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# Large-scale thickened tailings delivery and distribution system upgrade and optimisation

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## Abstract

*This paper presents the design aspects and challenges involved in upgrading an existing thickened tailings delivery and distribution infrastructure with the aim of utilising the system for a newly constructed tailings storage facility (TSF). The operation is Oyu Tolgoi, the largest copper and gold mine in the Inner Asia region with a total throughput of 40 Mtpa. The thickened tailings are currently discharged to the existing TSF cell at a solids concentration of 56 – 64%. Similar to the existing TSF cell, a new cell is designed as a turkey-nest-type TSF which will be raised annually using the mine waste. The new TSF cell is about 2 km long by 2 km wide and the tailings will be distributed to the TSF from the western and northern walls via multiple manifolds and spigots using a specifically designed linear distribution system.*

*The proposed upgrades to the tailings delivery pipeline and the modified linear distribution system will significantly improve the operation of the existing tailings pumps and optimise the tailings deposition into the new TSF. The proposed modifications also minimise the need for relocation of the excessively large tailings pipes during the operational life of the TSF.*

*The proposed upgrades and alterations to the existing infrastructures are discussed and presented in this paper.*

**Keywords:** *thickened tailings, tailings delivery, linear distribution system, operations improvements*

## 1 Introduction

Oyu Tolgoi is the largest copper and gold mining company in Mongolia, and is a partnership between the Government of Mongolia, Turquoise Hill Resources and Rio Tinto. This operation is located in the aimag (province) of Umnugovi, the south Gobi region of Mongolia which forms the border with China. It is located approximately 550 km south of Ulaanbaatar, the capital city of Mongolia (Figure 1).

Commissioned in 2013, the mine comprises a combined open pit mining and flotation plant, with a future underground project planned. Tailings from the concentrator are currently discharged into the existing TC1 TSF, which has been in operation since 2013 but is expected to reach its capacity in 2023. Therefore, the existing TSF needs to be upgraded with the construction of a new TSF, TC2.

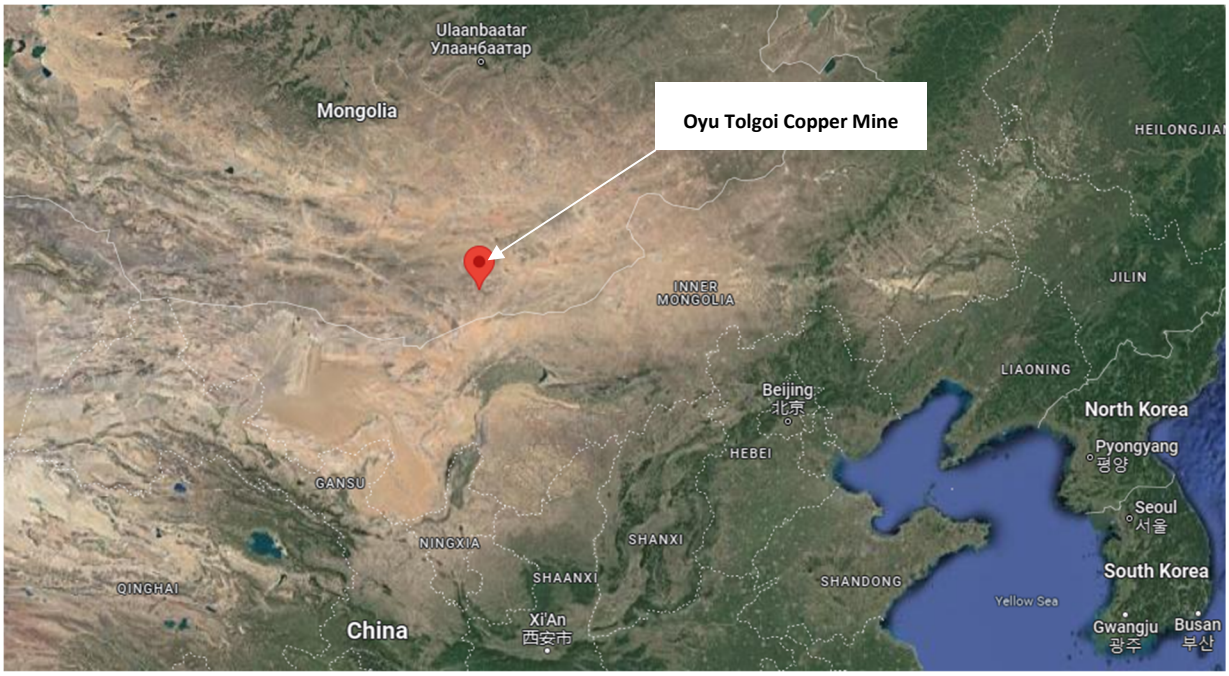



**Figure 1 Site location (Google Map)**

Figure 2 shows the current site infrastructure and the proposed location for the construction of the new TSF.

