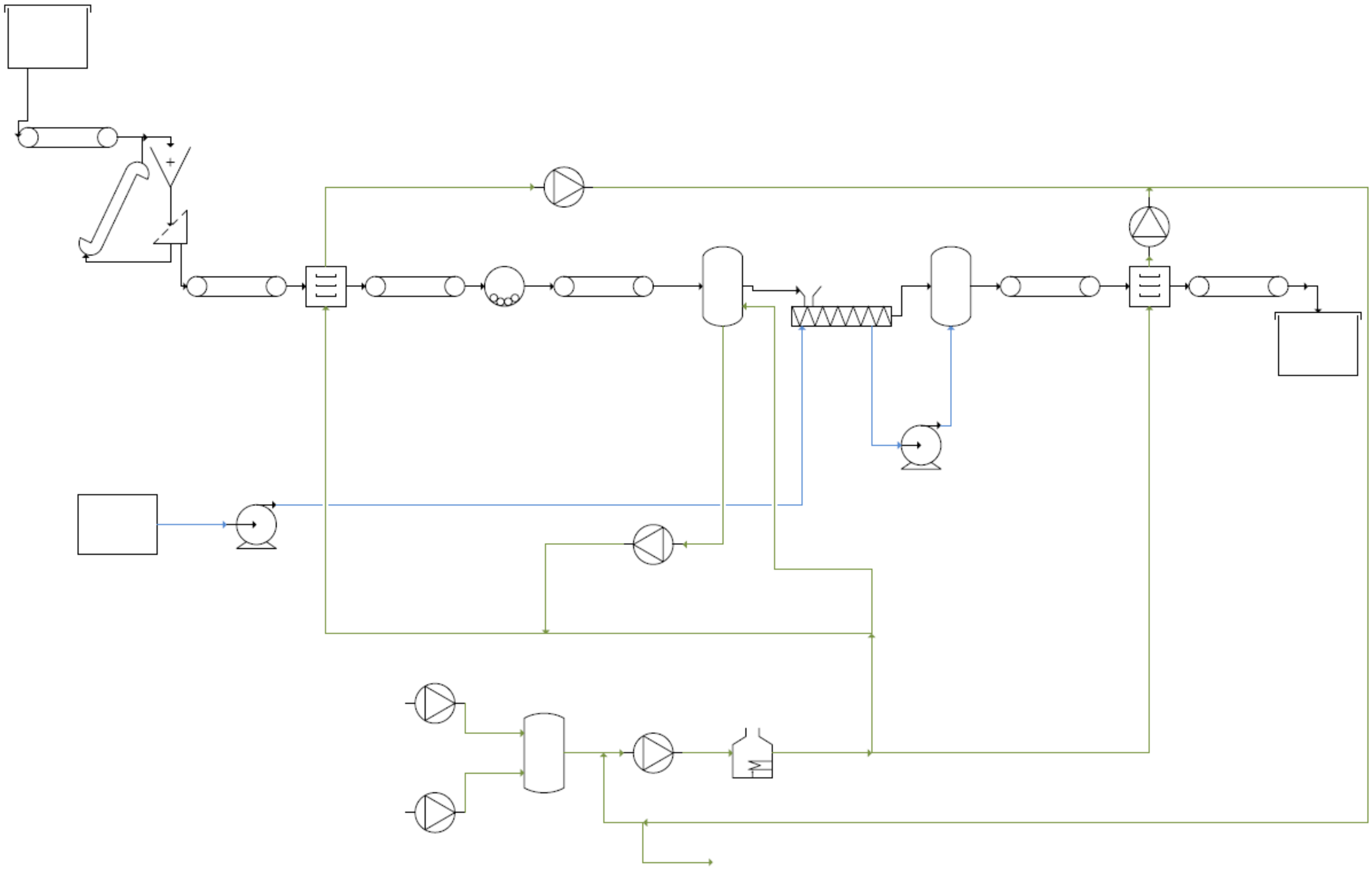
Gypsum boards from waste material: a cost effective process

Utility: Hot air
Substance: Gypsum



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Summary

A new process is developed for making gypsum boards from waste gypsum material with a capacity of 5000 kg/h. For this process 95 wt% of the feed consists of waste gypsum boards, the other 5% consists of boards made in this process which did not met the requirements. The waste gypsum boards were crushed in such a way that the particle size distribution was comparable to mining and flue-gas gypsum. The gypsum boards consisted out of 9 wt% water, which was removed before the calcination step. After the calcination, the stucco was rehydrated and the slurry was put between paper to make the final gypsum boards, which had to be dried for the last time. All the heating was provided by a hot air system.

This process was focused on winning back energy from this system, to make it overall more cost effective. This was done by using the hot air coming out of the calciner in the first dryer. This saves the process €446.- each day since less gas is needed to supply the devices with hot air.

Looking back to the research question it is concluded that it is possible to make gypsum board from waste gypsum board is a more energy efficient process than the current process.

For further research it is important to establish whether or not it is possible to produce gypsum board from 95 wt% waste gypsum board without deteriorating the material. This could be done by increasing the particle size more effectively, for example by recrystallization with seed crystals added to it. For further research it is also important that the heat loss during transportation is taken into account, because in this research it is assumed that there is no heat loss during transportation. A last option for further research is the possibility to add less water in the rehydrater which significantly reduces the amount of hot air needed to evaporate the water in the last drying step. This could be possible when adding water reducing additives.

Chapter 1: Introduction

List of abbreviations

ATO	Air to open
BDP	Block diagram process
CR	Crusher
D	Dryer
G	Gas phase
ISBL	Inside Battery Limit
K	Fan
L	Liter
L	Liquid phase
OBD	Overall block diagram
OSBL	Outside Battery Limit
P	Pump (in PFD)
P&ID	Piping & Instrumentation Diagram
PFD	Process Flow Diagram
PSD	Particle Size Distribution
PSV	Pressure safety valve
R	Reactor
S	Screen
S	Solid phase
t	ton (metric)
T	Storage tank (in PFD)
TIC	Temperature indicator controller
TSL	To safe location
TV	Temperature Valve
USGC	U.S. Gulf Coast
V	Vessel

Research question

Is it possible to make gypsum board from waste gypsum board in a more energy efficient process than the current process?

Introduction

Gypsum board consists of hardened gypsum sandwiched between two sheets of paper. It is extremely light and has a density of approximately 1000 kg/m^3. It has several useful properties such as fire-resistance, heat insulation and sound insulation. Therefore gypsum board is widely used for construction all over the world. Because of this there is a very large amount of waste gypsum board discharged each year. In Japan alone this is 1.700.000 ton/year[1]. Therefore it is highly desirable to use waste gypsum boards as feed to produce new gypsum boards. For this process the feed consists of 95 wt% waste gypsum boards and 5 wt% gypsum boards made in the process which did not met the requirements.

The current process for making gypsum boards is not very cost efficient due to the large amount of water that has to be evaporated. Therefore a more efficient process is developed which reduces the amount of hot air which is used to evaporate the water.

To see the process in detail, see attached .bkp file 'complete process Dina Boer.bkp'.
To see the pre-aspen assignment in detail, see attached .bkp file 'Classifier Dina Boer.bkp'.

Chapter 2: Process and technology

Process description

Gypsum boards are manufactured using 95 wt% waste gypsum board. The resulting 5 wt% comes from rejected gypsum boards from this process, because the boards did not met the requirements. Until now only up to 30 wt% of recycle material is used as feed for new gypsum boards[2]. This is because the gypsum dihydrate particles become too small during the dehydration process. When the particle size is less than 5 μm the gypsum hemihydrate can set too quickly and the quality of the product deteriorates. In order to recycle greater quantities of waste gypsum board, particle size of the gypsum dihydrate needs to be much larger. Kojima[1] has done research to increase particle size and with the use of 40 μm seed crystals he was able to obtain characteristics of gypsum dihydrate from waste gypsum boards with characteristics similar to those of natural gypsum and flue-gas gypsum. Therefore it is assumed that it is possible to use 95 wt% waste gypsum boards and to still receive high quality products. The waste gypsum boards may have a maximum contamination of 2 wt% other than paper. This contamination mainly consists out of nails, screws, wood and insulation material.

The waste gypsum plates, as well as the rejected plates from the process, are crushed by a hammer mill. This hammer mill has a size reduction ratio of 10:1. The reduction ratio is broadly defined as the ratio of the feed size to the product size[3]. We assume that the waste gypsum has a d_{50} of 100cm. This means that the d_{50} after the hammer mill is about 10 cm.
The crushed material will go through a screener which will remove the contamination and which will separate the coarse from the fines. The coarse is transported back to the hammer mill. The largest form of contamination is paper, of the gypsum waste about 95 wt% turns out to be recycled gypsum powder and about 5 wt% is paper. This can be further recycled to make new paper.

The fines are transported to the first dryer. Waste gypsum boards contain up to 10 wt% water, which needs to be removed at the rotating drum dryer. The dry gypsum is led to a ball mill to reduce the particle size to create a d_{50} of 0,1 mm.

The very fine material is transported to the calciner. In the calciner gypsum dihydrate is converted to gypsum hemihydrate, which is also known as stucco. The temperature needed for this reaction is 140°C. The calciner is further explained in the next section; technology.

When gypsum is converted to the hemihydrate, it will leave the reactor vessel. In this report the conversion of gypsum to hemihydrate is set as 1, but in reality this of course would not happen. If the conversion is 0.99, it would not be harmful because later on in the process the hemihydrate is converted back into gypsum.

To enter the rehydrater, the material is not allowed to have a temperature above 40°C, since additives are added to the water for better product properties. Also chemical soap is added, which creates air bubbles to make the board more light-weight. In the Aspen file (see chapter 4) it can be seen that the temperature of the hemihydrate is 143°C so it is necessary to cool it down. In the Aspen file a heat exchanger is shown, in real life this is of course not possible since the hemihydrate is a solid. Therefore the solid is transported through a screw conveyer with double walls, in which cold water flows. This way the water, which needs to be added in the next step is pre-warmed and the solid is cooled.

When the solid has the right temperature, it is added to the rehydrater. The amount of water that needs to be added is a 61 wt% of stucco[4]. This great amount of excess is needed to make a slurry, such that it can be correctly spread between the paper layers. Because the water which was needed in this step was already pre-warmed, as well as that the reaction is exothermic, a temperature of 85°C is reached for the slurry. This is favorable because the last step of the process is to dry the gypsum board, such that all the excess water is removed.

To get a better overview of this system, see the PFD later in this chapter or the Aspen drawing in chapter 4.

Technology: Calcination

The calcination is used for the dehydration of gypsum, which is the production of stucco. There are different kind of reactors possible for the calcination. The three most used processes are:

- Single-stage calcining in the MPS vertical roller mill
- Single-stage calcining in the gypsum kettle
- Multi-stage calcining

Gypsum kettle[5]

The key components of a gypsum kettle are an inlet and outlet slide, stirring device, hot air supply via the bottom of the kettle, hot air pipe system and the equipment for separate removal of flue gases and water vapours. The gypsum has to be pre-crushed before it enters the gypsum kettle. Then it enters via the inlet slide and it is heated indirectly by hot air, which can be of a temperature up to 750ºC. The stirring device ensures a uniform calcining process. The exhaust gases and the water vapours forming in the kettle are removed separately. The process is monitored by continuous temperature measurement. When the gypsum has reached 140ºC, which is the temperature required for the complete conversion of calcium dihydrate to calcium hemihydrate, the hot air generator switches to low-fire, and the finished product passes through the open outlet slide and into the buffer silo before the next batch enters the kettle.

The time required for processing a batch, and hence the dwell time of the gypsum in the kettle ranges from roughly one hour to three hours, depending on the purity and the degree of pre-calcination of the feed material.

The gypsum kettle has a relatively long setting time and its products are used above all as basic plaster for the production of wall plaster and as special products.

The gypsum kettle has throughput rates of 0.5-12.5 t/h, and requires a feed size smaller than 2 mm[6].

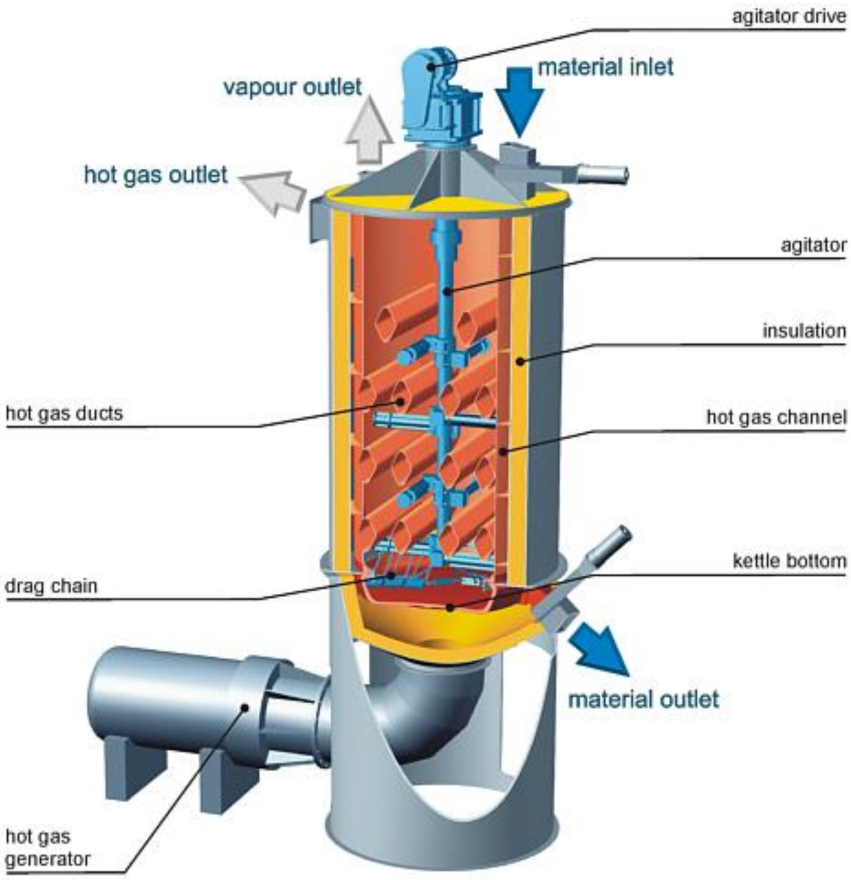

Figure 1: Gypsum kettle

MPS vertical roller mill[5,6]

MPS vertical roller mills are widely used in grinding raw material such as gypsum. The comminution is carried out between three stationary grinding rollers and a rotating grinding table. The material is drawn in between grinding rollers and grinding track and ground by pressure and shear. The compression force required for the comminution of the material is generated by a hydropneumatic tensioning system.

The material is ground and conveyed by centrifugal force towards the stationary nozzle ring, where the drying and calcining mainly takes place in a fluidized bed, through which the hot air flows directly. The hot air carries the material up to the classifier. In the separating zone a separating wheel separates the ground and dried material into fine finished product and grits. The grits fall back into the center of the grinding zone. The finished product leaves the classifier together with the gas stream and is separated in a downstream filter unit.

The MPS mill has relatively short setting times and its products are used above all for the plasterboard production, the production of structural gypsum elements, and as a basic plaster for the production of wall plaster.

The MPS mill has throughput rates of 1-60 t/h, requires a feed size smaller than 30 mm and will grind it to a target fineness of 0.02 – 2 mm.

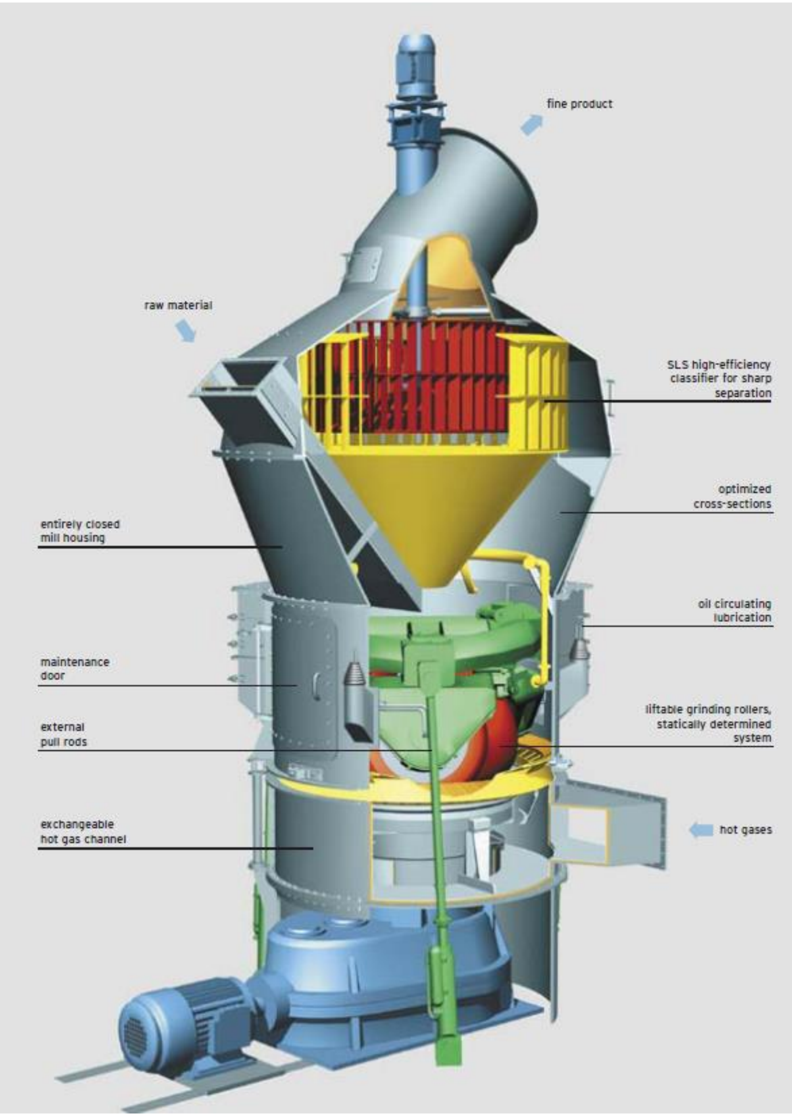

Figure 2: MPS vertical roller mill

Multi-stage calcination[5]

Prior to being fed into the gypsum kettle, gypsum has to be pre-crushed. At a multi-stage process this pre-crushing is done by a MPS vertical roller mill. In the kettle, the material is calcined further to form hemihydrate. The fact that this entails less heat transformation enables smaller kettle sizes to be used. If partial calcination takes place, the mill product, and hence the kettle feed material, usually still contains 10 to 15 wt% of crystal water.

