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Design of a multi-purpose plant to provide paste fill, hydraulic fill, concrete and shotcrete

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Abstract

Construction, production, and closure of any mine require cement-based building materials including ready-mix concrete, shotcrete, and various types of mine backfill. Often more than one type of material will be required at various stages, depending on the day-to-day needs. Usually, different plants, built for specific purposes, are mobilised to the mine site for specific stages, resulting each time in capital, mobilisation and de-mobilisation costs.

The authors were involved with a mine that required one such plant to enable transitioning between hydraulic fill and paste fill, based on the amount and variability of source material available, to meet the performance required. In response to the customer's specific needs, ISL Machinery designed a multi-purpose plant with the ability to provide paste fill, hydraulic fill, shotcrete, and concrete all from the same plant set-up at a relatively marginal increase in capital cost to the plant. Some of the key points to be taken into consideration in evaluating the use of a multi-purpose plant at a mine include capital availability, concrete quality and cost of production, use of low-cost waste materials, availability of production, and improved leverage relative to local aggregate and concrete suppliers. This paper outlines the innovative concept of the multi-purpose plant that allows for the flexibility in production required to produce a wide range of cement-based building materials.

1 Introduction

During the life of a mine, several types of cement-based materials are used for different purposes, in different quantities, and at different times. During the mine development phase there is considerable demand for concrete to build up infrastructure and some greater or lesser demand for shotcrete depending on the mine. As the mine enters the production stage, typically most of the required infrastructure has been completed, unless additional resources require an expansion of the mine. Finally, as the mine reaches the end of its productive life, it enters a closure stage that again may require some infrastructure type work to ensure the mine meets all the applicable environmental and safety standards and requirements. Figure 1 illustrates an example of the anticipated demands for concrete, shotcrete, and mine fill during the life of a 1,000 tpd underground mine. In this particular case, a peak demand of 125,000 m^3/year of cement-based building materials is used for shaft lining, underground crusher stations, sumps, mine backfill, bulkheads, and/or barricades, etc.

In order to produce all these materials, the following need to be considered:

- Sourcing of appropriate quality and quantity of component materials.
- Implementation of a good QA/QC program to ensure incoming materials meet the specified requirements.
- Accurate proportioning of the component materials.
- Mixing the component materials together.

With some advance planning, instead of using separate plants to produce each specific material, a single plant can be installed to satisfy all the material needs for the project throughout the life of the mine.

However the plant has to be specifically designed with the flexibility to produce the range of materials required.

