POLITECNICO DI TORINO

Collegio di Ingegneria Chimica e dei Materiali

Corso di Laurea Magistrale
in Ingegneria Chimica e dei Processi Sostenibili

Tesi di Laurea Magistrale

Process Simulation of a Mineral Processing Plant: water balance for environmental sustainability

Candidato

Vittorio Casali De Rosa

Relatori

prof. Roberto Pisano

ing. Roberto Tentori

Marzo 2019

Sommario

L'utilizzo di un *software* per la modellazione e simulazione di un processo industriale rappresenta un approccio rivoluzionario al settore. A partire dagli anni Novanta del ventesimo secolo l'uso di tali programmi si è diffuso sempre più nel settore industriale garantendo la possibilità di gestire in modo rapido ed efficace le principali variabili del processo osservando come esse variano al variare delle condizioni operative.

Le imponenti banche dati che sono state nel frattempo sviluppate hanno reso disponibili una notevole quantità di informazioni termodinamiche, fisiche e chimiche rendendo più accurate e dettagliate le previsioni ottenibili con l'utilizzo di tali programmi, sia per simulazioni su impianti già esistenti che per la progettazione *ex novo* di siti industriali.

Nel presente progetto di tesi uno di tali programmi, METSIM, verrà utilizzato per simulare un processo già esistente e consolidato, al fine di permettere un maggior controllo dell'operazione, effettuare studi previsionali sui prodotti a seguito di una variazione nei parametri in ingresso e ottimizzarlo. Tali esigenze sono di frequente riscontro nella processistica industriale e contribuiscono direttamente al conseguimento dei principali obiettivi fissati dall'ONU e raccolti sotto il nome di *UN sustainable development goals*.

La mossa da cui il progetto ha preso piede è stato un *Process Audit*, espressione con cui si indica uno studio approfondito e dettagliato del processo per come sta venendo condotto attualmente, al fine di individuarne eventuali criticità quali errato funzionamento dei macchinari o eccessivo consumo di risorse primarie come solventi o energia. Attraverso la campagna di campionamenti, che ha avuto come obiettivo la descrizione del processo correntemente svolto, è stato possibile ottenere l'implementazione su supporto informatico.

Il processo che è stato simulato è un processo di trattamento di minerali, nella fattispecie di silice cristallina, ed è quindi afferente al settore dei minerali industriali.

Il settore minerario in Italia benché erede di una lunga tradizione che affonda le radici agli albori del diciannovesimo secolo, può sembrare al giorno d'oggi come un comparto marginale ed a basso valore aggiunto.

Considerando tuttavia l'impatto che esso esercita sul territorio, in termini di possibilità economiche e industriali per le realtà produttive ad esso indissolubilmente legate, quali il settore della ceramica, quello dell'industria vetraria, quello della cosmesi, l'industria cartaia e molti altri, la prospettiva cambia decisamente.

In accordo con la Commissione Europea i minerali industriali si suddividono in energetici e non energetici, i primi sono quelli utilizzati per produrre energia (petrolio, carbone,…), mentre i secondi sono riportati in Tabella 1.1 e ne fa parte anche la sabbia silicea.

In Figura 1.1 è possibile vedere la diffusione dell'industria mineraria nel Paese, che si distingue soprattutto per la produzione di felspati (terzo produttore al mondo) e talco (decimo produttore al mondo).

La composizione chimica della sabbia silicea, che è il materiale oggetto del processo, può in genere variare sensibilmente, ma è generalmente caratterizzata da una percentuale di SiO_2 maggiore del 95% e usualmente si attesta la presenza di Fe_2O_3 e Al_2O_3.

La concentrazione di ossidi di ferro, in particolare, è prioritaria per la qualità del prodotto finale nel caso di vetro, poiché al crescere di tale concentrazione aumenta la colorazione verde del materiale. Specifiche generalmente accettate per vetro trasparente sono di concentrazione minore del 0.035% e per vetro piano compresa fra lo 0.04 e lo 0.1%.

La presenza di impianti di processo minerale pone, come tutti le installazioni industriali, problemi di natura ambientale e di accettazione pubblica, sia per l'impatto che l'attività estrattiva comporta sul territorio circostante, sia per i significativi consumi energetici sia infine per il vasto utilizzo di risorse primarie come l'acqua che, se non opportunamente

trattate, possono risultare pericolose in caso di rilascio nell'ambiente circostante il sito produttivo. La simulazione di processo permette quindi di individuare e minimizzare questi rischi.

L'impianto che è stato simulato è appartenente alla Sibelco Group e si trova a Robilante (CN), come visibile in Figura 1.3.

Il sito di Robilante è suddiviso in due sezioni principali: la cava e l'impianto di trattamento.

La prima è il sito estrattivo, suddiviso in più punti e la cui panoramica è riportata in Figura 1.4. Un tipico campione di materiale, in termini di composizione chimica è invece riportato in Tabella 1.2.

Nella cava il materiale, dopo essere stato estratto attraverso esplosione di cariche di dinamite, viene raccolto e sottoposto a due primi step di macinazione: la macinazione primaria e la macinazione secondaria.

La prima macinazione riduce i blocchi di minerale ad una dimensione compresa fra 0 e 15 cm, la seconda fra 0 e 4 cm.

Il materiale è quindi condotto al cumulo di stoccaggio attraverso un nastro trasportatore. Data la presenza di un dislivello altimetrico fra i due di circa 400 m, l'energia gravitazionale del materiale viene trasformata in elettrica (produzione circa 1 MW) attraverso un apposito impianto frenante.

L'impianto è invece formato dal cumulo, la macinazione terziaria e l'impianto di frantumazione e selezionamento vero e proprio.

Il cumulo ha la sola funzione di stoccare il materiale per permettere al resto dell'impianto di lavorare in continuo, da lì il minerale è prelevato e portato alla frantumazione terziaria, dove raggiunge una dimensione di 0-8 mm, come schematizzato in Figura 1.7.

La materia così lavorata viene nuovamente stoccata in un silo di cemento da cui poi viene mandata in alimentazione all'impianto.

La prima sezione dell'impianto di processo è quella di comminuzione, dove ovvero il materiale grezzo viene ulteriormente macinato all'interno di un mulino a sfere per il raggiungimento delle dimensioni utili alla sua vendita come prodotto intermedio.

La sezione prevede un ricircolo, come di frequente riscontro per l'apparecchiatura, e l'operazione unitaria avviene ad umido, come evidente dallo schema in Figura 1.8.

Successivamente la corrente macinata viene mandata ad un idrociclone che riduce la percentuale d'acqua e con essa una parte delle particelle solide più fini.

L'acqua è il solvente usato all'interno del processo ed ha principalmente due funzioni: quella di agevolare il trasporto del minerale attraverso le pompe e le tubature e quella di 'ripulirlo' dalla frazione più fine (generalmente al di sotto dei 75 μm) del minerale, ricca in ossidi di ferro e di cui è presentata un'analisi granulometrica e chimica in Tabella 1.5 e 1.6.

La corrente così processata viene vagliata da quattro vagli Lehmann posti in parallelo per l'ottenimento dei primi due prodotti dello stabilimento, che vengono chiamate sabbie da costruzione (Granella e Sabbia 1) per le loro dimensioni relativamente grandi rispetto a quelle degli altri prodotti. Un esempio di granulometria è riportato in Tabella 1.3 e 1.4.

Il materiale che esce al di sotto dei vagli viene inviato alla sezione di idroclassifica, in cui si individuano le tre pezzature delle sabbie da vetro, *core business* dell'impianto.

In questa sezione, come schematizzato in Figura 1.13, sono presenti due idroclassificatori, il cui principio di funzionamento viene brevemente spiegato nel capitolo 1.4.4.1. Gli idrocicloni di questa sezione dell'impianto, a differenza di quelli nella parte riguardante le sabbie ceramiche, non hanno una funzione di classifica ma piuttosto di rimozione dell'acqua e dei fini in essa sospesi. Le classifica viene ottenuta attraverso vagliatura e con gli idroclassificatori.

In uscita al primo idroclassificatore abbiamo la Sabbia 2, un cui esempio di granulometria è riportato in Tabella 1.7. Dal secondo si ottengono invece altri due prodotti, rispettivamente dall'*under* la Sabbia Speciale (granulometria in Tabella 1.9) e come *over* la Sabbia 5SN (granulometria in Tabella 1.11).

La corrente di acqua con i fini in sospensione viene inviata al *thickener* dell'impianto dove, grazie all'aggiunta di poliammine e polielettroliti, si ottiene la flocculazone e sedimentazione di solidi sospesi. Questi vengono successivamente trattati e ulteriormente suddivisi per la produzione di altri tre prodotti detti sabbia ceramiche, per l'industria in cui vengono prevalentemente impiegati.

La selezione dei diversi tagli granulometrici avviene, in questo caso, per idrociclonatura e un esempio di granulometrie e composizioni chimiche è dato nelle tabelle: Tabella 1.13, 1.14 (Sabbia 5RD), Tabella 1.15,1.16 (Sabbia 6RD) e Tabella 1.5,1.6 (Sabbia VVR).

L'acqua, all'interno dell'impianto, viene attualmente già riutilizzata dopo essere chiarificata epr rimuovere il contenuto di fini che ha rimosso dalla corrente minerale. Il circuito dell'acqua è strutturato in uno interno ed uno esterno. Il primo è costituito da ricircoli interni che, secondo un sistema a cascata in controcorrente (dall'acqua usata per i prodotti verso quella in uscita al mulino) ricircola l'acqua per asportare il maggior numero di fini possibili, l'altro è invece collegato col decantatore e riceve in ingresso direttamente l'acqua pulita.

La parte dell'impianto simulata nel presente progetto di tesi sarà quella descritta nella sezione del mulino a sfere, dell'idroclassifica e relativi prodotti, chiamata informalmente come "laveria" o *washing plant*.

Le principali apparecchiature presenti nella sopracitata sezione dell'impianto sono brevemente descritte nel capitolo 1.4. Se ne dà nel sommario una ancora più riassuntiva panoramica concentrandosi su quelle ritenute essenziali per la comprensione del diagramma industriale di flusso.

L'apparecchiatura che più influenza il successo del processo è il mulino a sfere. Un mulino a sfere consiste in un cilindro cavo posto in rotazione da un motore elettrico, all'interno del quale è posto un mezzo macinante (nel caso in esame esso è costituito da delle sfere in acciaio di diametro pari a 70 mm) che ricadendo sul materiale inserito lo frantuma, come schematizzato in Figura 1.13.

Il rapporto diametro/lunghezza del mulino è quello più geometricamente rilevante e va da valori di 0.5 fino a 3.5. all'aumentare della lunghezza si aumenta il tempo di residenza del materiale nell'apparecchiatura e quindi dell'efficacia della comminuzione, viceversa all'aumentare del diametro aumenta prevalentemente la capacità.

La frantumazione avviene attraverso la trasmissione di energia cinetica dal mezzo macinante verso il materiale da frantumare. Una misura della resistenza opposta dal materiale alla macinazione è data dall'indice di Bond, al cui crescere del valore corrisponde una maggiore difficoltà nell'effettuare l'operazione unitaria. Tre differenti meccanismi di frattura sono documentati: abrasione, lo sfaldamento e la frantumazione.

Il primo è dato da urti di bassa intensità e conduce prevalentemente alla formazione di fini, il secondo da urti più intensi e porta alla formazione di grossi pezzi, circa il 50-80% delle dimensioni originarie ed il terzo da urti rapidi e molto intensi, provocando la formazione di pezzi più piccoli e dalla granulometria varia.

Altra apparecchiatura critica all'interno dell'impianto, per la funzione di selezionatori che essi svolgono, sono i dispositivi vaglianti.

Vi sono essenzialmente due tipi di vagli nella laveria: il vaglio Trommel ed il vibrovaglio, come i quattro vagli Lehmann posti dopo il mulino a sfere.

Il vaglio Trommel, riportato in Figura 1.16, consiste in un cilindro cavo posto in rotazione le cui pareti sono formate da tele metalliche aventi struttura a rete con fori di varie dimensioni per permettere la vagliatura della corrente all'interno di esso inviata. Generalmente è possibile porre più strutture a tela con fori di diverse dimensioni crescenti in serie per ottenere più o una migliore vagliatura. L'apparecchiatura può anche essere elevata a partire dal punto di immissione della corrente di alimentazione per favorire lo scorrere della stessa.

I vagli vibranti usati invece sia dopo la macinatura nel mulino a sfere, che nella sezione delle sabbia da costruzione per suddividere Granella da Sabbia 1, sono dei ripiani ad area variabile costituiti da tele con fori di varie dimensioni a seconda del selezionamento desiderato. Essi possono essere inclinati per favorire l'avanzamento della corrente, come nel caso dei vagli Lehmann, e sono posti in vibrazione per favorire l'operazione di vagliatura da parte delle tele.

Come precedentemente accennato le operazioni di classifica possono essere fatte sia con i vagli descritti nel precedente paragrafo, sia con dei classificatori idraulici o degli idrocicloni.

Il principio di funzionamento dei primi sfrutta la velocità di sedimentazione delle particelle di solido in un fluido, in questo caso l'acqua. Le particelle in un mezzo fluido per effetto della forza di gravità saranno trascinate verso il basso ed accelerate.

A tale accelerazione si oppone la spinta di Archimede, costante, e la forza viscosa di attrito determinata dall'interazione fra il filetto di fluido solidale alle particelle e al primo in movimento. Tale forza determina una velocità 'di caduta' costante, raggiunta dopo una certa fase di transitorio. La forza di attrito che determina tale velocità dipende da forma e dimensione delle particelle, per cui inserendo, ad esempio, tali particelle in un cilindro pieno di liquido inviato in controcorrente rispetto alla loro direzione di caduta, si ottiene una selezionatura sulla base di tali velocità.

Le particelle con velocità di sedimentazione maggiori della velocità del liquido in controcorrente continueranno a precipitare, mentre quelle con velocità inferiore verranno trascinate dalla corrente in verso a lei concorde, come esemplificato in Figura 1.17.

A velocità maggiori corrispondo dimensioni maggiori delle particelle, così nell'idroclassifica la corrente di *underflow* sarà quella a granulometria maggiore, mentre quella di *overflow* minore.

Due tipi di apparecchiature presenti nella laveria sfruttano tale principio di selezionamento: i classificatori idraulici e gli idrocicloni.

I primi consistono in contenitori all'interno dei quali è inserita dall'alto la sospensione di minerale e da sotto l'acqua di processo. Si possono trovare configurazioni con più contenitori in serie, così da permettere una suddivisione in diverse granulometrie, come esposto in Figura 1.18.

Gli idrocicloni sono invece una delle apparecchiature largamente più utilizzate nell'industria mineraria, sia per la loro grande versatilità nel trattare correnti di fluido, sia per il costo relativamente basso, sia di investimento che di mantenimento.

Si strutturano di un corpo semi-conico inferiore ed uno cilindrico superiore, entrambe cavi, come mostrato in Figura 1.19.

Il flusso di materia è inserito lateralmente al corpo cilindrico, affinché ad esso venga imposto un moto vorticoso circolare. Tale moto, insieme al flusso di liquido, impone al solido l'azione di due forze: una forza centrifuga che tende a spingere verso la superficie dello strumento la particelle, ed una di trascinamento rivolta verso l'interno dovuta alla corrente di fluido. Le particelle più fini saranno trasportate dalla corrente (*overflow*), mentre quelle più grandi per effetto della forza centrifuga sospinte verso le pareti dello strumento causando così un loro progressivo rallentamento per fuoriuscire dal foro inferiore del cono (*underflow*).

La separazione di fase non ha luogo in tutto il volume dell'idrociclone, ma solo in un volume toroidale mostrato in Figura 1.21.

Il principale parametro geometrico che caratterizza questa apparecchiatura è il diametro, che ne determina la capacità e al diminuire del quale aumenta il recupero di solido nell'*underflow*.

Dal punto di vista operativo, i principali parametri che influiscono nelle prestazioni di un idrociclone sono già chiare nel modello presentato in (1.2) basato sulla teoria dell'orbita di equilibrio.

I modelli utilizzati per l'implementazione nei software di simulazione degli idrocicloni sono essenzialmente modelli puramente empirici basati sulla regressione di una notevole mole di dati sperimentali. I più utilizzati ed in particolare quelli presenti nel software METSIM, utilizzato nel presente progetto di tesi, sono quello di Lynch e Rao (1.3), di Krebs (1.4), di Plitt (1.5) e una versione modificata di quest'ultimo (1.6).

Nell'impianto sono posti dei separatori magnetici, che hanno il principale scopo di rimuovere la limatura di ferro provocata dall'usura degli strumenti e dal mezzo macinante, delle sfere di acciaio, del mulino.

Essi sono composti da un semplice magnete che lambendo in vario modo la corrente solida rimuove le particelle ferrose.

I filtri sono anch'essi apparecchiature presenti nell'impianto di lavaggio e sono costituiti da un supporto fisso sopra il quale è generalmente posto un mezzo filtrante, che permetta il passaggio di liquido e eviti o riduca quello del solido, così da formare un filtrato (fluido) e un residuo solido alla sua interfaccia.

Nello stabilimento sono presenti dei pan filter, posti prima degli stock di prodotto, al fine di ridurre il contenuto di acqua fino al valore di specifica ed eventualmente dilavare alla necessità residui di fini ancora presenti con acqua pulita. Uno schema è visibile in Figura 1.22.

A ciascuna apparecchiatura può essere associata una curva di efficienza, detta "di Tromp", in cui è riportata la percentuale di solido ad una data granulometria ottenuta in *underflow* e di cui un esempio è dato in Figura 1.23.

In (1.7) è riportata l'espressione di un parametro, detto efficienza, che misura la pendenza della curva di Tromp e quindi di quanto netto sia il 'taglio' che l'apparecchiatura riesce ad effettuare sulla corrente di materiale.

Essa può essere corretta, tenendo conto che nella realtà operativa una certa porzione di alimentazione andrà direttamente nell'*underflow* senza essere selezionata. Per rimuovere tale contributo dal grafico della curva è data un'espressione in (1.8).

Due modelli matematici di funzioni sono stati sviluppati per valutare la curva di Tromp di un'apparecchiatura a partire dalla conoscenza del suo d_{50} e della pendenza della curva nel dato punto. Questi sono quelli di Rosin-Rammler e di Lynch, riportati in (1.9) e (1.10).

Per l'implementazione del processo, un *team* di cinque ingegneri della Sibelco, fra cui il candidato, ha seguito un apposito *training*, in *Skypecall* con *City of Cape Town* la seconda settimana di Ottobre e la prima di Dicembre.

La maggior limitazione al presente progetto, dal punto di vista dell'autore, è sicuramente legata alla scarsità di campioni che il *team* è riuscito a prelevare all'interno dello stabilimento.

Aspetti pratici legati alla sicurezza dei punti di campionamento e alla loro accessibilità, nonché alla difficoltà nell'effettuare campionamenti di flussi estremamente voluminosi (nel caso del campione 4 circa 390 m^3/h), hanno imposto la possibilità di effettuare un unico campionamento per punto, fornendo così una visualizzazione abbastanza puntuale delle condizioni operative dell'impianto.

Le frequenti variazioni nelle condizioni operative date dall'eterogeneità della materia grezza e nelle condizioni di stoccaggio portano infatti ad una non facile caratterizzazione delle correnti in assenza di campagne di campionamento abbastanza lunghe da poter avere dei risultati medi.

In Figura 2.1-2.3 si riporta a titolo di esempio il caso del campione numero 4, per ottenere il quale è stata necessaria circa una settimana.

La procedura seguita per ottenere i campioni è stata la seguente:

- Ispezione del punto di campionamento.
- Decisione del giorno di campionamento insieme al personale presente sull'impianto

- Raccolta del campione.
- Asciugatura del campione.
- Analisi del campione.

La caratterizzazione granulometrica vera e propria del campione è stata fatta con l'utilizzo di uno vaglio vibrante. I setacci usati per caratterizzare il campione sono stati decisi insieme al responsabile del processo e agli addetti del controllo qualità presenti in laboratorio al fine di garantire una descrizione quanto più esaustiva della granulometria presente nel campione. Essi sono riportati in Tabella 2.1.

Le misure di densità sono state invece fatte pesando il campione e valutandone successivamente il volume nota la densità dell'acqua e della sabbia silicea, come descritto nel capitolo 2.1.

La valutazione finale del flusso di sospensione inviata al decantatore è stata fatta con un misuratore di flusso portatile che sfrutta l'effetto doppler schematizzato in Figura 2.7.

In Figura 3.1 e 3.2 sono riportati i punti di campionamento all'interno dell'impianto e contestualmente anche le misurazioni granulometriche effettuate in laboratorio.

Il *software* di simulazione utilizzato per il progetto di tesi è METSIM, un programma sviluppato negli USA che nasce come simulatore all'interno dell'industria metallurgica nel 1971, ma negli anni si è arricchito di moduli per la simulazione di reazioni chimiche, di bilancio di calore, di materia, di valutazione economica andando a toccare anche l'industria mineraria.

Il programma, come si vede in Figura 2.8, si compone di un'interfaccia utente intuitiva per il disegno dei *flowsheet* di processo, composta da vari moduli nella parte superiore (Figura 2.9) e di differenti menù per la selezione dell'operazione unitaria migliore ai fini della simulazione (Figura 2.10).

Il programma permette inoltre anche di creare più sezioni per gestire l'impianto, che possono essere fatte convergere separatamente per rendere più facile la convergenza complessiva del file.

Si possono eseguire dimensionamenti, calcoli predittivi in caso di variazione degli *input* sugli *output* e parametrizzazione delle apparecchiature.

Una volta definita la corrente in ingresso con un'apposita caratterizzazione della composizione chimica, delle condizioni fisiche e delle caratteristiche granulometriche sfruttando i vagli fissati dalle normative internazionali (ISO, USM,…), si possono poi inserire i dati da laboratorio e procedere alla simulazione *step-by-step* del processo eseguendo progressivamente tutte le operazioni unitarie di cui si compone.

Per il caso in esame, dato che nella laveria vengono effettuati unicamente trattamenti di separazione fisica che non coinvolgono trasformazione della natura molecolare della materia, si è deciso di approssimare la composizione della corrente solida come unicamente formata da SiO_2, trascurando così l'effetto contenuto della presenza di ferro e alluminia sulla densità del minerale.

Successivamente si è proceduto all'implementazione su software del processo precedentemente caratterizzato, seguendo la procedura qui riportata:

1. Tutte le correnti di processo (inclusa anche quelle idriche) sono state replicate sul *flowsheet* del programma, suddividendo l'impianto in più sezioni per una più facile visualizzazione
2. Si è fatta una prima parametrizzazione delle apparecchiature, inserendo i parametri geometrici ed operative di quelle attualmente presenti, un'ulteriore parametrizzazione è stata poi fatta a processo ultimato per ottenere una più esatta congruenza coi dati.

3. La corrente in ingresso è stata caratterizzata inserendo la granulometria campionata, la composizione e la portata.
4. Il processo è stato lanciato sezione per sezione, controllando che gli output delle differenti apparecchiature fossero congruenti con i diversi campioni prelevati.
5. L'intero processo è stato lanciato per garantire la convergenza globale e della coerenza fra i flussi.
6. Un'ulteriore confronto fra i campioni e le operazioni unitarie simulate è stato fatto per perfezionare la parametrizzazione delle apparecchiature
7. I prodotti sono stati controllati dal punto di vista della qualità e della quantità per accertarsi che la granulometria rientrasse nelle specifiche commerciali
8. Il consumo idrico del processo simulato è stato così valutato da lettura su programma

La prima sezione che è stata replicata su simulatore è quella che si riferisce al mulino a sfere, riportata in Figura 2.13. Questa sezione è sicuramente la più importante dell'impianto, dato che è l'unica in cui avviene una trasformazione vera e propria della materia di processo, cioè la riduzione di granulometria.

A causa delle modifiche sul mezzo macinante che si sono succedute nel tempo, l'attuale mulino risulta sovradimensionato per le condizioni operative in cui si opera attualmente. Per tale ragione si è deciso di parametrizzare il dispositivo su simulatore a partire dai dati campionati, così da essere certi che la granulometria in uscita alla sezione fosse molto vicina a quella misurata.

In Figura 2.14 è riportata la sezione creata per parametrizzare opportunamente il mulino a sfere.

La sezione del mulino prevede un ricircolo per ottimizzare la macinazione, un vaglio trommel posto dopo il mulino per evitare il passaggio di grani con diametro maggiore di 2.5 mm nelle sezioni successive. I dati geometrici delle apparecchiature sono riportati in Tabella 2.2, 2.3.

I nastri trasportatori e le pompe presenti nell'impianto sono state riportate nel *flowsheet* ma mettendole in modalità "*mass balance*", ovvero riportando l'*output* esattamente uguale all'*input* poiché un loro dimensionamento andava oltre lo scopo del presente progetto.

Le correnti di acqua aggiunte al mulino a sfere provengono dal circuito interno dell'acqua e contengono una certa percentuale di fini, la cui rimozione è prioritaria per ragioni qualitative dei prodotti. La portata di tali correnti è regolata e costante e nel simulatore sono stati utilizzati dei controllori di flusso, come riportato in Figura 2.16.

Segue poi la sezione dei vagli Lehmann, dove il frantumato viene suddiviso per l'ottenimento dei primi prodotti nella sezione delle sabbie da costruzione e quelle che proseguiranno per produrre le sabbie da vetro e quelle ceramiche nella sezione del decantatore.

Prima della vagliatura la corrente è sopposta ad un'idrociclonatura per rimuovere buona parte dei fini che si sono formati durante la macinatura, come mostrato in Figura 2.17.

In questo punto è presente un parziale riflusso dell'*overflow* del ciclone, nella corrente in *underflow*, questo tipo di modifica, illogica dal punto di vista degli intenti globali del processo, è stata apportata nel tempo dagli operatori per supplire alla necessità di acqua nella corrente per il successivo pompaggio.

Le caratteristiche geometriche dei vagli Lehmann sono riportate in Tabella 2.5. L'*over* di tali vagli alimenta la sezione delle sabbie da costruzione (Figura 2.20), la Granella e la Sabbia 1, mentre l'*under* prosegue verso l'idroclassifica per la produzione delle sabbie da vetro (Figura 2.23).

Ciascun vaglio Lehmann ha un'aggiunta di acqua per migliorare il processo di 200 m3/h, mantenuta costante e così simulata.

Al di sotto dei vagli Lehmann sono posti quattro recipienti che raccolgono le sabbie dell'*under* e per sedimentazione fanno passare al di sotto le sabbie da vetro, mentre in *overflow* rilasciano acqua di processo con fini che viene ricircolata in un apposito circuito interno ai Lehmann. La simulazione è mostrata in Figura 2.21 e per replicare la sedimentazione si sono utilizzati dei classificatori idraulici con i dati in *input* nel *template* di Figura 2.22 per garantire la corretta composizione delle correnti (essenzialmente particelle al di sotto dei 75 µm nell'*overflow*).

In Figura 2.23 è riportata la sezione degli idroclassificatori, essi sono due posti in serie e prima di tale separazione la corrente viene sottoposta ad un'ulteriore idrociclonatrua per rimuovere i fini dal materiale.

Le caratteristiche dei due idroclassficatori sono riportate in Tabella 2.8. Dal primo si ottengono in *underflow* la corrente della Sabbia 1, per la quale segue una nuova sezione prima dell'ottenimento del prodotto finito, dal secondo, che processa l'*overflow* del primo, la Sabbia Speciale (*underflow*) e la Sabbia 5SN (*overflow*).

Le ultime sezioni replicate sono quelle del circolo delle acque. Come già menzionato il circuito dell'acqua si divide in un circuito interno ed uno esterno. Il primo, quello interno presentato in Figura 2.28, ricircola le acque internamente all'impianto di laveria nell'intendo di ottimizzarne l'utilizzo, generalmente in controcorrente dalla parte finale dove si ottengono i prodotti a quella iniziale dove è necessario rimuovere il maggior numero di fini possibile. Esso è composto da due serbatoi.

L'acqua per tale circuito proviene dai due cicloni posti in parallelo prima degli idroclassificatori, dall'*overflow* del serbatoio di alimentazione degli spruzzatori posti sopra i vagli Lehmann e dall'*over* dell'idrociclone posto dopo il mulino a sfere.

Gli overflow dei due serbatoi del circuito sono direttamente inviati al decantatore per rimuovere i fini prodotti nel processo.

Il secondo, quello esterno presentato in Figura 2.30 è invece collegato direttamente all'acqua proveniente da thickener dell'impianto, quella che si ritiene come pulita. Lo formano tre vasche collegate, come da Figura 2.30 e 2.31, ai *makeup* di acqua pulita insieme alle correnti di alimentazione degli idroclassificatori, che devono essere costituite da acqua pulita e dei *pan filter* che anche esse devono essere costituite da acqua il più pulito possibile poiché vanno in contatto diretto col prodotto finito per eliminare eventuali residui di fini.

In Figura 2.32 è invece riportato un *mixer* creato nella modellazione dell'impianto, per ottenere il valore totale di acqua e solido inviata alla decantazione. Tali valori sono riportati in tabella 3.22. Evidentemente la differenza fra i due è dovuta all'acqua rimasta nei prodotti finali sotto forma di umidità residua, anch'essa fissata da appositi valori di specifica commerciale.

Per la validazione della simulazione implementata nel presente progetto di tesi, si è proceduto a confrontare i valori di granulometria rilevati dai campioni e quelli simulati con appositi grafici elaborati su Excel.

La procedura è riportata nel paragrafo 3.2 e si può notare una buona concordanza fra dati misurati e simulati. In particolare la parametrizzazione del mulino a sfere ha permesso di ottenere degli ottimi risultati del campione 4, come si evince dal grafico in Figura 3.3. I successivi confronti hanno permesso di perfezionare ulteriormente i parametri delle apparecchiature.

Per quanto riguarda la verifica sui prodotti si è proceduto invece a confrontare i prodotti simulati con le specifiche commerciali utilizzate per i clienti dello stabilimento. La scelta è stata così effettuata al fine di garantire, benché la misura avesse carattere puntuale, il rispetto degli intervalli medi entro cui i prodotti si presentano, nonché il loro valore economico nel caso si volessero testare condizioni operative differenti da quelle attuali con cui la misurazione è stata effettuata.

Sono state confrontate anche le portate dei prodotti ottenuti con gli intervalli medi dei rispettivi prodotti, forniti dal reparto di produzione dello stabilimento.

A titolo esemplificativo, si richiama in questo sommario esteso, il confronto fra granulometria simulata della Sabbia 2 e le specifiche commerciali da scheda del prodotto, nonché dei valori medi di produzione e quelli simulati, rispettivamente riportati in Tabella 3.16 e Tabella 3.17.

