CZECH TECHNICAL UNIVERSITY

FAKULTY OF MECHANICAL ENGINEERING

DEPARTMENT OF ENVIRONMENTAL ENGINEERING

PNEUMATIC TRANSPORT OF FLOUR

MASTER’S THESIS

TOMÁŠ VOLF

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Prohlášení

Prohlašuji, že jsem diplomovou práci s názvem *Pneumatic transport of flour* vypracoval samostatně, pod vedením doc. Ing. Jiřího Hemerky, CSc.,s použitím literatury uvedené na konci mé diplomové práce v seznamu použité literatury.

V Praze dne 28. 6. 2017 Bc. Tomáš Volf

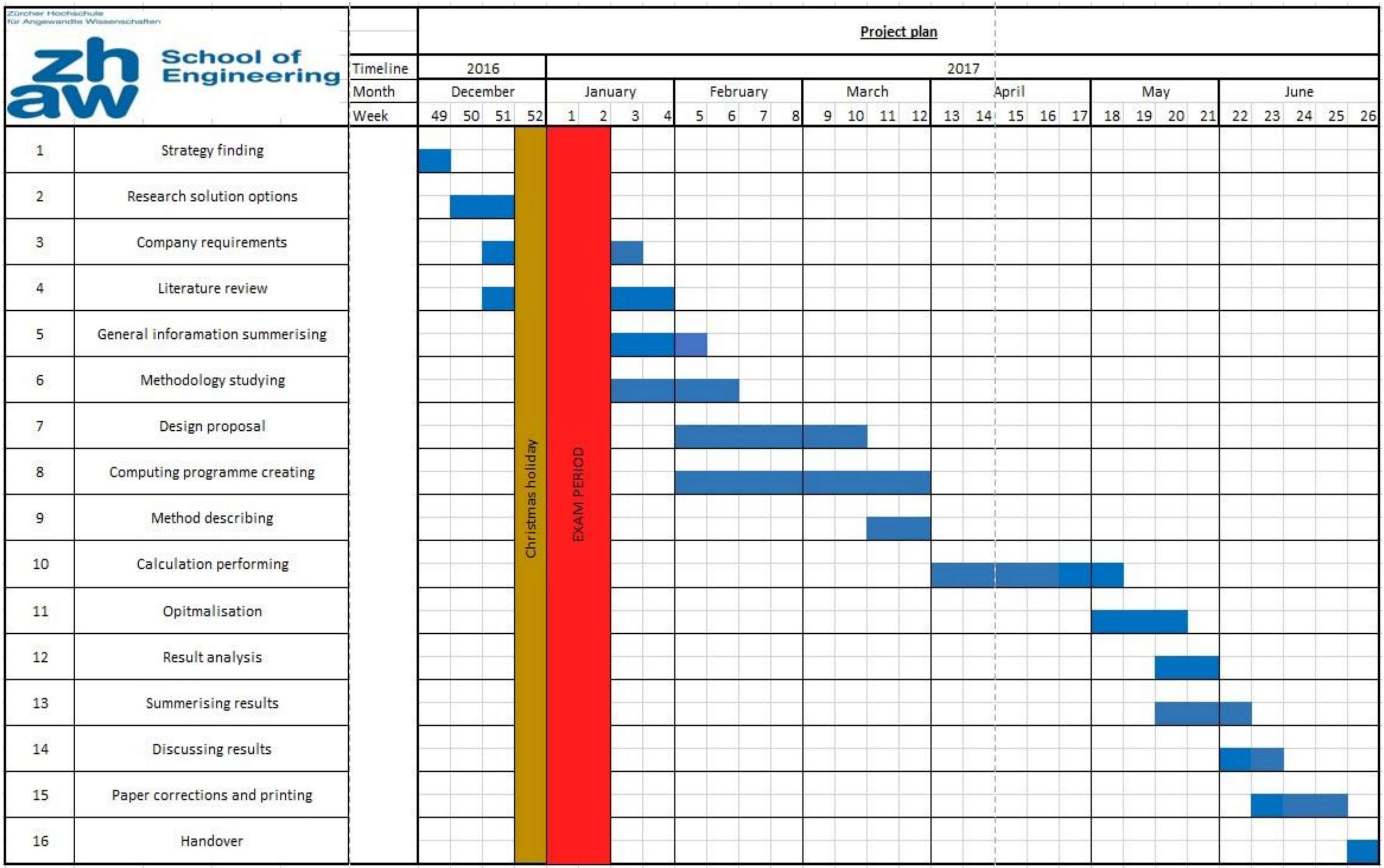
…………………...

Souhrn:

Cílem této diplomové práce je navrhnout pneumatické potrubí v budově mlýna. Součástí je určení odporových sil v kalkulaci tlakového poklesu, navržení zařízení a jeho implementace do potrubí. Modifikovaná metoda aditivnosti je způsob jak zlepšit přesnost výpočtu pneumatické dopravy. Díky výpočetnímu programu je výpočet rychlejší a jednodušší k porozumnění. Do projektu je možno pro zákazníka zahrnout možné budoucí rozšíření budovy.

Summary:

The aim of the Master thesis is to design a pneumatic piping in the mill. Determining a resistance forces in the pipeline using pressure drop calculation is necessary.The machine design and implementation into the pipe routing has to be done. The advanced method is a way how to make the pneumatic calculations more accurate. The calculation programme makes the calculation faster and easier to understand. The possible expansions plans might be needed in the future for the customer.


Zürcher Hochschule für Angewandte Wissenschaften
School of Engineering
Project plan
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EXAM PERIOD

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Symbol key

β	-	- velocity ratio
u	[m/s]	- material velocity
v	[m/s]	- gas velocity
u_{vz}	[m/s]	- floating speed
μ	-	- blend ration
$\dot{M}_m$	[kg/s]	- material mass flow
$\dot{M}$	[kg/s]	- gas mass flow
ε	-	- porosity
V	[m^3]	- volume
A	[m^2]	- pipe area
d	[m]	- pipe diameter
τ	[N/m^2]	- pipe shear stress
τ_m	[N/m^2]	- material shear stress
C_M	[kg/m^3]	- material concentration
ϑ	[°]	- pipe inclination
ρ	[kg/m^3]	- air density
ρ_m	[kg/m^3]	- material density
g	[m/s^2]	- gravitational constant
s	[m]	- pipe length
s_y	[m]	- pipe vertical length
s_x	[m]	- pipe horizontal length
k	-	- transport coefficient
p	[Pa]	- pressure
Δp	[Pa]	- pressure difference
Δp_f	[Pa]	- friction pressure difference
Δp_g	[Pa]	- gravitational pressure difference
Δp_a	[Pa]	- intial acceleration pressure difference
Δp_l	[Pa]	- local pressure difference
Fr	-	- Froude number

ξ	-	- bend coefficient
λ	-	- pipe friction coefficient
γ	-	- bend position difference
Re	[(kgm/s^2)/N]	- Reynolds number
υ	[Pa s]	- dynamic viscosity
$\dot{V}$	[m^3/min]	- gas flow
P	[W]	- performance
η	-	- efficiency
c	[m/s]	- floating speed coefficient
b	-	- safety coefficient
κ	[m/s]	- absolute roughness
α	-	- relative roughness

1. Introduction

Pipe conveying is widely used when transporting material from one point to another. Enclosed environment that is created protects the product from external impact. The total pipe length in the world is estimated around 4 000 000 km out of which 65% is located in the United States. There are many materials that can be transported among which we have fluid materials (fuels, slurry, water, beer), powdered materials (flour, ground coal, spices), granular materials (grains, corn, cereal) and many others. There are also several different ways of transporting the material: using gravity, mechanical shafts, or the compressed air known as pneumatic piping.

Pneumatic conveying, used commonly in food industry, is one of many ways of transporting products. It uses pressure force to create an unbalanced environment in the pipeline. This way, the product is pushed or sucked through the pipe from the feeding stations until the very end, where it is discharged. To design a functional and reliable pipeline, we must go through a lot of calculations and designing before we get to a suitable and satisfactory result.

The transport system consists of several important parts. Firstly, there arefeedings where the material gets inside the system and goes through the pipe itself. Then we have the discharge where material is separated from the conveyed air. The air then proceeds into the air collecting duct, to the filter and exits the system in the external outlet. The special part is the pressure source which can be placed at the beginning or at the very end.

In my work, I would like to focus on designing a pneumatic piping that transports flour from the mill's ground floor to the very top of the building. That means calculating the total pressure drop and power for the pressure source. From the top of the building the flour continues to the milling process. At the end of the milling process, we obtain a flour of various quality. When the flour reaches required quality, it is shifted further on in the mill. In order to guarantee a smooth transport that is strong enough for the mill's capacity and comes at a reasonable price, we must go through various mechanical calculations, thermodynamic estimations and shape designs.

One of the most commonly used theory for the pipe designing is the additive method, which I also use in my design. It consists of dividing the pressure drop into physical quantities, in which each quantity is calculated individually. Those quantities are friction, gravitational elevation, initial acceleration and local pressure drops.

In order to determine the final pressure, drop, it is necessary to establish the transport coefficient. This is the key step in the whole calculation. The transport coefficient is a value with huge influence on the final result. Its determination can be done by mathematical approximation method or an experiment. Inevitably, in the long piping the product properties are changing along the pipeline path such as velocity, density, temperature etc. In those cases, it is useful to use an advanced method where the pipeline is be divided into several sections with similar routing. In each section, the local conditions will be recalculated. This way we ensure that the result will be accurate enough.

In the next step of my work, I would like to focus on ventilator and power source planning. The more pressure drop and gas flow we have, the more powerful air compression is necessary. Therefore, the used pressure source should suit the given conditions.

As we know, the proposed solution may not fit unless we take price into account. As the next aim, I would like to optimize the designed work by creating the phase diagram that shows what is the ideal ratio of the velocity and pipe diameter. Using the diagram, we should be able to optimize the pipeline, examine other variants and set the ground for future possible expansion.

The computation of the system is a complex and sophisticated process, where a lot of combinations need to be tested out. That requires performing a calculation numerous times before we get to the satisfactory result. That would not be possible without creating a computing programme where the result is updated every time the input is changed.

Industry companies nowadays are facing a problem of not having enough educational material for newcomers. Understanding the computing method process is difficult and the initiation is lengthy. The next goal in my work will be to create a computing programme that is capable of giving instant results of the pressure drop and power required for performance. With a detailed description, this programme could serve as an educational programme created for the company newcomers describing the influence of each element on the system. Also, when the project is changed during the design period, the programme could serve as a quick estimation that could give the engineer a rough overview of how the change is going to influence the pneumatic system.

The outcome of my work should contribute to the design of the mill as a valid part of the project that will be built. Moreover it is making the pneumatic calculation clearer, quicker and easier to learn. The aims are as follows:

1. Pneumatic piping overview
2. Mathematical computing method description
3. Pressure drop calculation
4. Machine equipment proposal
5. Creation of the pneumatic computing programme

2. Flour mill

Mill in today's world is a building, where the initial source is wheat and the outcome product is flour. The concept of mill has been in a huge progress in recent centuries. A few centuries back the mills were wooden buildings usually with a huge wheel powered by water or animal. But even though the modern technology brought a lot new inventions and modernisation in the processing the original idea of creating flour from the wheat remained.

2.1 History

The oldest mills are dated in the ancient Greek in the 3rd century BC where we can find the first evidence of using the water wheel in Europe. The technology was then spread to the Roman Empire and the rest of the Europe. In the first century, the crank was used in the mill to improve its effectiveness. In the middle ages, there were more mills built not only for wheat but also for malt, paper or tanning. With arrival of electricity and industrial technology the new big and modern electric mills were built in the 19th century and as there were more people on the planet, more food was required and hence the modern milling have been through a big boom in the 20th century. However, the technology is speeding up every year nowadays thus we are witnessing of the biggest and fastest improvements of milling industry ever. [10] [11]

2.2 Modern mill

Nowadays, modern mills are automated buildings powered by electricity. They are situated usually outside of cities with a good access to the wheat. Most of the mills on the world ale fully automated and do not require the incessant human presence. All processes of wheat modifying are done by machines such as grinding, tempering, drying, cleaning, storing and so on. Machines are connected by piping carrying not only the product itself but also gas or wheat additives. In the figure *1* below we have an example of mill inner view.

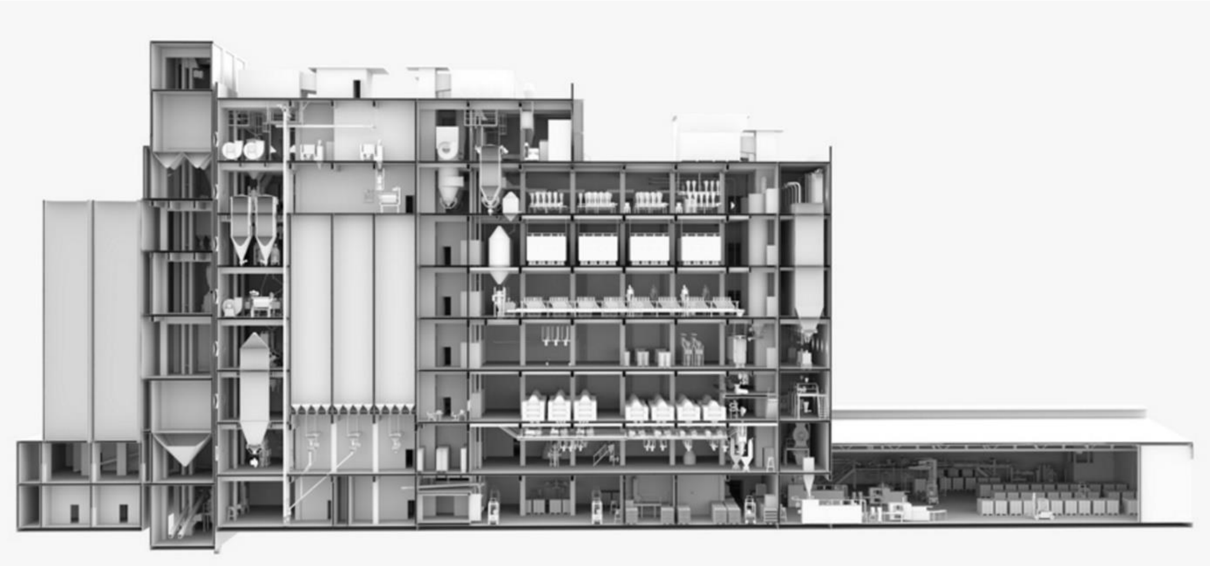


Fig. 1 – mill building cut [12]

In the industrial design, the machine layout is described in the most important document – flow sheet. You can see the example in the figure 2 below.

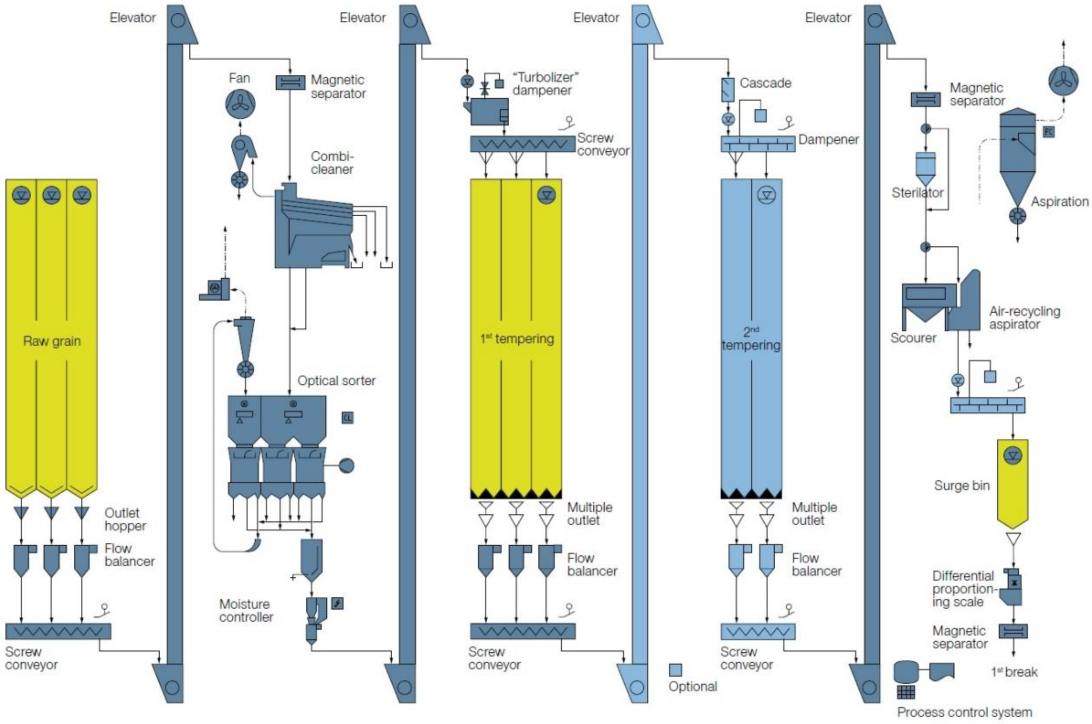


Figure 2 – flow sheet [13]

This layout document describes what is the order, connection and type of machines applied in the process. In general, the mill can be divided in several parts. Each of the part has indispensable position in the process. The Milling process is described more in the figure 3. We will go through each part separately and clarify what all the parts stand for. [12] [13]

Figure 3 – mill plant process [13]

Intake, Precleaning and Storage

In this section, the raw grain is delivered to the building using truck, ship or train. Truck delivery is the most common since the other two deliveries require special conditions. The grain that is brought enters the intake room unusually placed beneath the ground level. Than the material is transported using conveyers and elevators up to the top. The raw grain contains a significant amount of impurities and foreign material. This dirt material has entered the grain during harvesting and transfer. We must first get rid of these unwanted impurities in the precleaning. By that we ensure that the product will go through process safely and improve its quality and storing. Here we use machines detecting dirt stones, insect, soil and other unwanted particles. When the wheat is pre-cleaned it must be stored and prepared to get in the process. There must be always enough raw material available and prepared to go in process. That is why we must store the grain in the income silos. The material waits in the bins store in the environmental friendly conditions. That is why the intake and precleaning is a bit separated from the rest. The shortage of material could cause unnecessary lowering the capacity or in the worst case stopping the mill completely which is costly not only for the price of stopping and starting up but also the mill does not produce the outcome. [13] [14]

Cleaning and conditioning

In this part, it is important to prepare the material for the most important part of the process which is milling that comes afterwards. The cleaning has the same purpose as precleaning, but this time the material gets cleaned more properly and more carefully. This ensures us that there will be no impurities that could cause a damage to a sensitive milling machine. The most common impurities in the cleaning waste are straw, wood, foreign seeds or stones. Those will be detected and removed according to the differences in shape, weight, colour or magnetism. After the cleaning, the first tempering will take place. The water is added to the process and let the material rest to sink it in. This will take from 10 to 20 hours to achieve the required amount of moisture. This moisture is important for the process of removing the kernel's cover. This process is called the second cleaning. [15] [16]

Milling

Milling is often considered as the heart of the whole flour making. The wheat is grinded in the series of mills. There the endosperm is separated from the hull and germ. Than the material is transported to sifters where the product is sorted according to the reached quality of grinding. For sorting we use sieves with various size of the grid. If the product is not grinded enough it will be returned to the process of grinding. If the quality is sufficient the material proceeds to another stage of the mill. The flour has many level of qualities and types. [16] [17]

Weighing, proportioning and mixing

After the product reaches the desire quality it is important to check what has the industry modification done to the material and as well check how much material has been produced. For this we have a weighing mechanics. Sometimes, the various quality product can be mixed to create the desired flavour or mixture that is profitable on the market. That is why we use mixing and proportioning machines. The micro feeding systems provides product with other ingredients to meet the customers demand such as gluten or vitamins. After that, the product is heading to the storage silos. There will be storage waiting to get in the packing. [16]

Bagging and out loading

The out-going product can leave the plant same way as it came, which is usually truck, ship or train. Here in the bagging department the product will be placed in the bags by automatized machines. There is a wide range of bags you can put the flour in from light paper bags to rough wicked bags. The weight of the bag highly depends on the chosen bag material but it can vary from 10 – 50 kilograms. [16]

Quality control

Quality control does not take place in a special room or hall. It is being done along the way of the whole process. It is a real-time analysis of material from the early beginning until the very end of exporting. It stands for weighing, size verifying, dirt examining and many other checking that contributes to the product quality. In the advanced quality check, the samples from pipes can be taken and put to a chemical and physical testing. [16]

Automation

Automation is, same as the quality control, without an assigned room in the mill building. It consists of a long code programming which takes care of the smooth progress and process. That is mainly checked in the control room in the mill where all the mechanism can be monitored using active sensors. Those sensors can track most of the main important quantities such as pressure, presence, velocity or filling.