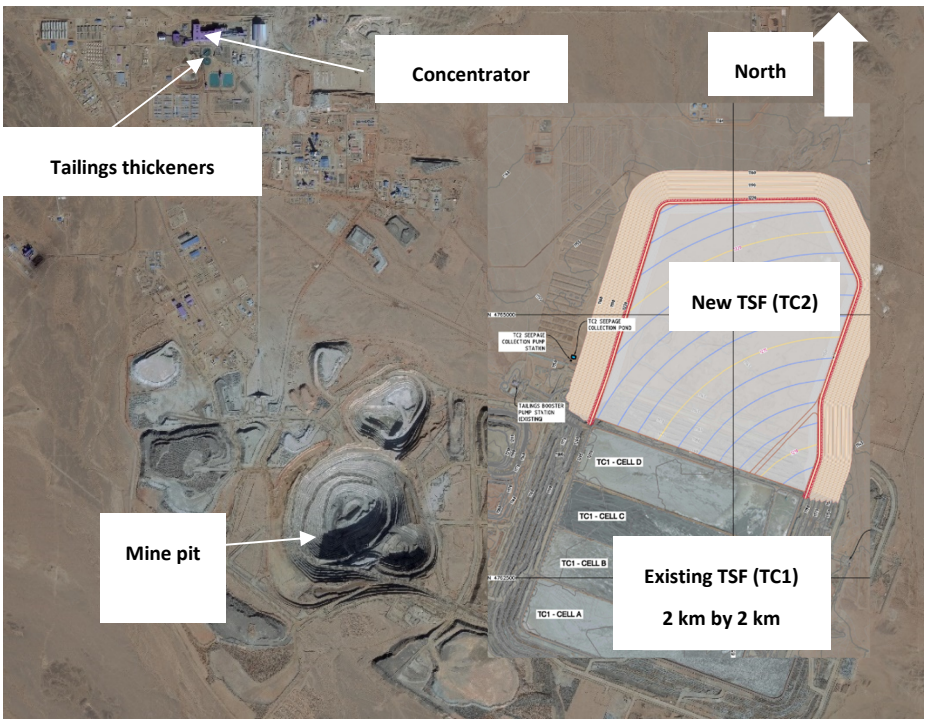



**Figure 2 Site layout**

TC1 accommodates tailings production in the order of 116,000 tonnes per day (tpd). TC1 embankments are typically raised by approximately 5 to 7 m per year to maintain tailings storage and flood freeboard capacity. The eventual height of the perimeter embankments will be approximately 70 m.

Similar to TC1, TC2 will be constructed in multiple stages to the north of TC1 (Figure 1), with the northern embankment of TC1 forming the southern embankment of TC2. TC2 will comprise a similar final height elevation to TC1.

# 2 Existing infrastructure

The tailings delivery system of the existing TSF consists of two high-rate thickeners and multiple stages of pumping, and a linear distribution system.

Two trains of tailings transfer pumps (two centrifugal pumps on each train, one train operating and one on standby) are used to deliver the underflow from each High-Rate Thickener (HRT) to the booster tailings pump station (BTPS). The thickeners are fitted with recirculating pumps to allow the temporary stopping of the tailings transport system in case of any emergency downstream.

The second stage pumps are located approximately 300 m downstream of the thickeners, which use centrifugal pumps and are equipped with variable frequency drives. Tailings from the two thickeners are combined to feed one of the two overland PE DN750 pipelines which transport the slurry to the tailings booster pump station.

Figure 3 shows the location of the tailings booster pump station which is in close proximity of the northeast corner of the TC1 embankment. This pump station transfers and distributes tailings to the TC1 sub-cells via two separate pipelines and multiple spigots.

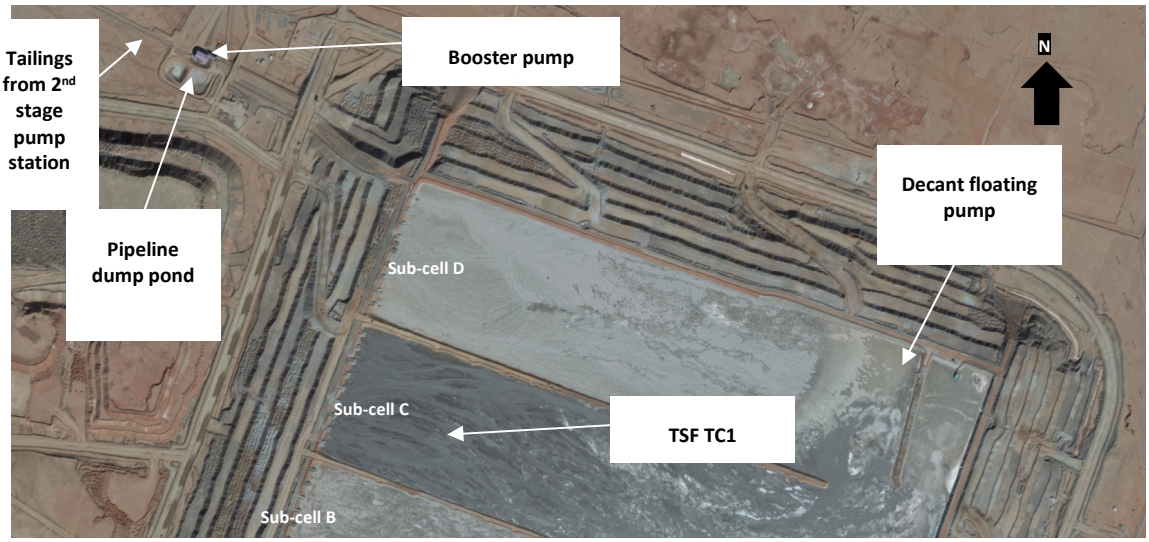



**Figure 3 Booster pump station and TC1 TSF**

The booster pump station is a key component of the existing tailings management system that accommodates the tailings delivery and distribution to TC1 for various stages. The pump station involves a three-staged centrifugal pumping using U-AHPP 20/18 Warman pumps with 1,900 kW electromotors. The third pump in each train was added in 2015–2016 when the required pumping duty exceeded the two-stage pumping head.

Two pipelines, one operating at a time, send pump station discharge tailings into the TSF. Line #1 delivers tailing to sub-cells C and D, and line #2 delivers tailings to sub-cells A and B. The tailings lines are interconnected after the pump's discharge to enable switchover from one line to another. The TSF has four sub-cells with one sub-cell operating at a time. The first 0.5 km of the pipelines up to the end of the TC1 ramp is rubber-lined carbon steel (CS) NB750. The second section of the pipeline (approximately 2.0 km), laid on the crest of the embankment, is HDPE DN800. The spigots are installed here to discharge into the sub-cells.

The spigots arrangement for the existing TSF has evolved since the commissioning in order to improve tailings distribution and the hydraulic performance of the system. The original spigot set-up had three spigots taken from the main header pipe at 130 m spacing (Figure 4) and all three spigots were active at a time.