Al termine della simulazione per valutare l'affidabilità del processo simulato è stata anche misurata la portata di acqua inviata al decantatori con un dispositivo di misura portatile. Il risultato della misura è riportato in Figura 3.3, i risultati simulati sono quelli riportati in Tabella 3.22.

Dal confronto emerge che tutti i prodotti simulati con METSIM, rientrano all'interno delle specifiche di produzione richieste per la commercializzazione della sabbia.

I grafici mostrano buona concordanza fra i campioni ed le correnti misurate che diminuisce leggermente dopo il campione 7.

Questo può essere spiegato dal fatto che i campioni precedentemente descritti sono stati ottenuti durante due campagne di campionamento effettuate in momenti diversi.

Inoltre, come già menzionato, ciascun punto è stato campionato una volta sola, per cui piccoli errori, anche di natura sperimentale, nella misura del campionamento del mulino, data l'alta portata di minerale (189 ton/h), si riflette in grandi variazioni nella portata e nella granulometria dei prodotti a valle che sono generalmente di un ordine di grandezza inferiore rispetto alla prima.

Si è notato un incremento dell'acqua presa dal sedimentatore all'aumentare della frazione di fini prodotta dal mulino, come spiegato nella versione più estesa del progetto.

Il processo così implementato inoltre, è stato successivamente sfruttato per la valutazione di fattibilità di una modifica impiantistica, accertando la possibilità di trattare il flusso di acqua da pulire che si sarebbe venuto a generare da parte del *thickener* attualmente installato nell'impianto.

Index

1. General introduction to the project

The following project was entirely performed in the Sibelco mineral processing plant in Robilante, starting from October 1st until the end of December, under the supervision of the Sibelco engineers Roberto Tentori and Jos Vandezande to which I am greatly thankful for the opportunity given and the availability shown for my necessities.

The team involved was composed by other two Sibelco process engineers, Stefano Santoro and Paolo Serra to which I am equally grateful.

The aim of the project was defined during the first meeting in Robilante and consists into the simulation of their mineral processing plant, starting from the analysis of the flowsheet in AutoCad, deciding the sampling points, performing the sampling, analyzing the samples in the laboratory and using them to simulate the process in a specific software tool.

The main difficulties met during the work were linked to the age of the plant, as in fact will be further explained, the Robilante site was built during the 50's and successive modifications were implemented into the existing plant to solve the problems progressively occurred.

These modifications were performed without a complete revision and rationalization of the full plant in order to provide, for instance, safe points for sampling or, in some cases, even without removing the old pipes that are no more currently used.

This kind of problems can be reasonably frequent in a post-industrial country as Italy is, where the majority of its industrial sites were built during the so-called 'industrial boom' that goes from the early Fifties to the late Seventies.

The interest shown by the industry into simulation software is due to the possibility of their control and into perform previsions on the utilities consumptions, in order to meet the company necessities and the environmental regulations (about emissions and natural resources consumption) that, following the global trend, are likely to become more and more restrictive in a close future.

For the implementation of the project a new simulator was used, METSIM (see chapter 1.5), for which the team followed a specific training 10-days-long in videocall from Cape Town City (South Africa).

The possibility to adopt the software in the company instead of the one that is currently used in some plants was evaluated in order to be presented by the candidate in a private conference held in Spain at the end of March.

1.1 Process Audit and Simulating for improvements, sustainability, design and control

The usage of process simulation software is a revolutionary approach to the old way to manage a plant [1].

Before its introduction every modifications, improvements or new design was almost entirely based on the operators experience, tying this way the correct operation of a plant to the presence of who designed it or to who was used to work on it for many years [1].

Software simulator allows the operator to model the process currently carried out in the plant, introducing physical and chemical data from databases that are being more and more developed by private companies or public institutions [1].

Once the simulated process is available, operators can check the equipment in the plant against various operative conditions (that means doing a so called ‘sensibility’ study), in order to evaluate how the whole system can react to different external stimuli. In the program mathematical models of the various devices are usually implemented, which are usually reliable for fast evaluation of the consequences due to a variation in the stream flow or composition.

Improvements that required a new equipment can be tested in a preliminary phase on this model, giving an easier and faster access to new scenarios, compared to the case where different aspects of modelling, simulation, synthesis, and design are simultaneously the equipment supplier is the only one who can simulate the process. Design approaches can also be performed, where are solved[2].

A more accessible model of the process can also lead to a faster job creation and industrial improvements that regard the global sustainable goals fixed by the United Nation. In particular, goals 8 and 9, which are “industry, innovation and infrastructure” and “decent work and economic growth”, are related to these issues [3].

The possibility to easily compare different scenarios allows the engineer to design a safety work environment and more efficient way of produce goods. Moreover the rapid accessibility of these software tools by even not too high-skilled workers can increase the number of new jobs, enhancing the economic growth and the total employment rate [3].

That way, moreover, a rough evaluation of the energy and other facilities consumptions can be done. This evaluation is not always easy to know because of the high cost of the in-line PAT used to monitor the flows.

Water is a widespread used solvent in industry because of its low cost and relatively high availability, but its consume is a concern posed by the United Nation because of its importance for the human life and the environment.

A responsible way of manage this resource is another global sustainable goal fixe by the institution, the number 6. Process simulation, as will be seen, allows the operator also to reduce and optimize its usage in an industrial plant where no possibilities to measure the flows are given [3].

One of the objective of this project is to evaluate the ideal total amount of water required by the mineral processing plant of Robilante and know if the equipment is working at the best or if it is wasting energy and natural resources.

Wasting energy and natural resources are, in fact, an issue not only for the economic costs but mainly for the long-term vision of the company. Its capability to accomplish the environmental legislation and its social responsibility are extremely fast growing in importance not only for the public opinion (that is already not positive for the mining sector) but also for financial possibilities as argued by BlackRock CEO Larry Fink in his annual letter to CEOS [4].

1.1.1 The process Audit

The previous step to the process simulation is called 'process audit': it consists into inspect the plant, identify the main streams and draw an accurate flowsheet of the process that is currently carried out.

A sampling campaign has to be organized in order to have detailed information on the composition (in this case the granulometry) of all the streams safely accessible to the operators. Usually not all the streams can be analyzed because of safety issues, in this case the unknown stream has to be rebuilt, usually by a mass balance, starting from the other ones that are available.

The samples have to be analyzed by the laboratory in order to characterize the streams in the flowsheet. At this step understand if an equipment is working correctly or not, is easy to achieve. In principle improvement even at this point could be allowed, but the main goal is still to have a simulation of the plant.

Once the analyses are available the modeling simulations can be launched, inserting the process characteristic as in the reality are and the equipment that best approximate the ones that are working on the site. Usually, as in this case will be, parametrize the software tool with the parameters of the existing equipment is possible, in order to adjust the model to the reality.

1.2 Mineral industry in Italy

Despite a long tradition of mineral extraction in Italy that starts from 1800's, the mineral industry can nowadays appear as a marginal and low-value sector if related and dependent industries are not taken into account.

The production of raw materials for industrial purposes is a fundamental aspect in order to guarantee the right supply to the factories of some manufacturing sectors (such as the glass industry, paper industry, cosmetic, pottery, etc) and is able to orient the industrial development of a certain region, as was happen in Sardinia at Iglesiente, in both post-worldwar periods [5].

Mineral resources can be classified, according to the European Commission, into energy minerals and non-energy minerals. The former are the ones related with the energy production (coal and petroleum, for instance) and the latter are divided into metallic, construction and industrial minerals [5].

Energy-minerals represent in Italy approximately 93% of the extractive sector turnover, despite industrial minerals represent nearly 97% of all firms and 51% of the total employees; but the industries for which industrial minerals are essential inputs count for the 20% of the national added value and the 30% of the total employment, for this reason the sector can be considered as vital for the domestic production of the country [5].

Industrial minerals, of which the raw material extracted and processed in Robilante, is a part, are, according to the European Commission, reported in Table 1.1.

Table 1.1: Industrial minerals according to the European Commission [5]

Compound name	Chemical formula (where available)
Barite	$BaSO_4$
Bentonite	$Na_{0,5}Al_{2,5}Si_{3,5}O_{10}(OH)_2$
Bromine	Br
Kaolin	$Al_2Si_2O_5(OH)_4$
Limestone	$CaCO_3$
Diatomite	$CaCO_3$-SiO_2
Feldspar	$KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$
Fluorspar	CaF_2
Phosphorite	P_2O_5-$Ca_5(PO_4)_3F$
Graphite	C
Magnesite	$MgCO_3$
Mica	$X_2Y_{4\text{-}}6Z8O10(OH)_2$ where X: K,Na,Ca, Y: Al,Mg,Fe, Z: Si
Perlite	Mainly SiO
Potassium	K
Quartz	SiO_2
Silica sand	Mainly SiO_2 (>95%)
Rock salt	NaCl
Sillimanite	Al_2SiO_5
Talk	$Mg_3Si_4O_{10}(OH)_2$
Sulphur and Pyrite	S and S-Fe

In Italy there are currently 2257 firms with 2290 local units spread all over in the country as shows in Figure 1.1.

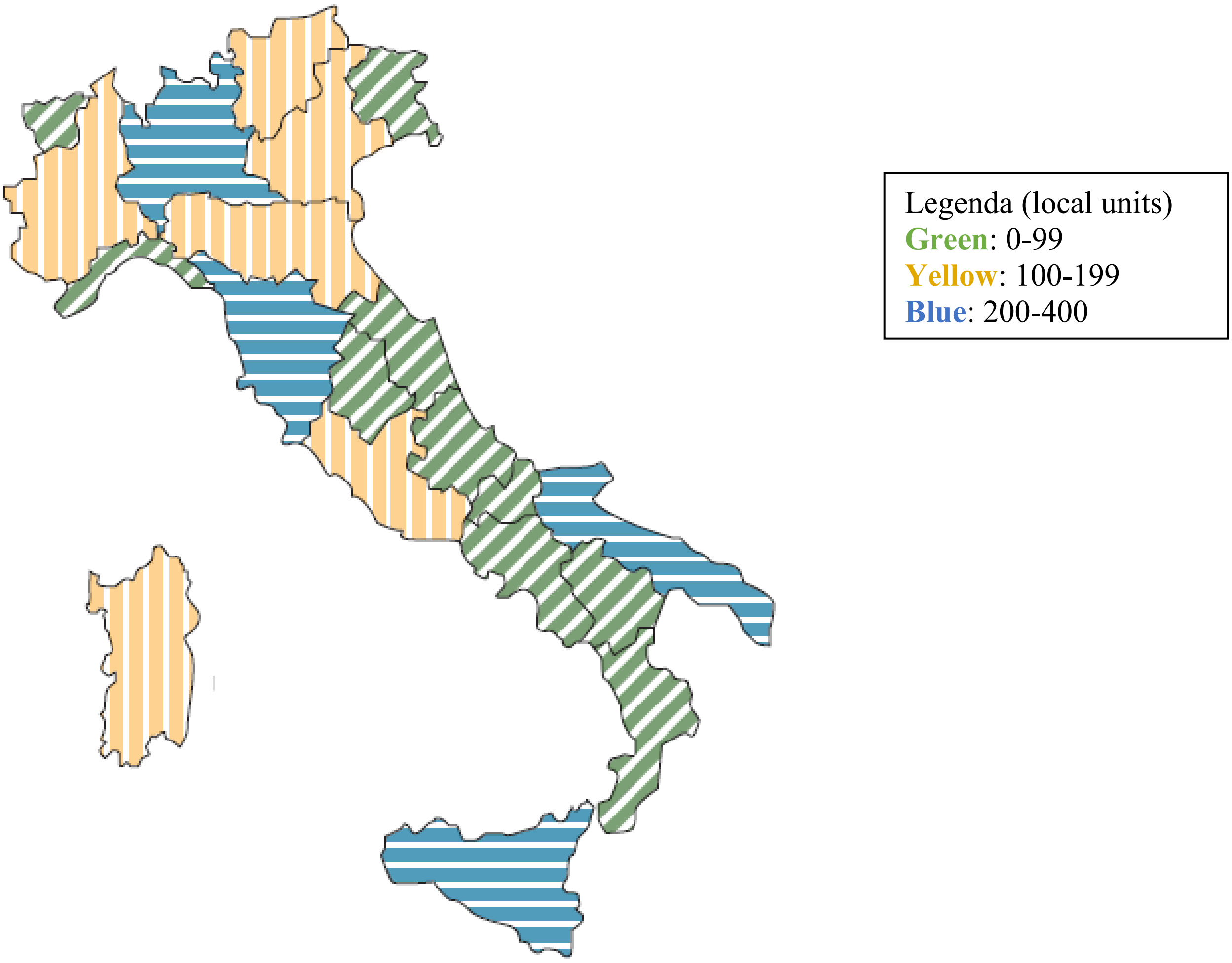


Figure 1.1: Mining activities density in Italy, from [5]

Lombardy and Sicily counts for the 25% of the total mining activities and are the regions with the highest concentration of companies in the sector [5].

Italy has a leading role in Europe (about 10% of the total production of industrial minerals between the 2010 and 2014 with over than 10 million tonnes) and worldwide, by the fact that it is the third larger producer of feldspar and the tenth of talc in the world. This allows to the country an important role in exporting these raw materials, in particular in Asia (46% of the total exported mineral sources) and in the remaining part of the European Union (37%).

Industrial minerals can be extracted from two kinds of sites: quarry and mines. The difference between them is not linked to the locations (if it is located out in the open or in the underground) but to the type of mineral extracted [5].

According to the Italian legislation (Royal Decree n.1443 of 1927) minerals are divided into two categories: strategic (category I) and less strategic (category II).

Mines are sites where are extracted strategic minerals (energy-minerals, metallic minerals and some industrial minerals) and quarry where are extracted less strategic minerals.

Feldspar, kaolin, bentonite, rock salt, talc and clay are industrial minerals that fall under category I, silica sands under category II [5].

As will be seen in the following pages the Robilante plant counts two different sections: an extractive site and a processing mineral site. The raw material extracted in the first part is crystalline silica sand and, according to the previous definition, the site can be classified as a quarry.

Silica sand is a raw material widespread used in industry. It can be found either in consolidated sand deposits or in cemented sandstones (Figure 1.2), that must be broken in order to obtain the wanted granulometry.

Figure 1.2: Silica rock

The different usage of this product, that goes from construction to the glass industry, implies different specifications for market supply. In particular, when it is used for glass industry, not only physical properties are required (that means granulometry) but also the chemical composition assumes a fundamental role for the supplier [6].

The chemical composition of silica sand can vary, but usually it is characterized by a percentage of silica higher than 95% and other components usually found are Fe_2O_3 and Al_2O_3. This quality aspect of the raw material strongly influences the one of the product; in the glass industry for instance, the specification required for colourless glass is $<0.035\%$ of Fe_2O_3 and for flat glass between 0.040 and 0.1% [6].

Usually raw material in the quarry is properly mixed in order to obtain an acceptable iron content.

The presence of a mineral processing plant often poses environmental issues and problems related to the public acceptance. The sector is quite energy-demanding and has an important impact in the environment that surrounds the plant both in the case of an extraction site (mountain erosion) or of a process plant (utilities demand of energy and water consumption) [7][8].

The water coming from the utilities of the plant can contaminate the surface water due to the high content of fine rock particles resulting from the operations carried out during the process.

Water is usually used during the crashing phase in the mill and in order to classify the different particles size of the sand to meet the specifications required.

Sediment resulting from this polluted water can smother the beds of receiving streams, affecting fish and benthic organism. The water used in the plant is usually recirculated in order to reduce the total amount of fresh water taken from and sent into the environment but some losses must be taken into account [7][8]. Process simulation with software tool allows also the operator to estimate and minimize the usage of fresh clean water with significant environmental and economic benefits.

1.3 The Robilante plant

The mineral processing plant is located near Robilante, in the province of Cuneo (Figure 1.3), and is composed by two different sites: the quarry and the processing plant.

Figure 1.3: Robilante plant position from satellite view

1.3.1 The quarry

Figure 1.4: The quarry in Robilante site

The quarry is located in a mountain near the plant at about 1400 meters above the sea level, in a place called Piagge.

It is divided into three sites: Muntacava, Snive, Monte Plunea (Figure 1.4) and have a quartzite reserve of about 15.000.000 m^3 [9].

Chemical composition of the quartz rock can strongly vary in the different point of the quarry, in particular regarding the iron content, that is the most important quality parameter for silica sand [9].

An example of a typical quarry sample chemical composition is reported in Table 1.2.

Table 1.2: Example of silica rock chemical composition [10]

SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	Na_2O	TiO_2	Cr_2O_3
96,1%	2,303%	0,124%	1,304%	0,051%	0,079%	0,017%	0,056%	0,0005%

One of the responsible of the quarry duty is to properly mix the raw material coming from the different quarry points (previously analyzed by the laboratory) in order to obtain an homogeneous mixture that respects as much as possible the product specification.

The extraction is performed through controlled explosions and the raw material is conveyed by trucks (Figure 1.5) and crushed directly on the site until it will reach a size of 0-4 cm. These steps are called primary and secondary crushing [9].

Figure 1.5: The quarry in Robilante site

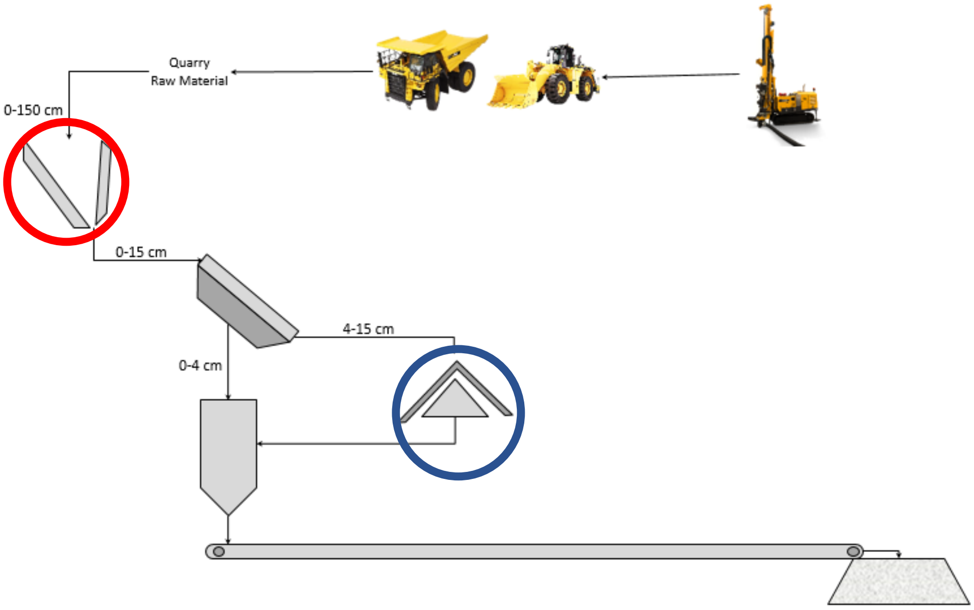


Figure 1.6: Primary and secondary crushing

These two preliminary steps are performed by a primary jaw (red circle) crusher and a secondary cone crusher (blue circle) as briefly described in Figure 1.6.

The rock is then reduced to a dimension of 0-4 cm and is then sent to the stockpile of the processing plant through a belt conveyor that converts the potential gravitational energy of the rock into electric energy (the plant is at about 800 meters above the sea level) [9].

The energy produced thanks to this system is about 1 MW [9].

1.3.2 The processing plant

The second part of the site is the processing plant. Here the raw material coming from the quarry is processed and reduced from at least 40 mm to the granulometries required for the commercial sands.

The raw material arrives from the belt conveyor to a stockpile that has a capacity of 380.000 tons. The material in this phase has a dimension of 0-40 mm and it has to be further reduced to 0-8 mm to be sent to the ball mill.

This further reduction is called 'tertiary crushing' and is performed by two cone crushers (red circle in Figure 1.7) as shown in Figure 1.7.

The stream is sieved (blue circle in Figure 1.11) in order to assure that the sand sent to the silo before the ball mill has a dimension between 0 and 8 mm.

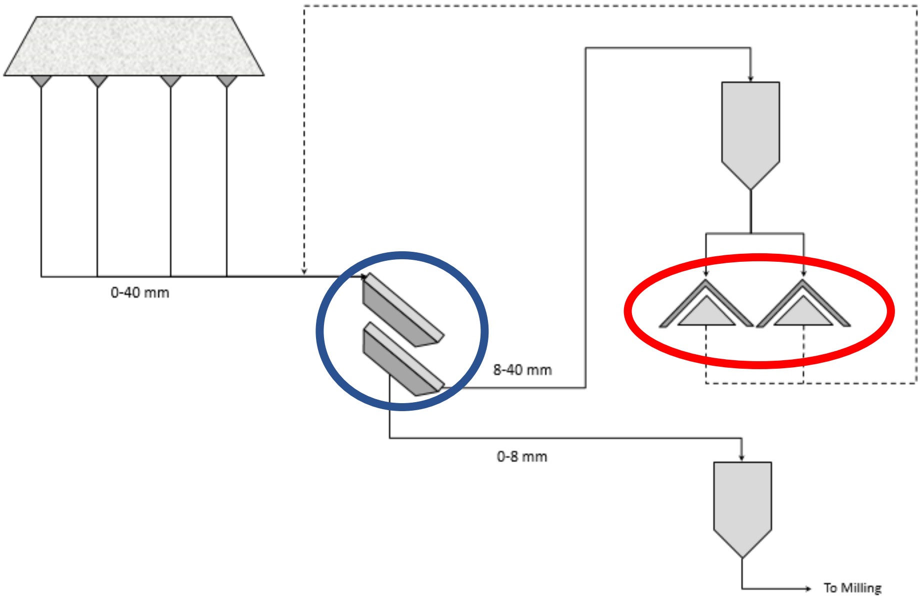


Figure 1.7: Tertiary crushing

Now a brief description of the process carried out in the plant will be given, in the following chapters will be deeper analyzed the so-called 'washing plant' that is the actual object of the simulation implemented and so of the project.

After the tertiary crushing, the raw material is sent to the ball mill of the plant (Figure 1.8) in order to be reduced to the desired dimensions for the final products. The ball mill will be the only unitary operation where the granulometry of the raw material changes, after the three crushing steps. The following operations will work as separators and sorters that are carried out in order to reach the right granulometry, required for the products specifications.

As shown in Figure 1.8 the ball mill reduces the raw material until a maximum dimension of 3 mm. The stream is then sent to an hydrocyclone to remove the fines particles that are unwanted into the final products.

The under of the hydrocyclone is sent to four sieves that work in parallel, cutting ideally at 1,5 mm.

The coarse fraction is sieved in order to obtain two products used in the construction sector and the under of the sieve (smaller than 1,5 mm) is recirculated to optimize the physical separation.

The products obtained in this section are “Sabbia 1” and “Granella”, both of them are commercialized mainly for construction purposes, for the production of concrete, for instance.

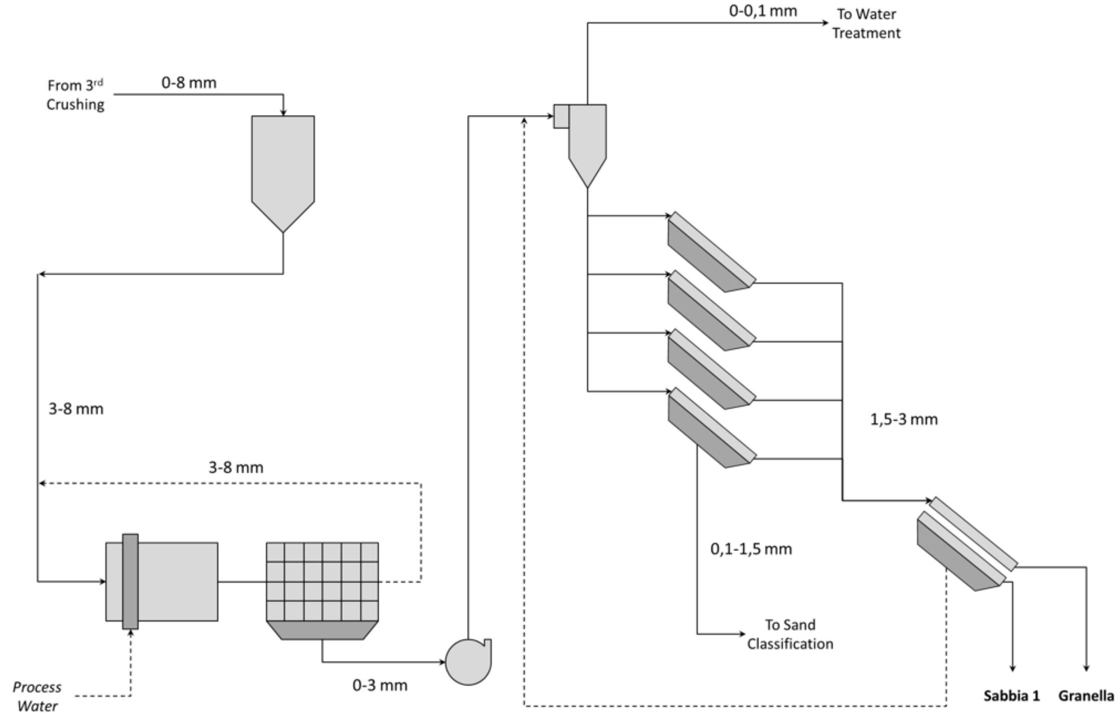


Figure 1.8: Ball Mill section

In Table 1.3 and Table 1.4 are reported two typical granulometries of these products [10].

Table 1.3: Typical granulometry for Granella [10]

Granella	
Sieve passed, µm	Weight percentage
3000	97.9%
2500	91.8%
2000	74.8%
1500	46.7%
1200	20.6%
1000	9.5%
800	2.3%
600	0.2%
63	0%

Table 1.4: typical granulometry for Sabbia 1 [10]

Sabbia 1	
Sieve passed, µm	Weight percentage
2000	97.9%
1500	88.9%
1400	78.5%
1180	56.6%
1000	28.5%
800	6.5%
600	0.6%
400	0.2%
63	0.1%

The four sieves underflow is then sent to another part of the plant, called ‘glass sand production’ (Figure 1.9), where other three products are obtained.

Fines are silica sand particles typically smaller than 100 µm, often than 75 µm. Their chemical composition (see Table 1.6) is usually much richer in iron than the average one of the quarry and than the percentage allowed by the product specifications. For this reason, together with the inadequate granulometry, their removal is of primary importance during the process and their production is limited to low-value products mainly used in the ceramic industry.

An example of fines chemical composition and granulometry is reported into Table 1.5, 1.6 [10].

Table 1.5: Typical granulometry for Sabbia VVR [10]

Sabbia VVR	
Sieve passed, μm	Weight percentage
192	99.9%
128	99.9%
96	99.9%
64	99.7%
48	98.9%
32	95.3%
24	89.9%
16	77.3%
12	63.5%
8	43.5%
6	32%
4	19.8%
3	13.2%
2	6.5%
1,5	3.7%
1	2%

Table 1.6: Typical Sabbia VVR chemical composition [10]

SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	Na_2O	TiO_2	Cr_2O_3
86,1%	8,362%	0,963%	3,417%	0,153%	0,412%	0,090%	0,133%	0,0056%

From Table 1.6 is easy to see how different the chemical composition is even from the average one of the quarry, and totally out of the desirable specification, as mentioned in [6].

The underflow of the four sieves is further processed in order to obtain the remaining products. In Figure 1.9 is reported the following section where glass-sands are collected.

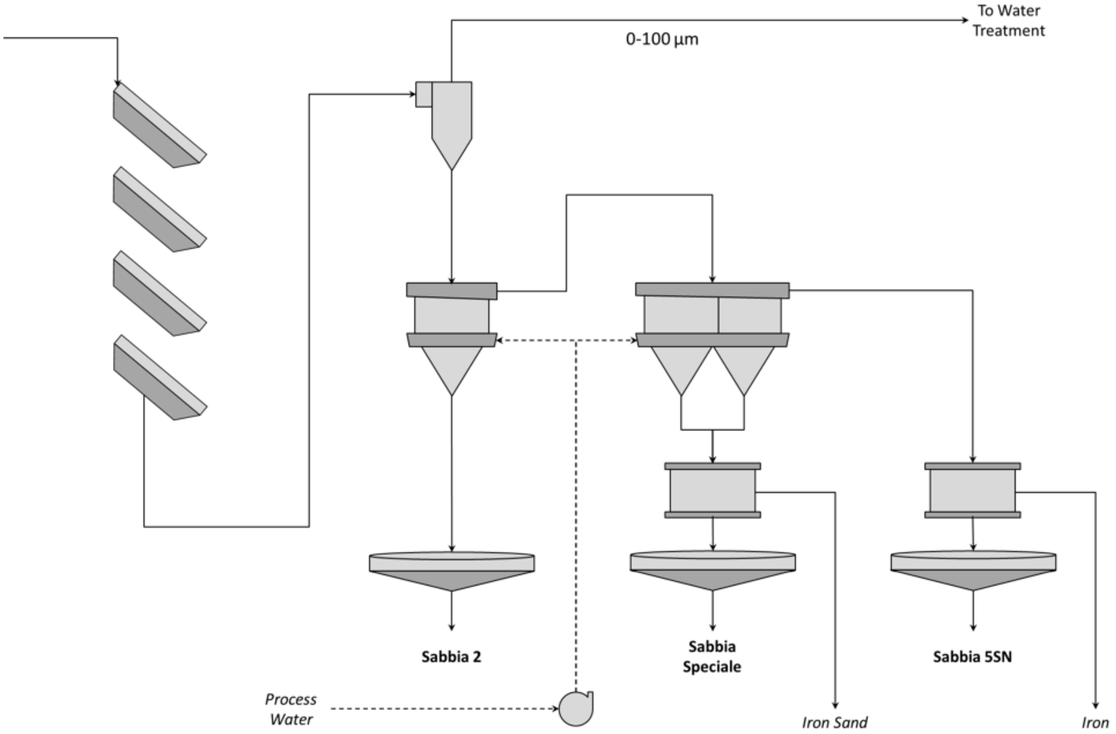


Figure 1.9: Glass sands section

Another hydrocyclone is placed after the four sieves to performer a further removal of the fines particles that will be processed, together with the ones removed after the ball mill crushing, in another section of the plant, called 'ceramic sand section' that will be shown after.

The underflow of the hydrocyclone is sent to an hydraulic classification and the underflow of this unitary separation is then dewatered by a pan filter filter in order to obtain another product, that is called "Sabbia 2".

In Table 1.7 and Table 1.8 are reported a typical granulometry and a chemical composition for this product [10].