The process of flour making has gone a long way and nowadays it is very difficult to keep up with the technology taking charge in the industry. All the technology contributed to a higher quality food processing in a big manner. [12] [16]

2.3 Transporting in milling

In order to put product through the whole process of milling it is necessary to transport product on large distances. The total length of the product transport can reach up to a several kilometres in one mill. The material is traveling in all kinds of transport devices. It might be pneumatic piping, gravity piping (spouting), elevators, conveyers (chain, screw or belt conveyer) and many others. Before we go through each part individually we must be familiar with the concept of product path in the mill. Let's go quickly through the process again, focusing mainly on the material transporting.

When material is brought to the mill using trucks, ship or train it is unloaded in the intake aperture. The intake is usually located a bit further from the mill because of the good access. To transport the flour in the main mill building we use chain or screw conveyers. The intake aperture is located under the ground so that the material can fall down from trucks.

When the material is brought to the main building it is important to lift it up to the top floor. The whole concept of milling stands on material falling from top floor through the spouting to the machines. For the first lift up we use the elevator. You can see the detail in the flowsheet figure no. 2.

As the material is lifted to the top floor it is than set off to the gravitational spouting. When it is falling down, material gets in all the machines including sieves, roller mills or sifters. Than it gets down to the bottom. This process is than repeated until we accomplish the required quality. Instead of the elevator it is also possible to use pneumatic piping as is common when the flour gets cleaned after the first cleaning section.

When the material gets at the end of the process, it can be stored in the silos and here the pneumatic piping is more than recommended. The flour that is ready for exporting will be transported to the bagging station. Then the transport is a bit easier as we now work with the bags. For bag transporting we use special machines.

In the mill, it is not only product that is transported. The machines in the mill usually need air for proper function. Therefore, we must get the clean exterior air using aspiration. The aspiration system spreads in the whole mill delivering air to most of the machines. [13], [18]

2.4 Transport mechanisms

As is described above, we use diverse transport mechanisms in the building. Also, various forces are applied for transporting. It might be pressure, gravity, torque and others. Let's go through each part separately.

<u>Gravity piping – spouting</u>

Spouting is used mainly in the milling section where the flour is sorted to units. Each unit needs to get its own piping and individual approach how to be handled. The spouting is a vertical piping going from the top point downwards. On its way, the product is pushed only by the gravitational force. In order not to get clogged, the piping must keep a minimal inclination so that the material would not stop. Also, we must take the material properties and pipe material into consideration.

Screw conveyer

Screw conveyer is a machine transporting powdery material. It is using the principal of screw in the enclosed pipe. The shaft has a thread along the way and as the shaft is rotating, the thread is pushing the powder forward to the spill point. The faster the revolving is, the faster is the transport itself.

Chain conveyer

Chain conveyer is pushing the material using pedals mounted to the chain. As the chain moves, pedals push and mix the material. This way of transport is less efficient that the screw conveyer and used less.

Elevator

Elevator is strictly vertical mean of transport. It consists of a line of shovels. Shovels scoop up the flour and take it up on the top where shovel rolls over and the substance is poured. When designing the elevators, we must keep in mind that when the shovel takes up the load it bends under the weight a bit. It is very common problem in the vertical conveying.

Pneumatic conveying

In this type of transport, we use the gas pressure created with pressure source to move the material. We will analyse the pneumatic conveying in detail in the next chapter. [19] [18]

3. Pneumatic conveying overview

For designing a suitable type of pneumatic conveyer, we have to answer a several basic questions first. For example, what material do we want to convey, what form do we want to convey in, what distance do we want to convey to and how long do we have the system running at once?

The amount of conveyed material is in the range to 1000 t/h. The reachable height that can be conveyed to can go up to 100m and the total length of 500m in the case of overpressure systems. Pneumatic conveying is suitable for transporting powder and grainy materials, with the grain size of 8 mm. Lighted materials might have bigger granularity. In case of special need, you can convey materials with granularity up to 50 mm [6]

There are a couple of systems that can be used for conveying. The most used systems are conventional, permanently in use and opened systems that work on one place. As a conveying force, we use overpressure or underpressure or some combination of theirs. In the figure *8* we can see the situation how all those systems can get combined. All the systems can be sorted out using more than one term. [5]

1. Opened and closed systems – Opened systems are one of the most common among pneumatic conveyers, closed systems can be used for highly flammable, toxic or aggressive materials
2. Overpressure and underpressure – To convey with the gas you can create high pressure at the beginning of the pipe or low pressure at the very end.
3. High-pressure, medium pressure and low-pressure – The material has to be conveyed with a certain amount of pressure created in the pressure source.

This pressure can vary depending on the size of the system. The bigger the pressure the more material behaviour differs.

4. Fixed or movable systems – Most systems are fixed in one place but in some applications, it is required to use movable systems.

Each of those systems will be described in more detail further in this chapter. [6]

3.1 Closed systems

In this type of systems, the inner environment is the main aspect. Enclosed pipeline protects the product from outside influence. This is convenient when the products are sensitive to contact with ambient surroundings. That also works the other way when surrounding environment would get contaminated by products, for example with toxic or radioactive material. Another advantage is that the gas used for conveying is circulating and is not replaced. This allows to convey with different conveying gas than air which is the most commonly used. It is useful when air do not have the required physical properties or in case that transported material would interact with air. This modification can lower the costs of the system significantly.

<u>System description</u>

The system is described in the figure *4* below. In the left bottom corner, one of the compressors is located marked with blue colour. His purpose is to drive the gas into the pipe. Behind, coloured green is material feeding that inserts the material into the pipe and simultaneously does not allow material to leak into the gas pipe. Due to this layout of machines, the system is overpressure. The material is accelerated and conveyed through pipe, then it comes to the discharge point, which is painted red here. Immediately after the discharger, the first filter is located. This filter separates particles of material and lets the gas go through. After that, another filter might take place. This filter is used mainly for safety reasons to get rid of the smallest particles that might damage following machines. This way of conveying is used for continuous operation.[5]

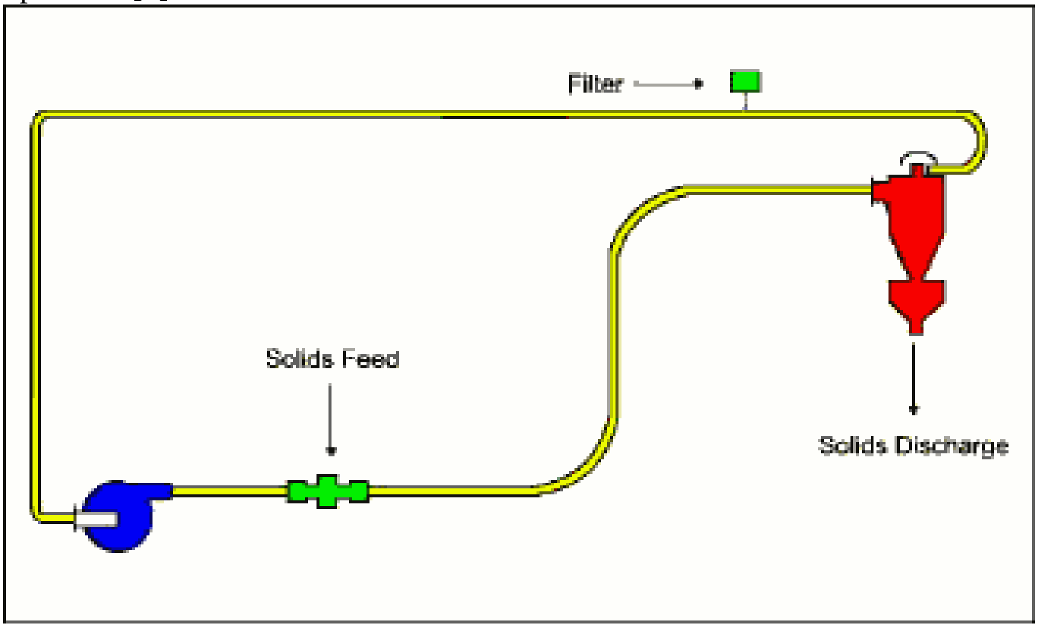


Figure 4 – closed system [20]

3.2 Opened systems

This way of pneumatic transporting is the most common in the industry. If the transporting material does not require any special gas vacation, then open system is the best solution because we do not have to build long gas pipe. On the other hand, the gas passing through pipe is taken from outer environment, hence it needs pre-clean moreover requires the exhaust pipe going out of the building.

System description

The system is in the figure *5* below. The blower is in the left bottom corner again bringing the air from the surrounding space. The product gets in the pipe the same way described in closed systems and discharges in the red cyclones. The line needs the filter too to prevent the dust and dirt particles to enter the line. This filter is situated in front of the pressure source. [5]

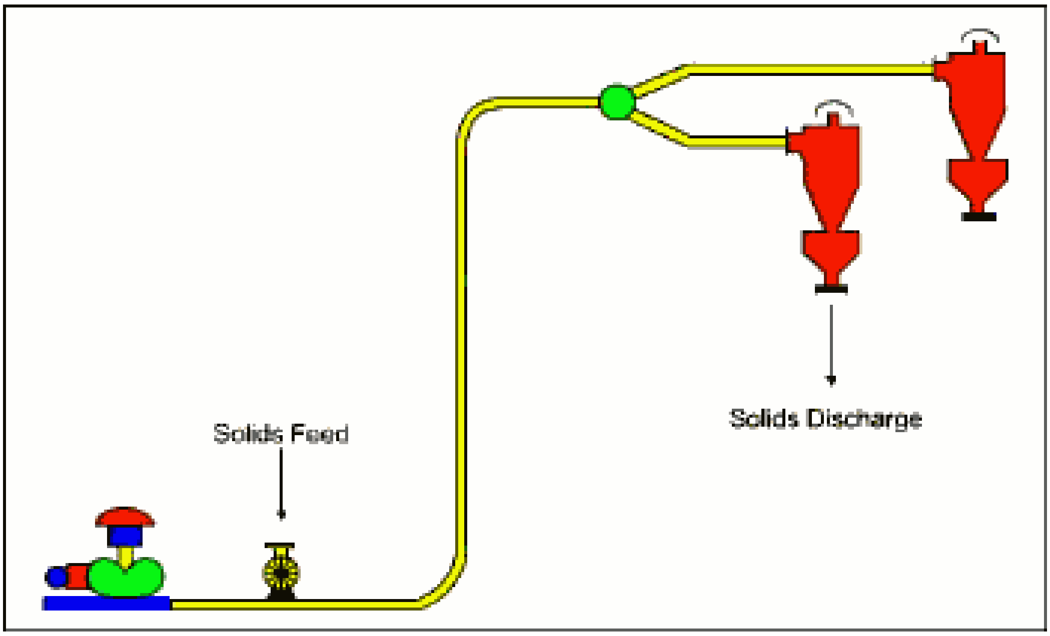


Figure 5 – opened, overpressure system [20]

3.3 Overpressure systems

Overpressure are most likely more common than the underpressure. This type has a lot of variations to use. It can be mounted with vertical, horizontal piping as well with vertical and horizontal valves and diverters. One of the big advantage is that this system can convey material from one place to many places distanced from each other. The example of the overpressure systems delivering material to more than one place is the figure 6. The system has the pressure source at the beginning of the line forcing the gas to go through the pipe. [5]

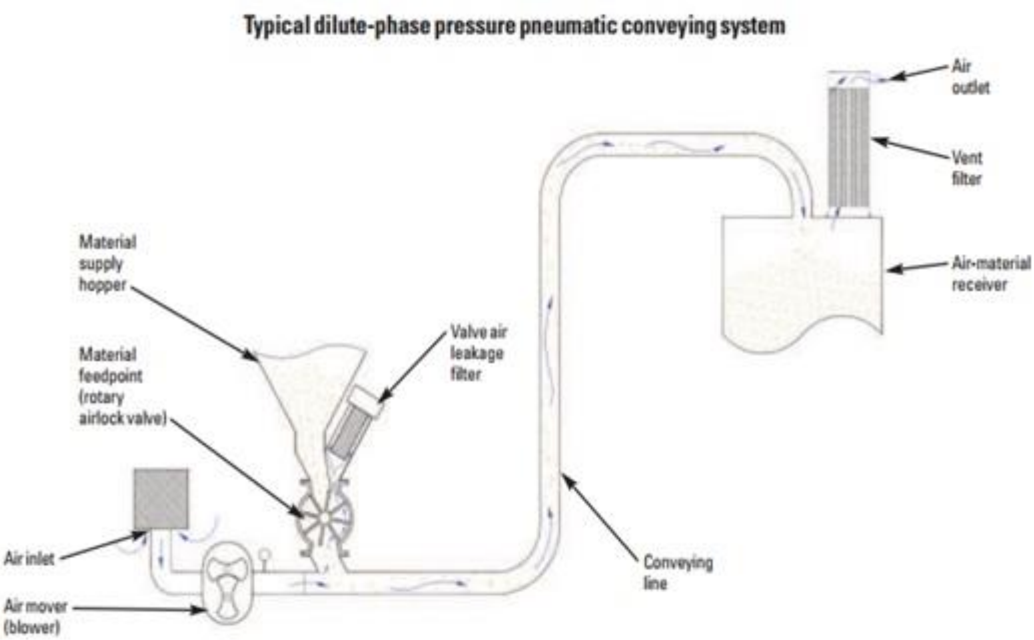


Figure 6 – overpressure system details[20]

3.4 Underpressure systems

In this type of conveying, the underpressure or vacuum is used. It is the blower placed at the end of the pipe system behind the cyclones as is shown in the figure *7* bellow. The main advantage of application of the underpressure system is when a lot of pneumatic lines are meant to aim to the one place. This system is more commonly used in the mill intake from the means of transport as ships or trucks and also at the very end where finish product leaves the factory. This intake and finish product transportation is described in the following article. There vacuum moving tube is used, followed by dust filter to reduce the impurities. [5]

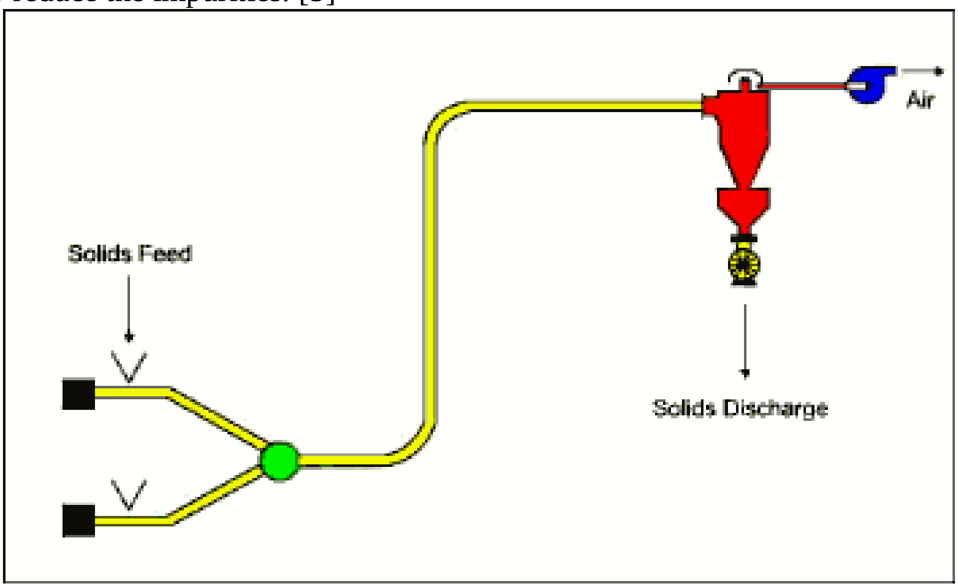


Figure 7 – closed system [20]

3.5 The combination of vacuum and pressure systems

This system works as a combination of two systems described above. Part of the material is transported using vacuum and the second part is pressurised. The system is described in the figure 8

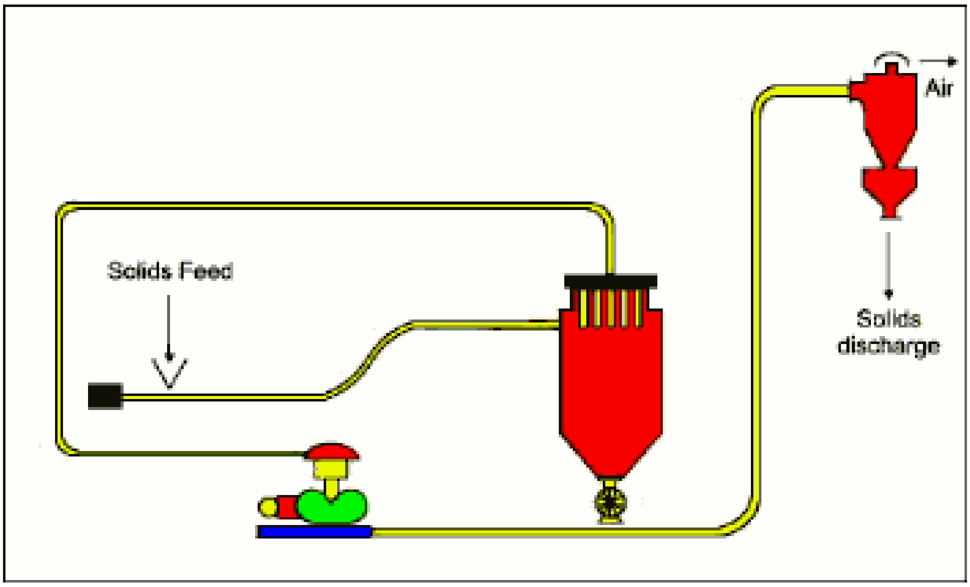


Figure 8 – combined pneumatic conveying system [20]

The system contains of one pressure source, product feeds, product discharges and two separators. Material comes through the vacuum pipe and it is separated from the convey line. Than the material falls through solids feeds into the pipe powered by the same pressure source like is shown in the figure 8. This system is used when the combination of advantages of both systems is required. [6]

3.6 Material delivery and outtake system

Pneumatic conveying system are usually located at one place in the building where conveyed material is than being processed or modified. In order to put the material in process it needs to be transported from its source to the processing hall. In this part, we will shortly go through the transport system that are preceding the pneumatic conveying. The most common form of transported material is in the powdery form; therefore, material should be either packed or bagged and stored. Those are three examples of material delivery and outtake.

<u>Road transport</u>

This is the most used material transport. The typical materials are cement, flour, sugar, polyethylene and many others. The market offers a variety of lorries or trucks. The big advantage is that almost all the locations are easily reachable via roads. On the other hand, the capacities of the factories are so big that it requires a lot of trucks to maintain the desired capacity. In the practise, there are a lot of lorries coming one after another bringing or taking loads. The underground gather storages are very often used for unloading the road vehicles.

<u>Train transport</u>

Very close to the road transporting. Here it is often used the pressure inside carrying car. Big pro is also the amount of transported material. The cars are specially fitted with inclined bottom to help the product reaching the discharge place. The con is that building railway is very expensive and requires a lot of space available around.

Ship transport

The ship transport is the most specified and rarest. The factory must be located near a body of water. The amount of material delivered at once is the highest out of all three possibilities. If the ship does not have his own unloading device the inshore outtake must take place. [12]

This overview describes roughly what types of system we are able to use. For engineer it is important to be aware of all the possible opportunities and situations that may occur. The general information about the pneumatic will help us in choosing the right solution for our system. By this I have fulfilled my task number one 1.

3.7 Material properties

During the conveying, the material travels around the piping and have a significant influence on piping. Material constants have large representation in the physical equations. They have a big impact on the final outcome. It is important to know, that not all materials can be transported the same way. If the incorrectly designed piping is built, the transport system breakdown or the material damage can happen. Here is the list of the most important material properties:

Adhesion

This property is causing big problems during intake, transport and outtake. In the praxis, it causes big problems when stacked to the rotation valve. This is the reason, why the blow through systems are used. Material also can get stuck in corners, edges or cavities and we are trying to avoid it as much as possible by designing the inner shape to be the simplest and straightest.