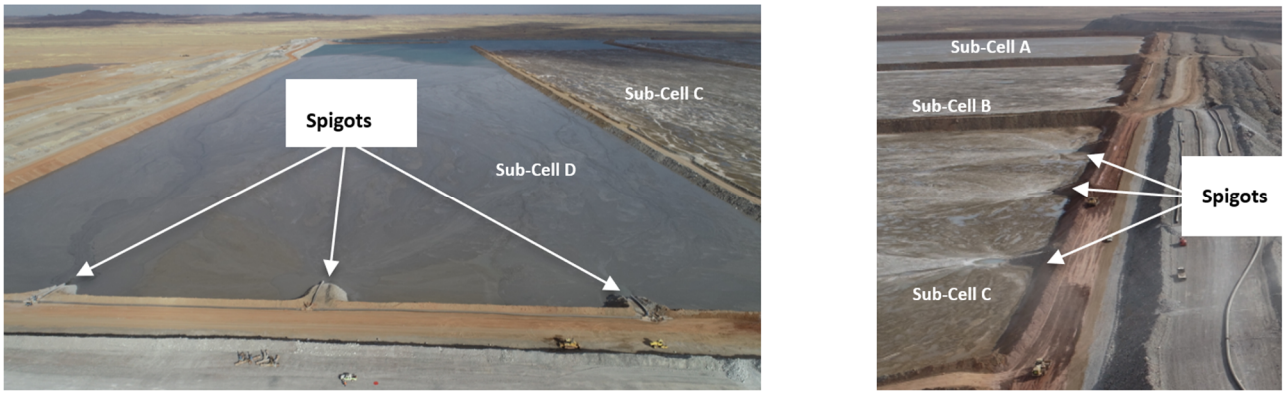
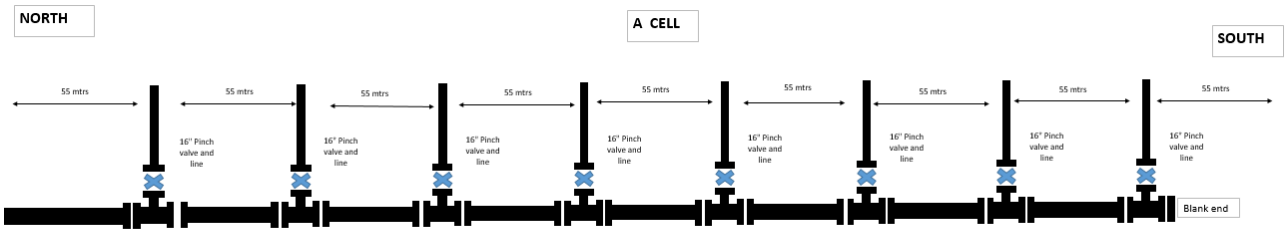
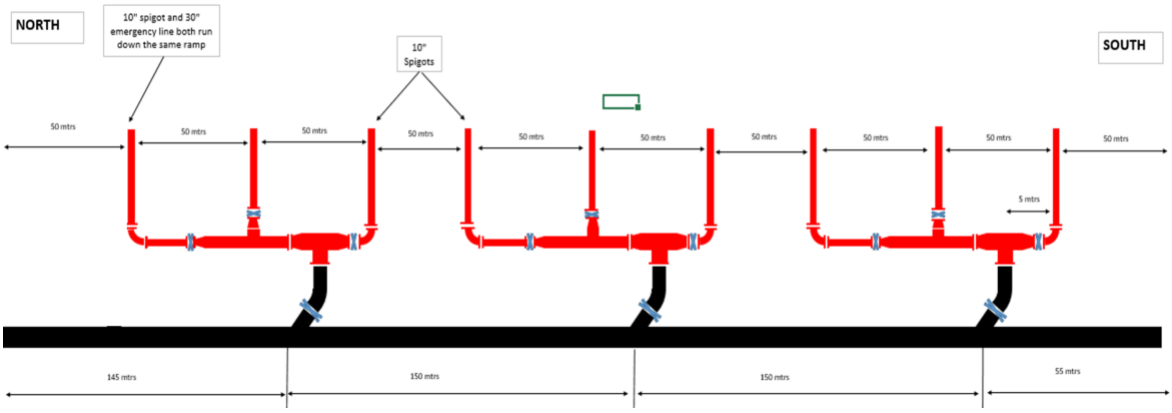



**Figure 4 Original arrangement of existing TSF sub-cells spigot**

With tailings deposition channelisation caused by continuous flow discharged from spigots and the problem with solids travelling to the decant pond, the number of spigots has been increased from three to over six outlets. A few other arrangements have been tried to improve the tailings deposition and distribution as part of the existing TSF operation. The arrangements on the other sub-cells are conceptually the same as those taken from the main header pipe, with slightly different set-ups as shown in Figure 5.




(a)




(b)

**Figure 5 TC1 sub-cells spigots current arrangement. (a) Sub-cell A; (b) Sub-cell B**

# 3 New TSF tailings delivery and distribution objectives

For the new tailings storage , a new tailings delivery and distribution system was required. The considerations and objectives for the design of the new tailings delivery and distribution system are:

1. A tailings distribution and spigots system upgrade to improve the tailings storage cell operation, i.e. to reduce the tailings channelisation and prevent solids from travelling to the decant pond.
2. A flatter beach slope to improve the cell storage capacity .
3. Minimum upgrading and alterations to the booster pump station.
4. Providing the opportunity to use the decant water return system for flushing of tailings lines.
5. Future tailings discharging into the new TSF, material characterisation and adaptation of an updated design based on the upstream operation that is critical for any operating system rather than relying on the original plant design (Javadi et al. 2020).

# 4 Proposed system

## 4.1 Tailings pipeline system

Two pipelines (one primary and one emergency) are proposed to deliver the tailings to TC2. The primary pipeline is new and will start from a new offtake from the existing pipeline just outside of the pump station. It runs in an easterly direction towards TC2, then turns to the northwest corner of the TC2 embankment and extends north until Ch. 2+000 m, where the access ramp to the TC2 embankment starts (as shown in Figure 6).

