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How tailing characteristics affect capex and opex in filtration: two case studies

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Abstract

The treatment of tailings is increasingly becoming the focus of discussion and decision-making in mining operations. Safety hazards, environmental risks and freshwater consumption are the main topics of discussion and most, if not all, of the problems could be reduced if the tailings were dry stacked and the water was recycled back into the process. However, this is not for free and requires significant capex and opex.

Many experts consider filtration with filter presses to be the solution when it comes to enabling dry stacking. From a process perspective, there is nothing wrong with this answer. However, the capex and opex of filter presses are the highest compared to most other options. For the South American mega tailing projects with capacities of 100,000–200,000 t/d and above, the capital expenditure for filter presses exceeds EUR 1 billion.

It is therefore important to take a closer look at a range of filtration equipment options for safe dry stacking.

The paper presents two case studies with different outcomes and discusses the reasons for the differing results. Case study 1 is for a 'fine' tailing with 35 %w/w < 10 micron and requires pressure filtration to achieve the moisture required for dry stacking. Case study 2 is for a 'coarse' tailing with 15 %w/w < 10 microns. High performance vacuum disc filters already achieve the moisture required for dry stacking. Switching from filter presses to high performance vacuum disc filters already reduces capital costs from over EUR 1 billion to less than EUR 0.3 billion as shown in case study 2.

Keywords: *tailings filtration, vacuum disc filter, high performance vacuum disc filters, TSF, backfill, dry stacking, moisture, filter press, capex, opex*

1 Introduction

The treatment of tailings has become increasingly important in the discussion in mining. Safety hazards, environmental risks and consumption of freshwater are among the main topics to be under discussion. However, most, if not all, of these issues are reduced, if tailings are filtered and dry stacked in a tailings storage facility (TSF) (Inci et al. 2023). To do this, it is important to dewater the tailings to a moisture level that ensures that liquefaction does not occur on the conveyor belt enroute to the TSF. In addition, the moisture must be low enough to meet all geotechnical requirements for stable and safe dry stacking (McKenna 2023). The moisture required for this depends on the tailing properties like particle size distribution, but also on the chemical and mineralogical composition like clay content. Not knowing all this data in detail at the early stage of a project has led to a rule of thumb figure which is a moisture of 15 %w/w. This corresponds with the opinion that filter presses can achieve this 15 %w/w moisture and subsequently, filter presses, as shown in Figure 1, are taken as the preeminent filtration solution in many conceptual studies as well as pre-feasibility studies.

During the conceptual stage, this is certainly the right way to proceed. While there is little risk that a filter press will not get to the 15 %w/w moisture which minimizes the time required to get to a study result since it avoids a need for detailed testing and analysis. it is vital to take a wider look at dewatering equipment that might be suitable for tailings filtration to ensure cost effectiveness.