Flammability

Many materials have the ability of self-ignition and burning when enough oxygen is around. Among those are not only coal, wood but also sugar, flour, cacao and synthetical materials such as plastic, chemical and pharmaceutical materials and metal powders. If the system is closed, there is a possibility of using some other convey gas than air, for example nitrogen. In case of opened system, other safety features are required which are valves or explosion protectors.

Electricity and electrostatic

When the material is transported in the pipe the electrostatic voltage is generated, mainly due to the high air humidity. This situation happens usually in the closed systems. If the material is dense enough, the air humidity does not require adjustment.

Humidity

When transporting materials with high humidity or materials that are wet, are more likely to clog the piping. One of the possible solutions is to use the pre-heated gas, that lowers the chance of material getting stuck in the track.

Granularity

If the grain size does not fit the conditions the material could not be lifted enough. It means that the material tends to fall down and get slower. This could be solved by thickening the matter.

Radioactivity and toxicity

This problem appears only when material with higher radioactivity or toxicity is transported. Transporting such a material must obey special requirements and safety rules. It must be conveyed in the enclosed system with the underpressure system. Also, other special machines must be applied.

[5]

4. Pressure drop calculation

4.1 Quantity implementation

Before deriving all the equation relationship we must implement several quantities that will take part in our calculations.

Velocity ratio β

It is the ratio of the gas and material velocity in the pipeline. It could be expressed like:

$$\beta = \frac{u}{v} \tag{1}$$

Where u is the velocity of the material and v is the velocity of the gas. Its value cannot exceed 1 as the material always has to be slower than the gas that is transported with. [2]

Blend ratio μ

It is the ratio of the mass flow of the material and the mass flow of the gas:

$$\mu = \frac{\dot{M}_m}{\dot{M}} \tag{2}$$

The value can vary from under one to tens. It depends on the type of conveying, material and many other factors. This value has a huge influence on the system. [3]

Porosity ε

This property describes the volume of the material that is in the examined part of volume. It is defined as:

$$\varepsilon = \frac{V_m}{V_{ex}} \tag{3}$$

Where the numerator V_m is the material volume and the denominator V_{ex} is the volume of the mixture of material and gas in the examined part. The porosity value cannot exceed value one as there always have to be the conveying gas in the pneumatic pipeline. [3]

Floating speed u_{vz}

It is also one of the most important quantity in the pneumatic conveying. It is defined as the velocity of the gas in the vertical pipe that is required to keep the bulk of material floating in the air. This property is closely imitating the inner environment in the pipeline. Let's go through a simpler explanation. We take a simple flour practical as an example, whose falling speed is very low (6 mm/s). Now consider a mound of material together as it will be in the pipe. Falling speed of such a dent is much higher than for one particle, therefore another physical approach must be applied. If we would consider the forces on the one particle of the material only, it would not reflect the real behaviour. The material in the pipeline forms into a stream of particles where each has its own aerodynamics but taken as a one unit, the aerodynamics changes. That is why using floating speed will be necessary. Sadly, determination of this velocity cannot be done by the calculation and an experiment will be required. For cases where we do not possess equipment for experiment we will take a bulk of material itself and letting it fall from a high distance while measuring the falling time. This way we can determine the floating speed. This method is not commonly used in the industry however we do not dispose of necessary equipment. The difference between the professional and the primitive method is not so high that the result should be influenced. [2]

4.2 Pressure drop equation

The most basic mathematical equation for the pressure drop calculation is the pressure drop equation. It consists of several parts where each stand for a certain part of the momentum. The elementary form is:

$$\dot{M}\,dv + \dot{M}_m\,du = -A\,dp - \pi d\,ds(\tau + \tau_m) - A\,ds\,C_M\,g\sin(\vartheta) - A\,ds\,\varepsilon\,\rho\,\sin(\vartheta) \tag{4}$$

This equation can be derivate from the conservation of momentum law which states that the change of the material momentum must be equal to the sum of the forces. On the left side, we have momentum change of the gas along with the momentum change of the material. On the right side, we have the pressure force, second part is a friction on the walls and the last two parts stand for gravitational force of the gas and the material. Now we perform a few adjustments to make the equation more suitable for calculations. First, we divide the equation with ($A\ ds$), which represents the volume of the examined part. The pressure force is moved to the left side of the equation and the momentum changes on the other hand were moved to the right-hand side.

$$-\frac{dp}{ds} = \frac{\pi\,\tau\,d}{A}\left(1 + \frac{\tau_m}{\tau}\right) + \left(\frac{\varepsilon\,\rho\,\mu}{\beta}\right) g\sin(\vartheta) + \varepsilon\,\rho\,g\,\sin(\vartheta) + \frac{\dot{M}}{A}\frac{d(v)}{ds} + \frac{\dot{M}_m}{A}\frac{du}{ds} \tag{5}$$

In this case we can substitute the tangential stress τ with friction coefficient λ this way:

$$\frac{\pi\,\tau\,d}{A} = \lambda\frac{1}{d}\frac{v^2}{2}\rho \tag{6}$$

The equation will now form into:

$$-\frac{dp}{ds} = \lambda\frac{1}{d}\frac{v^2}{2}\rho\left(1 + \frac{\tau_m}{\tau}\right) + \left(\frac{\varepsilon\,\rho\,\mu}{\beta}\right) g\sin(\vartheta) + \varepsilon\,\rho\,g\,\sin(\vartheta) + \frac{\dot{M}}{A}\frac{d(v)}{ds} + \frac{\dot{M}_m}{A}\frac{du}{ds} \tag{7}$$

And the same way we can alternate the two mass flows on the right side of the equation, where we know that the mass flow is a product of pipe area A, density ρ and velocity v. [1]

$$\frac{\dot{M}}{A}\frac{d(v)}{ds} = \frac{A\, v\, \varepsilon\, \rho}{A}\frac{d(v)}{ds} = \varepsilon\, \rho\, \frac{1}{2}\frac{d(v^2)}{ds} \tag{8}$$

Same for the other mass flow:

$$\frac{\dot{M}_m}{A}\frac{du}{ds} = \frac{A\, u\, (1 - \varepsilon)\, \rho_m}{A}\frac{du}{ds} = C_M\, \frac{1}{2}\frac{d(u^2)}{ds} \tag{9}$$

After those modifications, we can obtain the general differential pressure drop equation. The resulting image of the equation which will be used in the computing programme is:

$$-\frac{dp}{ds} = \lambda\frac{1}{d}\frac{v^2}{2}\rho\left(1 + \frac{\tau_m}{\tau}\right) + \left(\frac{\varepsilon\, \rho\, \mu}{\beta} + \varepsilon\, \rho\right) g\, \sin(\vartheta) + \varepsilon\, \rho\, \frac{1}{2}\frac{d(v^2)}{ds} + C_M\, \frac{1}{2}\frac{d(u^2)}{ds} \tag{10}$$

, where again the first part on the right side is the friction of the gas and material, second part represents the pressure drop due to lifting the mixture and in the last two parts we have the acceleration of both material and gas. [1] [4]

4.3 Transport coefficient

As you can see, in the first part of the pressure drop equation there is a ratio of the tangential forces that takes place on the pipeline surface. Quantifying those numbers would not be pleasant, hence this ratio can be substituted according to the following equation:

$$\frac{\tau_m}{\tau} = k\, \mu \tag{11}$$

k on the right-hand side is called Gasterstädt coefficient. The general equation will turn into from:

$$-\frac{dp}{ds} = \lambda\frac{1}{d}\frac{v^2}{2}\rho(1 + k\, \mu) + \left(\frac{\varepsilon\, \rho\, \mu}{\beta} + \varepsilon\, \rho\right) g\, \sin(\vartheta) + \varepsilon\, \rho\, \frac{1}{2}\frac{d(v^2)}{ds} + C_M\, \frac{1}{2}\frac{d(u^2)}{ds} \tag{12}$$

The Gasterstädt coefficient is one of the key index in the pneumatic conveying and its value has a huge impact on the whole calculation. [3] There are more approaches how to express it. In the practice, this transport coefficient could be determined by the experiment. Unfortunately, we do not possess such equipment. We have to find another way how to get the value. There are more mathematical ways how to obtain the coefficient. First is the equation for vertical transport. This equation is given for all the mill materials. For the vertical conveying, we have:

$$k_y = c\, \frac{d - 0{,}04}{v^{1{,}33}} \tag{13}$$

Where c is the coefficient for floating speed reaching the value of $c = 240$. [3]

And for the horizontal transport

$$k_x = \frac{150\ d}{v^{1,25}} \tag{14}$$

Although we can also use another formula brought in Vavra's book. This formula is a general expression for determining transport coefficient. The formula is

$$k = \frac{2\ \frac{u_{vz}}{v}\ \cos(\vartheta)}{\lambda \frac{u}{v}\ \frac{1}{Fr}} + \frac{\xi_y}{\lambda}\ \frac{u}{v} \tag{15}$$

Both options can be used. [23]

4.4 Determination of velocity ratio β

In the project, we need to determine by how much faster the gas has to travel to be capable of transporting the given amount of material. To find out we have two options. Either we can find answer in solving the Motion equation or approximate determination using the floating speed. For our purposes, we can use the approximate determination. For horizontal transport, the equation is:

$$\beta_x = 1 - \frac{u_{vz}}{v} \tag{16}$$

And for the vertical transport we will use

$$\beta_y = 1 - (\frac{u_{vz}}{v})^2 \tag{17}$$

[2] [24]

Now when we have all the quantities solved, let's go through each part of the pressure drop equation separately.

5. Solution of the general pressure drop equation for low pressure systems

5.1 Pressure drop from gas friction

It is represented by the first part

$$-\frac{dp}{ds} = \lambda \frac{v^2}{2d} \rho \tag{18}$$

Here we have to make some preconditions for the calculation as such: v, ρ and d will remain constant on the line. When integrated between two examined points on the pipeline, we get:

$$\Delta p_{f1} = \lambda \frac{v^2}{2d} \rho\ s \tag{19}$$

Where s stands for the length of the pipeline. [4]

5.2 Pressure drop from material friction

As mentioned above the friction from material is described in the equation:

$$-\frac{dp}{ds} = \lambda \frac{v^2}{2d} \rho\ k\ \mu \tag{20}$$

Here $v\ \rho\ k\ \mu$ and d will remain constant as we do not take the changes into consideration. Using integration, we obtain:

$$\Delta p_{f2} = \lambda \frac{v^2}{2d} \rho\ \ s\ k\ \mu = \ k\ \mu\ \ \Delta p_{f1} \tag{21}$$

[4]

5.3 Pressure drop from gravitational elevation of the gas

For determination of the gravity pressure drop we take the third part of equation:

$$-\frac{dp}{ds} = \varepsilon\ \rho\ g\ \sin(\vartheta) \tag{22}$$

Here again we assume that ε and ρ remain constant. Simple integration takes us to the form:

$$\Delta p_{g1} = \varepsilon\ \rho\ g\ s \sin(\vartheta) = \ \rho\ g\ s_y \tag{23}$$

Where s_y is the height elevation in the line. [4]

5.4 Pressure drop from gravitational elevation of the material

Pressure drop from the material lift is usually much bigger than in the case of gas and is guided by this equation:

$$-\frac{dp}{ds} = \frac{\varepsilon\ \rho\ \mu}{\beta}\ g\ \sin(\vartheta) \tag{24}$$

After another integration with $\varepsilon\ \rho\ \mu$ and β invariable. the resulting form is:

$$\Delta p_{g2} = \varepsilon\ \rho\ \mu\ \frac{v}{u}\ g\ s \sin(\vartheta) = \ \rho\ \mu\ \frac{v}{u}\ g\ s_y \tag{25}$$

[4]

5.5 Initial acceleration of the gas

At the very beginning where material and gas is being dropped from the feeding, it has zero velocity in the direction of the transport. Therefore, has to be speeded up to the transport velocity. This acceleration is expressed as:

$$-\frac{dp}{ds} = \varepsilon\ \rho\ \frac{1}{2}\ \frac{d(v^2)}{ds} \tag{26}$$

We assume that $\varepsilon\ \rho$ remain constant. This equation can be integrated after a small modification into the shape:

$$\Delta p_{a1} = \rho \frac{v^2}{2} \tag{27}$$

[4]

5.6 Initial acceleration of material

Same as in case of gravitational force, the material acceleration is incomparably larger than gas movement. Guided by equation:

$$-\frac{dp}{ds} = C_M \frac{1}{2} \frac{d(u^2)}{ds} \tag{28}$$

Integration takes place with C_M constant and again resulting in:

$$\Delta p_{a2} = \varepsilon \, \rho \, \mu \, v \, u \tag{29}$$

Neglecting ε and putting its value to 1 we will have:

$$\Delta p_{a2} = \mu \, u \, v \, \rho \tag{30}$$

[4]

5.7 Local pressure drop

Along the pipeline another non-standard pipe parts might be installed. All the irregularities that might affect the pressure have to be added to the equation. Most local pressure drop are bends, sudden enlargement or reduction or the equipment pressure drop. The relationship can be demonstrated using following equation for gas:

$$\Delta p_{l1} = \frac{v^2}{2} \rho \sum \xi \tag{31}$$

And this equation for material

$$\Delta p_{l2} = \mu \frac{v^2}{2} \rho \sum \xi_r \, \gamma \tag{32}$$

Where ξ is the bend coefficient and γ is a bend position coefficient. [3] [1]

All those parts of the equation can be put together using „additive method“, and using that the total pressure drop of the examined part can be expressed as the next relationship shows:

$$\Delta p = \sum \Delta p_i \tag{33}$$

[3] [1]

5.8 Total conveying pressure drop

When we are able to calculate each part separately, the total conveying pressure drop can be reached by summing all the partial pressure drops. That will be done by the following equation:

$$\Delta p_{conv} = \Delta p_{f1} + \Delta p_{f2} + \Delta p_{g1} + \Delta p_{g2} + \Delta p_{a1} + \Delta p_{a2} + \Delta p_{l1} + \Delta p_{l2} \tag{34}$$

This equation puts friction, initial acceleration, gravitational and local pressure drop together into one. By changing the route, velocity or diameter we always obtain a different pressure drop. This way the pipeline can be optimised. [4]

5.9 The pressure drop balance

When we deal with complicated nets of pipes we must be aware that the flowing material tends to choose the path that is easiest to go through. This principal can be demonstrated on a theoretical example when simple pipe splits to two routes and join back again. If we assume that both routes are same, the material will flow in both equally. However, if we put an obstacle in the second of the routes where material has to bypass, its pressure drop rises and we the material will not flow equally in both. Instead the flowing material in the blocked route will slow down to the exact speed to be in balance with the first route. On the other hand, the flow in the first route increases to maintain the same flow as in order to be with low of the conservation of the velocity.

This theory can be applied also when the pipes are joining from many destinations into one common location. The suction force will apply to all of them equally and when one pipe has lower pressure drop the velocity will be adjusted. As we want to maintain the velocity that has been designed we must now balance the pressure drop in all the pipelines. In our example, that would mean putting an obstacle in the first pipe to balance the flow. This will be done in a several steps. [5]

At the beginning we must find the main route that have the biggest resistance force from the beginning until the end where the pipes join. This route has the maximal pressure drop that can be reached in the system. All other routes must be adjusted accordingly to raise the pressure drop and equal it to the value of the biggest pressure drop possible in the main route. Each line must be adjusted individually as the pressure drop varies among all pipes. For that we can use pressure modifiers such as throttling pipe, pipe narrowing or pipe flaps. The pressure modifiers will be installed in each pipe and must be adjusted and regulated. This way the pressure will be maintained in the system. In our case the throttling valves will take place as it is easiest to regulate. Than each line must be connected to a regulator that responds to a real-time values from system gauges. [16]

5.10 The main route

First, we must establish the pipeline with the highest pressure drop. This line will be called the main route. This main route is usually the longest one or with special equipment along the path and does not have to contain the pressure modifiers as it has the highest pressure drop value. We must keep in mind that even though that there is only one line with the biggest pressure drop from the design, the local conditions can change and the maximal pressure drop can occur in more than one pipeline throughout the time. This can easily happen when more the one pipeline is close to the highest pressure drop in the system. [1]

Throttling

In order to throttle the pipe, we must install the pressure modifiers. We are trying to place them to the air pipe only if possible. They must be connected to the pressure and velocity sensors in the pipelines. The regulator will evaluate if there is a difference in velocity or pressure between the general conditions and the individual pipe. The difference will be balanced by regulators. [13] The idea can be explained by this equation for the main route and random route i.

$$\Delta p_{main\,route} = \Delta p_{i-throttling} + i\Delta p_{\,i-route} \tag{35}$$

As both pressure drop from main route $\Delta p_{main\,route}$ and $i\Delta p_{\,i-route}$ pressure drop from i line changes the $\Delta p_{i-throttling}$ value and must always balance the difference.

Regulation

For regulation, we can use the regulators with an immediate respond and good settlement. The regulator settings must be set at the site where the real conditions can be observed. The values from gauges and regulators are sent to the main control room where the main miller can see the real-time values. [13]

Flow synchronism

When we design the pneumatic system, we are given the required mass flow at the beginning and the system must be capable of transporting this mass. During the mills life, the mass flow can change due to various reasons. Those might be that the total material flow will decrease or that the miller decides to produce more of a certain quality. This desynchronism might bring a disbalance in the system. According to the customers' demands, the material flow will stay the same value and unless the conditions will be changed, we can calculate with the given amounts. [4]

The description of the mathematical calculating system is necessary not only for an engineer to summarise all the information but also for the people trying to reach out the solution used in the thesis. By this I consider the task 2 to be accomplished.

6. Plant project description

The pneumatic piping is widely used in the food production industry. There are high requirements for the sanitation and pneumatic transport is highly sanitized compared to other ways of transport. In our case we will deal with the pneumatic design for a mill plant producing all varieties of flour. The site will be composed of the intake building, cleaning section, mill building, outtake and the access route with a parking.

6.1 Building

In our case we will work with a four-floor mill building. The main milling part has a square shape foundations with a 16-m long side. The height does not exceed 15 meters for the roof. It is built from the concrete and steel beams with floor height of three or four meters. The main mill building is also connected to other buildings in the site. It is accessible to all floors to control and maintain all the machines.

6.2 Transport details

In the mill, we will use the combination of the gravitational spouting and pneumatic transport. The situation is clearer from the following figure.

