GERMAN - MONGOLIAN INSTITUTE
FOR RESOURCES AND TECHNOLOGY

The present work was submitted to the Faculty of Engineering

THE DESIGN OF THE REPRESENTATIVE SAMPLE TAKER MACHINE IN THE EXISTING GRINDING PLANT AT TECHNICAL UNIVERSITY OF BERGAKADEMIE FREIBERG (TUBAF)

Bachelor Thesis

By

Munkhjargal Sumiya

Supervisor 1 / Examiner 1 **Prof. Sungchil Lee**

Supervisor 2 / Examiner 2 **M.Sc. Oliver Schindler**

Ulaanbatar/Nalaikh, 05/16/2022

Statutory Declaration

Sumiya, Munkhjargal	15011475201083
Last Name, First Name	Student ID Number

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Abstract

The main goal of any mineral-related process is to extract the precious minerals from the ore cost-effectively and efficiently since these processes consume intense amounts of energy. Especially, milling circuits use a lot of energy than any other processes, so they are expensive to run. Thus, it is critical to optimize their operation to make them economically viable. These improvements can only be achieved by adopting new control strategies in existing milling plants. Same as other milling plants, the milling plant of “Institute for processing machines and recycling system technology” grind various ores and sieve them to perform certain tests. To have reliable test results, it is important to have correct and representative samples from the running circuit. But, the sampling method, which is used in the milling plant of TUBAF, is considered the wrong sampling method. As a result, it is hard to say that the samples can represent the whole running stream in the milling process. These ideas prompted the designing of the representative sample-taking machine from the running stream to have a reliable sample and control the process in the existing milling plant of TUBAF.

There are four different sampling points, which must be examined carefully to create the design of sampling machines. Because all the machines are already installed in the milling plants, it is impossible to move any machines and create the desired space for the sampling machines. Thus, each of the sampling machines has its different characteristics to fit into the milling plant’s different points. In addition, in the design process, Pierre Gy’s formulas and practical recommendations are used to create sampling machines’ ideas that the samples have an equal probability of being selected. Based on the advantages and disadvantages of these ideas, the perfect ideas that can be implemented in the milling plant are chosen and constructed in SolidWorks, a computer-aided designing program.

Acknowledgment

I would like to express my deepest gratitude to my supervisors, Mc. S. Oliver Schindler and Prof. Sungchil Lee for priceless guidelines, advice, and support. Their feedback pushed me forward and sharpened my thinking. Without my supervisors, it would be impossible to finish this thesis work on time.

I wish to express my thanks to Dr. Ing. Thomas Zinke and Dipl. Ing. Peter Eitz who gave me supports to find M. Sc. Oliver Schindler and my thesis topic.

I am extremely grateful to Dr. Pierre Maurice Gy, who studied the theory of the sampling of materials for more than 50 years and shared his knowledge without any hesitations with the world. His works helped me a lot to create the sampling machines' designs.

In addition, I am very grateful to all the members of "German-Mongolian Institute for Resource and Technology" and "The Technische Universität Bergakademie Freiberg". I hope that this thesis can be the result of their consistent hard work.

Finally, I would like to express my deepest graduate to my family and friends for unconditional supports and encouragements during my academic life.

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Abbreviation

TUBAF - Freiberg University of Mining and Technology

VRM – Vertical roller mill

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1. Introduction

Mining and mineral processing cost millions of dollars to operate and produce commercial end products. The success of this investment is dependent on the results of a few small sample tests. In other words, decisions involving millions of dollars are made based on a small proportion of the ore body's mass which is known as a sample. The correct sampling and sample preparation are crucial not only for the proper identification of ore resources but as well for the evaluation and control of following mineral-related processing operations to have high-quality end products (2). As a result, it is critical that this small portion of ore body or samples must be collected as correctly as possible.

1.1. Sampling in Mining and Mineral processing

Sampling is the extraction of a small amount of material from the ore body or running stream to analyze the different types of properties of mineral or ore in mineral-related processes. These small numbers of samples can be taken from a variety of places. For instance, in the mining industry, blast holes, feed and product streams, conveyor belts, trucks, railway wagons, and stockpiles are just a few of the places where samples are taken for grade control (3). Mining companies rely on this sampling process for resource optimization and profit maximization.

Not only for the mining sites but also in other places, especially for the mineral processing plants, proper sampling is one of the essential processes in order to obtain useful information on the input and output materials. Because the primary goal of a mineral processing plant is to produce highly valuable minerals using as low energy as possible and do not lose these valuable minerals, especially for the grinding circuits, optimizing the machines and devices in mining and mineral processing plants is to be economically, ecologically, and socially sustainable in the long run. One of the best-known ways to advance the comminution process is to use proper control based on the result of the sampling (1). In that way, not only the cost but also the quality of the products (minerals) can be improved significantly. From this point of view, sampling is extremely vital for mining and processing plants.

1.2. Current grinding laboratory of TUBAF

The grinding plant of "The Institute for processing machines and recycling system technology" does certain laboratory tests to determine the influence of different parameters for dry and wet grinding. The main unit of the grinding plant is the new type of laboratory Vertical Roller Mill (VRM). The VRM is equipped with a rotating table, which is driven by an electric motor, and three grinding rollers, which roll freely on the table. On the rotating table, rollers are at the fixed point. And using the hydraulic actuators, the fixed positions are changed to control the grinding ratio of VRM. If the space between rollers and the rotating table becomes narrower, the product becomes finer and vice versa.

In this existing grinding circuit (Figure 1), the fresh material is transported into the VRM by a belt conveyor. Then the minerals are ground between the rotating table and grinding rollers. Depending on the purpose and mineral properties, wet and dry grinding can be done in the laboratory. After the grinding process, the product directly falls into the tribble deck screening machine. The screening machine separates the ground product into fine and coarse materials. The fine minerals (undersized particles) go directly into the bottom container for further applications. The coarse particles (oversized particles) cannot be used in the future, due to the size of the particle. Thus, it is transported back into the VRM using the pressurized flow system and conveyor belt to be ground once more.

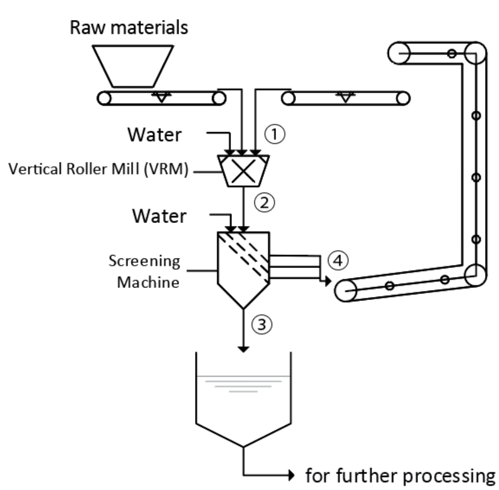


Figure 1. The flowsheet of the grinding and screening circuit of the grinding plant at TUBAF.

Current problem

The sampling process does not get the proper attention that it should deserve. Even though mining companies, laboratories, and Institutes spend a lot of resources and time to improve the sampling methods and devices, there are many cases where wrong sampling methods are silently used in the modern world (4). Like most milling plants, the grinding plant of TUBAF uses the manual sampling method to take representative samples from the running stream during the operation time. The collected samples are used to produce important information about the test. However the problem is that this manual method is the wrong sampling method (5) and these samples cannot represent the whole running stream, even though they are taken from the running circuits during the operation.

1.3. The suggestion of improvement of the grinding laboratory

One of the best ways to improve the grinding laboratory is to install apparatus which can collect a sample from a running circuit. Currently, there are four important points that the samples should be taken, or sampling machines must be installed. In Figure 1, these four different points are shown by numbers from 1 to 4. The first two points are related to the VRM, and the rest of the two points are related to the Screening machine.

1. Feeding point of the VRM: Right above the VRM, this point locates (point, where raw material is entering into the VRM)
2. Discharging point of the VRM: This point locates between the VRM and the screening machine (a point, where milled material is leaving VRM and entering the screening machine)
3. Undersized point of the Screening Machine: During the screening process, the screening machine divides the particles into two different places based on the size of particles. This point locates under the screening machine, where the fine particles go down into the container
4. Oversized point of the Screening Machine: It is a point where the coarse particles are transported back to the VRM using pipes and conveyor belts.

The first two points are extremely important to take representative sampling during the operation time. Based on the result of sampling the parameters of the milling circuit can be adjusted. But for the screening, there are not many parameters to be changed during the operation.

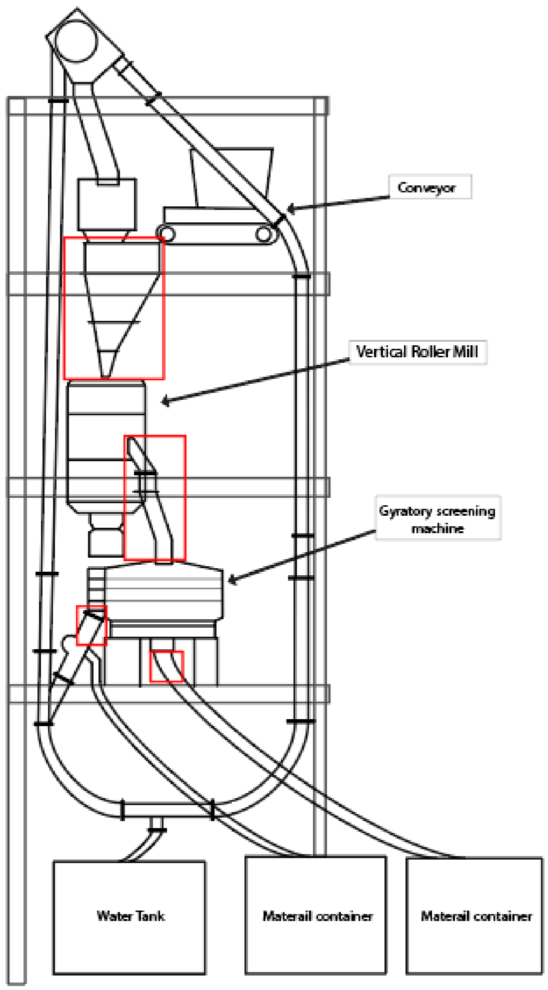
Sampling Point	1.	2.	3.	4.
Position	Right above the mill	Between Mill and screening machine	After the Screening machine (Coarse material)	After the screening machine (Fine material)
Particle Size in mm	0…8	0…8	0…8	0…0,3
Throughput in t/h	Up to 5	Up to 5	Up to 5	Up to 1
Bulk Moisture in %	Up to 20	Up to 50	Up to 20	Up to 95

Table 1. The basic information for each sampling point

The maximum diameter of the particles in this grinding circuit is 8mm. The maximum mass flow rate is up to 5 tph. The moisture content of the mineral is up to 95 percent, depending on the location.

1.4. Limitations

All machines, equipment, and other necessary devices of the grinding plant are already installed into the steel structure. Currently, it is impossible to change the location of the VRM and sieves to create desirable space, since there is not enough space left. As shown in Figure 2, there is very narrow and limited space that the additional sampling machines fit in. In Figure 2, the red boxes illustrate the space that machines have to fit. Thus, there are very few feasible points to construct the sampling machines. These points require very complicated designs of the sampling machines. The overall free spaces of the milling plants are shown in Table 2. For instance, point three requires sampling machines that have around 64 degrees inclination from the floor, and the length, height, and width should be less than 2000, 770mm, and 1000mm, respectively. Also, for the second point, there are two possible design free spaces in table 2. Because the sampling point crosses the T-Beam of the steel structure of the milling plant and this beam cannot be changed to install the sampling machine. Thus, there are two possible places for the second point. Therefore, the major restriction of designing the sampling machine is free space to install into the plant. In addition, there are other limitations, such as time to design the sampling machines and the budget to build these designs into the existing milling plant. Thus, during the designing process, these limitations are primarily considered to create a feasible sampling machine for each



point.

Figure 2. The overall sketch of the milling plant

	Length (mm)	Height (mm)	Width (mm)
Point 1	465	680	620
Point 2	1000	654	150
	1500	493	1000
Point 3	2000	770	1000
Point 3	270	700	1000

Table 2. The overall free space of the milling plant at each point

2. Literature Review

Extracting ores from the Earth's surface and treating these ores to separate valuable minerals from gangue materials are the most energy-consuming processes in the world. Especially, during the ore treating or mineral process, the comminution, including both crushing and grinding, consumes about 50% of the energy used in the ore recovery process, which consists of cutting, blasting, loading, hauling, hoist, crushing, grinding, and transportation (6). In addition, only grinding processes use approximately up to 4% of world electricity consumption (6). In 2019, the overall net electricity consumption worldwide was 21872 TWh (7). And Germany used 538 TWh of electricity in 2019, totally (8). In order words, the comminution process in mining consumes approximately two times more electrical energy than Germany used in 2019.

2.1 Mineral Processing

Mineral processing is the big process following mining to produce highly valuable metals or nonmetals from the mined ores or “run-of-mine”. Mining produces a big chunk of ores that contains both useful minerals and useless gangue materials. Then, these valuable minerals must be separated from the waste rocks or gangue materials to produce commercial end products, such as highly concentrated gold and copper for electronic devices. Mostly, these releases of the valuable minerals from the ore and separation from the gangue take place in mineral processing. Fundamentally, there are five main processes: Comminuting (increasing surface), agglomerating / Briquetting (Reducing surface), blending / Homogenizing (Mixing/kneading/stirring), Separating, and washing / Lautering (separation of organic, fines disperse, and other undesired substances) (9).

