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Title: **Sustainability of Belt Conveyor Systems**

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Subject: **Sustainability of Belt Conveyor Systems**

Belt conveyor is one practical solution of dry bulk material transport and handling. Conventionally, high efficiency and low cost are important criteria for the design & and operation of belt conveyors. However, such criteria normally neglect the impact that belt conveyor systems make on the environment and society. Therefore, qualitative and quantitative study of the sustainability is needed for modern design & operation of belt conveyor systems.

This literature assignment is to investigate the sustainability of belt conveyor systems. The research in this assignment should cover the following:

- What is the definition of sustainability?
- What side effects occur during operation of belt conveyor systems?
- How do the side effects of belt conveyor operation impact the environment and society?
- What techniques are available to minimize the impact of the belt conveyor systems on the environment and the society?

This report should be arranged in such a way that all data is structurally presented in graphs, tables, and lists with belonging descriptions and explanations in text.

The report should comply with the guidelines of the section. Details can be found on the website.

The mentor,

Yusong Pang

Contents

1 Introduction

1.1. Background

Specific dates for the invention of the first belt conveyor are not known. The solution that provides a continuous flow of material started to gain in popularity around 1900, however the British navy is thought to have the the honor of taking in use the first steam powered conveyor belt already in 1804. This machine fulfilled an important task as it was used to produce ship's biscuits. Around this time engineers started to combine the previously primitive belt systems and the recently invented steam engine. This created the first belt conveyor systems that resemble today's systems. Since this time the conveyor developed, but only until late in the 18th century the conveyor had become popular and was used in various industries. Henry ford's factory is a well known example of belt conveyor use. He created a continuous assembly line so that workers no longer had to move all their required tools to the car. Instead the cars were brought to them using a belt conveyor. Also the mining industry was revolutionized by the belt conveyor. Already in 1905 the belt conveyor was installed in an underground coal mine in Ireland, and in Sweden this system was used for the transport of bulk materials such as gravel and charcoal. The belt conveyor greatly increased the efficiency of operation in various industries, among which the mining industry and the bulk handling industry. The high efficiency and low costs make it a popular machine that is still used till this day. [1] [2]

In the times of the industrial revolution there was less attention for the conditions of the workers in their work environment. Steam power was new as an energy source offering great opportunities and it was widely applied. However, with the introduction of powerful machines also new hazards were introduced on the work floor. Also these machines increased the pace of production, increasing the pressure on the workers. With limited rights for workers and low pays it were hard times for most workers. Around this time the workers started to unite and call for regulations to ensure better working conditions. Also the physical effects of hard labor in poor conditions were being studied. This all lead to a shift in focus from the directors of industry, increasing the attention for the working conditions and the workers health. In the western countries issues like this are commonly addressed and valued, improving the quality of life. In other parts of the world this is still under development as we see the developing countries struggle with these issues. Belt conveyor system are often applied in heavy industry where there are many potential occupational hazards. This has also lead to regulation, also regarding belt conveyor systems. And this is still developing as we get to know more about the human body and how it is effected by external factors. Therefore working conditions are being regulated and improved till this day.

Currently a similar call from the public is noticeable asking attention for the environment on a global scale. As scientific research has created a better understanding of the world around us, the realization sets in that we have a greater influence on the world and the ecosystems then we expected. Where the world was first seen as an endless supply of resources, it is now commonly accepted that the earths resources are not endless. Currently it is also acknowledged that the human population has the ability to disturb natural balances in numerous environmental processes, either on a local scale, as well as on a global scale. Under the name *sustainability* these issues are currently being discussed in most levels of society and economy. This has resulted in a growing social dislike against organizations that operate in unsustainable ways, and an in-

crease in regulations form governments and authorities to stimulate sustainable development.

Motivation

The development of belt conveyor systems has mostly been driven by the financial aspect. The belt conveyor could bring cost reduction and increase efficiency of operation, both resulting in a better market position and more profit. Already attention for the working conditions has been increased and improved through legislation. With the increasing attention for the sustainability of our society and economy a similar extension of the focus is well underway. Although sustainability most of the time is associated with the environment both the social and environmental aspect of development are captured under the name sustainability.

This development increases the desire for more insight in the sustainability of belt conveyor systems, asking for the assessment of the systems sustainability. This probably will become important in order to maintain its position in the industry. This literature survey will investigate how sustainability has been developing, and how it applies for belt conveyor systems. The interaction of belt conveyors with the environment and society will be considered. Its contribution to society and economy will be excluded, as the focus will lie on the produced by-products and the side effects of belt conveyor use. The goal is to create an overview of possible impacts of belt conveyors in general. This overview can then be used to indicate how current systems perform. Also it will show what is being developed already to increase its sustainability, and what is currently in progress to develop this even further.

The main effects of belt conveyor systems considered in this survey are the high energy consumption, the possibility of dust generation and spillage, and the noise generated during operation. Energy consumption is a large contributor to the operational costs, as well as it is a large contributor to the environmental problems of these times. Dust generation forms a large concern as it endanger workers and ecosystems, making it a problem for both the environment and the society. Noise is added to the list as this causes problem for workers and inhabitants of the area.

1.2. Research scope

Sustainability of belt conveyor systems are the main focus of this survey. Sustainability itself is already a broad topic and can relate to many different aspects. In addition also belt conveyors come in a wide variety, as there are many different types of conveyors available on the market. The goal of this survey is to create an overview of the aspects of belt conveyor systems that influence its sustainability. Important to notice is that its sustainability refers to the impact of belt conveyor systems on external systems.

The term sustainability is a broad term and can be used in various contexts. It is a popular and relevant topic that leads to many discussions about the way modern life is organized. To evaluate belt conveyor systems in the context of sustainability asks for a general assessment of these systems. Therefore all aspects that can be included in the term sustainability will be considered in this survey, and narrowed down to relevant aspects the interact with belt conveyor systems.

There is a wide variety of belt conveyor systems available. New types of belt conveyors are being developed for specific circumstances, increasing the range of industries that can be served. These systems all overlap as they are all types of belt conveyors, but also can have very different characteristics. To narrow it down for this survey the choice was made to look into trough belt conveyor systems in particular. This is a basic belt conveyor design that is commonly used. Still there is a wide variety between these, looking at location, dimensions and material transported, but the functionality and design is comparable, allowing a general analysis. As the trough belt conveyor is used regularly it is relevant to assess its sustainability as it can have a considerable impact.

One type of belt conveyor system was selected to investigate the scope remains general. Therefore the focus of the survey will lie on the general systems and its sustainability aspects. Because of this general approach the survey will not quantify the sustainability assessment with target values. Also because this depends on multiple variable like the location of the belt conveyor. Aspects of sustainability in belt conveyor

systems that are relevant to observe during the design, development, and operation of belt conveyor systems will be presented.

1.3. Research questions

The aim of this survey is to investigate the sustainability of belt conveyor systems. In the previous section a more specific scope was depicted to create a clear context of what will be included and excluded in this literature survey. This leads to the following general research question that will be answered at the end of the report.

How do trough belt conveyor systems impact sustainability of the environment and the society?

The main research question is broken down into smaller questions to be answered and eventually be able to answer the main research question. These questions are listed below:

- What is the definition of sustainability?
- What side effects occur during operation of belt conveyor systems?
- How do the side effects of belt conveyor operation impact the environment and the society?
- What techniques are available to minimize the impact of belt conveyor systems on the environment and society?

These sub questions provide a guideline to gather information that will finally make it possible answer the main research question. By performing a literature survey on these subjects, insight in the matter will be provided and the gained knowledge will be documented in this report. Hopefully this will generate additional insight in the operation of belt conveyor systems, and the impacts that material transport using belt conveyor systems can have. Providing this overview should make it possible to improve both the technologies to prevent negative impacts of these systems and to suppress the negative impacts as much as possible. Therefore also the current technologies are presented, giving insight in what has been done already, and what requires more attention. Eventually this will hopefully lead to more sustainable operation of belt conveyor systems, and secure its place in the sustainable society of the future.