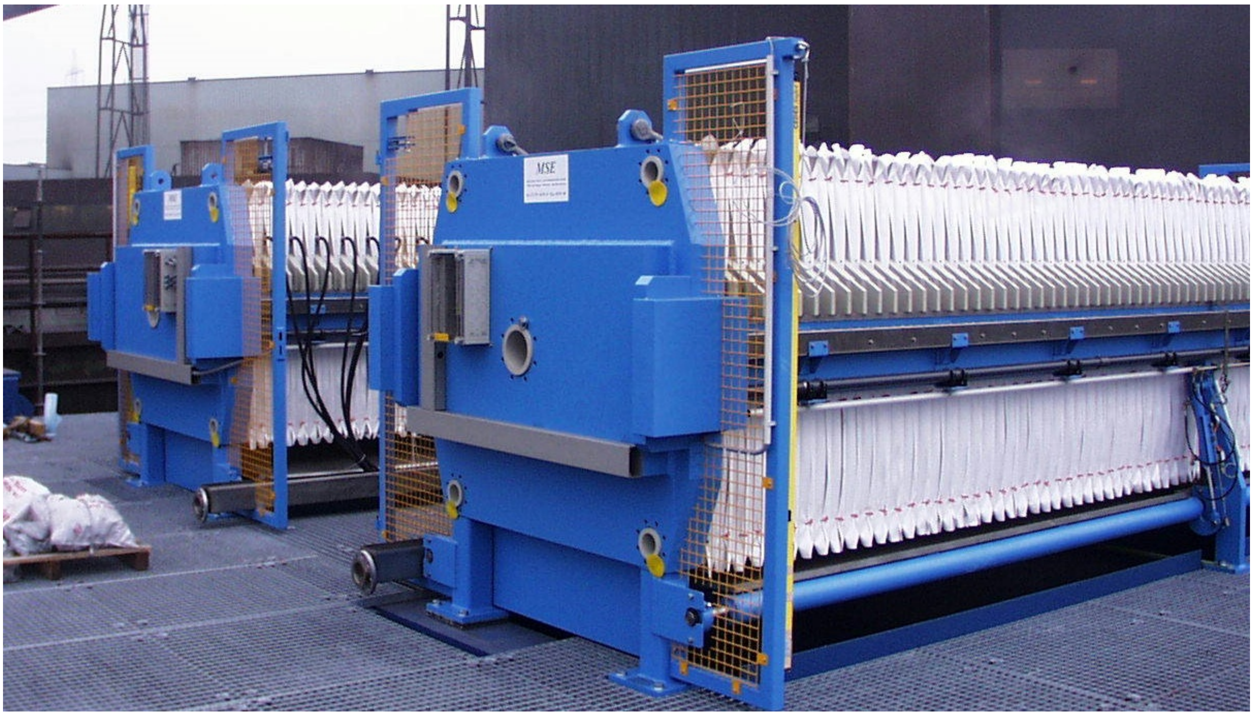


Figure 1 View of a filter press

2 High performance vacuum disc filters

For tailing filtration in mine backfill applications the use of vacuum disc filters is common practice. The moisture requirement for mine backfill is in the low 20 s as the tailings are typically mixed with cement and are hydraulically placed. The majority of mine backfill applications is < 10,000 t/d solids throughput and therefore, there is still room for standard vacuum disc filters as well as other vacuum filter types.

The situation changes, if TSF with 100,000 t/d or above are targeted. Now filters with high solids throughput and moisture < 20 %w/w are required. Now modern vacuum disc filters, so called 'high performance vacuum disc filters' as shown in Figure 2, are becoming an alternative to filter presses.

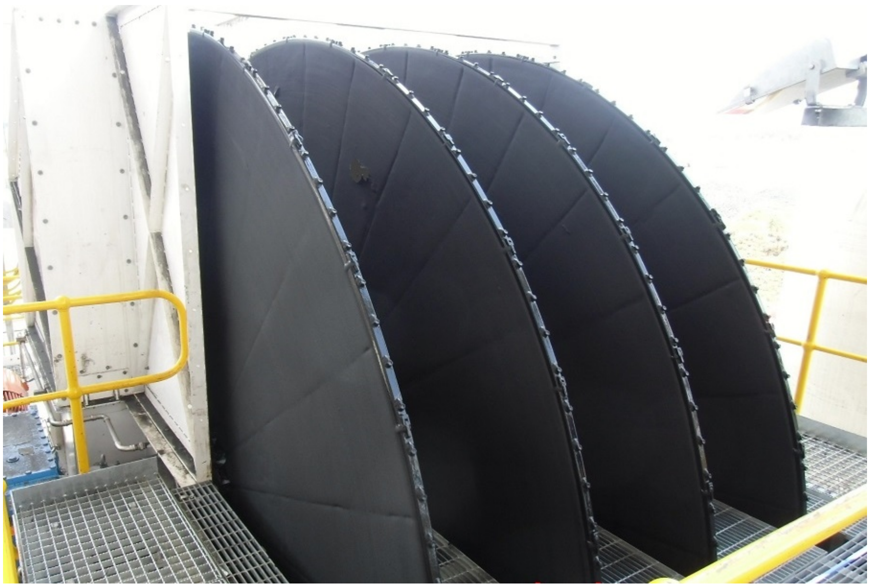


Figure 2 High performance vacuum disc filter

High performance vacuum disc filters (Hahn 2023) are designed for maximum solids throughput, which is why they can operate with slurry levels in the filter trough/bath of up to 50% as shown in Figure 3. At this high slurry level in the filter trough/bath, half of the filtration area is submerged in the slurry and can be used for cake formation while the other half remains for cake drying.