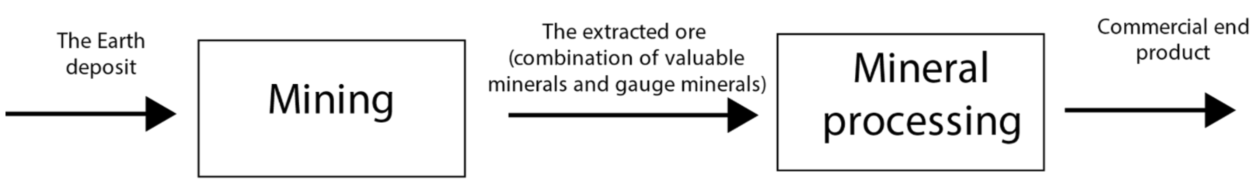


Figure 3. Illustration of process from mineral to commercial end product

Comminuting Process

Comminuting is very often the first process that run-of-mine must go through in mineral processing plants. The main purpose of this process is to liberate the valuable minerals from the gangue materials because of that all the waste and useful minerals are in the ore, together (Figure 5). It mainly uses crushing to reduce the size of the ore and, if necessary, the grinding can be used depending on the purpose. In this process, depending on the properties of the input and the output materials, the different types of crushers and mills can be used, as shown in Figure 4. Such as Jaw crushers, gyratory crushers, cone crushers, impact crushers, vertical roller mills, and other types of crushers and mills. To generate clean concentrates with minimum contamination from gangue minerals, the ore must be finely ground to release the associated metals (2). However, fine grinding leads to higher energy consumption and very small fine particles, which cannot be treated correctly. Thus, controlling the comminution machines is the key in mineral processing. Usually, controls are done based on collected samples.

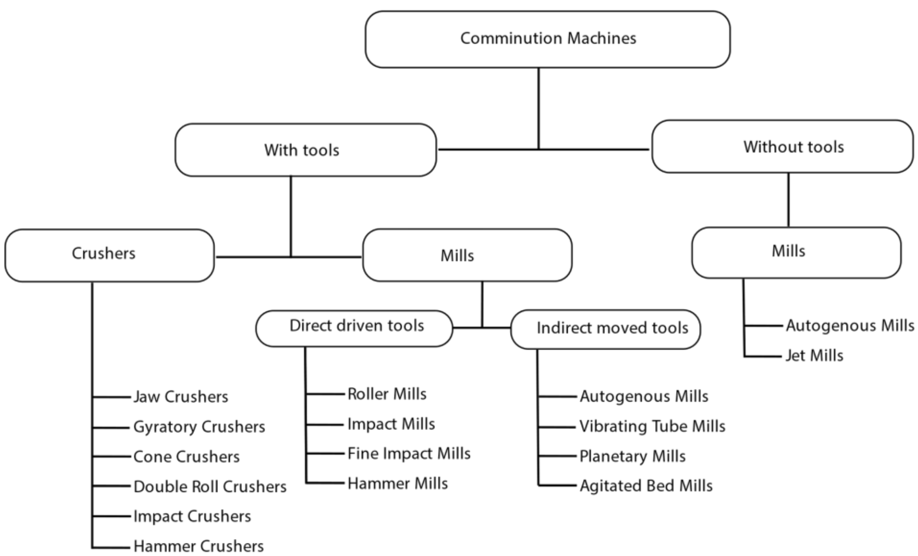


Figure 4. Main comminution machine types

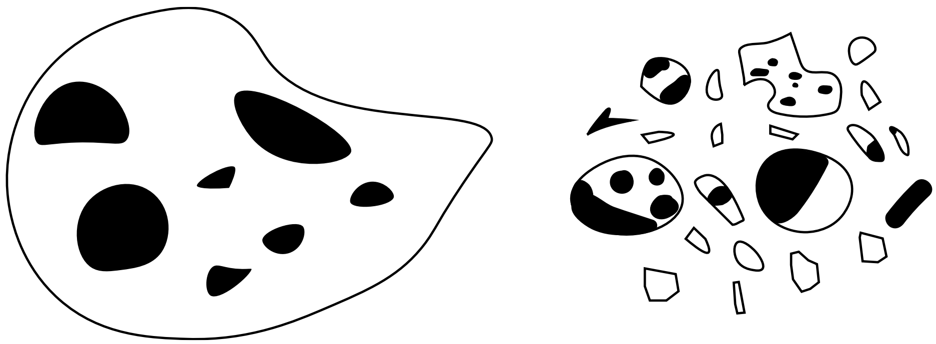


Figure 5. The principle sketch of ore before (a) and after (b) the comminution process

Separation process

The second big process of mineral processing is the separating process. Separation is the process to classify the particles according to the geometric dimension or sedimentation velocity in viscous media (depending on the particle shape, shape, density, magnetic ability, etc.). The most used separating machine depending on the particle geometry is screening machines for coarse, middle-sized particles and sometimes fine screening. Usually, for the fine and finest screening process, classifiers in fluid streams are used (e.g., sifters, air cyclones, and hydroceles).

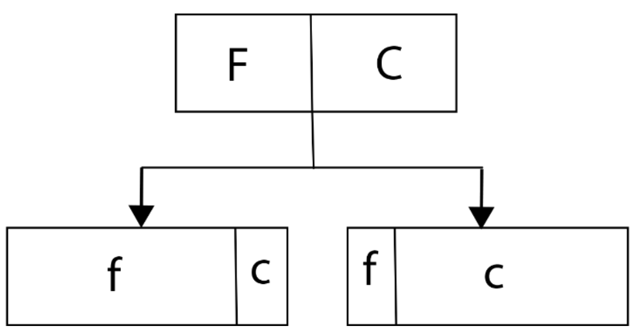


Figure 6. The illustration of the real separation process

Ideally, the screening machines must perfectly separate the particles into fine and coarse particles according to the geometry because of those only smaller particles than the opening of the screening can pass the screening deck. But, in real-life situations, there are a few percent coarse particles in the fine fraction and fine particles in the coarse fraction (Figure 4). Thus, the screening quality can be assessed by the shear of coarse particles in the fine fraction or of fine materials in the coarse fraction (9).

$$\eta = m - n \tag{2.1}$$

Where: η = Separation efficiency

m = shares of fine particles contained in the fines fraction

n = shares of course particles contained in the fines fraction

$$\eta = \frac{m_F \times f_F}{m_A \times f_A} - \frac{m_F \times g_F}{m_A \times g_A} \tag{2.2}$$

Where: m_F = mass of fine material

m_A = mass of feed material

f_F = fraction of fine material in the fine material

f_A = fraction of fine material in the feed material

g_F = fraction of coarse material in the fine material

g_A = fraction of coarse material in the feed material

$$\eta = \frac{(f_A - f_G) \times (f_F - f_A)}{f_A \times (1 - f_A) \times (f_F - f_G)} \tag{2.3}$$

Where: f_G = fraction of fine material in the coarse material

Three main factors influence the degree of screening quality: feed material property, feed process, and screen deck/ or screening deck/ screenings movement (9). The following parameters mainly affect to feed material's properties:

1. Particle size: The passage of the fine material through the sieve opening is a statistical process. It can be explained by the probability of passage through the sieve opening depending on the size ratio of the opening of the sieve (d) and the actual partition size (d_T).

   d << d_T High probability

d ≈ d_T Low probability

d >> d_T The probability of being passed is almost zero (9)

2. Particle size distribution. If there is a high percentage of near-size particles in the materials, the probability of pegging occurring is higher than normal. Thus, the particle size distribution must be distributed widely.

3. Particle shape. It is also another big factor that influences the efficiency of the screening machine. Normally, the spherical or cubical particle shapes are considered convenient types of shapes to use in the screening process. If the shape is irregular (e.g., needle or rectangular shapes), the oversized particles can easily pass the opening of the sieve. In that case, the efficiency decreases significantly.

4. Humidity. Another big factor impacting the degree of screening quality is humidity. If the humidity of the particle is much higher than the acceptable level, the efficiency can decline notably

2.2 Sampling

Sampling is one of the sub-processes that are needed to evaluate the main processes, such as comminution and separation process. Based on the sampling, all the decisions are made (e.g., changing parameters of crushers, mills and sieving machines) Mining companies, mineral processing plants, mineral-related laboratories and universities and other places are making a considerable effort for the sampling processes during operation time. Even so, there are still many cases that are breaking the fundamental sampling laws (10). For instance, the samples are taken by a manual sample cutter. During the removal of an appropriate amount of material from the flowing stream, the cutter must cover the entire cross-section of the stream. But, because of the inappropriate design of the cutter or manual operation, the whole stream section is not able to be covered. It covers only a part of the stream. As a result, the collected sample can be skewed in collecting. Due to this skewness, the test result changes. Thus, the sampling process must be improved and should get the proper attention.

According to Matthias Stiess, the following three fundamental rules must be always considered during the sampling process:

1. If possible, take samples from the flowing material stream
2. Take samples over the entire cross-section of the material stream
3. Many, small samples are better than big ones (11)

A minimum amount of mass required for the sampling process

According to Pierre Gy, the relationship between the dimension of the largest particle to the minimum amount of required mass is given as below (12):

$$\frac{ML}{L-M} = \frac{Cd^3}{s^2} \tag{2.4}$$

Where, M is the minimum weight of sample required, L is the gross weight of material to be sampled, C is the sampling constant for the material to be sampled, and d is the maximum diameter of the particle, s variance of allowable sampling error in an assay. Most of the time, M is tiny in comparison to L. Thus, the minimum mass of the sample required can be calculated as below:

$$M = \frac{Cd^3}{s^2} \tag{2.5}$$

The sampling constant (C) is directly related to the material characteristics and can be defined as:

$$C = P_S P_D P_L m \tag{2.6}$$

Where, P_S = particle shape factor (usually taken as 0.5, excerpts for gold ores, where it is 0.2)

P_D = particle distribution factor

P_L = Liberation factor

m = mineralogical factor

The mineralogical factor can be expressed by:

$$m = \frac{1-\propto}{\propto}[(1-\propto)\rho_M + \propto \rho_G] \qquad 2.7$$

Where, $\propto$ = fractional average mineral content

ρ_M = the specific gravity of the mineral

ρ_G = the specific gravity of the gangue material

Sampling points from a flowing stream

There are a lot of possibilities for the points where the sample can be taken, such as the beginning, midpoint, or discharge point of the running circuits. For example, only for the belt conveyor, there are commercially used sampling machines that use the midpoint (e.g., hammer sampler) and discharge point of the belt conveyor. However, according to Ralph J Holmes, the best point for taking samples from a running circuit is at the discharge point (10). Even the midpoints of operations can be used for sampling, the uncertain random error can occur and affect the result of the sampling. For example, the hammer cutter uses the midpoint of the running belt conveyor. Due to uncertainty (e.g., low maintenance), the conveyor belt's speed can be changed over time. In that case, the sample cutter cannot take the same amount of sample. These different amounts of samples change the probability of being samples of the running materials.

The shape of a stream

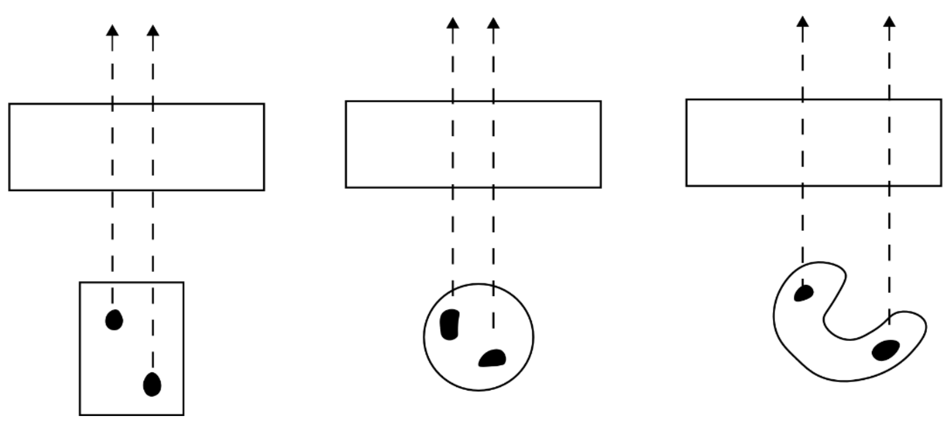


Figure 7. Different types of streams with correct sample cutter

The shape of the stream is a huge concern in designing the sampler. However, if the following statements are assumed, the shape of the stream is irrelevant (5).

- Stream is moving at a constant speed
- The cutter is moving across the stream at a constant speed
- The entire stream is passing well inside the cutter opening

Figure 7 shows that the shape of the stream cannot affect the sampling process only if the sampler is appropriate.

Effects of physical properties of materials on the sampler’s efficiency

The physical properties of minerals are another big concern. Depending on the type of mineral, the efficiency of the sampler might be changed. But P.W Cleary and G.W Robinson have researched how the physical properties affect the Vezin type sampler. They created a simulation that used the discrete element method and changed the properties of minerals. In the end, they reported that the effect of physical properties on the samplers is slightly but negligible (13). Thus, physical properties are considered a minor problem for the samplers.

Sample generation/taking process from the flowing stream

The sampling process is based on probability theory. Thus, the sampling is considered as correct when the probability of being selected is equal. In sample preparation from a flowing stream, to satisfy the equal probability, the following Gy’s sub-rules must be followed:

1. Sampler should cut a slice of material of constant thickness
2. This slice should be representative of the entire stream (5)

The sampler cutter should cross the stream completely to fulfil the second sub-rule. Otherwise, the sample cannot be considered representative. In addition, due to human errors, it is almost impossible to take the sample, which has the same probability of being selected, from a running stream. That is why the sampling machines are recommended to have better results.

Pierre M. Gy categorized the sample taking the process from a flowing stream into three different ways due to time and the cross-section, as below:

1. Taking the part of the stream **part of the time**
2. Taking the part of the stream **all the time**
3. Taking the **whole stream part of the time** (5)

1. Taking the part of the stream part of the time.

It is the easiest and most used operation in the mineral processing plant and laboratories. Figure 8 shows the sampling process that the taking part of the stream over part of the time. The black dots represent the samples that are taken. The main example of this type of sampling is the manual sampling method. The main reason why it is used commonly is that any structure, components, and sampling machine are not needed. Thus, this method is the cheapest and fastest way to take samples from the running stream than the other two methods. However, this method cannot meet Gy's second sub-rule. Therefore, this type of sampling method should be avoided.

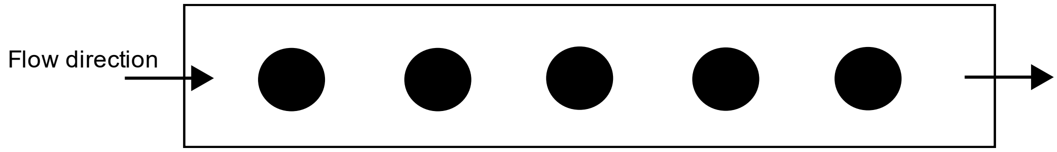


Figure 8. Taking the sample part of the stream part of the time

2. Taking part of the stream all the time.

This kind of sampling method is considered a node sampling method. Because it usually uses one point or one certain area of the entire stream constantly, as shown in Figure 9. Theoretically, this kind of operation works very well only for homogeneous streams. But only the liquid stream can be considered homogeneous. Solid streams are considered heterogeneous. Hence, because heterogeneous materials are used in mineral processing, this kind of method also cannot be used to generate highly reliable results.