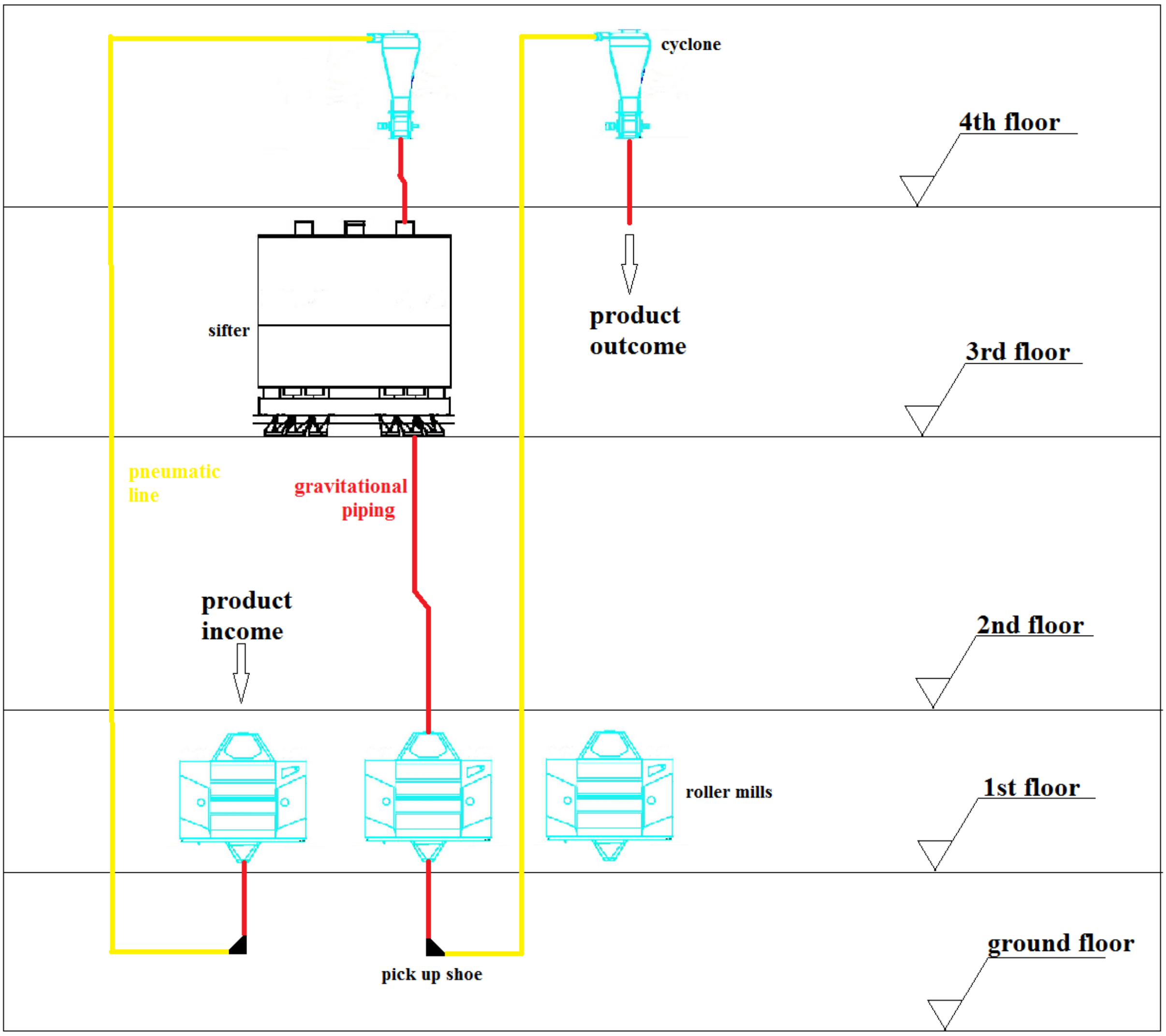


Figure 9 – mill system detail

Here we can see the gravitational piping going down from the sifters situated in the third flow. The gravitational piping is represented by the red colour. The corn gets processed on the way down in the roller mills and then when it reaches the bottom we require to lift it back up. That is where the pneumatic line will be used marked with a yellow colour. As the flour is being processed numerous number of times, it gets various corn sizes and various quality. We must make sure that the different qualities will not get mixed together. Therefore, we have over forty upgoing lines and we have a different quality in each.

6.3 Pipeline design

For our case, we will need 43 pipelines going from different floors in the building. They will all transport flour and deliver it in the destination. After discharge, all the pipes will join in the air collecting duct as it is shown in the model diagram.

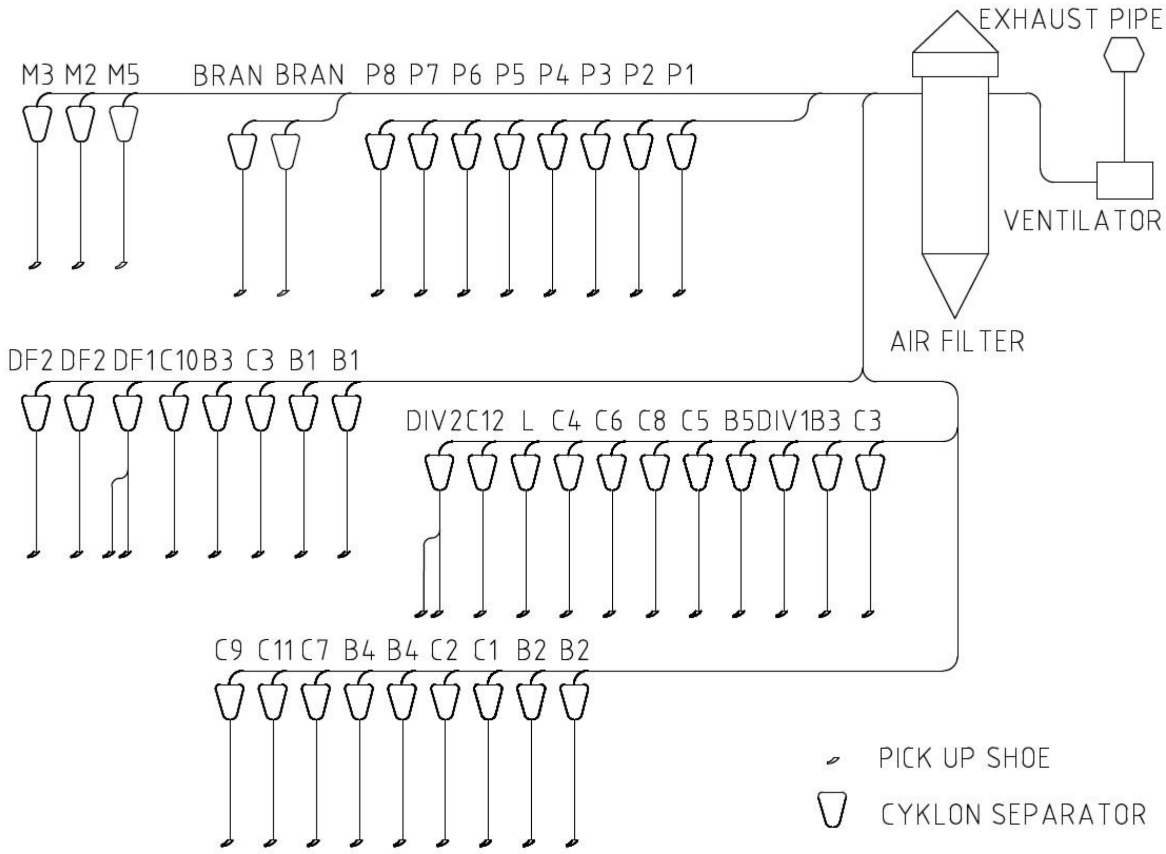


Figure 10 – system scheme

The example of the one typical pipeline can be seen in the next figure. There are solid feed giving the product that is discharged in the top cyclone.

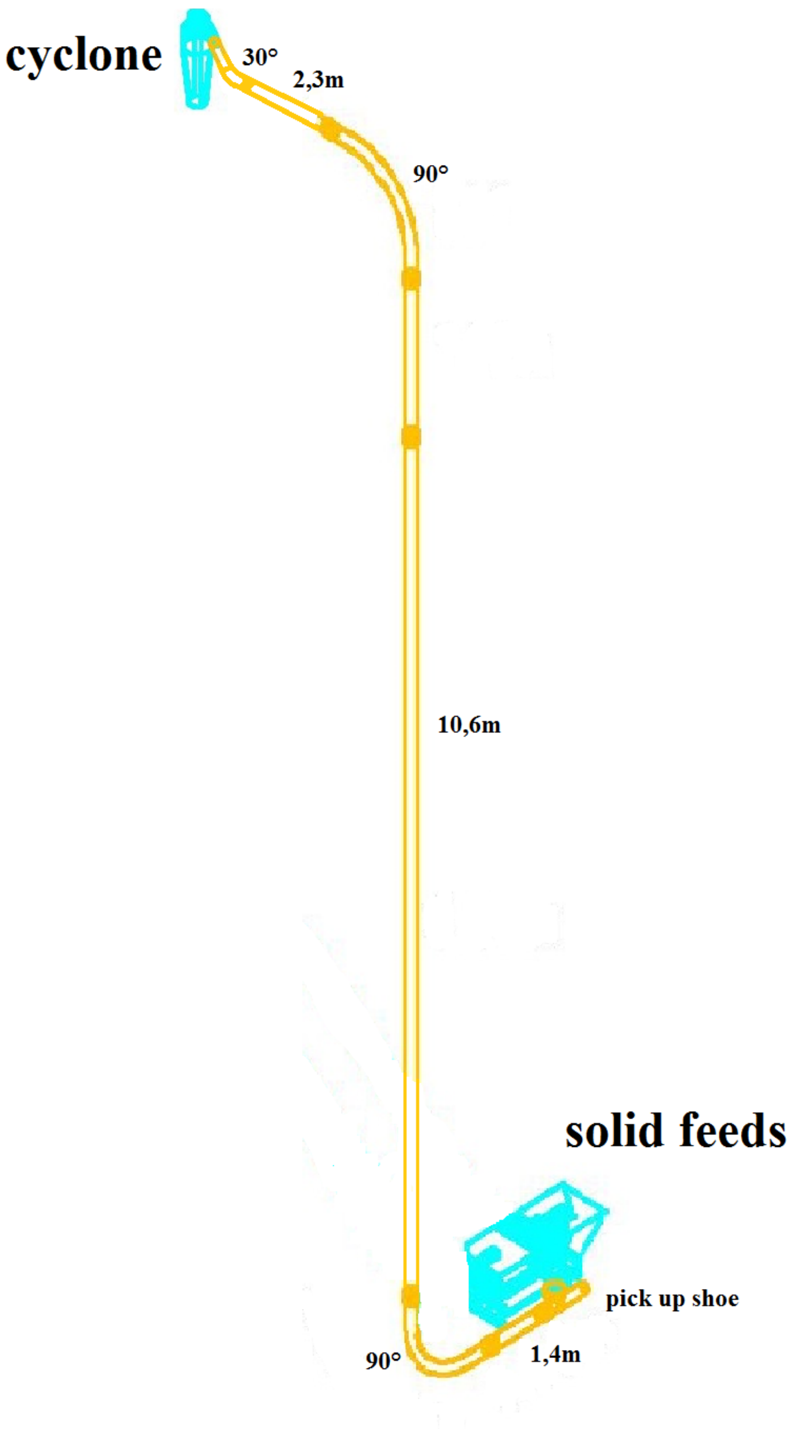


Figure 11 – piping detail

We can see, that the vertical transport is dominant in the overall length. There are 43 of those lines in our project.

Now we will need to know how to distinguish all the lines. We will label each line with a number and a mark. The numbering will start at 1 and going up to 43. The letter mark will represent, what quality of the product we are handling with. This marking is given by the employer to know what quality is in.

No.	Line		No.	Line		No.	Line
1	**B1**		16	**C4**		31	**P7**
2	**B1**		17	**C5**		32	**P8**
3	**B2**		18	**C6**		33	**Br1**
4	**B2**		19	**C7**		34	**DF1**
5	**B3**		20	**C8**		35	**Br2**
6	**B3**		21	**C9**		36	**Br3**
7	**B4**		22	**C10**		37	**L**
8	**B5**		23	**C11**		38	**M2**
9	**Div1**		24	**C12**		39	**M3**
10	**Div2**		25	**P1**		40	**Feed flour**
11	**Div2**		26	**P2**		41	**Bran**
12	**C1**		27	**P3**		42	**Bran**
13	**C2**		28	**P4**		43	**B4**
14	**C3**		29	**P5**			
15	**C3**		30	**P6**			

Table 1 – pipeline marking

The final design of the collecting pipe can be seen in the next figure:

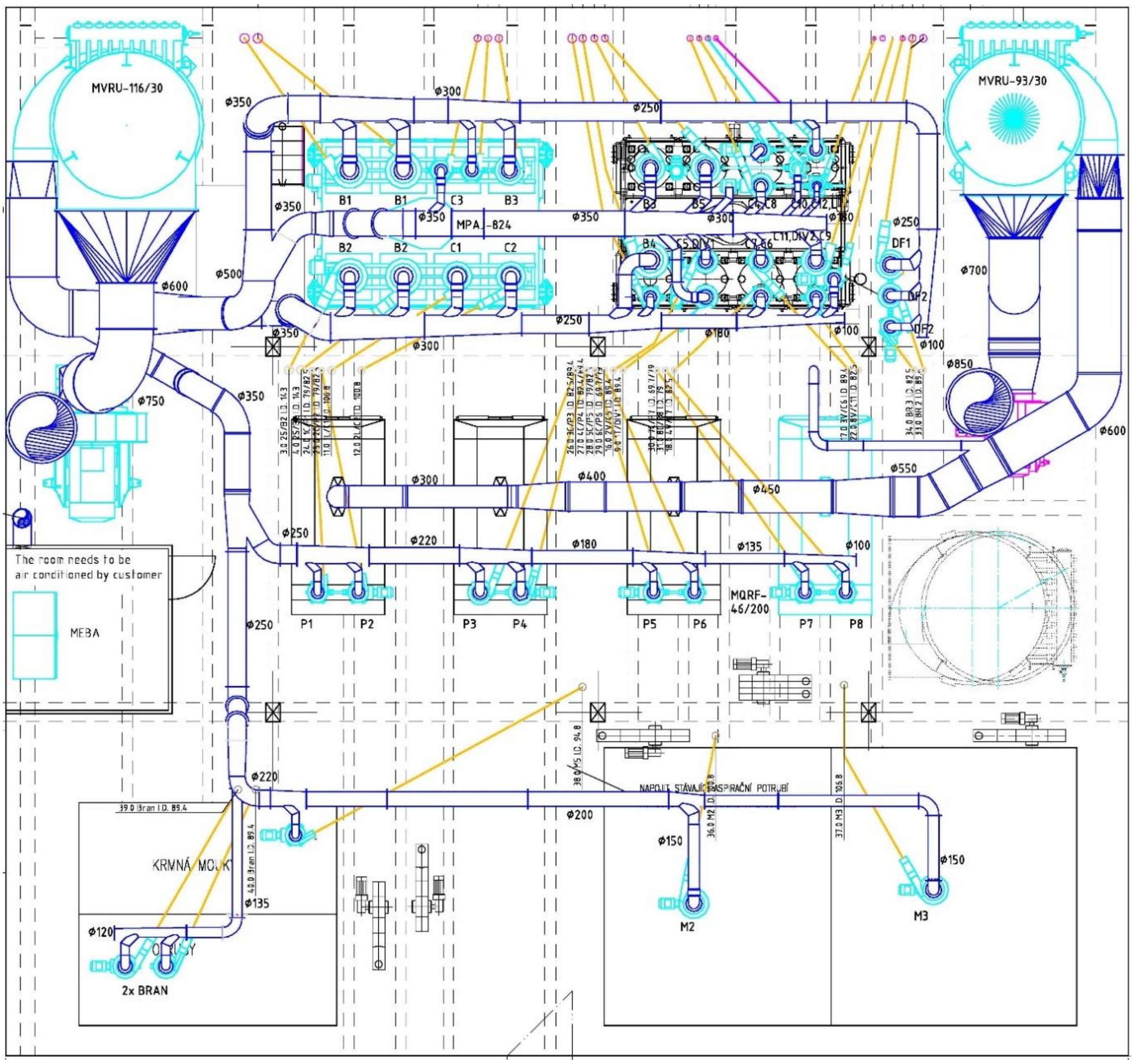


Figure 12 – top floor view

In the figure, we can see a top view of the top floor. There the pneumatic lines near the wall are aimed to its cyclones using yellow colour. The cyclone sends the material down and the air in the air collecting duct. From this on, only air is conveyed in the collecting duct. That is represented here by the blue colour. The air than proceeds into the filter which is displayed in the left top corner. From the filter, we get to the pressure source usually in the form of a ventilator. That is placed on the left side next to the filter. Both filter and ventilator are coloured with bright blue. The air from the ventilator moves on through the exhaust pipe outside the building.

6.4 Machine design

As a part of the project we must summarise which machines are we going to use on the way. It is necessary to determine the total pressure drop. Each machine that material pass through will create an additional pressure drop. This needs to be added to the total amount. When the material pops out of the milling machine it will fall down to the Pick-up shoe.

Pick up shoe

This machine, also called the Alphorn, is a simple piece of pipe which redirects the material flow from the falling down in gravitational pipe to a horizontal direction. It is made from a 90˚ bend with a special suction inlet. This way, the air can enter the system and using that get the product move. The detail can be seen in the figure 13:

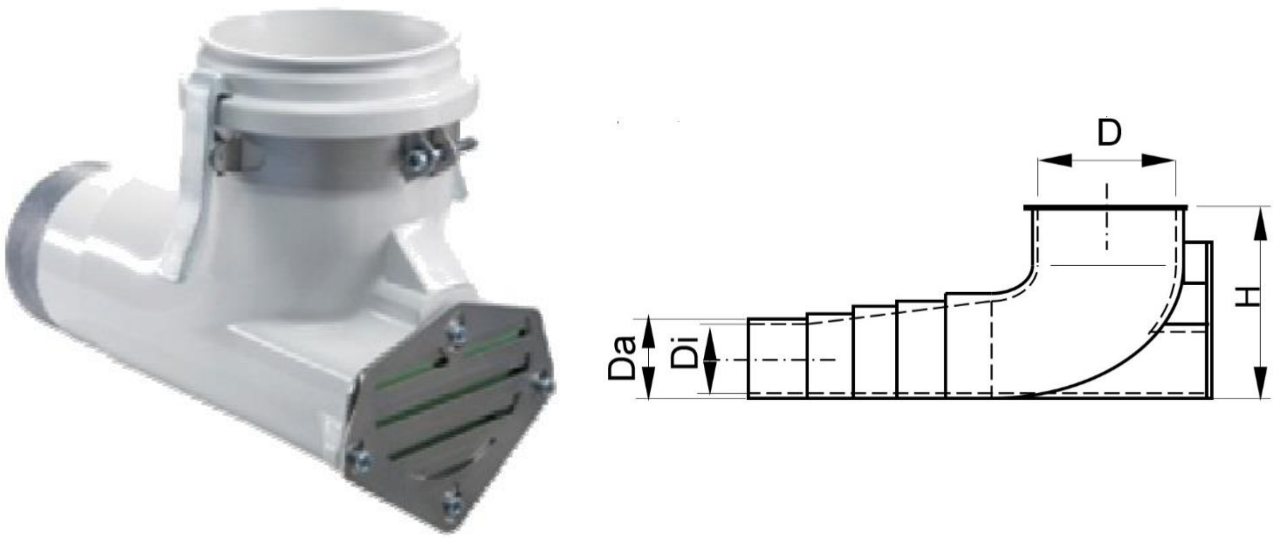
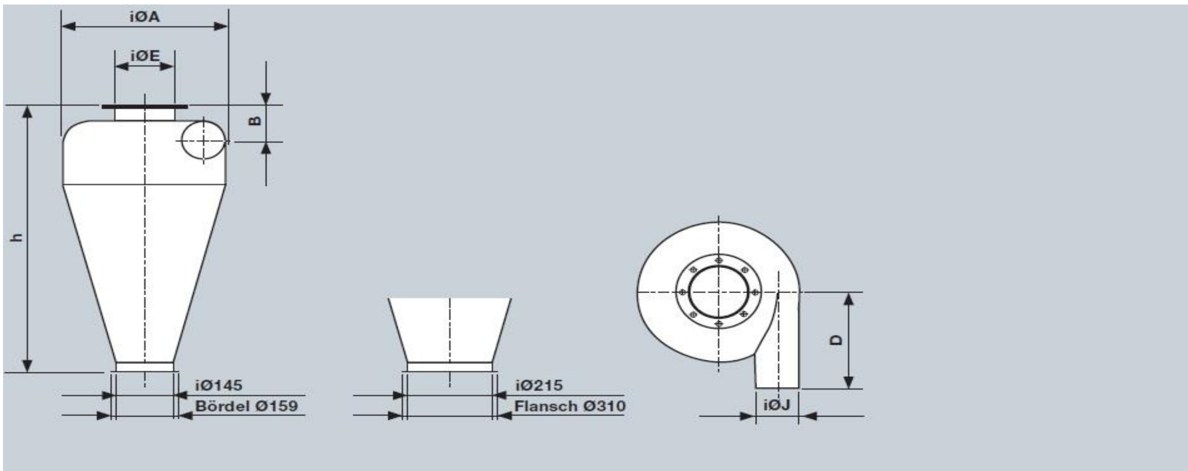


Figure 13 – pick up shoe details

This device will be mounted to all of the pipe lines. From the gravitational spouting, we are able to shift to all of the pipe sizes. [12]

Cyclones

The cyclones are located in the top part separating the mixture to an air and material. For a different mass flow of a material we must choose an appropriate size of the cyclone. We also must be sure that the cyclone is able to separate the given amount of the material. For our case, The MGXE machine fits the best. It has operating in the sufficient range of air flow we need. As will be further described the pressure drop is also small enough to fit. In the following figure, we can see a type that we can use. From the smallest one type 20 up to size 70. The number corresponds with the size of the inner diameter.



Technische Daten.