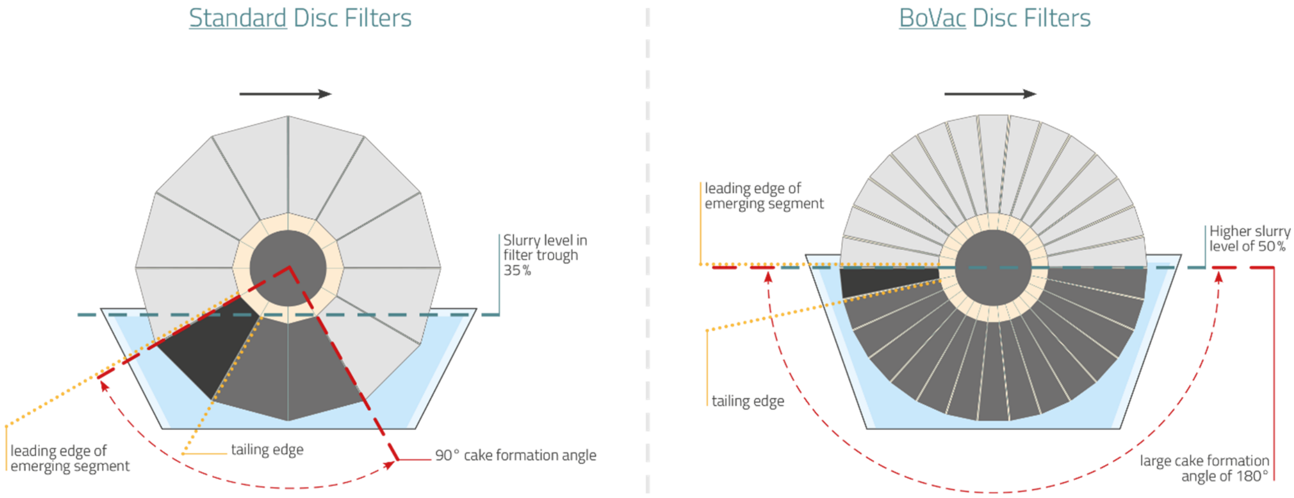
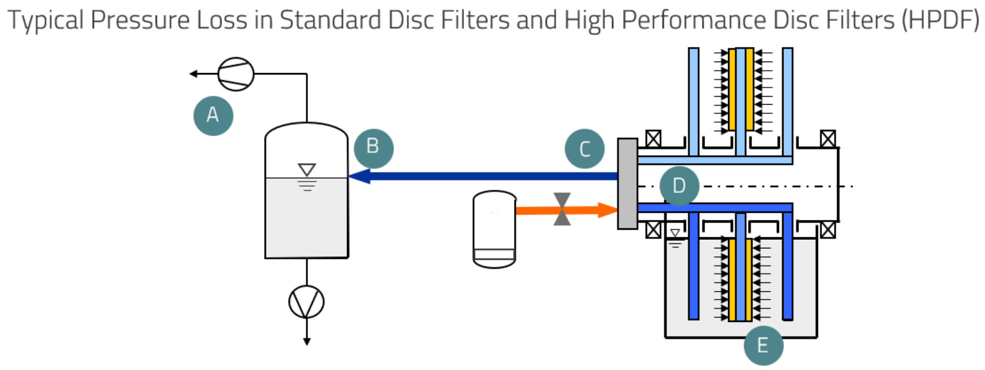


Figure 3 Slurry level and cake formation angle for standard disc filter and high performance disc filter

Furthermore, high performance vacuum disc filters are designed to minimise pressure losses by using:

- Trapezoidal filtrate pipes
- Pre-separation control heads
- High perforated filter segments
- Online cloth wash.

As a result, while standard vacuum disc filters get only half of the vacuum provided by the vacuum pump at the filter cake, high performance vacuum disc filters still get 80–95 % of the applied vacuum at the filter cake as the following Figure 4 shows.



Vacuum at:	A vacuum pump	B receiver inlet	C control head	D segment outlet	E filter cloth
Standard disc:	- 80 kPa	- 70 ... -75 kPa	- 55 ... -65 kPa	- 45 ... -55 kPa	- 30 ... -45 kPa
HPDF Tec:	- 80 kPa	- 78 ... -79 kPa	- 74 ... -78 kPa	- 70 ... -76 kPa	- 65 ... -75 kPa

Figure 4 Pressure drop on standard disc filters and on high performance vacuum disc filters

And this has a major impact on cake moisture. The diagram in Figure 5 shows the moisture of a tailing sample filtered at different vacuum levels.