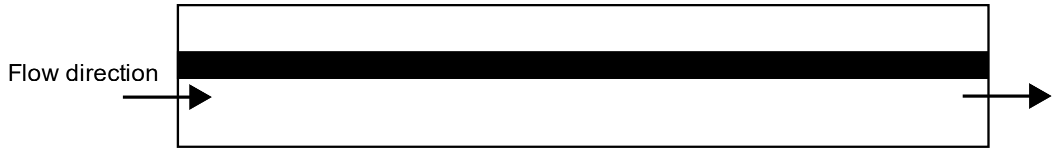


Figure 9. Taking the sample from the running stream using the part of the stream all the time

3. Taking the whole stream part of the time, also known as a cross-stream sampler.

This method is the best way to take samples from the running stream. The reason is that it satisfies all rules. The cross-stream sampler takes the sample in constant time by crossing the stream completely, as shown in Figure 10. In this type of sampler, speed is the most crucial thing to consider because to satisfy the rule (probability of being selected is equal) the same amount of speed should be used. Creating the constant speed all the time by manual way is almost impossible. Not only the manual way but also the magnetic, and hydraulic ways are also difficult to reach. Thus, Dr. Gy suggested using the electric drive-in order to create a reliable constant speed (Pitard, 1993).

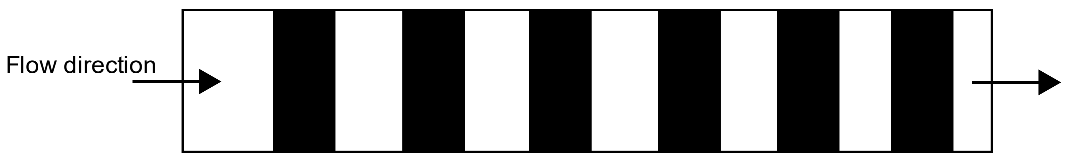


Figure 10. Taking the sample from the running stream using the whole stream part of the time

The distance between the falling stream and the sample cutter

The distance between the sample cutter and the falling stream should be decided carefully to produce reliable samples (Figure 10). If the distance is too long, the particles can hit the cutter's wall and bounce back from the sampler cutter. Thus, the distance should be at least three times longer than the maximum diameter of the materials (Equation 8).

$$U = 3D \qquad 2.8$$

Where, U = the distance between the falling stream and sample cutter

D = the maximum diameter of the particles

In fine particles, this formula cannot be used any further. Instead, the distance must be greater than 10 mm (Equation 9)

$$U \geq 10\ mm \qquad 2.9$$

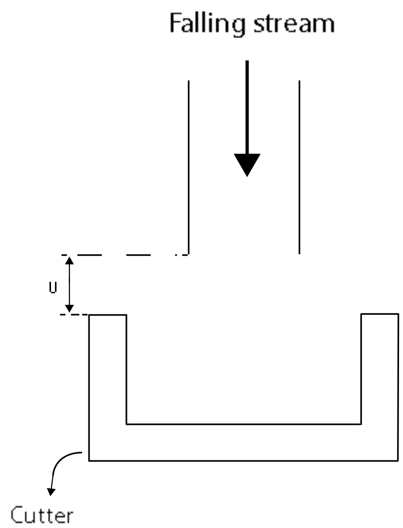


Figure 11. The distance between falling stream and cutter

If the distance U is much higher than it requires, the dust can enter the sample cutter while the sampler is not working. Thus, maintaining distance is another big concern.

3. Design of Sampling Machines for TUBAF's laboratory

There are four points that sampling particles must be taken to measure and control the grinding circuit perfectly. The first two points are located above and below the VRM to measure the mill. The rest of the points are at the undersize and oversize of the screening machine. Due to the fact that all the equipment and machines (e.g., VRM, conveyor belt, and screening machine) are already assembled and installed into the steel structure of the milling laboratory, all these points have their specific characteristics due to the limitations. Thus, different types of machines should be designed to fit and install in the milling laboratory. Some feasible design ideas are shown in Table 3. For instance, there are four different design ideas for changing the hopper at point 1. For point 2, seven different types of design ideas are created. In the following subchapters, these design ideas are to be examined for the selection of the best one.

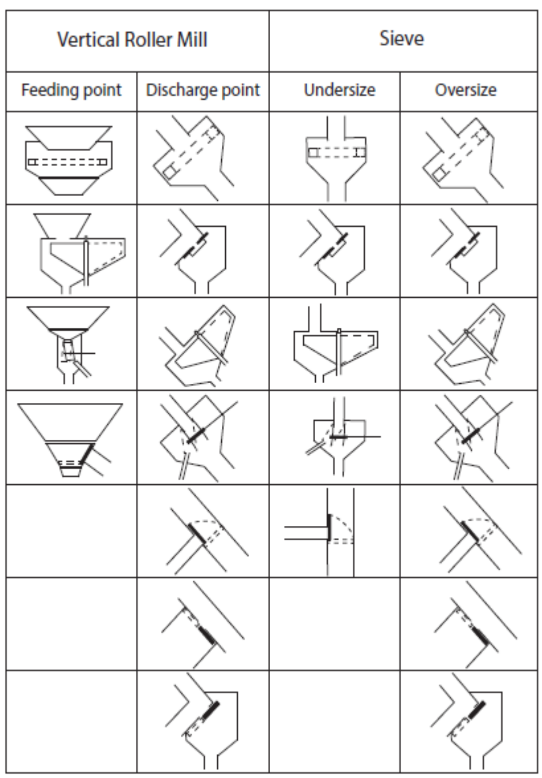


Table 3. Most possible design ideas for each point.

3.1 Sampler design concepts

3.1.1 Design ideas for point 1

At this point, fresh or raw materials are entering into the milling circuit. These materials must be collected to know what minerals are entering the grinding circuit. The fresh materials directly feed into the conveyor belt which is located right above the Vertical Roller Mill (VRM). The conveyor belt transports the minerals into the VRM. In addition, the opening space of the top of the mill is much smaller than the conveyor belt's discharge. Thus, in order to transport the material effectively without losing, the feed chute is used between the conveyor belt and the VRM.

According to Ralph J Holmes, a conveyor belt cannot be used as a sampling point due to the following reasons:

- Rather than being cut, the selected portion of the material flow is pushed towards the sample cutter.
- The coarsest or finest minerals are generally not collected in representative proportions
- If the motor, which is used in the conveyor belts, is not powerful enough, it affects the speed of the mineral and causes a different amount of samples in the end.
- If the motor is too powerful than it requires, the materials hit the cutter's wall and bounce back to the conveyor belt instead going into the sampling chamber. (3)

Thus, the feed chute is used in this thesis as a sampling point 1 instead of the conveyor belt.

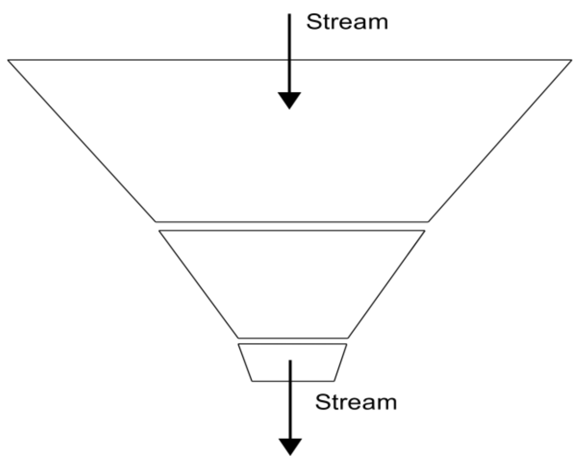


Figure 12.Simplified illustration of feed chute which locates between the conveyor belt and VRM

The feed chute has a cubic shape but is narrowed from top to bottom. The opening length of the feed chute is approximately 600 mm. At the bottom of the chute, the closing diameter is decreased to 15 mm and the height is around 120 mm. For this point, there are four different design ideas for the sampling machines. All of these four ideas are explained in the following subsections.

Design Idea 1.1: Straight path Cross-Stream cutter.

The feed chute consists of three individual parts, as illustrated in Figure 13. In this design idea, the middle part of the feed chute is replaced by a Cross-Stream cutter. This type of design is the simplest but most effective design. The rectangular-shaped cutter crosses the stream completely from right to left or left to right as in Figure 14. During this crossing time, the cutter collects the same amount of particles all the time. The collected particles are directly transported to the sample container by gravity for further tests.

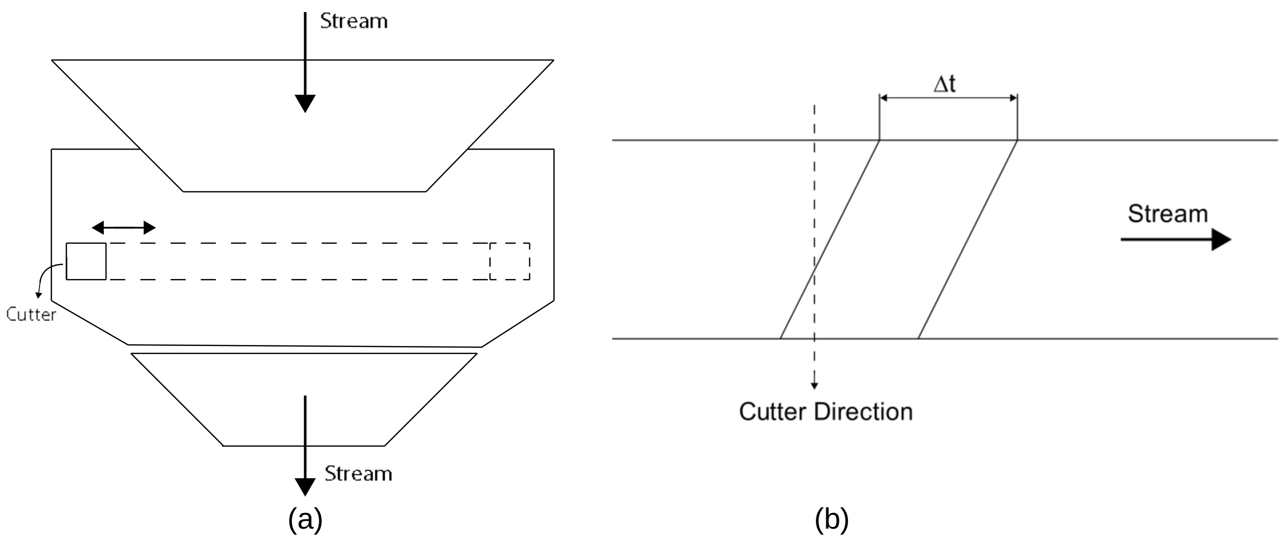


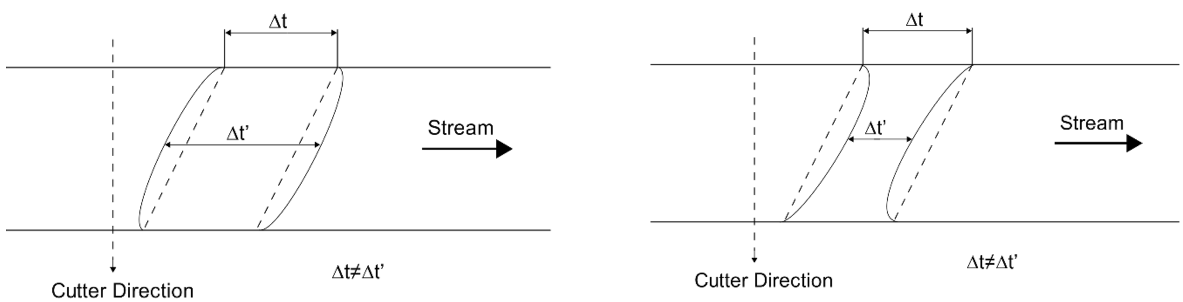
Figure 13: Simplified design idea (a) and working principle (b) of straight path Cross-Stream cutter at Point 1

In the designing process, three conditions are assumed to have an equal probability of being selected:

1. Stream is moving at a constant speed
2. The cutter is moving across the steam at a constant speed
3. The entire stream is passing well inside the cutter (14)

The second and third conditions are extremely important for the designing process. If the cutter is moving with not a constant speed, more or fewer particles will be collected in the sample container. In this case, the probability of being selected is not equal for each sample.

In order to satisfy the third assumption, the cutter must be made of strong materials, maintained, and cleaned regularly. If the cutter is made of weak material, the shape of the cutter can change as shown in Figure 12(a). Therefore, it will cause the collect more particles. In this case, the sample cannot represent the whole stream. Also, the sticky materials can stick to the wall of the cutter. In this case, also it will affect the shape of the samplers (Figure 12(b)). There is a probability that a less amount of sample can be extracted from the running circuit than expected. Thus, these two conditions must be considered carefully during the designing process for all of the sampling machines.



(a) (b)

Figure 14: illustration of sampling operations for weak material (a) and sticky materials (b)

Design idea 1.2: Circular path cross-stream sampler in the feed chute, well known as Vezin type sampler.

Figure 16 illustrates the working principle of the Vezin type sampler. The cutter rotates and crosses the stream completely. In order to rotate the sampler, an additional mechanical driver is needed. During the crossing time, it collects particles and collected particles will be transported into the sample container by gravity. In this type of sampler, the space between the conveyor belt and VRM is the primary concern. The size of the cutter must be bigger than the stream to cover the stream completely (Figure 16(b)). In other words, the height will be much higher than existing the feed chute. But in the milling plant, there is not enough space to build a big sampling machine. Thus, this design idea should be avoided.