The dwell time of the partly calcined gypsum in the kettle in a water vapour atmosphere is still significantly longer than when the whole calcination procedure takes place within the vertical roller mill. As a consequence, the product thus obtained does not differ significantly from kettle plaster produced without partial calcination in a mill.

The extra cost of gearing an MPS grinding plant to partial calcination is significantly lower than the cost saved as a result of the reduced heat transformation in the kettle. On the whole, while the quality of the product is similar, multi-stage calcination tends to be more cost-effective than carrying out the complete calcination procedure in the gypsum kettle.

Multi-stage calcining has medium to long settling times and are used above all for the plasterboard production, the production of structural gypsum element, as basic plaster for the production of wall plaster and as special plaster[6].

Calcination in this process

For this process a MPS vertical roller mill is chosen. It is has a shorter settling time, which is costs favorable. Also, in a MPS mill, heat is transmitted to the gypsum directly from the hot air in the fluidized bed. In the case of the kettle, however, the heat is introduced indirectly, via the bottom and the walls of the kettle and the pipes. This leads to a fuel consumption which is approximately 10 – 20 vol% higher than using a MPS mill[5].

A MPS mill alone is chosen above a multi-stage process because the dwell time is significantly shorter for the MPS mill.

Chemistry

Gypsum occurs in three forms, gypsum dihydrate, gypsum hemihydrate and gypsum anhydrate. Depending on the method of calcination of gypsum dihydrate, specific hemihydrates are distinguished: α-hemihydrate and β-hemihydrate. They appear to differ only in crystal shape. α-hemihydrate crystals are more prismatic than β-hemihydrate crystals and, when mixed with water, form a much stronger and harder structure. Because of this reason for gypsum boards β-hemihydrate is preferred.

The chemistry in the process can be divided into two parts: the calcination and the rehydration.

Calcination

During the calcination ¾ of the chemically bonded crystal water is evaporated. This reaction is shown below.

$$CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 \cdot 1/2\, H_2O + 3/2\, H_2O$$

This reaction is endothermic (-348.5 kJ/kg[22,23]), which means that it will absorb energy, in the form of heat, from its surroundings. For this reaction to occur, a temperature of 140°C is needed.

Rehydration

The rehydration reaction is the reverse of the calcination reaction. This reaction is thus as follows:

$$CaSO_4 \cdot 1/2\, H_2O + 3/2\, H_2O \rightarrow CaSO_4 \cdot 2H_2O$$

This reaction is exothermic, which means that it will release energy in the form of heat.

Block diagrams

Two types of block diagrams are constructed. The first is an Overall Block Diagram (OBD). In the block diagram the in- and outflow of each component is shown, as well as the temperature and the pressure. To design this process, it is important to know that this process is product driven, as it was the assignment to produce 5000 kg/h Gypsum.

Since the mass flow of the product is known it is possible to classify the process with respect to size:

- tiny (< 1 kg/h) ~ < 100 kg/yr laboratory size
- small (1 - 10 kg/h), ~ 1 - 10 tons/yr bench scale
- medium (10 – 1000 kg/h) ~ 0.01 - 10 ktons/yr pilot scale
- large (1000 – 10000 kg/h) ~ 10 – 100 ktons/yr large production plant

With a mass flow of 5000 kg/h it is clear that the process is classified as a large production plant.

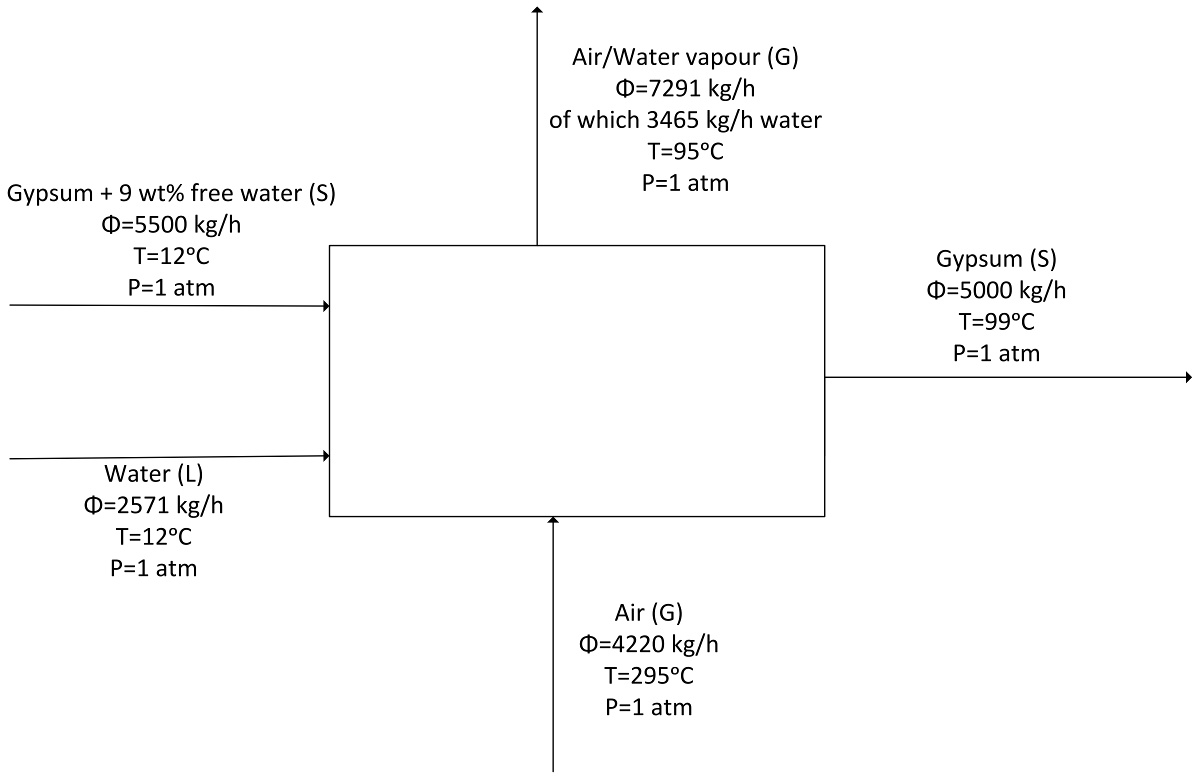

Figure 3: OBD for complete process

The second block diagram used is a Block Diagram Process (BDP). This diagram is used to identify the separate main functions within the process. For this process three different sections are distinguished:

- Feed purification section
- Reaction section
- Product recovery/purification

The feed purification section is needed to adjust the feed stream to the required specification needed for the reactor conditions. In this process it means that the not chemically bound water must be removed before the calcination can start. Therefore the drying of the wet gypsum is shown in the first block.

The reactor section is to define the chemical reaction type, in this case a calcination and a rehydration. These two reactions are shown together in block 2.

The product recovery/purification section has to be defined based on the reactor performance. For this process we have a very high conversion because a large excess of water is added in the rehydration of the second block. It also not harmful for the quality of the product if the conversion is not completely 100%, therefore it is not necessary to separate unconverted material. It is however necessary that the excess of water that is added in the second block is removed.

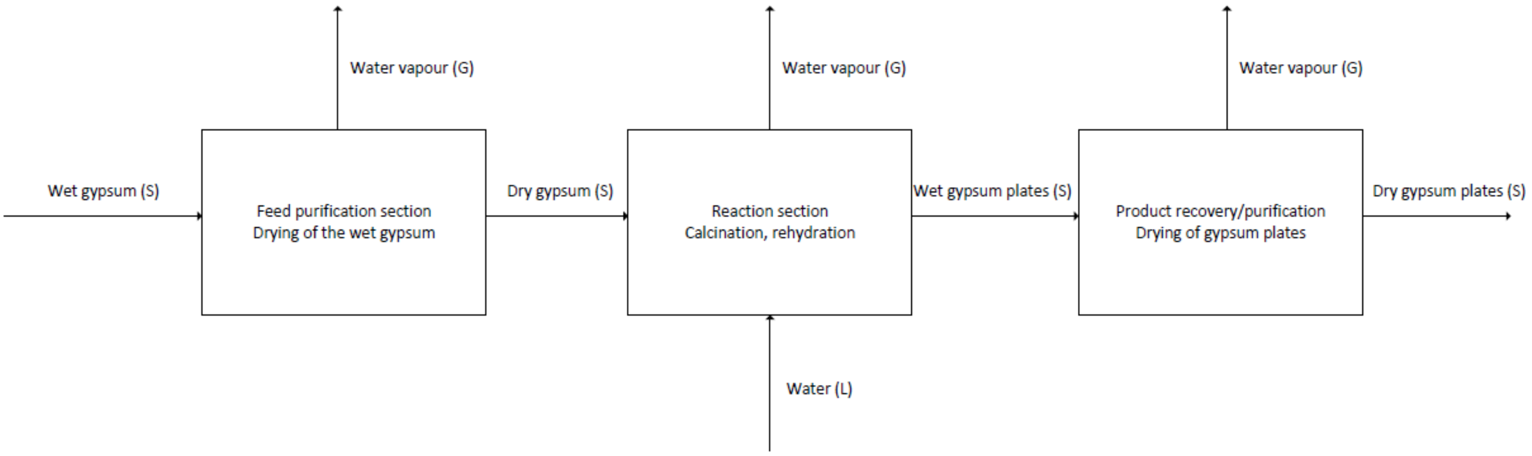

Figure 4: BDP for complete process

PFD

A process flow diagram(PFD) is constructed (see figure 5) to have an overview of the process. This PFD is divided into four sections:

- Feed purification
- Reaction
- Product recovery
- Utility

Section 1: feed purification

The hammer mill (which is named a jaw crusher on the PFD), screen, dryer and ball mill are used to prepare the gypsum for the reaction steps. Without these steps the reaction would not be possible. Therefore this first section is named feed purification. These devices can be found in the PFD with the code 110x. In which the first 1 stands for the plant, the second 1 describes the section and the x describes the number of the equipment in this section.

Section 2: reaction

The main reactions in this process are the calcination and the rehydration. For this reason these are divided into the reaction section. The screw conveyor is also part of this section since it connects these two reaction vessels.

Section 3: product recovery

Drying and storage are the last steps in the process which really form the product. The gypsum wall boards are finished before these steps but without the drying the boards would be useless. Therefore this is called product recovery.

Section 4: utility

The utility is taken as a separate section, since it does not follow the same path as the product stream.

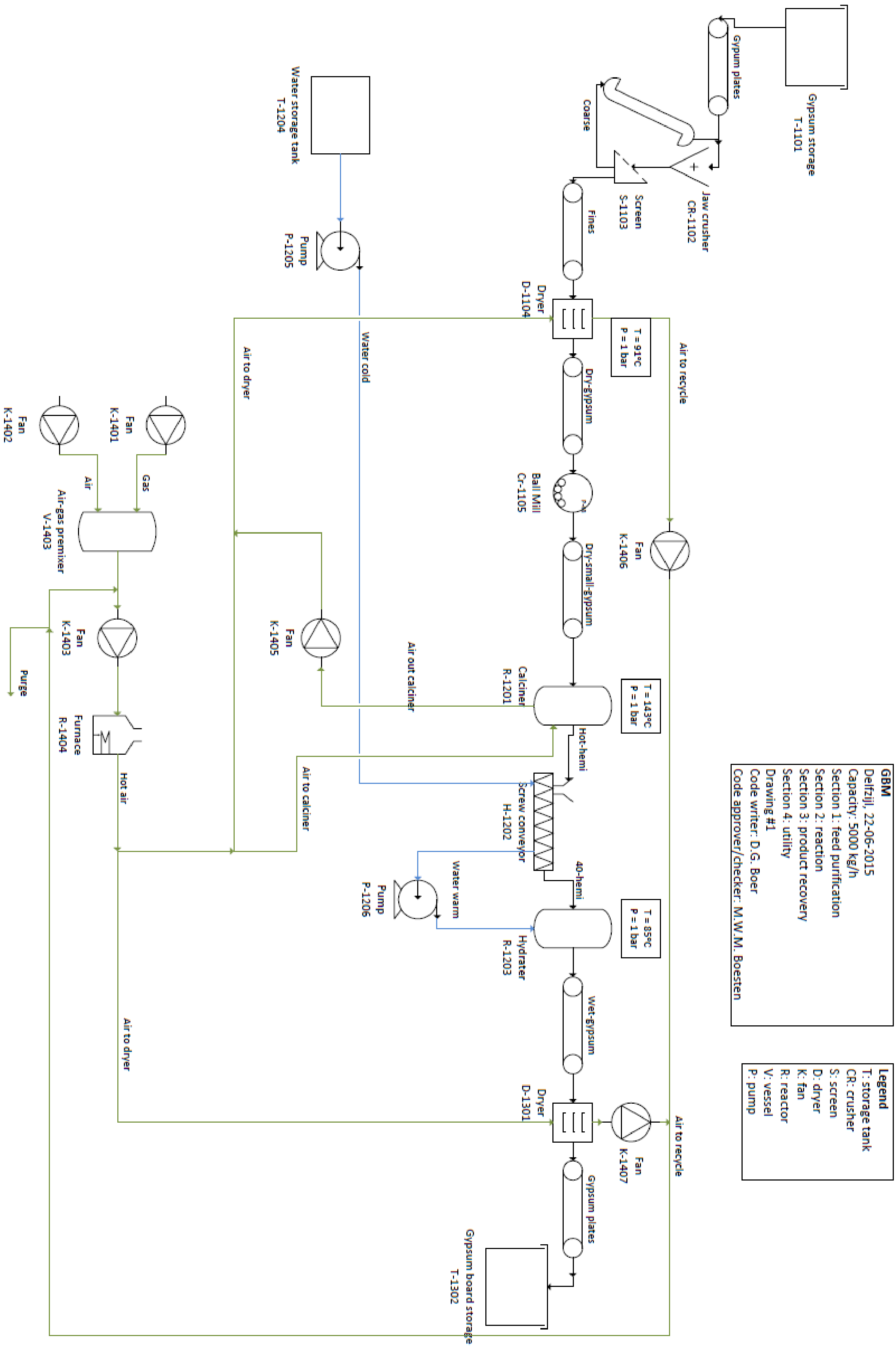

Figure 5: PFD for complete process

Chapter 3: Utility and specification

Explanation utility

The utility for this system is a hot air system. The hot air system is shown below in figure 6. In this figure the hot air stream with a relative low percentage of water is shown with a bold green line. The bold purple line shows hot air streams with a significantly large amount of water vapour present.

The hot air is generated by a fired heater, which uses natural gas (81.3 vol% methane and 3.5 vol% longer-chained hydrocarbons, 15.2 vol% incombustible gases, primarily nitrogen and a little carbon dioxide) as a fuel, as it is cleaner burning than fuel oil and therefore it is easier to fit NO_x control systems and obtain permits. Natural gas also requires less maintenance of burners and fuel lines[7].

On the bottom left the a green stream comes into a mixer (1). This incoming stream consists of pre-mixed gas-air. This is done to make sure that there will be a maximal value of 7.5 mol% oxygen after combustion, for safety issues. This 7.5 mol% is taken of dry air, so the water content does not count. The incoming gas-air mixture is mixed in the mixer (1) with the recycle stream of air. This stream goes to the furnace (2). Here the natural gas will be burned to make hot air. The hot air is split (3) into two streams, of which one goes to the first dryer and the calciner and the other goes to the dryer for the plates.
The first stream splits (4) again such that one part goes to the calciner (5,6), this hot air gets colder and the amount of water vapour is increased. The other stream mixes (7) with the stream coming out of the calciner. Together these streams go to the first dryer (8). The outlet of this dryer again is colder and the amount of water vapour is increased further. The outlet stream of this dryer is 91°C (see the Aspen drawing in chapter 4). This is to be sure of a driving force because the dew point in the dryer is 86°C.
The second stream from splitter (3) goes to the dryer for the gypsum plates (9). To make sure that there is a driving force over this dryer the outlet stream has a temperature of 99°C, since the dew point in the dryer is 87°C.

Both the outlet streams of the dryers are combined in a mixer (10). This combined stream goes to a splitter (11) to purge air with the excess of water vapour. Then the stream can be recycled and it goes back to the mixer (1) as well as the fresh gas-air mixture.