Table 1.7: Typical granulometry for Sabbia 2 [10]

Sabbia 2	
Sieve passed, µm	Weight percentage
1500	100%
1180	99.8%
1000	98.2%
800	89%
600	58.9%
400	25.8%
200	9.4%
100	3.6%
63	0.8%

Table 1.8: Typical Sabbia 2 chemical composition [10]

SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	Na_2O	TiO_2	Cr_2O_3
95,8%	2,136%	0,119%	1,197%	0,042%	0,068%	0,017%	0,054%	0,0005%

The upper stream of the first hydraulic classification is sent to another hydraulic classification in order to obtain the two remaining product of the glass-sand section.

The first is called “Sabbia Speciale” and the second one “Sabbia 5SN”. Before to send the final products into the respective silos, other two steps are carried out, and these are a single passage through a magnetic separator in order to remove mainly the iron dust released by the cast iron ball, used in the mill to obtain the crushing, and another one in a pan filter in order to dewater the product.

In Table 1.9, 1.11 and Table 1.10, 1.12 are reported a typical granulometry and chemical composition for these products [10].

Table 1.9: Typical granulometry for Sabbia Speciale [10]

Sabbia Speciale	
Sieve passed, µm	Weight percentage
1000	100%
750	100%
600	99.8%
400	94.9%
300	70.9%
200	34.6%
150	13.3%
100	1.7%
63	0.3%

Table 1.10: Typical Sabbia Speciale chemical composition [10]

SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	Na_2O	TiO_2	Cr_2O_3
95,438%	2,265%	0,119%	1,389%	0,044%	0,069%	0,018%	0,058%	0,0005%

Table 1.11: Typical granulometry for Sabbia 5SN [10]

Sabbia 5SN	
Sieve passed, µm	Weight percentage
600	100%
500	100%
400	100%
300	100%
200	99.8%
150	95.8%
100	58.3%
75	26.1%
63	11.8%

Table 1.12: Typical Sabbia 5SN chemical composition [10]

SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	Na_2O	TiO_2	Cr_2O_3
95%	2,762%	0,116%	1,845%	0,056%	0,077%	0,021%	0,080%	0,0005%

The last section of the plant is the one called “ceramic sands section”.

This section (Figure 1.10) is placed after a thickener necessary to remove the fines particles from the process water used in the plant.

The water coming from the first two sections is added with a flocculant and then is sent into the thickener, here the fines particles can deposit into the bottom and can be extracted through a pump to be further processed.

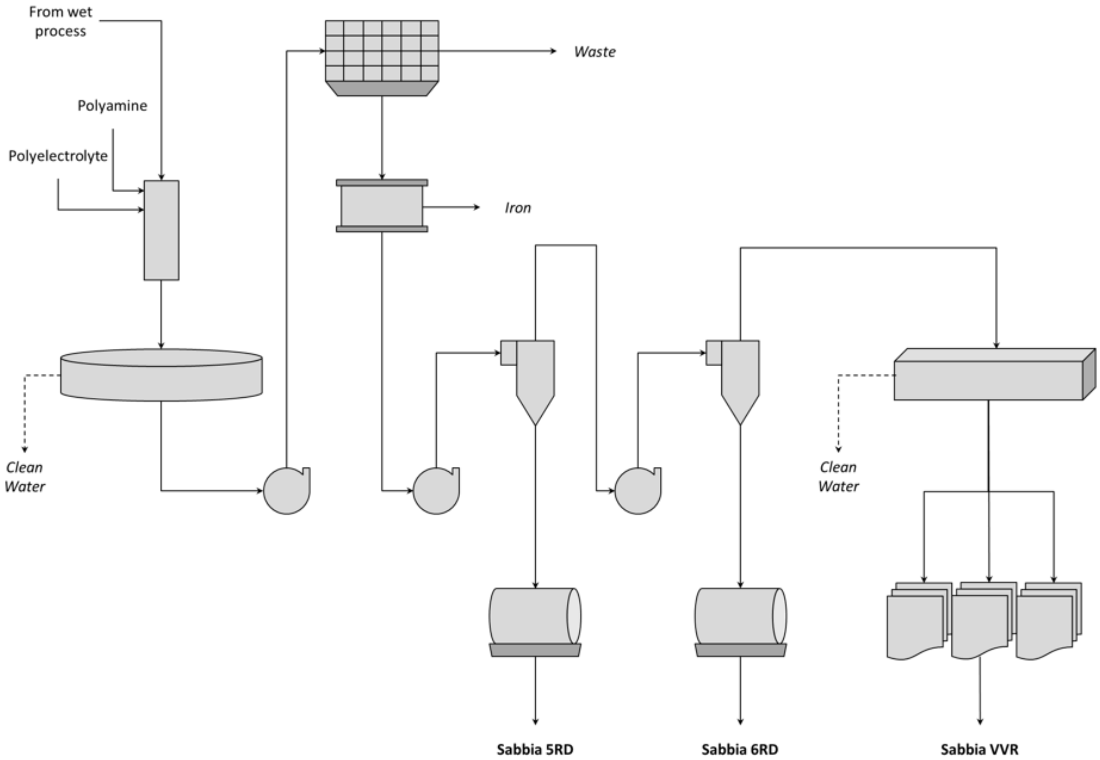


Figure 1.10: Ceramic sands section

The stream is pumped into a sieve placed to remove waste that can be entered into the stream during the thickening (leafs, etc) and the iron sand is so removed as happened for the glass-sand section.

Two hydrocyclones are placed after the magnetic separator: the bottom of the first one is the first product, “Sabbia 5RD”, the bottom of the second one, that is fed by the over of the first hydrocyclone, is the second product, “Sabbia 6RD”.

The over stream of the second hydrocyclone is then dewatered by a press filter and the cake so obtained (the finest part of all the process) is stocked as the last product, “Sabbia VVR”.

In Table 1.13, 1.15 and Table 1.14, 1.16 are reported a typical granulometry and chemical composition of these product. For “Sabbia VVR” the results were already shown previously in the paragraph about fines (Table 1.5, 1.6) [10].

Table 1.13: Typical granulometry for Sabbia 5RD [10]

Sabbia 5RD	
Sieve passed, μm	Weight percentage
192	99.9%
128	99.1%
96	94.7%
64	76.8%
48	56.9%
32	38.2%
24	30.2%
16	22.6%
12	17.7%
8	11.9%
6	9%
4	5.9%
3	4%
2	1.9%
1,5	1.1%
1	0.8%

Table 1.14: Typical Sabbia 5RD chemical composition [10]

SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	Na_2O	TiO_2	Cr_2O_3
93,7%	3,340%	0,321%	1,773%	0,082%	0,228%	0,048%	0,081%	0,0050%

Table 1.15: Typical granulometry for Sabbia 6RD [10]

Sabbia 6RD	
Sieve passed, μm	Weight percentage
192	100%
128	100%
96	99.6%
64	93.4%
48	81.9%
32	62.7%
24	50.6%
16	36.3%
12	27.5%
8	18.4%
6	14.1%
4	9.6%
3	7%
2	4%
1,5	2.6%
1	0.7%

Table 1.16: Typical Sabbia 6RD chemical composition [10]

SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	Na_2O	TiO_2	Cr_2O_3
93,1%	4,038%	0,422%	1,945%	0,122%	0,254%	0,053%	0,087%	0,0051%

What will be called, since this paragraph, as "washing plant", and will be the object of this project, are the first two sections of the plant overview here briefly shown.

These, which was called "Construction sands section" and "Glass sands section", will be simulated because of their importance in terms of the products obtained (that are the most valuable) and of the water consumption.

1.3.3 The water circuit

Water in the plant is used to obtain a pulp together with the ore that can be easily moved and pumped. Water is necessary also in order to obtain the classification in hydrocyclones and for hydraulic classification, as will be shown after, and to remove the fines from the final product. The water that circulates in the plant contains mainly fines (particles with a diameter smaller than 75 μm) that are considered as pollutant for the products quality. As will be seen in the following chapters, water recirculation is possible, but to avoid contamination, it is allowed only from the last steps of the process to the first ones and not vice versa (in countercurrent respect to the flow of the ore). Doing differently, in fact, leads to transport fines into the final products, that means contamination.

The water circuit in the plant already reuses, where it is possible, the water streams, in order to treat in the thickener only the ones that cannot longer be used. The thickener is an outdoor circular vessel where the fines are removed from the water streams. The concentration of fines usually removed is of about 50 g/liter and chemicals (polyelectrolytes, flocculant) are used to achieve the sedimentation [9][10].

In the "washing plant" there are two water circuits, a closed one and another that can be filled with fresh water. Fresh water means water treated in the thickener to remove fines, water from aqueduct is considered as a reinstatement for the water coming from the thickener and is added to it in hydraulic classification. The current withdrawal from the aqueduct is about 114 m^3/h; this amount of water is collected in a vessel and only partially used, the remaining part is then sent again to a river close to the plant. Accurate data about the water consumption in the washing plant are required in order to optimize the withdrawal from the aqueduct, reduce it making the process more sustainable, respect the legal obligations and foresee future restrictions that are likely to be applied in environmental legislation.

Fresh water enters into the washing plant by two ways: in one of the water internal circuit as reinstatement for the unavoidable water leaks and as feed in the hydraulic classifiers, where is necessary to have water as clean as possible to obtain the solid separation and avoid fines contamination.

Water in the 'closed' circuit is taken from the hydrocyclones overflows and then used to dilute the ore streams to pump them or achieve solid classifications and separations as will be shown later.

The closed circuit is partially split in order to send a water stream that carries also fines to the thickener and so avoid fines accumulation in the circuit.

1.4 Washing plant and equipment description

As mentioned before the first two sections of the processing plant are the ones called "washing plant".

Here the silica sand stream is further crushed by the ball mill and sorted by hydrocyclones and hydraulic classifications.

A brief description of all the main equipment with some design and control aspects will be given in the following paragraphs.

1.4.1 Silos

Silos can be found at the beginning of the process, after the stockpile, and at its the end, in order to stock the final products [11].

Silos are structures used to store bulk materials. They can have various shape and dimensions, but nowadays mostly three types of them are used: tower silos, bunker silos and bag silos [11].

Tower silos are cylindrical structure made by different materials (concrete, wood, steel panels, etc) with a diameter typically between 3 and 27 meters and an height between 10 and 90 meters [11].

The silo placed after the stockpile (Figure 1.11) in the plant is a tower silo made by concrete high 30 meters with a diameter of 16 meters [9].

Figure 1.11: Silo after the stockpile in Robilante plant

Bunker silos are trenches, usually with concrete walls, filled by tractors and loaders. They are usually easy to manage and good for very large operations [11]. Silos placed at the end of the processes, used to store the final products, are bunker silos.

Bag silos are plastic tubes of usually 2,4 to 3,6 meters in diameter and various height [11].

1.4.2 Ball mill

The ball mill is placed directly after the tower silo, it is fed by a recirculated coarse material stream (as usually done to improve the mill efficiency) to which is added the fresh one.

Ball mills are equipment used to reduce the size of particles with various physical and chemical composition. They are widespread used in mineral and mining processes, but also in food and pharmaceutical industries. They can be involved also in processes of mixing, blending and dispersing, amorphisation of materials and mechanical alloying [12].

Ball mill usually consists into a cylindrical vessel (Figure 1.12) fixed on an appropriate basis at both ends which allows rotation of the vessel around the center axis that is usually obtained thanks to a synchronous motor.

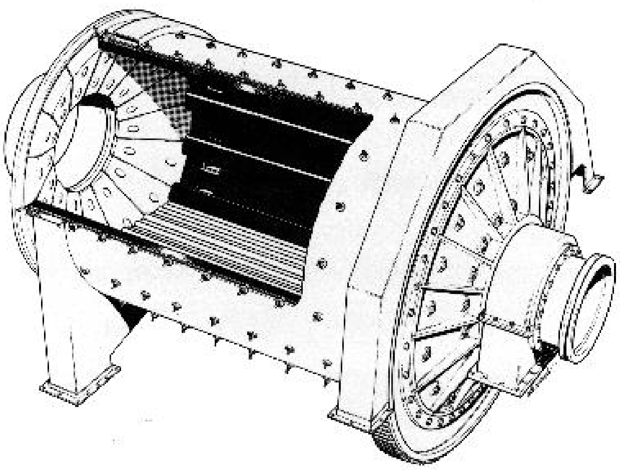


Figure 1.12: Ball Mill for minerals crushing, from [12]

The mill is so charged with the feed material (in this case the silica sand coming from the stockpile) and the grinding media balls, whose material can strongly varies, depending on the case. Some examples of balls material are: iron balls, ceramic balls and metal cylindrical bodies called “cylbeps”.

The size reduction takes place during the rotation, as a result of the transfer of kinetic energy from the rotating grinding media to the feed material as shown is Figure 1.13.

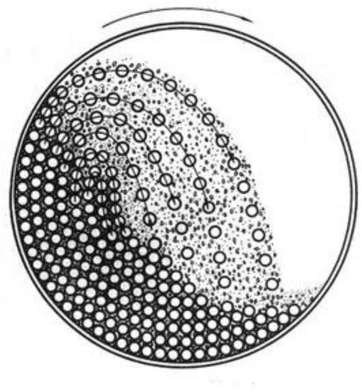


Figure 1.13: Ball Mill comminution principle, from [15]

The size of a mill is usually fixed by the ratio "length to diameter" that often goes from 0,5 to 3,5. They are generally divided by the different way used to discharge the equipment, so that there are three types of ball mill: overflow discharge mill, grate discharge mill (as in "washing plant") and center-periphery discharge mill [12].

Basic operative parameters of a ball mill are: the speed of rotation, characteristics of the material charged in the mill (mass, volume, hardness, density and the size distribution of the charge), characteristics of the grinding media (mass, density, ball size distribution, percentage of grinding media load), slurry density in case of wet grinding operations.

In particular, the speed of rotation determines the ball mill operation mode: slow rotation (cascading), fast rotation (cataracting) and very fast rotation (centrifugation) [12][15].

The ball mill placed in the "washing plant" is fed by iron balls as grinding media and operates at slow rotation (17,76 rpm) as will be shown in chapter 2.2.

The production capacity, measured in tons of production per hour, is one of the main parameters for an industrial ball mill. It depends on mill dimensions, the type of the mill, the speed of rotation, the mill loading, the final product size required from a given feed size, the work index of the material, the mill shaft power and the specific gravity of the material [13][14][15].

The work index of the material, that is one input requested by the software tool template, is the comminution parameter that expresses the resistance of the material to crushing and grinding. It is experimentally determined and an exhaustive lists of it for many materials is given by [13] [14][15].

During the comminution operations the feed particles are progressively reduced by the kinetic energy, given by the grinding media, that disrupts their binding forces. Three main fragmentation mechanisms are supposed to exist in order to justify the different products obtained at the end of the grinding phase. They are: abrasion, cleavage and fracture as shown in Figure 1.14 [13][14][15].

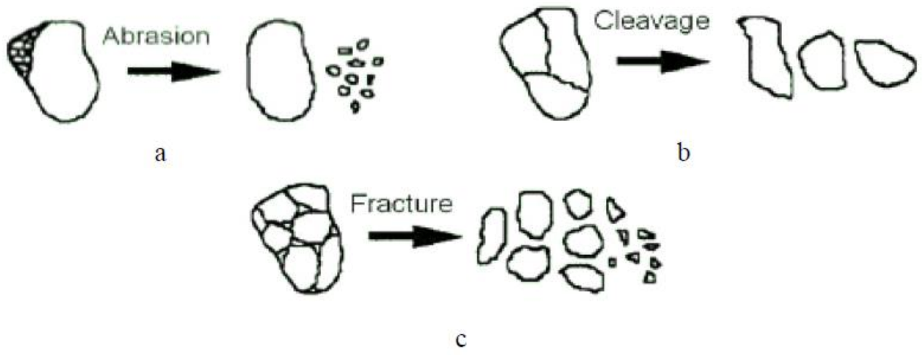


Figure 1.14: Grinding phases in detail, from [15]

Abrasion occurs when low intensity stresses are applied and leads mainly to the formation of fines particles [15].

Cleavage occurs when slow and relatively intense stresses are applied and leads to product fragments of size 50-80% of the initial particle size [15].

Fracture occurs when rapid and intense stresses are applied and leads to the production of fragments with small sizes and a relatively wide size distribution [15].

Usually these three mechanisms appear together and the final size distribution in the product is the result of their combination.

Main difficulties in control and product standardization in ball mill technology come from the quite various composition (both chemically and by the point of view of the size distribution) of the feed and from the unknown exact phenomena that take place inside the ball mill [13][14][15].

1.4.3 Screens

Screens are widely used to achieve solid separations from 300 mm to even 40 μm. They can have different applications in mineral processing industry: sizing or classifying, scalping, grading, media recovering, dewatering, de-dusting and trash removal [15].

In the “washing plant” is possible to find some example of these usage, in particular as classifier (vibrating screens), scalping (trammel screens) or dewatering (pan filters).

A screen consists into a surface with many apertures, usually with similar dimensions. Particles present at this surface can pass through them or not. Thanks to this passage, the screen achieves the solid separation[15][16].

Is clear from it that the apertures dimension determines the maximum dimension of the particles in the underflow

An efficiency for screens can easily be calculated starting from data samples of the feed and the outputs.

The cut point is the value of size at which a particle has 50% of probability to be found in the underflow or in the overflow.

At least two products are obtained with a screen, a coarse fraction of the feed and a fine one. The fine fraction generally is collected under the screen and the coarse at its end as summarized in Figure 1.15 [15].

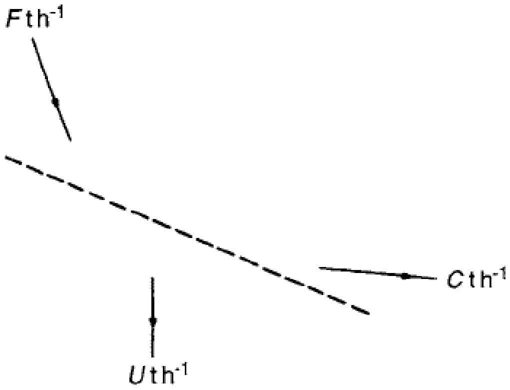


Figure 1.15: Sieving principle

Where F is the feed stream in tons per hour, C is the feed at the end and U the one coming from the underflow [15].

If *f* is the fraction of material above the cut point in the feed, *c* the fraction of it at the ending stream and *u* at the underflow, assuming that $u = 0$ (generally the coarse fraction in the underflow, if the screen has no damage, is almost zero), we can define an efficiency *E* as shown in (1.1).

$$E = \frac{c - f}{c \times (1 - f)} \tag{1.1}$$

Efficiency can be affected by some factors, the screening process, in fact, is usually described as a probabilistic event that the particle of a given size will pass through the apertures [15].

For the particles that have dimensions close to the ones of the mesh, the probability that they will pass decrease dramatically, moreover this kind of particles could obstruct the mesh, provoking a strong decrease in the screen efficiency [15][16].

Factors that can affect the screen efficiency are also [15]:

- Screen angle: varying the particle trajectory from the perpendicular one, the efficiency decreases because is less likely that the particle can pass.
- Particle shape: spherical particles have the same probability to pass in every orientation, if the shape is non-spherical the probability will not be the same in every dimension (that is why, as will be shown after, the program template allows the operator to insert if the silica sand is from crushing or from a natural sand deposit).

- Vibrating: screens can be vibrated in order to permit to the particles to be presented to the surface screen many times and increasing that way the possibility they can pass through it.
- Moisture: a wet feed is usually harder to be screened because of the conglomerates that can be formed by the water content.

1.4.3.1 Trommel screen

The trommel screen (Figure 1.16) is a rotatory screen that allows to the operator to separate materials, is used mainly in the mineral industry and in companies where solid waste has to be treated [17][18].

It is composed by a perforated cylindrical drum that can be elevated to a certain angle by the feed side. The physical separation is achieved thanks to the passage of the feed material into the inner cylindrical drum. The undersized material falls down into the screens openings and the coarse fraction, reached the end of the trommel, is then collected [19].

In the "washing plant" a trommel screen is placed at the output of the ball mill, in order to screens the crushed silica sand and separates the particles that have not already reach the wanted dimensions (0-3 mm) from the others. The out stream at the end of the trommel is then recirculated to the ball mill in order to enhance the efficiency, as previously mentioned [17][18].

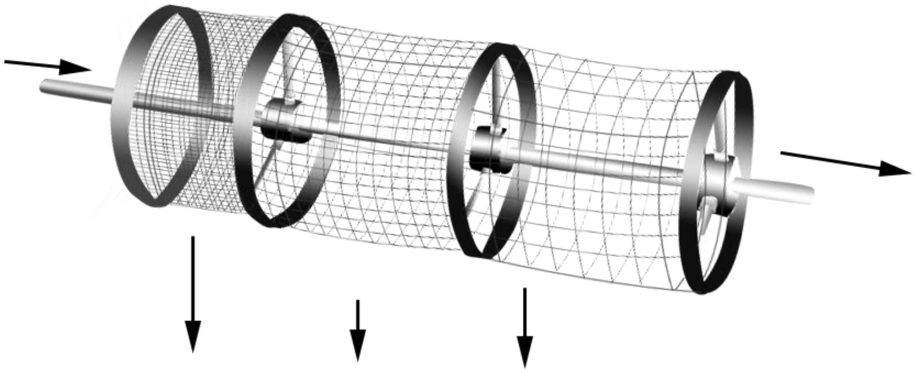


Figure 1.16: Trommel and output streams, from [19]

Many parameters must be taken into account in order to perform the wanted separation, but the practical approach used into design and operative phases of trommel technology remains still too heuristics for a strong mathematical modeling [18][19].

The efficiency of separation is given by the probability that an undersized particle has to pass through the fixed screen openings. This probability increases increasing, for instance, the residence time in the trommel or the water content of the feed [18][19].

A certain number of times that the material must impinge on the screen surface is required to achieve a wanted efficiency. It can be evaluated by statistics probability models [19] and from this also the residence time and the rotational speed [17][18] [19].

For the purpose of this project the trommel was considered only as a screen with a certain efficiency, in order to be in accordance with the samples data. An exact modeling of the trammel sieve goes, in fact, beyond the intentions of the project.

1.4.3.2 Vibrating screen

Vibrating screens are the most important and used devices for material separations in the mineral processing industry.

They are vibrated screens, usually with a rectangular screen surface and can have more than one screen deck in order to obtain a more detailed separation thanks to different cut size.

They can have different motions: circular motion, linear-vibration and oval motion.

The different vibrating screens placed in the "washing plant" will be modelized, as will be shown after, using the right screens dimensions (in particular the mesh) and with a certain efficiency to be in accordance with the collected samples [16].

1.4.4 Classificators

Classificators are basically used to achieve a solid separation when the particles are too fine to be separated by sieving.

It is a method of separation mixtures of minerals into two or more products, on the basis of the velocity with which the grains fall through a fluid medium (Heiskanen, 1993). If a solid particle falls into the vaccum, its velocity increases in an undefined way because of the gravity acceleration applied to it; otherwise, if the particle falls passing through a fluid medium, a force between the particle surface and the medium is applied. This force is due to the 'friction' between them and is called viscous resistance. The velocity of the particle so will increases, falling in a fluid medium, until a certain value will be reached, at which the resistance to the motion, due to the viscous resistance, will be equal to the gravity force that accelerates the particle. This velocity is called 'terminal velocity' [15].

In the mineral sector fluid medium are usually air or water (as the case of this project).

Classifiers are basically a sorter column, where a fluid is inserts countercurrent respect to the solid stream. The separation is achieved thanks to the settling velocity of the particles that depends not only on the specific gravity of the material, but also on its dimension and shape. The particle that have a settling velocity smaller than the velocity of the fluid will go into the overflow, and the ones with a settling velocity bigger than the one of the fluid will go into the underflow as shown in Figure 1.17 [15].

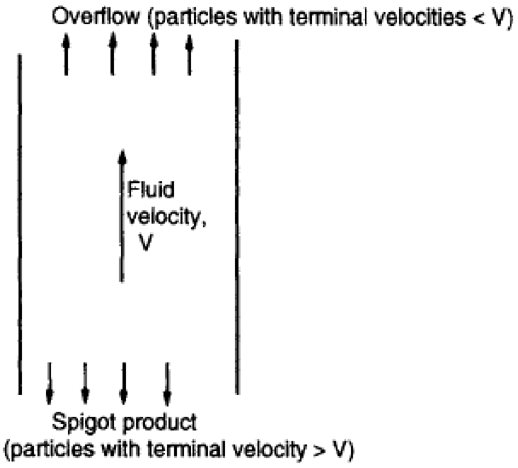


Figure 1.17: Classification with fluids principle

Two main regimes can be determined in separation, depending on the water content of the slurry: free settling regime and hindered settling.

The former appears when the water content of the slutty is quite high, and the solid concentration is above 15% (Taggart, 1945), so that the particles crowding is negligible. In this conditions Stokes law and Newton law are valid and two statements can be obtained:

- If two particles have the same density, then the particle with the larger diameter has the higher settling velocity.
- If two particles have the same diameter, then the heavier particle has the higher terminal velocity.

The latter appears when the solid percentage of the slurry starts to increase and with it its viscosity. In this regime the particles crowding is not more negligible and the Newton law has to be modified. As a result of the crowding regime, the effect of size is reduced and the effect of density is enhanced in the classifications process. In order to increase the effect of size in classification, is so necessary to increase the water content of the slurry, decreasing, for instance, its solid percentage [15].

1.4.4.1 Hydraulic classifiers

These equipment are characterized by the addition of water to the current processed slurry. They usually consist into a series of vessels, where the water is added to the stream from the bottom at a certain velocity and the ore feed is inserted from the top.

This configuration allows the water to drags as overflow the particles of the stream that have a settling velocity lower than the velocity of the water flow and to collect as coarse fraction the ones with a higher settling velocity than the one of the water flow [15].

In order to obtain a better separation some vessels are put in series, as previously pointed out, fed with water at different velocities. Operating in this way a different product for each vessel can be obtained. In the first one the water will flow at an higher velocity, so that the coarsest fraction will be collected. The following water velocity will be decreased progressively in order to collect smaller and smaller fractions as shown in Figure 1.18.

.

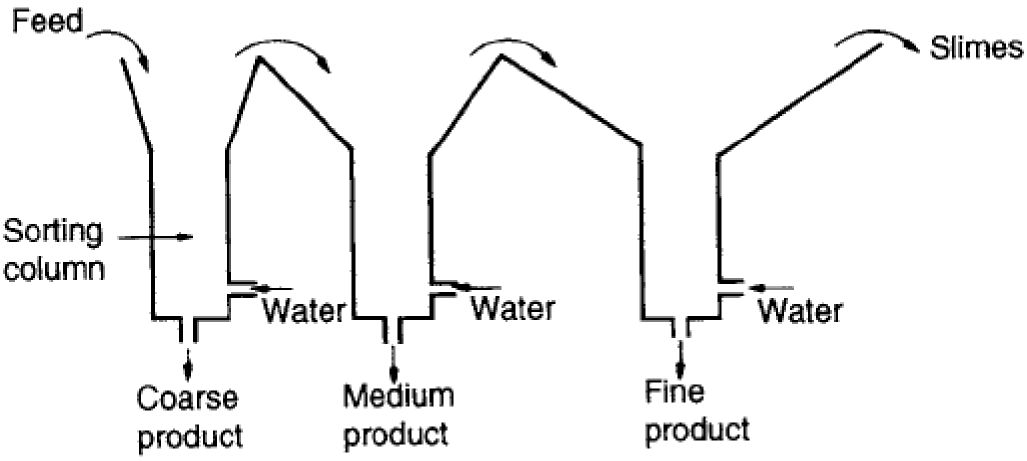


Figure 1.18: Scheme of an hydraulic classifier, from [15]

The regime in which the operation is usually carried out is the one that was called “hindered settling” in the previous chapter, it allows the process to save water and to achieve a good separation even if mainly based on specific gravity and not on the sizes of the particles [15].

In the “washing plant”, as was seen, there are two hydraulic separators. They work classifying on size basis even if the regime is of hindered obtaining only two flows for each. These equipment receive a water supply of fresh clean water, directly coming from the thickeners, because the water has to be as cleanest as possible to avoid product contamination in this process phase.

1.4.4.2 Hydrocyclones

Hydrocyclones are one of the most used equipment in mineral processing sector [15].

They are a continuous device, that accelerates the settling rate of particles with the centrifugal force. Their spread usage is due to the relatively high efficiency, combined with a good capacity and light design. They can be used for classification, dewatering and as thickeners[15][20].

They consist into a conical vessel (as shown in Figure 1.19), open at the underflow (apex), with a cylindrical section and a tangential feed inlet. The top of the cylindrical section is closed by a plate (vortex finder) through which there is a pipe that goes into the body of the cyclone. The mainly function of this pipe is to avoid short-circuit of the feed in the overflow [15][20].

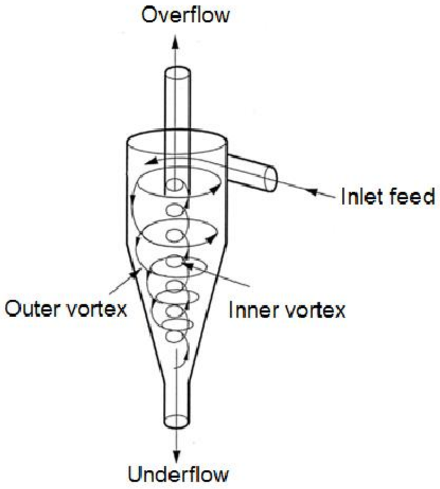


Figure 1.19: Scheme of the internal flow in an hydrocyclone, from [15]

At the inlet the feed is insert under pressure with a tangential entry, in order to impress a swirling trend to the slurry. This way a vortex is formed into the body of the cyclone, with a low pressure zone at the vertical axis where there is an air cone (at atmospheric pressure) that starts from the vortex finder.

The classical theory used to explain the hydrocyclone functioning involves the presence of two different forces that act on the particle: the drag force, due to the flow of the slurry, and the centrifugal force, due to the vortex formed into the body of the cyclone, as shown in figure 1.20 [15][20].