1.4. Overview of content

The first chapter of this literature survey discusses the concept of sustainability and highlights different approaches to the concept. The growing environmental awareness is explained as part of the motivation for this survey. The economy, society and environment are identified as cornerstones of the society as we know it today. There are relations between these cornerstones as they overlap, and conflicting interests exists within these overlaps. The concept of sustainable development helps to structure the debate of such conflicts in the society of today. Also in chapter one legislation and regulation is identified as a tool to stimulate change towards a sustainable society for the future. The development of more sustainability legislation is on the way and different standards are available to create more sustainable processes and products. It was found that especially local legislation sets strict rules for the operation of belt conveyor systems.

In chapter two the functionality and design of belt conveyor systems is described as this is the subject of this survey. It creates a basic understanding of belt conveyor systems and its functionality. All basic components and their function in the system are described. In this chapter the parts and functionality of the belt conveyor system to evaluate will be determined.

Chapter three addresses the operation of belt conveyor systems and how this can influence its sustainability. First relevant aspects that can be effected by a belt conveyor are identified. Next, life cycle thinking is used for a general and brief analysis of the system to find out what life stages effects its surroundings the most. This is brought together showing the environmental and social concerns that are to be considered during the operation of belt conveyor systems.

In the fifth chapter all aspects of the high energy consumption are discussed. First te downside of this was motivated, both in the interest of the operator and the economy, and in the interest of the environment. What contributes to the total energy consumption is explained next, and possible techniques to minimize this were discussed. Also an overview of some research aiming to bring down the total energy consumption of a belt conveyor systems is included.

The by products dust and spillage are discussed in the sixth chapter. First the negative effects of dust and spillage were identified, for the operator, employees, nearby communities and the environment. Next the sources of dust and spillage are investigated, and possible solutions to the problem are discussed. different techniques are presented to solve this problem. It was found that this problem is well manageable with current techniques, and this results in limited new developments in this area.

Chapter seven is about the impact noise generated by a belt conveyor can have on the society, and on the environment. The impact of the noises is mainly local as it effects communities and can cause harm to the employees. The general sources of noise are identified and here regular maintenance is an important factor to control the noise generation. It was found that noise regulation is regularly found, and is applied effectively on a local scale.

The final chapter concludes the survey as it gives an overview of the interesting findings in the survey. In this chapter also the research questions are answered. Also recommendations for further research and the development of a better way to assess the sustainability of belt conveyor systems are mentioned.

2

The definition of Sustainability

Before it will be possible to look into the sustainability of belt conveyor systems, the concept of sustainability of be defined. It is a concept that is used frequently these days and it seems all companies are trying to create an image of being sustainable, most often referring to the environmental aspects of the concept. However the concept includes much more than being *'environmentally friendly'* and *'good for planet earth'*, although this is what the public will probably think, hearing these sustainability claims in advertisements. Sustainability is a popular word, used to try to stand out from competitors. To be able to evaluate the sustainability of any product or process, it is important to define the concept in more detail and create a better understanding of sustainability,and what the concept means for products or processes.

2.1. Sustainability in general

To start defining the concept *sustainable* the meaning of the word is looked up in both the Cambridge and the Oxford dictionary and cited below:

Able to continue over a period or time [3]

Able to be maintained at a certain rate or level [4]

These definitions are quite clear but straight away show that the concept is subjective as the context is left open. The Cambridge definition of the word *sustainable* shows that a certain period of time must be defined, while the Oxford definition indicates that a certain rate or level must also be defined. In addition, the word *sustainable* is an adjective and refers to a specific product or a system. Therefore the context is of importance. This applicability to multiple contexts is illustrated as being economically sustainable has another meaning than environmentally sustainable. Either of these can be perfectly achieved completely regardless of the other.

For example a company cutting down trees and selling the wood with profit over a long period of time can be labeled economically sustainable. But solely cutting downs trees without planting new ones is considered the be harmful to the environment, and therefore environmentally unsustainable. The other way around is also possible. For example think of an organization that protects rhinos in the wild against poachers. This operation ensures that the rhino population is maintained which can be considered environmentally sustainable. However, this is a costly operation that is not creating any earnings for the organization. Therefore solely protecting rhinos can be considered as economically unsustainable. This makes clear that solely *sustainable* is a widely applicable concept, but can not stand alone. Additional information defining the context is required.

As the concept is widely applicable it leaves a lot of room for discussion. The concept is well debated and there is no consensus about an exact definition. What systems or products are desirable to sustain can differ a lot depending on ones point of view. For a good definition of the concept it is required to know what to sustain and how it performs in terms of sustainability. According to Costanza [5] there are 3 basic questions that help defining the context.

- **What system** or subsystems or characteristics of systems persist?
- For **how long?**
- **When** do we asses whether the system or subsystem or characteristic has persisted?

Regarding **what system?** it is often possible to define the system to persist. Depending on ones point of view or ones operation, an important system or multiple important subsystems can be identified. Seen from a biological point of view this often means avoiding extinction and living to survive and reproduce, while from an economical point of view it often means avoiding major disruptions and collapses. In both cases it requires a level of fitness with the environment, and adaptation to changes in that environment. When one looks at larger systems it may not be possible to persist the system as a whole, yet often characteristics of that system can be defined that are desirable to persist. When changes in the environment require changes in the system the focus lies on sustaining the characteristics of that system instead of the system as a whole.

The question of **for how long?** is also important. As the world, with all we know about it, may not even last forever, it is not adequate to desire sustainability of a system till forever. This would create a time scale that can not be overseen creating a definition of sustainability that discourages any change or development at all. The life span can differ per system. In the biology this is clearly visible as some bacteria can reproduce within hours. As generations succeed each other rapidly they are capable of adapting quicker to changes in their environment, simply because they pass on their genes more often. This speeds up the evolution within that species. In the case of the human population the reproduction rate is a lot lower. Depending on the type of system and its context it can operate in various time scales.

Answering the question of *how long?* almost immediately raises the question of **when to asses?** In trying to sustain a system, or characteristics of a system, the time scale of that system is of importance. In the case of the bacteria colony it could be too late when assessing the survival of the colony after a moth. As many generations will have passed by that time it could be that the colony is already extinct at the time it is assessed. In this case more frequent assessment of the colony could have allowed to adapt the colony's environment, making persistence possible. On the other hand, in the case of mankind, it would be useless to asses the sustainability on a monthly basis as this is to short compared to the time scale as differences might not even be noticeable yet. What can be learned from this is that in assessing the sustainability of a system the time scale of that system must be kept in mind to select a useful frequency that allows to alter the system before the system has stopped to exist, while on the other hand the frequency must also allow changes in the systems to be noticeable.

In the biology, evolution accounts for adaptations within species due to selection of the fittest genes. However, evolution is not applicable to many man-made systems and therefore it may take more effort to sustain. In attempts to do so it is important to prepare for possible future changes, and this may require some sort prediction of the future. Therefore it is common to make analysis of trends and developments in society, or a more specific context the system operates in. Predictions of the future can help create proper policies that allow to adapt to changes in the future. This increases the chances to succeed in sustaining the system, or characteristics of the system.