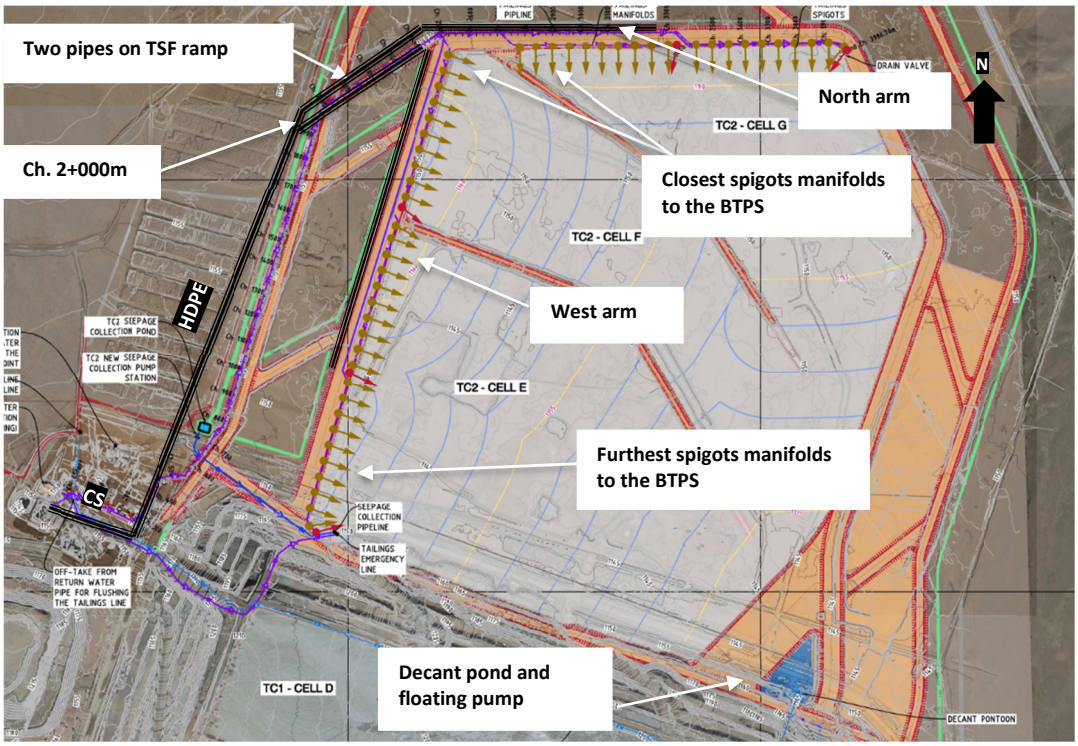



**Figure 6 New TSF tailings pipework arrangement (Stage 1)**

The new pipeline will be laid on a new access road along the western embankment until Ch. 2+000 m, where the pipe ramp to the crest of the TSF starts. This provides a platform to connect the delivery pipe to the perimeter pipes. Unlike the delivery pipeline access road, this ramp must be raised with each TSF raise.

To prevent the tailings delivery interruption while raising this ramp, two pipes (one connecting to the western arm and a second connecting to the northern arm) are installed on it. The ramp is designed to allow the raising of half of it while the second pipe is operating (Figure 7). Once the first pipe is reinstalled on the lifted ramp and commissioned, the second pipe can be decommissioned and relocated to enable the raising of the second half of the ramp. After the ramp raise is complete, the second pipe can be reinstated.

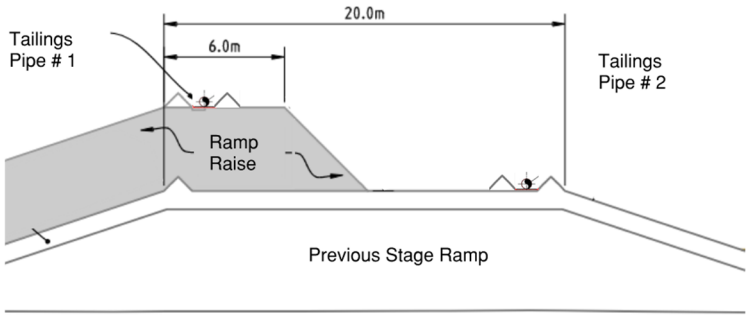



**Figure 7 Tailings pipe arrangement on the ramp**

The proposed new pipeline is a combination of CS and HDPE pipeline. From the Stage 1 to Stage 3 embankment raise, the pipeline consists of rubber-lined CS NB800 ASTM A53 Gr. B 9.53 mm (or CS NB 800, 11.13 mm wall bare steel), then DN1000 PN20 HDPE followed by DN1000 PN16 HDPE. At the Stage 4 raise, the HDPE pipe laid on the tailings pipeline access road is required to be replaced with a rubber-lined DN800 CS 9.53 mm wall pipe (or CS NB 800, 11.13 mm wall bare steel) to cater for high pressure.

The perimeter pipes consist of two arms: one running along the western embankment crest and the other running along the northern embankment crest. The north and west arms will feed three and two spigot manifolds, respectively.

These arrangements are necessary to keep the duty points within the preferred region of the pump performance curves when the tailings are discharged through different spigot manifolds.

The pipeline is sized and selected based on the updated design to reflect the recent tonnages and rheological testing results obtained from future tailings samples. Depending on the tailings solids concentration, a transitional velocity of 2.5–3.6 m/s is predicted (Javadi et al. 2020).

In order to avoid selection of a very conservative pipe size, a maximum deposition depth of 40% for extremely low flow at the maximum solids concentration is accepted, given that the current operation shows the materials are resuspendable once the nominal flow is achieved.

Figure 8 shows the predicted hydraulic gradient line (HGL) for tailings delivery pipelines to the furthest spigots. The pipeline operating pressure is also compared with the maximum allowable operating pressure (MAOP) of the proposed pipes for three different flow rates. The blue dashed line represents the MAOP for the worn pipe.

For used HDPE and CS pipes, the pressure is de-rated based on pipe wall erosion. A wear rate of 1 mm/year for HDPE pipe and no wear rate for the rubber-lined steel pipe are adopted.

Particle deposition in the pipeline is expected at high (64%) solids concentration (Cw) and low tonnages, but the overall depth of deposition is well below 40% of the pipe diameter, which is often acceptable for resuspendable material.

Figure 9 shows the HGL for the final stage of TC2 while discharging from the furthest spigot. The maximum required pumping pressure for the furthest spigot at the last stage is associated with the minimum tonnage (i.e. 4,750 t/h) and the maximum solids concentration (i.e. 64%) is approximately 2,280 kPa. The required pumping head is approximately 143 m slurry head. For a nominal operation (i.e. a flow rate of 5,350 $m^3$/h, Cw = 60%), the total required pumping head is 120 m of slurry. The head losses are predicted based on the Wilson & Thomas (2006) model.

