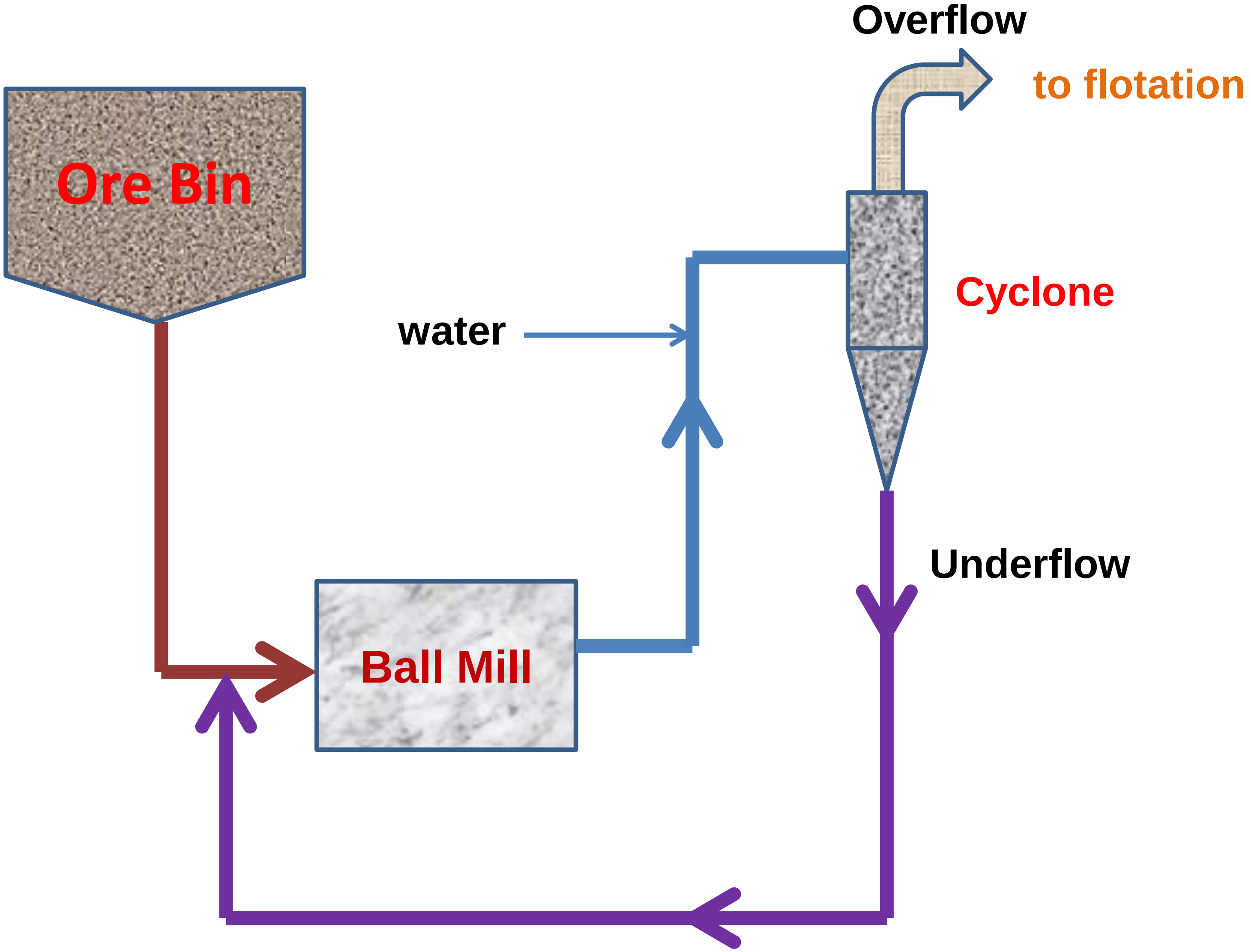


Figure 3: Rod Mill – Ball Mill – Cyclone Circuit

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

Solution

A water balance on the cyclone gives:

$$\frac{67\,F}{33} = \frac{85}{15} \times 25 + \frac{35U}{65}$$

where F = cyclone feed (dry t/h)
U = cyclone underflow (dry t/h)

The mass flowrate of feed from the ore bin = 25 t/h (since input to circuit = output).

Therefore, F = 25 + U

and

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

Solution

$$(25+U)\frac{67}{33}=\frac{85}{15}\times 25+\frac{35U}{65}$$

$$\text{from which}\quad \mathrm{U}=61.0\ \text{dry t/h.}$$

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

Solution

The circulating load is therefore 61.0 t/h, and the circulating load ratio is 61.0/25 = 2.44.

The ball mill feed = ore from bin + circulating load

Water in ball mill feed = 25 x 5/95 + 61.0 x 35/65 = 34.2 m^3/h

Water in cyclone feed = (25 + 61.0) 67/33 = 174.6 m^3/h

Therefore, water requirement at cyclone feed = 174.6 – 34.2 = **140.4 m^3/h**

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

Example 5

Calculate the circulating load in the grinding circuit shown in Fig. 4 and the amounts of water added to rod mill and cyclone feed.