Modell MGXG	Dimensionen in mm iØA	B	D	h	iØE	iØJ	Approx. Gewichte in kg Standard Version	Verstärkte Version	Rostfreie Version	Volumen Seeverpackt m^3
20	200	81.5	200	800	65	58.9	7	–	7	0.11
24	240	87.5	220	800	80	70.9	9	–	9	0.13
28[1]	280	93.5	240	800	100	83.1	11	24	11	0.16
34[1]	340	100	260	800	120	95.8	13	29	13	0.21
41[1]	410	106.0	290	800	150	107.9[3]	15	33	15	0.27
41[1]	410	118.2	290	800	150	132.5[3]	15	33	15	0.27
50[1]	500	118.2	330	800	180	132.5[3]	18	40	18	0.37
50[1]	500	132.1	330	800	180	160.3	18	40	18	0.37
60[1,2]	600	144.3	400	1350	250	184.7[3]	43	95	43	0.9
70[1,2]	700	157	450	1350	300	210.1[3]	50	111	50	1.2

Figure 14 – cyclone sizes [12]

With the machine description, we must take care that inner volume is able to separate desired amount and have a pressure drop low enough. This we can verify in the pressure drop/air volume graph:

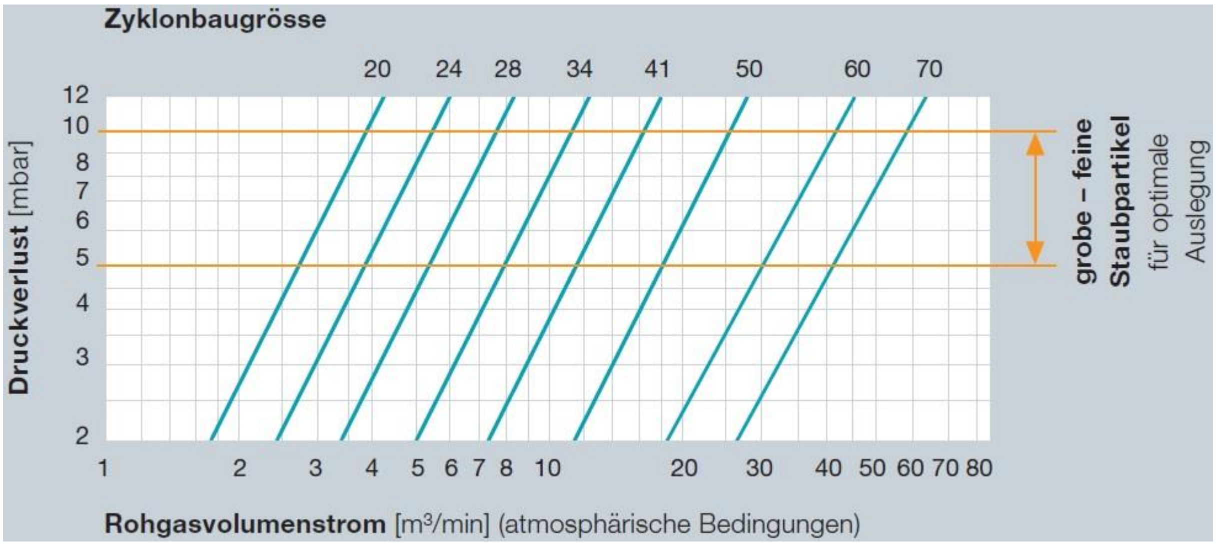


Figure 15 – cyclone pressure drop diagram [12]

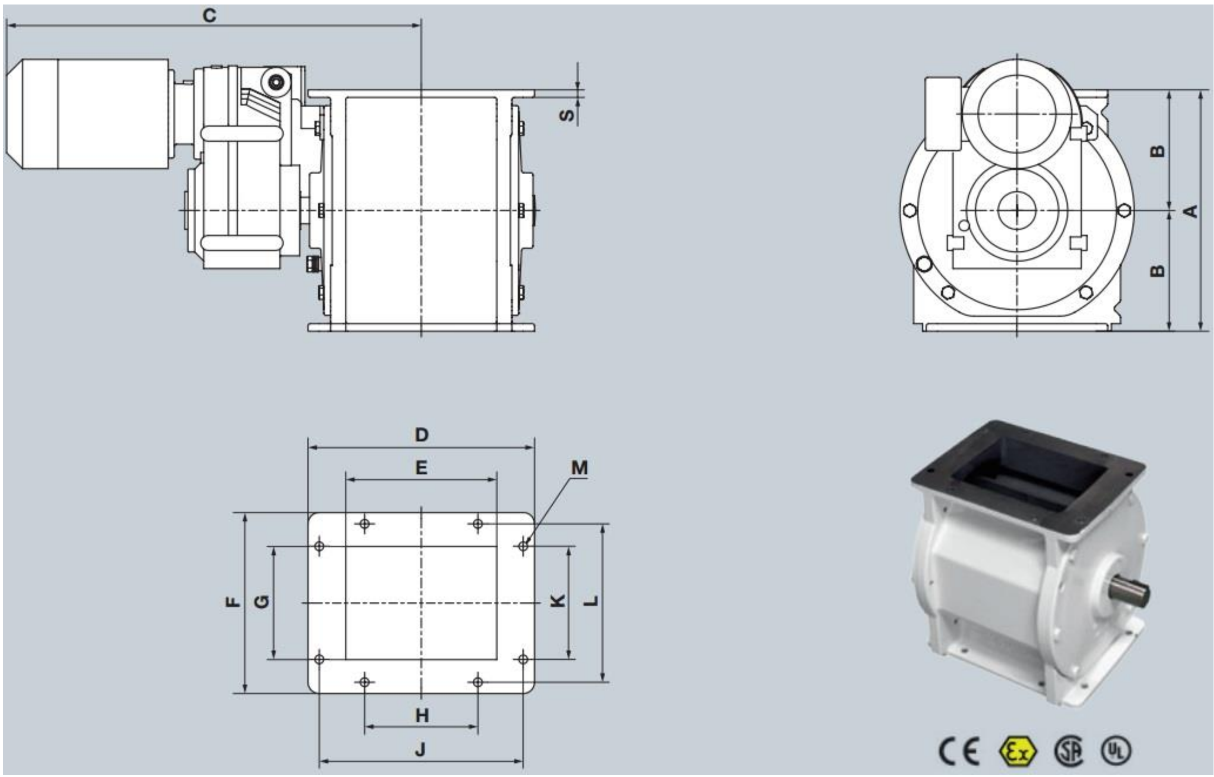
Here we have all kinds of cyclones available and with a known air flow we can determine the pressure drop.

No.	air flow [m3/min]	MGXE type	dp [Pa]	No.	air flow [m3/min]	MGXE	dp [Pa]	No.	air flow [m3/min]	MGXE	dp [Pa]
1	**18**	50	500	16	**6,4**	34	310	31	**4,7**	28	370
2	**18**	50	500	17	**6,4**	34	310	32	**4,7**	28	370
3	**14,8**	50	350	18	**6,4**	34	310	33	**12**	50	225
4	**14,8**	50	350	19	**5,5**	28	520	34	**7,7**	-	0
5	**14,8**	50	350	20	**4,7**	28	400	35	**6,4**	34	325
6	**9,8**	41	400	21	**4,7**	28	400	36	**5,5**	28	500
7	**9,8**	50	350	22	**5,5**	28	550	37	**4,7**	24	650
8	**8,5**	41	275	23	**5,5**	28	550	38	**10,3**	41	400
9	**6,4**	34	320	24	**2,3**	20	350	39	**11,8**	41	550
10	**8,5**	34	550	25	**5,5**	28	500	40	**8,9**	34	650
11	**6,7**	-	0	26	**5,5**	28	500	41	**6,4**	34	330
12	**9,8**	41	375	27	**6,4**	34	320	42	**6,4**	34	330
13	**8,5**	41	275	28	**6,4**	34	320	43	**5,6**	28	520
14	**5,2**	28	450	29	**5,5**	28	510				
15	**5,2**	28	450	30	**4,7**	28	370				

Table 2 – cyclone pressure drop

Air lock

When the corn gets separated, we need to make sure that what the material leaves the cyclone, there will not be too much air leakage from the system. For this reason, we use air locks.



Dimensions (mm)

Airlock MPSN	A	B	C	D	E	F	G	H	J	K	L	M	S
25/15	320	160	520	220	120	240	150	100	175	100	205	M10	5
25/23	320	160	560	300	200	240	150	150	270	150	210	11.5	5
28/30	350	175	640	370	270	320	220	200	335	200	285	13.5	6

Technical data

Airlock MPSN	Rotor volume	Weight (incl. drive)	Volume (incl. drive)	Pressure range	
				Operating pressure	Maximum pressure
25/15	5.8 dm^3	85 kg	0.14 m^3	0.6 bar	0.8 bar
25/23	9.0 dm^3	100 kg	0.16 m^3		
28/30	14.6 dm^3	115 kg	0.20 m^3		

Configuration

Standard	No ATEX zone
ATEX	Zone 22 (external)
ExP	Explosion pressure shock resistant until 3.5 bar EC type examination for ATEX zone 20/dust class 1

Figure 16 – air lock machine dimensions

The air lock is mounted right under the cyclone making sure that there is no air leaving the enclosed system. The air lock passes the material to the next stage of process and designing this kind of machine does not depend on the mass flow. The presence of the machine itself does not have a big influence on the total pressure drop. [12]

Filter

In order, not to get the pressure source jammed we need to install the filter in the air collecting duct. This filter will protect the pressure source from dust and corn particles to get in and cause a breakdown. The filter requires more space compared to other machines and that is why in needs to be placed close to the pressure source. The size of the filter will have to be determined by the amount of air. For this following table will help us:

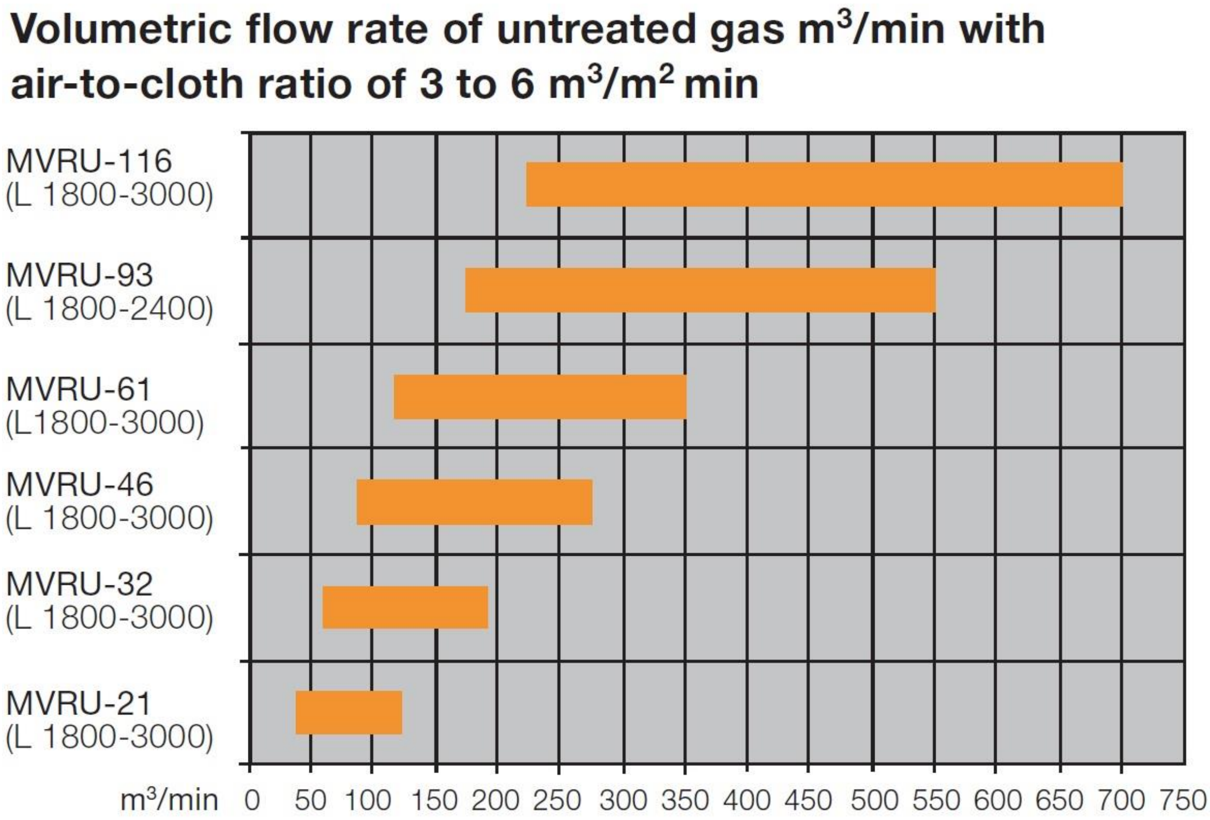
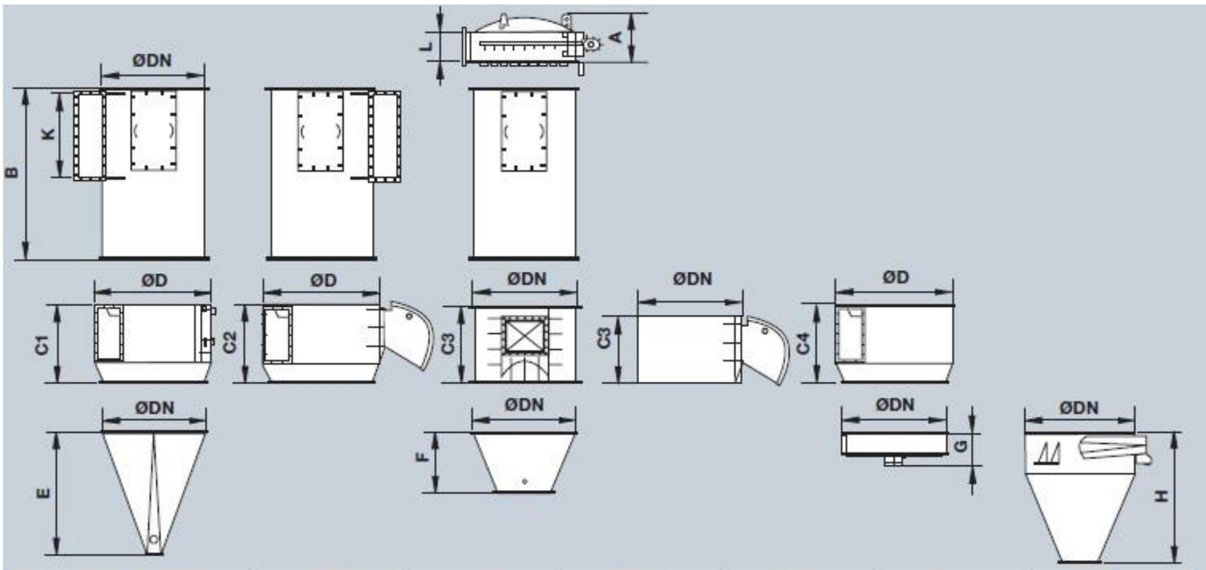


Figure 17 – filter size diagram

As our air flow reaches over $330\ m^3/min$ we should use the biggest type MVRU-116. This will guarantee the safety coefficient to be big enough not only for the current system, but also for the possible future expansion. The characteristic of the chosen filter is:



Filter type MVRU		21			32			46			61			93			116		
Bag length [dm]		18	24	30	18	24	30	18	24	30	18	24	30	18	24	30	18	24	30
Filter area [m²]		13.4	18.1	21.1	20.4	27.5	32.0	29.5	39.6	46.0	39.1	52.5	61.0	59.6	80.8	93.0	73.6	99.8	116.0
Top filter section	A	720			720			720			720			720			720		
Bag chamber	B	1990	2530	3130	1990	2530	3130	1990	2530	3130	1990	2530	3130	1990	2530	3130	1990	2530	3130
Intermediate section	C1	990			990			1140			1140			1290			1290		
Intermediate section	C2	1040			1040			1290			1290			1290			1290		
Intermediate section	C3	750			750			1000			1000			1000			1000		
Intermediate section	C4	990			990			1140			1140			1290			1290		
Diameter	DN	1000			1140			1340			1500			1840			2020		
Diameter	D	1200			1340			1540			1700			2040			2220		
Height of cone	E[1)]	1000/1200			1200/1400			1460/1660			1600/1860			2230/2430			2330/2540		
Height of cone	F	310			500			770			890			1450			1720		
Height of discharger	G	620			620			620			620			1010[2)]			1180[2)]		
H. of total separator	H[3)]	1270/1510/1510			1730/1730														
Air outlet (height x width)	L	424 x 450			424 x 600			424 x 750			424 x 950			424 x 1400			424 x 1900		
Air inlet (height x width)	K[4)]	590 x 215/ 750 x 215			590 x 270/ 850 x 270			740 x 300/ 1100 x 300			740 x 360/ 1250 x 360			890 x 500/ 1250 x 500			890 x 550/ 1550 x 500		

1) To MPSN and MPSJ airlock, mild or stainless steel
2) For MVRU-93 and MVRU-116, discharger of MVRU-61 with transition cone
3) MVRU-21 to MPSJ-36/38 / MPSJ-45/45 / MPSJ-60/60 airlock, MVRU-32 to MPSJ-45/45 / MPSJ-60/60 airlock
4) Mild steel and stainless bottom inlet / stainless top inlet

Rotation increments of the components
MVRU-21 and -32 15°
MVRU-46 and -61 11.25°
MVRU-93 and -116 9°

Figure 18 – filter dimensioning

The space in the mill is big enough for the filter to be placed. The filter will be taking air from the pipe of from cyclones. After the filtration, the air will go directly to the pressure source. [12]

Now we must make sure that we have chosen the right size of the filter. The dust particles will get stuck in the filter cloth. For this we have to make sure that the filter is capable of proper filter function. We will verify using the air-to-cloth ratio. This value describes how much air will get cleaned compared to the size of the filter cloth. It is given by:

$$\varphi = \frac{\dot{V}}{A} \tag{36}$$

Where $\dot{V}$ is the total air flow and A represents the area of the filter cloth? The value is usually around 1 – 3,5. When we take the total air flow which we will obtain, when we sum the air flow from all of the pipelines, we get $\dot{V} = 339\ m^3/min$. Now we will substitute the values from our chosen filter 116 with $116\ m^2$ colth area and get:

$$\varphi = \frac{\dot{V}}{A} = \frac{339}{116} = 2{,}92 \tag{37}$$

This value of A/C is higher than usual for us. The conveyed material is rough, cooled and dry which are conditions making the situation safer. The mixture is also unstuck and as the safety feature, every thirty second the counter air will blow through the filter cloth to make it unpolluted. This will keep our filter more jam resistant and improve the lifetime. The filter is also a part of the air system therefore we must include the machine pressure drop in the equation. The new machine will have lower pressure drop as during the time the filter will get more and more clogged. Hence, we calculate with the values at the end of the anticipated lifecycle. The machine pressure drop in the air flow of range $300 - 350\ m^3/min$ is $\Delta p_{filter} = 1500\ Pa$.

7. System pressure drop calculation

We have pipeline in our system that will be conveying the material up to its destinations. The pressure drop calculation will be performed with the pressure drop equation (10). For easier orientation, we have split the equation into four parts where each part represents the force that is causing the pressure to drop. As we have two substances flowing in the pipe (gas and material) we will have to calculate the force for each one individually.

7.1 System overview

System in the mill requires forty-one lines transporting matter from a specific machine in the bottom part to the milling machines at the top. As we have a material transported from a lot of places around to building to the top narrow part, it is convenient to choose a under pressured system. In the figure, we can see a diagram of our system.