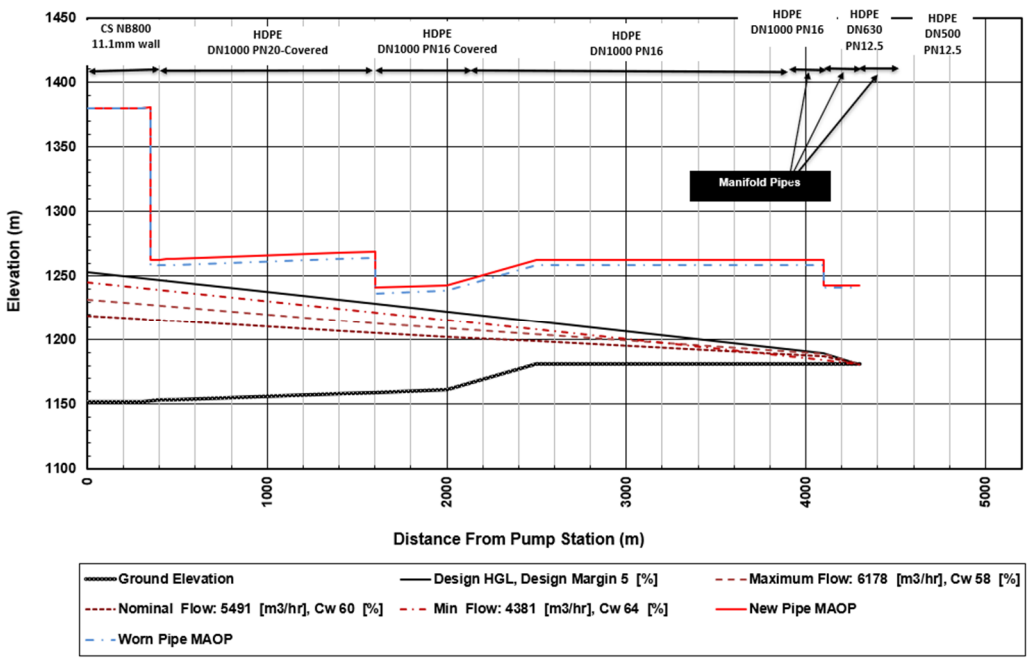



**Figure 8 HGLs for the furthest spigot – Stage 3**

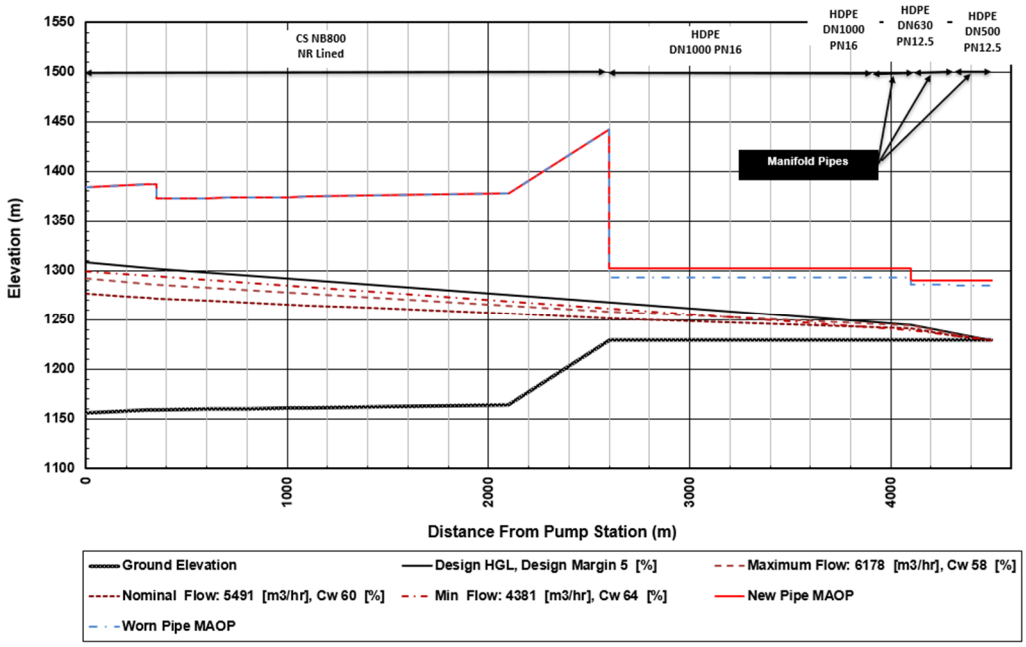



**Figure 9 HGLs for the furthest spigot set (G02) – Stage 11**

## 4.2 Tailings distribution system

Two different tailings distribution and spigot arrangement systems are usually used for flow splitting: the linear discharge system (LDS) and central discharge system (CDS). Each has pros and cons in terms of hydraulics, operational challenges, and effectiveness in flow splitting and minimising flow remerging on the beach to achieve a uniform deposition and required beach slope. Overall, it is concluded that in most cases, the CDS is a more effective, easier to operate and less costly design in comparison to the LDS (Pirouz et al. 2020).

For this case, given the TSF geometry and existing operation, the LDS system is preferred and an improved arrangement for the tailings spigots is proposed based on the lessons learned from the existing operation. The spigots will be installed on a manifold instead of the main header (distribution pipe). Five manifolds, three on the western wall (E01, E02 and F01) and two (G01 and G02) on the north wall, each approximately 600 m long and accommodating 10 spigots, are proposed. Depending on which manifold is under operation, the others can be isolated from the main perimeter pipe using manually operated hydraulic knife gate valves.

An NB500mm knife gate valve is also proposed for installation after the last spigot. The valve is to drain the manifold and also purge the line at the extremely low flow rates . To purge the manifold, the proposed valve should be opened while spigots 1, 2, 3 and 4 are closed.

Figure 10 shows the typical proposed spigot manifold arrangement. The TC2 deposition modelling is based on one active manifold and five running spigots. The spigots are NB150 fitted with an isolation slurry valve. To achieve an even tailings distribution via these multiple spigots, pinch valves are recommended as they may require throttling.

Also, given the considerable length of the manifolds (i.e. 600 m), the manifold pipe size is designed to be telescopic (i.e. the pipe size reduces along the manifold to DN630 and DN500) as the flow rate reduces along the manifolds after each spigot offtake. The pipe size reduction maintains the flow in a transitional regime and prevents the pipes' partial or full blockage.