2.2. Environmental awareness

The impact of industry on the environment has become an issue of increasing concern since the late 1980s, particularly in western economies [6]. Over the years more and more awareness for the effects of industrialization, growing global population and consumption of natural resources has grown steadily. In the beginning of industrialization the awareness of effect on the environment was low but over the years it has gained attention and currently the theme often appears on the world leaders agenda's. In 1987 the World Commission of Environment and Development published a report named *Our Common Future* [7] which can be seen as the start of global interest in the topic. In this report the vastly increasing human numbers and the development of new technologies are mentioned to have altered the relation between the human world and the planet for the worse as unintended changes appear in the atmosphere, in soils, in waters, among plants and animals and in the relationships among all these. Since this report the awareness of mankind's impact has grown and slowly these effects are acknowledged by the majority of the western world. Nowadays themes like

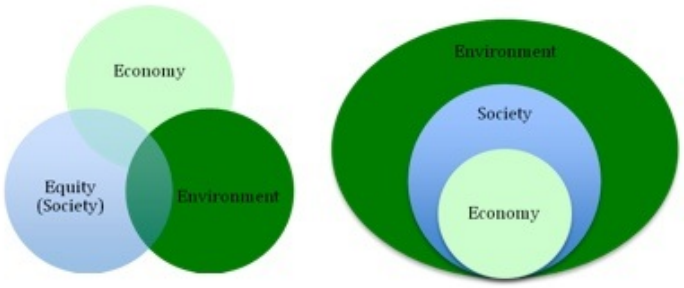

Figure 2.1: Schematized views of the main aspect of the modern world [8]

global warming, climate change and overpopulation can be considered common knowledge and more and more companies and countries try to integrate these themes in their own strategies and policies.

The previous section shows that *sustainable* is a diverse term that can apply to many contexts, depending on the system or characteristics of a system. For most companies and organizations, being sustainable, as defined by the dictionaries, is trivial as maintaining their very existence is what they set out to do on a daily basis. However, the term sustainability is only seen in companies advertisements, visions and policies since the last few decades. This indicates that these sustainability claims or the desire to be sustainable refers to the way they would like to do business. This is the result of the growing environmental awareness and as a results more and more companies and organizations seem to pay attention to the way they want to maintain or persist their business. The interest in environmental sustainability has grown among the public triggering the economies to act more conscious about the environment and invest in sustainable solutions and developments.

2.3. Economy, Society and Environment

Many schematize the human world to consist of three main pillars, being the economy, the society and the environment. These three are known to interact with each other as one supplies an other, or is effected in an other way. This is often illustrated by three overlapping circles as is illustrated on the left in figure 2.1. This already shows that the activities within one area can have an effect on both of the other areas as well, and consents with modern day view of the world. Yet, the mayor part of each circle is not overlapping and suggests that also many actions within one area do not influence the others. This is incorrect to many progressive thinkers as they see a hierarchy between these three main areas. This is illustrated on the right in figure 2.1. In this figure the economy is only a small part of society, and cannot exist without the society. The society again is only a small part of the environment, and cannot exist without the environment. Both views indicate some sort of relation between the three main areas. The difference is the hierarchy, where in the one there seems to be a more or less equal relation, while in the other there is a clear hierarchy established. Both agree on the fact that activities in each area can have its effects on other areas. Sustainability is a term often used when looking at the relations between these areas pillars to make sure all three can co-exist.

2.4. Sustainable development

The current status of environmental awareness leads to more attention for sustainability. However, views on how to minimize and change the impact of human life on the planet differ vastly among many people. It is difficult to combine all thoughts and desires of different individuals and communities into one plan of action. In the most extreme cases some people are willing to give up many aspects of modern society and prefer to go back to a living standard close to nature and without modern day technologies,. Others are barely willing to give in on their welfare and only seek to enhance it. The majority probably is willing to contribute to a more sustainable way of life, but only without making big sacrifices. It is important realize that there is a natural desire for people to maintain and improve their welfare.

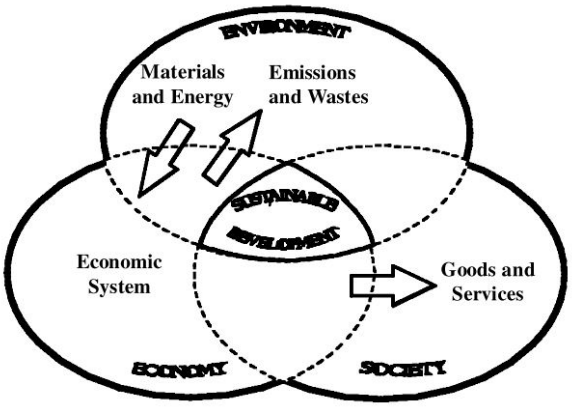

Figure 2.2: Illustration of sustainable development [9]

Mankind will keep developing, in attempts to improve the quality of life. This leads to new innovations making daily life better and more fun. The human world will keep moving forward, developing itself. But while these developments take place, the focus can no longer only lie on the development itself. It is important to look at the bigger picture and analyze what the impact of current technologies and future innovations will be. Also the development of new technologies to replace current polluting processes with more sustainable processes is important. Mankind is developing both society and economy, but this can not go at the cost the other areas. This is often called *sustainable development* and emphasizes development with care the environment and the society. Looking at figure 2.2 sustainable development is indicated as the area where all three aspects of modern life overlap.

Sustainable development is where the different interests form different groups within the human world meet, providing a framework to bring together all the different points of view, and try to satisfy as much as possible. The concept of sustainable development was defined in a clear way by Brundtland [7] and his commission in their report *Our common future* about the environment and development:

"To make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs"

The definition provided by Brundtland and his commission is the basis from which more interpretations and refinements to the concept are made, depending on the involved parties and the matter at hand. An interesting framework of the different interests in play is mentioned by Barry Ness [10] and Robert Kates [11] and states that there are three important questions to define sustainable development.

- What is to be sustained?
- What is to be developed?
- The inter generational component

According to Barry Ness [10] what is to be sustained comes down to three main areas being nature, life-support systems, and community. The three main areas that are to be developed are identified as people, society and economy. These main areas all can be divided in smaller subareas. The inter generational component is essential to include as it provides an explicit time-horizon for each specific sustainability goal. This structure of sustainable development is shown in figure 2.3 and gives some examples for subareas of each main area.

The concept of sustainable development has been defined properly which makes it better usable in real life situations. According to Robert Kates et al. [12] one of the successes of the concept sustainable development has been its ability to serve as a grand compromise between those who are principally concerned with nature and the environment, those who value economical development, and those who are dedicated to improving the human condition.

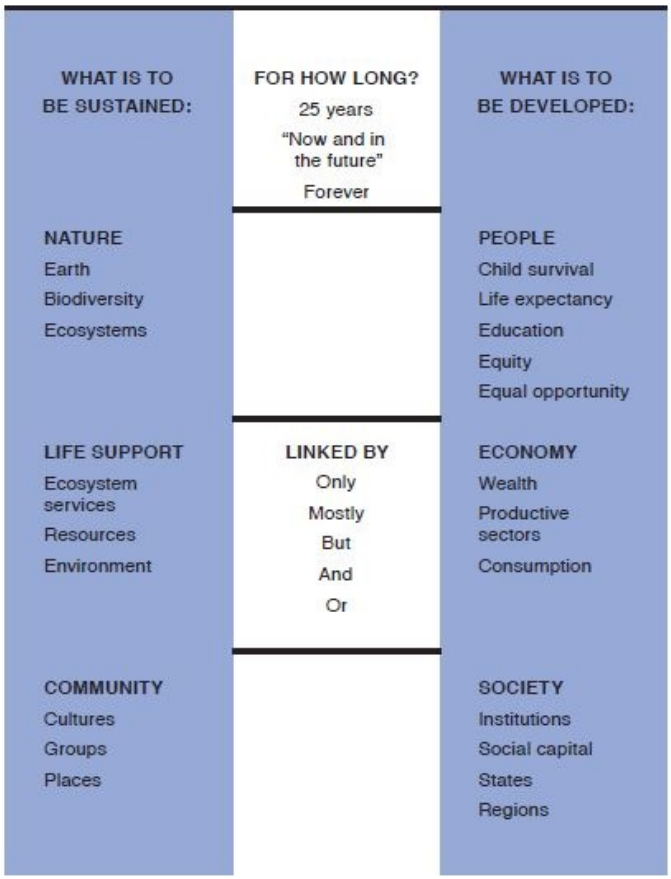

Figure 2.3: Areas of sustainable development [11]