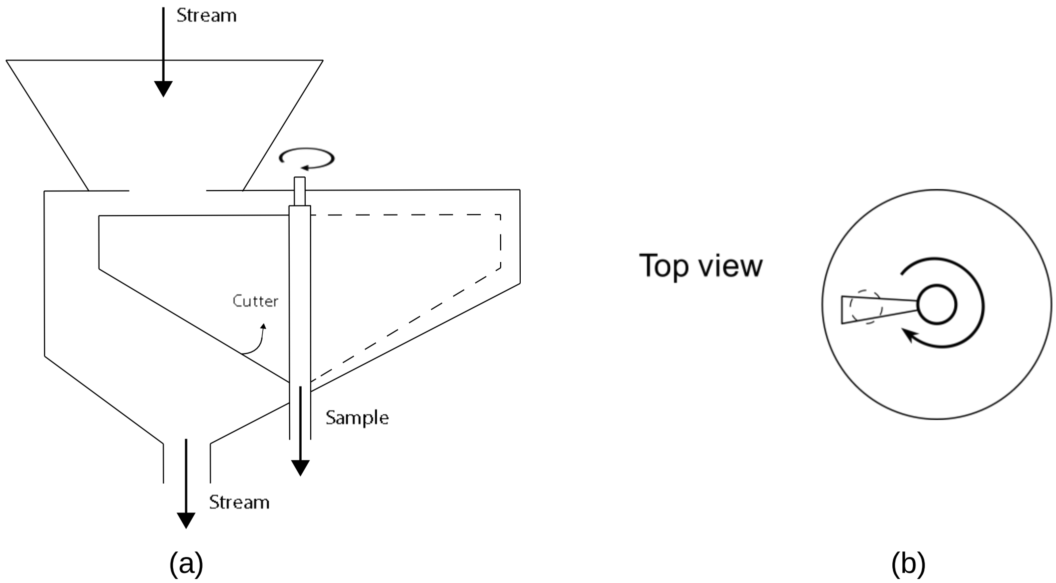


Figure 15. Simplified illustration of Circular path Cross-Stream cutter (a) side view, (b) top view

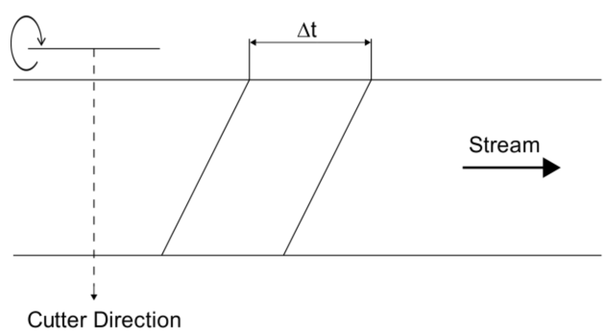


Figure 16. Simplified illustration of flowing stream during the sampling

Design idea 1.3: Flexible hose sampler

The third idea is a flexible hose sampler. In this design instead of any external motors or drivers, the flowing stream's direction is changed by a connecting rod (Figure 18). The rod moves right and left by manual operation. During that time the direction of the flowing stream changes into the sampling pipe. These materials, which are in the sampling pipes, will be used in further tests.

It is one of the easiest methods to make a sampling machine since only the hose moves by manual operation. The main disadvantage of this design is that the lifetime of the machine is very short. Therefore, it requires regular maintenance to have reliable operations. The second problem with this hose sampler is the shape of the feed chute. In order to fit the hose into the existing feed chute, the feed chute must be reshaped completely. Due to these two reasons, it is hard to use this design idea in the milling plant

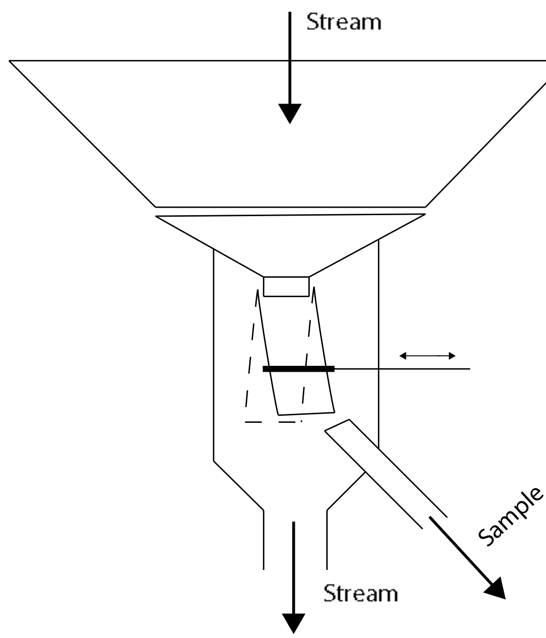


Figure 17. Simplified illustration of Flexible Hose sampler

Design idea 1.4: The flap divider sampler

The last design idea for point 1 is the flap divider sampler: The sampling collecting pipe and hoppers are connected by the sliding door (Figure 19a). In this case, the hopper or the feed chute's shape does not need to be changed, only one opening door (deflector) should be added to the chute. When the deflector opens, it blocks the way of the stream and the stream hit the sliding door and goes to the sample collecting pipe. The ideal working way of this kind of sampling is that when the sliding door reaches the ending position, it must directly go back to the initial position, where it blocks the sampling pipe, as shown in Figure 19(b). However, it does not usually happen. When the sliding door reaches the position where the stream is blocked, it tends to stay there for extra seconds. Because of this problem, during the opening and closing time, the sampler could collect more or fewer particles (Figure 20). It will cause not an equal probability of being selected for materials. Thus, also these types of sampling machines would not be considered in the designing process.

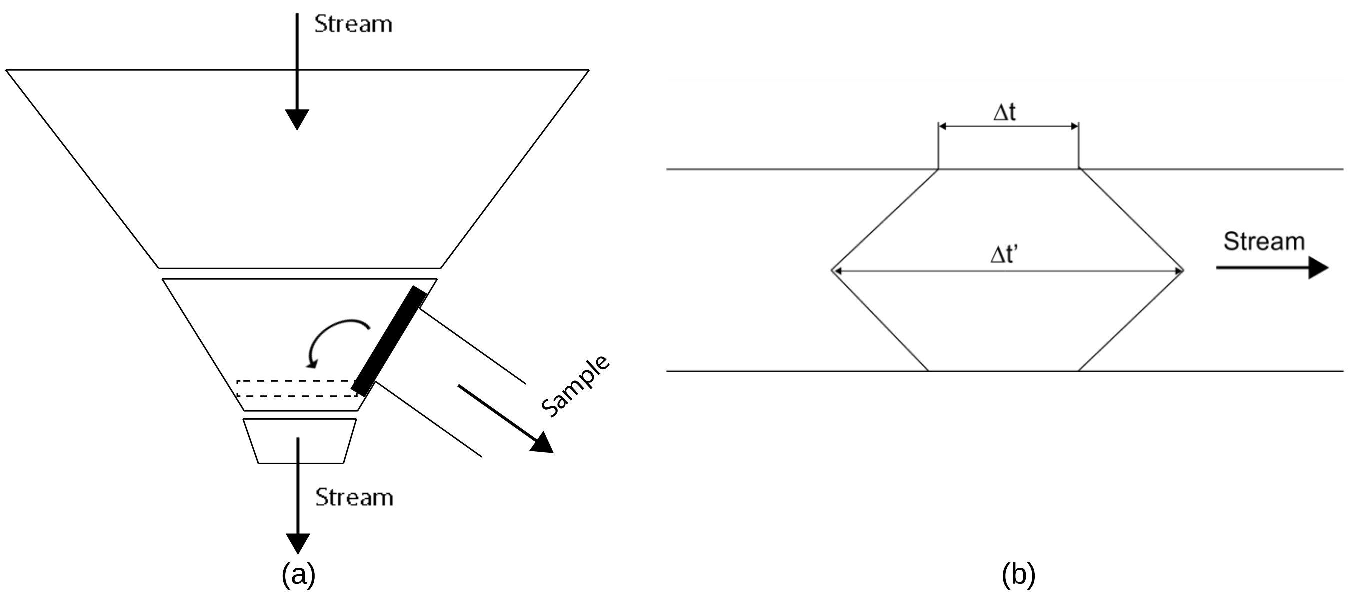
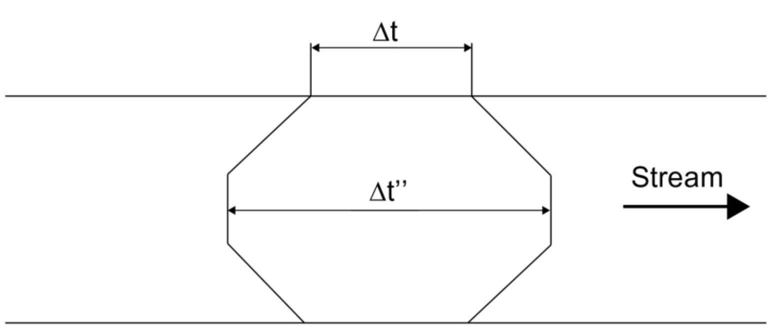


Figure 18:The simplified illustration of flap design idea (a) and Ideal working principle (b)



$\Delta t'' \neq \Delta t' = \Delta t$

Figure 19: Real-life problem of flap sampler

3.1.2 Design ideas for point 2

The second sampling point is located between the mill and the screening machine. These two machines are connected by three different pipes, as shown in Figure 21. Each pipe has its different length, radius, and angle. However, the angle of pipe number 1 and pipe number 3 are approximately the same. Thus, in the following subsections, the same design ideas for the first pipe can be used for pipe number 3.

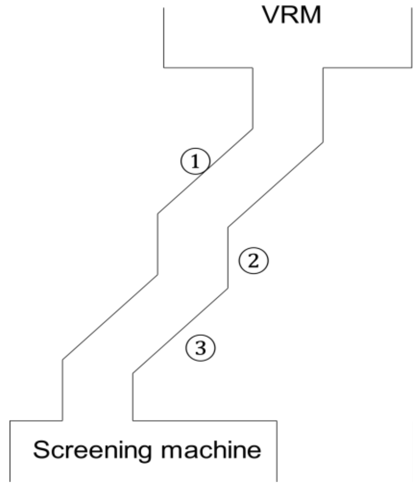


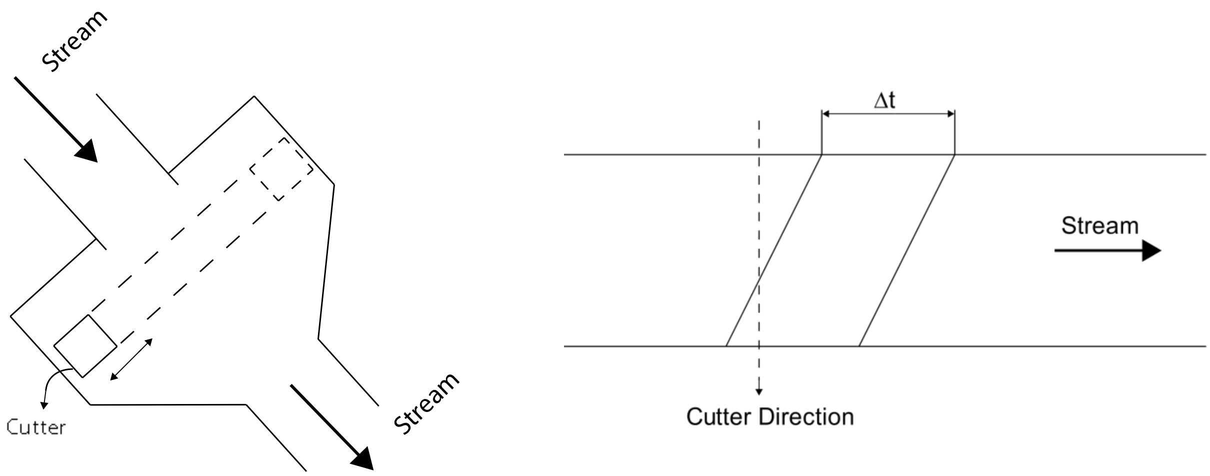
Figure 20: Simplified illustration of pipe connections between VRM and screening machine

(1) Pipe number 1

For the first pipe which is located right below the VRM, five different design ideas are considered. Each of them is explained below.

Design idea 2.1: Straight path Cross-Stream Cutter

As explained in Design idea 1.1, this type of cutter uses the same working principle as a straight path cutter. The rectangular-shaped cutter crosses the entire stream completely during the operation time (Figure 20). Only the difference between design idea 2.1 and design idea 1.1 is an angle. But due to the high mass flow rate, there will be no difference in the working principle of this design idea.

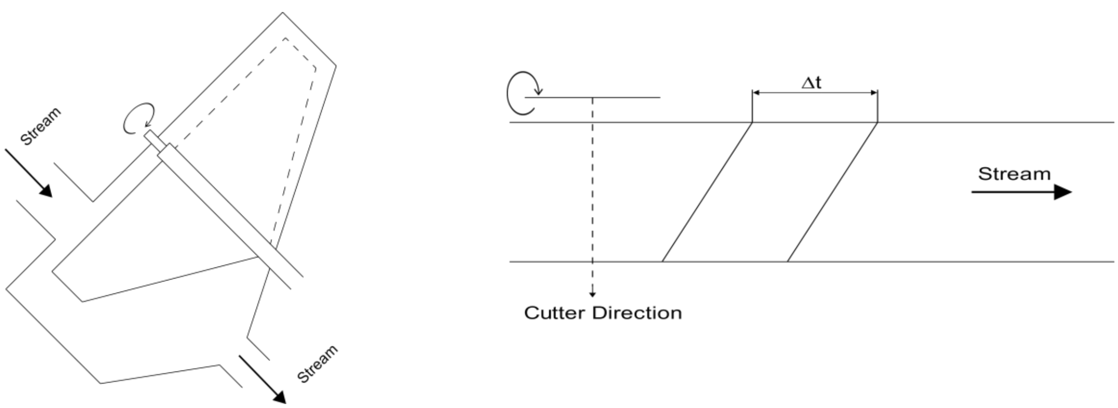


(a) (b)

Figure 21: Simplified illustration of Straight path Cross-Stream cutter at Point 2 (a) and working principle (b)

Design idea 2.2: Circular path Cross-Stream Cutter (or Vezin type sampler)

The circular path Cross-Stream cutter is used in this design. Instead of the horizontally placed design idea (as in design idea 1.2), it has a certain angle, approximately 45 degrees. Also, it requires much more space than any other type of samplers. Thus, it might be not the best solution for this point.