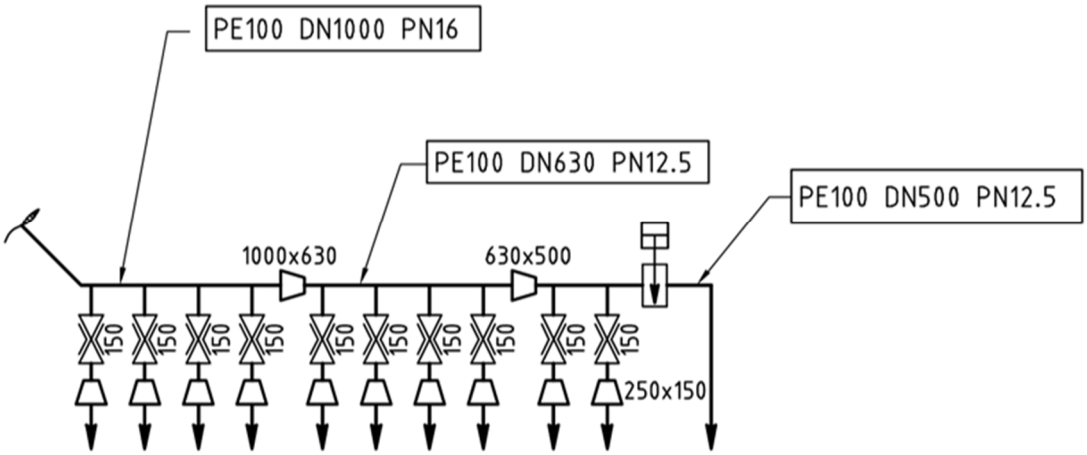



**Figure 10 New TSF spigots arrangement**

Figure 11 shows the predicted discharge flow from the active spigots for various flow cases (nominal, minimum and maximum) for the proposed manifold arrangement. The flows from the spigots are predicted using an orifice coefficient of 0.75. Various orifice sizes and manifold arrangements have been checked to achieve a reasonably evenly distributed flow from the active spigot. As seen, the distribution for the nominal and the maximum flow rates are reasonably uniform (with ± 10%). However, for the minimum flow, due to the possible deposition in the manifold pipe, the performance of the manifold is expected to be slightly reduced.

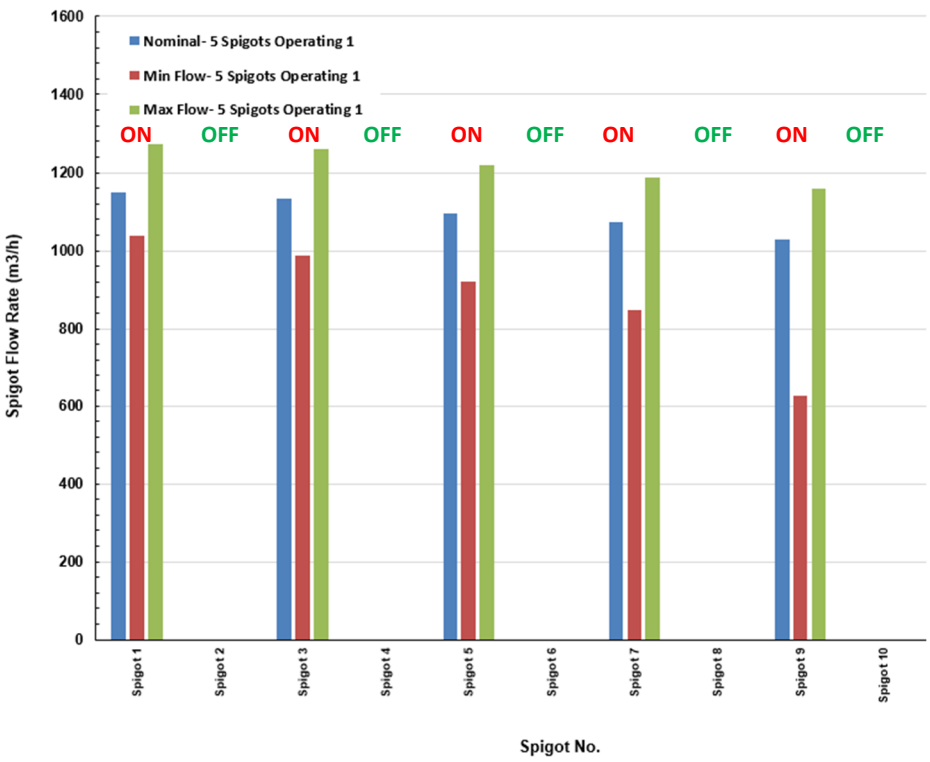



**Figure 11 Manifold flow distribution (five open and five closed): Cd=0.75**

# 5 Tailings booster pump station

## 5.1 Pumping requirements

The BTPS, as one of the major existing infrastructures, was required for utilisation by the new TSF. Using it will considerably reduce the initial cost for TC2 infrastructure provision and fulfills one of this design's objectives, which is to minimise the level of upgrading and modifications required on the BTPS for the new TSF while operating the pumps in the required range.

The hydraulic assessment of the proposed pipework and spigot systems showed that no modification and alteration was required up to Stage 6 of the new TSF. After that, upgrading the pumps' gearboxes to enable them to run at a higher speed (i.e. 440 rpm) is required, but the pump speed will still be within the range recommended by ANSI/HI 12.1-12.6. The new gearboxes will be dimensionally the same as the existing ones, requiring no rearrangement inside the pump station. The installed motors were found suitable with a reasonable design margin except for the final stage of TC2, based on the hydraulic power calculated.

Figures 12 and 13 present the predicted pumping requirement for tailings delivery to the furthest and closest spigots, respectively. The pumping heads are for the nominal and extreme cases of flow rate, i.e. nominal tonnage at nominal solids concentration, minimum tonnage at maximum solids concentration and maximum tonnage at minimum solids concentration. With the above minor modifications after Stage 6, the existing three-staged pumping will be adequate to handle the new duties, even when the tailings are deposited via the furthest spigots to cell E. Therefore, no alteration to the BTPS is expected. The existing tailings transport pipeline length is approximately 2.5 km, while the new one will be 4 km.