When the word sustainable is used it often refers to the definition sustainable development and expresses the desire to respect the three three main areas to be sustained, while developing the three main areas to be developed. Depending on the specific context of the matter at hand, the focus within can shift between areas within the concept. Examples are the planning of sustainable cities and sustainable livelihoods, sustainable agriculture and sustainable fishing, and efforts to develop common corporate standards like the UN Global Compact and the World Business Council for Sustainable Development. The ability of the concept to adapt and apply to numerous of areas and situations is a welcome feature, and makes the concept applicable to a wide variety of cases. However the real-world experience has shown that creating consensus is an often difficult and painful process as different stakeholder values are forced to the surface, to be compared and contrasted, criticized and debated. [12]

2.5. Sustainability and legislation

As the environmental awareness is growing, and the demand for sustainable development increases one can think that everybody in the world is doing the best they can to become sustainable themselves. However, with the ongoing discussion and different points of view there is no consensus about how to attack the sustainability problems. To stimulate organizations and companies to become sustainable themselves legislation can be in helpful. Examples of such legislation are emission rights, energy labels for houses and cars, and taxes on fossil fuels. Also a lot is done to stimulate sustainable development by giving out subsidies for the development of new sustainable technologies. Local initiatives can be found all around the world, but are often still in the starting phase, or on small scale. The national and global governments are also increasing the focus on sustainability, and mainly on climate change. An example of this is the recent climate summit in Paris in 2015.

2.5.1. The Paris Agreement

In 2015 the United nations conference on climate change took place in Paris to discuss how the world should address the problem of climate change. The summit was concluded with an agreement signed by all 195 participating countries, the *Paris Agreement*. This shows that climate change is seen as an important topic and most countries are willing to do something about this. The agreement mainly includes global goals, but does not provide a precise path achieve those goals. This is left open for the national and local governments to arrange, as each country or area might require a different approach to the problem. One of the main items in the agreement are to maintain the earlier set 2 degrees limit of the warming of the world compared to pre-industrial levels, and even including a section recognizing the importance of pursuing an even lower limit of 1.5 degrees. Another goal is have the greenhouse-gas emissions balanced with the removal of sinks by 2050, meaning that at least the same amount of greenhouse-gas is taken out of the atmosphere as there is produced. This goal can be achieved by both minimizing the emissions and maximizing the greenhouse-gas sinks, preferably natural sinks like forests and oceans. This agreement applies to national governments, and they will have to provide local legislation and measures to ensure these goals are met. Eventually this means that the changes have to be made by the society and the economy.[13][14]

2.5.2. Emission Trading System and energy labels

The European Union itself has already created some legislation to stimulate sustainable development. One example is the EU Emission Trading System (EU ETS) [15]. This systems first sets a limit of emissions that the European Union may produce. Next, so called emission rights are auctioned to European companies on a yearly basis. In this way it creates specific costs for emissions for a company. Over the years the limit is lowered, and less emission rights become available. This ensures that the total of the emissions by the industry will decrease. Unfortunately, because of the current low carbon price the influence of the EU ETS is fairly limited [16]. To make sure that the companies to not exceed the levels of emission they have the rights for the emissions are monitored closely. In the Netherlands this is done by an independent organization which is called Dutch Emission Authority [17].

The emission trade is not directly applicable to belt conveyor systems as these systems can be part of wide variety of processes in different industries. However, the emission trade stimulates minimizing the overall emissions of industry, and when belt conveyor systems are part of an industry it is also desirable to minimize

its emissions. This will help bring the overall emissions down. What percentage the belt conveyor systems contribute to the total emission of a process of industry differs per case.

The Emission Trading System is one example of European legislation to stimulate sustainability and environmental care in industries. However, the European legislation acts mostly on a large scale covering multiple countries, but has limited influence directly on small subsystems, as most of these measures give no specific sustainability demands for specific products or processes. This included in European law which states that the EU is not allowed to create specific legislation on local issues that do not cross a countries border [18]. However more specific legislation can be found in most national industries. Also the Dutch government tries to stimulate sustainable development by investing in research into sustainable technologies and sustainable economic growth [19]. For instance in the housing market in the Netherlands it is not allowed to sell a house without an official energy label. This label consists of multiple categories used to let the buyer know how energy efficient the house is. The same label system is applied to a lot of electrical devices, like washing machines, vacuum cleaners and cars. This system should stimulate the consumer to choose the more energy efficient products from its category. On the other side it should also stimulate the producer to increase the energy efficiency of its products. This is mainly focused on the consumer market. Also it does not give insight in the production process as it only labels the energy efficiency of the product during operation.

2.6. Assessment

From the previous sections is has become clear that both industry and governments pay attention to sustainability and sustainable development, and both try to improve on the matter. To do so, it is important to assess operations regarding sustainability, but this requires proper indicators to do so. For industry this has led to several measures in efforts to create insight in the performance on sustainability. The number of companies that include an environment report on their own sustainability in their annual business report has grown over the years.

Standardization of indicators can help to asses the sustainability of a company. However finding proper indicators on sustainability may differ per industry. In general some industry-generic indicators can be identified. These alone might not be sufficient so sector-specific indicators can be added depending on the case. The standardized indicators would help enable identification of more sustainable options as it makes proper comparison between products possible. The following five points are examples given by Azapagic et al. [9] of what becomes possible using standardized indicators:

- comparison of similar products made by different companies
- comparison of different processes producing the same product
- bench-marking of units within corporations
- rating of a company against other companies in the (sub-)sector
- assessing progress towards sustainable development of a (sub-)sector.

This shows that comparisons and bench-marking is valuable for corporations to investigate where they stand on sustainability. It gives insight in where they can improve, and reporting on this regularly drives sustainable development within the organization.

A framework is proposed by Azapagic [9] covering all three aspects of sustainable development. Figure 2.4 gives an overview of possible indicators. These indicators can be quantified but there is not yet total consensus of how to do this. Many of these indicators are derived form other methods used in industry and mainly make comparisons between processes, products and sectors.

2.6.1. ISO 14001

The International Organization for Standardization (ISO) gives guidance to structuring the assessment of sustainability within cooperations by providing the ISO 14001. This is the ISO standard for Environmental management systems, and provides requirements and guidance for use [20]. A lot of companies, including

Figure 2.4: Indicators of sustainable development for industry: a general framework [9]

in the mining industry, adopting this standard in order to structure their efforts to become more sustainable [21]. ISO 14001 helps to improve the companies environmental performance by focusing on changes valuable for the environment, the company and possible interested third parties. It also facilitates a framework for the companies compliance obligations, and help create and achieve environmental targets.

2.6.2. Life Cycle Assessment

One method to analyze the environmental impact of a product or process is to perform a Life Cycle Assessment (LCA). It is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle [22](figure 2.5). LCA makes it possible to compare the environmental performance of products and identify the least burdensome. A comparison between two different products is possible using LCA because it looks at the entire life, and documents the performance in each stage. The total sum can be compared and a better choice can be made between the products. For example, comparing a regular petrol car with an electric car is difficult. During the operational life the electric car probably has less impact on the environment, yet seen over the entire life cycle this may differ as the battery pack from the electric car requires dangerous chemicals to be produced. Also, the life time of a battery pack is shorter than the life time a petrol engine, and the batteries can barely be recycled. So in the long run the outcome of the comparison may differ from what is expected, and LCA offers a systematic approach for such a comparison.

To be able to use LCA to its full potential it is required that lots of LCA data is created within a sector. When multiple assessments have taken place on different products, the quality of the comparison will go up as more date becomes available. Currently LCA it used in a wide variety of industries, however it is not applied on a large scale in the mining industry.