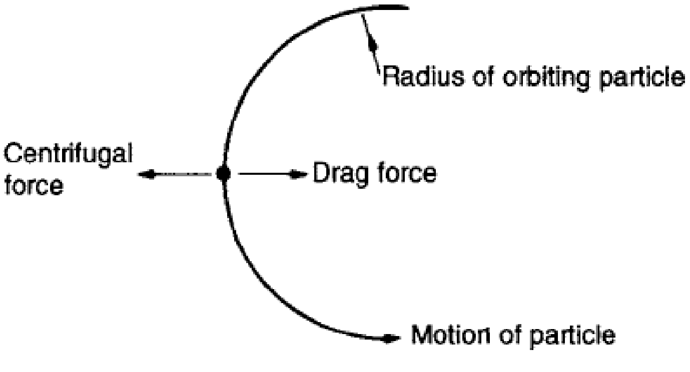


Figure 1.20: Forces in an hydrocyclone, from [15]

The presence of these two forces implies the presence of a certain radius value, at which the sum of the former and the latter gives zero. Where the drag force is equal to the centrifugal one. Particles that are at this radius in the vortex have the same possibility to go both in the underflow or in the overflow.

In reality, following studies carried out by Renner and Cohen (1978), shows that the classification does not take place in all the volume of the hydrocyclone body, but only in a limited space. The whole equipment can be divided into four region as shown in Figure 1.21 [15].

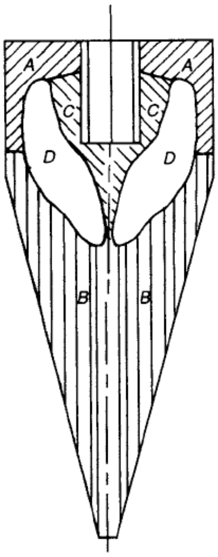


Figure 1.21: Hydrocyclones' selecting sections, from [15]

Figure 1.21 shows the results of the study of Renner and Cohen (1978), according with which the body of an hydrocyclone can be divided in sector A, B, C, D.

- A: Unclassified feed.
- B: Fully classified coarse material (it occupies a very large pat of the equipment).
- C: Fully classified fine material.
- D: Toroid section where the solid separation takes place.

Many operative and geometrical parameters can define the output of an hydrocyclone, the main are: the feed volumetric flowrate, the pressure drop at the input, the density of the slurry, the viscosity of the slurry, the solid content of the slurry, the diameter of the hydrocyclone, the diameter of the apex and of the vortex finder [15][20].

About the effect of these parameters on the efficiency of the hydrocyclone, as a general rule, was pointed out that every geometrical modify that increases the resistance to the flow, increases also the solid recovery, even if decreases the device capacity. This means that decreasing the dimension of the apex and the vortex finder, can increase the solid recovery but decreases the capacity of the hydrocyclone [15]. Pressure drops shown to have a strong effect on the solid recovery, increasing the inlet pressure, the efficiency of separation increases with it. Also the density has an important effect: increasing the solid percentage, the separation efficiency falls rapidly, because of it usually hydrocyclones are used with dilute feeds [20].

Many models were developed for hydrocyclones during the years in order to evaluate the cut size (that is the particles size which separates at 50% of efficiency, is common used to characterize its performance) and the outputs, starting from the geometrical characteristics and the operative values of the equipment.

One of the first models, that was developed by Bradley in 1965, is based on the classical theory (equilibrium orbit hypothesis), briefly explained before, of hydrocyclones. The model is not reliable at all because things in reality, as was shown, work not in accordance with the classical theory, but can be useful to see it by the fact that it involves the parameters previously mentioned [15][20].

According to the Bradley's model, the cut size is shown in (1.2).

$$d_{50} = k \cdot [\frac{D_c^3 \cdot \eta}{Q_f \cdot (\rho_s - \rho_l)}]^n \tag{1.2}$$

Where:

- D_c is the hydrocyclone diameter.
- η is the fluid viscosity.
- Q_f is the feed flow rate.
- ρ_s is the solids density.
- ρ_l is the fluid density.
- k is a constant that incorporates other parameters, in particular the hydrocyclone geometry.
- n is an hydrodynamic constant (0,5 for particle laminar flow).

The equilibrium orbit theory give important information on which are the leading factor in the separation, but is not applicable for design and control purposes.

Moreover the models follows this ratio. Also the following models, and the ones implemented on METSIM, in fact, try to estimate these hydrocyclone values starting from the operative and geometrical parameters.

The most reliable and used models are some empirical ones developed by Lynch and Rao (1975), Krebs, Plitt (1976) and a modified Plitt model version (1980) which are not based on any specific hydrocyclone theory, but are purely obtained through fitting experimental data.

Thanks to the high number of experimental data used, they are reliable for hydrocyclone design and control. These four models are the ones implemented in METSIM and will simulate the equipment on the "washing plant".

In (1.3), (1.4), (1.5), (1.6) will be given the expression for the cut size of these models.

Lynch and Rao's

$$log_{10}d_{50} = 0.41log_{10}\Phi_v - 0.0695 \cdot Spig + 0.0130 \cdot VF + 0.0048Q_f + 0.35log_{10}\eta + K_3 \tag{1.3}$$

Where

- Φ_v is the percentage of solid in the feed.
- VF is the diameter of the hydrocyclone vortex.
- $Spig$ is the diameter of the hydrocyclone spigot.
- K_3 is a constant.

Krebs's

$$d_{50} = 2.84 \cdot D_c^{0.66} \cdot \left(\frac{53-\Phi_v}{53}\right)^{-1.43} \cdot 3.27 \cdot \Delta P^{-0.28} \cdot \left(\frac{1.65}{\rho_s-\rho_l}\right)^{0.5} \cdot Factor \tag{1.4}$$

Where

- ΔP is the pressure drop inside the hydrocyclone.
- Factor is a constant that takes account of possible geometric differences.

Plitt's

$$d_{50} = F \cdot \left[\frac{50.5 \cdot D_c^{0.46} \cdot D_i^{0.6} \cdot VF^{1.21} \cdot \exp(0.063 \cdot \Phi_v)}{Spig^{0.71} \cdot h^{0.38} \cdot Q_f^{0.45} \cdot (\rho_s-\rho_l)^{0.5}}\right] \tag{1.5}$$

Where

- F is a factor to correct the cut size value.
- h is the free vortex height in hydrocyclone.

Plitt's modified

$$d_{50} = F \cdot \left[\frac{39.7 \cdot D_c^{0.46} \cdot D_i^{0.6} \cdot VF^{1.21} \cdot \exp(0.063 \cdot \Phi_v) \cdot \eta^{0.5}}{Spig^{0.71} \cdot h^{0.38} \cdot Q_f^{0.45} \cdot \left(\frac{\rho_s-1}{1.6}\right)^{k}}\right] \tag{1.6}$$

The validity of (1.3), (1.4), (1.5), (1.6) models, as for all the purely empirical ones, is limited to the field of the experimental data, out of their range no interpolation is allowed and so the models are not reliable at all.

For a deeper description of the models see [15][20].

As will be shown in the following pages METSIM includes the possibility to adapt these models, adding three correction factors, to the real equipment that are placed into the plant. Thanks to this function the software can be tailored to the real plant and its operative conditions.

1.4.5 Magnetic separators

As mentioned in Chapter 1.2, the iron content in silica sand is a fundamental issue for the final product specifications, by the fact that it influences the final quality of, for instance, the glass produced.

In order to remove the iron dust that can be formed during the process because of the machinery wear (the silica sand is obtained by crushing, so is very abrasive compared to sand naturally formed), or in the ball mill, where the grinding media consist into some iron balls (the iron balls consumption in known and is about 440 grams per tons of processed silica rock), a magnetic separator can be placed in the process.

Recent significant improvements have been made thanks to the involvement of multi-dimensional finite elements analysis (FEA), to determine the magnetic field and distribution, in design simulation [21].

Magnetic separators usually consist into a permanent magnet (in many different configurations: grids, drums, etc) that is ran over by the stream in order to remove the iron dust from it. The magnets are cleaned both continuously and discontinuously, depending on the type of equipment, and do not require electricity to work [21].

In this project magnetic separators will be modelized as simple splits, by the fact that a chemical composition description of the streams is not the purpose of the study and the small amount of iron powder removed, compared to the total amount of material processed (about 440 grams per each ton), does not represent a significant contribute.

1.4.6 Filters

Filtration consists into separate solids from liquid involving a medium that retains solids allowing the passage of liquid [15].

Formation of a certain thickness of solids, called cake, on the medium surface during the process is always present in filtration. The formed cake on the surface grows in time increasing the resistance to the liquid passage through the medium. The resistance to flow through the medium depends on many factors: the pressure drop between the feed and the filtrate, the area of the filtering surface, the viscosity of the filtrate, the resistance of the filter cake (that increases with time) and the resistance of the filter medium.

The filter medium is one of the most important parameters to assure the efficiency of a filter. It regulates the dimensions of the particles that can be separated from the liquid and has to assure the mechanical resistance to the process. It can be made by different materials (cotton, silk, porous carbon, metals, synthetic fibers, etc) or the coarse parts of the solids itself, that are used to form an initial cake layer to start the filtration [15].

Many types of filters exist, in the washing plant, as in general in the mineral industry, are used cake filters (under vacuum) to recover a large amount of solids from a concentrated slurry. In this project vacuum filters are present in the last step before the products silos, to dewater and wash the product obtaining the wanted humidity to meet the specifications [15].

1.4.11 Tilting pan filter

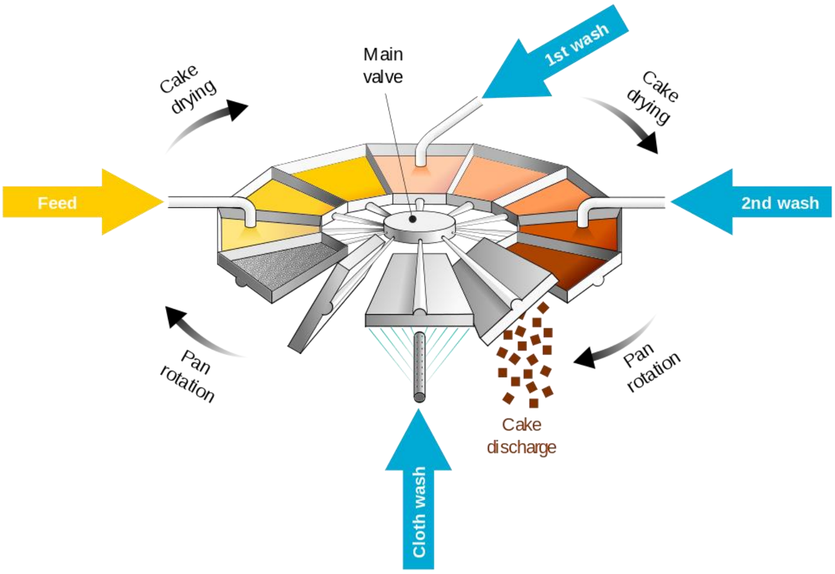


Figure 1.22: Tilting pan filter scheme [15]

In Figure 1.22 is schematized a tilting pan filter as the ones placed in the washing plant.

The feed is sent to the first section to dry the solid product, one or more clean water streams are sent to the filter in order to wash the solid, while it is dewatered from the bottom (under the filter medium is possible to place a pump in order to obtain the vaccum and achieve a more efficient process). At the end of the circle the dewatered product is discharged in the silo [15].

1.4.7 Data representation and cut size efficiency curve

Each equipment where a solid separation takes place (that means change the stream granulometry) can be characterized by an efficiency curve of the separation.

The curve usually used is called “Tromp curve” (Figure 1.23) and was developed by Klaas Frederik Tromp in 1937 [15].

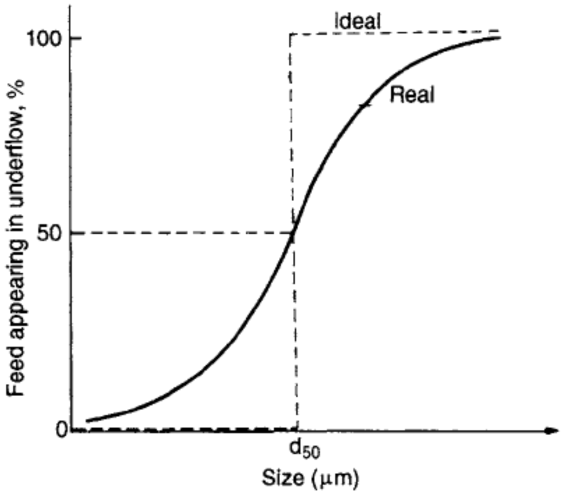


Figure 1.23: Cut size efficienty curve, from [15]

As shown in figure 1.23, the ideal Tromp curve implies that at a certain particle diameter value (the cut size, or d_{50}) the granulometry is completely divided in two fractions: the one composed by particles bigger than d_{50} in the underflow, and the one composed by particles smaller than d_{50} in the overflow [15].

In reality the efficiency is not ideal and so the curve assumes a sigmoidal shape as shown in Figure 1.23. That means can be found particles having a smaller diameter than d_{50} in the underflow and vice versa.

Starting from the real efficiency curve, an evaluation of the equipment efficiency can be performed by using a parameter called imperfection (I) that has the form shown in (1.7).

$$I = \frac{d_{75} - d_{25}}{2 \cdot d_{50}} \tag{1.7}$$

Where d_{75} and d_{25} are the values of the diameters at which a recovery of the 75% and the 25% of the feed is obtained in the underflow [15].

Intuitively I is a measure of the shape of the curve, the bigger its value will be, the less efficient the separation will be. The curve can be plotted for every separation equipment having the feed, overflow and underflow granulometries.

In case of feed short-circuits, that means the feed that directly goes into the underflow, without being separated (something that in various measure happens often in hydrocyclones), the partition curve has to be corrected as shown in Figure 1.24.

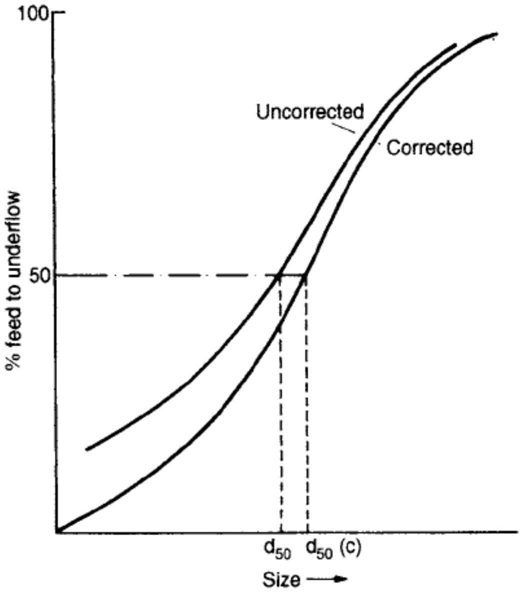


Figure 1.24: Short-circuit correction for the cut size efficiency curve, from [15]

The effect of the short-circuit is to bypass the separation step and carries directly fines into the underflow, this results into a certain amount of fine already found in the underflow, as shown in the “uncorrected curve” in Figure 1.24 by the presence of a percentage value at very small particles diameters. This is due to the fact that the finest particles do not participate to the separation phase, they are just carried with the water in the overflow [15].

In order to remove this contribute and obtain the real efficiency curve an equation is given in (1.8).

$$y' = \frac{y - R}{1 - R} \tag{1.8}$$

Where y' is the corrected mass fraction of a particular size reporting to the underflow, y is the actual mass fraction of a particular particle size reporting to the underflow, and R is the fraction of the feed liquid which is recovered in the coarse product of the stream [15].

According to the corrected curve, another value for the cut size can be evaluated and it is called corrected d_{50}.

To describe the particles size distribution across the device some expressions were developed, the most used are the Rosin-Rammler and the Lynch curves [15].

Both of them involve the usage of two parameters, the d_{50} of the equipment and another value, m, the sharpness of the efficiency curve at $y'(d_{50})$.

Their expressions are given in (1.9) and (1.10).

Rosin-Rammler

$$y'_i = 1 - \exp(-0.693147 \cdot \left(\frac{d_i}{d_{50}}\right)^m) \tag{1.9}$$

Where d_i is the geometric mean of the size interval.

Lynch

$$y_i' = \frac{\exp\left(\alpha \cdot \frac{d_i}{d_{50}}\right) - 1}{\exp\left(\alpha \cdot \frac{d_i}{d_{50}}\right) + \exp(\alpha) - 2} \tag{1.10}$$

Where $\alpha = 1.54 \cdot m - 0.47$.

Chapter 2

Mathematical modeling and Experimental methods

2.1 Experimental Methods

2.1.1. Methods of sampling

The main limitation to the present project, by the candidate’s point of view, is about data sampling. Because of the operative conditions (the plant must work in ordinary conditions), the inaccessibility of some sampling points (for safety or practical issues), the difficulty to perform some measurements (huge streams to be sampled), the team was able to obtain only one sample for every sampling point. About their reliability a detailed discussion was made with the laboratory technicians, who are used to control the quality in the processing plant, in order to be sure that the data obtained, even if few, can be consider as realistic and reasonable.

It must moreover be considered that the raw material processed in the plant is not homogeneous. From the quarry, rocks with different chemical compositions are extracted. The mineral is stored in the stockpile close to the plant as previously mentioned and then, after the tertiary crushing, in a silo close to the stockpile. During these steps different storing conditions can influence the stream of the raw material. For instance, if the silo is almost empty, the percentage of fines in the raw stream will be high, because fines tend to flow from the top (especially in wet weather conditions) to the bottom and as a result the top of the silo content will be poorer in fines than the bottom. This has consequences in the operative conditions of the plant and can influence the sampling phase. Having only one sample for each point in this sense is a strong limitation because is difficult to be sure about the average reliability of the measure. A better method could be to perform many different samples over a period of time (one mount) in order to have an average and more realistic value of what is being carried out in the plant.

To give an idea of the difficulties met in performing the samples, some photos (Figure 2.1, 2.2) with descriptions of the sample 4 are given.

Figure 2.1: Sample 4

Figure 2.2: Sample 4

To sample the ball mill underflow (sample 4) the team had to use a plastic container with a capacity of one cubic meter. The flow rates that are in the plant are usually very high (in this case, about 390 m^3/h), and, in order to obtain a significant and reliable sample, an enough big volumetric flow rate has to be taken.

Figure 2.3: Sample 4 coring

In the days following the taking, the container was left in quite, in order to sediment the slurry and separate the aqueous phase from the solid one. The sedimentation was achieved after 3 days and the water so obtained was drained doing some holes in the plastic container walls.

Thanks to an iron pipe, a coring was performed (as shown in Figure 2.3) and the sample obtained. After the measure was done by drying the taking and sieving it.

Because of the difficulties met in sampling the streams, some of them has been rebuilt starting from the ones accessible sampled.

The measurement procedure follows the following steps:

- Inspection on the sampling point.
- Scheduling the day (together with the plant workers) to perform the measurement.
- Sample collecting.
- Sample drying.
- Sample analysis.

The samples analysis was performed by the candidate in the laboratory using the vibrating screen for granulometry analysis shown in Figure 2.4.

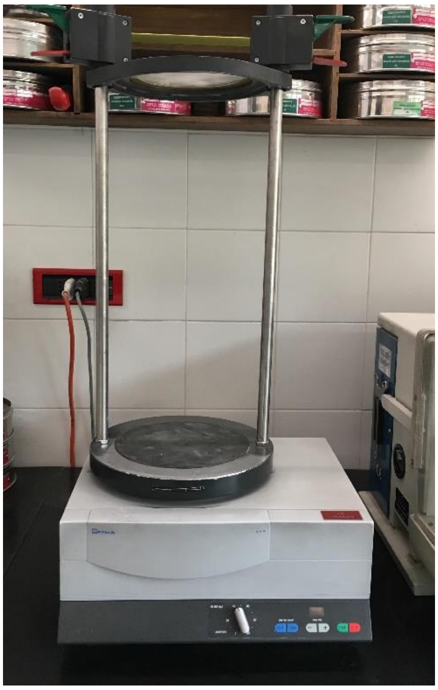


Figure 2.4: vibrating screen for granulometry analysis

The sieves (Figure 2.5) for the granulometry of the samples were previously decided by the team in order to have a good description of all the possible particles seizes in the “washing plant” and are reported in Table 2.1.

Figure 2.5: Example of a sieve for vibrating screen

Table 2.1: Sieves used for the granulometry measures

Sieve mesh dimension
12000 µm
10000 µm
8000 µm
6000 µm
2500 µm
2000 µm
1400 µm
1000 µm
600 µm
400 µm
200 µm
100 µm
75 µm
Fondo

The last sieve, called “Fondo”, collects all the particles smaller than 75 μm.

Performing a granulometry measure consists in a relatively simple procedure.

The samples are dried by a ventilated oven in order to avoid the formation of conglomerate due to the humidity that can invalidate the measurement.

Conglomerates, in fact, are composed by many particles joined together so that their diameter is no more the one of the single particles but it consists in many of them added together, the measure, so, does not represent the real stream granulometry but an apparent one.

The same problem can also be met after drying. Dried samples can present some conglomerate that must be broken by mechanical force (using, for instance, a laboratory spoon) before to perform the measure in order to reach the real particle size and not the apparent one.

Also the presence of fines, if too significant, can be a problem to perform the measure (the fines can obstruct the sieves mesh or remain in the bigger meshes and invalidate the measure). In case the percentage of fine is bigger than 20-25%, the sample was washed through a 75 μm sieve, in order to remove them. A comparison between the initial weight and the “washed” weight was done in order to evaluate the percentage of fines removed. After that the granulometry measure was performed as shown before.

Density measures were performed to obtain the stream solid percentage, necessary to right set up the simulation controllers.

These measures are easier to be done than the granulometric ones and are made as follows:

- Inspection on the sampling point.
- Scheduling the day (together with the plant workers) to perform the measurement.
- Take the sample.
- Weight the sample.
- Fix by a sign the level of the slurry in the weighted vessel.
- Fill the vessel with fresh water until the sign.
- Weight the water and evaluate the occupied volume with the knew water density.
- Divide the weight of the slurry by the evaluated volume and calculate the slurry density.

Knowing the slurry density, the weight percentage can be easily calculated by the quartz density (2.65 kg/m^3).

To measure the water flow to the thickener a portable flow meter (Figure 2.6) was used.

Figure 2.6: Portable flow meter

Its working principle is based on doppler effect: the sensor injects high frequency sounds through the pipe wall and the liquid. Gas bubbles or solids suspended reflect the sound with a different frequency back to the sensor as shown in Figure 2.7. This frequency difference is called doppler effect and can be used to evaluate the velocity of the suspended particle and so the flow in the pipe.

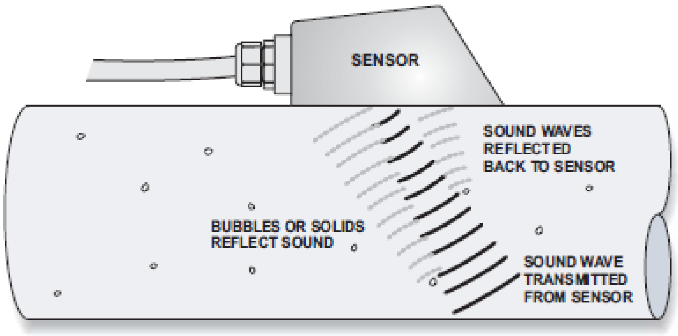


Figure 2.7: Doppler effect

2.2 *Mathematical Models*

2.2.1. *Software*

METSIM is a software simulator for process engineering born to be used in the metallurgical industry in 1971 [22].

It started only taking into account of the mass balance but following improvements were been introduced in order to allow the engineers also to perform heat balances, chemistry, process controls, equipment sizing, cost estimation, and process analysis [22].

The program works as a process simulator with an user interface (Figure 2.8) where is possible to draw the flowsheet of the desired process and to add the equipment that simulate your real case at the best [22].

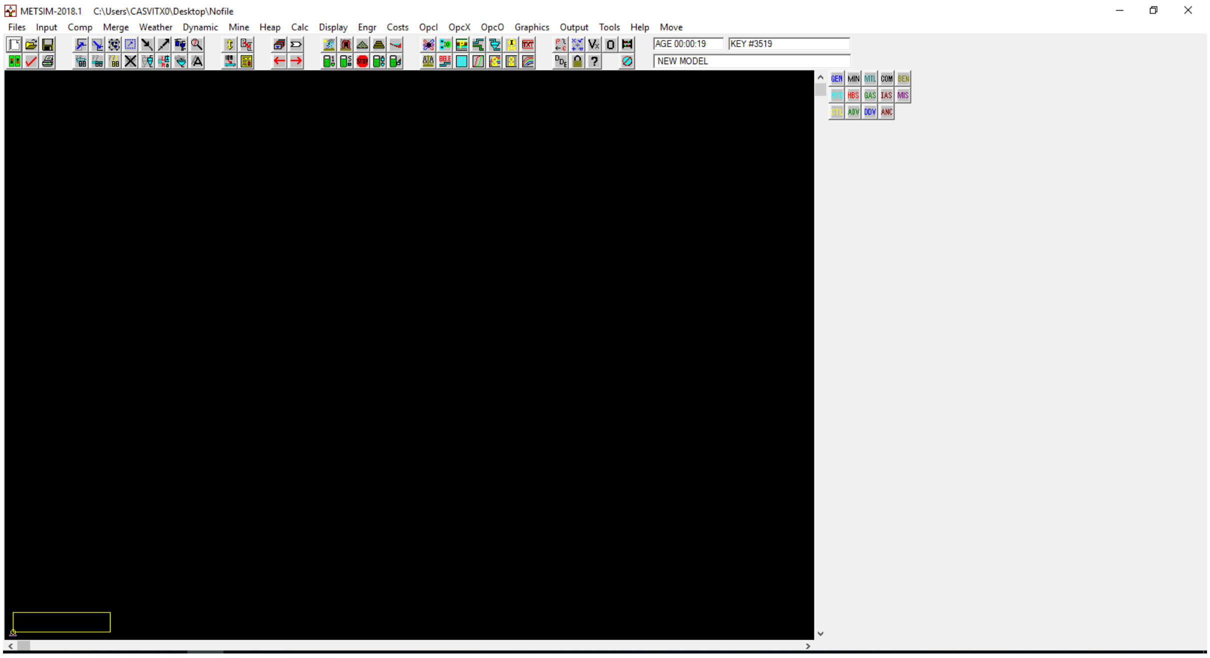


Figure 2.8: METSIM interface

It is composed by several interconnected modules (Figure 2.9), each module contributes to the process definition and to give an holistic vision of your simulated process, since it allows to look at every aspect of it from a different point of view (e.g. energy consumption, mass balance, dynamic simulation, etc) [22].

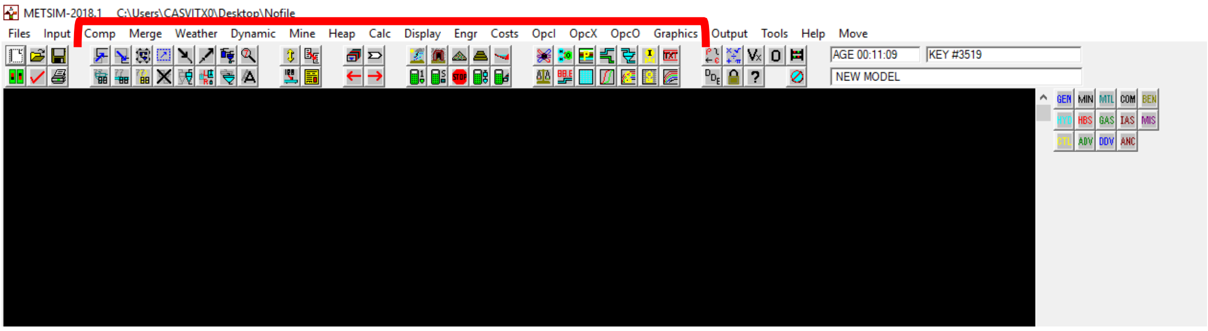


Figure 2.9: METSIM modules

The modelized equipment are in a library at the right of the user interface as shown below in Figure 2.10.

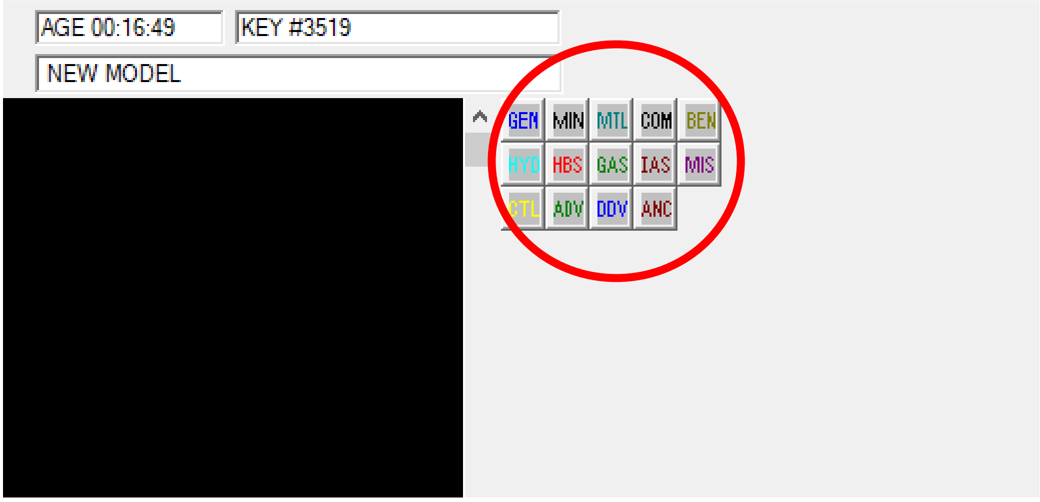


Figure 2.10: METSIM equipment library

They are divided into various interest areas that reflect the sector where they are supposed to be used (e.g. comminution, mining, gas and streams, etc) [22].

In METSIM it is also possible to perform a first design of equipment having a stream with a given flow and composition, allowing, that way, a more conscious dialogue between the company operator and the equipment supplier [22].

As will be seen in the following pages, METSIM can adapt the mathematical model implemented in the software to the the plant configuration and the experimental data resulting from the samples.

That way a characterization of the current process is possible, opening the possibility for a sensibility study (testing the modelized equipment against different operative conditions) or an evaluation of the current performances of your equipment, comparing it with the ideal model [22].

METSIM template allows the operator to select the materials involved in the process (in the project case it will be silica) and, which is of strong interest in the mining sector, to associate to each stream a certain granulometry for the solid fraction. Experimental data can be insert by hand in the template using the sieves chosen by the operator, a linear interpolation will be made by the software to obtain the corresponding values in the international sieves series (ISO, TYM, USM, BRM).

In METSIM is possible to create new sections (Figure 2.11) in the flowsheet that can be ran separately, this tool allows us to separate the process into different parts that can converge alone, solving many calculation issues, and can easily be managed if the user is looking for some specific aspect of the process. In our case study two separated sections for the water balance will be created, so that it will be easy to see how much fresh water and where is used in the washing plant. Every single unit can also be ran alone, obtaining only the outputs for it to fill the empty streams in the flowsheet and have an easier simulation when all the section, or the process are ran.