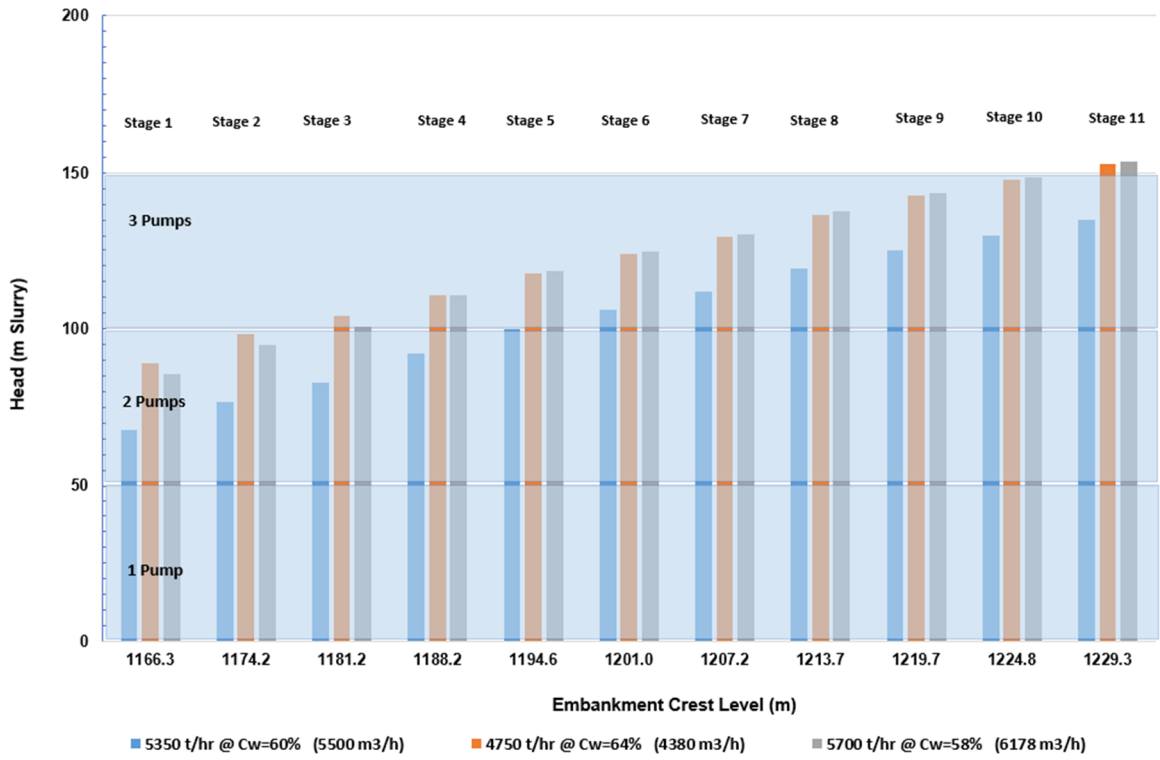



**Figure 12 Number of pumps required for each stage – furthest spigot manifold**

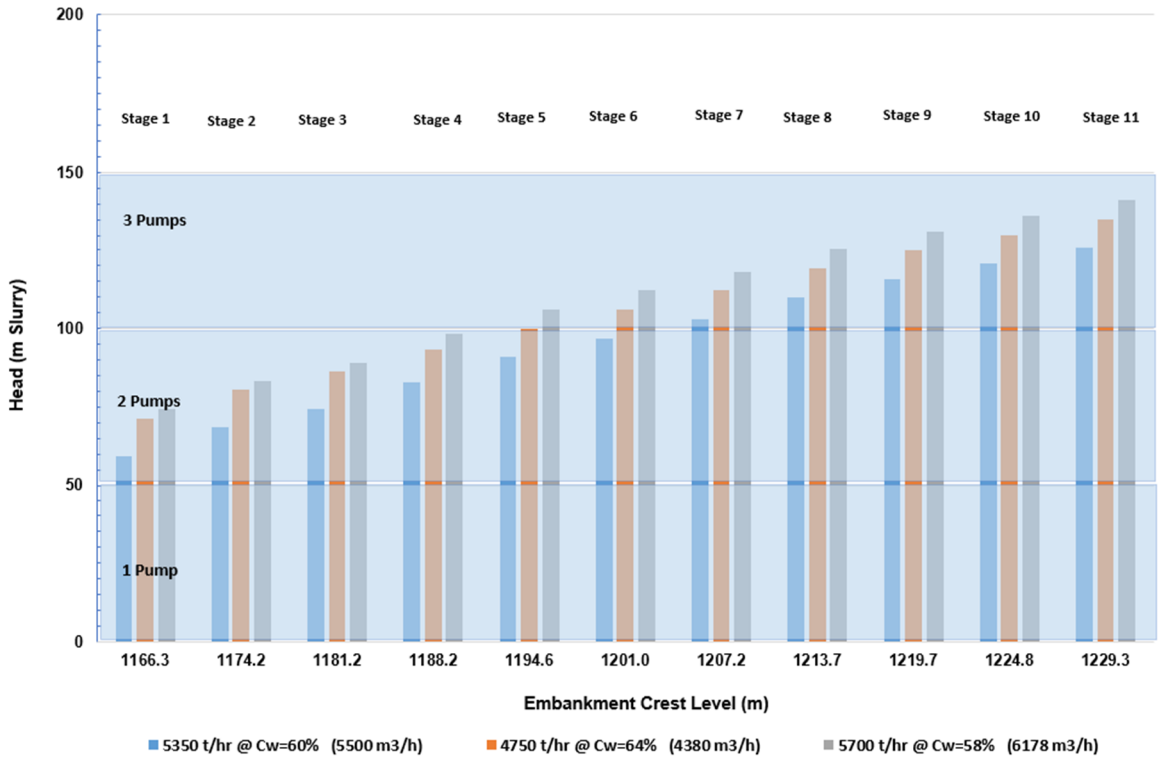



**Figure 13 Number of pumps required for each stage – closest spigots**

## 5.2 Pump performance

Furthermore, with the proposed pipework and selected pipe size, pump operation will be significantly improved compared to the existing operation where pumps are operated off-curve as presented in Figure 14.