2.7. Sustainability and Belt Conveyor Systems

The previous sections discussed different aspects of sustainability, and shows how it is used in current society. The world currently faces several challenges that have to do with sustainability. Different aspect that relate to these challenges and try to address them are mentioned. Some of these can also effect the design, development and usage of belt conveyor systems. In this section relevant aspects of sustainability will be selected and defined so that it is applicable to belt conveyor systems.

Figure 2.5: The life cycle of a product [23]

2.7.1. General Definition of Sustainability

Sustainability is a concept that can be interpreted in a wide variety of ways, and depending on the point of view the interests can differ a lot. However there seems to be a general consensus about what is commonly meant when the terms *sustainable* or *sustainability* are mentioned in the context of a company or business and it refers to the way they try to do business.

The definition of *sustainable development* is probably the best way to capture this. The concept identifies that there are three areas within the human world that are all important, but conflict where they overlap. These three areas are the *society*, the *economy* and the *environment* and the overlap between them shows that they are all connected. As they all interact in some way they can conflict with each other. Sustainable development has the goal to continue development of all three areas but not at the cost of the others.

Further investigation of the concept shows that the three main areas of interest to be sustained are often defined as *nature, life support and community*. These area's to sustain may conflict with areas that are to be developed. The three main areas to develop are *people, economy and society*. Finding the balance between what to sustain and what to develop will be an ongoing debate, and as mankind gets to know more about the environment, the planet and all its subsystems, it will become easier to oversee the effects of new developments allowing a sharper debate and more conscious development.

The growing awareness of sustainability and environmental issues is acknowledged by more and more people and the Paris Agreement shows that also the world leaders are willing to invest in a more sustainable society and economy. These topics will be on government's agendas and they try to achieve the needed changes. Industry is also starting to adapt its policies and adapt to the growing demand for sustainable products and services, coming from both consumers as well as governments. Already multiple initiatives to stimulate sustainable development can be found. However, achieving the goals set in the Paris Agreement are still a long way. For the future the trend of sustainable development is expected to grow, as well as the actions taken on this matter. The incentives given by the world leaders will spread to local governments who shall develop and implement appropriate legislation for society and industry, depending on the local conditions.

More legislation can be expected and should stimulate more sustainable products and services. This also asks for more tools to asses the sustainability of products and systems. The sustainability of a product refers to how it effects its surrounding, during any stage of its life. The theory of Life Cycle Assessment is developed to help create an overview of a products impact on the environment by assessing the entire products life, from material extraction and manufacturing till the products afterlife. This provides an overview of what aspects of a product have the most negative impact, making is possible to improve the product in areas where it is most needed. An other theory to help assess and manage sustainability aspects within a company or cooperation is the ISO 14001 which is currently used within several heavy industrial organizations. However, these tools are still in development and it is proven difficult to come up with adequate and appropriate sustainability values

that are accepted across industries. Life cycle thinking is thought to improve the management of continual improvement which is key for ISO certified environmental management systems [22]. Some industries are already subjected to legislation on environmental assessment by the government. An example of standardized assessment is the energy label for consumer goods or the emission rights.

Lots of activity can be seen in the struggle for sustainability. However, there is not yet any legislation directly concerning the sustainability of belt conveyor systems. As belt conveyor systems are found in different industries they can not be typified by one particular industry only, but belt conveyor systems do contribute to the performance of different industries. As more and more industries have to deal with environmental legislation, all components within an industry should be assessed concerning sustainability. And belt conveyor systems will not be excluded.

2.7.2. The sustainability Context of Belt Conveyors

The sustainability of belt conveyor systems will become increasingly important in the future and this should be investigated now so that it is possible to adapt for the future. The belt conveyor system itself is not the systems that is to be sustained, however it is the system that has to be developed. The development of belt conveyor systems contributes to the economy as it performs an operation within a bigger process that is part of some industrial company. Depending on the company, the belt conveyor indirectly contributes to the development of the economy, the development of society and eventually to people's quality of life. What is to be sustained is the environment and the society that the belt conveyor comes in contact with. The environment can be influenced directly by belt conveyor system, as direct interaction occurs. This is also the case for society, where entire communities or individual people can be effected. These areas to sustain are the basis of life as we know it, and therefore we can say that these should be sustained for now and in the future.

Assessing the sustainability of belt conveyor systems is part of the ongoing debate and political campaigns. Assessing is possible when it is known what the possible effects of the belt conveyor systems are. Values that can be tolerated by society and the environment must be defined. This is something that receives a lot of attention currently as governments develop new legislation including values to measure. In some cases these are defined adequately already. As we know many things that can influence the environment and people or society, the assessment is possible already. This requires for example monitoring air quality and energy consumption during operation. The frequency of such assessments has to be determined depending on the specific situation.

3

Belt conveyor systems

The belt conveyor originates from the 19th century, and the first machines from that time were primitive versions of the advanced belt conveyor system we see nowadays. At the end of that century the development of belt conveyor systems was taking of and the technology was used in different industries, for example to transport coal and ore in the mining industry, raw material for the German coffee industry and later the technology was also used in the production facilities of Henry Ford. Currently there are all sorts of conveyor systems based on the same principle: The use of a continuous belt or chain to transport material or goods to its destination.

In the bulk solid material handling industry belt conveyor systems are used to transport large volumes of material over long distances as well as over shorter distances. One can think of conveyor systems transporting material over relative short distances such as within a facility between two machines or on a terminal between a stockpile and a vessel. But also on a lager scale belt conveyor systems are used, for example to transport coal from a mine straight to the energy plant tens of kilometers away. What makes a conveyor a unique piece of equipment is that it can be used to create a continuous flow of material, over a specific desired distance, while operating more or less automatically, as long as material is supplied to the conveyor. These characteristics make that belt conveyor systems can be found in many industries with various applications.

This chapter will provide more insight in the through conveyor specifically as this is one of the most common used types of conveyors in the bulk handling industry. First the general anatomy and technology is discussed, followed by the a deeper insight in how the system functions and how the components interact.

3.1. Basic components of a conveyor

The conventional design of a conveyor used to transport bulk solid material is build up with a few basic components. The basic design consists of two or more pulleys, and a continuous belt that rotates around it. At least one of the pulleys is powered to move the belt and idlers are placed every short distance to support the belt over a longer distance. Depending on the load on the belt the spacing between the idlers is determined. In figure 3.1 the basic structure and its components are shown. As the material for the belt must be flexible to run over the pulleys it will also be able to stretch during operation. To compensate for this a take-up must be included in the system. Depending on the belt material, the length of the belt and the load on the belt this take-up will vary in design. A loading chute is required to direct the material onto the belt and make sure the load is spread evenly over the belt.

The drive pulley is where the power it applied to the belt in order to move it. Commonly the drive pulley is powered using an electric motor and a gearbox to reduce the RPM of the motor to the required RPM for the desired belt speed. In figure 3.2 a typical drive train configuration is shown. As belt conveyors are designed for longer distances, carrying heavier loads and crossing rougher terrain the design will become more complex.