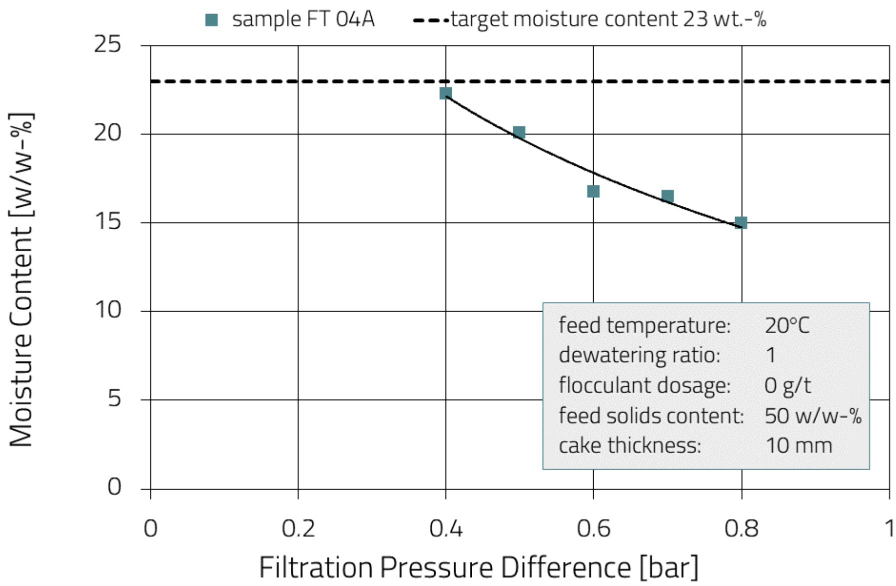


Figure 5 Moisture versus active pressure difference at the filter cake

The standard vacuum disc filter provides a vacuum of about -40 kPa (-0.4 bar) at the filter cake and thus, the moisture will be 22 %w/w. Due to the reduced pressure losses of the high-performance vacuum disc filters, it provides a vacuum of about -70 kPa (-0.7 bar) and thus a moisture of 16.5 %w/w. This is more than 5 %w/w points less moisture than the standard design disc filters. Therefore, it is recommended to consider high performance vacuum disc filters as an option for tailings filtration in case of dry stacking.

Not only is the moisture reduction significantly improved on high performance vacuum disc filters, but the solids throughput will, at the same time, more than double per 1 m² filtration area. A brief look into the filtration theory will explain why. The solids throughput of a rotational filter can be determined using the following equation:

$$M_s = m_s \,.\, A_f = \rho_s\,(1-\varepsilon) \,.\, \sqrt{\frac{2}{\eta_L\, r_C}} \,.\, \sqrt{\kappa} \,.\, \sqrt{\Delta p}\, \sqrt{\frac{n}{60}} \,.\, \sqrt{\frac{\alpha_1}{360°}} \,.\, A_f \,.\, 3{,}600 \quad (1)$$

where:

M_s = solids throughput of the filter (on dry solids basis)

A_f = filtration area of the filter

ρ_s = specific gravity of the solids in the slurry

ε = porosity of the filter cake

η_L = dynamic viscosity of the liquid in the slurry

r_C = relative resistance of the filter cake

κ = solids content coefficient defined as $k = c_v / (1 - \varepsilon - c_v)$

c_v = %volume/volume of the solids in the slurry

Δp = filtration pressure difference at the filter cake

n = rotational speed of the filter

α_1 = cake formation angle.

Table 1 highlights the parameters to be used in the above equation for both disc filter types.

Table 1 Differences between a standard vacuum disc filter and a high performance disc filter

	Unit	Standard disc filter	High performance disc filter
Maximum cake formation angle	°	90	180
Pressure difference at the cake	kPa	37.5	70
Rotational speed	rpm	0.5–1.0	1.0–2.5

The standard disc filter at its maximum rotational speed of 1.0 rpm is used as the baseline for the specific solids throughput in Figure 6. According to filtration theory, the pressure difference at the filter cake, the rotational speed of the filter and the cake formation angle all increase the solids throughput in relation to their square root. If the figures of Table 1 for the high-performance vacuum disc filter design are used, then the maximum solids throughput of the high performance vacuum disc filter design will be 305% compared to the 100% of the standard vacuum disc filter design. In other words, a project needs only a third of the filtration area if high performance vacuum disc filters are used instead of standard vacuum disc filters.