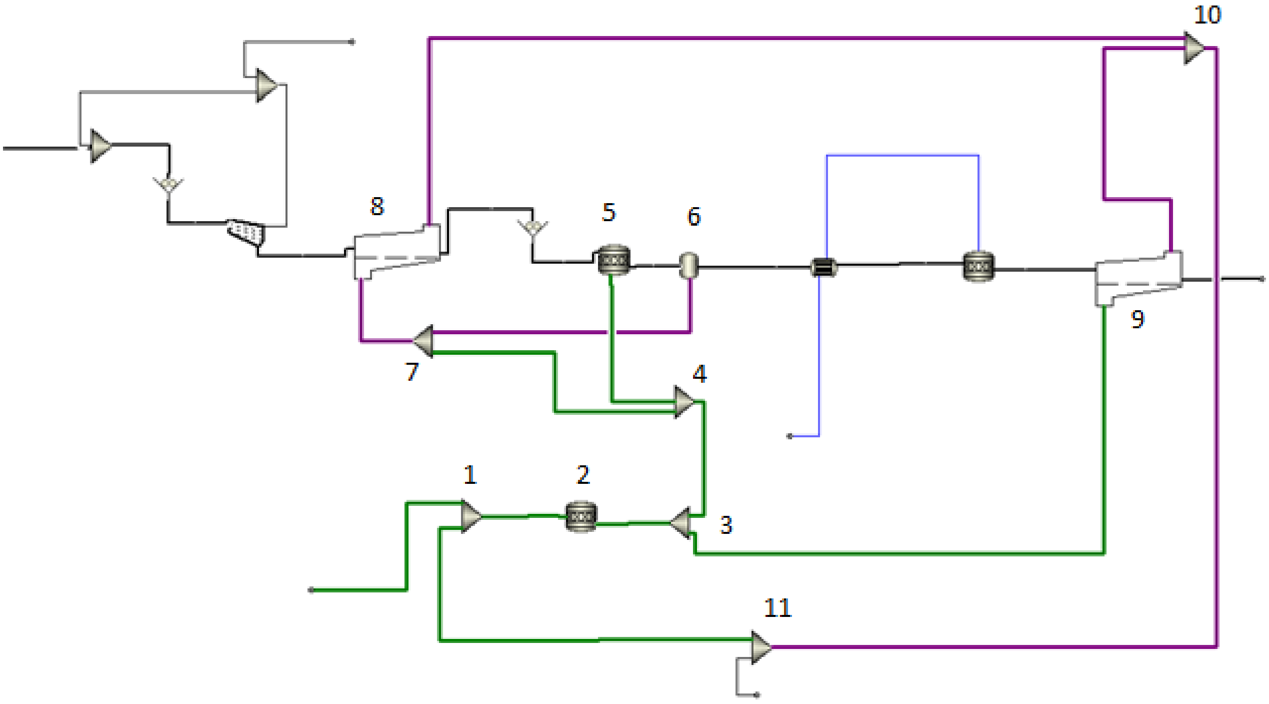

Figure 6: Utility system

Utility requirements

The utility needs to meet some requirements.
It has to be effective for drying wet gypsum, for the calcination and for drying the wet gypsum boards.
It has to be recyclable.
It has to be cost effective.

To meet this requirements a hot air system is build using:

- Furnace: to burn natural gas to make hot air.
- Splitters and mixers: to divide the streams into as much streams as necessary and to let them combine again.
- Fans: to keep the air flowing through the pipes.
- Air-gas pre-mixer: to make sure that the air/gas ratio in the furnace is stable.

Specification OSBL

The complete process can be divided into two parts, inside the battery limits (ISBL) and outside the battery limits (OSBL). ISBL is typically the process units and the focus of the project. OSBL consists of all connections necessary to make ISBL function: feed and product streams, utilities, waste streams, etc[8].
The utility system thus is part of the OSBL. To design the utility system it is important to know how much of this utility is necessary for the ISBL, which is calculated by Aspen.

Pinch

One of the goals of this research was to make the overall process more energy, and thus cost, effective in comparison to the current way of producing gypsum board. To compare the current way and the way of this research, an Aspen model is constructed for the current way. The current process is shown below in figure 7.

For this process a gas-air inflow of 4750 kg/h is necessary, of which 190 kg/h natural gas and 4560 kg/h air. For the process of this research a gas-air inflow of 4220 kg/h is necessary, of which 169 kg/h gas and 4051 kg/h air (see Aspen drawing in chapter 4. This difference is because in the current process the hot air coming out of the calciner and both dryers are not re-used. In the process of this research, the hot air coming out of the calciner is used for partly heating the first dryer, thus less hot air is needed in the system.

The difference between the regular and the new process is thus 21 kg/h natural gas, which is 29.5 m^3/h at P = 1 bar, T = 12°C. The gas price in The Netherlands at 11 February 2015 was €0.63/m^3 gas. This means that if the plant is on stream 24h/day, this will safe €446.- each day.

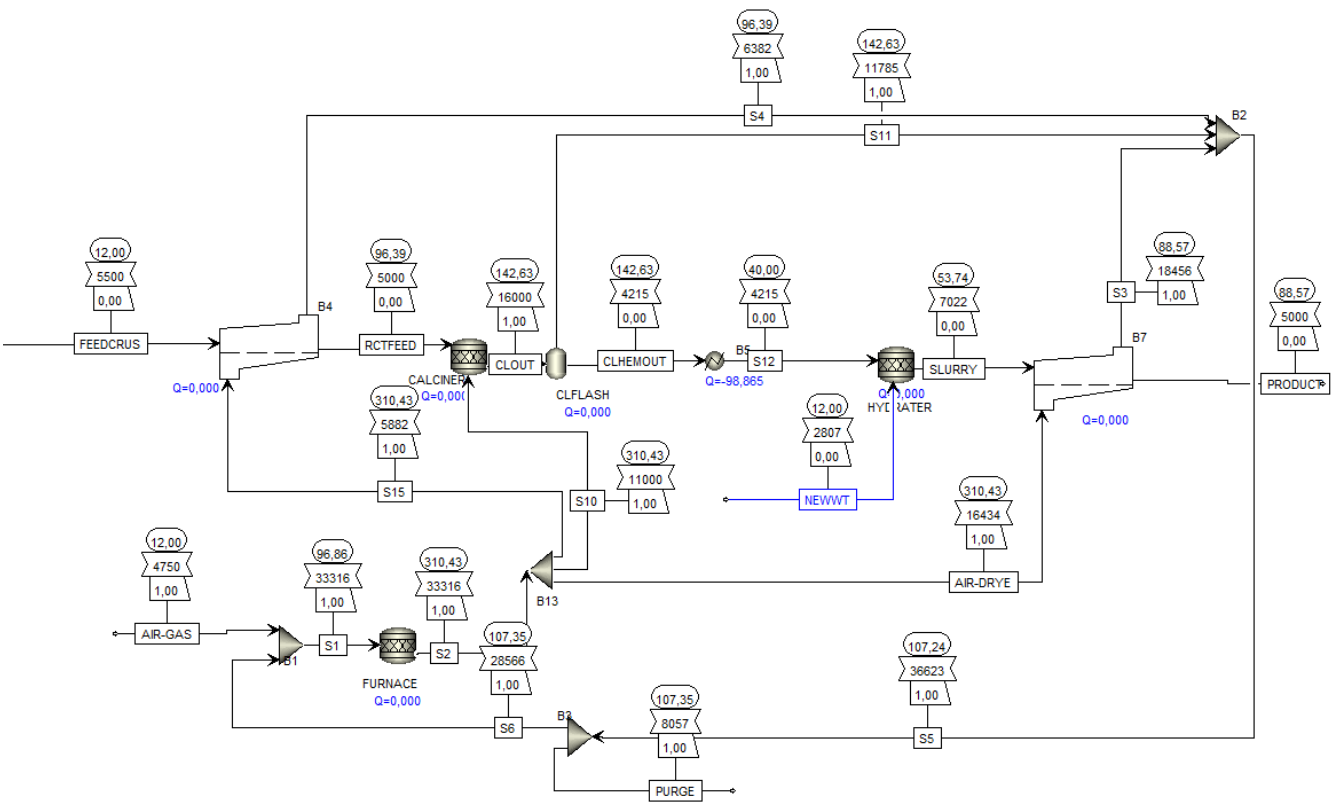

Figure 7: Gypsum board process without energy recovery

To take a better look at the system to use pinch technology normally a temperature-enthalpy diagram is constructed. From this temperature enthalpy diagram the maximum feasible heat recovery is reached at the point where the hot and cold curves touch each other on the T-H plot.

For each step with heating and cooling based on heat exchange a T-H plot can be constructed. In this process the wet gypsum dryer, the calciner, the screw conveyor and the gypsum board dryer are included in the T-H composite diagram.

To get a good overview of the possible heat recovery, a T-H composite diagram is constructed. In this composite diagram the heat duty of the steps are added together to receive a composite curve for the hot and the cold stream. The curve of the cold stream however is placed too far to the left, since at the cold end the hot stream must pass the cold stream and at the hot end the cold stream must pass the hot stream. Therefore a second composite diagram is made in which the cold stream is shifted to the right. This is allowed because the pinch is about the changes in enthalpy, so it is possible to treat the enthalpy axis as a relative scale and slide either the hot stream or the cold stream horizontally. By sliding the cold stream to the right, also the minimum temperature difference between the streams, ΔT_{min} and the amount of heat exchanged and the amount of hot and cold utilities required change.

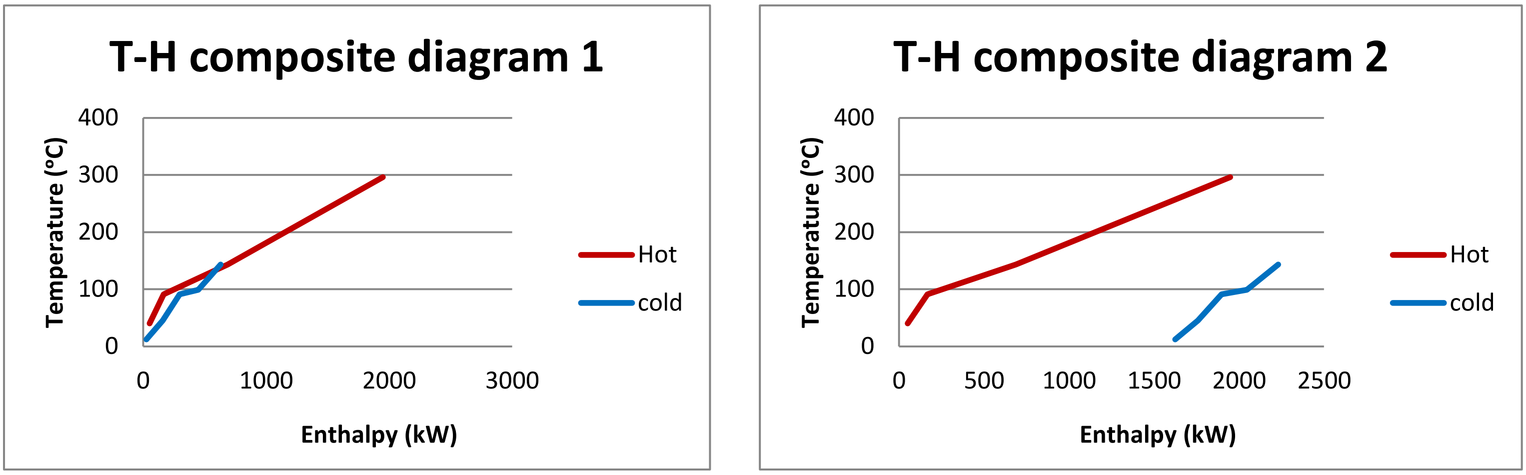

Figure 8: T-H composite diagrams for possible heat recovery

Chapter 4: Mass and Energy balance

Process control and P&ID

When designing a process it is necessary that there will be some sort of control to maintain safe operation. For this process the pressure, temperature and level are controlled. To see clearly how these parameters are controlled, a piping and instrumentation diagram (P&ID) is constructed for a part of the process, see figure 9. The calciner is chosen since this was the main technology for this research.

Pressure control

Pressure control is necessary for this system since it is a system handling a vapour. To make sure that the pressure will not be too high, a pressure safety valve (PSV) is placed on top of the reactor. This is a mechanical safety valve, which will open if the pressure exceeds a pre-defined value. This means that it is closed during normal operation. The PSV operates like a spring, such that if the power goes down, it still works.

Level control

In any equipment where an interface exists between two phases (in this case solid and vapour), some means of maintaining the interface at the required level must be provided. This can be done by control of the flow from the equipment.
To make sure that there is not too much and not too little gypsum in the reactor, a level transmitter (LT) is connected to the reactor. If the level becomes too high or too low, it will send a level alarm high (LAH) or a level alarm low (LAL), respectively. The level indicator controller will adjust the outflow of hemihydrate such that for a LAL the outflow will go slower/stops. For a LAH, the outflow will go faster such that the reactor empties faster than it is filled.

Temperature control

To make sure that the temperature in the reactor will not become too high, a temperature transmitter (TT) is connected to the reactor vessel. This is connected to a temperature indicator controller (TIC), which will give a signal to the furnace. When the temperature in the reactor will become too high, the TIC will give a signal to the furnace to lower the temperature. This is done by letting less gas into the furnace, which will cause the temperature to drop, but it does not significantly reduce the air flow. This way the hot air that reaches the reactor has a lower temperature.
There is also a valve on the pipeline to the reactor which is opened during normal operating, which means that it is an air to open (ATO) valve. Thus when it loses its signal, the valve closes and the hot air will not reach the reactor, which means that the temperature cannot become too high during failure.

It is not possible for this process to control the temperature by closing the valve in the hot air pipeline to the kettle, because the calciner uses a fluidized bed to perform the calcination. So if the air flow decreases the calciner would not work well anymore.

Maintenance

On both sides of the valve connected to the air inflow pipe, and on the air outflow pipe there are flanges. These are useful for maintenance to the pipes.
The circle in the reactor is a manhole, this is also useful for maintenance.

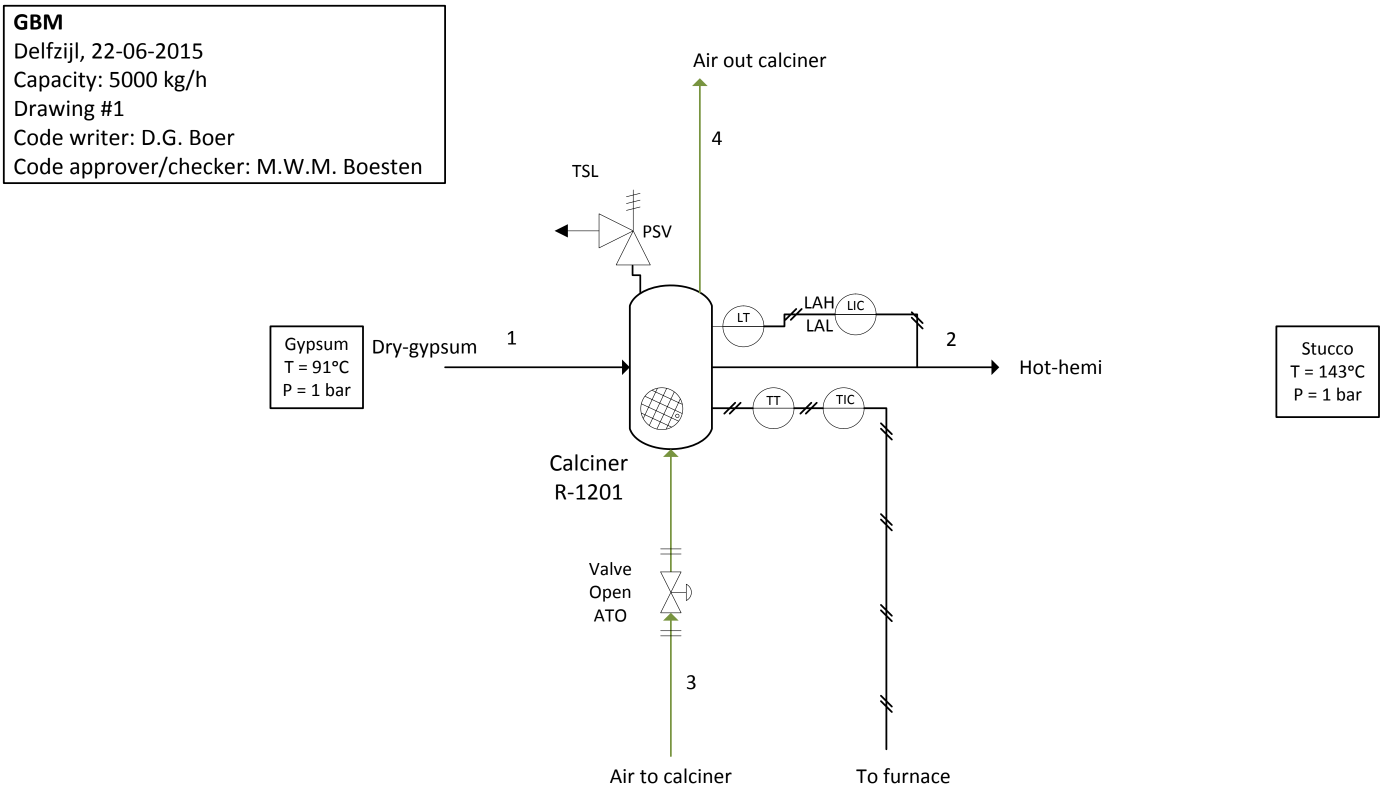

Figure 9: P&ID for calciner

HAZOP

A hazard and operability study is a systematic procedure for critical examination of the operability of a process.[7] When applied to a process design or an operating plant, it indicates potential hazards that may arise from deviations from the intended design conditions. For this report, a small HAZOP study is performed over the calcinator and the streams (1 t/m 4) which are embedded in the P&ID.
For the HAZOP study the intention, deviation, cause, consequence and hazards of each stream is determined, which can be seen in the table on the next page.