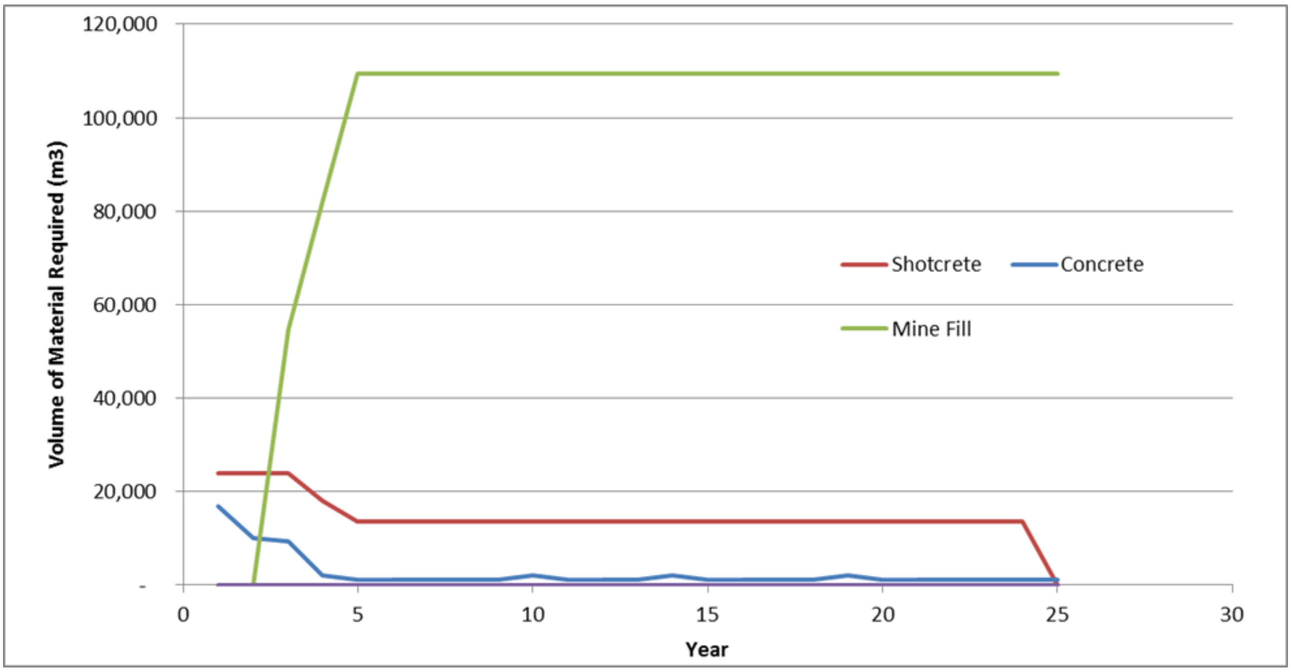

Figure 1 Anticipated demands for concrete, shotcrete and mine fill during the lifetime of an underground mine

Shotcrete, concrete, and backfill (paste, hydraulic fill) all have different criteria for transport. Paste backfill by definition is a non-segregating, non-Newtonian fluid; hence pipeline transport is achieved by plug/ laminar flow, whereas hydraulic fill is a settling slurry, requiring flow velocities in excess of 1.8 m/s depending on solids grind. Concrete or shotcrete is generally transported by truck or slicklines to underground mine workings and has a minimal tendency to segregate. Dedicated delivery systems for each product are generally needed since demands for concrete, shotcrete, and minefill may overlap at times. The specifications of these distribution systems influence the plant design. The ability to load trucks and feed pipelines simultaneously and at the appropriate production rates affects equipment sizing and layout.

1.1 Production demands for cementitious based materials

In the initial mine development stage, concrete of various specifications may be used for foundations, floor slabs, buildings for heavy industrial facilities (underground crushers, mine dewatering stations, garages, shaft installations, ore and rock pass dumping, control gate arrangements), material pads, and sometimes even roadways. For an integrated mine and mill project, large floor slabs and foundations will be required on the surface for crushers, grinding mills, processing plants, offices, etc. Ideally, the mix designs used to produce the concrete for these different applications should be selected to meet the specific requirements of each installation. During this stage there may also be significant demand for shotcrete if required in the underground developments.

Once the underground mine has transitioned into production, the mine will normally require some form of backfill. Depending on the mine, this fill may be supplied in the form of paste, hydraulic, cemented or uncemented rock fill. In many operations, more than one type of backfill is used to optimise the financial payback of the mine.

Shotcrete requirement usually continues along with the underground development during production. The need for shotcrete is site-specific and largely dependent upon the ground conditions, barricade and possibly bulkhead design. However, the actual quantity of shotcrete needed is always a small proportion compared to backfill needs. Increased use of single pass fibre reinforced shotcrete support in lieu of bolts and screen can offer productivity and safety advantages (Epps, 1997). However, dosing of fibres into the shotcrete and concrete requires additional equipment. The majority of infrastructure development is generally completed early in this production stage of the mine life, requiring less concrete for above-ground applications.

Once a mine nears the end of its life and transitions into closure, related activities such as capping shafts and ventilation raises, ramps and portals, or providing infrastructure for long term environmental mitigation will require cementitious based materials. Construction of these facilities normally requires a combination of backfill, shotcrete and/or concrete, depending on the designs.

In order to facilitate the design of a multi-purpose plant, as with any paste plant, a design basis is needed. The production rates (hourly, daily, monthly, annual), the recipes, the distribution and application of each type of cement-based material that will be produced from this plant needs to be taken into consideration. Which materials will need to be produced concurrently also needs to be decided to determine the design criteria for each piece of equipment in the plant. Although mine planning generally is completed based on mass flow rates, it is important to note that the volumetric flow rates are critical in the design and sizing of the equipment in this type of plant, and becomes one of the governing parameters in the design basis.

2 Financial comparison

2.1 Contractual and mobilisation costs

The continuous demand for cementitious based materials throughout the mine's life suggests the installation of a single multi-purpose plant to handle all those needs from the very beginning to the end of the project – particularly if the mine plans to use some sort of mine fill (paste, hydraulic or rock) – could be beneficial.