There are many different types of belt conveyors, yet in the solid bulk material handling industry the

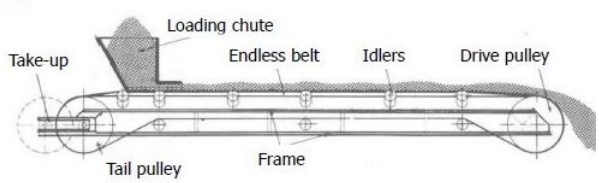

Figure 3.1: Main components of a belt conveyor [24]

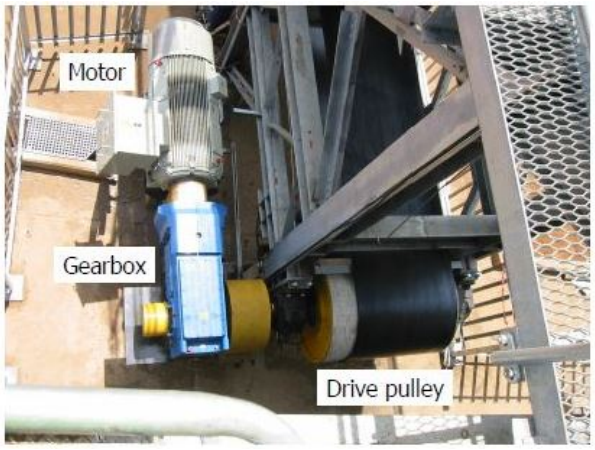

Figure 3.2: Conventional drive train [24]

through conveyor (figure 3.3) is mostly used. The advantage of this type of conveyor is that the idlers are positioned in such way that the sides of the belt are folded slightly upwards creating a V shape in the cross section of the belt. As the transported material is made up of separate particles it could easily fall of the sides if the belt was just flat. With this through created in the belt the material can not fall of that easily allowing more material to be loaded on the belt per meter of length. This increases the capacity of the belt making this type of belt popular in this industry.

3.1.1. The drive chain

The components of a conventional drive chain are shown in figure 3.2. An electric motor is used to convert electric energy into mechanical energy, ideally according to equation 3.1. In this equation the P_e is the electrical power supplied, T_e is the torque produced by the motor, and ω_r is the rotational speed of the rotor. This is a simplification of reality as electric motors do have loses in the systems and therefore are not a 100% efficient.

$$P_e = T_e \omega_r \tag{3.1}$$

The rotor speed that is produced by the motor can not be transferred to the drive pulley directly as it is too high, while on the other hand, the torque is often too low to be able to move the entire load directly. Therefore the output of the electric motor can not be transferred to the pulley straight away. A gearbox is added to the drive chain to make this possible as it reduces the rotational speed from the motor to the desired rotational speed for the pulley ω_p. The ratio i of a gearbox is calculated according to equation 3.2.

$$i = \frac{\omega_r}{\omega_p} \tag{3.2}$$

As a gearbox decreases the rotational speed, it increases the torque by the same ratio. However, due to losses in the gearbox the torque will not be increased exactly by ratio i. Therefore the output torque T_p of the gearbox can be calculated using equation 3.3. In this equation T_e stands for the torque input from the motor and η_d stands for the efficiency of the gearbox.

$$T_p = i T_e \eta_d \tag{3.3}$$

While designing a belt conveyor system choosing the right components for the drive chain is important. The criteria for the system give a desirable capacity for the conveyor. The capacity depends on the material that

Figure 3.3: Through conveyor loaded with coal [24]

can be loaded on the belt, and the speed at witch the belt is running. Basically the desired belt speed V_b and the diameter of the pulley D_p determine the ω_p that is required (equation 3.4), while the total load or drive force F_t and the diameter of the pulley determine the torque T_p that is required (equation 3.5). Using these figures the right motor and gearbox are selected and the diameter of the pulley is determined. These components are most of the time standardized and and are most of the time selected from catalogs. The components have to cope with the maximum loads on the system. These have to be determined and are typically found in scenarios like starting up a fully loaded conveyor. Selection of the proper drive chain components is important if one wants to make sure the design criteria are met. And this can only be done when the loads on the system during every reasonable scenario are known.

$$\omega_p = \frac{2V_b}{D_p} \tag{3.4}$$

$$T_p = \frac{D_p}{2} F_t \tag{3.5}$$

3.1.2. The conveyor belt

The belt is the trivial component in any belt conveyor as the belt carries the load, and transfers the power from the drive chain along the systems. As the loads can be enormous the belt has to be made of strong and durable material. It has to be both flexible as it has to pass the pulleys and bend in the through shape, but is also has to be strong to withstand the tension in the belt. Depending on the load to carry it might need other characteristics as well like heat resistant, cold resistant, fire resistant, oil resistant etc. depending on the material to be transported. Also, the belt material used on the outer layer should provide the required friction between belt and pulley.

To meet these requirements the belt consists of a strong carcass to transfer the drive through the belt, and a cover that is used to protect the carcass (figure 3.4. The cover is often made of rubber, or a rubber mixture because of its flexible, durable qualities and high friction coefficient. The carcass of the belt if often made of though fabric for the lighter applications, and steel cord for the heavy duty belts.

3.1.3. Take-up systems

The belt is driven by the drive pulley and these two components only rely on friction to transfer the power from the drive pulley to the belt. Without enough friction the belt would slip over the pulley resulting in a stand still of the system. To ensure enough friction the belt must be kept under tension during operation.

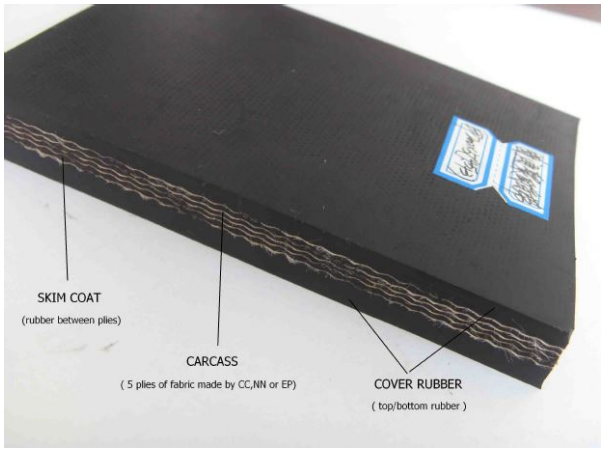

Figure 3.4: Example of belt material layers [24]

also the belt tension is important to minimize belt sag, as will be explained later on. This is done using a take-up system, often placed at the head pulley of the conveyor. As the belt can stretch the length vary depending on the situation, and this might require a take-up system that can cope with the changing length of the belt. However this is not always necessary, for instance when the system is shorter.

There are three types of take-up systems that are seen most often.

- Gravity take-up system
- Winch take-up system
- Screw take-up system

These three types differ in size and application. Both the winch and the gravity take-system can cope with variations in belt length during operation and result in constant tension on the belt.These two types mainly differ in size and complexity. The screw take-up is used for belts with a constant length as the pulley is fixed at a certain position. This also results in differences in tension exerted by the take-up systems depending on the operation.

3.1.4. Idlers

Idles form an important component in the efficiency of the conveyor. Idlers are used to support the belt, both on the loaded side, as well as on the return side of the conveyor. On the loaded side more idlers can be found as there is more load to be supported. Although this sounds trivial it is a difficult consideration to make on how much idlers there should be used. In general the less friction in the systems is desirable, but both less and more idlers can induce more friction, and therefore an optimal must be obtained.

As the belt rolls over idlers the belt indents inducing resistance. Also the idlers that starts spinning induced resistance because of its bearings. This leads to the conclusion that less idlers is desirable, but to little idlers also causes friction in the form of belt sag. The belt between two sets of idlers tends to sag under its load. This sag must be pulled up towards the next idler again again asking for more power. The amount of sag is an effect of the distance between rollers. This asks for a lot of idlers close together, contradicting the previous again. When we also add the influence of wear on the idlers, maintenance and costs in the equation there are quite a lot of factors to bear in mind.

3.2. Material transfers at belt conveyors

Belt conveyor systems may include more than one conveyor, and have to be connected to a source of material. Also the material has to be unloaded at some point, where it is transferred to an other mode of transport, put in stock for later use, or used in another process. The material can arrive at the beginning of a conveyor

Figure 3.5: Ship unloading into a hopper before it is loaded on the belt conveyor [25]

from various sources, typically straight from a mine or stockpile, or from an other mode of transport like a vessel or train. Also multiple conveyors are linked together to make it possible to transport material over longer lengths, or to create a flexible system with multiple routes. This last option is seen for example in bulk terminal or production plants, as material form different places has to be fed to the same output point. Also in longer conveyors transfers points are made when a sharp turn has to be made, or when the length creates other problems.