Vessel -Calciner **Intention - to perform calcination of gypsum particles**			
Guide word	Deviation	Cause	Consequences and Action
Line No. 1 Intention - transport gypsum (1 bar, 5000 kg/h, 91°C) into the calciner			
NO	Flow	Transport belt failure, inlet blockage	Too little gypsum in calciner (LAL)
MORE	Flow	Transport belt failure	Too much gypsum in calciner (LAH)
LESS	Flow	Inlet blockage	Too little gypsum in calciner (LAL)
Line No. 2 Intention - transport of demihydrate (1 bar, 4215 kg/h, 143°C) from the calciner to rest of process			
NO	Flow	Outlet blockage	Too much gypsum in calciner (LAH)
LESS	Flow	Outlet blockage	Too much gypsum in calciner (LAH)
Line No. 3 Intention - transport of air (1 bar, 12205 kg/h, 296°C) into the calciner			
NO	Flow	Fan failure, inlet blockage	Fluidized bed will not work, so calcination will not be performed well.
MORE	Flow	Fan failure	Calcinator will become too hot, pressure increases. Hazard!
LESS	Flow	Fan failure, inlet blockage	Fluidized bed will not work, so calcination will not be performed well.
Line No. 4 Intention - transport of air (1 bar, 16169 kg/h, 91°C) out of the calciner			
NO	Flow	Outlet blockage, fan failure	Calcinator will become too hot, pressure will increase. Hazard!
LESS	Flow	Outlet blockage, fan failure	Calcinator will become too hot, pressure will increase. Hazard!

Aspen drawing

The process for the manufacturing of gypsum boards from waste gypsum boards is simulated in Aspen. In this system the contamination, (such as paper, nails, screws and insulation) of the feed is not included. In this model it is also assumed that there is a conversion of 1 for gypsum to hemihydrate and the reverse reaction.

To make a recycle loop in the model for the gypsum boards which are too large for the screener, a purge needed to be incorporated. In a real process it is not necessary to purge a part of these too large pieces of gypsum boards. Therefore this is only incorporated in the Aspen drawing but not in the rest of the report.

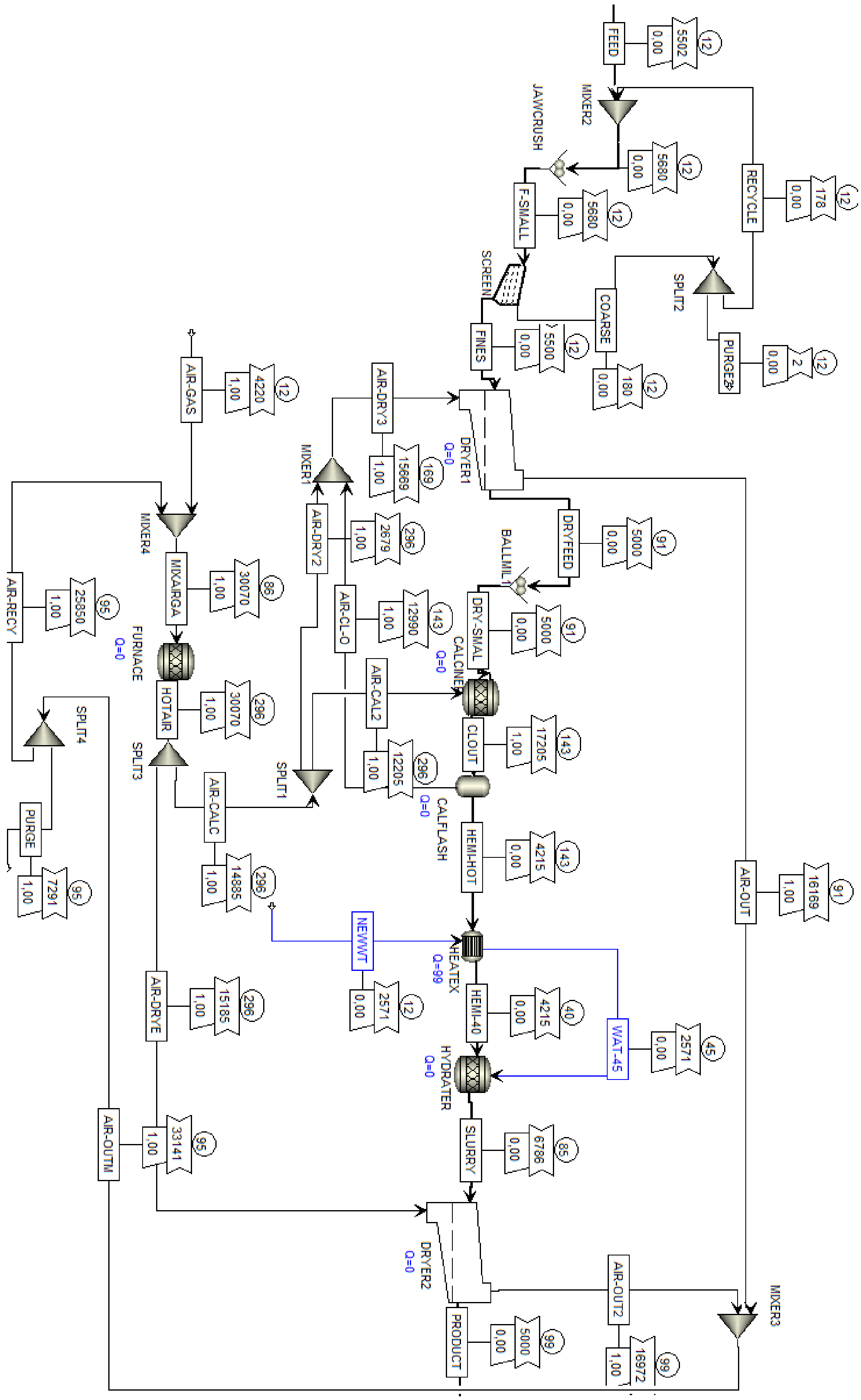

Figure 10: Aspen system

Stream summary

A stream summary from Aspen is obtained and showed in the two tables underneath. The first table shows the values for the pressure (bar), temperature (°C), vapor fraction, enthalpy (kW) and density (kg/m^3) for all the streams of the Aspen model (see Aspen drawing). In the second table, the total mass flow (kg/h) is shown for each stream, as well as the mass flow for each different component. To keep it compact, the mass flow of ethane, propane, butane, pentane and hexane are added and shown in one column.

Stream	Pressure (bar)	Temperature (°C)	Vapor Fraction	Enthalpy (kW)	Density kg/m^3
AIR-CAL2	1	296	1	-20200	0.5
AIR-CALC	1	296	1	-24634	0.5
AIR-CL-O	1	143	1	-23813	0.7
AIR-DRY2	1	296	1	-4434	0.5
AIR-DRY3	1	169	1	-28247	0.6
AIR-DRYE	1	296	1	-25132	0.5
AIR-GAS	1	12	1	-258	1.2
AIR-OUT	1	91	1	-30576	0.8
AIR-OUT2	1	99	1	-32901	0.7
AIR-OUTM	1	95	1	-63471	0.8
AIR-RECY	1	95	1	-49507	0.8
CLOUT	1	143	1	-36419	0.7
COARSE	1	12	0	-588	
DRY-SMAL	1	91	0	-16219	
DRYFEED	1	91	0	-16219	
F-LARGE	1	12	0	-19135	999
F-SMALL	1	12	0	-19135	999
FEED	1	12	0	-18553	999
FINES	1	12	0	-18547	999
HEMI-40	1	40	0	-12705	
HEMI-HOT	1	143	0	-12606	
HOTAIR	1	296	1	-49766	0.5
MIXAIRGA	1	86	1	-49766	0.8
NEWWT	1	12	0	-11369	999
PRODUCT	1	99	0	-16206	
PURGE	1	95	1	-13964	0.8
PURGE2	1	12	0	-6	
RECYCLE	1	12	0	-582	
SLURRY	1	85	0	-11269	966
WAT-45	1	45	0	-23974	987

Stream	Mass Flow (kg/h)	HEMI-SOL (kg/h)	GYPS-SOL (kg/h)	WATER (kg/h)	CO2 (kg/h)	O2 (kg/h)	N2 (kg/h)	ARGON (kg/h)	METHANE (kg/h)	ETHANE-HEXANE (kg/h)
AIR-CAL2	12205			5147	925	569	5436	129		
AIR-CALC	14885			6277	1128	694	6629	158		
AIR-CL-O	12990			5931	925	569	5436	129		
AIR-DRY2	2679			1130	203	125	1193	28		
AIR-DRY3	15669			7061	1128	694	6629	158		
AIR-DRYE	15185			6403	1151	708	6763	161		
AIR-GAS	4220			0	8	1017	2946	70	164	15
AIR-OUT	16169			7561	1128	694	6629	158		
AIR-OUT2	16972			8190	1151	708	6763	161		
AIR-OUTM	33141			15751	2278	1401	13392	318		
AIR-RECY	25850			12286	1777	1093	10446	248		
CLOUT	17205	4215		5931	925	569	5436	129		
COARSE	180		180							
DRY-SMAL	5000		5000							
DRYFEED	5000		5000							
F-LARGE	5680		5180	500						
F-SMALL	5680		5180	500						
FEED	5502		5002	500						
FINES	5500		5000	500						
HEMI-40	4215	4215								
HEMI-HOT	4215	4215								
HOTAIR	30070			12680	2278	1401	13392	318		
MIXAIRGA	30070			12286	1785	2110	13392	318	164	15
NEWWT	2571			2571						
PRODUCT	5000		5000							
PURGE	7291			3465	501	308	2946	70		
PURGE2	2		2							
RECYCLE	178		178							
SLURRY	6786		5000	1786						
WAT-45	2571			2571						

Chapter 5: Equipment list and estimation costs

Specification ISBL and OSBL

As stated in chapter 3, the complete process can be divided into two parts, inside the battery limits (ISBL) and outside the battery limits (OSBL). ISBL is typically the process units and the focus of the project. OSBL consists of all connections necessary to make ISBL function: feed and product streams, utilities, waste streams, etc[8].

For this system the ISBL consists of the feed storage, the crushers, the screener, the dryers, the calciner, the screw conveyor with double wand, the hydrater, transport belts and the gypsum boards storage place.

The OSBL consists of the feed to the wet gypsum storage, the hot air system, the water for the hydrater, the transport of the gypsum boards and the waste stream in the form of the purge.

Equipment list and vendor information

An equipment list is constructed for the equipment which is part of the ISBL.

Equipment	**Code**	**Capacity**	**Vendor**	**Power**
Gypsum waste board storage	T-1101	400 ton		
Hammer mill	CR-1102	3-8 t/h	XINFEI	55.5 kW
Screen	S-1103	5 t/h	W.S. TYLER	
Rotating drum dryer	D-1104	2-6 t/h	FTM	11 kW
Ball mill	CR-1105	1.5-5.8 t/h	SAM mining equipment	55 kW
Calciner (MPS vertical roller mill)	R-1201	1-160 t/h	PFEIFFER	7.5 kW
Screw conveyor (double wand)	H-1202	35 t/h	Reno Machinery	
Hydrater	R-1203	5.3 m^3	STAES DYNAMIX	
Gypsum board dryer	D-1301	6 t/h	Grenzebach	
Transport belt (5x)		6 t/h	SANDVIK	
Gypsum board storage	T-1302	400 ton		

Gypsum waste board storage

Equipment	Code	Capacity	Vendor	Power	MOC	Temperature	Pressure
Gypsum waste board storage	T-1101	400 ton	-	-	Bricks	12 °C	1 bar

The storage of gypsum waste board is done in a large indoor place, which is necessary to make sure that the water content does not exceed 10 wt%. The capacity for this hall is 400 ton, to make sure that the continuous process does not have to be stopped when there is no feed supply during the weekends. Since gypsum board has a density of approximately 700 kg/m^3, this means that the storage must be 571 m^3.

Hammer mill[9]

Equipment	Code	Capacity	Vendor	Power	MOC	Temperature	Pressure
Hammer mill	CR-1102	3-8 t/h	XINFEI	55.5 kW	304 Stainless steel	12 °C	1 bar

To crush the large waste gypsum boards a crusher is necessary. To ensure the highest reduction ratio for the size, it is chosen to use a hammer mill.
A wood crusher from XINFEI, model 800, is used for this size reduction. The main structure of the machine is composed of rack, housing, motor housing, shaft, hammer, screw conveyor and fan.
The capacity of the process is within the range for the capacity of the equipment. However, the feeding width is too small. Therefore the plates either have to be crushed before entering this machine or the machine has to be custom made such that the feeding with is applicable for this process.

Screen[10]

Equipment	Code	Capacity	Vendor	Power	MOC	Temperature	Pressure
Screen	S-1103	5 t/h	W.S. TYLER		304 Stainless steel	12 °C	1 bar

For the classification of the gypsum particles, a screen is necessary. For this operation the TYCAN 1100 F-class model from W.S. TYLER is used. This model however has a maximum capacity of 5 t/h which is exactly the amount of gypsum processed. To make sure that the process can be optimized for a higher capacity, it is preferred to have equipment which can process for example 1 or 2 t/h more than the current process.
This type of screener has cut sizes up to 15 cm and a maximum lump size of 30 cm.

Rotating drum dryer[11]

Equipment	Code	Capacity	Vendor	Power	MOC	Max temperature	Pressure
Rotating drum dryer	D-1104	2-6 t/h	FTM	11 kW	304 stainless steel	169 °C	1 bar

For the first drying step, a rotating drum dryer, model Φ1200x12000 is used from FTM. The dryer is able to process a capacity between 2-6 t/h, which will cost 11 kW of power. The intake air temperature must be lower than 700°C, which is not a problem in this process since the temperature of the hot air coming into the dryer is 169°C.

Ball mill[12]

Equipment	Code	Capacity	Vendor	Power	MOC	Temperature	Pressure
Ball mill	CR-1105	1.5-5.8 t/h	SAM mining equipment	55 kW	304 stainless steel	91 °C	1 bar

To perform the second crushing step a ball mill is used. The model used is Φ1200x4500 from SAM mining equipment. The capacity of the ball mill is 1.5 to 5.8 t/h. It is possible to choose another model to increase the capacity, however when choosing a model with a capacity of 3-6 t/h the power needed is 110 kW. For the chosen model the required power is only 55 kW. Therefore it is chosen to use a model with relatively low possibilities for upscaling.

Calciner[6]

Equipment	Code	Capacity	Vendor	Power	MOC	Max temperature	Pressure
Calciner (MPS vertical roller mill)	R-1201	6 t/h	PFEIFFER		304 stainless steel	296 °C	1 bar

For the calcination a MPS vertical roller mill from PFEIFFER is chosen. This equipment is able to process a very large range of capacities. It is chosen to use one which has a capacity of 6 t/h.
The product fineness and product characteristics can be varied within a wide range (0.063 to 0.5 mm).

Screw conveyor[13]

Equipment	Code	Capacity	Vendor	Power	MOC	Max Temperature	Pressure
Screw conveyor (double wand)	H-1202	35 t/h	Reno Machinery		304 stainless steel	143 °C	1 bar

A screw conveyor of Reno Machinery is chosen, this piece of equipment has to be custom made because the capacity of the standard equipment is much higher than needed. Another reason it has to be custom made is that the conveyor has to be equipped with a double want, in which water can flow to cool down the hemihydrate in the screw conveyor.

Hydrater

Equipment	Code	Capacity	Vendor	Power	MOC	Max temperature	Pressure
Hydrater	R-1203	5300 L	STAES DYNAMIX		304 stainless steel	85 °C	1 bar

For the hydrater a stainless steel storage tank is used with a mixer. The capacity of the tank is 5300 L. The minimal capacity is 4000 L, but it is not preferable to have a completely filled tank when stirring. Therefore a bigger one is chosen from STAES. The material used is stainless steel 304. The diameter and the height of the tank are 1.6 meter and 3.6 meter respectively[14].

The mixer used is a mixer from DYNAMIX agitators, of the DMX line of industrial mixers. This heavy duty mixer is designed to be portable and flexible enough to be applied to an industrial tanks with the used size of 5.3 m^3. [15]

Gypsum board dryer[16]

Equipment	Code	Capacity	Vendor	Power	MOC	Max temperature	Pressure
Gypsum board dryer	D-1301	6 t/h	Grenzebach		304 stainless steel	296 °C	1 bar

The gypsum board dryer used is a BSH Screen Belt dryer from Grenzebach. This dryer provides speciality drying for gypsum and other materials, having low strength when wet. The dryer has to be specially designed for this process since the number of decks and conveying widths are different for each process. The gypsum board dryer will be designed for a capacity of 6 t/h.

Transport belt[17]

Equipment	Code	Capacity	Vendor	Power	MOC	Max temperature	Pressure
Transport belt (5x)		6 t/h	SANDVIK		304 stainless steel	143 °C	1 bar

The transport belts used in this system are horizontal and from SANDVIK. These belts can handle a large range of capacities. For this process a belt of 0.5 meter wide and 5 meter length is chosen with a capacity of 6t/h.

Gypsum board storage

Equipment	Code	Capacity	Vendor	Power	MOC	Temperature	Pressure
Gypsum board storage	T-1302	400 ton			Bricks	99 °C	1 bar

The storage of gypsum boards need to be a large indoor place. It needs to be at least 400 ton, that the production of the weekend can be stored and it can be distributed after the weekend.