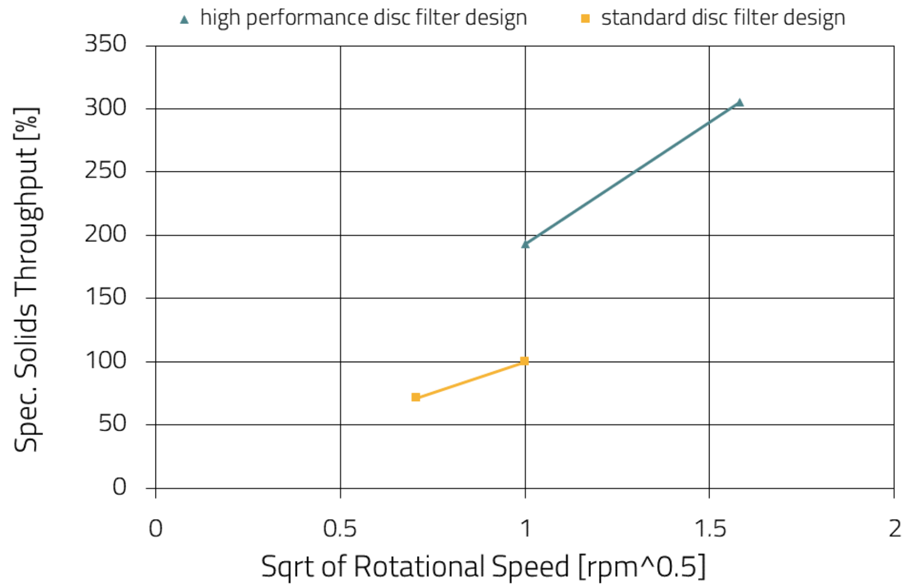


Figure 6 Specific solids throughput versus rotational speed

These high-performance vacuum disc filters are available with sizes up to 352 m² filtration area now. And with the moisture improvements and solids throughput increase shown, they are challenging filter presses for the filtration of tailings to be deposited on TSFs.

3 Case studies

The treatment of tailings becomes increasingly important if the metal content in the ore is low and if the production of concentrate is high. Both conditions fit very well to copper mining and processing in South America. Two projects were chosen for case studies. In both cases 100,000 t/d of tailings need to be filtered. However, the characteristics of the tailings are different as shown in Table 2. While the tailings of Project 1 in the Peruvian Andes were quite fine with 35 %w/w < 10 micron plus a high clay content, the tailings of Project 2 in Chile were coarser with 15 %w/w < 10 micron and a low clay content. Furthermore, the 94 kPa ambient pressure of Project 2 at an elevation of 600 masl is also good for vacuum filtration.

Table 2 Data of tailings of two mega tailings projects in South America

	Unit	Project 1	Project 2
Particles < 10 micron	%-w/w	35	15
Clay content	–	high	low
Target moisture	%-w/w	15	15
Plant elevation	masl	1,000	600
Ambient pressure	kPa	89	94

3.1 Case study: Project 1

The filtration data of Project 1 for both high performance vacuum disc filters and filter presses (Mantovani 2023) are listed in Table 3. The largest units available on the market are used for the comparison. While the filter presses benefit from the high pressure and the huge filtration area, the high-performance vacuum disc filters benefit from the short cycle time and generate a much thinner cake that can be discharged during continuous operation (Kern & Stahl 1986). Taking all these aspects into account, the performance data results for 100,000 t/d tailing filtration are as shown in Table 3.

Table 3 Performance of data high performance disc filter and filter press for 100,000 t/d tailing filtration

	Unit	High performance disc filter	Filter press
Total solids throughput	t/d	100,000	100,000
Total filtration area of filter	m^2	352	2,800
Solids throughput per filter	t/d	3,275	8,050
Number of filters in operation	–	31	13
Number of filters installed	–	34	15
Energy requirement per filter	kW	310	750
Total energy requirement per year	MWh/y	84,200	85,400
Flocculant dosage	g/t	0	0
Moisture	%-w/w	19.5	14.5

Since the moisture target is 15 %-w/w, and only the filter presses are able to reach this moisture, no further comparison of the two filtration technologies is warranted for this Project 1.