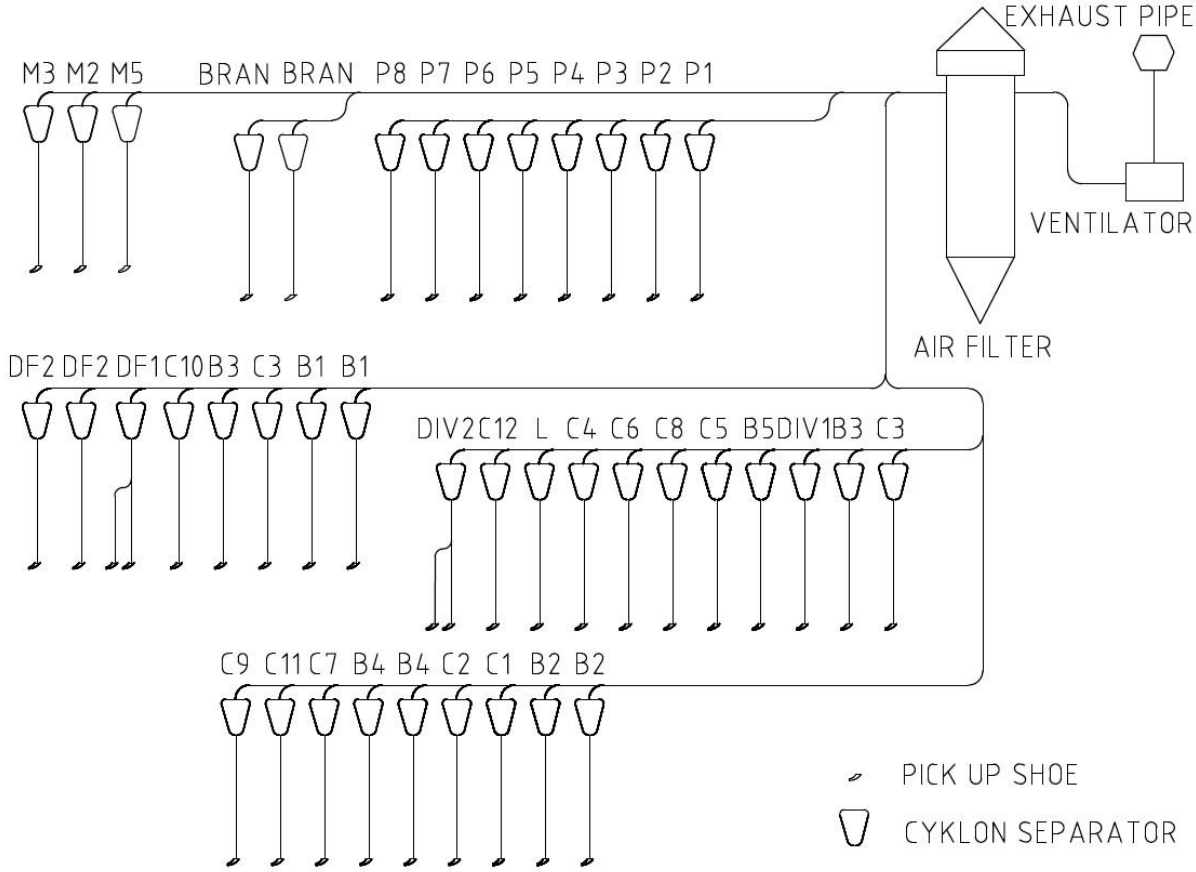


Figure 19 – system diagram

In the figure, we can see the layout of all the lines. There material is picked up in the bottom of the building. That is performed in the pick-up shoe and then transported to the cyclone separator. In the cyclone separator material gets separated from the air and falls down to the mills in the gravitational pipe. The air than proceeds to the air filter where it is cleaned from unwanted dust. The air filter is installed mainly to protect the upcoming pressure source from getting jammed. The air is than pushed out of the building using the exhaust pipe.

7.2 System design

When we know what machines we are going to use and where the piping should go in the building, we have to propose a design of the pipe itself. We will have to deal with the diameter and the air velocity first. Those two parameters will be the key values we must define. Those two parameters are also bounded together. When we try to maintain the material mass flow given by the customer we must bear in mind that the bigger diameter we choose, the lower velocity will be required. It is not an exception in praxis that the calculation must be repeated many times before we reach the appropriate result.

I have chosen an appropriate diameter for each pipe. Those diameters have been chosen according to my company tutors recommendation and with respect to older calculations of a similar project and also in relation to keep the value of area load. I have tried to keep the rule of designing as following: For the lowest mass flows of $\dot{M}_m = 0 - 1500\ kg/h$ I have chosen a small diameter around $d = 64 - 77{,}3\ mm$, for $\dot{M}_m = 1500 - 2500\ kg/h$ it should be $d = 83{,}1 - 95{,}8\ mm$. Than for $\dot{M}_m = 2500 - 3500\ kg/h$ we have large diameter $d = 95{,}8\ -$

102,2 mm and over $\dot{M}_m = 3500\ kg/h$ there is the biggest diameters $d = 120 - 132\ mm$. In the design, we will also have some exception for those rules. Those are the lines which are significantly short or shaped differently than others.

The correctness of those diameter design will be proven in the optimisation chapter where we will see what is the best theoretical diameter for the given conditions.

For our case, we will use these values of diameters:

No.	Type	Mat. flow	diameter	No.	Type	Mat. flow	diameter	No.	Type	Mat. flow	diameter
		[kg/h]	d [mm]			[kg/h]	d [mm]			[kg/h]	d [mm]
1	**B1**	5100	132,5	16	**C4**	1800	83,1	31	**P7**	1500	70,9
2	**B1**	5100	132,5	17	**C5**	2000	83,1	32	**P8**	1500	70,9
3	**B2**	4100	120,6	18	**C6**	1800	83,1	33	**Br1**	2500	102,2
4	**B2**	4100	120,6	19	**C7**	1600	77,3	34	**DF1**	500	83,1
5	**B3**	3100	102,2	20	**C8**	1500	70,9	35	**Br2**	2000	83,1
6	**B3**	3100	102,2	21	**C9**	1400	70,9	36	**Br3**	1800	77,3
7	**B4**	4500	120,6	22	**C10**	1400	77,3	37	**L**	600	64,8
8	**B5**	2500	95,8	23	**C11**	1500	77,3	38	**M2**	2000	95,8
9	**Div1**	2000	83,1	24	**C12**	600	49,4	39	**M3**	1500	102,2
10	**Div2**	3500	102,2	25	**P1**	1600	77,3	40	**Feed flour**	1000	89,2
11	**Div2**	800	77,3	26	**P2**	1600	77,3	41	**Bran**	1500	83,1
12	**C1**	3000	102,2	27	**P3**	1800	83,1	42	**Bran**	1500	83,1
13	**C2**	2500	95,8	28	**P4**	2000	83,1	43	**B4**	700	70,9
14	**C3**	1300	77,3	29	**P5**	1600	77,3				
15	**C3**	1300	77,3	30	**P6**	1500	70,9				

Table 3 – pipeline diameter proposal

The diameters are in a ratio with a material flow. The lower the material flow, the smaller diameter will be necessary. Now we will focus on the air flow. By knowing the material mass flow and diameter we have obliquely determined the air flow as $\dot{M}_m = f(d, u, v, \rho)$. The velocities will be:

No.	Type	Mat. flow	velocity	No.	Type	Mat. flow	velocity	No.	Type	Mat. flow	velocity
		[kg/h]	v [m/s]			[kg/h]	v [m/s]			[kg/h]	v [m/s]
1	**B1**	5100	21	16	**C4**	1800	19	31	**P7**	1500	19
2	**B1**	5100	21	17	**C5**	2000	19	32	**P8**	1500	19
3	**B2**	4100	21	18	**C6**	1800	19	33	**Br1**	2500	21
4	**B2**	4100	21	19	**C7**	1600	19	34	**DF1**	500	23
5	**B3**	3100	19	20	**C8**	1500	19	35	**Br2**	2000	19
6	**B3**	3100	19	21	**C9**	1400	19	36	**Br3**	1800	19

7	**B4**	4500	20	22	**C10**	1400	19	37	**L**	600	23
8	**B5**	2500	19	23	**C11**	1500	19	38	**M2**	2000	23
9	**Div1**	2000	19	24	**C12**	600	20	39	**M3**	1500	23
10	**Div2**	3500	17	25	**P1**	1600	19	40	**Feed flour**	1000	23
11	**Div2**	800	23	26	**P2**	1600	19	41	**Bran**	1500	19
12	**C1**	3000	19	27	**P3**	1800	19	42	**Bran**	1500	19
13	**C2**	2500	19	28	**P4**	2000	19	43	**B4**	700	23
14	**C3**	1300	18	29	**P5**	1600	19				
15	**C3**	1300	18	30	**P6**	1500	19				

Table 4 – pipeline gas velocity

7.3 The gas friction pressure drop

As it was said earlier the gas friction is guided by the equation no. 19

$$\Delta p_{f1} = \lambda \frac{v^2}{2d} \rho\, s \tag{38}$$

The pipeline length s is determined from the 3D design. For the calculation, we also need to know λ which is a pipe friction coefficient. This value will be determined by the Arching equation. For that equation, we need to know the Reynolds number Re of the pipe.

This value of Reynolds will be different for each pipe as the relationship is dependent on the gas velocity:

$$Re = \frac{v\, d}{\nu} \tag{39}$$

Where ν stands for dynamic viscosity and its value can be $\nu = 1{,}8\ 10^5$ for air with temperature around $20^o C$.

The friction coefficient will be determined by the Altsul equation:

$$\lambda = \frac{1}{(1{,}82 \log\left(\frac{Re}{100}\right) + 2)^2} \tag{40}$$

Out that we are able to determine the friction coefficient λ. [4]

After this we can substitute the values into the equation and obtain:

No.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]
1	18	520		12	9,8	610		23	5,5	900		34	7,7	760
2	18	550		13	8,5	720		24	2,3	1020		35	6,4	670
3	14,8	510		14	5,2	1040		25	5,5	530		36	5,5	650
4	14,8	550		15	5,2	1000		26	5,5	460		37	4,7	1570
5	14,8	620		16	6,4	910		27	6,4	540		38	10,3	870
6	9,8	650		17	6,4	770		28	6,4	480		39	11,8	1060

7	9,8	540	18	6,4	720	29	5,5	510	40	8,9	1360
8	8,5	590	19	5,5	870	30	4,7	550	41	6,4	900
9	6,4	620	20	4,7	910	31	4,7	670	42	6,4	900
10	8,5	580	21	4,7	1040	32	4,7	760	43	5,6	1470
11	6,7	1140	22	5,5	930	33	12	690			

Table 5 – gas friction pressure drop

7.4 The material friction pressure drop

For material pressure drop calculation we have equation no. 21

$$\Delta p_{f2} = \lambda \frac{v^2}{2d} \rho \; s \, k \, \mu = \; k \, \mu \; \Delta p_{f1} \tag{41}$$

Where we already have a transport coefficient k determined according to equation 13 and 14. However we have two transports coeffects k_x for horizontal transport and k_y for vertical transport. We must now split the equation and calculate horizontal and vertical equation separately. As the Δp_{f1} is dependent on the pipe length $\Delta p_{f1} = f(s)$ we must substitute in the equation and we obtain following:

$$\Delta p_{f2} = \; \mu \, \lambda \; \frac{v^2}{2d} \rho \; (k_x \, s_x + k_y \, s_y) \tag{42}$$

The blend ratio μ is also known as a ratio of the material flow given from the customer and gas flow known from the design. [4] Now we only need to substitute the real values resulting in:

No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]
1	18	780	12	9,8	780	23	5,5	690	34	7,7	120
2	18	840	13	8,5	830	24	2,3	400	35	6,4	680
3	14,8	660	14	5,2	840	25	5,5	500	36	5,5	610
4	14,8	720	15	5,2	800	26	5,5	420	37	4,7	300
5	14,8	820	16	6,4	840	27	6,4	540	38	10,3	500
6	9,8	870	17	6,4	730	28	6,4	520	39	11,8	460
7	9,8	890	18	6,4	600	29	5,5	470	40	8,9	450
8	8,5	660	19	5,5	700	30	4,7	480	41	6,4	690
9	6,4	620	20	4,7	650	31	4,7	620	42	6,4	690
10	8,5	1230	21	4,7	730	32	4,7	620	43	5,6	340
11	6,7	280	22	5,5	680	33	12	610			

Table 6 – material friction pressure drop

7.5 The gravitational forces from gas

The gravitational force from gas is guided by the equation no. 23

$$\Delta p_{g1} = \varepsilon \, \rho \, g \, s \sin(\vartheta) = \rho \, g \, s_y \tag{43}$$

In this case we only need the vertical part of the pipe, as we do not consider the material lift within the horizontal pipe. [4] The result is:

No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]
1	18	130	12	9,8	130	23	5,5	140	34	7,7	90
2	18	130	13	8,5	130	24	2,3	60	35	6,4	90
3	14,8	130	14	5,2	140	25	5,5	50	36	5,5	90
4	14,8	130	15	5,2	140	26	5,5	50	37	4,7	150
5	14,8	140	16	6,4	130	27	6,4	50	38	10,3	130
6	9,8	140	17	6,4	140	28	6,4	50	39	11,8	130
7	9,8	130	18	6,4	140	29	5,5	50	40	8,9	120
8	8,5	130	19	5,5	140	30	4,7	50	41	6,4	130
9	6,4	90	20	4,7	140	31	4,7	50	42	6,4	130
10	8,5	130	21	4,7	140	32	4,7	90	43	5,6	150
11	6,7	140	22	5,5	140	33	12	90			

Table 7 – gas lift pressure drop

7.6 The gravitational forces from material

The gravitational forces lifting up the material are significantly higher that the gravitational forces for air lift. The equation for material gravitational force is written in the previous chapter as number 25:

$$\Delta p_{g2} = \varepsilon \, \rho \, \mu \, \frac{v}{u} \, g \, s \sin(\vartheta) = \rho \, \mu \, \frac{v}{u} \, g \, s_y \tag{44}$$

In this case we have all the necessary values for the calculation, [4] so the calculation comes up with values:

No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]
1	18	570	12	9,8	620	23	5,5	570	34	7,7	80
2	18	570	13	8,5	600	24	2,3	240	35	6,4	460
3	14,8	530	14	5,2	560	25	5,5	230	36	5,5	470
4	14,8	550	15	5,2	560	26	5,5	230	37	4,7	280
5	14,8	660	16	6,4	560	27	6,4	230	38	10,3	370
6	9,8	660	17	6,4	650	28	6,4	260	39	11,8	250
7	9,8	630	18	6,4	570	29	5,5	230	40	8,9	210
8	8,5	570	19	5,5	620	30	4,7	250	41	6,4	460
9	6,4	460	20	4,7	650	31	4,7	260	42	6,4	460
10	8,5	870	21	4,7	630	32	4,7	430	43	5,6	270
11	6,7	240	22	5,5	540	33	12	310			

Table 8 – material lift pressure drop

7.7 The initial acceleration of the gas

The gas which is the main driving medium also needs to be speeded up to the required velocity as to transport the material. For this we used equation no. 27.

$$\Delta p_{a1} = \rho \frac{v^2}{2} \tag{45}$$

[4] The quantities are also known and they are resulting in:

No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]
1	18	280	12	9,8	230	23	5,5	220	34	7,7	330
2	18	280	13	8,5	230	24	2,3	240	35	6,4	230
3	14,8	270	14	5,2	200	25	5,5	220	36	5,5	220
4	14,8	270	15	5,2	200	26	5,5	220	37	4,7	330
5	14,8	230	16	6,4	230	27	6,4	230	38	10,3	340
6	9,8	230	17	6,4	230	28	6,4	230	39	11,8	340
7	9,8	250	18	6,4	230	29	5,5	220	40	8,9	330
8	8,5	230	19	5,5	220	30	4,7	230	41	6,4	230
9	6,4	230	20	4,7	230	31	4,7	230	42	6,4	230
10	8,5	180	21	4,7	230	32	4,7	230	43	5,6	330
11	6,7	330	22	5,5	220	33	12	280			

Table 9 – gas acceleration pressure drop

7.8 The initial acceleration of the material

Again, the initial acceleration of the material is significantly larger than in the case of air. It is caused by the difference in densities of the materials. The initial material acceleration represents a large part in the whole pressure drop. [4] The determining equation is the equation number 30.

$$\Delta p_{a2} = 2 \ \mu \ \frac{u}{2} \ \rho v^2 \tag{46}$$

The results are shown in the following table:

No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]	No.	air flow [m3/min]	dp [Pa]
1	18	2130	12	9,8	1910	23	5,5	1620	34	7,7	570
2	18	2110	13	8,5	1760	24	2,3	1570	35	6,4	1860
3	14,8	2060	14	5,2	1290	25	5,5	1650	36	5,5	1930
4	14,8	2050	15	5,2	1300	26	5,5	1670	37	4,7	1150
5	14,8	1970	16	6,4	1670	27	6,4	1610	38	10,3	1750
6	9,8	1960	17	6,4	1910	28	6,4	1810	39	11,8	1130
7	9,8	2100	18	6,4	1730	29	5,5	1650	40	8,9	970
8	8,5	1800	19	5,5	1740	30	4,7	1890	41	6,4	1390
9	6,4	1870	20	4,7	1990	31	4,7	1860	42	6,4	1390
10	8,5	1880	21	4,7	1830	32	4,7	1930	43	5,6	1100

11	6,7	1080		22	5,5	1510		33	12	1520				

Table 10 – mass acceleration pressure drop

7.9 Local pressure drop

In our building, the local pressure drops are mainly caused by pipe bending, inlets, outlets and machines such as filters or sensors. The pressure drop from the machines is always known from the machine brochure. I will focus mainly on the pressure drop from bends in the pipe track. That is written in the equation number 31:

$$\Delta p_{l1} = \frac{v^2}{2} \rho \sum \xi \tag{47}$$

And for material there is an equation number 32:

$$\Delta p_{l2} = \mu \frac{v^2}{2} \rho \sum \xi \gamma \tag{48}$$

Here we have ξ as a bend coefficient which is related to the pipes we are using. This coefficient has to be obtained from the manufacturers. Second multiple γ is bend position coefficient. The value comes into 1 or 4 depending on the bend position. In case the bend is redirecting the material flow from horizontal to vertical direction heading up the bend position coefficient comes to the value of 4. In all other cases, the coefficient reaches value 1. [3] Now we look at the pressure loss from the gas in each pipe is:

No.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]
1	18	30		12	9,8	20		23	5,5	30		34	7,7	0
2	18	30		13	8,5	20		24	2,3	20		35	6,4	20
3	14,8	30		14	5,2	20		25	5,5	20		36	5,5	20
4	14,8	30		15	5,2	20		26	5,5	20		37	4,7	30
5	14,8	20		16	6,4	20		27	6,4	20		38	10,3	50
6	9,8	20		17	6,4	30		28	6,4	20		39	11,8	70
7	9,8	40		18	6,4	20		29	5,5	20		40	8,9	50
8	8,5	20		19	5,5	30		30	4,7	20		41	6,4	20
9	6,4	20		20	4,7	20		31	4,7	30		42	6,4	20
10	8,5	20		21	4,7	20		32	4,7	20		43	5,6	30
11	6,7	30		22	5,5	20		33	12	30				

Table 11 – gas local pressure drop

And for the material:

No.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]
1	18	250		12	9,8	220		23	5,5	290		34	7,7	0
2	18	250		13	8,5	210		24	2,3	190		35	6,4	220

3	14,8	240		14	5,2	150		25	5,5	200		36	5,5	230
4	14,8	240		15	5,2	150		26	5,5	200		37	4,7	130
5	14,8	230		16	6,4	200		27	6,4	200		38	10,3	300
6	9,8	230		17	6,4	330		28	6,4	220		39	11,8	270
7	9,8	370		18	6,4	200		29	5,5	200		40	8,9	170
8	8,5	210		19	5,5	310		30	4,7	230		41	6,4	160
9	6,4	220		20	4,7	230		31	4,7	350		42	6,4	160
10	8,5	230		21	4,7	210		32	4,7	230		43	5,6	130
11	6,7	120		22	5,5	180		33	12	180				

Table 12 – material local pressure drop

[3] [1]

7.10 Total conveying pressure drop calculation

In order to obtain the pressure drop from the conveying part we now must sum all the partial pressure drops. This will be done by simple equation:

$$\Delta p_{conv} = \Delta p_{f1} + \Delta p_{f2} + \Delta p_{g1} + \Delta p_{g2} + \Delta p_{a1} + \Delta p_{a2} + \Delta p_{l1} + \Delta p_{l2} \tag{49}$$

The final table shows and determine which line will be our main pipeline route.