Feed to rod mill = 55 tonnes of dry ore per hour

Rod mill discharge = 62 % solids

Cyclone feed = 48 % solids

Cyclone overflow = 31 % solids

Cyclone underflow 74 % solids

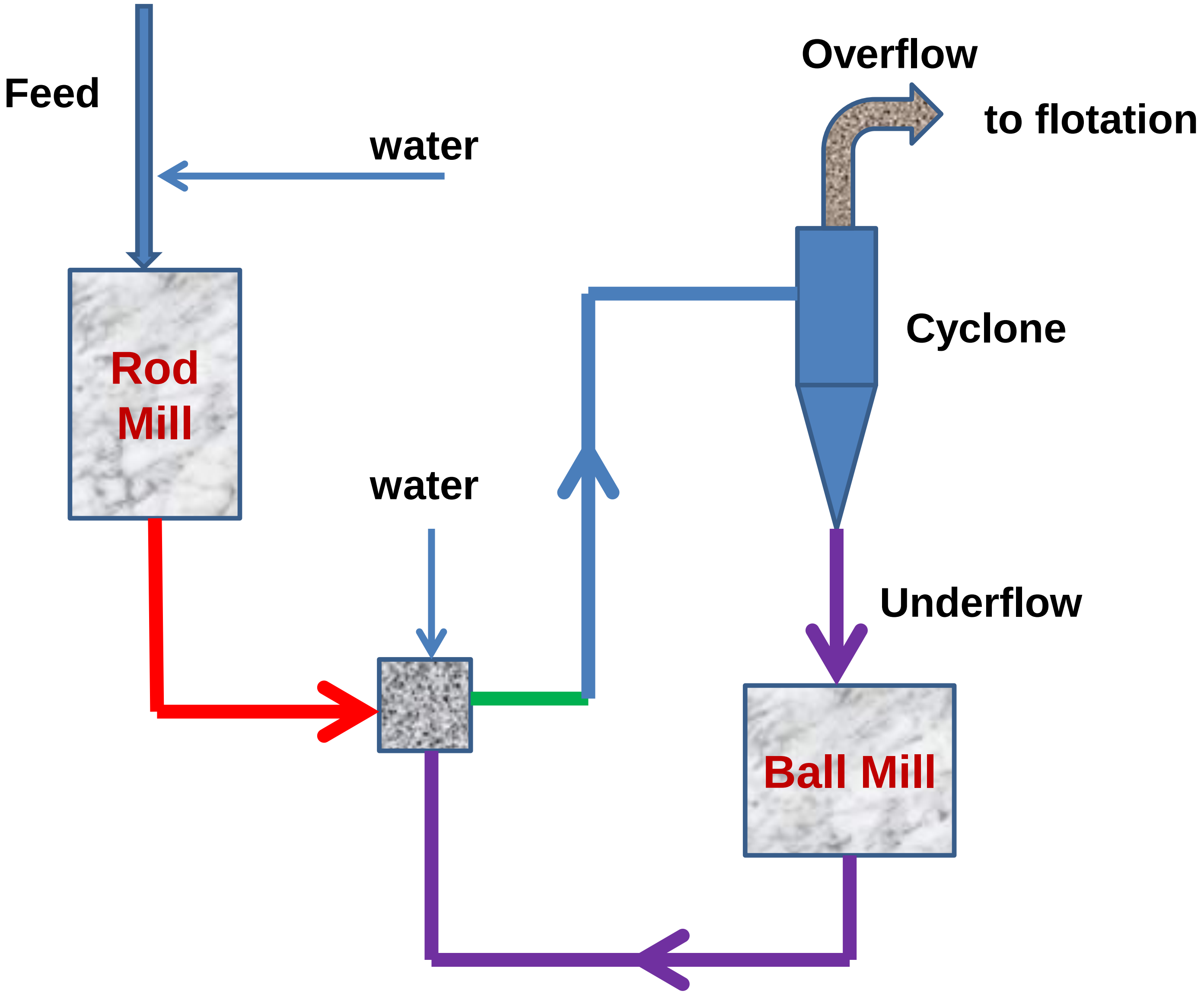


Figure 4: Rod Mill – Ball Mill – Cyclone Circuit

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

Solution

Since input to circuit = output, the cyclone overflow contains 55 t/h of solids.

A water balance on the cyclone gives:

$$(U + 55)\frac{52}{48} = \frac{26U}{74} + \frac{26}{31} \times 55$$

Mass Balancing Methods

The Use of Dilution Ratios in Mass Balancing

Solution

which gives **U = 85.8 t/h.**

The circulating load ratio is thus **85.8/55 = 1.56**.

Water in rod mill discharge **= 55 x 38/62 = 33.7 t/h**.

Therefore, water addition to rod mill is **33.7 m^3/h.**

Water in ball mill discharge **= 85.8 x 26/74 = 30.1 t/h.**

Water in cyclone feed **= (55 + 85.8) x 52/48 = 152.5 t/h.**

Therefore, water requirement to cyclone feed **= 152.5 – (33.7 + 30.1) = 88.7 t/h**

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