Mobile mixing plants are typically brought on site for the initial stages of the project when concrete works are being constructed. This plant is either purchased or leased by the owner, or supplied by a contractor. Either way, mobilisation and demobilisation cost for the plant is either directly paid by the owner, or through the terms with the contractor.

Upon completion of the construction phase, operations can elect to keep the plant on site to cover future concrete and shotcrete needs, or it can be removed. If the plant stays on site, the owner needs to do some minimum maintenance on the plant to keep it in good working order.

There are many options that should be considered for providing concrete for a mine site as discussed above (concrete shipped to site in trucks, mobile plant erected on site and removed once completed, etc.) For an in-depth analysis, several of these options should be considered. In this paper, we will limit our analysis to two options that are simple to compare and give an indication of the capital cost involved. Pricing in Table 1 is based on a recent quote for supply and install of a paste fill plant using excavated tailings (see Figure 2).

- Option A: Purchase and install a dry batch concrete plant for the initial construction in year 1. Build a paste fill plant to deliver the mine fill once it is needed (in this example that would be three years into the mine life).
- Option B: Purchase and install a multi-purpose plant in year 1 to supply both the concrete and mine fill needs for the mine.

The comparison of the capital and operating costs show that savings are available by going with a single multi-purpose plant instead of separate concrete and paste fill plants. Note that the cost of the component materials is the same for both options and has not been included in the OPEX cost for this example.

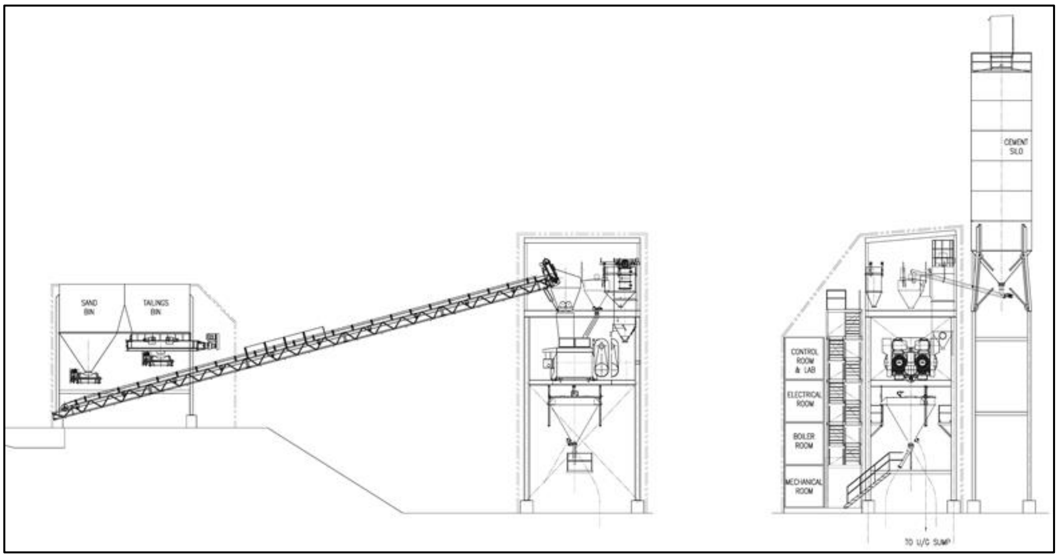

Figure 2 Layout of an excavating tailings plant

Table 1 Comparison of capital cost for a multi-purpose plant (US$)

Option	A	B
CAPEX		
Concrete plant	645,000	
Paste fill plant	4,330,000	
Multi purpose plant		4,454,000
Total	4,975,000	4,454,000
NPV – CAPEX	4,402,000	4,105,000
NPV – OPEX (labour and maintenance only)	2,624,000	2,047,000
Net Present Value (NPV)	7,026,000	6,152,000
NPV based on interest of 8.5% and inflation of 1.75%		

2.2 Flexibility in production

Many concrete batch plants operate using ‘clean’ and/or washed sand and gravel (fine and coarse aggregates) to produce the shotcrete and concrete required on site. The supply of this product is more often than not contracted to local material suppliers. Significant savings in the cost of the material could be available if the plant on site can substitute part of the aggregates with other waste streams from the site (such as tailings or waste rock). Not only does this reduce the cost of the material, but it may also be a method for reducing the environmental footprint of the mine. For example, in mines with acid generating waste rock, utilising this waste rock where applicable to produce cement-based materials may be advantageous.