Capital costs[7]

The fixed capital investment is the total cost of designing, constructing, and installing a plant and the associated modifications needed to prepare the plant site. The fixed capital investment is made up of:

- The ISBL investment – the cost of the plant itself
- The modifications and improvements that must be made to the site infrastructure, known as offsite or OSBL investment.
- Engineering and construction costs
- Contingency charges

ISBL plant costs

The ISBL plant cost includes the cost of procuring and installing all the process equipment that makes up the new plant. The direct field costs include:

- All the major process equipment such as vessels, reactors, columns, furnaces etc. including field fabrication and testing if necessary
- Bulk items, such as piping, valves, wiring, instruments, insulation, paint, lube oils, solvents etc.
- Civil works such as roads, foundations, piling, buildings etc.
- Installation labor and supervision

In addition to the direct field costs there will be indirect field costs including:

- Construction costs such as construction equipment rental, temporary construction, temporary water and power etc.
- Field expenses and services such as field canteens, specialists' costs, overtime pay and adverse weather costs
- Construction insurance
- Labor benefits and burdens
- Miscellaneous overhead items such as agent's fees, legal costs, import duties, local taxes etc.

OSBL plant costs

OSBL investment includes the cost of the additions that must be mad to the site infrastructure to accommodate adding a new plant or increasing the capacity of an existing plant. OSBL investments may include:

- Electric main substations, transformers, switchgear, power lines
- Power generation plants, turbine engines, standby generators
- Boilers, steam mains, condensate lines, boiler feed water treatment plant, supply pumps
- Cooling towers, circulation pumps, cooling water mains, cooling water treatment
- Water pipes, water demineralization, waste water treatment plant, site drainage and sewers
- Air separation plants to provide site nitrogen for inert gas, nitrogen lines
- Dryers and blowers for instrument air, instrument air lines
- Pipe bridges, feed and product pipelines
- Tanker farms, loading facilities, silos, conveyors, docks, warehouses, railroads, lift trucks
- Laboratories, analytical equipment
- Offices, canteens, changing rooms, central control rooms
- Workshop and maintenance facilities
- Emergency services, firefighting equipment, fire hydrant, medical facilities et c.
- Site security, fencing, gatehouses, landscaping

OSBL costs are typically estimated as a proportion of ISBL costs in the early stages of design. For typical chemical projects, ISBL costs are usually between 20% and 50% of ISBL cost, and 40% is usually used as an initial estimate if no details of the site are known.

Engineering costs

The engineering costs include the costs of detailed design and other engineering services required to carry out the project:

- Detailed design engineering of process equipment, piping systems, control systems and offsites, plant layout, drafting, cost engineering, scale models, and civil engineering
- Procurement of main plant items and bulks
- Construction supervision and services
- Administrative charges
- Bonding
- Contractor's profit

Engineering costs are best estimated individually based on project scope, as they are not directly proportional to project size. A rule of thumb for engineering costs is 30% of ISBL plus OSBL cost for smaller projects and 10% of ISBL plus OSBL cost for larger projects.

Contingency charges

Contingency charges are extra costs added into the project budget to allow for variation from the cost estimate. All cost estimates are uncertain and the final installed cost of many items is not known until installation has been successfully completed. Apart from errors in the cost estimate, contingency costs also help cover:

- Minor changes in project scope
- Changes in prizes (e.g., prices of steel, copper, catalyst etc.)
- Currency fluctuations
- Labor disputes
- Subcontractor problems
- Other unexpected problems

A minimum of contingency charge of 10% of ISBL plus OSBL cost should be used on all projects. If the technology is uncertain then higher contingency charges are used.

Costs

To make an estimation of the ISBL cost, first the equipment cost was estimated. For the equipment estimation the following formula was used:

$$C_e = a + b \cdot S^n$$

In which

C_e = purchased equipment cost on a U.S. Gulf Coast basis, Jan.2010

a, b = cost constants

S = size parameter

n = exponent for that type of equipment

For the equipment for which it was possible to determine the costs using this formula, the prices are shown in the table on the next page. The formula used gave a price for the equipment made of carbon steel. For this process it is however preferable to use stainless steel equipment. Therefore the material factor is taken into account. It is also necessary to calculate the include the other costs which belong to the ISBL costs, for example piping, process control and electrical work. To calculate the ISBL cost for the 304 stainless steel equipment the following formula was used:

$$C = \sum_{i=1}^{i=m} C_{e,i,CS} \left[\left(1 + f_p\right) f_m + \left(f_{er} + f_{el} + f_i + f_s + f_l\right) \right]$$

In which
$C_{e,i,CS}$ = purchased equipment cos of equipment i in carbon steel
M = total number of pieces of equipment
f_m = material cost factor
f_p = installation factor for piping
f_{er} = installation factor for equipment erection
f_{el} = installation factor for electrical work
f_i = installation factor for instrumentation and process control
f_c = installation factor for civil engineering work
f_s = installation factor for structures and buildings
f_l = installation factor for lagging, insulation or paint

For this process these factors are known since it is a solid process.
$f_m = 1.3$
$f_p = 0.2$
$f_{er} = 0.6$
$f_{el} = 0.15$
$f_i = 0.2$
$f_c = 0.2$
$f_s = 0.1$
$f_l = 0.05$

Equipment	S	a	b	n	Ce ($)	C ($)
Hammer mill	5 t/h	68400	730	1	72050	206063
Drum dryer	1,13 m^2	15000	10500	0,9	26721	76422
Ball mill	5 t/h	242000	-23000	0,4	198216	566898
Hydrater	5,3 m^3	61500	32500	0,8	184897	528805
Belt 1	5 m	41000	730	1	44650	127699
Belt 2	5 m	41000	730	1	44650	127699
Belt 3	5 m	41000	730	1	44650	127699
Belt 4	5 m	41000	730	1	44650	127699
Belt 5	5 m	41000	730	1	44650	127699
Belt 6	5 m	41000	730	1	44650	127699
Pump 1	0,714 l/s	8000	240	0,9	8177	23387
Pump 2	0,714 l/s	8000	240	0,9	8177	23387
Fan 1	211 m^3/h	4450	57	0,8	8574	24521
Fan 2	3307 m^3/h	4450	57	0,8	41725	119335
Fan 3	37909 m^3/h	4450	57	0,8	266793	763027
Fan 4	19361 m^3/h	4450	57	0,8	157706	451039
Fan 5	21143 m^3/h	4450	57	0,8	168890	483026
Fan 6	22822 m^3/h	4450	57	0,8	179257	512674
Water tank	61,7 m^3	113000	3250	0,65	160377	458679
Furnace	3 MW	80000	10900	0,8	106250	303874
Total calculated					1.855.709	5.307.329

For the equipment for which it was not possible to use the formula for the purchased equipment cost, the cost is estimated. The estimated prices of these equipment are shown below. The formula for the ISBL costs is used again, but now without the material factor:

$$C = \sum_{i=1}^{i=m} C_{e,i,CS}\left[\left(1 + f_p\right) + \left(f_{er} + f_{el} + f_i + f_s + f_l\right)\right]$$

Equipment	Estimated cost ($)	ISBL cost ($)
Screen	10000	25000
Calciner	800000	2000000
Screw conveyor	150000	375000
Board dryer	1500000	3750000
Waste storage	100000	250000
Board storage	100000	250000
Total estimated	2.660.000	6.650.000

The total calculated and estimated costs together are the ISBL cost, which are $11.957.329,-. Since this ISBL cost is calculated on a U.S. Gulf Coast basis (USGC), it is necessary to include a location factor to overcome differences between infrastructure, labor cost, import duties etc. This is calculated with the following formula:

$$Cost\ of\ plant\ in\ location\ A = cost\ of\ plant\ on\ USGC\ \cdot LF_A$$

In which LF_A is the location factor for location A relative to USGC basis.

The location factor for the Netherlands is 1.19, but is based on 2003 data. It is updated by dividing by the ratio of U.S. dollar/local currency in 2003 and multiplying by the ratio U.S. dollar/local currency in the year of interest. Since the exchange rate in 2003 averaged about €1 = $1.15 and the current exchange rate is €1 = $1.105, the location factor for the Netherlands in 2015 is 1.143. Multiplying this to the ISBL cost gives a corrected ISBL cost of $13.667.227,-.

To calculate the total capital cost, the OSBL plant costs, engineering costs and contingency charges have to be determined. For these costs a percentage of the ISBL is taken:

Part of fixed costs	Percentage of ISBL	Cost ($)
OSBL cost	40%	4782932
engineering cost	20%	2391466
contingency charges	10%	1195733

Adding the ISBL costs, OSBL costs, engineering costs and the contingency charges will give $22.037.357,- of fixed capital investment.

The working capital is 15% of the fixed capital investment, which is $3.305.604,-. Adding this to the fixed capital investment results in the total investment required of $25.342.961,-.

Appendix 1: Literature

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Appendix 2: Substances and specifications

The substances used are gypsum (s), stucco(s), water(l), natural gas(g) and air(g). The most relevant properties of gypsum and stucco are shown below, as well as the health risks.

Gypsum[18]

Product name	Calcium sulfate dihydrate
Formula	$CaSO_4 \cdot 2H_2O$
CAS-number	10101-41-4
Molecular weight	172.17 g/mol
Intrinsic density	2320 kg/m^3
Melting point	127-162°C it loses its water
Boiling point	-

Health and safety[19]

The feed consists of 95 wt% gypsum waste plates, and 5wt% plates made in the factory which did not met the product specifications. The gypsum plates are not expected to produce any unusual hazards during normal use. It does not present an inhalation, ingestion or contact health hazard. But when the gypsum plates are crushed, airborne particles are generated, as well as high dust levels, which may irritate the skin, eyes, nose, throat, or upper respiratory tract.

Stucco[20]

Product name	Calcium sulfate hemihydrate
Formula	$CaSO_4 \cdot 1/2H_2O$
CAS-number	10034-76-1
Molecular weight	145.15 g/mol
Intrinsic density	2960 kg/m^3
Melting point	-
Boiling point	-

Health and safety

Stucco is made in the factory by calcinating the gypsum. This is a very fine powder. It is slightly hazardous in case of skin contact, of eye contact, of ingestion and of inhalation. The substance may be toxic to the upper respiratory tract. Repeated or prolonged exposure to the substance can produce target organs damage.

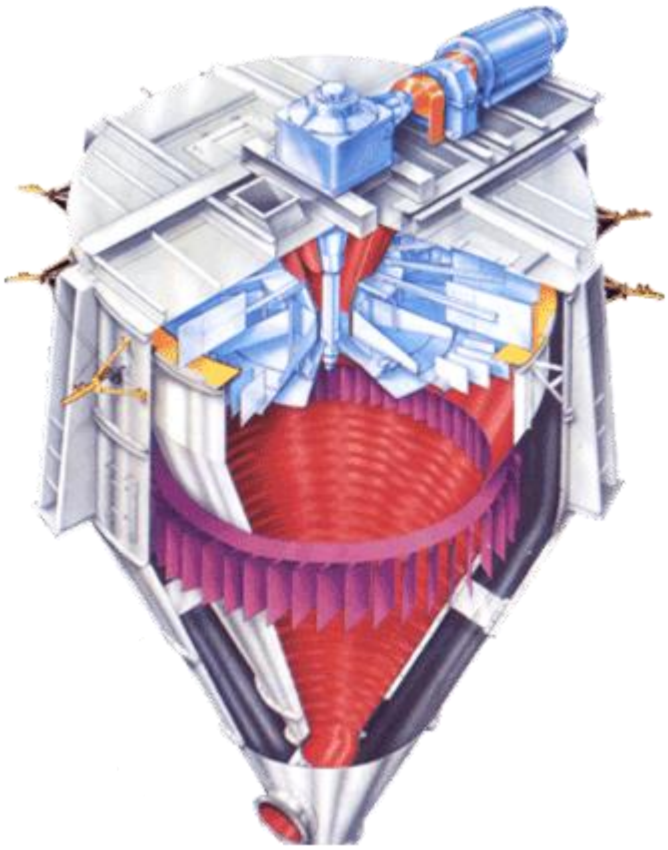
Natural gas[21]

Natural gas is burned to generate hot air for the utility system.

It is chosen to use natural gas from the gas field in Groningen. This consist of approximately 81.3 vol% methane and 3.5 vol% longer-chained hydrocarbons, such as ethane, propane etc. It also contains approximately 15.2 vol% incombustible gases, primarily nitrogen and a little carbon dioxide. Natural gas from other reserves generally contains other percentages of methane, a higher percentage of hydrocarbons and less nitrogen.

Appendix 3: Pre-aspen assignment: Classifier

Aspen manual: classifier
Substance: gypsum ($CaSO_4 \cdot 2H_2O$)



Dina Boer
S2206897
22-06-2015

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The classifier

Classifying is the process where material is separated based on a combination of size, shape and density. The product enters the feed inlet by gravity and the particles fall onto the distributor plate[1]. A centrifugal force directs the particles into the classification zone. The larger particles fall off the distributor plat into the coarse cone, so they can leave at the coarse outlet. An internal fan conveys smaller particles upward. Selector blades separate large particles from the airflow in such a way that it is not possible for the large particles to move upward due to the air flow. The finer particles fall eventually into the fines cone, so they can leave at the fines outlet. This piece of equipment is able to separate fine particles as small as 2.5 µm[2]. The possibility to classify products with a particle size range of less than 100 µm is the main advantage above a screening machine, since it is not possible to classify that fine particles with a screener.

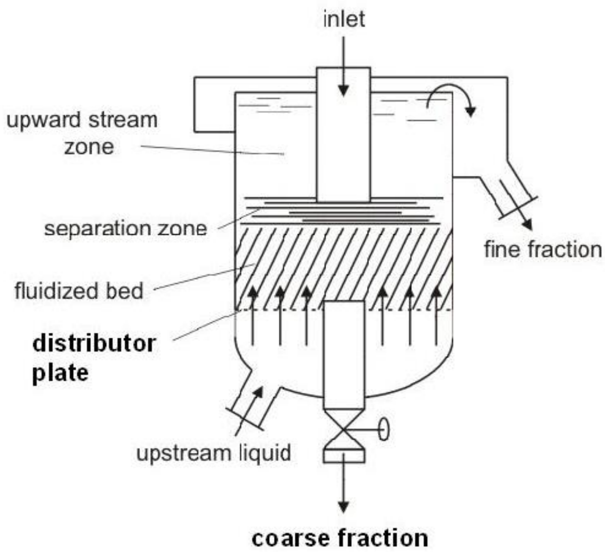

Figure 11: Schematic overview of classifier

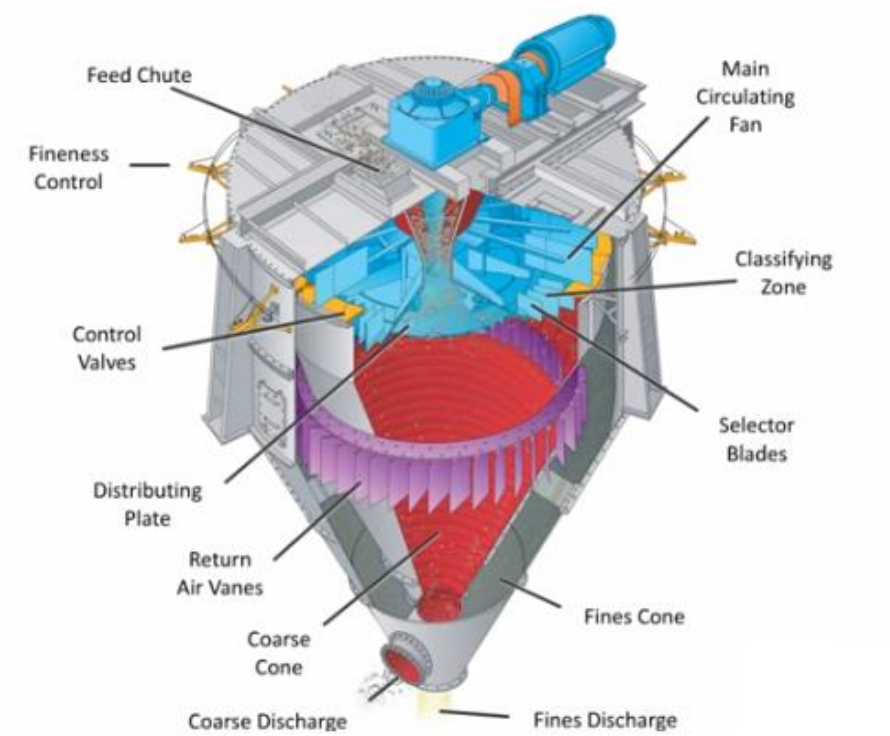

Figure 12: Cross section of classifier

Separation and selection functions

Ideal separation

In ideal separation, a cut point can be defined which marks the border between the fines and coarse product. Below this value, the particles are flowing upwards with the air, these are the fines. Above the value the particles will fall down in the coarse cone, these are the coarse particles. A mass density plotted against particle size can be seen in figure 3. In figure 4, a selection function (also known as 'grade efficiency curve' or 'separation curve') shows a sharp separation between coarse and fine particles. An ideal separation would not occur in practice because in practice the particle size distributions of the products do overlap.

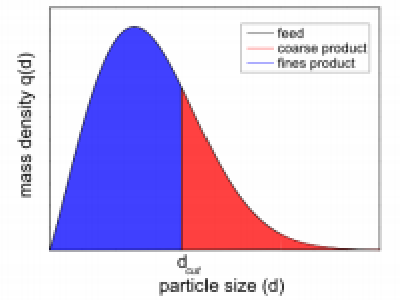

Figure 3: Mass density vs particle size, ideal separation

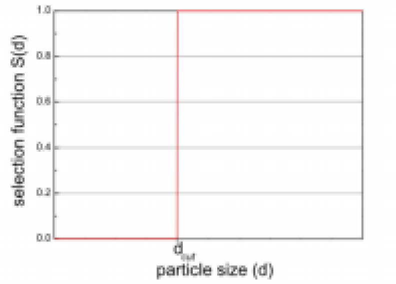

Figure 413: Selection function, ideal separation

Real separation

In contrast with ideal separation, real separation is achievable. Here it is taken into account that some of the feed material can be found as misplaced material in the wrong product. Particles which are smaller than the cut size and are nonetheless part of the coarse product (misplaced material of coarse fraction) or which are larger than the cut size and appear in the fines product (misplaced material of fines fraction). In the corresponding selection function, a s-shaped function around the d_{cut} can be seen, where the shape is quite similar to the selection function of ideal separation.