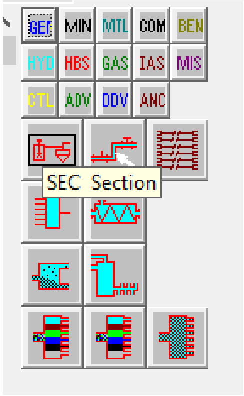


Figure 2.11: METSIM new section button

Controllers (Figure 2.12) can be insert to regulate or fix some variables during the process, the solid content of a stream for example, that is fundamental to ensure the proper pumps operation or to achieve the right cut size in an hydrocyclone as shown before.

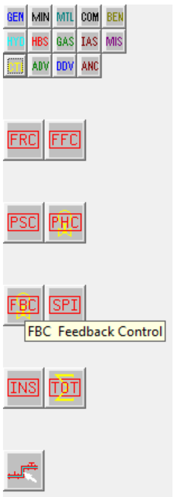


Figure 2.12: METSIM controllers library

In this project the raw material chemical composition will be considered as homogeneous and entirely composed by silica (100% SiO_2). Of course this is a simplification (as shown before chemical composition of the raw material is not homogeneous and strongly depends on the stream granulometry as on the quarry conditions) but is justifiable by the fact that only physical separations are carried out in the washing plant and not chemical ones. Specific gravity or bond index, in fact, are not strongly influenced by small chemical composition variations (about 6-7%) that the raw material presents in the real case.

Thanks to the direct communication with the METSIM developers team is possible to customize the program and insert new features, specific for the processes that want to be carried out in the company. This was also the case of this project: because of the presence of some optical sorters used in a glass-recycling plant, the developer was asked to implement a device in METSIM able to simulate them.

A team composed by six Sibelco engineers and the candidate followed a tutoring to learn how to use the software from a consulting society based in Cape Town City (South Africa) the second week of October and the first of December.

During this two-week-long training some basic commands were shown and three examples coming from the mining industry were performed.

This tutoring was the basis for the following implementation of the process currently carried out in the Robilante plant.

2.2.2. Methods of software implementation

The simulation was developed by recreating the washing plant flowsheet on METSIM, inserting the real geometrical and operative equipment parameters and by doing some approximations. By the fact that, as in many simulation tools, in METSIM only the stream in input to the whole process can be directly characterized, data samples have not been used to characterize the streams, but as a measure of the simulation reliability.

The procedure carried out during this step was the following:

1 All the process flowsheet (included the water circuit) was replied in the software interface, with different sections to have an easier flow visualization.
2 The equipment were roughly parametrized, inserting the real geometrical and operative parameters of the real ones, a further parametrization was done after that the process was ran to be in a closer accordance with data samples.
3 The input stream was characterized by inserting the sampled granulometry, composition and flow.
4 The process was ran section by section looking at the outputs of the different equipment and if they were in accordance with the different samples taken.
5 The whole process was ran to look for the convergence and the flows coherence.
6 A further comparison between the samples and the simulated unit operations was done in order to optimize the equipment parametrization.
7 The products were controlled by the point of view of the quantity and the quality to make sure that their granulometry met the one of the commercial specifications.
8 Water consumption of the simulated process was evaluated.

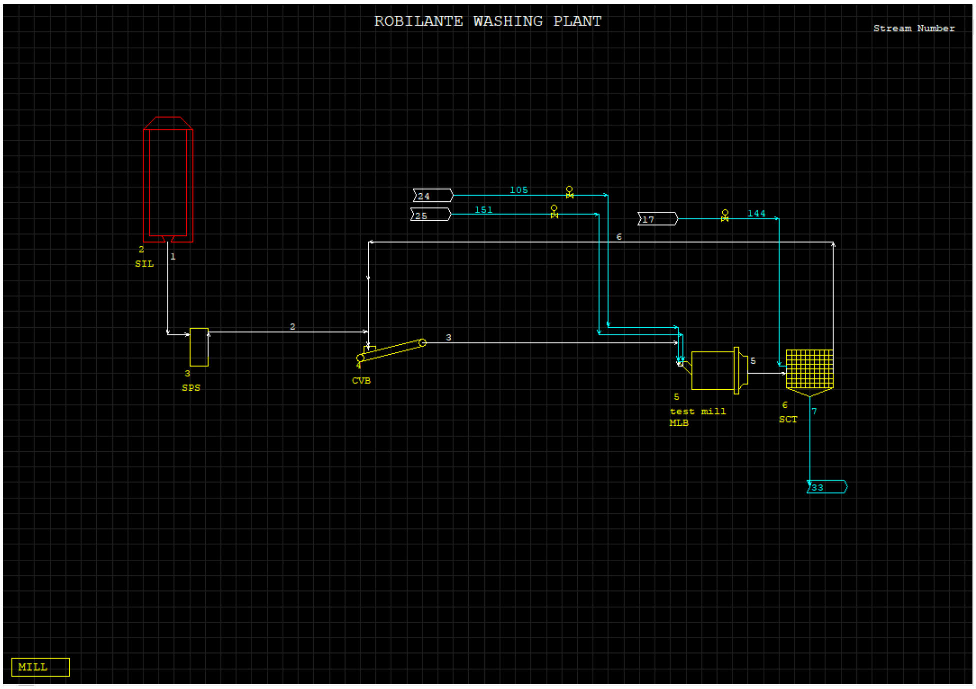


Figure 2.13: Ball Mill section on METSIM

In Figure 2.13 is shown the first section of the washing plant, the ball mill one. In this section the comminution step takes place and the granulometry of the stream coming from the silo after the plant stockpile (Sample 1, Table 3.1) changes because of crushing.

Because of problems present in the ball mill currently placed into the real plant (oversizing due to a crushing media change over the time) the team decided to not rely only on the ball mill mathematical model implemented on the software (outputs were too different from real data) but to parametrize the simulated mill with the samples, to obtain outputs close to the real data, even if not purely based on the model.

In a certain sense this step could be seen as a ‘normalization’ and so a loss of data on the ball mill and the input streams. This is partially true, of course the global reactivity of the system against a variation in operative parameters (input flows of granulometry) will not be strongly reliable, but this parametrization does not change the current operative conditions, and so the possibility to evaluate the water consumption and to do some considerations about the remaining part of the plant.

The water streams are the ones in blue, they are usually not composed only by water but they have a solid content (often of fines) carried with it. In METSIM all the streams with a water content in weight bigger than the solid one are visualized as blue, otherwise are white.

In order to parametrize the mill was done an extra section (Figure 2.14).

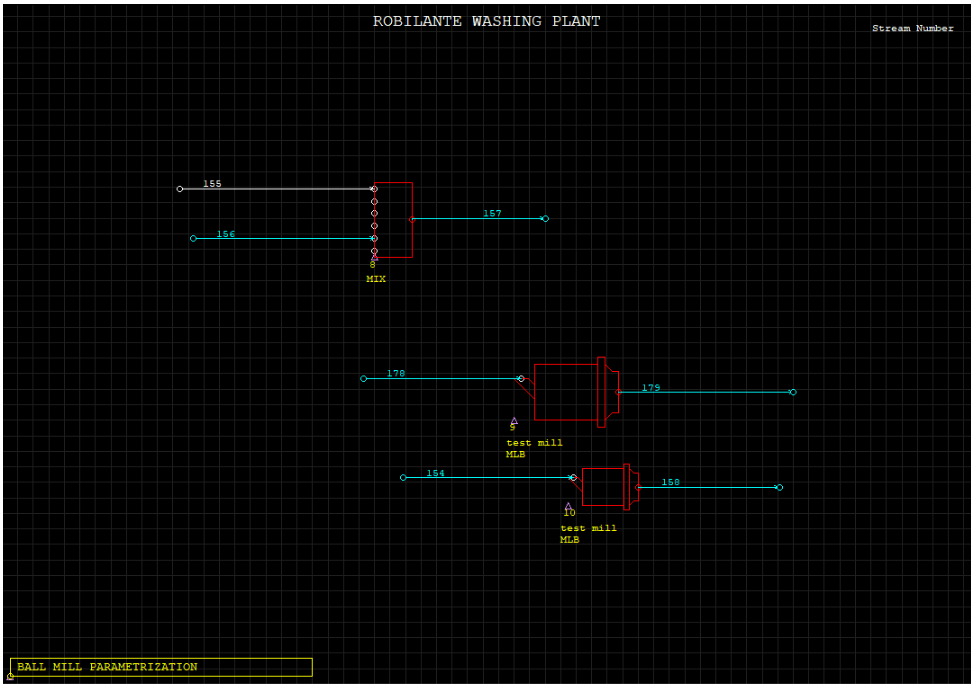
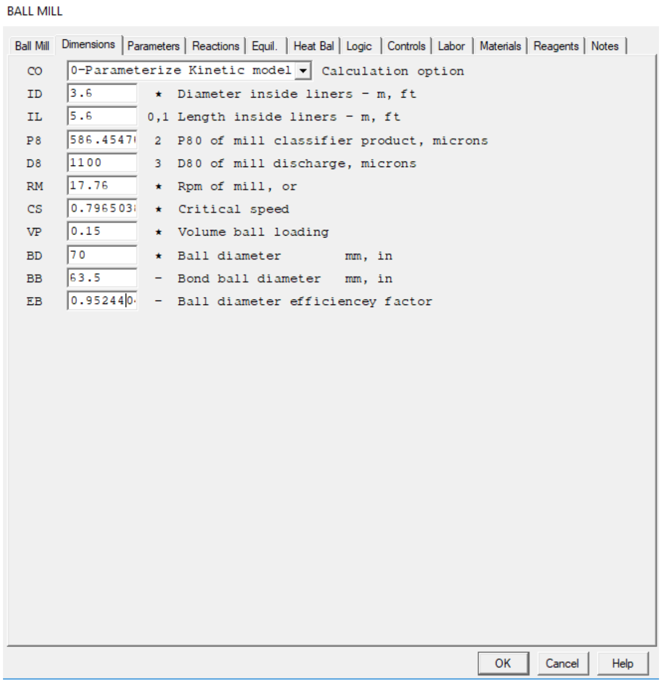


Figure 2.14: Ball Mill parametrization section on METSIM

In the section of Figure 2.14, data from the recycled stream (Sample 3, Table 2.3) with a flow of 28 tons/h of solids and the trommel overflow (Sample 2, Table 2.2) were combined using a mixing device to obtain the one of the ball mill discharge. The feed was built mixing data of the recycled stream and the silo output (189 tons/h of solids). Through an option on the ball mill template (Figure 2.15), inserting the streams data, the geometrical parameters of the ball mill, the diameter of the crushing media, the volume ball loading and the velocity of rotation, the software calculates the coefficients to parametrize the equipment and obtain the wanted output on the simulation.



```
CO  0-Parameterize Kinetic model      Calculation option
ID  3.6          *   Diameter inside liners - m, ft
IL  5.6         0,1  Length inside liners - m, ft
P8  586.4547     2   P80 of mill classifier product, microns
D8  1100         3   D80 of mill discharge, microns
RM  17.76        *   Rpm of mill, or
CS  0.796503     *   Critical speed
VP  0.15         *   Volume ball loading
BD  70           *   Ball diameter       mm, in
BB  63.5         -   Bond ball diameter  mm, in
EB  0.952440     -   Ball diameter efficiencey factor
```

Figure 2.15: Ball Mill template

In Table 2.2 are reported the main geometrical and operative ball mill parameters.

Table 2.2: Real Ball Mill parameters

Ball Mill parameter	
Diameter inside liners	3.6 m
Length inside liners	5.6 m
Rpm of mill	17.76
Volume ball loading	0.15
Ball diameter	70 mm
Silica Bond Index	15 kWh/ton

Setting the Calculation Option to Herbst Data Point the software allows the software to best approximate the ball mill output to the real one.

The trommel sieve placed after the ball mill was sized using the geometrical parameter of the structure and the one of the mesh that defines the cut done by the equipment. The only operative parameter inserted was the one about the oversize solids weight fraction, fixed to 0.875 knowing the humidity of the recycled stream.

In Table 2.3 are reported the geometrical parameters for the trammel sieve.

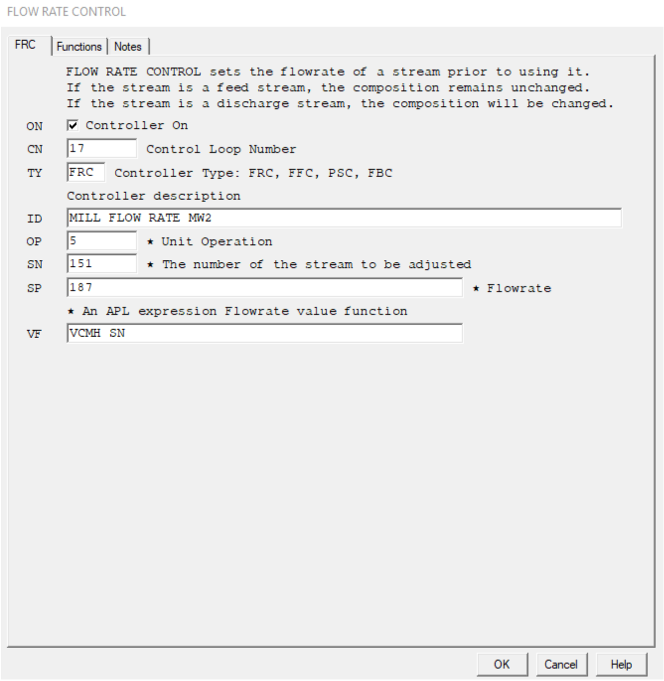
Table 2.3: Real Trommel sieve parameters

Trommel sieve parameter	
Lenght	2.4 m
Width	0.9 m
Mesh opening size	2.5 mm
Mesh length width ratio	0.18

The conveyor belts and all the pumps in the project have been set up in "mass balance" function, they only carry the mass because their design, even if allowed by the software, was beyond the project purpose.

The water streams added in the ball mill section are three, two coming from the internal water circuit that will be shown later in Figure 2.28 and the last one coming from the circuit that receives water clean water from the thickener Figure 2.31. All of these streams carry with water also fines in different percentages, fines removal will be a priority to meet the product specifications. In the simulation tool, three flow rate controllers (Figure 2.16) were added in order to regulate the water flow to the ball mill and the trommel sieve. This is not an approximation: also in the real plant these streams are controlled, because of the importance of the water percentage as parameter for the ball mill, as seen in paragraph 1.4.2.

A detailed description of each stream can be found in annexes.



FLOW RATE CONTROL sets the flowrate of a stream prior to using it.
If the stream is a feed stream, the composition remains unchanged.
If the stream is a discharge stream, the composition will be changed.

ON ☑ Controller On
CN 17 Control Loop Number
TY FRC Controller Type: FRC, FFC, PSC, FBC
Controller description
ID MILL FLOW RATE MW2
OP 5 * Unit Operation
SN 151 * The number of the stream to be adjusted
SP 187 * Flowrate
* An APL expression Flowrate value function
VF VCMH SN

Figure 2.16: Flowrate controller template

The following section (Figure 2.17) simulates the four Lehmann sieves that divide the construction sands (overflow) from the glass and ceramic sands (underflow).

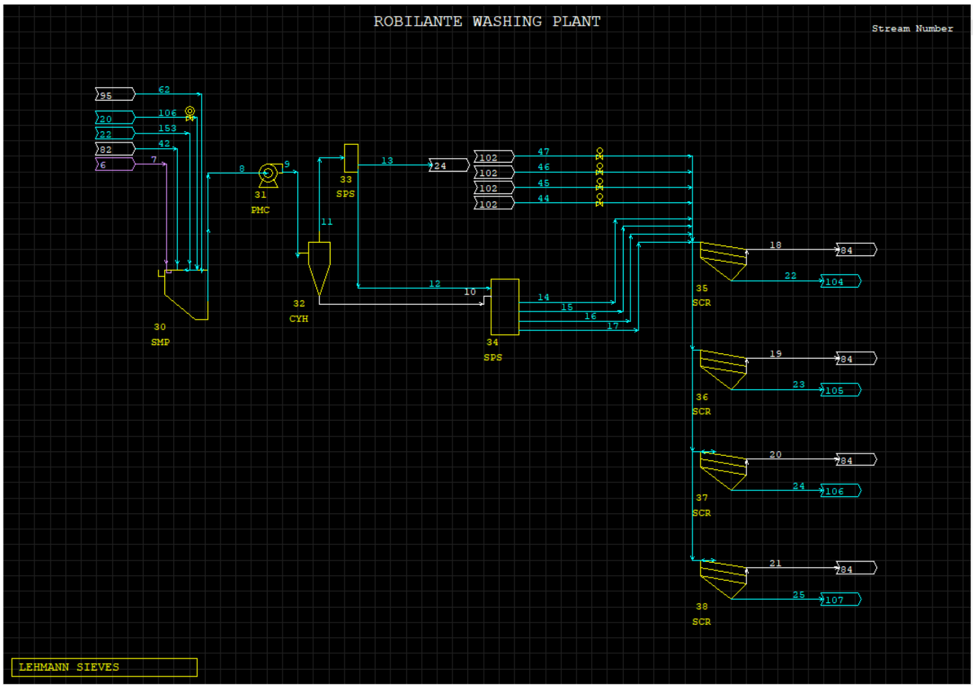


Figure 2.17: Lehmann sieves section on METSIM

After the ball mill section the stream (stream 7) is sent to a vessel where is diluted by water coming from both internal and external circuits. The water stream 106 is regulated by a feed back controller that controls the solid weight percentage in the vessel (SMP 30). The optimal solid weight percentage for a slurry that has to be pumped and processed in an hydrocyclone is between 0.2 and 0.3, in order to have a water content that allows the hydrocyclones to work and to avoid excessive pumps energy consumption. The value to be set was choose every time in this range in order to obtain an output stream in accordance with experimental data. As can be seen from Figure 14 the solid stream is sent to an hydrocyclone to remove fines and then the hydrocyclone overflow with an high content of fines is split and partially re-mixed with the main stream. This step could be seen as illogical by the point of view of the fines removal, that is a priority in the process, but is however the kind of practical solutions easy to find in a conservative sector as mining is. The operators, over the time, needed to add water to the stream to achieve the separation in the Lehmann sieves and so directly re-sent a part of the hydrocyclone overflow (mainly water) into the underflow.

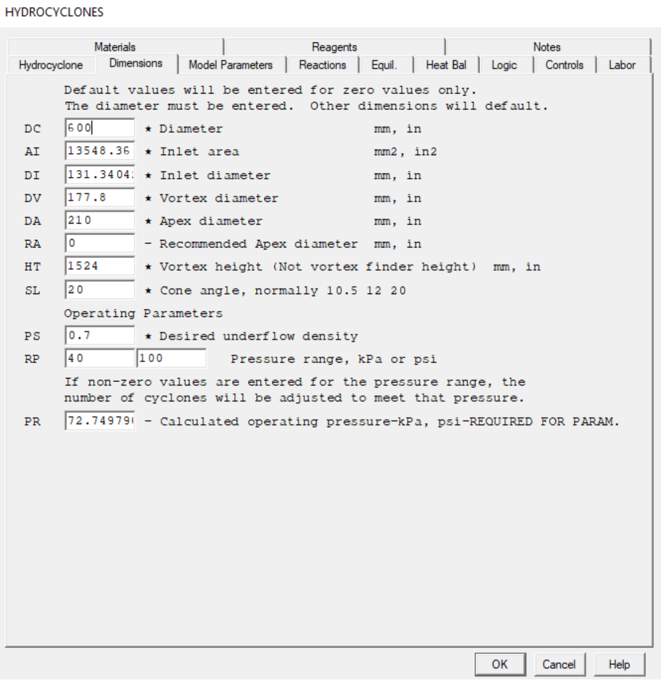
The solution so built did not allow to sample the real underflow of the hydrocyclone, but only the one already added with the split overflow. In fact, the sample 5 is referred to streams 14-15-16-17 and not 10. The percentage of split moreover was unknow, so is was evaluated comparing the fines content in the simulation and the one in the sample 5.

The hydrocyclone template (Figure 2.18) allows the operator to insert the geometrical data (diameter of the hydrocyclone and of the apex) that were taken from the suppliers tables. The operative pressure of the equipment was measured by barometers that are placed in correspondence of the hydrocyclones and is between 50 and 100 psi, these values were insert as range values to allow the software to calculate it as shown in Figure 2.18.

In Table 2.4 are reported the main geometrical and operative parameters for hydrocyclone 32 placed in Figure 2.17.

Table 2.4: Real Hydrocyclone parameters

Hydrocyclone parameter	
Hydrocyclone diameter	600 mm
Apex diameter	210 mm
Cone angle	20°
Pressure range	50-100 kPa



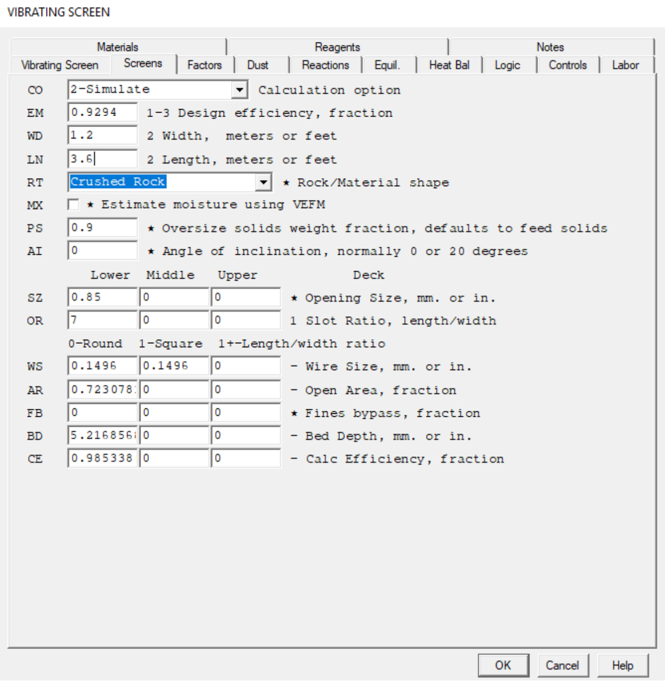
```
     Default values will be entered for zero values only.
     The diameter must be entered.  Other dimensions will default.
DC   600        * Diameter                  mm, in
AI   13548.36   * Inlet area                mm2, in2
DI   131.3404:  * Inlet diameter            mm, in
DV   177.8      * Vortex diameter           mm, in
DA   210        * Apex diameter             mm, in
RA   0          - Recommended Apex diameter  mm, in
HT   1524       * Vortex height (Not vortex finder height)  mm, in
SL   20         * Cone angle, normally 10.5 12 20
     Operating Parameters
PS   0.7        * Desired underflow density
RP   40        100        Pressure range, kPa or psi
     If non-zero values are entered for the pressure range, the
     number of cyclones will be adjusted to meet that pressure.
PR   72.74979(  - Calculated operating pressure-kPa, psi-REQUIRED FOR PARAM.
```

Figure 2.18: Hydrocylone template

The underflow density for hydrocyclone is usually between 0.6 and 0.8. The values were set in this range depending on the experimental data, in order to be in accordance with them.

The model used for every hydrocyclone is the Krebs one, that allows the software to give good result without a parametrization based on experimental data. Hydrocyclones in these simulation mainly have to dewatering and remove fines, they are not really used for classification. Classification in the washing plant is achieved by hydraulic separators and sieves, as Lehmann ones.

The last equipment are the Lehmann sieves, that have the same model of a vibrating screen. Their template is shown in Figure 2.19.



VIBRATING SCREEN

CO 2-Simulate Calculation option
EM 0.9294 1-3 Design efficiency, fraction
WD 1.2 2 Width, meters or feet
LN 3.6 2 Length, meters or feet
RT Crushed Rock ★ Rock/Material shape
MX ☐ ★ Estimate moisture using VEFM
PS 0.9 ★ Oversize solids weight fraction, defaults to feed solids
AI 0 ★ Angle of inclination, normally 0 or 20 degrees

	Lower	Middle	Upper	Deck
SZ	0.85	0	0	★ Opening Size, mm. or in.
OR	7	0	0	1 Slot Ratio, length/width
	0-Round	1-Square	1+-Length/width ratio	
WS	0.1496	0.1496	0	- Wire Size, mm. or in.
AR	0.723078	0	0	- Open Area, fraction
FB	0	0	0	★ Fines bypass, fraction
BD	5.216856	0	0	- Bed Depth, mm. or in.
CE	0.985338	0	0	- Calc Efficiency, fraction

Figure 2.19: Lehmann sieves template

In the template is possible to insert the mesh dimension as previously done for the trommel screen, the design efficiency that was supposed to be 0.9 for each screen, if the solid comes from a crushing step or from sand (different particle geometries influence its possibility to pass through the mesh, as previously seen).

In Table 2.5 are reported the main geometrical parameter for Lehmann sieves.

Table 2.5: Real Lehmann sieve parameters

Lehmann sieve parameter	
Lenght	3.6 m
Width	1.2 m
Mesh opening size	0.85 mm
Mesh length width ratio	7

Is possible to define the oversize solid weight fraction and this was set up in order to be in accordance with the experimental water content.

Four water streams are added (44, 45, 46 and 47), one per each screen. They come from an internal water circuit. Every stream was set up at a value of 200 m^3/h because they are controlled. A water reinstatement is provided from the water plant circuit.

Following the overflow of the Lehmann screens, the next section (Figure 2.20) is the one for the construction sands.

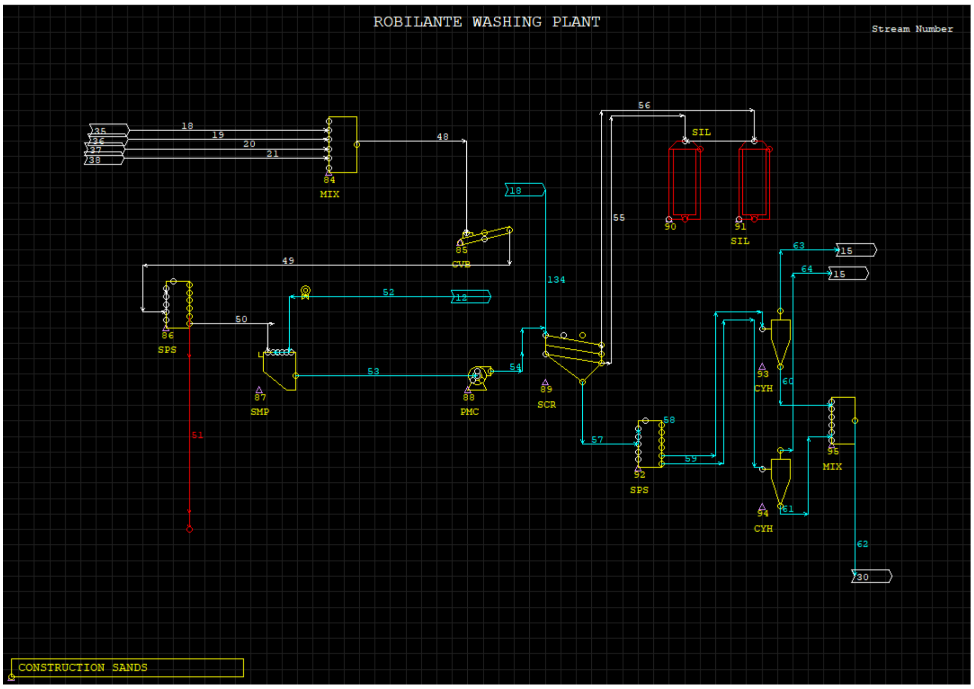


Figure 2.20: Construction sands section on METSIM

Two silos are placed in this section, the first one for the product called Granella and the second one for Sabbia 1.

The feed back controller was set to a solid weight percentage of 0.26 in order to pump the slurry. The main geometrical data for vibrating screen (SCR 89) are reported in Table 2.6.

Table 2.6: Real Vibrating Screen parameters

Vibrating sieve parameter	
Lenght	6 m
Width	3 m
First desk mesh opening size	1.1 mm
First desk mesh length width ratio	10.9
Second desk Mesh opening size	0.6 mm
Second desk Mesh length width ratio	18.3

has two desks, the first one has a mesh of 1.1 mm and a length width ratio is 10.9 and is used to obtain the Granella, the second one has a mesh of 0.6 mm and a length width ratio of 18.3 and is used to obtain Sabbia 1.

The water stream fed to the vibrating screen is controlled and set up at 15 m^3/h. This water comes directly from the thickener and must be clean, in fact is the water used to wash the product before to send it into the silos. Fines contamination in this step must be avoided.

The average production of each product is known and is reported in the specifications tables. As a measure of the simulation reliability, this values (as for the other products) were used together with the product specifications to do a comparison with the simulation outputs in paragraph 3.2.1.

The vibrating screen underflow is sent to two hydrocyclones (geometrical and operative parameters in Table 2.7) that operate in parallel to recover the sand passed through the second desk and recirculate it into the first vessel in the Lehmann sieves section. The hydrocyclones overflows are then recirculated as will be shown in the water circuit sections in Figure 2.28, 2.30.

Table 2.7: Real Hydrocyclone parameters

Hydrocyclone parameter	
Hydrocyclone diameter	500 mm
Apex diameter	75 mm
Cone angle	20°
Pressure range	40-100 kPa

Each Lehmann sieves underflow, in the real plant, is sent to a vessel (Figure 2.21), where the solids thicken and are removed from below, while from above the water with fines overflows and is recirculated at the sieves feed streams, after being reintegrated in Tank 103.