In some cases, the use of tailings has been shown to increase strength in the mine fill relative to only using excavated sand, as in the case with some sulphides and ground iron blast furnace slag/cement binder interaction. In other cases, the opposite has been found. There may be a potential at some mine sites to reduce the cement content and still produce the same strength concrete and shotcrete, if tailings can be used as one of the aggregates. This option generally would not be available with a mobile concrete plant as they are not designed to handle tailings material unless modified.

Early characterisation of tailings is essential in determining the application of mine and mill waste streams. Use of deposited sulphide tailings, as an example, may generate large amounts of dilution if strengths cannot be obtained or retained over time. There may even be variations in fill strengths depending on what part of the orebody the tailings are produced from. Flexible production plants can optimise the production blends for the material being prepared based on ongoing testing.

Generally, batch and continuous production plants are not designed for the range of mixes and throughputs required from a multi-purpose plant. A plant purchased specifically for the project should be custom designed to ensure the production of a quality product over the full range of material produced. Product quality means production of a consistent product. Product consistency allows for better mix design optimisation and has a direct impact on the plant's operating cost.

2.3 Logistics

Having an on-site concrete plant can provide logistical advantage on some projects. The on-site plant provides independence for the owners so that they can produce as much material as they need, when they need it. External suppliers may become unreliable sources due to many factors:

- Seasonal dependence on roads (frost limitations, winter roads, etc.).
- Labour and population unrest, limiting traffic in and out from the mine site.
- Capability and willingness of outside suppliers to meet volume or quality demands.

3 Technical concerns

3.1 Variety of cementitious based materials

Naturally, the applications of the various concretes, shotcretes, and backfills are diverse, and hence it is expected that the physical properties of each material will be different. It is these very diversities in the application of the product that defines the ideal properties of each material, and thus also stipulates the raw materials being consumed to produce the concrete or fill. One of the attractions of cement-based materials is that such a wide range of material properties can be generated by varying the mix of a limited number of key ingredients.

Table 2 summarises some key properties of paste backfill, hydraulic fill, shotcrete, and concrete. Note that these are typical ranges of the materials and are not meant to be considered an exhaustive and all inclusive range. Cement-based materials can be designed to generate slumps from zero slump (roller compacted concrete) to self-consolidating (which spreads so well it no longer is measured in slump but rather in the width of the spread). The compressive strengths of cementitious materials can be made to meet the design requirements in a continuum all the way up to 250 MPa (35,000 psi) for some specialty type mixes.

Table 2 Physical properties of cement-based materials

Physical property	Strength (MPa)	Slump (mm)	Setting time* (min)
Paste backfill	0.3–1	175–250	120
Hydraulic fill	0.3–1	N/A	120
Shotcrete	20–70	100–250	<20
Concrete	10–40	75–150	90

* Time until the material no longer flows freely

Generating the wide range of material properties discussed in a paste plant may only require one additional type of aggregate and manipulation of the proportions of the ingredients. Table 3 shows a list of a typical range of mix designs or recipes for paste, shotcrete and concrete. Note again that this is by no means an authoritative and exhaustive range, but rather an indication of typical values used in many applications.

There are also some special ingredients that may or may not be advantageous to the mixture based on the application and use. Additional admixtures may need to be added in the plant. If fibre reinforcing is being used for the mixes, a fibre dosing system needs to be installed to allow easy and accurate metering of the fibres.

Table 3 Typical mix designs for cement-based materials

Component material	Water (wt %)	Cement (wt %)	Aggregates * Fine (< 9mm)	Coarse (9–20 mm)
Paste backfill	20–27	3–10	70–85	0
Hydraulic fill	25–35	5–10	65–75	0
Shotcrete	7–15	15–25	30–50	30–40
Concrete	7–15	10–20	20–40	30–50

* Size refers to particle size distribution with 80% of material by weight passing

The particle size distribution (PSD) curves for the different materials are illustrated in Figure 3. Note the large variation between some of the paste mixes relative to the concrete mixes. This difference in the material PSD's makes for a substantial range in the bulk material properties of the different materials and needs to be considered when designing material handling systems as described in the next section.