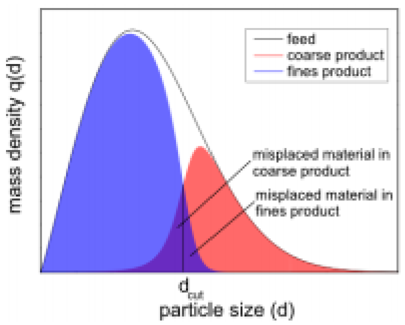

Figure 514: Mass density vs particle size, real separation

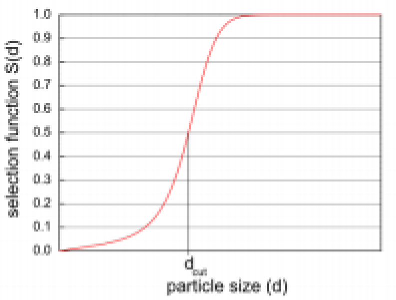

Figure 6: Selection funcction, real separation

Fines product / coarse product

The fines product is the fraction of the feed which can flow upwards due to the air. The coarse product is the fraction which does not flow upwards with the air flow but falls down into the coarse cone. A plot of the mass density against the particle size is shown in figure 7 for fines and in figure 8 for coarse. In these plots it can be clearly seen that there are some fines in the coarse product and some coarse particles in the fines product, as the plots cross the $d_{cut.}$

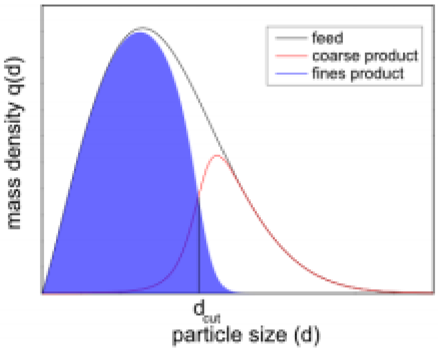

Figure 15: Fines product

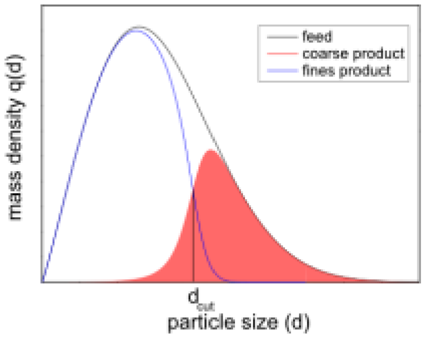

Figure 16: Coarse product

Misplaced material and median cut point

Misplaced material is the fraction which appears on the wrong side of the classifier. A separation which contains misplaced material is called a real separation. Furthermore, in real separation 50% of the particles of size equal to the median cut point exit the process in the coarse product stream, the other 50% exit in the fines product stream. Note: this is different than the d_{50} of the inlet particle size distribution. This d_{50} corresponds to a value of 0.5 of the selection function, which will be explained in the next chapter. The cut size d_{cut} is the characteristic size which forms the desired upper limit of particle size in the fines and desired lower limit of particle size in the coarse product. For many models based on selection functions, the cut size equals the median cut point if there is no offset of fines.

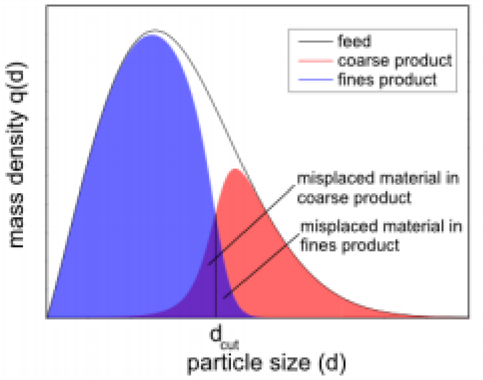

Figure 17: Misplaced material in products

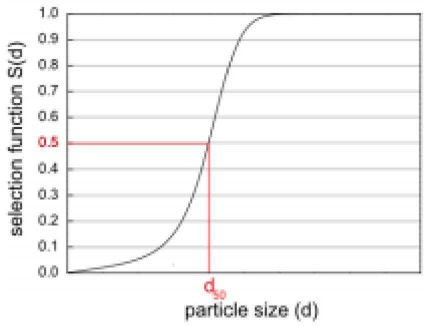

Figure 18: Median cut point

Selection function

The selection function Si of a screen is defined as the mass fraction of material within the size I in the feed ($m_{i,inlet}$) that leaves the classifier in the coarse stream ($m_{i,coarse}$):

$$S_i = \frac{M_{i,coarse}}{M_{i,inlet}}$$

Which can be calculated as:

$$M_{i,coarse} = S_i \cdot M_{i,inlet}$$
$$M_{i,fines} = (1 - S_i) \cdot M_{i,inlet}$$

The selection function can also be expressed in terms of the coarse fraction c and the mass density distribution of the inlet and the coarse streams as:

$S(d) = \frac{c \cdot q_c(d)}{q_{in}(d)}$ With $c = \frac{M_{coarse}}{M_{inlet}}$

The graphical representation of the selection function shows the fraction separated with the coarse stream for all particle size classes in figure 11. Based on its definition, the selection function has the following attributes:

- Below of du the value of S(d) is 0, which means that none of this material can be found in coarse product.
- Above of d0 the value of S(d) is 1, which means that all of this material can be found in the coarse product.
- At d50 the value of S(d) is 0.5

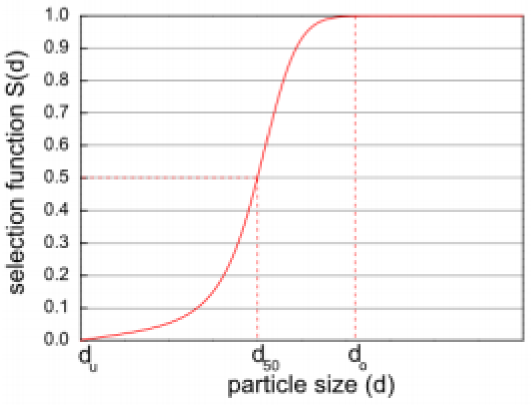

Figure 19: Selection function

Separation sharpness

Separation sharpness describes how close a real separation is from an ideal separation where the quality of the classification can be quantified by the steepness of the selection function curve. The higher the steepness of the selection curve, the higher the sharpness of the separation. A typical characteristic value is the degree of separation by Eder:

$$x = \frac{d_{25}}{d_{75}}$$

Where d_{25} and d_{75} are the particle sizes for which the selection function S(d) = 0.25 and 0.75 respectively (but these values are different than the d_{25} and d_{75} of the inlet particle size distribution).

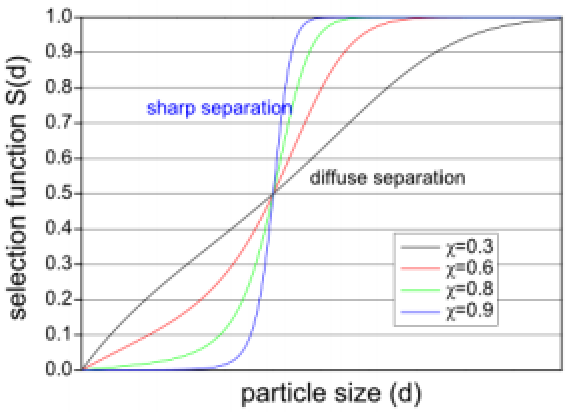

Figure 20: Separation sharpness

Aspen Manual

Click on File, new. To build the model in Aspen it is necessary to choose one of the installed templates. Since classifying is a process with only solids, the template solids with metric units is chosen. After selecting the template, the following screen will open up. Before drawing the simulation it is necessary to specify the components which are used in the process. Therefore we click on Components-Specifications. The tabs Start Page and Exchange can be closed because they are not needed.

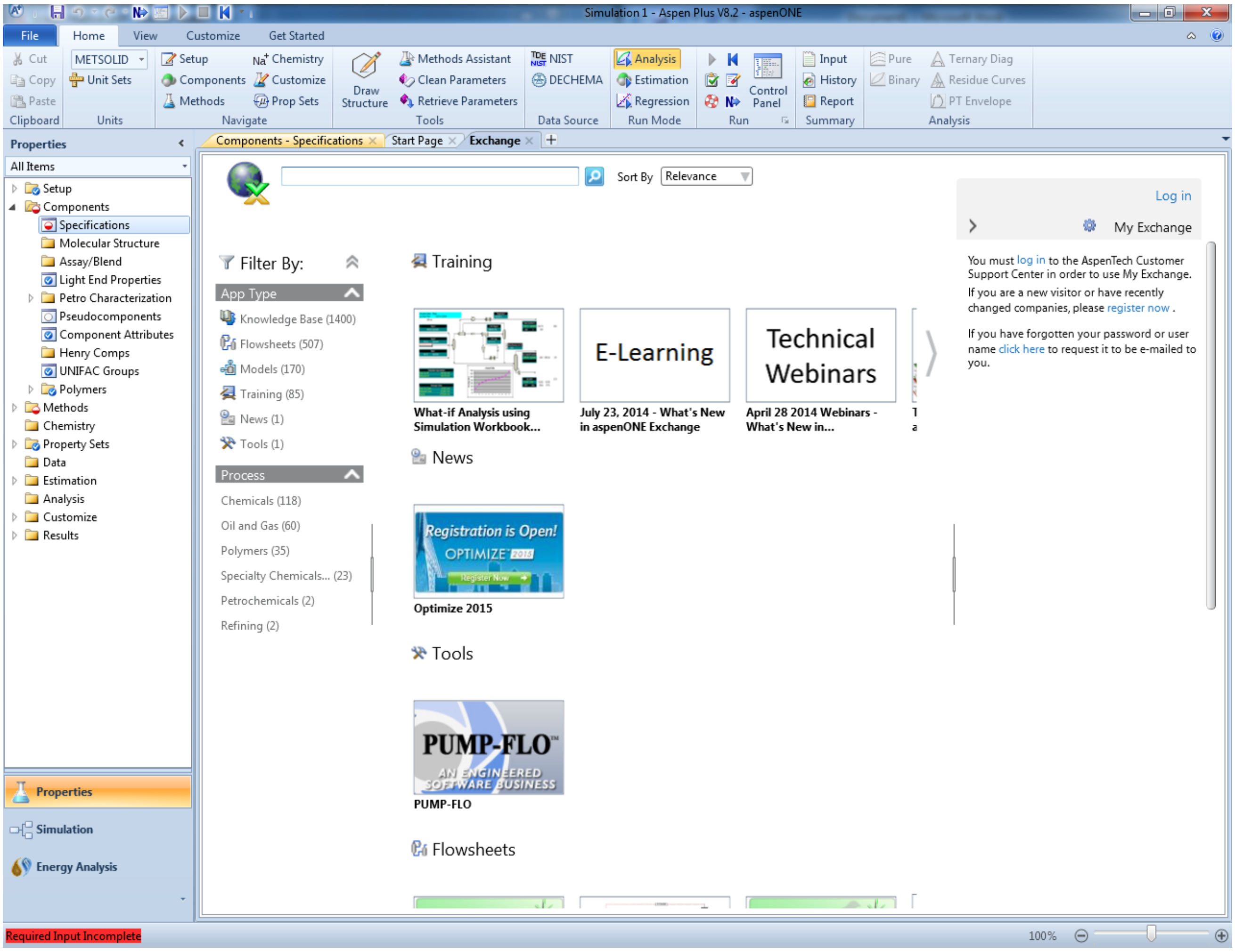

Figure 21: Aspen startup screen

In the Components-Specifications tab the components used for the design are specified. For this design only gypsum has to be added. Select for gypsum the type to be solid.

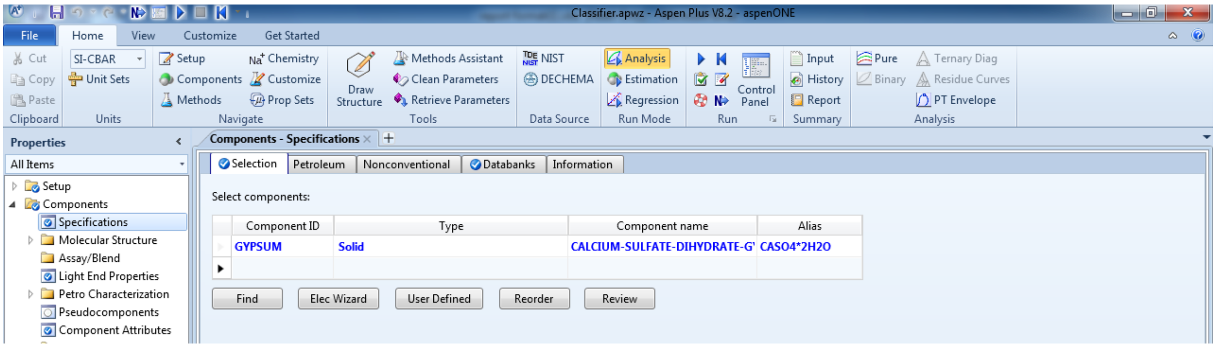

Figure 22: Components specification

Click on next input. Automatically the screen Methods-Specifications will open. Select for Method filter: ALL and for Base method: SOLIDS. Aspen will automatically fill in for Method name: SOLIDS.

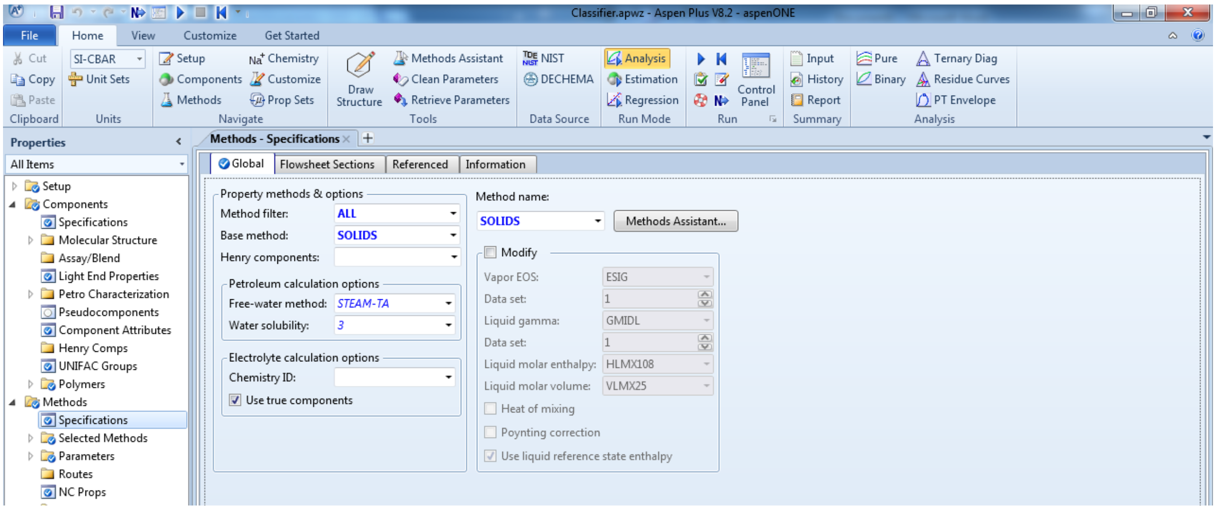

Figure 23: Methods specifications

Click on next input and run the simulation. Aspen will give an error, but this is due to a mistake in Aspen so click ok. The results are shown in the Control Panel. Now go to simulation in the bottom left corner.