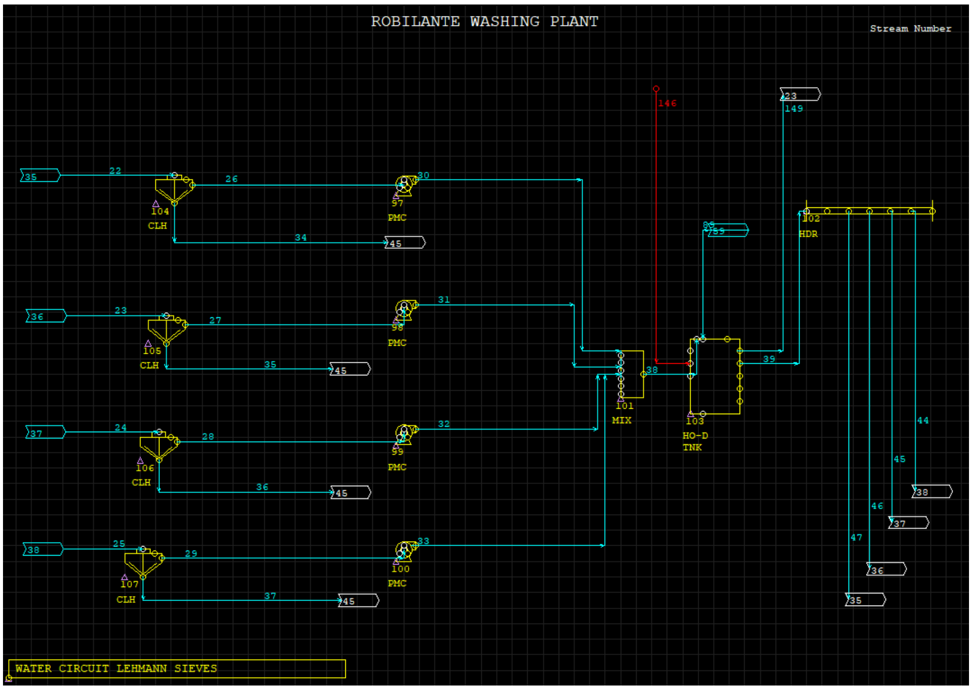
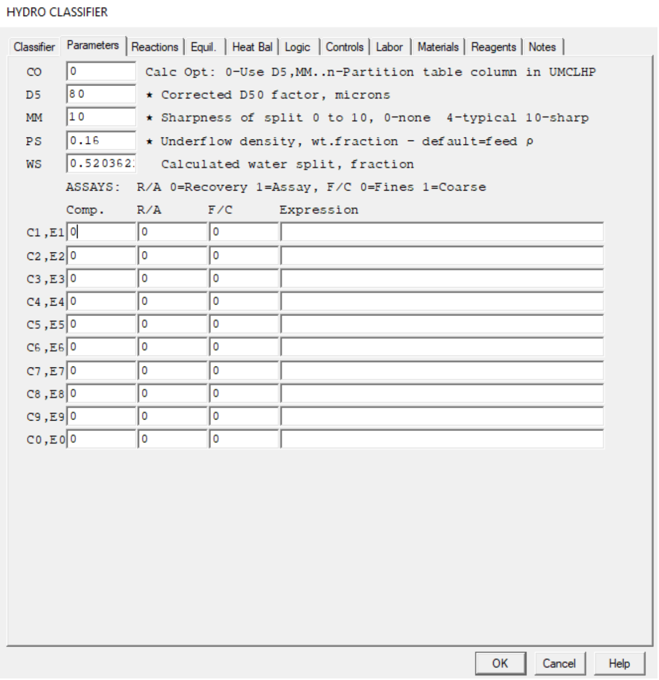


Figure 2.21: Lehmann sieves underflows on METSIM

These vessels in METSIM were simulated by four hydraulic classifiers. The hydraulic classifier template is shown in Figure 2.22. As can be easily seen it allows the operator to define the d50, the underflow solid weight percentage and the sharpness of split (which is a measure of the separation efficiency) as parameters in order to have a solid composition in the vessels overflows of fines as it is in reality and so simulate the sedimentation at the underflows.



CO 0 Calc Opt: 0-Use D5,MM..n-Partition table column in UMCLHP
D5 80 * Corrected D50 factor, microns
MM 10 * Sharpness of split 0 to 10, 0-none 4-typical 10-sharp
PS 0.16 * Underflow density, wt.fraction - default=feed ρ
WS 0.520362 Calculated water split, fraction

ASSAYS: R/A 0=Recovery 1=Assay, F/C 0=Fines 1=Coarse

	Comp.	R/A	F/C	Expression
C1,E1	0	0	0	
C2,E2	0	0	0	
C3,E3	0	0	0	
C4,E4	0	0	0	
C5,E5	0	0	0	
C6,E6	0	0	0	
C7,E7	0	0	0	
C8,E8	0	0	0	
C9,E9	0	0	0	
C0,E0	0	0	0	

Figure 2.22: Hydroclassifier template

The vessels overflows are after collected in a vessel that receives also the overflow of another hydrocyclone and four water streams (44-45-46-47), that constitute the Lehmann sieves water circuit, are fed by this vessel in order to guarantee a regulated flow of 200 m^3/h for each sieve.

The following section (Figure 2.23) is where the hydraulic classification takes place.

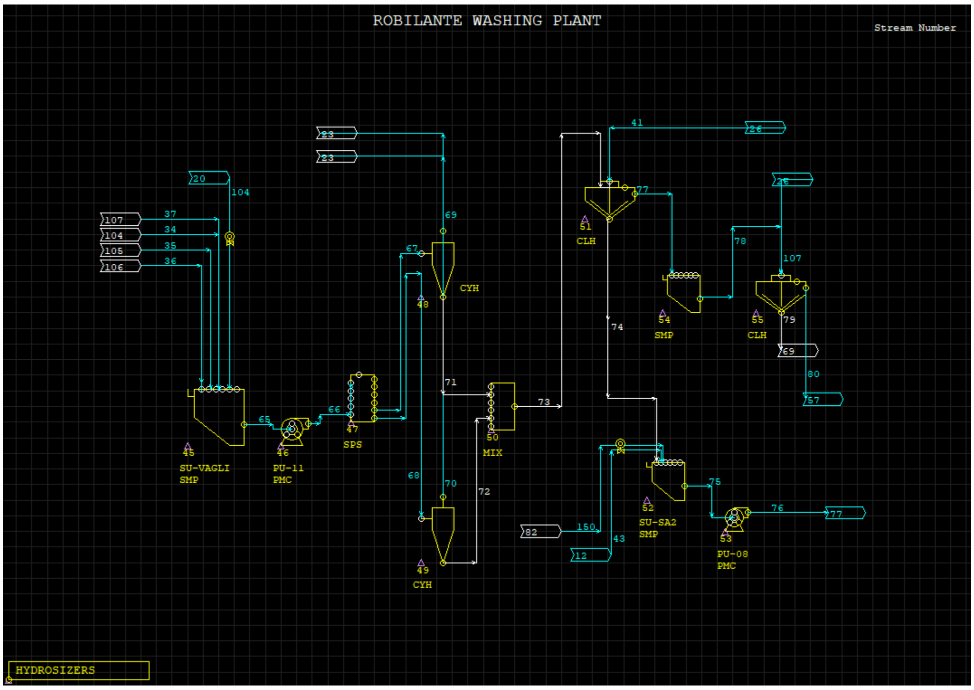


Figure 2.23: Hydraulic classification section on METSIM

Two hydrosizers are placed in the washing plant to separate the solids obtaining Sabbia 2 in the first hydrosizer underflow, Sabbia Speciale and Sabbia 5SN respectively in the second hydrosizer underflow and overflow. Hydrosizers parameters are reported in Table 2.8.

Table 2.8: Hydrosizers parameters

Hydrosizers parameter	
First hydrosizer d50	160 μm
Second hydrosizer d50	110 μm
Hydrosizers sharpness of split	4

The underflow stream of the first hydrosizer, as previously mentioned, consists into almost the finite Sabbia 2 product. Its section is shown in Figure 2.24.

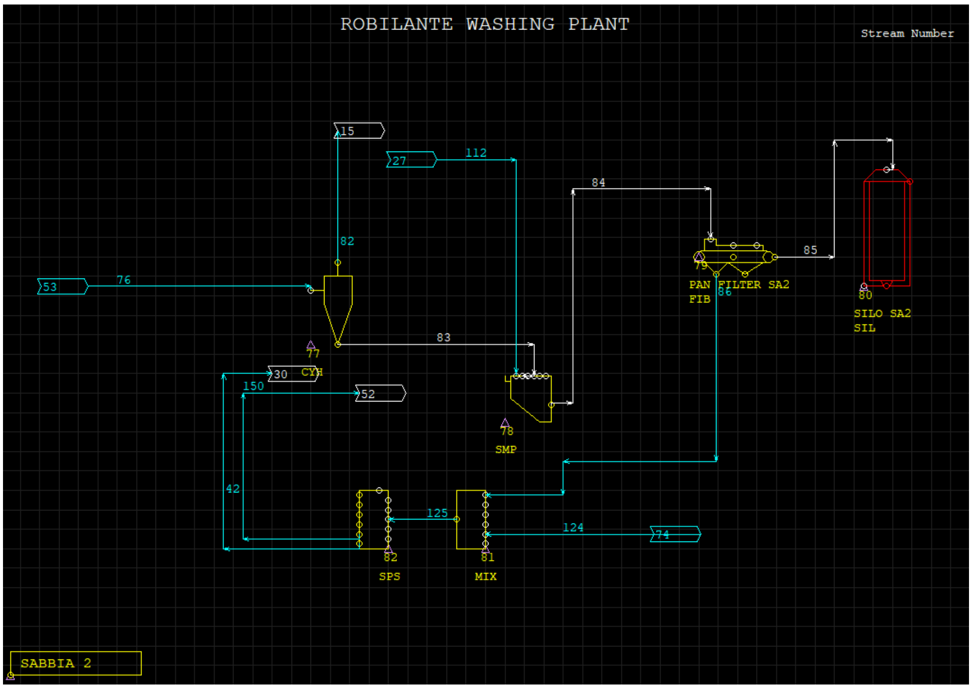
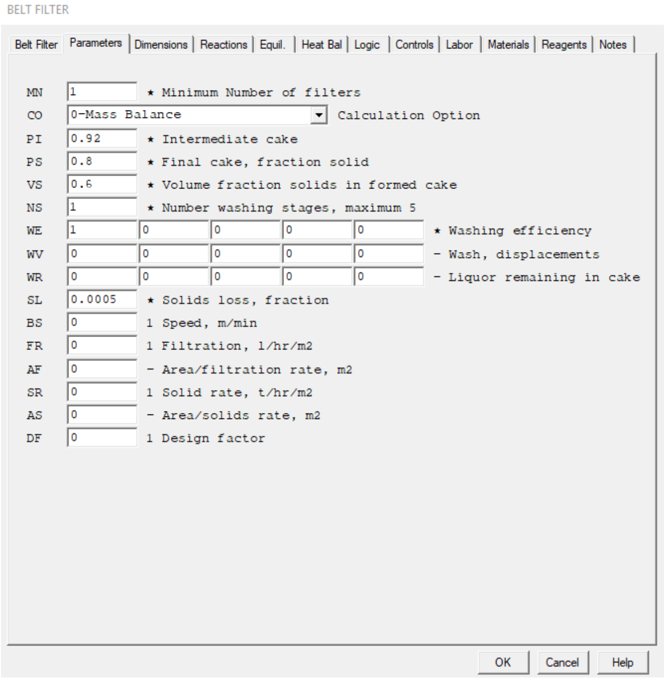


Figure 2.24: Sabbia 2 section on METSIM

Another hydrocyclone is placed in this section in order to further remove fines (data on Table 2.10), that are almost completely washed out by the last pan filter (PAN FILTER SA2), fed by clean water (stream 112). The pan filter template is shown in Figure 2.25 and was used in mode “mass balace” because in reality it works with the only purpose to dewatered the solid that is almost already the final product. In order to obtain the right water content and achieve the commercial specification, a weight percentage of 8% was set up.

Table 2.10: Real hydrocyclone parameters

Hydrocyclone parameter	
Hydrocyclone diameter	762 mm
Apex diameter	103 mm
Cone angle	20°
Pressure range	40-100 kPa



MN 1 * Minimum Number of filters
CO 0-Mass Balance Calculation Option
PI 0.92 * Intermediate cake
PS 0.8 * Final cake, fraction solid
VS 0.6 * Volume fraction solids in formed cake
NS 1 * Number washing stages, maximum 5
WE 1 0 0 0 0 * Washing efficiency
WV 0 0 0 0 0 - Wash, displacements
WR 0 0 0 0 0 - Liquor remaining in cake
SL 0.0005 * Solids loss, fraction
BS 0 1 Speed, m/min
FR 0 1 Filtration, l/hr/m2
AF 0 - Area/filtration rate, m2
SR 0 1 Solid rate, t/hr/m2
AS 0 - Area/solids rate, m2
DF 0 1 Design factor

Figure 2.25: Bel filter template

In order to have a measure of the simulation reliability, a comparison between the granulometry of the final product Sabbia 2 in METSIM and the commercial specification (Table 3.16) was made in paragraph 3.1.2.

The water collected under the pan filter is mixed with the one coming from the Sabbia Speciale section and is recirculated.

The second hydrosizer underflow is the access to the Sabbia Speciale section (Figure 2.26).

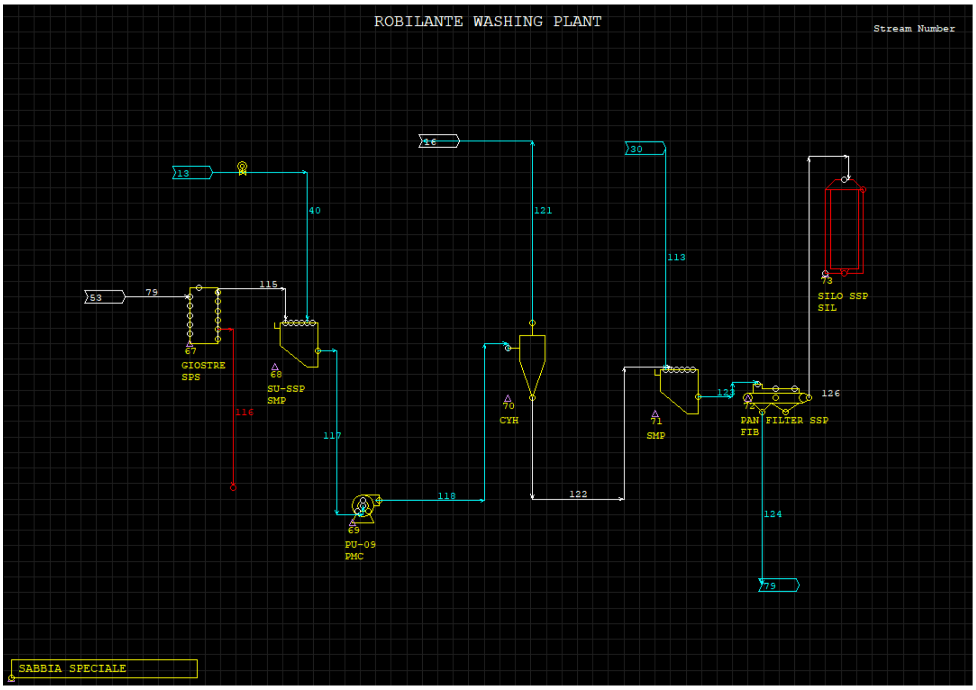


Figure 2.26: Sabbia Speciale section on METSIM

The equipment placed in this section were already shown before. The equipment 67 represents a magnetic separator that in the simulation is simulated as a splitter, by the fact that its contribute to the total mass is quite neglectable in reality (it splits a flow of 1%) and the simulation does not take into account the ore magnetic properties.

The density controller was set in order to achieve a solid weight percentage in stream 117 (that is sent to the following pump) of 0.111 as measured.

The last product section (Figure 2.27) is the line of the second hydrosizer overflow. It generates the line of Sabbia 5SN.

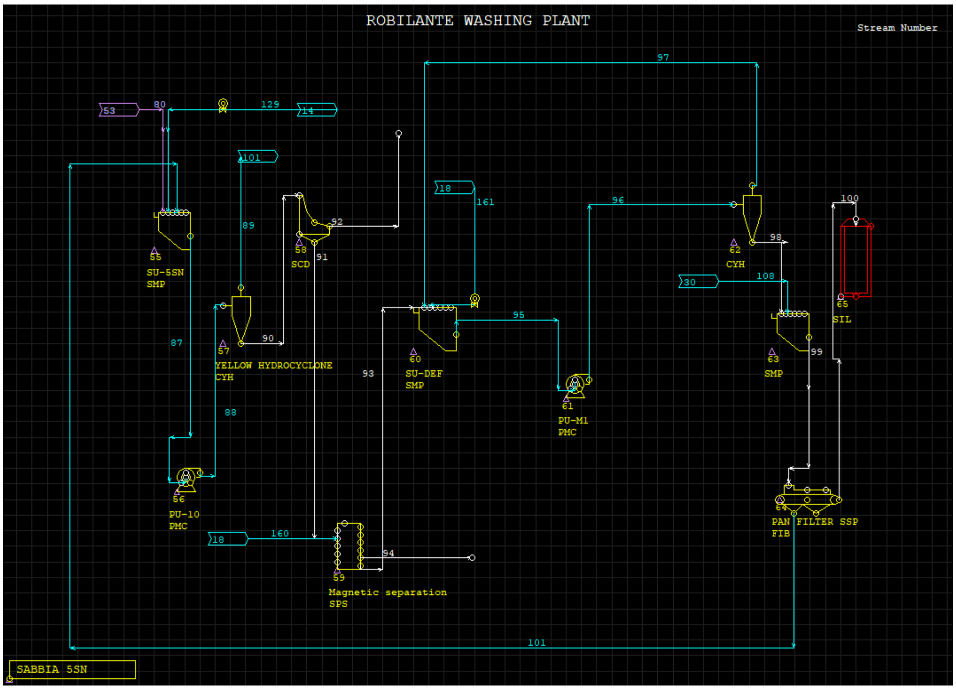


Figure 2.27: Sabbia 5SN on METSIM

This line is the richest in fines, as will be seen in the product specifications in Table 3.20. Two recycled streams are placed. The first one is external and takes water directly from the pan filter sending it to the first pump (recycles are necessary to reach the right slurry water percentage to pump the ore, in this case they are not operating a solid removal) and the second one is internal taking the hydrocyclone 62 (parameters on Table 2.11) overflow and sending it to the vessel 60 of pump M1. There is a safety screen placed in the software to have a realistic graphical description of the equipment (the file is exportable in Autocad for the mechanic company division) that in the simulation remove 0.001% of the feed (in reality it was designed to removed wood or other impurities that could pollute the streams but this case were not taken into account in the project). Also here is placed a magnetic separation that removes 1% of the total feed. Hydrocyclone 57 removes fines and dewaters the stream, its parameters are reported in Table 2.12.

Table 2.11: Real hydrocyclone parameters

Hydrocyclone parameter	
Hydrocyclone diameter	650 mm
Apex diameter	100 mm
Cone angle	20°
Pressure range	40-100 kPa

Table 2.12: Real hydrocyclone parameters

Hydrocyclone parameter	
Hydrocyclone diameter	450 mm
Apex diameter	100 mm
Cone angle	20°
Pressure range	40-100 kPa

Commercial specifications of Sabbia 5SN (Table 3.20) were used, as previously sad, to have a measure of the simulation reliability in paragraph 3.1.1.

Last sections regard the water circuit. As mentioned before there are two main water circuits in the washing plant, one is called internal and another is called external. The first one is not directly linked with the clean water flow coming from the thickener while the second one it is. Clean water is also directly fed to the washing plant in the hydrosizers section (streams 41 and 107) and in the products sections by the water added to pan filters (streams 113 and 112).

The water internal circuit is shown in Figure 2.28.

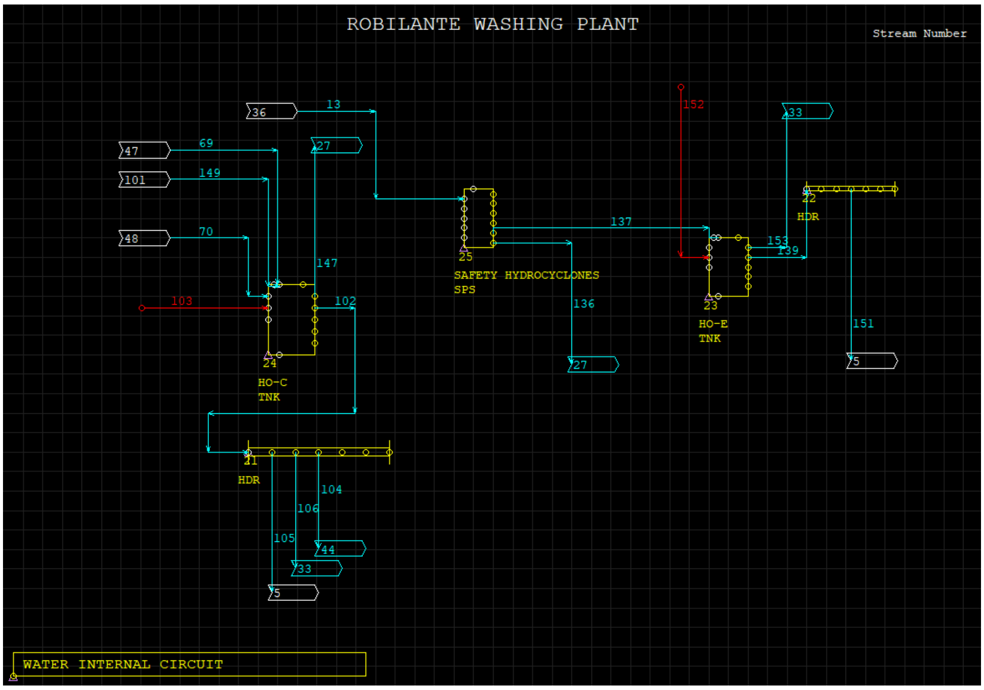
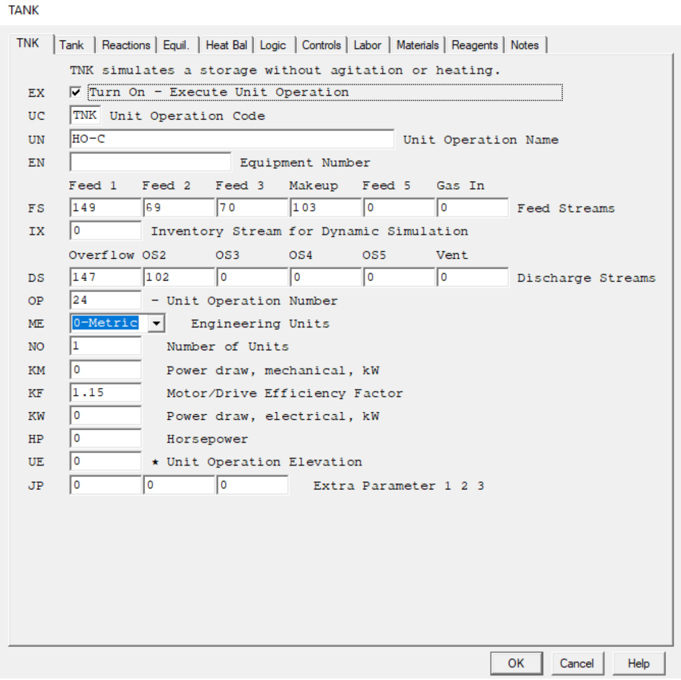


Figure 2.28: Water internal circuit on METSIM

The water internal circuit is composed by two vessels, schematized in METSIM as two tanks with floats where the template (Figure 2.29) allows the programme to calculate the water demand, and gives the difference between the demand and the feed as a makeup. As can be easily seen in Figure 2.28 makeups are red (that means empty) because the system is balanced. The equipment allows the software to evaluate also the overflow, that by the fact that these streams are the ones richest in fines, is sent to the thickener to be clarified.



TNK simulates a storage without agitation or heating.

EX	☑ Turn On - Execute Unit Operation						
UC	TNK	Unit Operation Code					
UN	HO-C	Unit Operation Name					
EN		Equipment Number					
	Feed 1	Feed 2	Feed 3	Makeup	Feed 5	Gas In	
FS	149	69	70	103	0	0	Feed Streams
IX	0	Inventory Stream for Dynamic Simulation					
	Overflow	OS2	OS3	OS4	OS5	Vent	
DS	147	102	0	0	0	0	Discharge Streams
OP	24	- Unit Operation Number					
ME	0-Metric	Engineering Units					
NO	1	Number of Units					
KM	0	Power draw, mechanical, kW					
KF	1.15	Motor/Drive Efficiency Factor					
KW	0	Power draw, electrical, kW					
HP	0	Horsepower					
UE	0	* Unit Operation Elevation					
JP	0	0	0	Extra Parameter 1 2 3			

Figure 2.29: Tank template

Equipment 25 shown in the water internal circuit section, simulates two safety hydrocyclones placed in the plant in order to remove coarse particles that could be drag by the water flow. The underflow of these two hydrocyclones is recycled to the ball mill and the overflow is sent to the thickener. After a direct inspection on the plant in fact, these two hydrocyclones were seen to not work (too low pressure and too fine solid slurry composition) but simple split the streams. For this reason they were modelized as a simple split.

The water external circuit is shown in Figure 2.30.

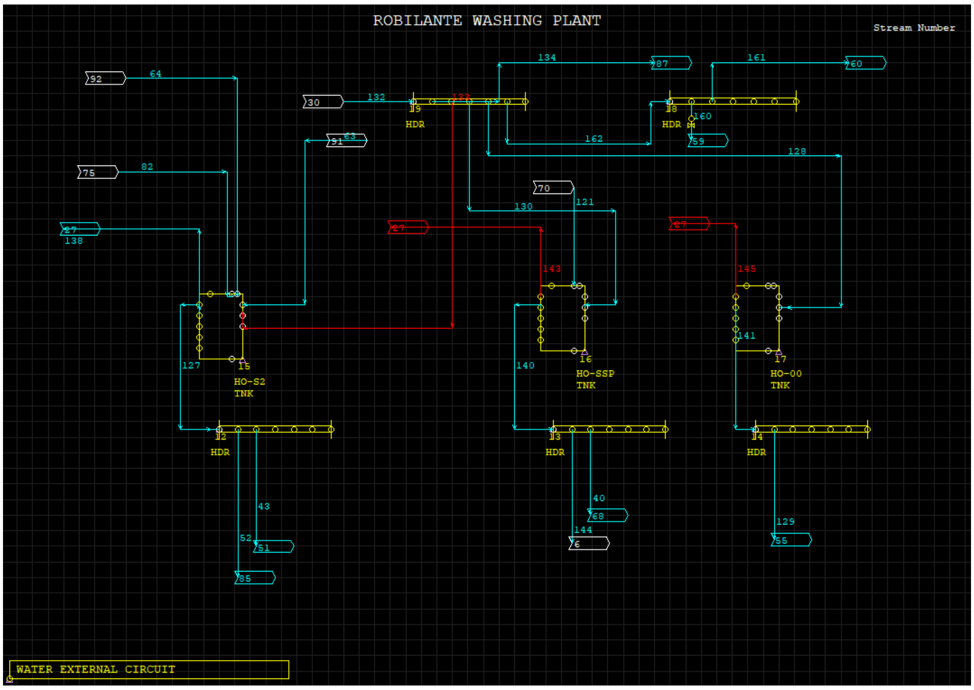


Figure 2.30: water external circuit on METSIM

It is composed by three vessels, modelized as the two ones in the water internal circuit. Their three makeups (streams 133, 130 and 128) are linked together as clean water demand, that is further joined as shown in Figure 2.31 to the fresh water demand of the hydrosizers and pan filters.

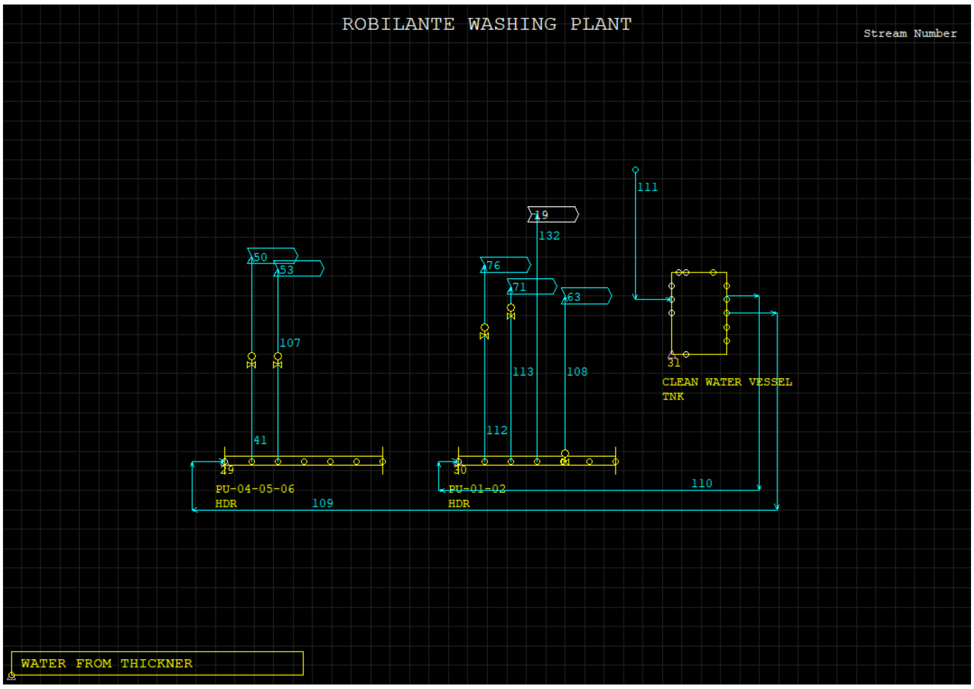


Figure 2.31: Makeups and clean water demand on METSIM

The last section (Figure 2.32) created in METSIM was a mixer to calculate the total 'dirty' water that has to be sent to the thickener in order to easily obtain the water mass balance.

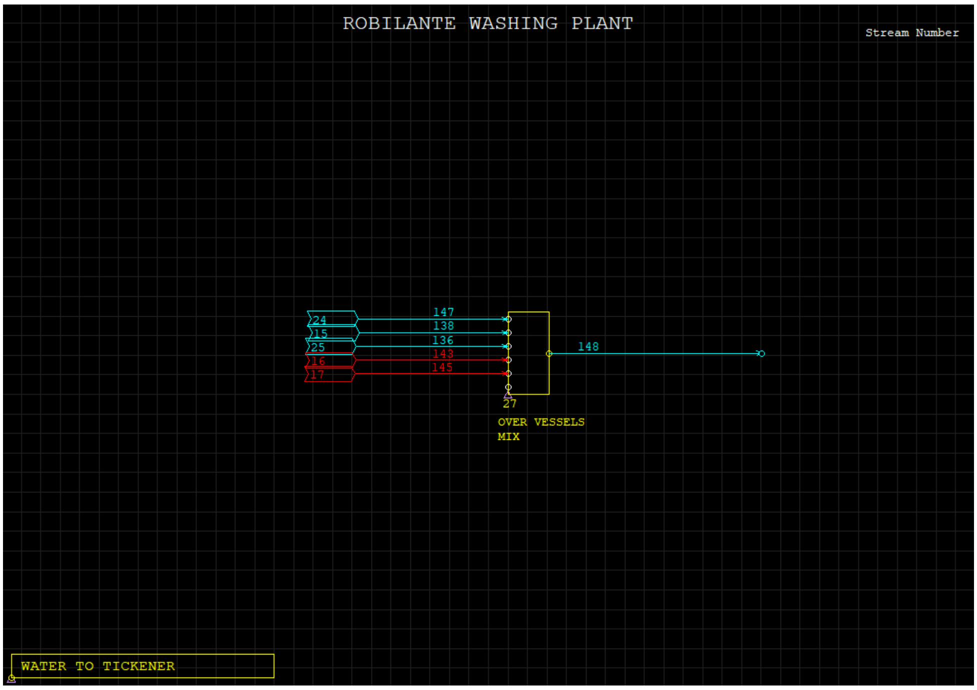


Figure 2.32: Dirty water with fines sent to thickener on METSIM

From the last two sections (Figure 2.31, 2.32) can be easily evaluate the water balance (Table 2.13) of the washing plant.