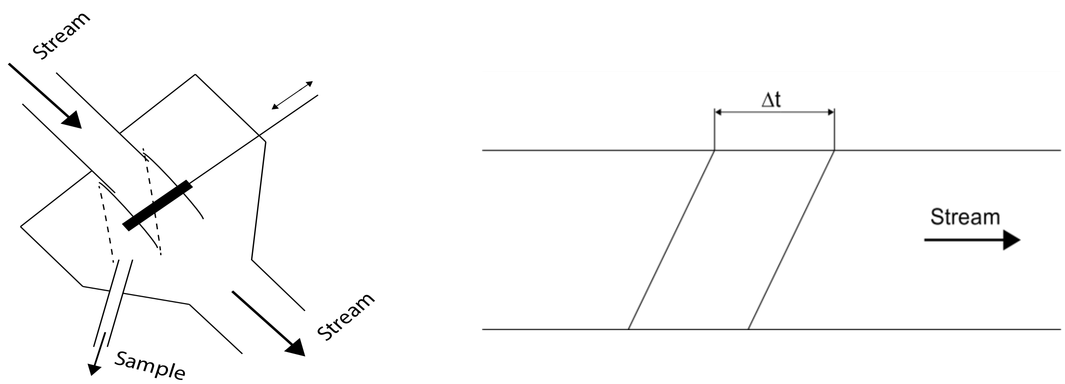


(a) (b)

Figure 22: Simplified illustration of Circular path Cross-Stream cutter (a) and working principle (b)

Design idea 2.3: Flexible Hose cutter

It is the same as explained in design idea 1.3. It is the simplest and cheapest idea to build the sampling machine. The main difference is that it has around 45 degrees inclination from the floor, as shown in Figure 23(a). Because of the lifetime of the hose and the connection between the rubber hose and metal tube, it must be checked properly.



(a) (b)

Figure 23: Simplified illustration of flexible hose cutter (a) and working principle (b) for point 2

Design idea 2.4: Cross-Stream Flap cutter

A cross-Stream flap cutter, also known as a leverage type sampler, is widely used in mineral processing plants. Theoretically, it can show the best result, shown in Figure 25(b). But, in reality, when the flap is closing and opening, the sampler collects more or fewer particles than it must do (Figure 20). Then it causes a different probability of being selected. Thus, this type of sampling design should be avoided for this point.

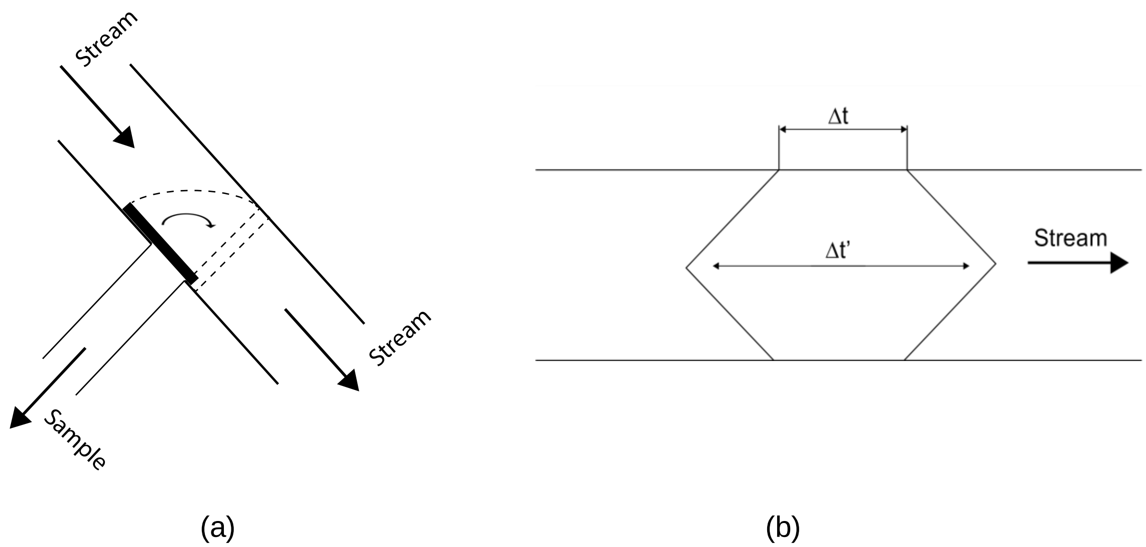


Figure 24: Simplified illustration of Cross-Stream Flap cutter (a) and ideal working principle (b)

Design idea 2.5: Sliding gate

The sliding gate is mostly used in the hopper to open and close the circuit. This design can be used in the sampling process. However, due to the angle and high mass flow, all the particles might not go into the sampling pipe, because, in the flowing stream, the big or heavy particles tend to be gone at the bottom of the pipe due to the gravity and the small particles most likely to go upper parts of the pipes. Therefore, in this design, a lot of big or heavy particles might be collected than it should be and, this design must not be considered.

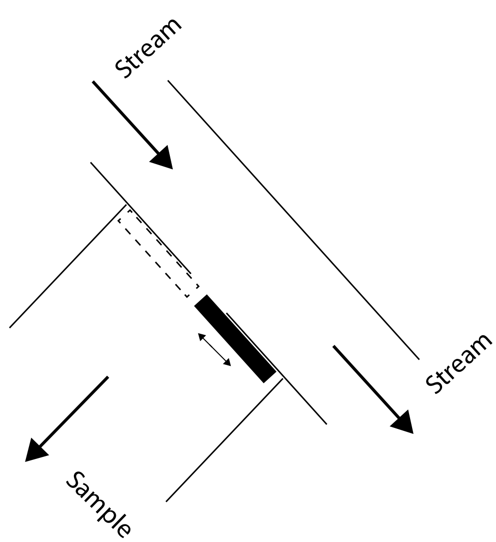


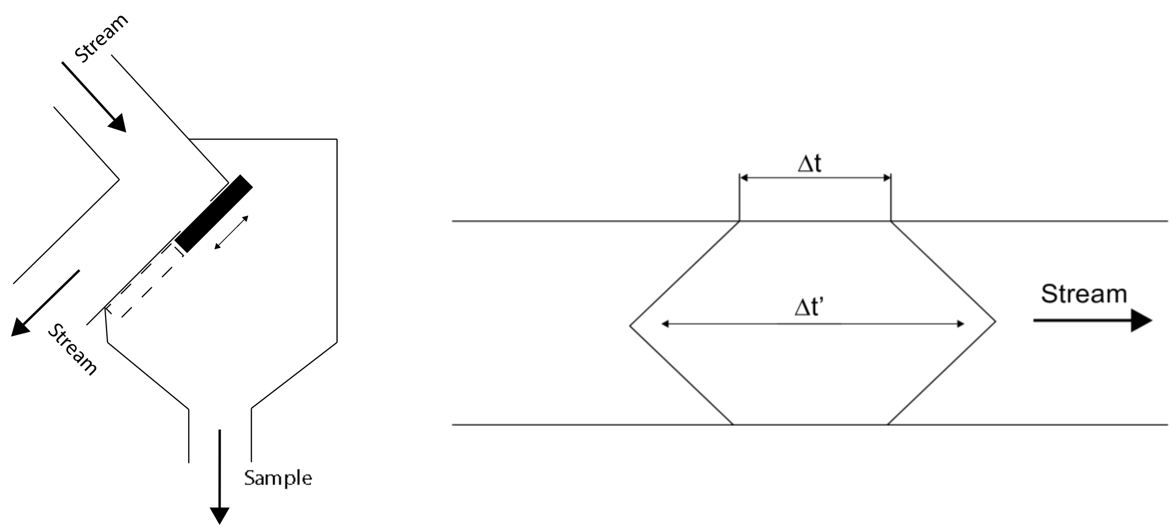
Figure 25: Simplified illustration of sliding gate

(2) Pipe number 2:

For this type of pipe, there are 2 possible ideas. The working principle of these two ideas are similar but the results are completely different (Figure 27 (b) and Figure 28 (b)).

Design idea 2.6: Sliding door at the edge of the pipe.

In this design, a rectangular solid deflector is used as a door to control the opening of the sampling chamber. At the initial position, it blocks the opening and does not collect any materials. During the sampling process, the door slides down and opens the sampling chamber, as shown in Figure 25 (a). Ideally, it collects the same amount of materials during every opening and closing time (Figure 25 (b)). But there is a certain probability that the door stops at the final position and waits there for a few seconds then goes back to the initial position. If this occurs, the sample cannot represent the whole running stream. Thus, this type of design idea also should be avoided.

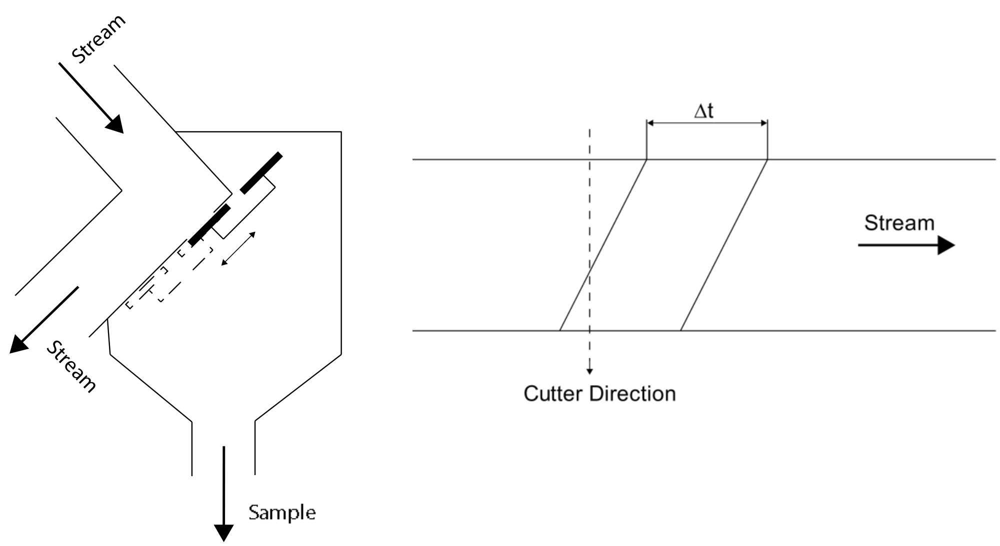


(a) (b)

Figure 26. Simplified illustration of the sliding door (a) and working principle (b)

Design idea 2.7: Straight path Cross-Stream Cutter at the edge of the pipe.

The working principle of this sample is the same as the design idea 2.6. Instead of one rectangular solid deflector, the cutter consists of two flat deflectors, which have a fixed small opening between them. Figure 28 (a) shows the working principle of this design idea. During the operation, the deflectors will go up and down, and the particles will enter the sampling chamber by the space between these deflectors. The main advantage of this type of sampler is that even with the low mass flow rate, it will work perfectly and produce reliable representative samples because it has a fixed opening to collect materials.



(a) (b)

Figure 27. Simplified illustration of Straight path Cross-Stream Cutter at the edge of the pipe (a) and working principle (b)

3.1.3 Design ideas for point 3

The third necessary sampling point locates right below the screening machine. This point is well known as the undersized particles of the screening machine. At this point, all the fine particles, which pass the screening machine, fall down into the next container for the further process. One of the design requirements at this point is that the sampler should place vertically. There are five potential design ideas, and each idea is explained below.

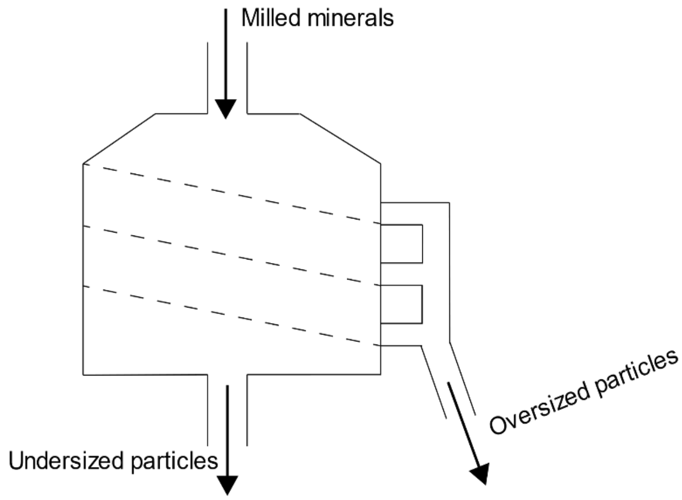


Figure 28. The simplified illustration of the screening machine.

Design idea 3.1: The straight path cross-stream sampler

The straight path Cross-Stream cutter can place right below the screening machine vertically and take samples during the operation time. Figure 27 illustrates the main design idea of the straight path Cross-Stream. The distance between undersized particles point to the floor is 700mm and it is possible to install this kind of device in that space. In addition, the sampler can be driven by an electric motor or human force in this case.

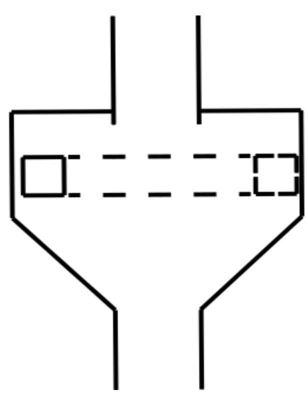


Figure 29. Simplified illustration of the straight path cross-stream for the point 3

Design idea 3.2: Circular path cross-stream sampler.

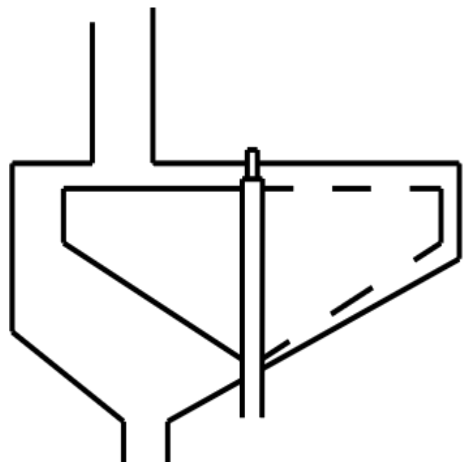


Figure 30. Simplified illustration of the Vezin type sampler for the point 3

One of the most effective sampling designs is the circular path cross-stream sampler. Figure 31 shows the main design idea of the Vezin sampler. It requires a big space and budget. Due to the current limitation, it might be difficult to construct this type of design in the milling laboratory.