No.	air flow [m3/min]	dp [Pa]		Nr.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]		No.	air flow [m3/min]	dp [Pa]
1	18	5210		12	9,8	4940		23	5,5	5060		34	7,7	1980
2	18	5290		13	8,5	4820		24	2,3	4120		35	6,4	4590
3	14,8	4810		14	5,2	4730		25	5,5	3940		36	5,5	4780
4	14,8	4920		15	5,2	4660		26	5,5	3810		37	4,7	4630
5	14,8	5130		16	6,4	4890		27	6,4	3770		38	10,3	4750
6	9,8	5200		17	6,4	5140		28	6,4	4120		39	11,8	4290
7	9,8	5330		18	6,4	4550		29	5,5	3900		40	8,9	4360
8	8,5	4500		19	5,5	5190		30	4,7	4100		41	6,4	4350
9	6,4	4480		20	4,7	5270		31	4,7	4470		42	6,4	4340
10	8,5	5690		21	4,7	5280		32	4,7	4710		43	5,6	4380
11	6,7	3400		22	5,5	4800		33	12	3980				

Table 13 – total pressure drop

7.11 The air collecting duct calculation

The air collecting duct is a gas pipe that is gathering all the air that is separated in cyclones. As the gas is the only one flowing in the pipe, we choose the shortest way to connect all the lines and aim the pipe into the blower room. There the filter and blower are places. From the blower, the pipe is heading outside of the building through exhaust pipe. This layout is visualised in the figure 12. The Air collecting duct does not usually represent a big pressure drop in the system, but in order to cover all the possible threads, we will now perform the air collecting duct calculation. [5]

In the air collecting duct we will only deal with gravitational and friction forces and local pressure drop. The initial acceleration will not take a part since the air already comes from a cyclone with at given velocity. The calculation will be guided by the equations 19, 23 and 31. The diameter, and air flow changes a lot along the pipe so for that we need to divide the pipe into zones where the pipe conditions are similar and we can use our equation. The zones can be seen in the figure 20.

Now we must apply our equations to all of the zones separately and the sum the pressure drops for each zone as well according to the following equation:

$$\Delta p_{ACD} = \Delta p_{ACDf} + \Delta p_{ACDg} + \Delta p_{ACDl} \tag{50}$$

The collecting duct pressure drop will have three elements to calculate. We have a gas friction Δp_{ACDf}, then we must add the gravitational pressure drop Δp_{ACDg} and finally we must also take local pressure losses into account with Δp_{ACDl}.

After the substituting in all the sections we obtain:

$$\Delta p_{ACD} = \lambda \frac{v^2}{2d} \rho \, s + \rho \, g \, s_y + \frac{v^2}{2} \rho \sum \xi \tag{51}$$

The three sums represent the three elements described above. In that case λ is a friction coefficient from equation number 40. The velocity can be calculated from the air flow in each given zone according to:

$$v = \frac{4 \, \dot{V}}{\pi \, d^2} \tag{52}$$

The route s is known from the design and local drop coefficient ξ is known from the pipeline type. [5] Now we will calculate the sections of air collecting duct. First, we will have to divide the piping into sections with the same attributes. The sections can be seen in the following figure:

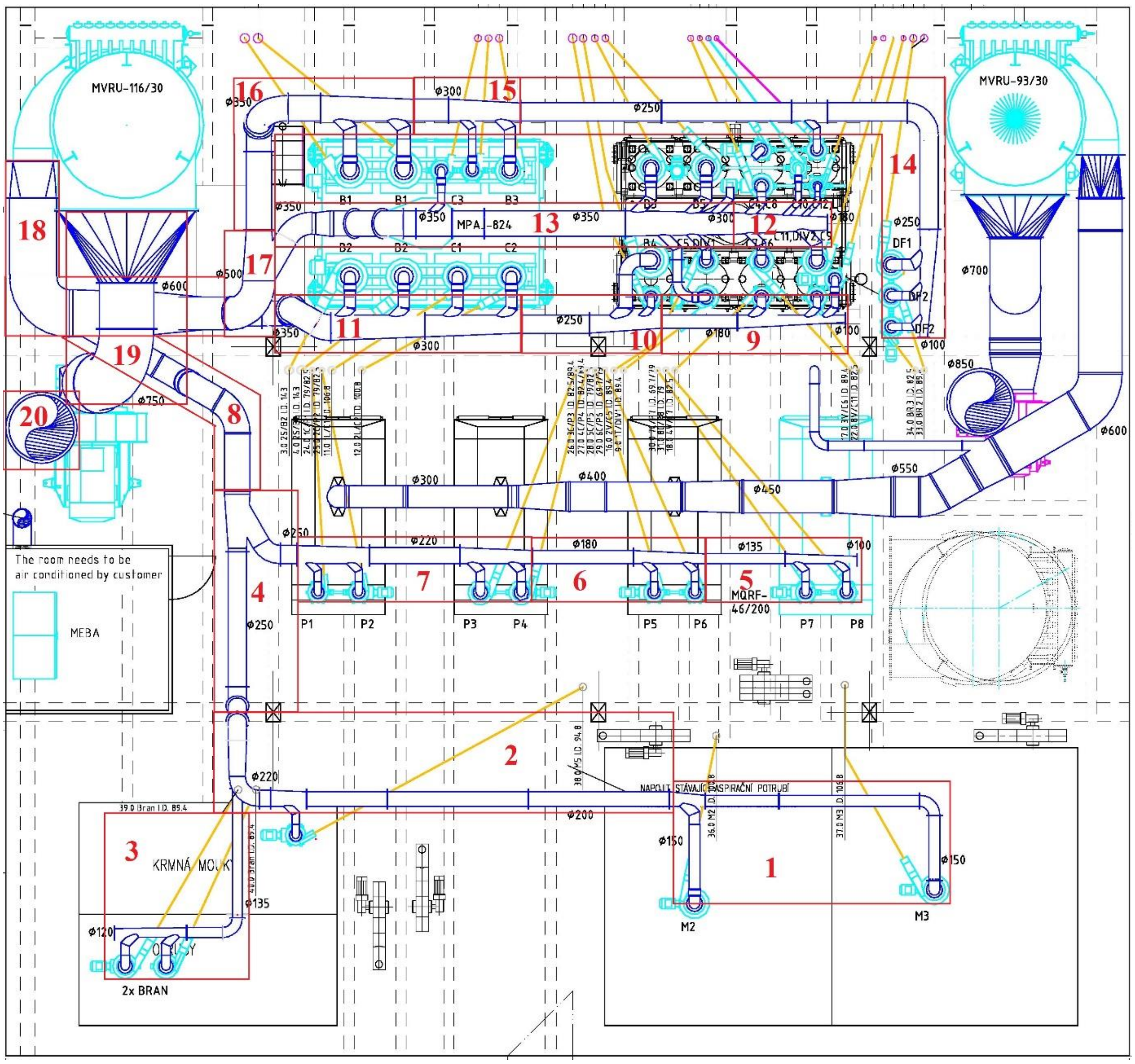


Figure 20 – air collecting duct sections layout

In each section, we will calculate the pressure drop and add it to the total pressure drop. The velocities should obey the rule, that the air velocity should increase moderately from the lines to the filter and after filter drop to low speed. In the figure 20 we can see, that some sections have pipelines joining along the path of a section. My calculation was based on simplification that the air joining the section from lines would run through pipe from the beginning until the end of a section. This way we can be sure that our pressure drop value cannot be exceeded.

The final image of results is:

No.	velocity	diameter	pressure drop	No.	velocity	diameter	pressure drop
	v [m/s]	d [mm]	dp [Pa]		v [m/s]	d [mm]	dp [Pa]
1	10	150	60	11	12	300	40
2	11	200	100	12	12	250	10
3	14	135	110	13	11	350	80
4	11	250	30	14	10	250	60
5	10	135	20	15	10	300	0

6	12	180	30		16	14	350	60
7	14	220	40		17	13	500	10
8	13	350	50		18	13	600	30
9	10	180	20		19	8	750	40
10	12	250	10		20	6	900	60

Table 14 – air collecting duct pressure drop

From the result, we can see that the real pressure drop values of collecting pipe are too small to make a difference in the total overall amount of pressure drop. This theory can be verified in the pressure drop comparison. The average value of the pneumatic line is $\Delta p_{pa} = 4600\ Pa$. The average value of a pressure drop in the air collecting duct after summing the section to the paths $\Delta p_{ACDa} = 230\ Pa$. The air collecting duct makes only 5% of the overall pressure drop. Therefore, we will only add the values to the main line. The next chapter describes the main line.

8. The main line

When we now have all the pressure drops from all lines we must now determine the main route. Out of the calculation we can see that the highest-pressure drop is in the line 10-Div 2 with 5690 Pa. This line goes from the bottom of the mill and reaches up to the top of the building. It is one of the longest pipelines. We also must keep in mind that not only the conveying part but also the air collecting duct system must be involved. Nevertheless, as is clear from the air exhaust calculation the air collecting duct has a negligible value of the pressure drop. This is caused by a very short route from the cyclones and primarily by the fact that only the air is transported in the pipes.

All the final calculation will be concentrated around this line. Its detail can be seen in the following figure.

Figure 21 – the main line routing

The main line sets up from the pick-up shoe and using two 90° bends, going up to the cyclone level. Now we will add the air collecting duct pressure drop to the line. The pressure drop from air collecting duct will be easily calculated by summing the sections along the path to the ventilator. That means summing all pressure drops from the cyclones up to the end of the pipe exhaust. This we can do by summing all the parts from the figure 20 using the data from the table no. 14. If we have a look on the figure 20, we can see that the main line is going through sections 12,13,17,18,19 and 20. There we can see that we must sum the sections:

$$\Delta p_{ACD} = \Delta p_{12} + \Delta p_{13} + \Delta p_{17} + \Delta p_{18} + \Delta p_{19} + \Delta p_{20} = 235\ Pa \tag{53}$$

To this we also must add a pressure drop from the connecting air coming from the pipe fitting. We will do this by calculating the pressure drop from the air joining the main pressure line. This calculation will be done for the all the side gas flows joining the main line. In the figure 20 we can see that we have nine pipes joining the main line. The calculation will be performed according to:

$$\Delta p_{side} = \xi \frac{v^2}{2} \rho \tag{54}$$

Where ξ is a coefficient of pipe fitting depending on the angle and ratio of air flow. For our case, the average value of the coefficient will be 0,15 taken from the general air piping tables. The v in this case is a velocity of a stream after the fitting.

In the following table we can see the results of the pressure drops from the joining air streams. If we have a look on the figure 20, we can see that the main line is going through sections 12,13,17,18,19 and 20. In this main line we have 9 pipes joining starting with C12 until the last joining of different section. Each line represents one air stream joining the main line. The table shows all 9 pipes on the main line and now we must sum all of them to get the total pressure drop Δp_{side} acting on the main line.

No.	type	velocity [m/s]	dp [Pa]
1	C12	12	13
2	C10	12	13
3	C6	12	13
4	C4	12	13
5	C5	11	10
6	B5	11	10
7	B3	11	10
8	C3	11	10
9	pt 16	14	17

Table 15 – the main line fitting pipe

Summing is making this fitting pressure drop $\Delta p_{side} = 109\ Pa$. This value will be added to the conveying pressure drop Δp_{conv} along with the pressure drop of the filter Δp_{filter} and the air collecting duct pressure drop Δp_{ACD}. Those are all pressure drops we calculated for the main line we calculated in the previous chapters. This is an important value for filter design.

$$\Delta p_{ctot} = \Delta p_{conv} + \Delta p_{ACD} + \Delta p_{filter} + \Delta p_{side} = 5694 + 235 + 1500 + 109 = 7539\ Pa \tag{55}$$

This value is also a confirmation that we are indeed handling with the low-pressure system.

<u>Pneumatic calculation programme</u>

All the values and results have been calculated in the pneumatic calculation programme created in Microsoft excel. In the programme, it is possible to change values real time and obtain results instantly. This will come in hand in the optimisation performed in the next following chapters. The programme can be used not only for pressure drop of the piping, but also includes the section for adding the machine pressure, quick overview tables and interactive optimisation graphs. The computation pages have all the parameters displayed with respective equations and basic explanation. By doing this I have accomplished the aim number 5.

8.1 The pressure drop balance

The throttling

For throttling we will have to place a pressure modifier in the piping. In our building, we will use the throttle valve placed right above the cyclone. We can see that as the air passes through the device there are paddles placed in the way. These paddles have an adjustable angle and as the angle rotates from perpendicular to parallel, the pressure drop can be regulated. The exact angle and must be determined at the site.

The regulation

Every throttle valve will be fitted with the regulator and connected to pressure and velocity gauges in the pipeline. The most suitable will be PID regulator with short time response. Every change of conditions has an immense consequence in velocity difference. The difference must be corrected in the matter of seconds if possible.

The pressure drop calculation is the key in this master thesis and reaching the total pressure drop I have fulfilled the task number 3.

8.2 Pressure source design

The pressure source design is one of the crucial parts of the work. It is one of the most expensive part of the equipment in the project. Pressure source, in our case ventilator, is a machine creating the required underpressure in the pipe. If we neglect the initial cost of equipment purchase (piping, machines and other equipment) and maintenance is the only one machine that will consume a lot of power energy and therefore the cost of running are significantly higher than for other machines. For those reasons, we should make sure that our chosen ventilator will cover the system requirements with a sufficient safety coefficient and also fit to the economic plans of the company.

A ventilator design is working with a several properties. We must first calculate values for the total air flow $\dot{V}$ and also for the total pressure difference Δp. We also must be aware that ventilator will have its own efficiency that must be taken into account. The total air flow $\dot{V}$ will be obtain by simple summing all the air flows from the lines:

$$\dot{V} = \sum b\,\dot{V}_i = 6{,}2\ [m^3/s] \tag{56}$$

Where b is a safety coefficient with a value of 1,1. Sometimes during installation, the pipe may be exposed to a defection and air leakage. By adding the safety coefficient, we will try to compensate the air leakage effect.

Next, we need to calculate the required performance using formula:

$$P = \dot{V}\ \Delta p \tag{57}$$

This way we determine what performance we require from the ventilator to be delivered in the system. Now we have to consider the ventilator efficiency η. This value states how much actual energy will be given to the system. For the total ventilator input power, we must calculate with:

$$P_I = \frac{P}{\eta} \tag{58}$$

The value of η should be provided by the seller. This way we can calculate the required power for of the ventilator. [4] Now we must insert the the calculated values into equation 57:

$$P = \dot{V}\ \Delta p = 6{,}215 \times\ 7539 = 46\ 852\ W \tag{59}$$

We must now choose suitable ventilator machine.

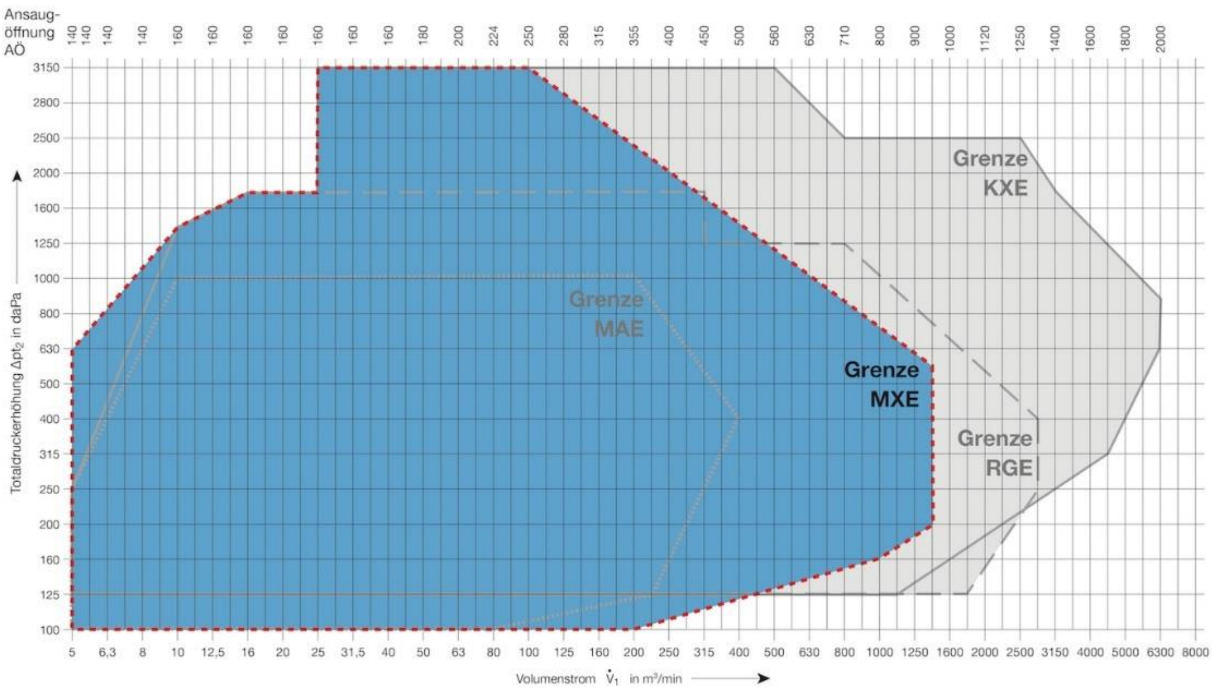


Figure 22 – ventilator type diagram

In the figure from Reitz Group we can see that the MXE type is powerful enough to fulfil the system requirements. From the Reitz company, it is possible to write down the ventilator properties to a form and order a ventilator suited for given conditions.

The Reitz ventilator will have an efficiency of $\eta = 0{,}68$ as it is shown in the document in the appendix. Therefore, the resulting Income power is established by:

$$P_I = \frac{P}{\eta} = \frac{46\ 852}{0{,}68} = 68\ 900\ W. \tag{60}$$

Now as the ventilator is one of the most important parts we must now be sure that it will be meeting the demands. In our calculation, we have made a several simplifications to make the calculation easier. Moreover, as has been said the design conditions may have differ from the real conditions. For those reasons we have to bring the safety condition in. Out of the experience of the designer and the recommendation from the employer we will rise the required conditions by 20%. It will be assuring that the negligences, inaccuracies, and condition differences will be eliminated. The safety coefficient will gain the value of $b = 1{,}2$. This will transform out final equation no. 60 into:

$$P_I = \frac{P\ b}{\eta} = \frac{46\,852\ \times 1{,}2}{0{,}68} = 82\,680\ W. \quad (61)$$

The chosen ventilator has the following characteristics:

Manufacturer:	Reitz Group
type:	MXE
medium:	Air
rotation speed:	2850 [1/min]
Motor power:	92 [kW]
Motor frequency:	50 [Hz]

Table 16 – ventilator characteristics

Figure 23 – ventilator details

Together with the ventilator we can have a look on the ventilator characteristics sent directly from the Reitz company.

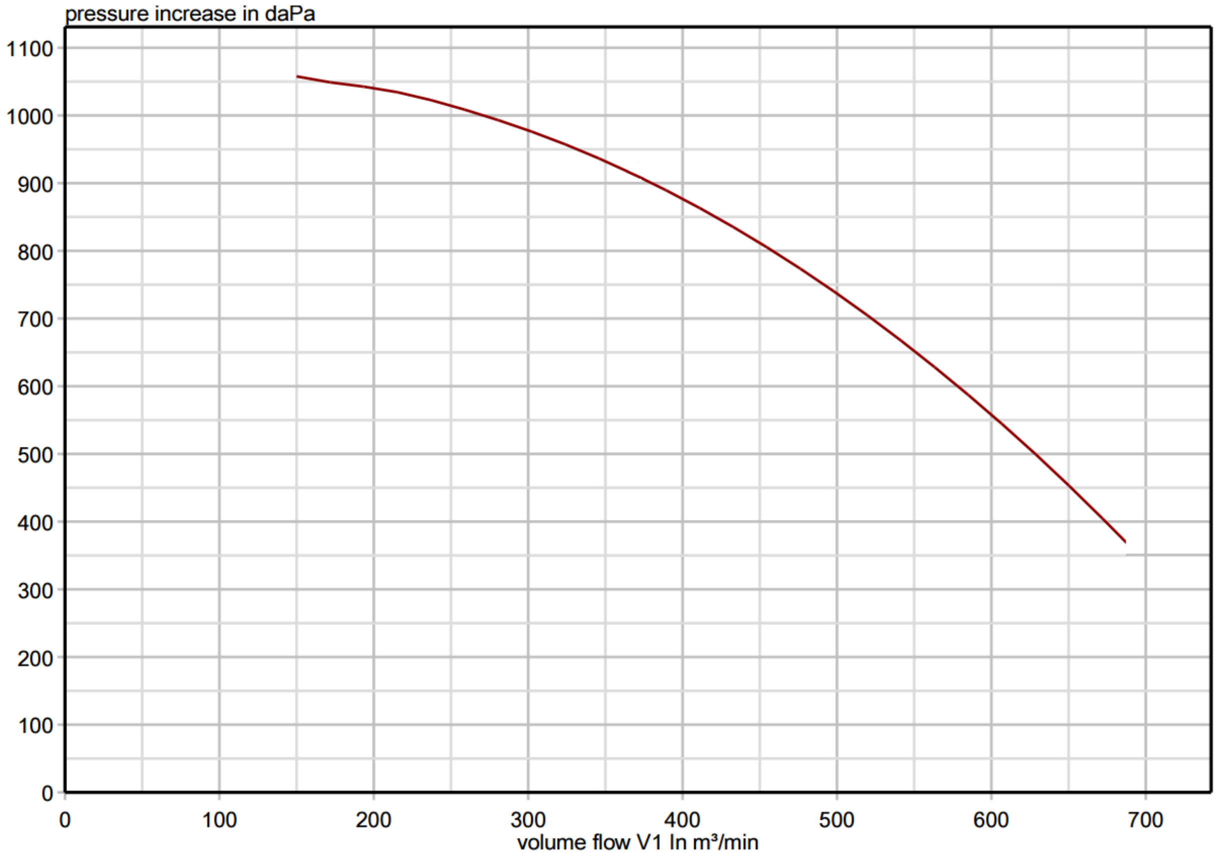


Figure 24 – Ventilator characteristics

<u>Ventilator regulation</u>

In the system, the changes in the total overall pressure drop can occur. It can be from various reasons out of which the most common are:

1. The total mass flow will be changed due to the customer demand
2. The aging of the machines can cause lowering the efficiency of the system and therefore the system will require more power to run properly.