Table 2.13: Water from and to the thickener

Water	Flow
Taken from the thickener (stream 111)	733.56 tons/h
Send out to the thickener (stream 148)	724.82 tons/h

Chapter 3

Results and procedure validation

3.1 Results

3.1.1 Sampling granulometries results

In the following flowsheets (Figure 3.1, 3.2) are shown the sampling points with the associated measured granulometries (Table 3.1,3.2,3.3,3.4,3.5,3.6,3.7).

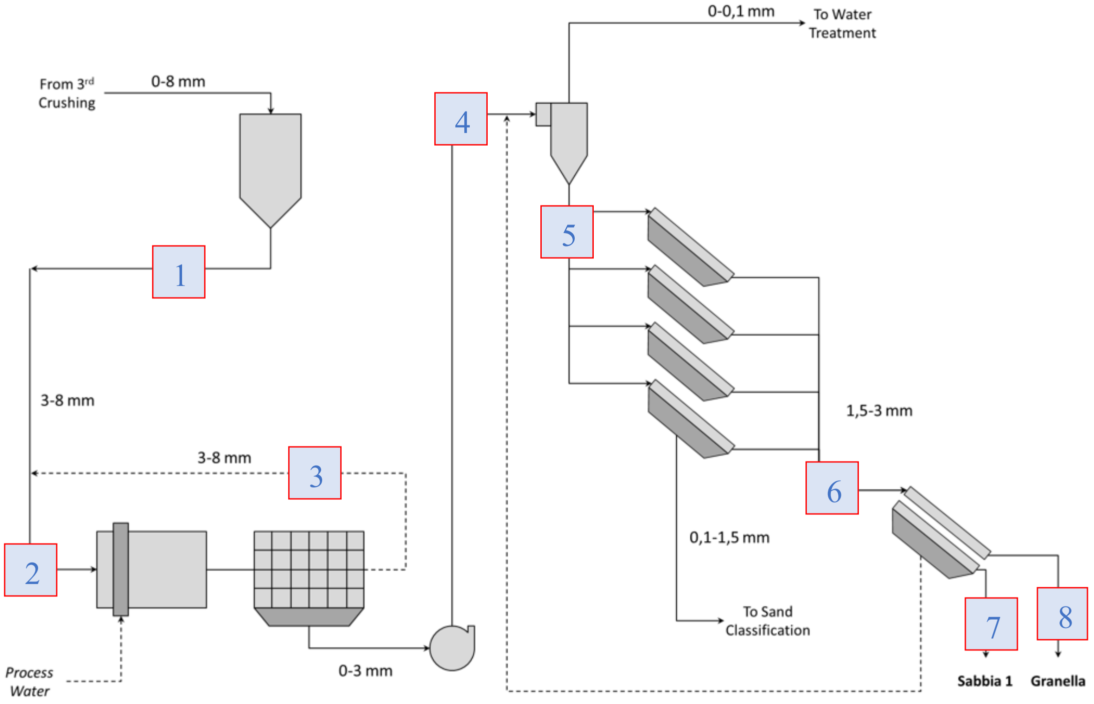


Figure 3.1: Simplified flow sheet with sample points - Part 1

Table 3.1: Sample points 1 and 2 granulometries

Point 1		**Point 2**	
Sieve passed , µm	Weight percentage	Sieve passed, µm	Weight percentage
12000	98.45%	12000	99.89%
10000	95.96%	10000	98.46%
8000	87.80%	8000	88.35%
6000	76.22%	6000	72.60%
2500	46.89%	2500	35.23%
2000	40.86%	2000	27.24%
1400	33.33%	1400	19.01%
1000	27.53%	1000	14.53%
600	20.22%	600	10.43%
400	15.97%	400	8.36%
200	9.90%	200	2.45%
100	5.65%	100	0.97%
75	3.76%	75	0.51%

Table 3.2: Sample points 3 and 4 granulometries

Point 3		**Point 4**	
Sieve passed, µm	Weight percentage	Sieve passed, µm	Weight percentage
12000	100%	12000	100%
10000	98.71%	10000	100%
8000	90.44%	8000	100%
6000	75.27%	6000	100%
2500	31.34%	2500	99.57%
2000	20.67%	2000	98.22%
1400	9.74%	1400	93.70%
1000	4.64%	1000	86.51%
600	1.65%	600	72.73%
400	0.93%	400	64.25%
200	0.55%	200	49.90%
100	0.45%	100	37.83%
75	0.38%	75	32.81%

Table 3.3: Sample points 5 and 6 granulometries

Point 5		**Point 6**	
Sieve passed, µm	Weight percentage	Sieve passed, µm	Weight percentage
12000	100%	12000	100%
10000	100%	10000	100%
8000	100%	8000	100%
6000	100%	6000	100%
2500	99.15%	2500	97.63%
2000	97.14%	2000	90.99%
1400	91.35%	1400	65.18%
1000	82.57%	1000	22.98%
600	67.07%	600	0.81%
400	57.92%	400	0.46%
200	43.45%	200	0.40%
100	30.97%	100	0.40%
75	25.93%	75	0.40%

Table 3.4: Sample points 7 and 8 granulometries

Point 7		**Point 8**	
Sieve passed, μm	Weight percentage	Sieve passed, μm	Weight percentage
12000	100%	12000	100%
10000	100%	10000	100%
8000	100%	8000	100%
6000	100%	6000	100%
2500	100%	2500	91.80%
2000	97.9%	2000	74.80%
1400	78.5%	1400	44.50%
1000	28.5%	1000	9.50%
600	0.5%	600	0.20%
400	0.1%	400	0.00%
200	0.1%	200	0.00%
100	0.1%	100	0.00%
75	0.1%	75	0.00%

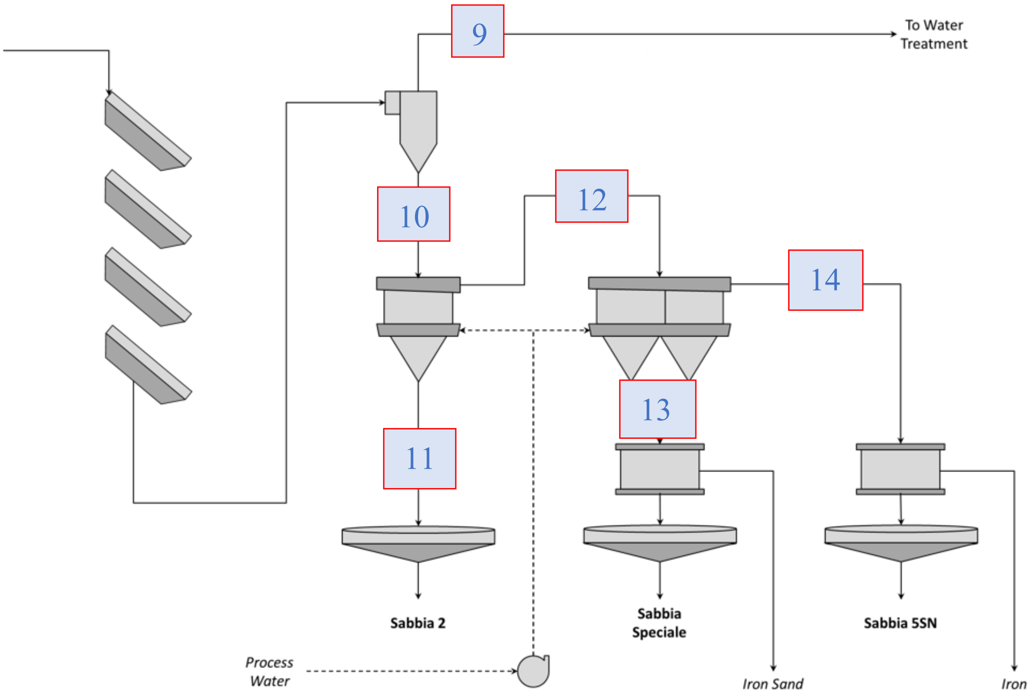


Figure 3.2: Simplified flow sheet with sample points - Part 2

Table 3.5: Sample points 9 and 10 granulometries

Point 9		**Point 10**	
Sieve passed, μm	Weight percentage	Sieve passed, μm	Weight percentage
12000	100%	12000	100%
10000	100%	10000	100%
8000	100%	8000	100%
6000	100%	6000	100%
2500	100%	2500	100%
2000	100%	2000	100%
1400	100%	1400	100%
1000	100%	1000	99.20%
600	100%	600	75.30%
400	100%	400	56.10%
200	100%	200	27.80%
100	99.54%	100	10.60%
75	96.57%	75	6.10%

Table 3.6: Sample points 11 and 12 granulometries

Point 11		**Point 12**	
Sieve passed, μm	Weight percentage	Sieve passed, μm	Weight percentage
12000	100%	12000	100%
10000	100%	10000	100%
8000	100%	8000	100%
6000	100%	6000	100%
2500	100%	2500	100%
2000	100%	2000	100%
1400	0.00%	1400	100%
1000	98.40%	1000	100%
600	54.60%	600	100%
400	20.20%	400	99.80%
200	1.10%	200	66.00%
100	0.20%	100	32.00%
75	0.10%	75	19.10%

Table 3.7: Sample points 13 and 14 granulometries

Point 13		**Point 14**	
Sieve passed, μm	Weight percentage	Sieve passed, μm	Weight percentage
12000	100%	12000	100%
10000	100%	10000	100%
8000	100%	8000	100%
6000	100%	6000	100%
2500	100%	2500	100%
2000	100%	2000	100%
1400	100%	1400	100%
1000	100%	1000	100%
600	100%	600	100%
400	99.20%	400	99.90%
200	43.94%	200	99.49%
100	0.40%	100	80.25%
75	0.10%	75	49.13%

For the glass-sand final product another hydrocyclone separation is performed in order to further remove fines. In Table 3.8, 3.9 are reported the sampling results for every product.

Sabbia 2

Table 3.8: Sample point of Sabbia 2 after fines removal

Sabbia 2 after fines removal	
Sieve passed, μm	Weight percentage
12000	100%
10000	100%
8000	100%
6000	100%
2500	100%
2000	100%
1400	100%
1000	100%
600	60.66%
400	23.43%
200	2.80%
100	0.2%
75	0.1%

Sabbia Speciale

Table 3.9: Sample point of Sabbia Speciale after fines removal

Sabbia Speciale after fines removal	
Sieve passed, µm	Weight percentage
12000	100%
10000	100%
8000	100%
6000	100%
2500	100%
2000	100%
1400	100%
1000	100%
600	100%
400	99.30%
200	43.30%
100	0.50%
75	0.10%

Sabbia 5SN

Sabbia 5SN line follows two hydrocyclone separations before the dewatering. In Table 3.10 and 3.11 are reported the results of both the hydrocyclones.

Table 3.10: Sample point of Sabbia 5SN after the first hydrocyclone

Over 1		**Under 1**	
Sieve passed, µm	Weight percentage	Sieve passed, µm	Weight percentage
12000	100%	12000	100%
10000	100%	10000	100%
8000	100%	8000	100%
6000	100%	6000	100%
2500	100%	2500	100%
2000	100%	2000	100%
1400	100%	1400	100%
1000	100%	1000	100%
600	100%	600	100%
400	100%	400	100%
200	100%	200	99.80%
100	97.51%	100	62.66%
75	89.92%	75	25.23%

After, the over of the second hydrocyclone is recirculated and in Table 3.11 is shown samples coming from the feed (after the add of the recycle) of the second hydrocyclone, and its underflow.

Table 3.11: Sample point of Sabbia 5SN after the second hydrocyclone

Feed 2		**Under 2**	
Sieve passed, μm	Weight percentage	Sieve passed, μm	Weight percentage
12000	100%	12000	100%
10000	100%	10000	100%
8000	100%	8000	100%
6000	100%	6000	100%
2500	100%	2500	100%
2000	100%	2000	100%
1400	100%	1400	100%
1000	100%	1000	100%
600	100%	600	100%
400	99.90%	400	100%
200	99.70%	200	99.50%
100	61.80%	100	52.55%
75	31.20%	75	20.18%

3.1.2 Sampling densities results

The density measures results are shown in Table 3.12. These values were used in chapter 2.2.1. to properly set the density controllers.

Table 3.12: Measured streams densities

Stream number	**Measured density**
8	1.175 Kg/l
53	1.196 Kg/l
65	1.108 Kg/l
75	1.229 Kg/l
87	1.018 Kg/l
95	1.165 Kg/l
117	1.072 Kg/l

3.1.3 Flow measurement result

The water to the thickener flow was measured and the red value on the display is 715.978 m3/h, as reported in Figure 3.3.

Figure 3.3: Portable flow meter display after the water to thickener flow measure.

3.2 Procedure validation

3.2.1 Streams granulometries and commercial specifications comparison

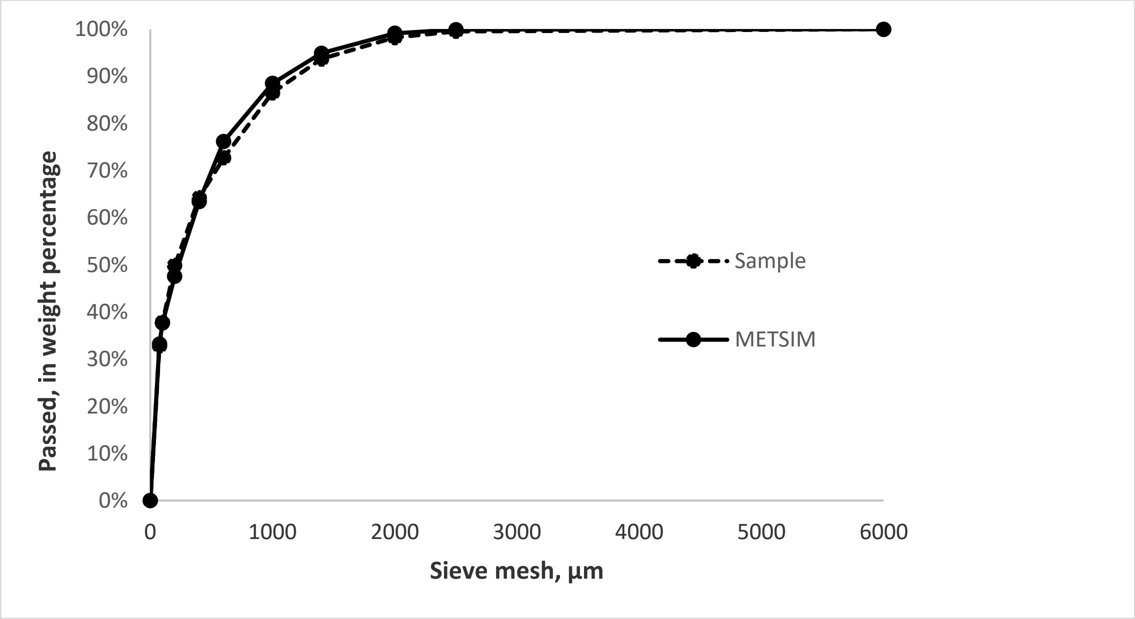


Figure 3.3: Comparison between sample and simulated granulometries after the Ball Mill

All the sampled streams were compared to the simulated ones, as previously mentioned about the followed procedure in chapter 2.2.2, in order to validate the simulation and set the equipment.

In particular the resulting stream 8, after the ball mill parametrization, was compared to the sampled one (Sample 4, Table 3.2) as shown on the graph in Figure 3.3.

The same procedure was followed for the recycled stream (Sample 3, Table 3.2), and the ball mill feed (Sample 2, Table 3.1) as shown in Figure 3.5 and 3.4.

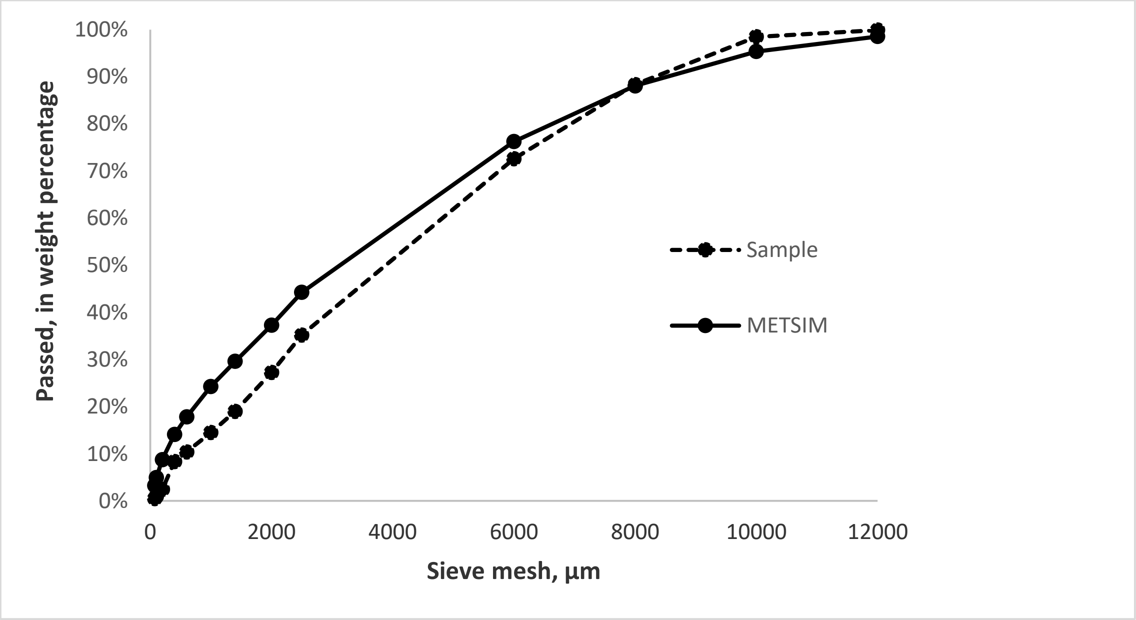


Figure 3.4: Comparison between sample and simulated granulometries for the feed stream

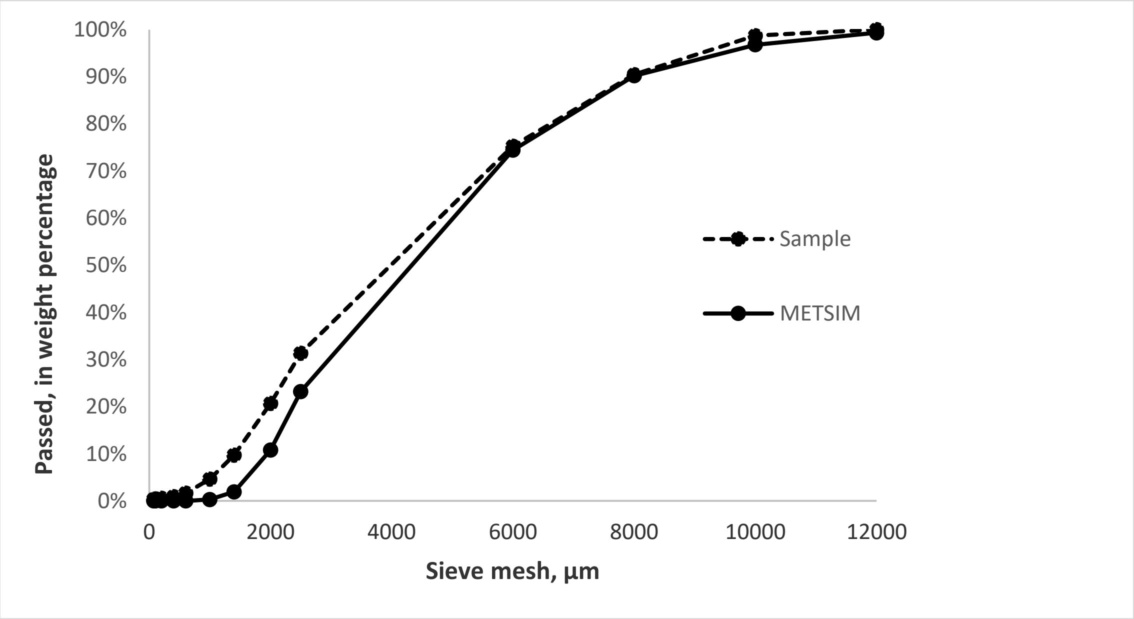


Figure 3.5: Comparison between sample and simulated granulometries for the recycled stream

Samples data were available for the hydrocyclone underflow and for the Lehmann sieves overflow as previously mentioned (sample 5, Figure 3.1 and sample 6, Figure 3.2). The comparison is shown in Figure 3.6 and 3.7.

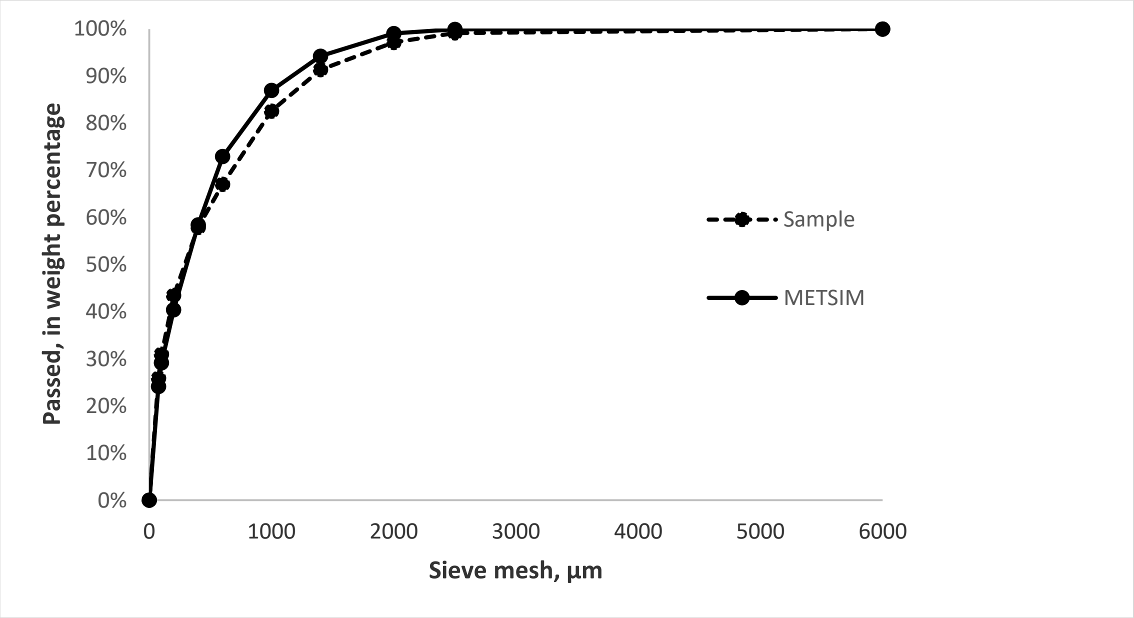


Figure 3.6: Comparison between sample and simulated granulometries for the first hydrocyclone underflow

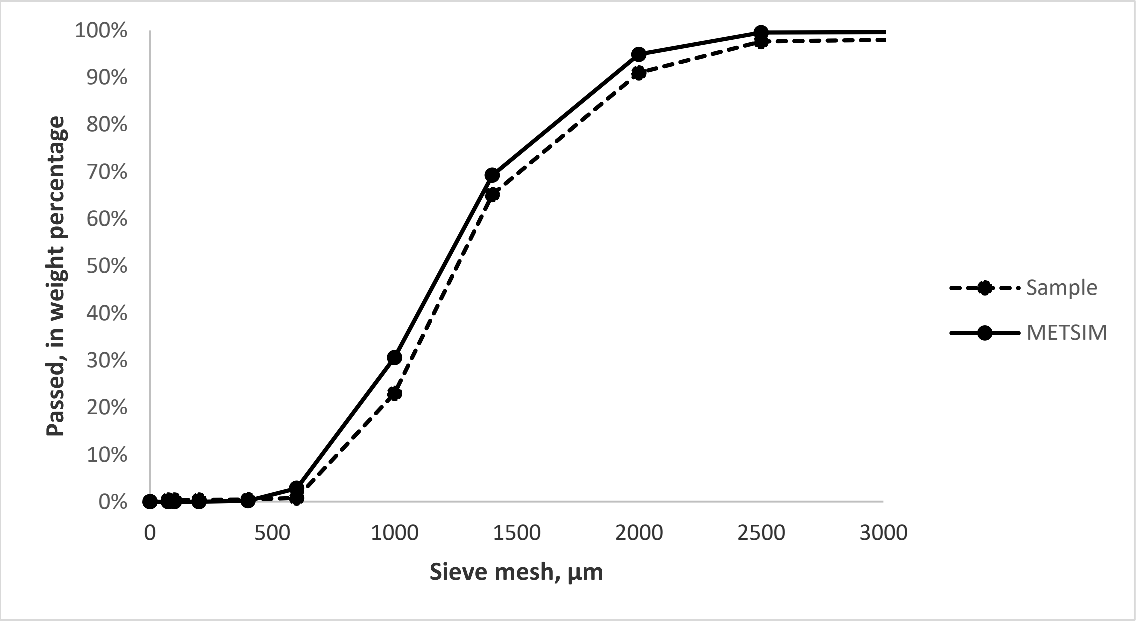


Figure 3.7: Comparison between sample and simulated granulometries for the Lehmann sieves underflows

The products specifications are reported in Table 3.13 and 3.14 (only granulometry and water content values were reported by the fact that the simulation does not take into account the silica sand chemical composition). These data were compared with the simulated ones, reported in Table 3.15.

Table 3.13: Granella commercial specifications

Granella	
Granulometry	**Water content**
> 2.5 mm = 25% max	8% max
< 1 mm = 25% max	**Average production**: 30-35 tons/h

Table 3.14: Sabbia 1 commercial specifications

Sabbia 1	
Granulometry	**Water content**
> 2.0 mm = 2% max	10% max
< 0.6 mm = 5% max	**Average production**: 10-15 tons/h

Table 3.15: Granella and Sabbia 1 simulated granulometries and productions

Granella		**Sabbia 1**	
Sieve passed, μm	Weight percentage	Sieve retained, μm	Weight percentage
12000	100%	12000	100%
10000	100%	10000	100%
8000	100%	8000	100%
6000	100%	6000	100%
2500	99.31%	2500	100%
2000	92.95%	2000	100%
1400	57.48%	1400	100%
1000	11%	1000	77.24%
600	0.08%	600	0.088%
400	0.00%	400	0.00%
200	0.00%	200	0.00%
100	0.00%	100	0.00%
75	0.00%	75	0.00%
Production	27.08 tons/h	**Production**	8.42 tons/h

The contained water in the final product is definitely lost by the plant and must be reintegrated from the aqueduct.

The comparisons between the samples data on the hydrocyclones (samples 9,10 in Table 3.5) and the simulated ones are shown in figures 3.8, 3.9.

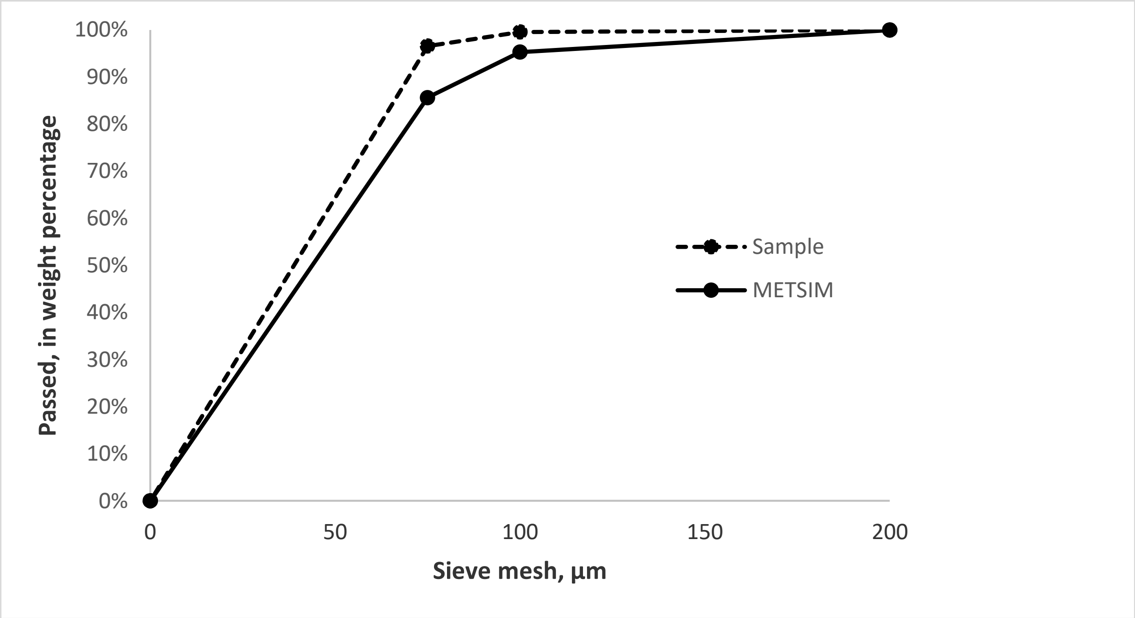


Figure 3.8: Comparison between sample and simulated granulometries for the hydrocylone overflow

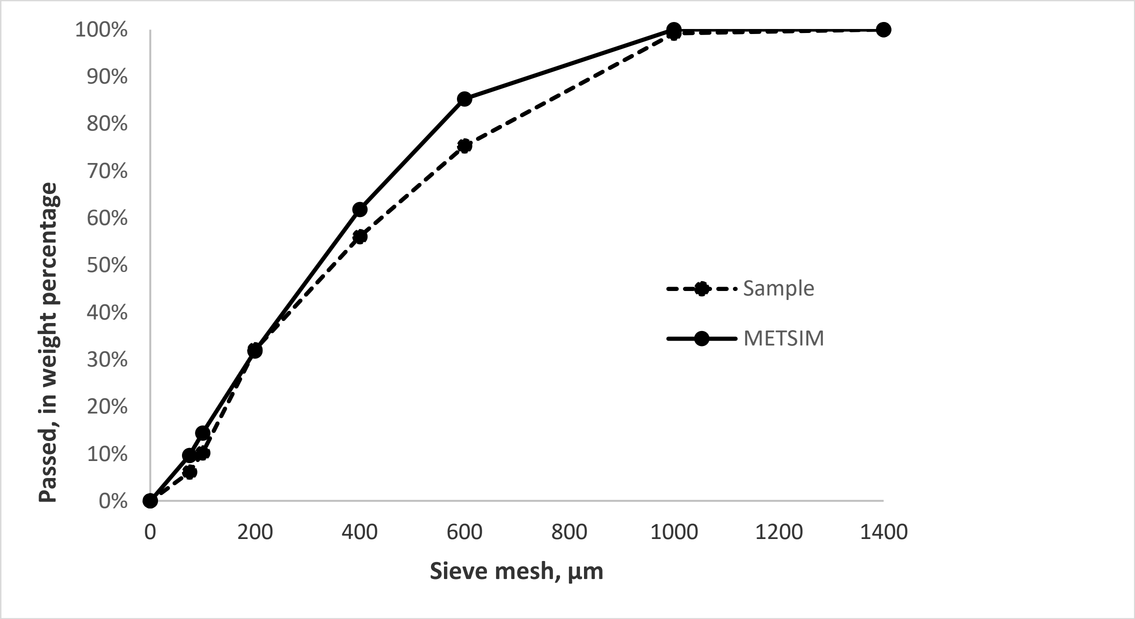


Figure 3.9: Comparison between sample and simulated granulometries for the hydocyclone underflow

In Figure 3.10 and 3.11 are shown the comparison between the samples data of the first hydrosizer underflow and overflow (sample 11 and 12 Table 3.6) and the simulated ones.