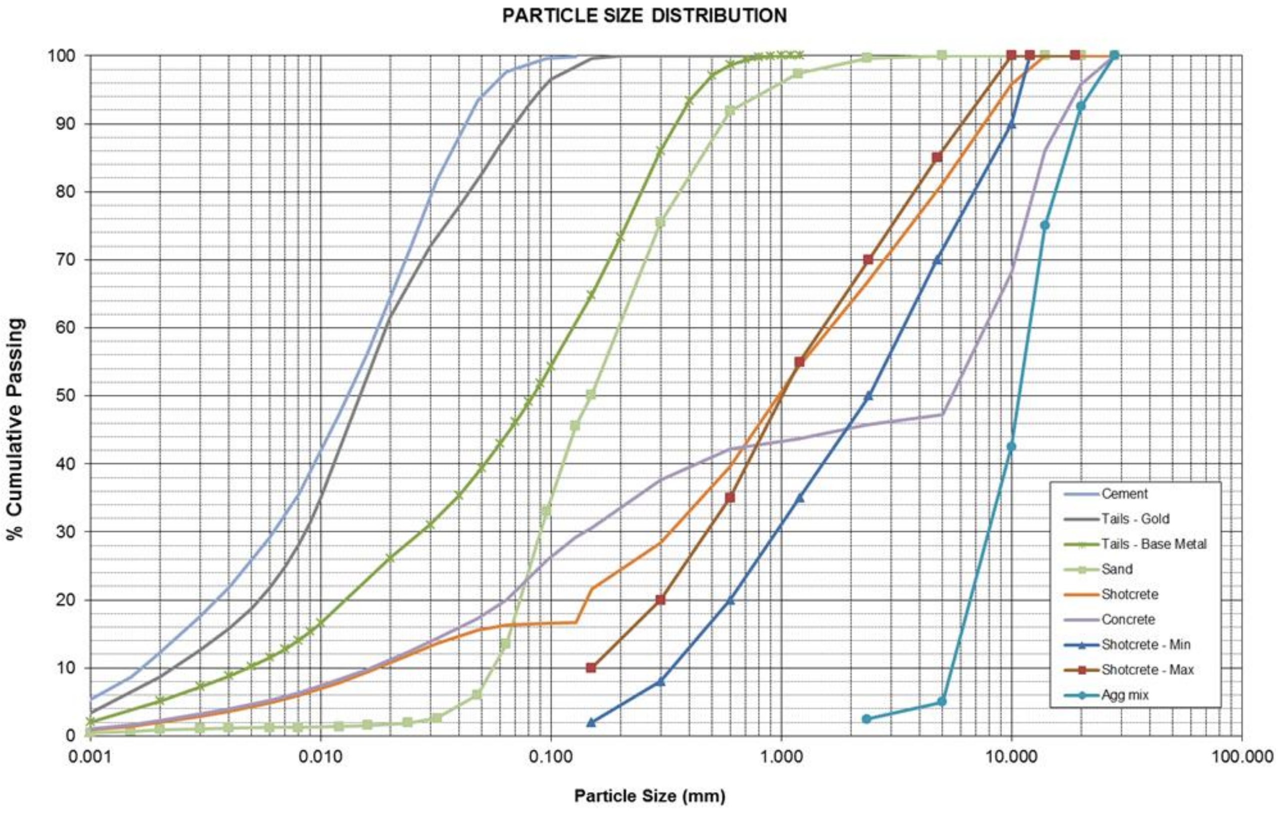

Figure 3 PSD curves of various cement-based mixes and their component materials

(Ferraris et al., 2004; Jolin and Beaupré, 2003; Wikipedia, 2013a; Wikipedia, 2013b)

3.2 Raw material handling and proportioning

Off-the-shelf concrete and shotcrete plants are designed to handle relatively dry fine and coarse aggregates. Coarse aggregates are easily conveyed on belts and stored in bins, and are usually not a problematic material when it comes to material flow. For the finer aggregates, the bulk material properties can change based on the moisture content in the material. When moisture is introduced into a silty–sand type material (like tailings) it becomes problematic to handle the same way as a dry material. The material develops an apparent cohesion due to the colloidal properties of the fine silt–clay size particles and generates many issues that a regular concrete or shotcrete plant is unable to deal with, such as bridging in bins, clumping, and sticking to surfaces.