3.2 Case study: Project 2

Project 2 is processing a copper ore from Chile that results in a coarser particle size distribution for the tailings with only 15 %w/w of the solids < 10 micron (see Table 2), whereas Project 1 had more than double this amount of fines at 35 %w/w < 10 micron. Furthermore, the tailings of Project 2 contain less clay. The lower proportion of fines combined with the lower clay content in the fines have a significant influence on the specific solids throughput per m^2 of filtration area as well as on the moisture (Meiring 2023). Table 4 lists the performance data of both filter types for the 100,000 t/d tailing filtration required.

Table 4 Performance of data high performance disc filter and filter press for 100,000 t/d tailing filtration

	Unit	High performance disc filter	Filter press
Total solids throughput	t/d	100,000	100,000
Total filtration area of filter	m²	352	2,800
Solids throughput per filter	t/d	6,140	12,230
Number of filters in operation	–	17	9
Number of filters installed	–	20	11
Energy requirement per filter	kW	572	900
Total energy requirement per year	MWh/y	85,100	70,960
Flocculant dosage	g/t	0	0
Moisture	%-w/w	14.5	12.0

Project 2 also has a moisture target of 15 %w/w. Now both filter types reach this moisture target. The high performance vacuum disc filters achieve an average moisture of 14.5 %w/w while the filter presses get down to 12.0 %w/w. This puts Project 2 into the favorable position of being able to choose the filtration equipment from two options. Now it is important to have a closer look at and compare the opex and capex figures of both filter types.

4 Opex for Project 2

The operational expenditures (opex) of a filtration project are the sum of the following main factors:

- Energy consumption
- Filter aid consumption
- Freshwater consumption
- Consumables (mainly filter cloths)
- Operational and maintenance staff
- Spare parts.

Table 5 lists the technical data required to calculate the operational expenditures for both filter types. The total energy consumption for the filtration of 100,000 t/d tailings was already listed in Table 4 and is repeated in Table 5. The energy cost used for the calculation is 0.08 EUR/kWh (80 EUR/MWh). Surprisingly the total energy consumption of the high-performance vacuum disc filters is higher with 88,100 MWh/y than the requirement of 70,960 MWh/y for the filter presses. This is in line with the results for other commodities such as coal where the energy consumption of vacuum filtration is higher compared to pressure filters as moisture levels approach the minimum achievable with vacuum (Hahn & Elsmore 2023).

Filterability enhancers such as flocculants which improve solids throughput or dewatering aid were not incorporated either for vacuum filters or for pressure filters.

The water consumption differs for the two filter types. Each high-performance vacuum disc filter consumes about 1 m³/h water for cloth wash plus an additional volume of the same range for make up water for the vacuum pump seal water circuit. But the exact volume depends on the circuit design and whether heat exchange or a cooling tower is used to reduce water temperature. Typically, each filter press requires 145 m³/h of process water. for the purposes of this case study the opex calculation and comparison is based on the use of recycled water so the water cost is taken as zero.

Table 5 Opex of Project 2

	Unit	High performance disc filter	Large filter presses
Total solids throughput	t/d	100,000	100,000
Number of filters in operation	–	17	9
Energy			
Energy requirement per filter	kW	572	900
Total energy requirement per year	MWh/y	85,100	70,960
Total energy cost per year	**EUR/y**	**6,808,600**	**5,676,500**
Filter aid			
Flocculant dosage	g/t	0	0
Total filter aid cost per year	**EUR/y**	**0**	**0**
Consumables			
Number of cloth changes per year	–	6	8
Quantity of cloths per filter	–	180	560
Cost per filter cloth	EUR	50	300
Cost per filter per year	EUR	54,000	1,344,000
Total cost of cloths per year	**EUR/y**	**918,000**	**12,096,000**
Spare parts			
Cost per filter with auxiliaries	EUR	40,000	260,000
Total cost of spares per year	**EUR/y**	**680,000**	**2,340,000**
Total opex	**EUR/y**	**8,406,600**	**20,112,500**

Consumables in filter presses are mainly the filter cloths required to be changed on a regular basis because they block up with particles and scale (e.g. calcium) over time and they develop holes or tear due to mechanical stress. Here we see a big advantage of the high-performance vacuum disc filters. Firstly, they require fewer cloths per filter and secondly, the single cloth last longer (approximately 2 months compared to 1.5 months on the filter presses) and finally, the cost per cloth is much less. There are therefore less manpower and man hours required for the cloth change on the vacuum filters compared with filter presses. In terms of cost, the filter cloth cost of the vacuum filter is only 7% of the cloth cost of the filter presses.