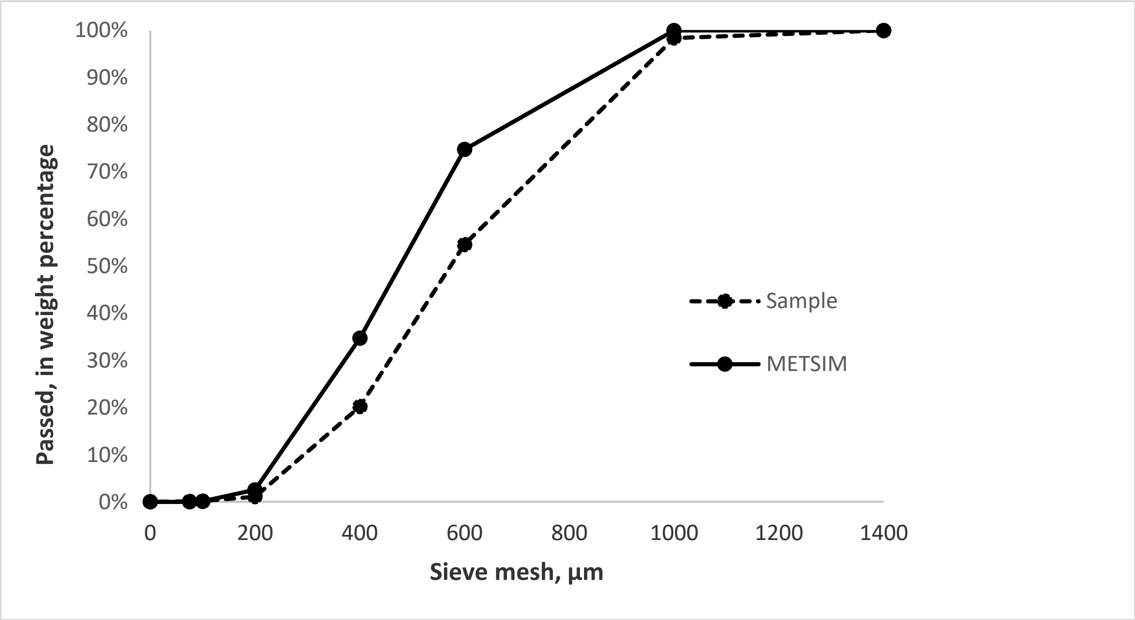


Figure 3.10: Comparison between sample and simulated granulometries for the first hydrosizer underflow

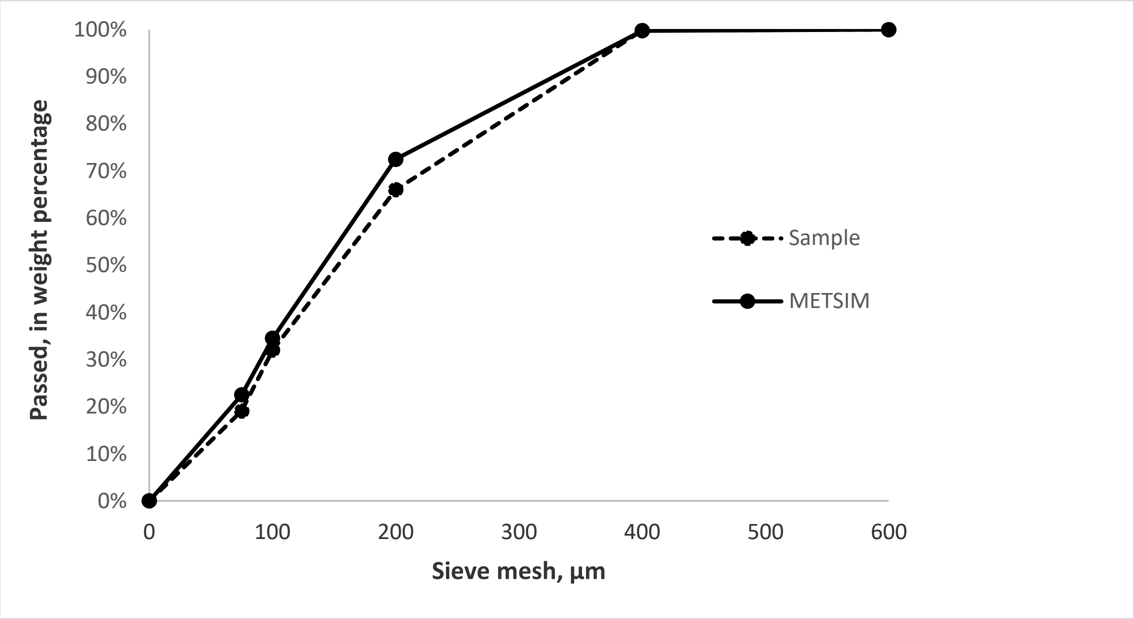


Figure 3.11: Comparison between sample and simulated granulometries for the first hydrosizer overflow

The hydrocyclone 75 underflow in Figure 2.24 was sampled, and the comparison with the simulated stream is shown in Figure 3.11 .

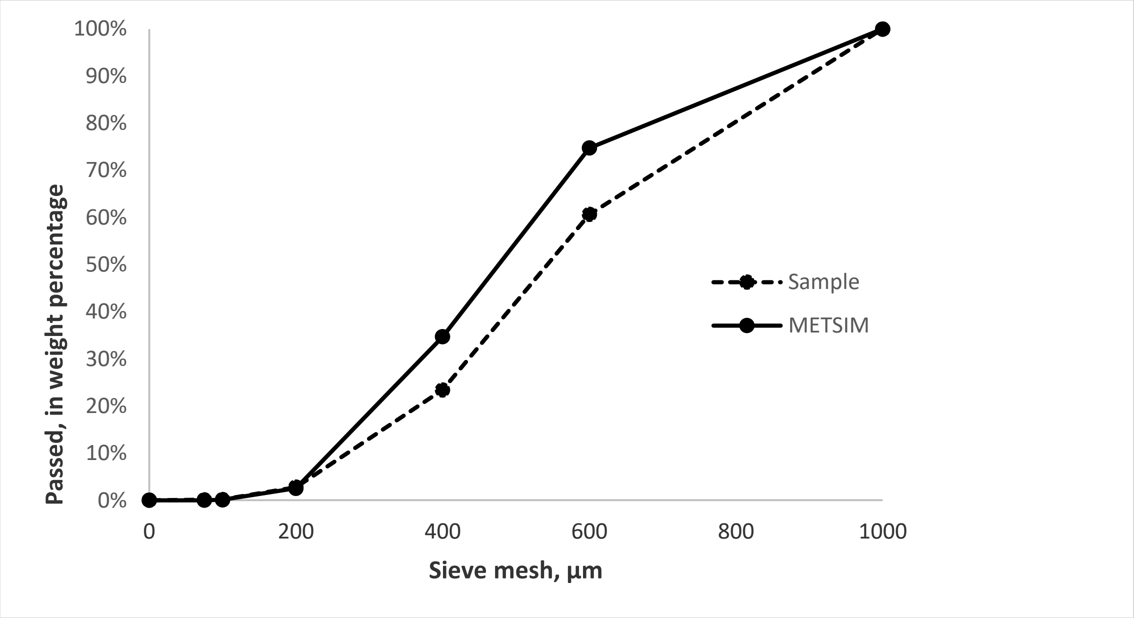


Figure 3.11: Comparison between sample and simulated granulometries for the hydrocyclone 75 underflow

A final comparison between the commercial specification of Sabbia 2 (reported in Table 3.16) and the values of the simulation (Table 3.17) was made in order to ensure the procedure reliability.

Table 3.16: Sabbia 2 commercial specifications

Sabbia 2	
Granulometry	**Water content**
> 1.5 mm = 0.1% max	8% max
> 1 mm = 10% max	**Average production** : 65-70 tons/h
< 0.1 mm = 10% max	

Table 3.17: Sabbia 2 simulated granulometries and productions

Sabbia 2	
Sieve passed, µm	**Weight percentage**
12000	100%
10000	100%
8000	100%
6000	100%
2500	100%
2000	100%
1400	100%
1000	100%
600	74.76%
400	34.72%
200	2.6%
100	0.1%
75	0.00%
Production	69.41 tons/h

As shown in chapter 2.1, also the second hydrosizer underflow and overflow were sampled (sample 13 and 14, Figure 3.1 and 3.2). Their comparison with the simulated data are shown in Figure 3.12 and 3.13.

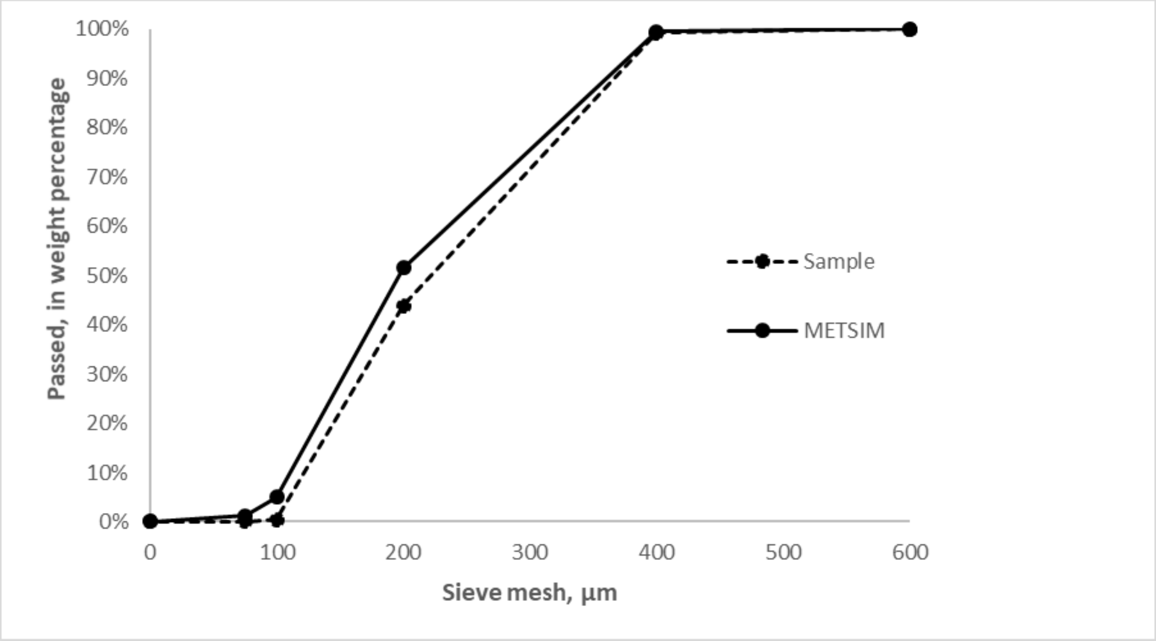


Figure 3.12: Comparison between sample and simulated granulometries for the second hydrosizer underflow

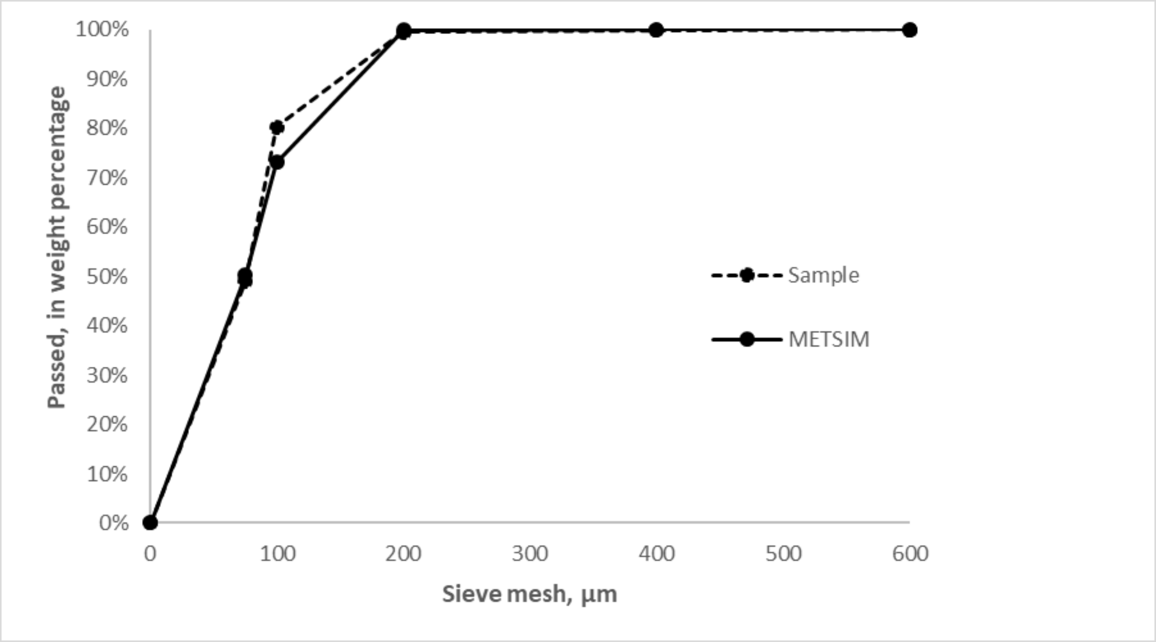


Figure 3.13: Comparison between sample and simulated granulometries for the second hydrosizer overflow

An hydrocyclone 70 is placed to further remove fines. The underflow hydrocyclone 70 was sampled and the comparison with METSIM data is shown in Figure 3.14.

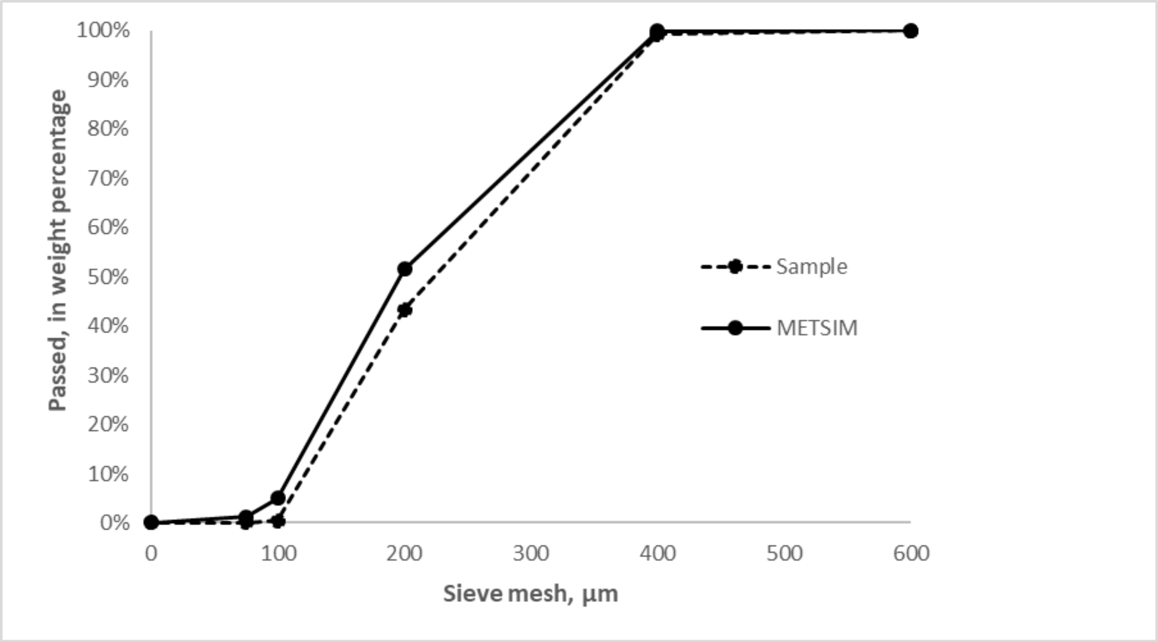


Figure 3.14: Comparison between sample and simulated granulometries for the hydrocyclone 70 underflow

A final comparison between the commercial specification of Sabbia Speciale (reported in Table 3.18) and the values of the simulation (Table 3.19) was made in order to ensure the procedure reliability.

Table 3.18: Sabbia Speciale commercial specifications

Sabbia Speciale	
Granulometry	**Water content**
> 1 mm = 0% max	8% max
> 0.75 mm = 0.5% max	**Average production** : 30-35 tons/h
> 0.6 mm = 3% max	
< 0.1 mm = 5% max	

Table 3.19: Sabbia Speciale simulated granulometries and productions

Sabbia Speciale	
Sieve passed, µm	**Weight percentage**
12000	100%
10000	100%
8000	100%
6000	100%
2500	100%
2000	100%
1400	100%
1000	100%
600	100%
400	99.56%
200	51.49%
100	4.95%
75	1.2%
Production	27.67 tons/h

Hydrocyclone 57 (Figure 2.27) removes fines and dewater the stream, its underflow was sampled (Table 2.11) and as done before a comparison with METSIM simulated data are shown in Figure 3.15.

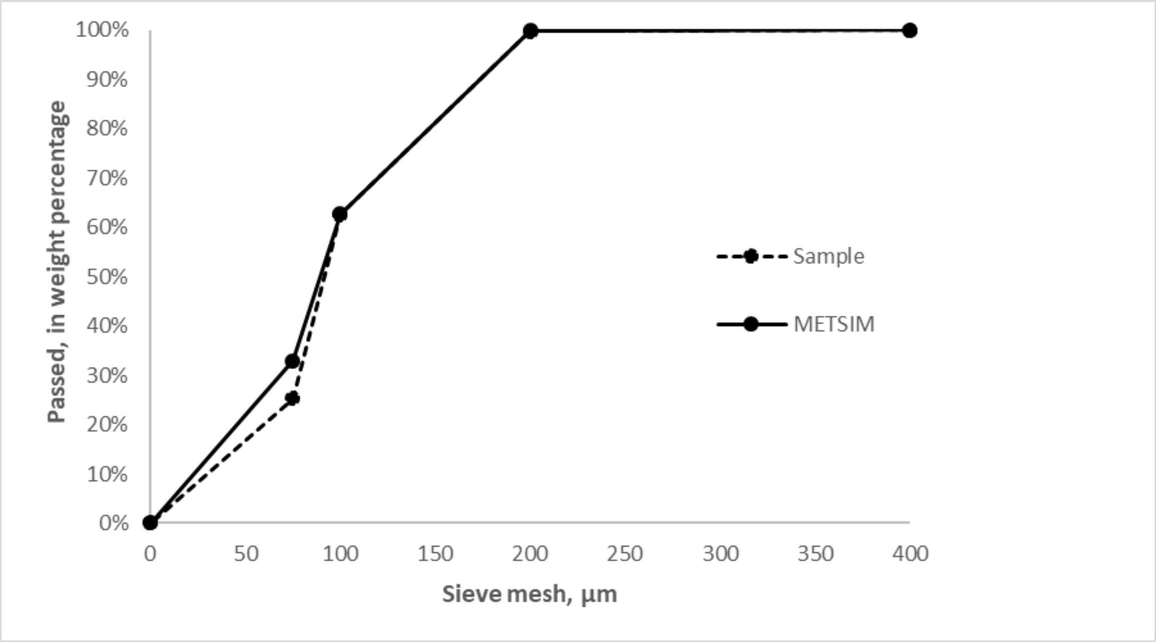


Figure 3.15: Comparison between sample and simulated granulometries for the Sabbia 5SN first hydrocyclone underflow

Also hydrocyclone 62 (figure 2.27) was sampled (Table 2.12), in Figure 3.16 is shown the comparison with simulated data.

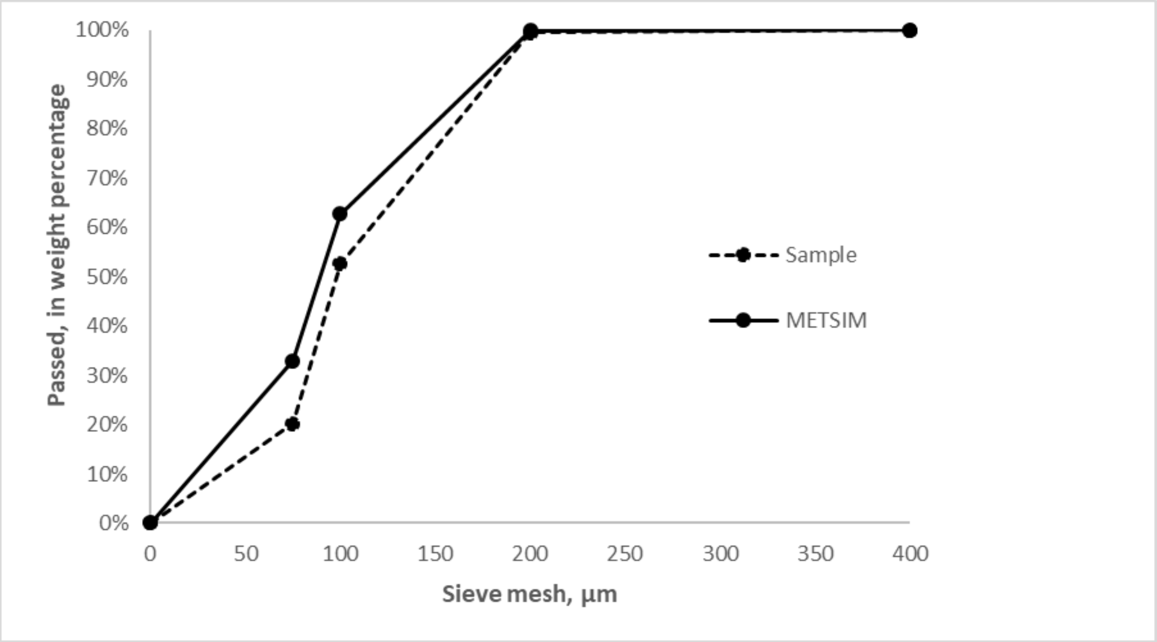


Figure 3.16: Comparison between sample and simulated granulometries for the Sabbia 5SN second hydrocyclone underflow

Table 3.20: Sabbia 5SN commercial specifications

Sabbia 5SN	
Granulometry	**Water content**
> 0.5 mm = 0.5% max	8% max
> 0.2 mm = 2% max	**Average production**: 10-15 tons/h
<0.075 mm = 35% max	

Table 3.21: Sabbia 5SN simulated granulometries and productions

Sabbia 5SN	
Sieve passed, μm	**Weight percentage**
12000	100%
10000	100%
8000	100%
6000	100%
2500	100%
2000	100%
1400	100%
1000	100%
600	100%
400	100%
200	99.87%
100	62.71%
75	33.00%
Production	15.9 tons/h

3.2.2 Water to thickener stream comparison

A last comparison was made, between the water sent to the thickener in the simulation, reported in Table 3.22, and the one measured by hand in the plant with a portable flow meter, that is 715.078 m3/h, as shown in Figure 3.3.

Table 3.22: Water from and to the thickener

Water	Flow
Taken from the thickener (stream 111)	733.56 tons/h
Send out to the thickener (stream 148)	724.82 tons/h

Conclusions

Every product fulfills the commercial specification, as shown in chapter 3.2.1, and the production in tons/h is almost always in the expected range.

By the comparison between the experimental data and the simulated streams comes up a good accordance, for sample 2,3,4,5,6 (Table 3.1, 3.2, 3.3), as it could easily be predicted by the fact that the ball mill was parametrized with samples 2,3,4.

The following samples, 9,10,11,12,13,14 (Table 3.4,3.5,3.6,3.7), show a bigger discrepancy with the simulated streams. This is probably due to the fact that the samples were obtained during two different sampling campaign.

During the first campaign, performed in the second week of October, samples 7-14 were collected and during the second, performed in the last week of October, samples 1-6.

Operating conditions and raw material strongly vary over the time, and two sampling campaigns performed in different weeks can give slightly uncoherent results.

Furthermore, as before mentioned, samples were collected only one time per each, because of the shown difficulties in streams measure and collect. This lead to a stream punctual measure that is not reliable as an average one, came up from many samples collected over a period of time.

In particular small fluctuations in the stream composition at the ball mill discharge can lead to important differences in the final products. The product granulometries, in fact, are already contained in the ball mill discharge, but its flow is one magnitude order bigger than the product ones (189 tons/h). Considering that the granulometries are evaluated on percentage of passing per sieve, few percentage points of error in the mill discharge can strongly vary the product flows and compositions.

The difference between the evaluated water flow value and the measured one can be due to these fluctuations. The water total demand, in fact, strongly depends on the density controllers necessary to reach the right solid percentage to pump the slurry. An increase in the fines composition of the ore stream influences the total water supply, by the fact that in the last part of the washing plant (Figure 2.24, 2.25, 2.26, 2.27) will be necessary more water to compensate the increase in solid content.

The hydrocyclone overflows comparison between experimental and sampled data were not reported because their composition, as shown in Figure 3.8, almost entirely consists into particles smaller than 75 µm, for which no analysis were performed.

The process simulation was performed to have a reliable description of the process that allows the process engineering division to make a rough evaluation of new expansions or improvement projects feasibility by the point of view, for instance, of the total water demand necessary in the new plant.

The thickener currently placed in the plant, in fact, have a maximum capacity of 1300 m^3/h and every modify must face this limitation.

An improvement project for a new ball mill, in fact, the following weeks was implemented in the software to evaluate the possibility for the current thickener to treat the new total water demand and the its capacity, as well as the fulfillment of the product commercial specifications.

In general it was observed that for the reasons briefly explained before, an increase in the finest fraction of the ore stream results into an higher water demand to remove and transport them into the plant.

Changing the d80 of the ball mill, in fact, from 1150 µm, which is the one of the sampled output stream, to 750 µm in order to minimize, for instance, the production of Granella sand, the total water demand rises up until 772.81 tons/h against the value 733.56 tons/h shown in Table 3.22.

List of Symbols

ISO: International Organization for Standardization

USM: United States Mesh

Bibliography

[1] Rhodes C. L., 1996, The Process Simulation Revolution: Thermophysical Property Needs and Concerns. *J. Chem. Eng. Data*, **1996**, *41* (5), pp 947–950

[2] Gani R., Pistikopoulos E.N., Property modelling and simulation for product and process design. *Fluid Phase Equilibria, Vol 194–197*, **2002**, pp 43-59

[3] Sustainable Development Goals, https://www.un.org/sustainabledevelopment/sustainable-development-goals/, date last seen 14/11/2018

[4] BlackRock, Larry Fink's 2019 letter to CEOS: Purpose & Profit, https://www.blackrock.com/corporate/investor-relations/larry-fink-ceo-letter, date last seen 13/11/2018

[5] Assomineraria, 2017, Minerali per l'industria studio IRE, https://www.assomineraria.org/settori/minerali-per-lindustria/, date last seen 13/11/2018

[6] British Geological Survey, September 2009, Silica sand, https://www.bgs.ac.uk/downloads/start.cfm?id=1369, date last seen 19/11/2018

[7] Saviour M.N., Environmental impact of soil and sand mining: a review. *International Journal of Science, Environment and Technology, Vol. 1, No 3*, **2012**, 125 – 134

[8] Environmental Risks of Mining, http://web.mit.edu/12.000/www/m2016/finalwebsite/problems/mining.html, date last seen 13/11/2018

[9] Sibelco, 2016, Didactical presentation of Robilante site

[10] Sibelco, 2016, Laboratory analysis report 2016 of Robilante site

[11] Wikipedia, Silo, https://en.wikipedia.org/wiki/Silo, date last seen 15/11/2018

[12] Monov V., Sokolov b., Stoenchev F., Grinding in ball mills: modelling and process control. *Cybernetics and Information Technologies, Vol 12*, **2012**, No 2, pp 51-68

[13] Bond F.C. Crushing and Grinding Calculations. *Part I. – British Chemical Engineering, Vol. 6,* **1961**, No 6, pp 378-385

[14] Bond F. C. Crushing and Grinding Calculations. *Part II. – British Chemical Engineering, Vol. 6,* **1961**, No 8, pp 543-548

[15] Barry A. W., Finch J., 2015, Wills' Mineral Processing Technology: An Introduction to the Practical Aspects of Ore Treatment and Mineral Recovery 8th Edition, Butterworth-Heinemann

[16] Wikipedia, Hight frequency vibrating screens, https://en.wikipedia.org/wiki/High-frequency_vibrating_screens#Range_of_applications, last seen 16/11/2018

[17] Brentwood recycling systems, Trommels 101 : Understanding Trommel Screen Design, https://brentwood.com.au/trommels-101/, last seen 15/11/2018

[18] Wikipedia, Trommel screen, https://en.wikipedia.org/wiki/Trommel_screen, last seen 15/11/2018

[19] Alter H., Gavis J., Renard M.L., Design models of trommels for resource recovery processing. *Resources and Conservation, Vol 6, Issues 3–4*, **1981**, pp 223-240

[20] Svarovsky L., 2000, Solid-Liquid Separation 4th Edition, Butterworth-Heinemann

[21] 911metallurgist, magnetic separators, https://www.911metallurgist.com/equipment/magnetic-separators/, last seen 21/11/2018

[22] METSIM, The Premier Steady-State & Dynamic Process Simulator, https://www.metsim.com/, date last seen 13/11/2018