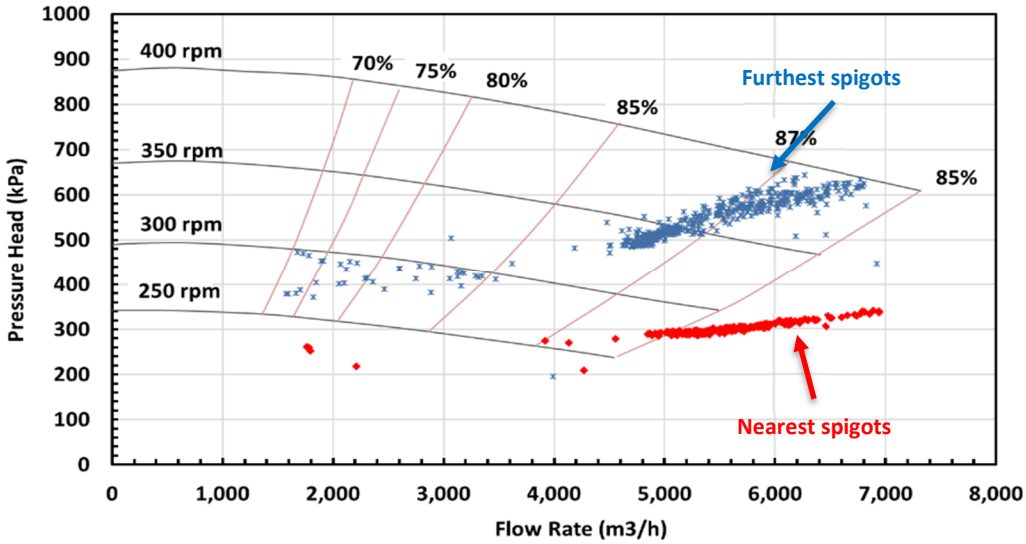



**Figure 14 TC1 pump performance**

Figure 15 plots the predicted duty points for the tailings delivery. The duty points are for the tailings delivery to the nearest spigots of TC2 Stage 1 and the furthest spigots of the final stage. It is evident that for the early operation, while two pumps are running in series, the pump's cavitation issue is totally resolved. Ideally, the duty points should be on the left-hand side of the best efficiency point (BEP). To achieve that, the existing pumps would require replacement with larger pumps, but this is an extremely costly option that is not preferred by the client.

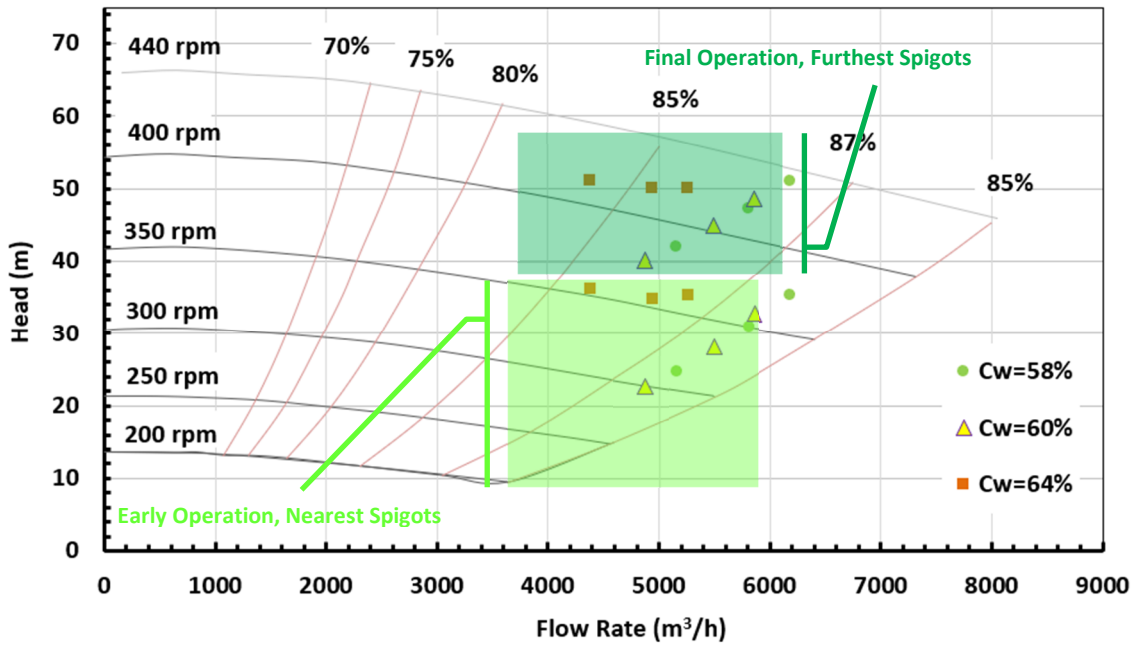



**Figure 15 Duty points – tailings delivery to TC2 manifold**

For the final stage, as seen in Figure 15 and discussed previously, the existing three pumps could handle the pumping duty; however, the existing pump's gearbox should be upgraded in order to achieve a slightly higher pumping speed (i.e. 440 rpm).

# 6 Conclusion

An overview of the proposed design for the tailings delivery and distribution system for a new TSF at the Rio Tinto Oyu Tolgoi copper mine in Mongolia was presented in this paper.

The new proposed design maximises the utilisation of the existing BTPS without any upgrades and alterations required for the early stages of the TSF life (some alterations will be required after Stage 6 of TSF life). With the proposed pipe alignment and selected pipe size, considering the rheological parameters of tested tailings and the current operation process figures, the existing pump station with the current three stages will handle the required pumping duty, even if the transport length is increased from 2.5 km (existing TSF) to 4 km (new TSF) with the same static head.

Furthermore, the followings improvements are achieved in the new design:

- An absence of pump cavitation is expected for the different stages of TSF and different active spigots.
- Given the lessons learned from the current operation, an upgraded tailings spigots manifold system is proposed in the new design which will improve the tailings deposition by achieving a more uniform tailings distribution that minimises beach channelisation and prevents partial blocking of the main header tailings pipe.
- Interconnection from the decant water return system to the tailings line is provided for flushing purposes and the dilution of the tailings line (if necessary).
- An emergency tailings pipeline utilising the existing system is provided to act as a temporary backup in case of any failure in the primary pipeline.
- A flexible pipework alignment and arrangement is proposed in the new design that prevents tailings discharge interruption during the TSF raises.

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