For this case study, the required man hours of operational and maintenance staff could not be determined in detail and were therefore excluded from this comparison.

Finally, the cost of spare parts has been calculated on the basis of the number of filters in operation. Two per cent of the investment costs for both filtration options and associated auxiliary units are considered as the annual requirement of spare parts. This leads to about three times the cost for spare parts for the filter presses compared with the high-performance vacuum disc filters.

In summary, it can be stated that the operational expenditures for Project 2 will be EUR 20,112,500 for the filter presses compared to EUR 8,406,600 for the high-performance vacuum disc filters. This means that the filter presses require almost 2.5 times the opex compared to high-performance vacuum disc filters. And this is mainly a result of the high cost for consumables and spare parts. Even, if the cost for water consumption and for staff were to be included in this comparison, there would not be a significant difference. However, based on experience from running plants, it is expected, that the water consumption and the manpower requirement of the filter presses will be higher, which will further increase the differential in opex.

5 Capex of Project 2

To accommodate the 100,000 tpd throughput, the biggest available filters on the market were used for the case studies of both projects. Since both are relatively new on the market, the price basis is not as firm as it is for smaller units. Furthermore, the political turbulences in the last two years following the COVID-19 period have led to significant increases of energy and metal cost, a rise in inflation, difficulties in supply chains, as well as a several other factors. Therefore, the capex figures for Project 2 will have an accuracy of no better than ± 25%. Nevertheless, since these issues apply to the capex of both options this does not have a big influence on the final outcome as Table 6 shows.

Table 6 Performance data of Project 2

	Unit	High performance disc filter	Large filter presses
Total solids throughput	t/d	100,000	100,000
Total filtration area of filter	m²	352	2,800
Number of filters in operation	–	17	9
Number of filters installed	–	20	11
Cost per filter including auxiliaries	EUR/unit	2,000,000	13,000,000
Total equipment cost	**EUR**	**40,000,000**	**143,000,000**

The cost for the 11 filter presses required for the 100,000 t/d tailing filtration is EUR 143,000,000 compared to the Eur 40,000,000 for the high performance vacuum disc filters and this is the filtration equipment only. If the filter building, the piping, cabling, electric and electronic equipment, the engineering, construction and commissioning is included, these figures have to be multiplied with a factor in the range of 2.5 to 3.5. This means the turnkey cost will be in the range of EUR 100,000,000–140,000,000 for the high-performance vacuum disc filters option and EUR 357,500,000–500,500,000 for the filter press option, and because both filter types provide a cake with a moisture of < 15 %-w/w, both filter types are suitable and acceptable for the project. The project could save between EUR 257,000,000 and 360,000,000 with the vacuum filter option.

6 Conclusion

The importance of tailings filtration as a means to reduce safety hazards, environmental risks and freshwater consumption will become an increasing factor for the longevity of mining operations and the permitting of new processing plants, but the investment cost as well as the high operating costs for tailing filtration remain high causing owners to think twice about going down the filtration route. However, a closer look at the characteristics of the tailings and their filtration properties may offer alternative filtration technologies such as high-performance vacuum disc filters that will have lower capex and opex in comparison to pressure filtration, as shown in Project 2, provided the tailings characteristics are as such as to enable the target moisture to be achieved with the vacuum filters. The comparison of the two copper tailing projects provides answers to the question raised in the abstract of the paper. The comparison clearly show that coarser particles and less clay increase the chance of reaching the target moisture already with high performance vacuum disc filters, and even if the tailings are as fine as the tailings of Project 1, there are still options for the use of alternative filtration technologies. One option is to split the tailings (e.g. with cyclones) and filter the coarse fraction with high performance vacuum disc filters and the fine fraction with filter presses or belt presses. Another option is to use the high-performance vacuum disc filters and spread out the filter cake at the TSF for further drying by sun and wind until the target moisture is reached. And the reduction in filtration opex and capex would further improve the lifecycle cost of the tailings treatment especially when including cost for water, land, carbon tax and mine closure (Carneiro & Fourie 2019) into the calculation.

Which filter technology or combination of technologies will reach the target moisture can be assessed with lab testing at an early stage of a project with very little cost impact, and if this confirms the use of high-performance vacuum disc filters for the project, then the project can benefit by a 70% lower capex in comparison with the filter press capex as well as 60 % lower opex by installing high performance vacuum disc filters. This could make the difference for a project to be feasible and going ahead or not.

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