Alternately, a typical paste plant is designed only to handle tailings or a blend of tailings and sand. To enable production of a wider selection of products, the plant design needs to be altered to facilitate storage and use of additional raw material streams, typically an unblended Portland cement, and both a fine and coarse aggregate.

Ensuring individual batching or metering of each product provides the ability to produce an optimal blend of materials to provide the most economical mix designs for each purpose. Pre-blending of aggregates can be considered to reduce the number of compartments required in the aggregate bin. But pre-blending with a loader is costly (operationally) and relatively inaccurate compared to the capital cost of dividing bin capacity in order to separate the materials, which is generally relatively affordable and will always produce a more consistent quality.

It should also be noted that once this is done, the multi-purpose plant would need to have the capability to produce materials with a wider range of material proportioning. This means any metering device needs to be accurate over a larger range, or in the case of batch process, the scales for each material need to be big enough for the extreme case, or must allow for double batching of this material to produce the full range of materials required.

3.3 Mixing

Technical literature for many mixers claims that the mixer will mix anything from zero slump to self-consolidating mixes using the same mixer with the same setup. Of course this is generally true, but for true optimisation, the mixing technique should be adjusted for each specific material. In the case of a paste plant, large volumes of paste fill may be required and using an off-the-shelf concrete or cement slurry mixer is not likely to provide the most cost effective result. Improved mixing can be obtained by changing the mixing technique for the paste relative to the concrete or shotcrete. In other words, refining the mixer design and adapting the mixing speed for producing paste and concrete independently.

3.4 Distribution and load out

If the plant is to be used for concrete, shotcrete, paste backfill, and hydraulic fill, the different distribution requirements of the products need to be considered.

Paste backfill distribution can be implemented through a pipe system either through gravity or by use of a positive displacement pump to boost pressures. Sometimes the paste is transported from the plant to remote boreholes or piping systems using above ground or underground transit mixers. A trade-off study is usually done to determine what is the most economical solution over the duration of the life of the project.

For hydraulic fill, settling of the solids is a real concern. The velocity in the pipeline must be high enough to keep the solids in suspension until the product reaches the filling point. As such, either the hydraulic fill needs to be produced on a continuous and on-demand basis, or an agitated surge tank needs to be considered. Several options are available to the plant designer including altering the mixer design so it not only acts to mix the materials but also as a surge tank for the process.

If a pumping method is selected to distribute paste backfill, one should also consider using this pump to convey the concrete required during the construction phase. The distance between the construction location and the multi-purpose plant may, however, render this unpractical, in which case the plant has to be constructed with the option to feed either a pump or a truck depending on the material being produced.

If shotcrete is also going be produced at the plant, it is likely that a truck load out will need to be added in order to allow for shotcreting and paste backfilling to take place concurrently or scheduled appropriately.

It is also important to note that production volumes for the plant need to be such that the 'instantaneous' capacity meets the maximum requirement of all the concurrent needs in the mine. This again may seem like a costly endeavour, while in practise the added cost may not be excessively high.

4 Example of alternative plant layouts

A sample flow sheet of a simple paste plant is shown in Figure 4. In this case, the plant is coupled with an operating mill and uses a thickener for initial dewatering, followed by a disc filter to bring the solids content above the final target level. A single cement silo is used to store a binder or a binder blend, which has been optimised through laboratory testing, to provide optimal strength versus cost for the production of cemented paste backfill.