Now the model flow sheet is open and it is time to build the set-up. Select ‘Solids’ and ‘Classifier’ by the Model Palette (bottom of the screen). The Classifier is called B1, change the name to ‘CLASSIFI’. Add an input stream called ‘GY-1’ (referring to gypsum) and two output streams called ‘GY-COURS’ and ‘GY-FINES’ (referring to respectively gypsum coarse particles and gypsum fine particles). If correctly carried out, you will have the following screen:

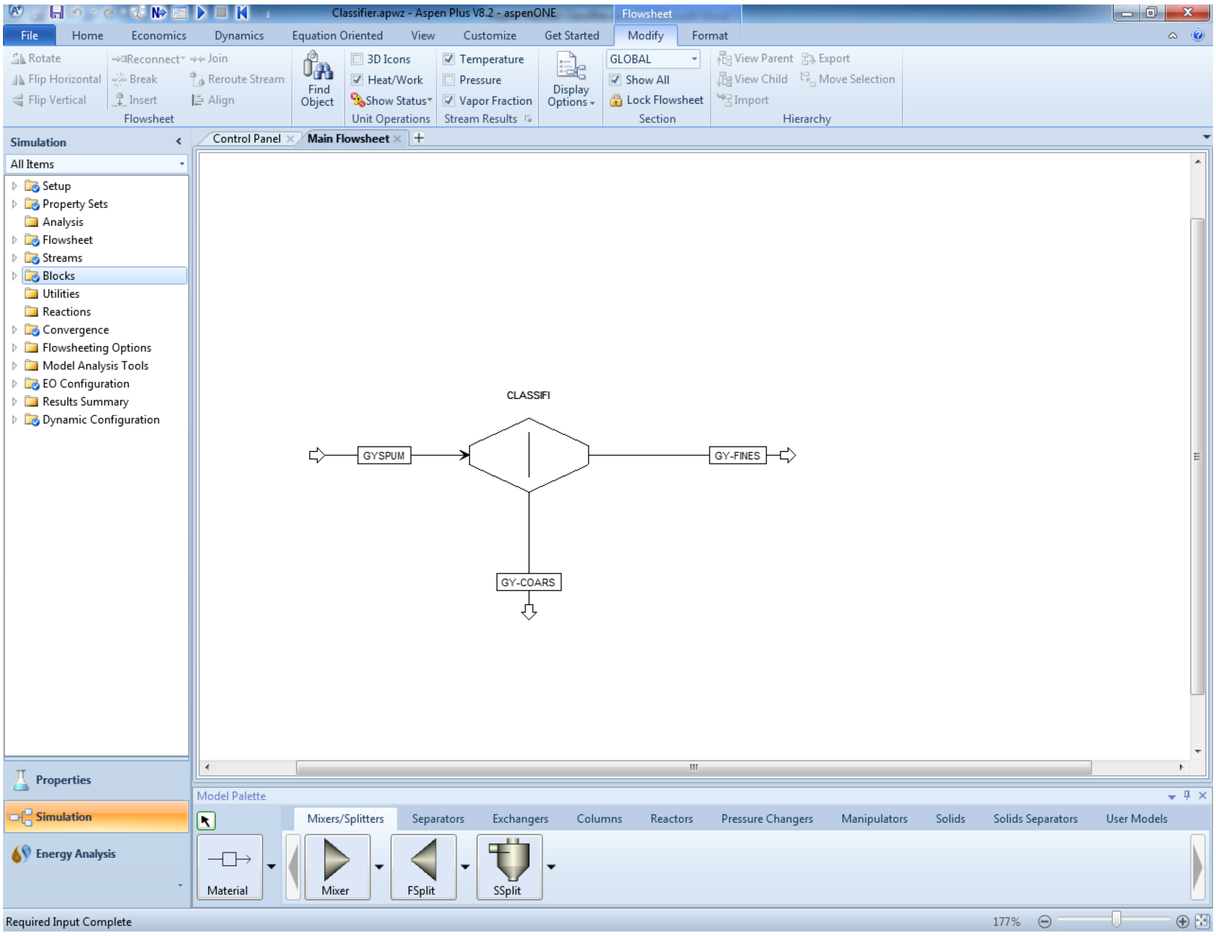

Figure 24: Simulation drawing

Now the specification of the classifier needs to be added. Click on ‘Setup’ and ‘Specifications’ in the upper left corner. Add for the title ‘Classifier’. Set the Global unit set to SI-CBAR and set the operational year to 1 year.

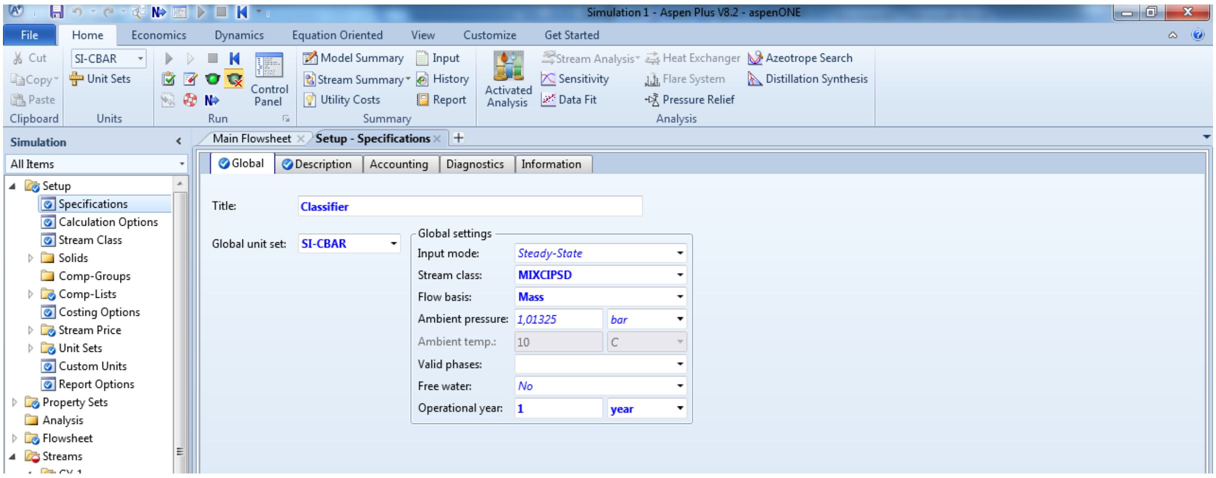

Figure 25: Setup specifications

Click on next input and Aspen will automatically open the tab GY-1(MATERIAL)-Input. This means it is time to fill in the specifications for the input stream.

GY-1 is a solid stream with only solid gypsum present. Therefore the Mixed sheet is not defined. The CI Solid sheet needs to be defined, so click on the CI Solid tab. The solid particles are specified with sub stream name CIPSD. The temperature is set to 10°C, the pressure is 1 bar and the total flow rate is 1000 kg/hr. At the composition selection the mass fraction needs to be selected where GYPSUM = 1.

Important: the output streams GY-COARSE and GY-FINES are defined by aspen after the simulation, so no values needs to be added for them.

Do not click on next input yet but open the Particle Size Distribution part, underneath the specifications part.

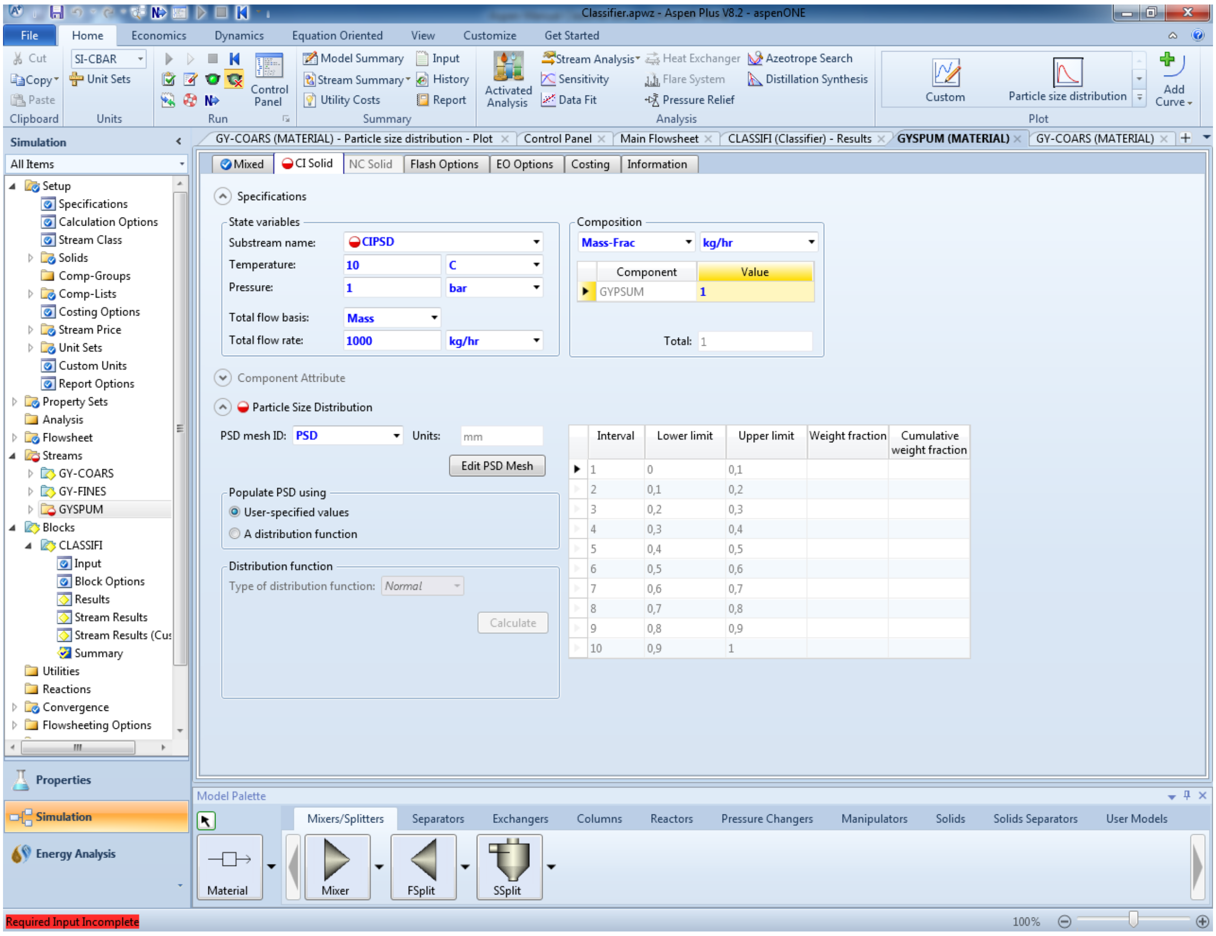

Figure 26: CI Solid

The following step is adding the particle size distribution for the GY-1 stream. It is assumed that the particles are fine grinded and that the particle size of gypsum particles is between 1 and 100 µm.

Click on Edit PSD Mesh, a new screen will pop up. Change the size units to mu (this means µm). Set for the number of intervals 30. This number can be varied, more intervals means a better PSD, less intervals will not give a smooth line. Because the particle size deviates between 1 and 100 µm, make sure that the first interval starts with 1 and the last interval ends with (approximately) 100. When it is not exactly 100 Aspen will normalize it automatically. It is most easy to make the PSD first in excel and then copy and paste it into Aspen.

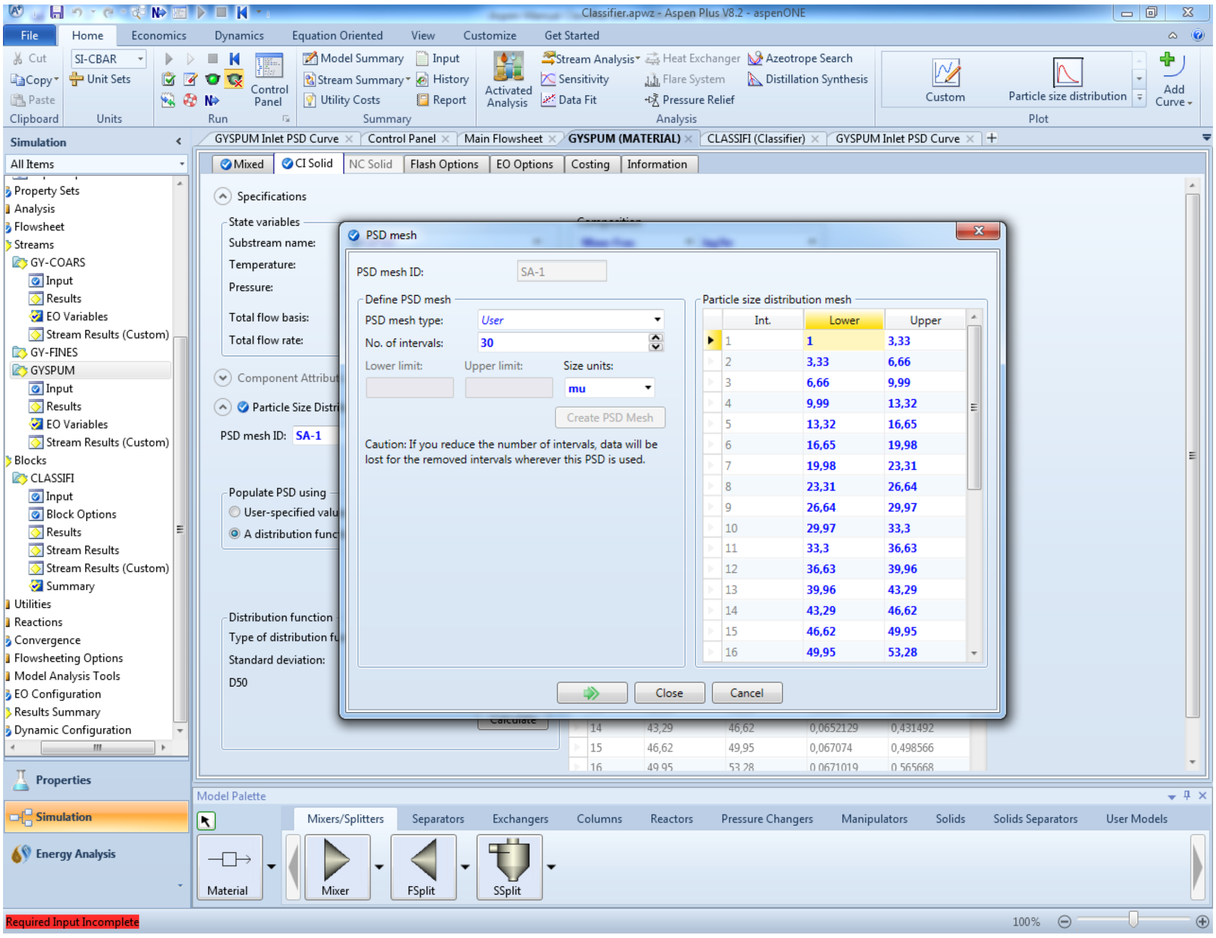

Figure 27: PSD mesh

Click on the green arrow at the bottom of the pop up. It is a lot of work to add the weight fractions by hand, so let Aspen do it. Click on: Populate PSD using A distribution function. Add a D50 of 50 µm and a standard deviation of 20 µm and click on calculate. Aspen will ask if you want to normalize the cumulative weight fraction to 1. Click on yes.

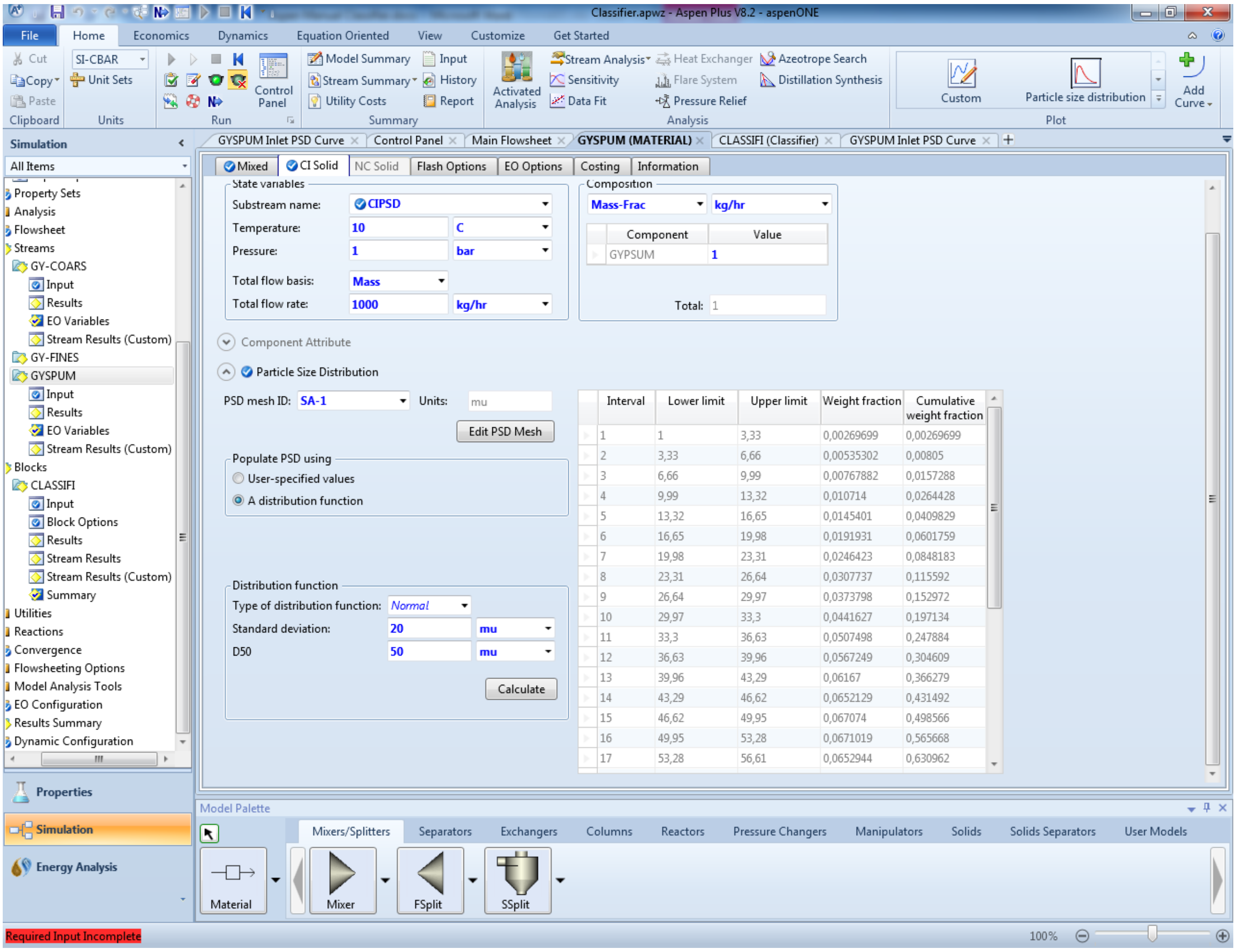

Figure 28: PSD weight fractions

After clicking on yes, Aspen will show the PSD curve for the inlet stream.