Depending on how the material is fed to the conveyor a different setup for the transfer point is required. Preferably a continuous material flow is to be created to load the conveyor as this allows the conveyor to transport the material more efficiently. When the material is picked up using a grab to feed it to the conveyor a small buffer is required to even out the loading process. When the conveyor is connected to a continuous source of material there is no need for a buffer zone for the material. In that case it is important that the material is fed at constant rate, and in volume that can be handled by the conveyor. It that is not the case additional equipment is required to feed the material to the belt so that the conveyor is capable of handling it. For example a bucket excavator or bucket re-claimer are able to create a continuous material flow for the conveyor. These machines include a conveyor themselves which transport the material to the main conveyor. This is possible as long as sufficient material is available. When the material is loaded onto the conveyor using an ordinary excavator a small buffer is used to even out the scoops of material from the excavator so that again the material is loaded onto the conveyor in a continuous stream.

3.2.1. Loading

The load on a belt should be evenly spread across the cross section to make sure the weight is distributed evenly. If this is not done it can result in the belt running of its supports, causing breakdown of the systems. Also it is desirable to load the belt with a constant flow of material so that the load on the entire system is constant. This will minimizes peeks in power consumption. To achieve this a chute is used. There are two basic designs of chutes. The first one consists of hopper or silo that holds some quantity of the material so that it can be deposited on the belt at a constant rate. The hopper is for example filled one scoop at the time by an excavator or grab and holds a small buffer of material to make sure the flow out of the hopper is constant. For example this is used while unloading a vessel. A crane with grab is used the take the material out of the vessel and loads it into a hopper, form where it is loaded on the belt conveyor (figure 3.5). The other main type of loading chute is used in transfer points from one conveyor to the next as is illustrated in figure 3.6. Such transfers can be made because of different reasons making a sharp turn being one of them. In this case the material is flowing of the precious conveyor and the chute is used to 'catch' the material and deposit it properly onto the next conveyor. The prupose of the chute is to guide the material onto the belt so that it is spread out evenly, seen from the cross section area, and to match the materials speed and direction with the belt speed and direction to minimize wear to the belt.

Figure 3.6: Configuration of belt conveyor and chute at a transfer point [26]

3.2.2. Unloading

Unloading a conveyor is done often done in a simple way. At the end of the conveyor the belt rolls over the drive pulley and its direction is reversed. The material however will not follow the belt because of its inertia and is thrown of the conveyor in the direction is was moving. In the case of a sticky material this might not be enough, so a scraper can be installed to scrape the last bits of material of the returning belt. As the material is thrown of it can be difficult controlling the trajectory of the material. Heavier parts fly further, as smaller parts decelerate quicker. When the material is to be dumped on a stockpile this could not be a problem, but when the material is to land a more specific zone some aid might be required. Then again a chute or hopper can be used to direct the material to its destination.

3.2.3. Transfer points

Where two conveyors are connected the material is loaded form one conveyor onto the other. This happens at so called transfer points, which are designed to guide the material that is coming from the first belt onto the second belt. Most of the previously mentioned aspects are important in such a connection. Transfer points are often used when a sharp turn has to be made. It is possible to make a turn within a single through conveyor, but only with a large radius. When a sharper turns are required a transfer point is used. Here the material comes of the first belt and is caught using a chute configuration that directs the material in the direction of the new conveyor, and preferably give the material the same speed as the belt speed to second conveyor to minimize wear.

4

Sustainable operation of belt conveyor systems

Belt conveyors systems are currently used in various industries. Especially for the transport of bulk solid material these systems are valued because of their high efficiency and low costs. To maintain its position between competitive transport modes further development of belt conveyor systems is required. Part of the development of belt conveyor systems is dealing with trends like sustainability. Currently additional demands from the market are created for most products. Not only low costs and high efficiency is valued in industrial products but this must be achieved with respect to sustainable aspects. In chapter 2 the definition of sustainable development is used as a good concept that defines how to develop a product while keeping in mind other valued aspects of our society, environment and economy. As sustainability is a recent demand from society it is now the time to look into belt conveyor systems and investigate its sustainability, to gain insight in how current systems perform, and make future sustainable development possible. In this chapter first the aspects of sustainability are evaluated with respect to belt conveyor systems to select relevant areas for further investigation. Next, life cycle thinking will be used to define the stages of a belt conveyor's life where its effects on the relevant aspects of sustainability are significant. Also specific aspects with considerable impact from the life stages will be selected to investigate further.

4.1. Context for assessment of belt conveyor systems

In figure 2.2 three aspects to modern life are mentioned that all have to be respected in their needs. These three aspects are the society, environment and the economy, and are all important for life as we know it. Where the three aspects meet sustainable development is defined. Taking a closer look at belt conveyor systems it is observed that these operate serving the economy. The economy overlaps with industry which provides goods and services for the society. Belt conveyor systems are used in production processes of food, consumer goods and energy. Often early in the entire chain where they are used to supply raw materials for different processes. How these three aspects relate to and interact with belt conveyor systems is discussed in this section.

4.1.1. Economy

As mentioned belt conveyor systems can be seen as part of the economy. The economical advantages of a belt conveyor are the reasons for its existence as belt conveyors were developed to improve efficiency and cut cost of certain operations. These two aspects and are still important selection criteria as the economy is structured to be costs driven. Governments attempt to stimulate more attention for sustainable development by introducing costs for unsustainable behavior, but this is relative new and has not yet reached all regions of the economy, leaving minimal costs still a major selection criterion in choosing a transport system.

As costs and efficiency is already embedded in how the operators and developers look at belt conveyor systems this will not be included in main focus of this survey, but it can not be left out completely. Side effects

of operation are interesting to minimize when these could lead to additional costs.

4.1.2. Society

Society includes most that has to do with humans directly, how they live and what they do. Different groups people (communities) and individual people make up the society. Belt conveyor systems are part of the economy that serves the society with goods and services. But the society also delivers labor to the economy to keep it running. Belt conveyor systems can operate more or less autonomously but still some human interference is required for example when maintenance has to be performed. Also conveyor systems can be part of larger operations of production processes which may include manual activities. That is why it is to be expected to have employees around and interacting with a belt conveyor system. For them it must be safe to work with the belt conveyor system, and health risks should be excluded or minimized. This is one aspect that will be considered regarding society.

An other aspect that will be considered under society is the effect of belt conveyor systems on communities in the area of where the conveyor operates. Belt conveyors in operations can cause nuisances to inhabitants in all sorts of ways. If the presence of a belt conveyor system is noticeable in a nearby residential area it can cause protest from inhabitants. This is something to keep in mind a it can result in bad publicity and has to be dealt with carefully. Also possible effect on the health of nearby residents should be a concern. Therefore it is important to include these aspects in the scope as sustainability is about the coexistence of multiple systems. Belt conveyor can also provide an important service to a nearby community, for example the supply of resourced or local economy creating jobs. This is excluded from the focus of this survey as this connection is not always evident, and has little to do with the sustainability of the systems itself.

Belt conveyor systems can also effect important life support systems in a community like ground water, etc. but this will be covered in the next section about the environment.

4.1.3. Environment

The environment is the basis of all life on earth and is essential for society as it provides important life sources. Examples are raw materials to fulfill industrial and social energy demands, and water and food for humans other life forms. Also vegetation is of vital importance as plants convert carbon dioxide into oxygen. Besides this the nature is valued by a large part of the people, including the biodiversity and natural ecosystems, contributing to the healthiness of our planet. Industrial processes can have negative effects on nature as emissions and spillages can pollute and disturb ecosystems that are part of the natural world. Also natural resources can be depleted when it is used at a higher rate than the recourse is generated again by nature. And all this can effect the human world as well as the biodiversity and natural balance in the ecosystems. Most ecosystems have been around for many decades, but with the intervention of humans these systems can easily be thrown of balance and decay. Since human population has been growing at extremely fast rates the impact of mankind on the planet has also grown substantially. The world population has grown from around 750 million in 1750 till around 7100 million in 2000 [8]. Not only are there vastly more humans on the planet also industrialization has increased the use of resources per person as well, creating an exponential growth in impact on the natural resources and ecosystems of the planet.