Design idea 3.3: Flexible hose sampler

This flexible hose sampler can be used at point 3, as shown in Figure 32. But the reliability is the main concern for this design because it is operated manually. Also, due to the wrong movement, there is a certain possibility that the running stream cannot enter the sampling chamber. Thus, this design idea should be avoided to have reliable samples.

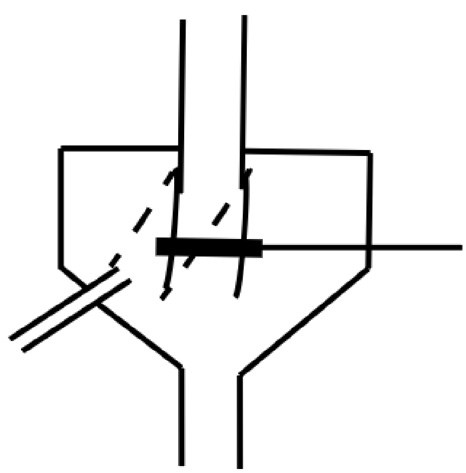


Figure 31. Simplified illustration of Flexible hose sampler for the point 3

Design idea 3.4: Flap divider sampler

The next design idea is a flap divider sampler. Figure 33 shows the main working principle of the sampler. Same as design idea 1.4, there is a certain possibility that this type of samplers collects more materials than it must. Therefore, these types of samplers should be avoided.

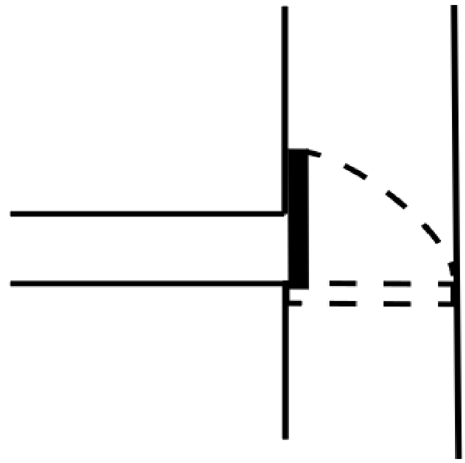


Figure 32. Simplified illustration of flap sampler for the point 3

Design idea 3.5 Sliding gate sampler

In this design, the gate slides up and opens the sampling chamber, as shown in Figure 34. The falling particles can enter the sampling chamber but, only a few parts of the stream might enter the chamber. The rest of the particles falls for the further process during the sample taking process. Thus, these design ideas cannot collect samples that can represent the whole stream.

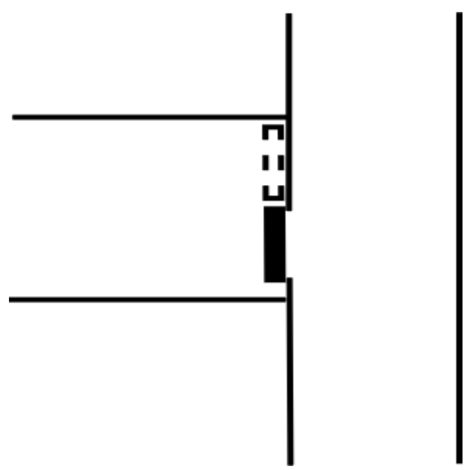


Figure 33. Simplified illustration of sliding gate sampler for the point 3

The design ideas for point 4

The fourth necessary point locates at the oversized particles point. From this point, the coarse particles come out from the screening machine. This point directly connects to the conveyor belt at the top of the VMR. From the screening machine to the conveyor belt, the particles travel inside the pipe, which has a radius of 10 cm. Thus, all the design ideas are focused on the pipe. At this point, there are seven possible design ideas, and all of the ideas are explained below:

Design idea 4.1: The Straight path Cross-Stream sampler

Figure 35 illustrates the straight path Cross-Stream sampler for point 4. This design idea is the most reliable and useful to create sampling machines. But the main problem related to this design is the free space. The additional big chamber, which contains a cutter and supporting devices, has to be installed between the pipes.

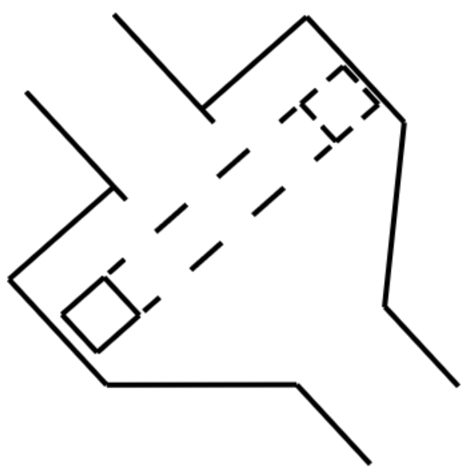


Figure 34. Simplified illustration of The Straight path Cross-Stream sampler for the point 4

Design idea 4.2: The Straight path Cross-Stream cutter at the bending of the pipe

The Straight path Cross-Stream cutter at the bending of the pipe is shown in Figure 36. It is an improved idea of design idea 4.1. Instead of adding a cutter into the pipes, it uses the bending of the pipes. In that case, the space needed can be minimized. To construct this design, the circular pipe should be changed into a rectangular pipe to fit the chamber and pipe into each other perfectly.

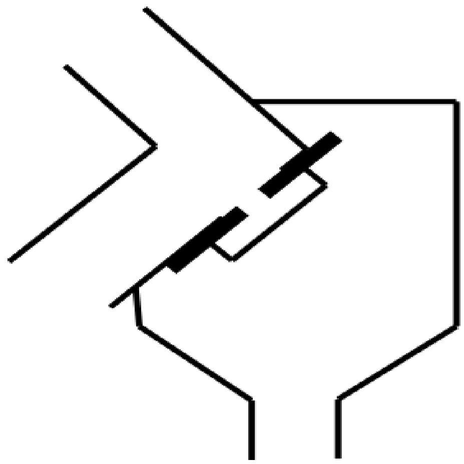


Figure 35. Simplified illustration of The Straight path Cross-Stream at the bending of the pipe

Design idea 4.3: The Circular path Cross-Stream cutter

Same as design idea 4.1, this design has to be installed between the pipes, as shown in Figure 37. At point 4, adding pipe length is almost impossible. Thus, this design idea also should be avoided because it uses a lot of space.

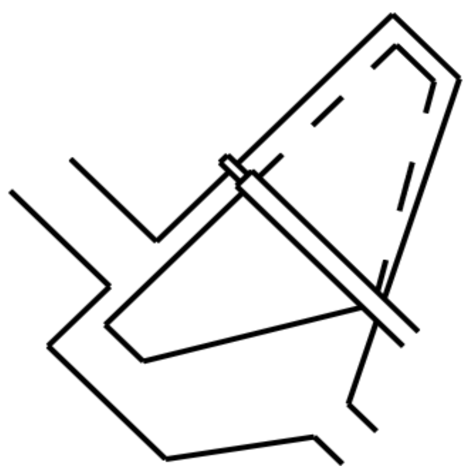


Figure 36. Simplified illustration of Vezin type sampler with 45 degrees inclination

Design idea 4.4: Flexible hose sampler

Like design idea 2.3, this design idea uses the same principle to generate the samples from the running stream, as shown in Figure 38. It locates between two pipes. This design idea has the same disadvantage, which is explained in design idea 2.3. Therefore, it should be avoided.

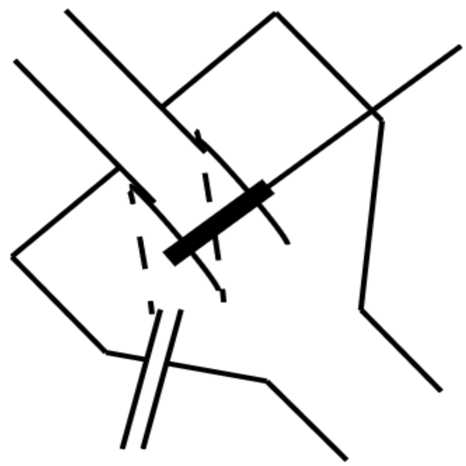


Figure 37. Simplified illustration of flexible hose sampler for the point 4

Design idea 4.5: Flap divider sampler with 45 degrees of inclination

This type of sampler is equipped with a deflector that moves across the stream to open the sample collecting pipe and collect the samples (Figure 39). But, on the side of the closed idle position, the flap divider sampler machine usually collects more materials. Then, the sampling probability changes.

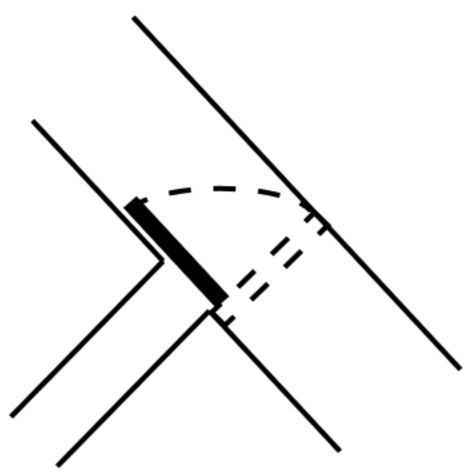


Figure 38. Simplified illustration of flap divider sampler for the point 4

Design idea 4.6: Sliding gate sampler

Figure 40 shows the main working principle of the sliding gate sampler. As explained before, this sampling design cannot collect all of the particles, which are falling down inside the pipe. Only the particles, which are close to the opening, can be collected. In that case, the samples cannot represent the whole stream.

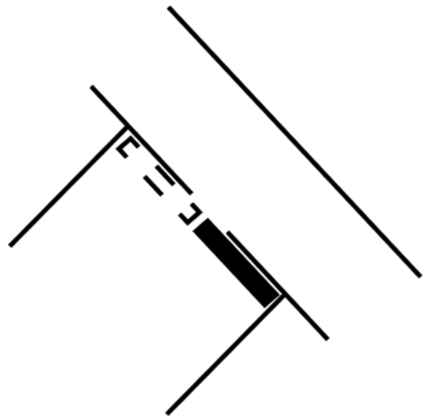


Figure 39. Simplified illustration of the sliding gate sampler

Design idea 4.7: Sliding gate sampler at the edge of the pipe

A sliding gate at the edge of the pipe is the improved design idea of the sliding gate (design idea 4.6). Figure 41 illustrates the main design of the sliding gate sampler at the edge of the pipe but, the main problem with this design is that the flap opens and stops at the end of the position for a certain time and then goes back to the closing position. During the stopping time, the sampler collects more particles. These additional materials can affect the probability of the sampling process.

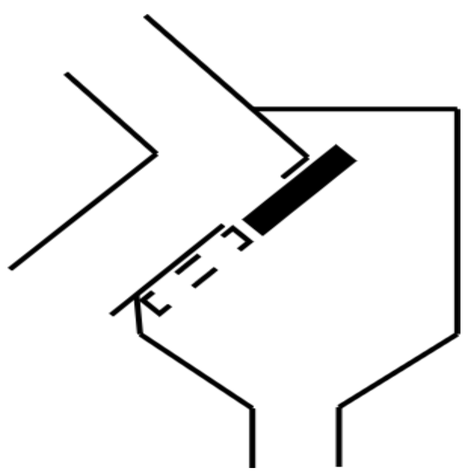


Figure 40. Simplified illustration of sliding gate sampler at the bending of the pipes

3.2 Selection of proper sampling designs

Even though there are more than three possible design ideas for each point, due to the current limitations only a few of them are thought possible to construct. Thus, based on the size of the sampling machines and working principles, the following sampling designs are chosen to implement, as shown in Table 4.

For point 1, the Straight path Cross-Stream sampler is the best option to construct since it does not require changing the whole part of the feed chute. It is only needed to change the bottom parts of the feed chute. The top can be used again in this sampling machine design. It will save construction time, labour to construct the sampling machines, space, and budget in the future. The Straight path Cross-Stream at the 90 degrees bending of the pipe is chosen for point 2. At point 3, also the Straight path Cross-Stream will be constructed. In point 4, the Straight path Cross-Stream at the 90 degrees bending of the pipe is chosen to collect representative samples from the running stream.

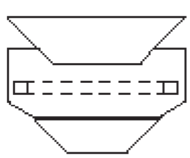
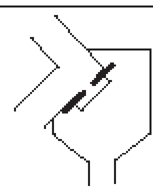
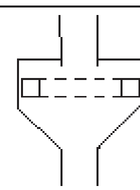
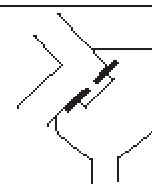
Vertical Roller Mill		Sieve	
Feeding point	Discharge point	Undersize	Oversize
			

Table 4. The chosen designs for the sampling machines at each point

4. Implementation of Sampling Machines in Computer-aided design

Based on the selected design ideas, the computer-aided designs of sampling machines are created on the SolidWorks program. Each of the designs is explained below.

4.1 Sampling machine for point 1

Figure 42 shows the sampler's CAD model of the first sampling point, in four views. In the front view (b), the individual components are explained further. This construction consists of a frame which contains the guide (2) for the sample cutter (1) and motor (3). The frame is connected to the existing feed chute by bolts. The sample cutter is moved by the lead screw driver across the material flow. An electric motor ensures a constant movement through the material flow in order to sample the same amount of particles. In that way, the samples can represent the whole running stream. Also, the protector (4) is assembled on the mainframe to protect the sample cutter while it is not collecting samples. Thus, at the initial or final position, the sampling machine does not gather any extra materials. In addition, this sampling machine requires a feed chute which has two outputs. One output is for the sample collection. Another outlet is for the main running stream, like the chamber of the sampling machine for point 3 (Figures 45 and 46).