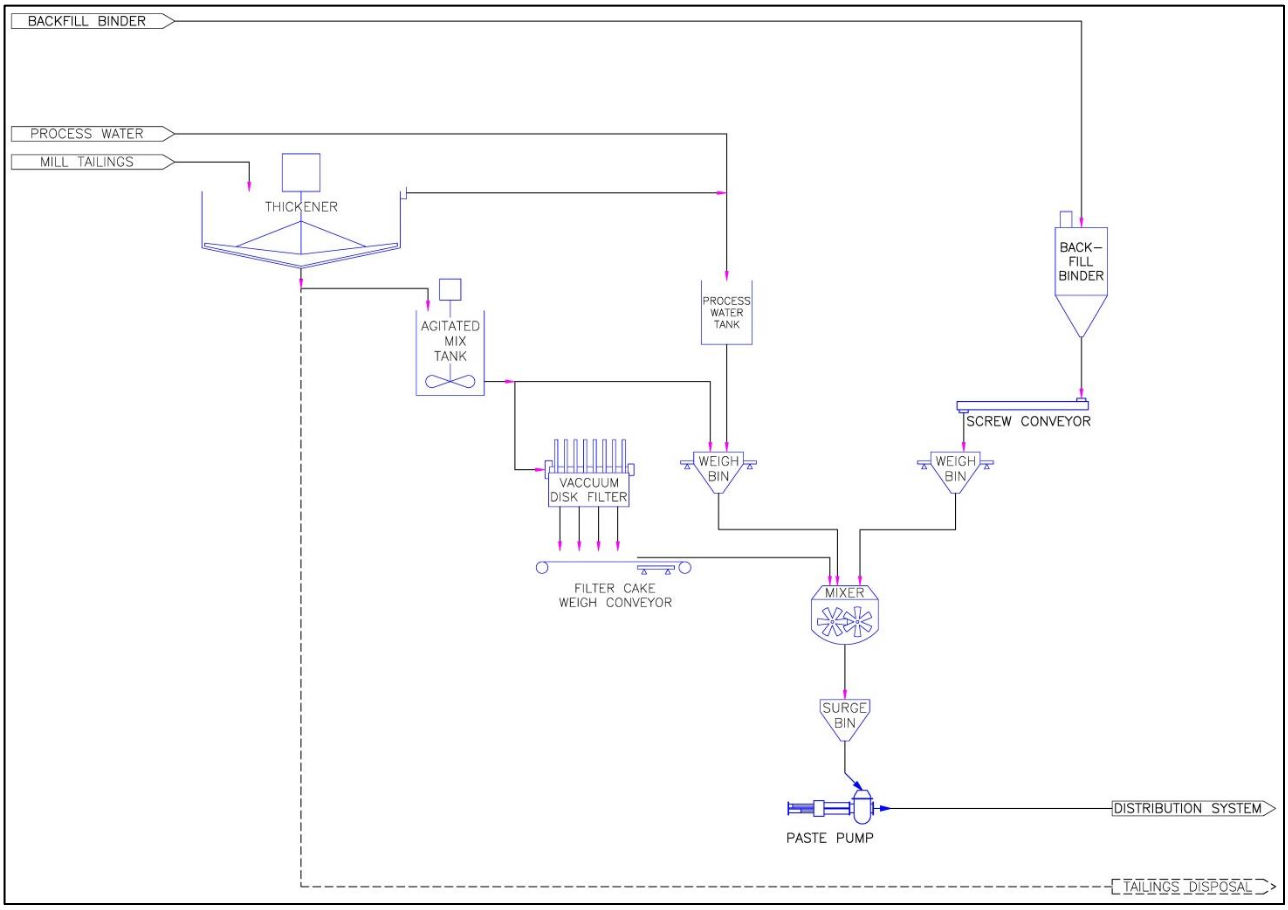

Figure 4 Simple paste plant

Figure 5 illustrates the same plant but with the added equipment to make concrete and shotcrete from the same plant. Note that a second binder silo has been added to provide storage for Portland cement (or additional capacity). In addition, a two compartment aggregate bin has been included with a scale to allow addition of a fine and coarse aggregate. A truck load out has been included as well, but does not add much cost as the elevation already exists at this point due to the need for a paste hopper under the mixer to feed the paste pump.