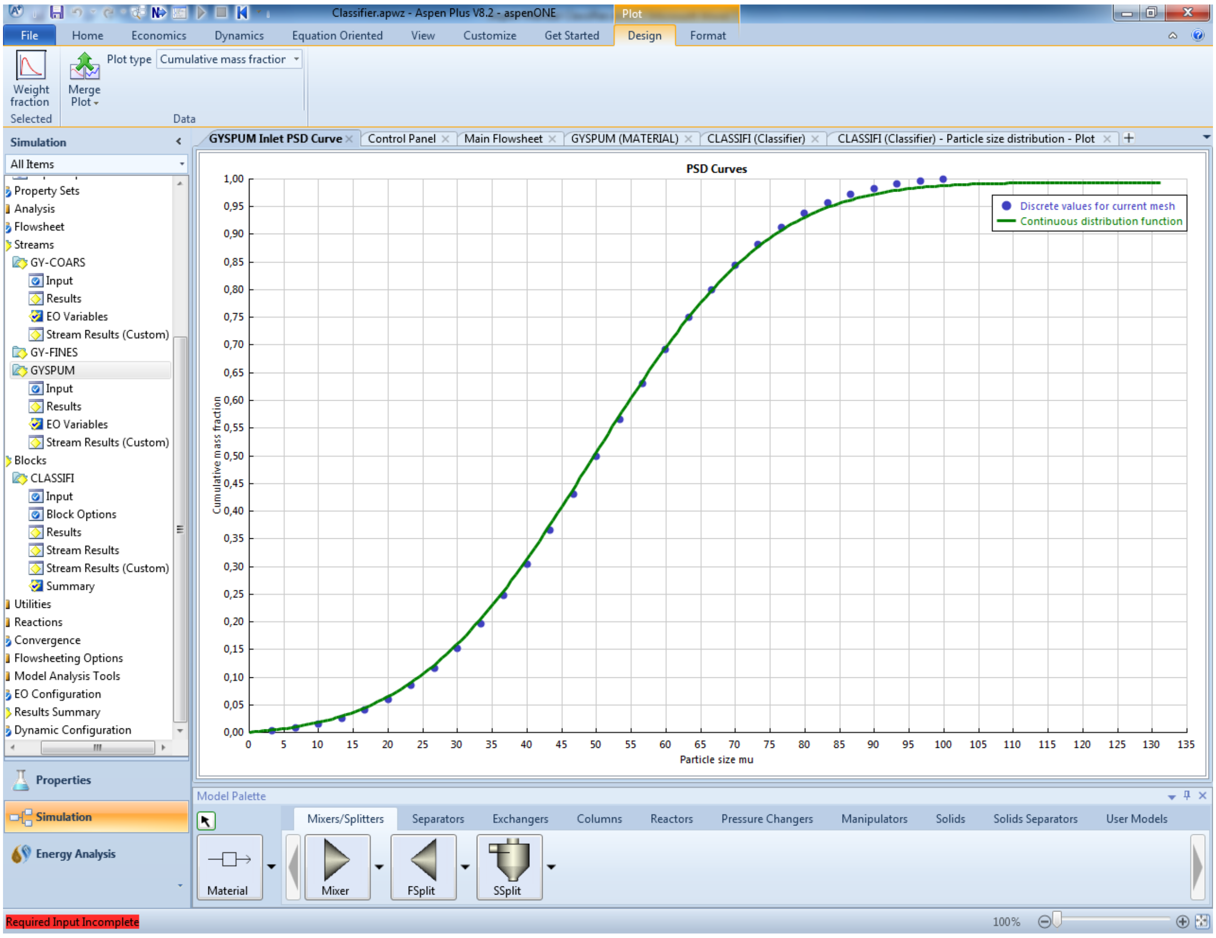

Figure 21: PSD curve

Click on next input, Aspen will automatically open the CLASSIFI(Classifier)-Input tab. The specifications need to be added. Select for Method: Use a classification function. Choose as the classification function ROGERS.

Choose as the classification characteristic: particle size. For the classification model parameters add for the cut size 50 µm and for the separation sharpness 0.7.

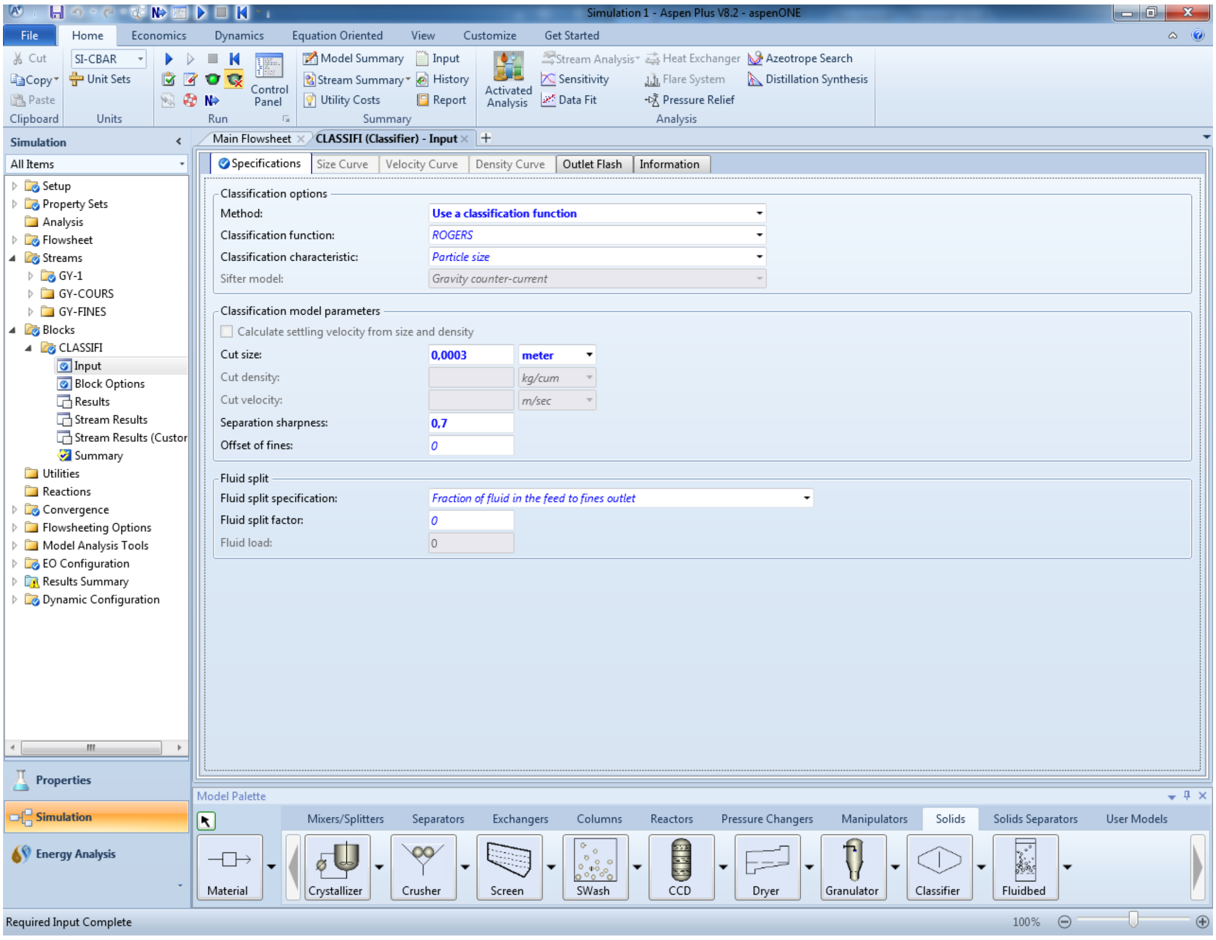

Figure 29: Specification classifyer

Click on next input and run the simulation. An error will occur but this is again the mistake of Aspen, so just click on ok. The results will show in the control panel and if it is done correctly the control panel will show no errors. Go to the Main Flowsheet tab to see some results of the simulation.

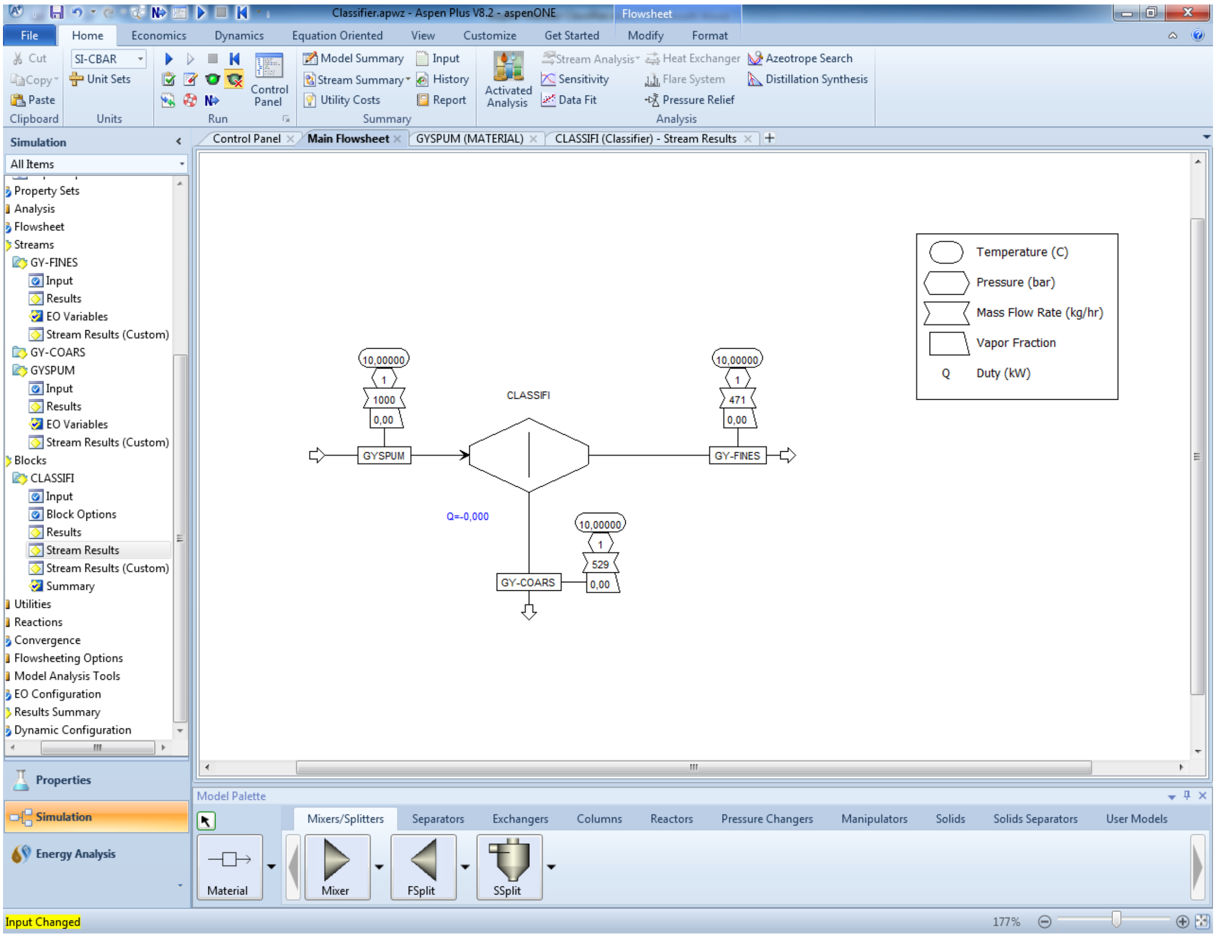

Figure 30: Stream results

To check the efficiency go to 'Blocks' and 'CLASSIFI' and then 'Results'. The overall separation efficiency is given as 0.53.

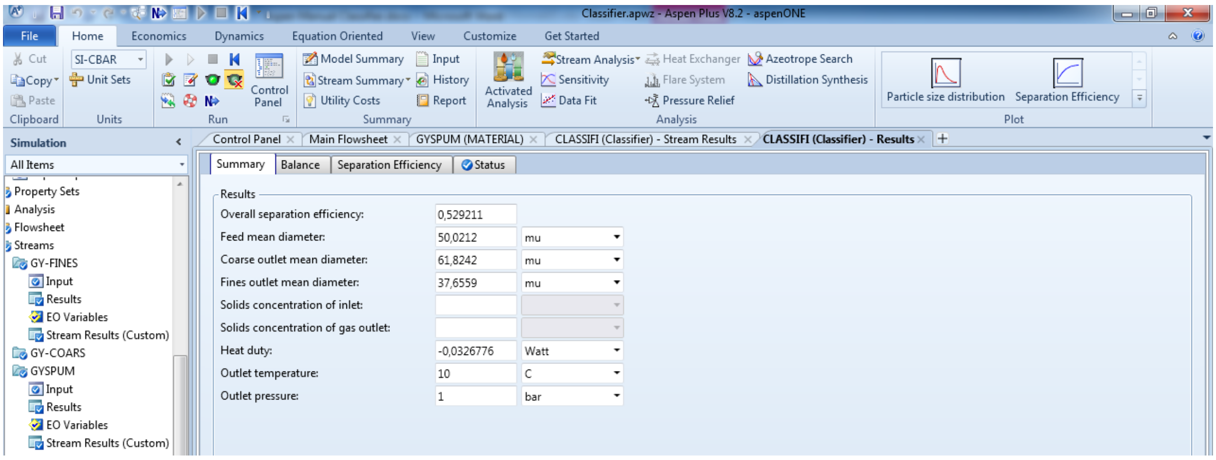

Figure 31: Efficiency

Click on the particle size distribution in the right upper corner to see the PSD curve of the gypsum feed, the fines and the coarse.

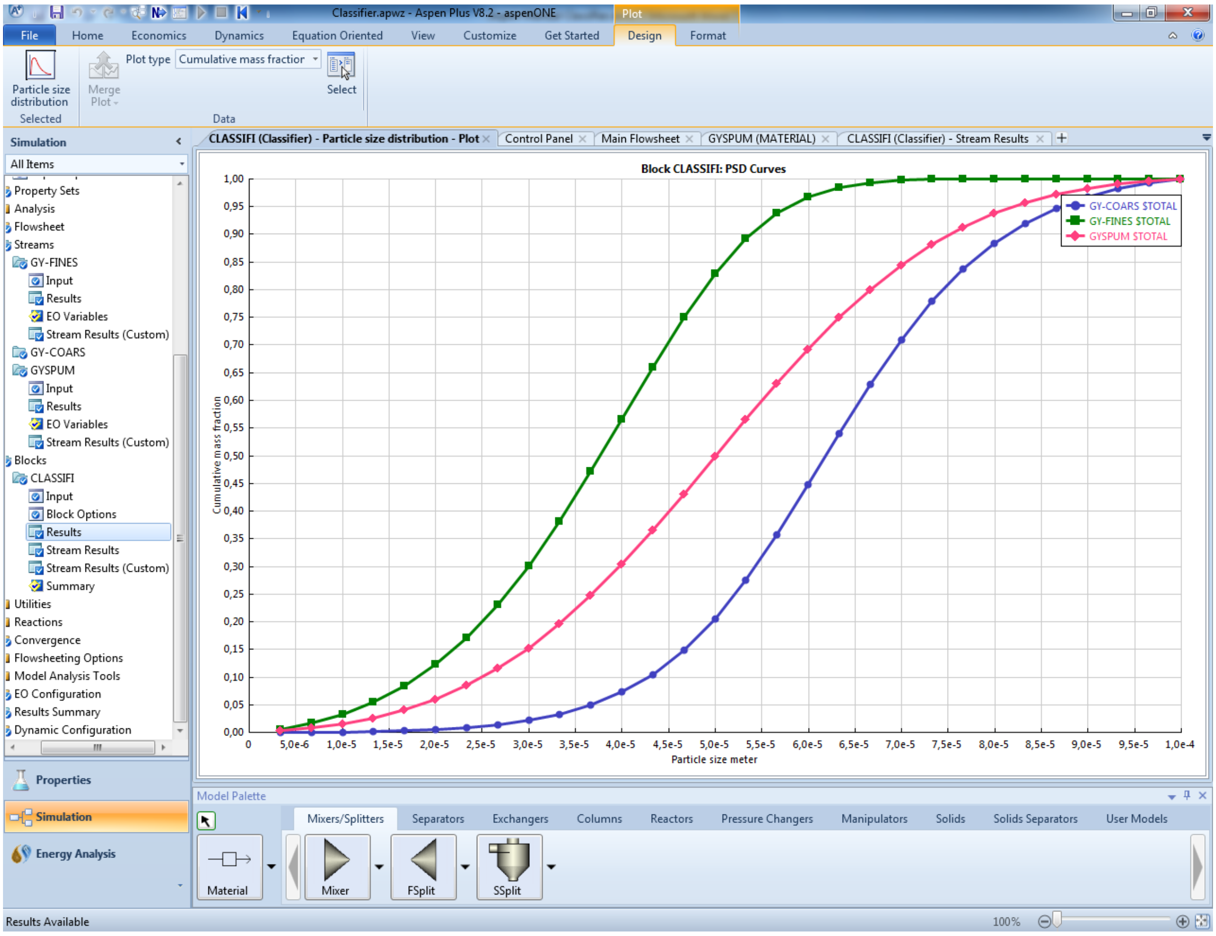

Figure 32: PSD total, fines, coarse

Literature

1) http://www.sturtevantinc.com/products/product/whirlwind-air-classifier/

2) http://www.netzsch-grinding.com/en/products-solutions/classifying/inlinestar-inline-classifier.html#!tabs/technique

3) Plus, Aspen. Help Function. [Aspen Tech] s.l. : Aspen Tech, 2013