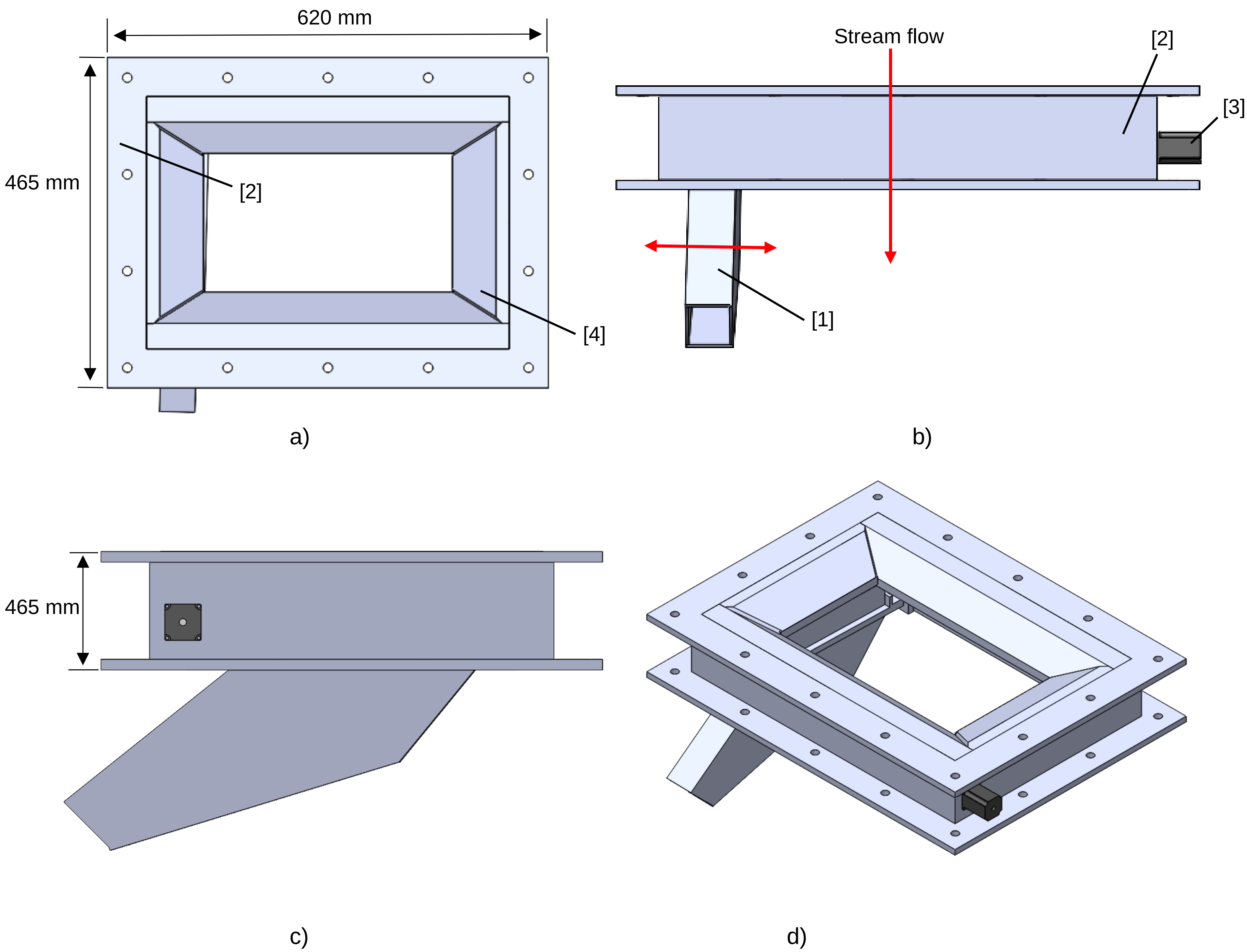


Figure 41. The computer-aided design of the Straight path Cross-Stream sampler for the point 1 from a) top view, b) front view, c) side view d) isometric view

In addition, Figure 43 shows the cross-section view of the sampling machine. The sample cutter [4] is connected to the cutter holder [3] by bolts. The cutter holder moves on the guide [5] using the lead screw [1] and rollers [2]. The lead screw is directly connected to the electric motor which is assembled into the outside of the mainframe. The falling particles change flow direction when the sample cutter is moving. These particles enter into the sampling section instead of falling down and are used the further tests.

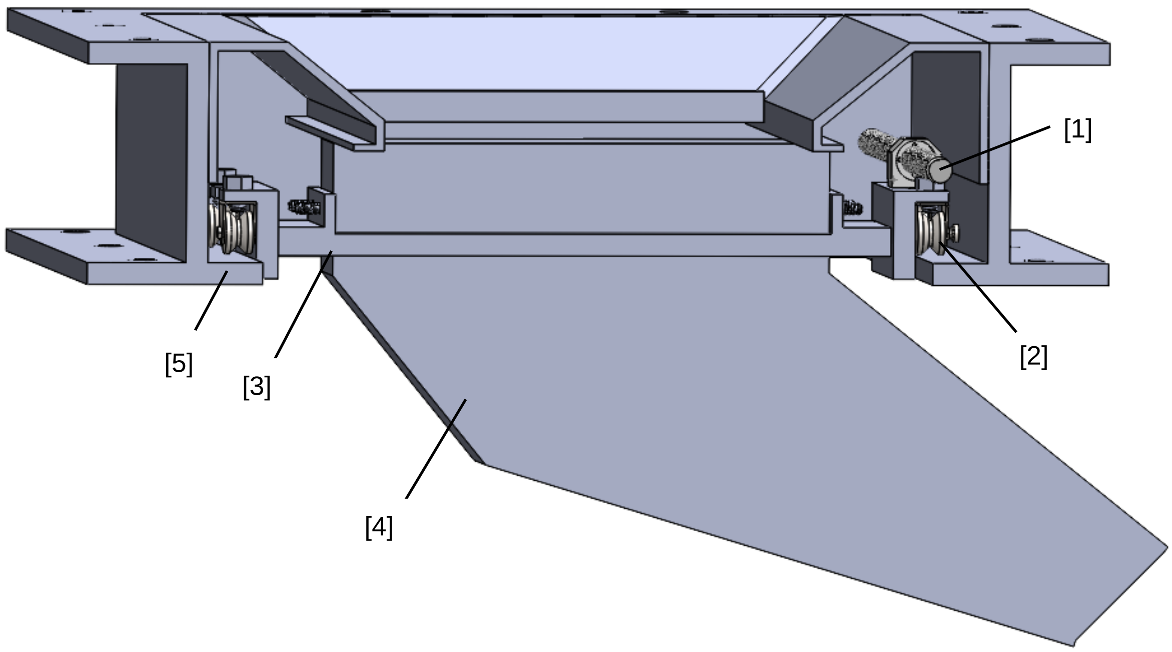


Figure 42. Cross-Section View of the sampling machine for the point 1

4.2 Sampling machine for point 2

Figure 44 displays the sampler's CAD model of the second sampling point, in four views. The particles flow from top to bottom inside of the pipe [1]. The bold red arrows represent the stream flow direction of materials. The sampling chamber [3] is directly installed right below the pipe to collect samples correctly. The sampling machine is driven by the electric motor to rotate the lead screw with constant speed and move the two deflectors.

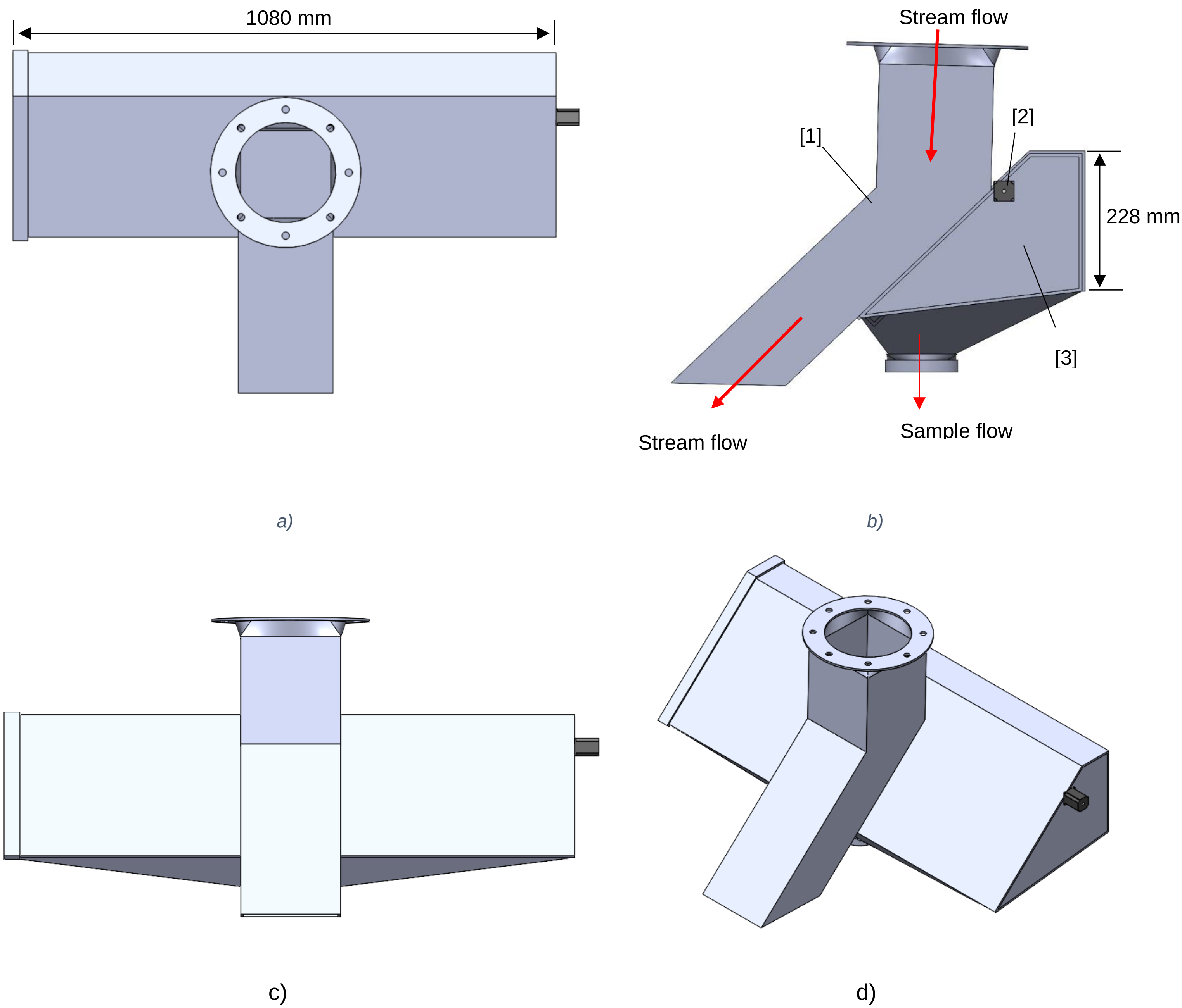


Figure 43. The computer-aided design of the Straight path Cross-Stream at the bending of the pipe for the point 2 a) top view, b) front view, c) side view d) isometric view

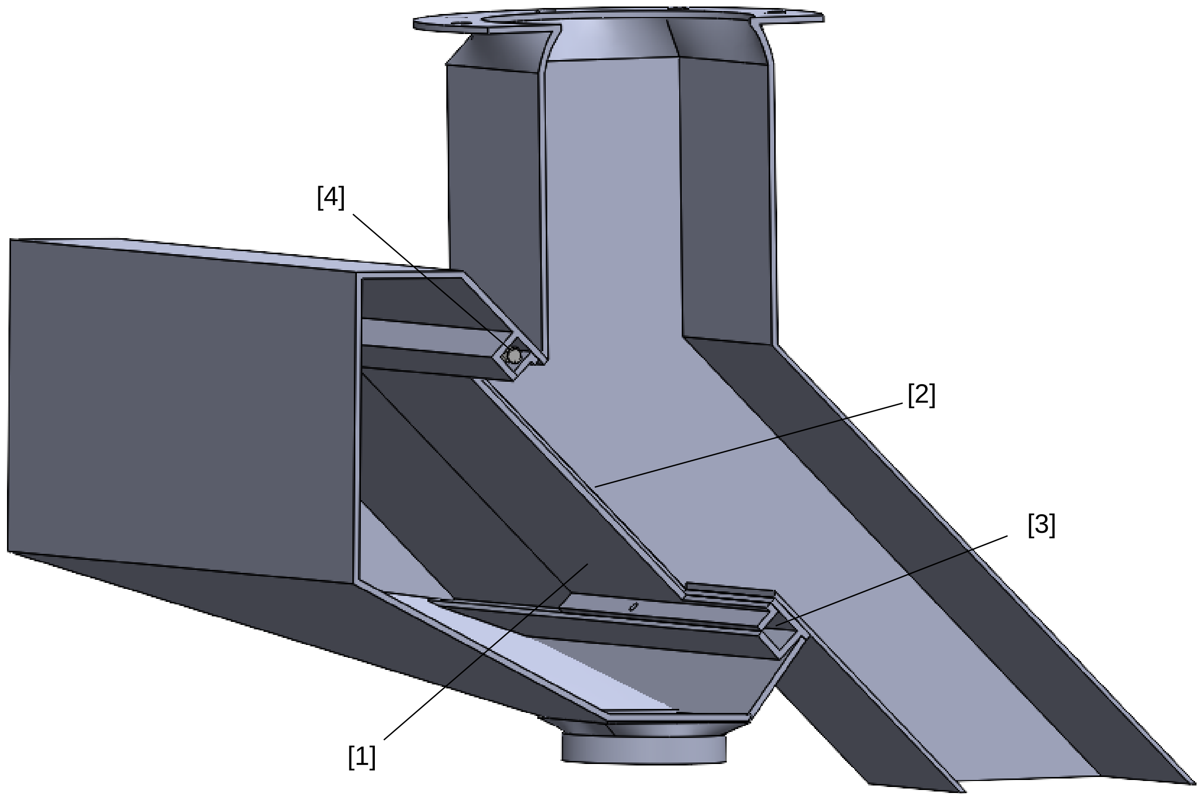


Figure 44. Cross-Section View of the sampling machine for the point 2

In Figure 45, the two deflectors [1] and the opening of the pipe [2] are shown. These deflectors have a fixed opening between them. When these deflectors are in the initial position, the opening of the pipe is closed by the first deflector and no particles can enter the sampling chamber. While the motor is rotating the lead screw [4], the deflectors also move along the roller's guide [3]. During this time, the materials can enter the sampling chamber using the fixed opening of the deflectors. At the final position, the opening is closed by the second deflector.