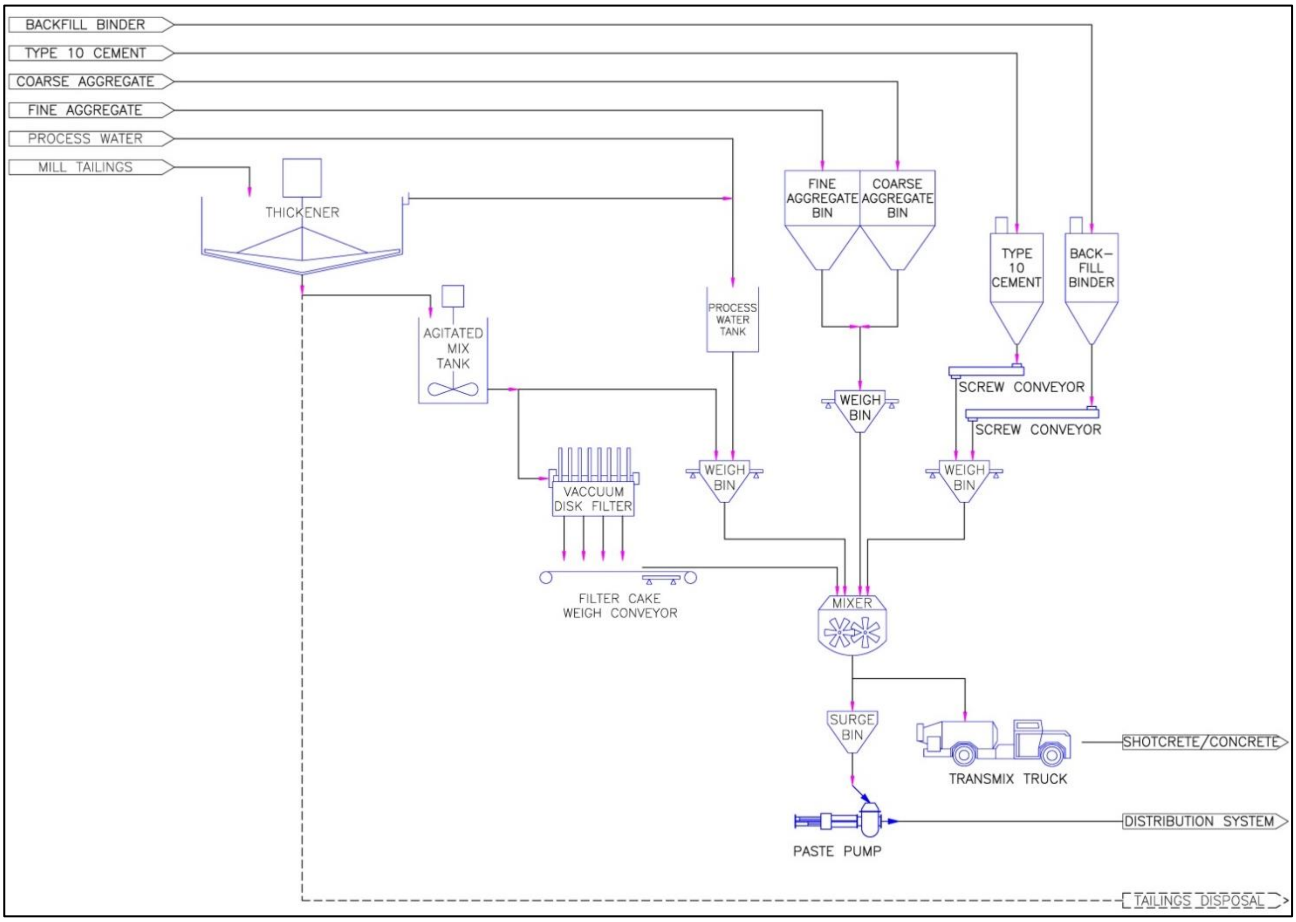

Figure 5 Multipurpose paste plant

5 Conclusions

During the life of a mine, various operational requirements arise for cemented and uncemented building materials for both above grade and underground installations. The materials that are required to be produced cover a wide range of physical properties to meet the specific needs of that application. If an underground mine requires a plant for producing backfill, it is recommended that an analysis be made to evaluate the added benefits of making that plant a multipurpose plant. In many cases, the additional cost is relatively low and provides several benefits:

- Increased independence from outside contractors and road access.
- In the case of remote plants where shotcrete and concrete must be produced on site, elimination of the additional equipment cost and maintenance associated with two plants (fill plant and concrete plant).
- Flexibility to produce a wider range of materials allows for adapting to changes in the economics of a mine during the life of that mine.
- Financial savings in mobilisation and demobilisation of mobile concrete plant.
- Flexibility to use tailings in shotcrete and concrete as well, particularly for projects where the tailings produced exceed the requirement for underground fill (typical for low percentage ore).

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