Due to those and many other reasons the ventilator must be adaptable to the respective conditions in the system. It is required for the filter to be able to alter the pressure source to the demanded value. There will be sensors for pressure drop and velocity in the pipeline. Those probes will answer to the main control room. When the control room detects the change, it will immediately modify the pressure source sending an information the ventilator.

The ventilator is creating the pressure source using a wing propeller. The propeller has its own revolving speed. There is also a Frequency changer in the ventilator. Changing the frequency in the ventilator's engine will cause the change in the revolving speed of the propeller and additionally also change in the pressure. This way the ventilator can be regulated and the system will reach its balance every time the pressure drop varies.

The machines represent a significant part of the overall pressure drop and in the previous chapters I have chosen the machines that fit our system the most including filter, cyclones, pick up shoes, airlocks and pressure source. By this the task number 4 is fulfilled.

9. Pipeline optimization

9.1 Diameter optimisation

When designing the piping it is required to seek for alternative or modified ways of designing. Changing one part of the design can lead to a huge difference in resulting image. As was described in a previous chapters we have a lot of inputs that we can change to modify the piping including pipe diameter, air velocity and many others. Certain changes can lead to a significant savings.

In order to obtain the best result of the pipeline we will now perform a diameter and gas velocity optimisation. The diameter optimisation is made by looking for an optimal diameter which would have the lowest pressure drop.

It is logical that the pressure drop Δp will decreace when the diameter d is increasing as it has a direct influence on the gas flow $\dot{V}$. When the diamter d is getting smaller, with the gas velocity v constant, the gas flow will decreses as well. That has a direct influence on the mass flow $\dot{M}$ of the gas. With the bigger mass flow of the gas, we have our blend ratio μ influencing the total pressure drop falling rapidly.

On the other hand, when we consider the increasing the diameter, with again the gas velocity constant, we have a quadratic growth of the gas flow $\dot{V}$. Both gas flow $\dot{V}$ and pressure drop Δp are key components of the resulting system power P. [4]

$$P = \Delta p \ \dot{V} \tag{62}$$

After substituting to the equation using eq. 10 and for the gas flow, after a few modifications, we can obtain:

$$P = d^2 C_1 + d C_2 + d^{-1} C_3 + C_4 \tag{63}$$

where C_1 to C_4 are costants. Solving this equation using the d as a parameter would lead us to the U shape curve. The lowest Power required will for the system to work will be in the lowest point of the curve and that is also where our optimal diameter d_{opt} will be.

The optimisation graph is shown in the following figure.

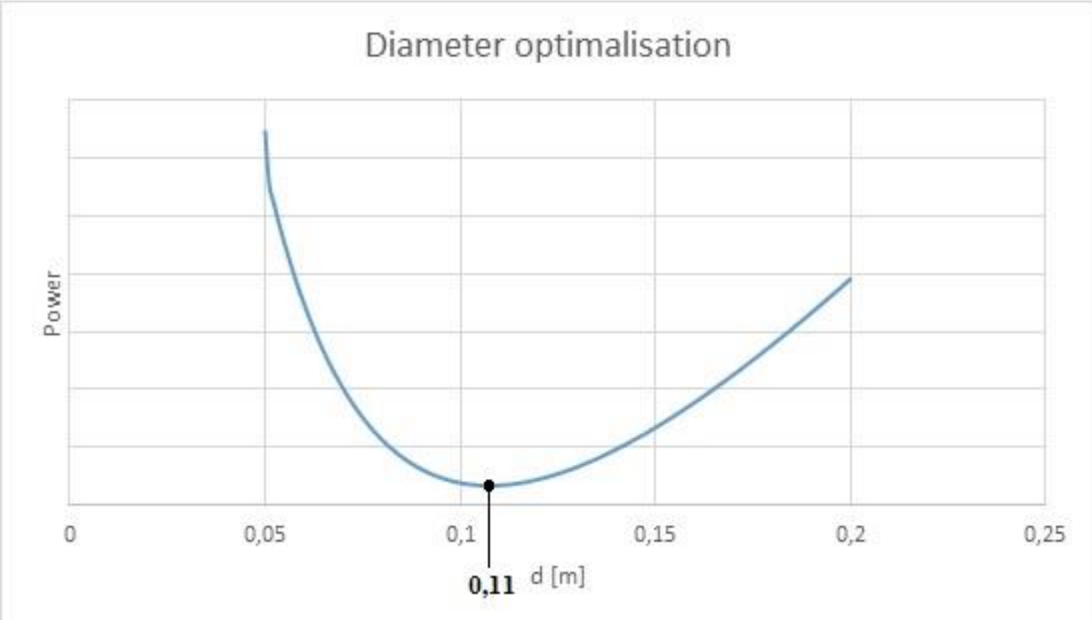


Figure 27 – the diameter optimisation graph

From the figure, we can see that our d_{opt} reaches the value of 110 mm. As our available pipe diameters are 102 mm and 120 mm, our value of 102 mm has been proven as sufficient. This optimisation has been applied to all the lines that has had a similar pressure drop as the main line. [21] [4]

9.2 Phase diagram

Phase diagram is a graph showing dependence of total pressure drop on air mass flow and can be used as a protection from jamming. It can be obtained from the general pressure drop equation where we are able to separate the reliance of the pressure drop on the air and material mass flow. In the ideal situation, we can imagine that the total pressure drop consist of two main sections. They are material pressure drop Δp_{mat} and air pressure drop Δp_{air}.

$$\Delta p = \Delta p_{air} + \Delta p_{mat} \tag{64}$$

We are trying to modify the general pressure equation into form where we are able express pressure drop in dependence on air mass flow with the material mass flow as parameter. When taken other quantities as constant we turn the equation into the from:

$$-\frac{dp}{ds} = C_1\, f\big(\dot{M}\big) + C_2\, f(\dot{M}, \dot{M}_m) \tag{65}$$

The most important part of the diagram is the point where the pressure drop reaches its lowest value. That point is the most economical in terms of the air mass flow. We can see the phase diagram in the next figure.

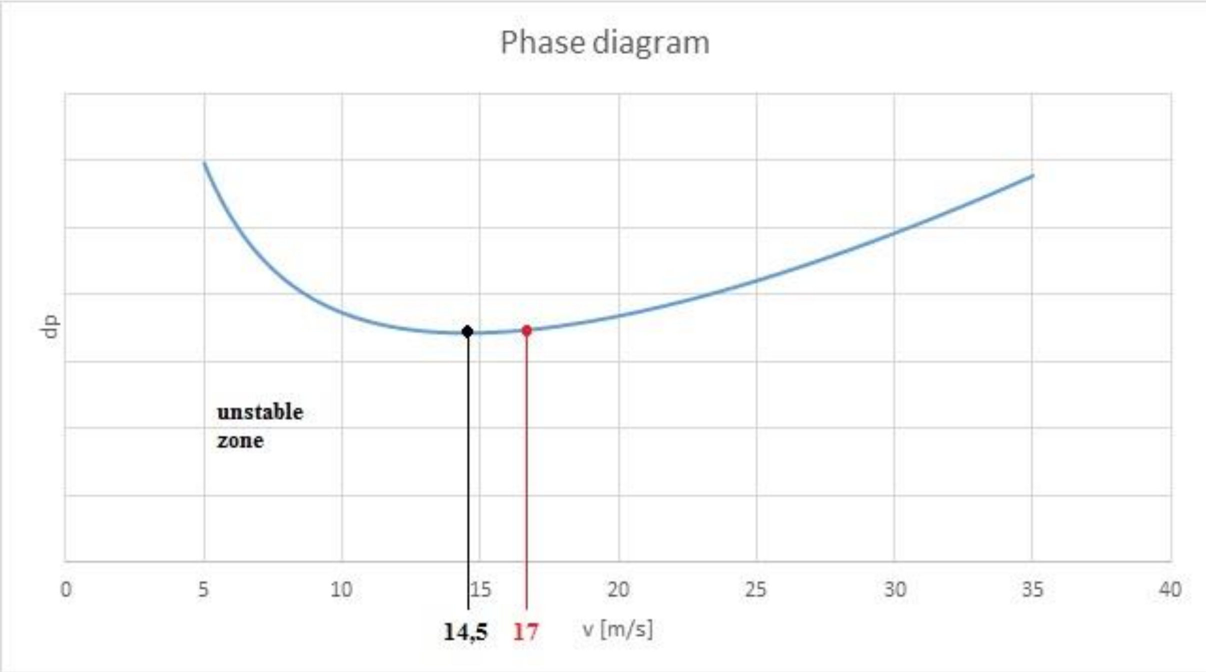


Figure 28 – the phase diagram

The area on the right side from the lowest pressure drop is called a stable zone. We should choose our gas velocity to be placed in this zone. The closer we put it to the left part of the diagram the more unstable is the transport. On the other hand, putting it too much on the right, deep in the stable zone, would mean increasing the costs for the system. The lowest point of the graph represents the minimum velocity we are able to use. We know that our gas velocity should be higher approximately than a minimal pressure drop by around 20%. The lowest point of the phase diagram refers to the speed of $v_{low} = 14{,}5\ m/s$. Out of the diagram we can see that our chosen velocity of $v = 17\ m/s$ is fulfilling this conditon. [21] [4]

Finishing the optimisation was one of the tasks laid down in the introduction and by this I have fulfilled the last one of them.

10. Modification for the medium pressure systems

Solution of the general equation written above can be used for the low-pressure systems only. Low pressure systems are usually shorter, operating with smaller forces and inner environment is more stable.

10.1 Pipeline division

When we calculate low-pressure systems, we are allowed to use one equation for the whole length of pipe as the properties vary insignificantly. This approximation usually makes computation a lot easier, however the result might differ from reality. This method should be used only by experienced technician, who knows how much can this approximation influence the results. The principal is shown in the figure 29. With the piping being short the inner properties do not vary in the line. After the calculation, we obtain only one result from the equation.

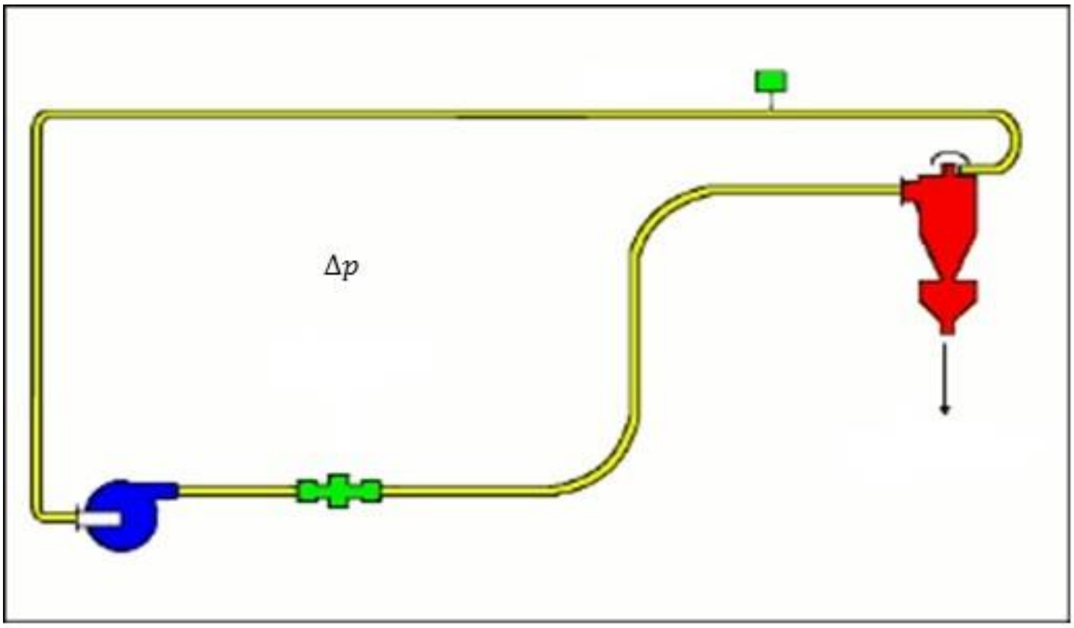


Figure 29 – pipeline separation [20]

Although when we calculate the pipeline pressure drop of a long line and with strong forces, the inner material properties and general physical properties alter along the pipeline. The alternation has a non-negligible influence on the inner environment. This force us to use the additive method designed for medium pressure and high-pressure system. This method divides the pipeline into several parts where each part will be calculated separately as is shown in the following figure. [4]

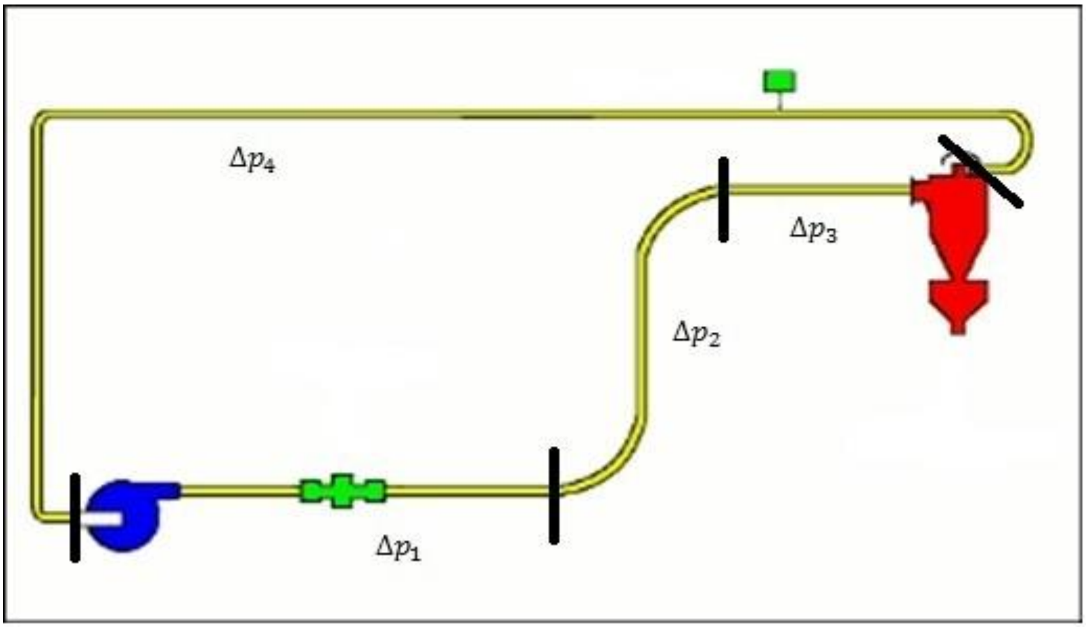


Figure 30 – pipeline separation [20]

This way we ensure that the property alternation will be taken into consideration. First, we must establish the initial pressure p_1 at the beginning of the part 1. This could be done by the experienced miller. Than using the general pressure drop equation, we calculate the pressure at the end of the part 1. Than the pressure at the end of each part must equal to the pressure at the beginning of the following part. We now assume that the temperature does not alter along the path. [22] That way we have an isothermal reaction in the pipe and the inner environment will be guided by those rules:

$$p\, v = const. \tag{66}$$

When we know the pressure, we can use the condition to calculate the velocity. At the same time, also we have the condition for the velocity ratio. This also must remain constant as well.

$$\beta = \frac{u}{v} = const. \tag{67}$$

This way the u velocity must change as well. The transport coefficient k is also dependant on the gas velocity and its value must be recalculated. We put together all the pipe parts and we calculate the pressure at the end. The ending pressure must obey the minimal pressure requirement. If this condition is not obeyed the calculation must be done again until the requirement is fulfilled. By determination of the right initial pressure we can reach the satisfying result. Every time we recalculate the gas and material velocity we reach to a difference of velocities at the beginning and at the end. This acceleration should be taken into consideration in the pressure drop calculation. Therefore, we must add another equation for gas

$$\Delta p_{u,v} = \varepsilon\, \rho_1\ v_1\ (v_2 - v_1) \tag{68}$$

And one for the material

$$\Delta p_{u,m} = \varepsilon\, \rho_1\ v_1\ \mu\ \beta (v_2 - v_1) \tag{69}$$

To obtain the whole pressure drop necessary for the pressure drop design. In each part, we calculate all the pressure drops described above and then sum their value to obtain the real total pressure drop.

$$\Delta p_{total} = \sum \left(\sum \Delta p_i\right)_j \tag{70}$$

Using the advanced method is always more precise, but we must bear in mind that splitting the piping will make the calculation much more difficult. [22] [4]

11. Conclusion

This thesis has been going over the topic of designing a pneumatic piping in the mill for flour production. The piping, designed for the mill, will be transporting the flour in the milling section of the flour plant. The raw grain will come to the mill section and after the process, the flour of all kinds will leave the system.

In the work, we have focused on the pressure drop calculation. The additive method has been used as one of the most common methods for calculating pneumatic piping. This method is fitting more for smaller systems with short pipe routing. Our specific case of piping had a few abnormalities, such as very complicated routing or many routes that are joined together. This brought us to the conclusion that the additive method for low pressure systems are suitable.

As it was written above, the calculation process has to be repeated several times before we reach the optimal situation. Here, creating the calculation programme is more than helpful. I have created the program in Microsoft Excel where by inserting the known values, choosing the required parameters and watching the optimisation diagrams can be done easily. The programme can be used not only for the low-pressure system calculation, but also for the medium pressure calculation where we deal with variable conditions.

In the pneumatic designing, we are facing a problem with not enough literature material describing how exactly the calculation is performed. Using the piping overview and mathematical description method explained in this thesis, we can reach more practical knowledge and apply it to creating a sustainable pneumatic system. The modified method is an advanced approach to the pipe design, giving us precise results applicable in the long-distance conveying.

The value results from the calculation have shown us how the system can by designed, what machines are required for a smooth flow and how we can verify that the system is properly designed. Those results will be presented in the company and will become valid part of the project plan. Doing this, I have reached all of the aims I have set for myself in the introduction.

With the effort to reach the best results and finding the best solutions, we must not forget to look back at our ideas and try to validate how our solution will fit to the problem. This is one of the reasons why we will have to optimise our designs and look for paths that are simplest and aimed to the problem spot. The optimisation of the pneumatic system consist of the diameter and velocity optimisation. Those optimisations have been performed in the final chapter and they confirm the correctness of the original design proposal. With this optimisation, we will lower the costs for the customer. Usually, it is not the initial cost we are lowering here, but the expenses throughout the life of the mill. The customer's first feedback will be expressed even before the mills first day of production, however, it is the years of functionality and good production that can make the customer place their next order on the table for us.

The piping design is becoming a bigger topic nowadays when humankind is reaching for new resources that need to be transported quicker, safer and more directly into its destinations. We are experiencing the fastest growth of science in human history. As the science goes further, the market demands rise as well. There are more people on Earth every day requiring more food. The food production has been automatised and brought up to its limits to get the most from minimum of this indispensable commodity. The pneumatic piping is a key in the food transport for its sanitation, effectiveness and quickness. In the near future, many of the new pipe connections have to be built and this thesis contributes not only to one particular mill but also to its awareness, easier understanding and the overview of this topic.

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