4.3 Sampling machine for point 3

The working principle of this design is very similar to the sampling machine of the first point. Figure 44 shows the sampler's CAD model of the third sampling point, in four views. The main difference between the sampling machine of the first point and the third point is that instead of the main frame, the sample cutter is placed inside the sampling chamber [1]. The red arrows represent the mainstream flow. The particles, which come from the underside of the sieving machine, slide horizontally until the opening of the pipe [2]. Then the particles fall down into the container for further usage. During the falling of particles, the sampler cutter changes the particles' direction and collects these particles as samples. The sampling chamber has one input and two output openings. One output opening is for the particles' main flow and another one is for the sampling. Also, the cross-sectional view of the sampling machine of the third point is shown in Figure 47.

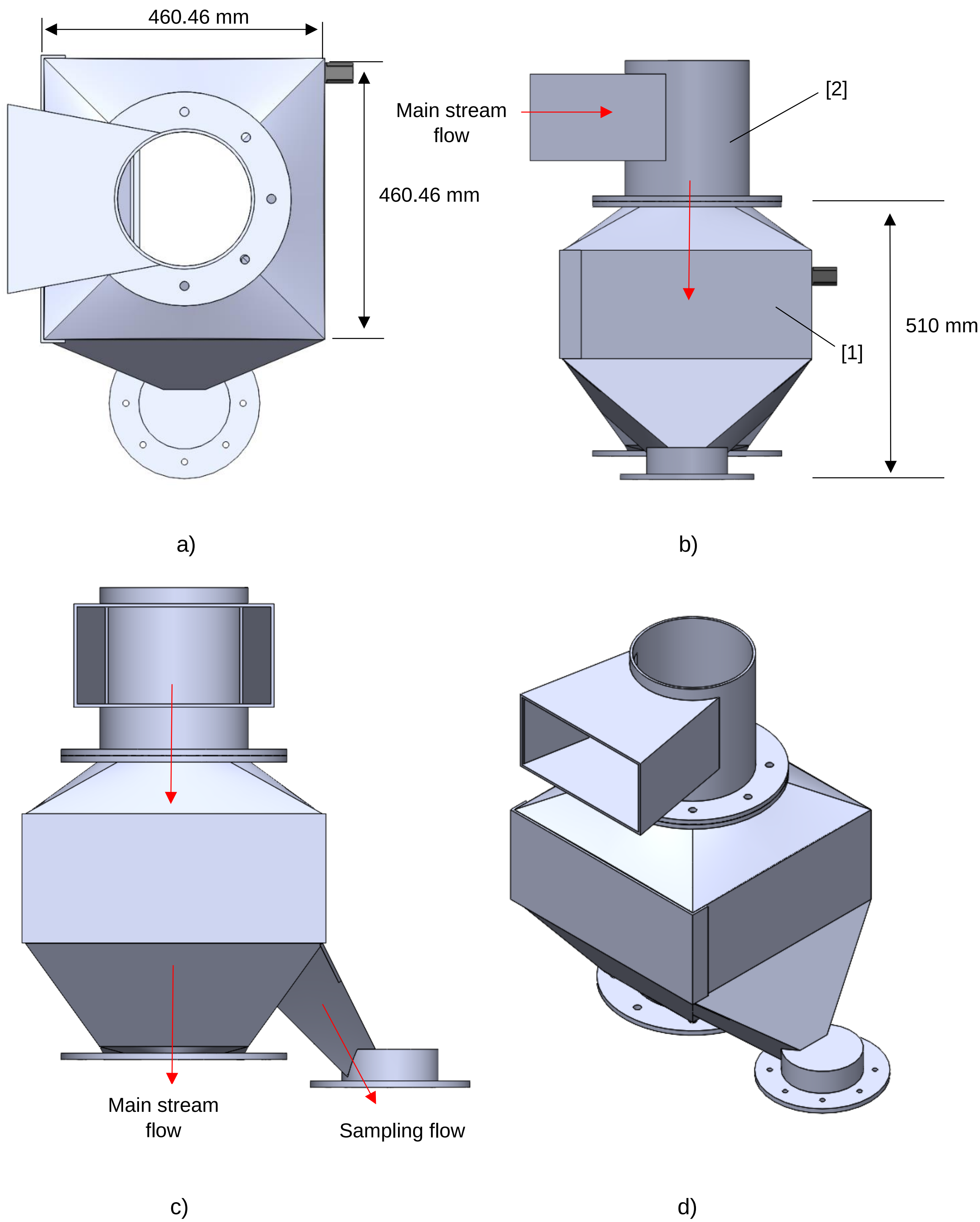


Figure 45. The computer-aided design of the Straight path Cross-Stream for the point 3 a) top view, b) front view, c) side view d) isometric view

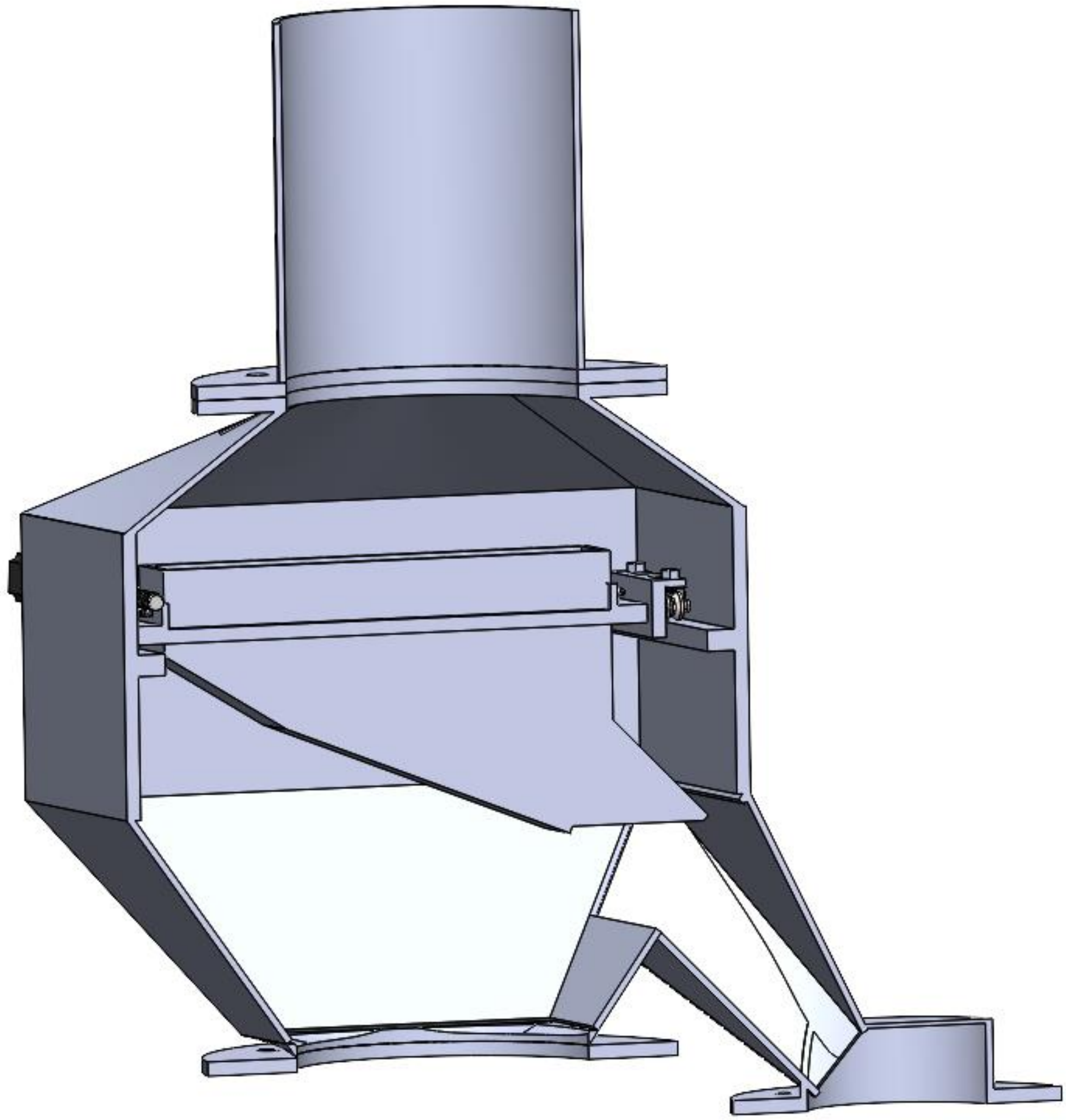


Figure 46. Cross-Section View of the sampling machine for the point 3

4.4 Sampling machine for point 4

Figure 48 shows the sampler's CAD model of the fourth sampling point, in four views. This sampler is similar to the sampling machine of the first point. The big difference is the overall size of the sampling machine.

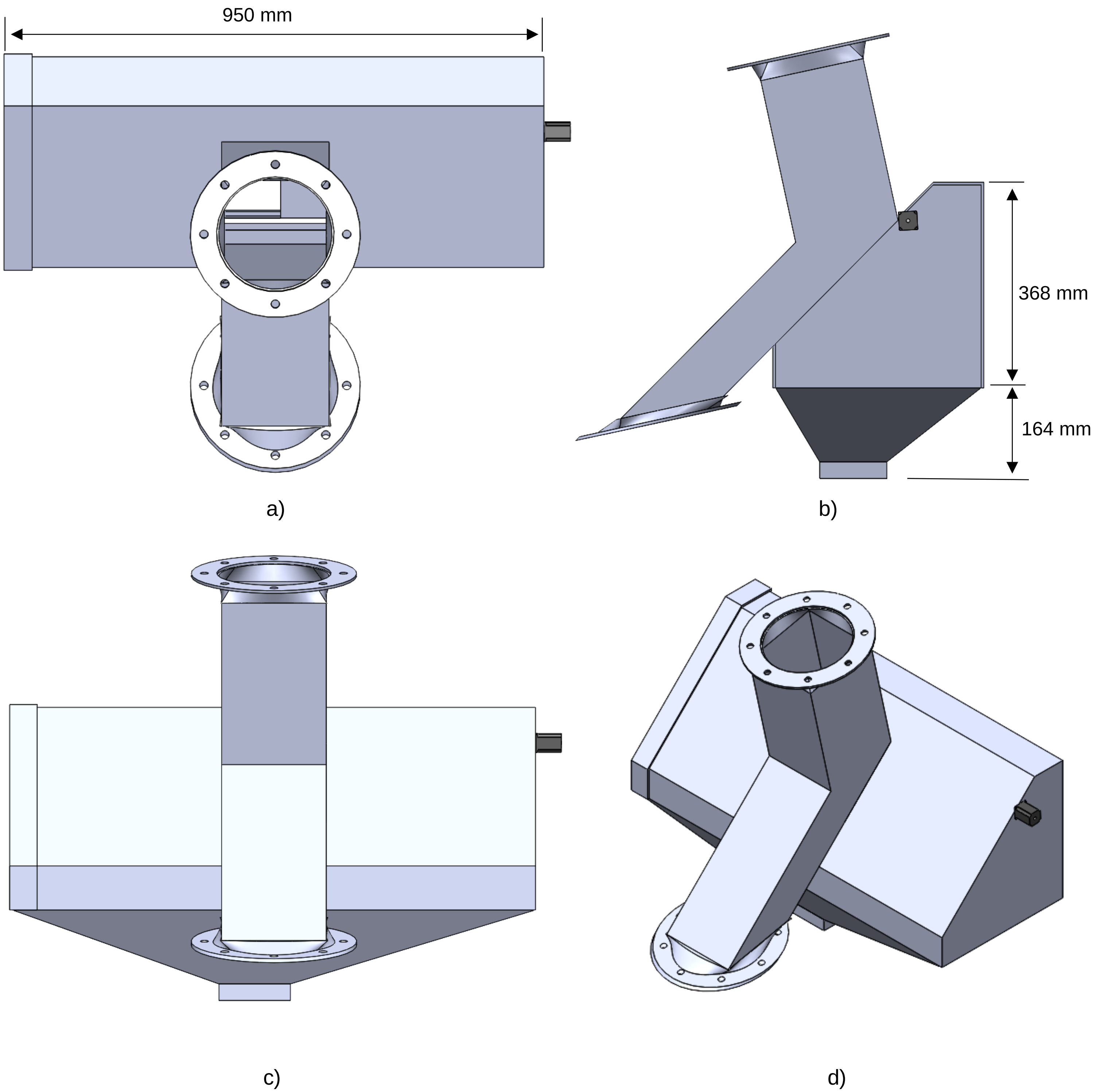


Figure 47. The computer-aided design of the Straight path Cross-Stream at the bending of the pipe for the point 4 a) top view, b) front view, c) side view d) isometric view

4.5 The future improvements

In this design, the following basic calculations must be done to improve the sampling machines:

- The wall thickness of the chamber and pipes
- The diameter and length of the screw
- The power of the motor
- The thickness of the sample cutter
- The width of the supporting plate of the sample
- The size of a roller
- The size of the bolts
- Support of the sampling machines

In addition, the material should be decided to build a sampling machine, which has a high life. In the last, the structure of the supporting system of those samplers should be decided to install the sampling machines into the steel structure of the milling plant.

5. Conclusion

Cutting samples from the milling plant's process streams using well-designed samplers and appropriate sampling methodologies has been shown to be a dependable approach to taking samples that represent the whole running streams. However, there are many cases where mineral processing plants use the wrong sampling methods or poorly designed sampling machines to take samples. One of the examples is the existing milling plant of “Institute for processing machines and recycling system technology”. Thus, this research aimed to improve the plant by designing the sample-taking machine based on Pierre Gy’s theoretical and practical suggestions.

In this design, first of all, background research was conducted and concluded that there are four important points where the sampling machines need to be installed in the plant. Then totally 23 design ideas were created and examined for the four sampling points and the best four points were chosen so that they can fit into the existing plant. The main criteria to choose the point were the free space for the installation of sampling machines and sampling techniques. Since all of the machines and equipment are already installed, changing the position of machines is nearly impossible. Thus, designing the sampling machines that can fit into the existing plant was the primary goal. In addition, these design ideas must use correct sampling techniques to produce reliable representative samples from the running circuit.

Based on the chosen design ideas, the sampling machines were drawn in the SolidWorks, computer-aided designing software. During the operation time, these machines will work under high pressure and load. Thus, in order to prevent any failure, the maintenance of the machines is considered in the design phase of the sampling machines so that most of the parts of the machines can be disassembled and repaired further.

In the future, the optimization of these sampling machines can be achieved based on the proposed designs.

6. Referencess

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