Specific environmental problems that occur on a large scale have been listed by the *Milieuloket*, a Dutch initiative from the government that aims to inform about environmental policies and issues. These are important topics that currently receive a lot of attention in attempts to solve or control them. Therefore these are should be considered while assessing the impact of belt conveyor system. The following subsections refer to the information about environmental problems provided by the *milieuloket*. [19]

Climate change

Climate change is a tough problem of global scale. The usage of fossil fuels is the largest contributor to the problem, but as our energy supply relies on these fuels it is hard to eliminate this factor. However, if we are to decrease the emission of greenhouse gasses the production and usage of energy must change.

Decreasing biodiversity

Human activities have claimed much living area for plants and wildlife. Also the wastes form society and economy threaten species, causing a decrease in the biodiversity. Only by taking better care of nature this can be stopped. Important is to control wastes and emissions better and protect environmental domains by stopping the deterioration of living space for plants and animals.

Noise nuisance

Noise can be a nuisance to people and communities and it comes from all kinds of sources. Industry is one of those possible sources as heavy machinery and industrial equipment can be noisy. For the comfort of people in the neighborhood it is best to keep noise production to a minimal and take measures from noise spreading over larger areas.

Air pollution and emissions

Exhaust gasses and industrial emissions are threatening peoples health as these are known to cause lung and heart problems. To guarantee good air quality regulations are imposed on industry and other sources of exhaust gasses and emissions.

4.2. Brief life cycle assessment for belt conveyor systems

Life Cycle Assessment was found to be a helpful method to map the impact of a certain system. It can be used for complete in depth analysis tool to quantify the impact of a system, but it can also be used to map what aspects of a system have a large impact in a more general way. Life cycle thinking requires to look at all stages of a system to identify elements or aspects that have a large impact. In this review life cycle thinking is used to identify important aspects to the belt conveyor system that are worth assessing on its sustainability. The five stages on a products life cycle as illustrated in figure 2.5 are listed below. These five stages will be briefly discussed for belt conveyor systems.

- Extraction
- Processing
- Manufacturing
- Use
- End of life

Extraction

Extraction concerns the retrieval of raw materials from nature. In includes materials that are used for the production of electricity, for the production of chemicals and for the production of construction materials for products or constructions of any scale. There extraction processes require the use of heavy machinery and industrial processes which can impact the environment in several ways. Also lots of energy is required during operation.

For a belt conveyor several materials would have to be extracted from the earth. Lots if steel is used, requiring iron ore. An other material that is used a lot in belt conveyors is material for the belt. Both synthetic material as natural material can used for the belt material. As there are lots of varieties in both belt cover and carcass it is not directly clear where the material comes from. Other metals, polymers and more also can be used. These are mostly materials that are also used in lots of other industries and processes. This makes it less interesting to investigate in further detail regarding belt conveyors specifically.

Processing
To create the building materials that are used in the manufacturing stage of a belt conveyor's life the raw materials have to be processed. This includes a wide variety of processes, for example, to create steal out of iron ore. Again, this requires processes that can impact its surroundings and can be costly in terms of energy consumption. For the same reason as in the previous paragraph this is not investigated further in this survey. These processes serve a wide variety of industries, and can can each be topic of a separate survey themselves. This would deviate to much from the topic of the sustainability of belt conveyor systems for this survey.

Manufacturing
During the life cycle assessment of the manufacturing stage of any product the thing that are looked at are the materials used to create the final product, and how efficient this is done. If the manufacturing creates a lot of waste material this is considered unsustainable. This can be minimized to recycle the waste materials and reuse them in the same or an other process. Again the energy consumption is included, as well as the impact of the manufacturing processes on the environment.

Many components of a belt conveyor systems can be ordered from different specialized manufacturers. Think of the components of a drive train, and the idlers. Other components are designed and manufactured specifically for belt conveyor systems. Depending on the location standardized components will be sufficient, but for more demanding location of projects some components might have to be designed for that location and operation specifically. When the components are standardized, manufacturing of the belt conveyor's components can easily be optimized, while for an unusual location this is a lot harder. Especially installation on site can be challenging when it comes to remote locations in hostile environments.

The manufacturing of components includes a wide variety of possibilities making difficult to assess the general impact of this stage of the life of a belt conveyor system. This will only be interesting when a specific case of a belt conveyor is assessed, and is therefore not included further in this survey.

Use
The usage stage of a belt conveyors life cycle is a mayor contributor to the impact of a belt conveyor system. Also it is possible to asses the impacts of this phase in a general way as there are a couple a side effects of operation that occur in most situations. Still this depends the location of the belt conveyor system and the material that is transported. As belt conveyor are build to last for many years the usage stage of its life will probably have a high impact considered to the other stages. Belt conveyor systems are build to last a life time, and are not consumer goods. When it breaks down, it is often repaired. This makes the impact of the usage stage interesting when assessing the sustainability of a belt conveyor system.

One aspect that is applicable to the usage stage of all belt conveyor systems is the energy consumption. Moving large amounts of material costs a lot of energy. Currently most of the world energy is produced using fossil fuels which have a considerable impact on the planet and its ecosystems. Also it depletes the worlds resources. The amount of energy used can differ depending on the terrain that is crossed, but is always effected by several system components. These components are therefore interesting to investigate further. The effects of energy consumption on the environment, together with the energy consumption of belt conveyor operations and how this can bi minimized will be discussed in later chapters.

Side effects of operation of a belt conveyor system can occur during operation. Although the side effects that occur depend on the material that is transported, there are several phenomena that are know to occur in most cases. Common side effects are noise and dust generation. Depending on the material, and the location this can be a problem that has to be dealt with as well. These two side effect will also be included in the following chapters.

Besides energy consumption also the location of a belt conveyor system can have a considerable effect of nature. Especially overland conveyor can cross living space of wildlife and communities of different people. As the systems are build to last a long time it is can be interesting to include the impact of its location. However, this is not included in great detail as this is very specifically depending on the location and therefore

should be investigated case by case. But since it can have various effects that are with mentioning these will be discussed briefly later in this chapter.

The usage of belt conveyor systems also include interference with people that perform maintenance, or other tasks regarding the operation of the system. This is included as well in the focus as the sustainability included the impact on society as well.

Maintenance
Although belt conveyor systems are often designed to last long, still maintenance is required. The system consists of many different components of which many will wear because of the use. With popper design and installation of the system the wear can be kept to a minimum, but still wear will occur. And wear can lead to negative side effects, like an increase in noise generation or an increase of friction in the system. On top of that failure of certain components can cause failure of the entire system, and even cause damage to the systems as well. For example, when the belt ruptures the system will come to a abrupt standstill resulting in possible damage to the idlers and lots of spillage of material. The result of such event can be dangerous to nearby employees ass well and will lead to a long stand still of the system.

To prevent scenarios like discussed above regular maintenance is of significant importance. Both to monitor the state and functioning of the system, as well as to replace faulty or worn out parts before is causes dangerous situations and failure of the system. Therefore maintenance is to be considered an important part of usage stage of the life cycle of a belt conveyor system.

Maintenance helps the guarantee up time of the system, and lengthen the life time of a belt conveyor. In the light of life cycle thinking this is considered valuable as well. With proper maintenance on the systems, new materials to rebuild the system are kept to a minimum. The systems long life time however can also have a negative effect as well because when the system gets older, it is possible that its efficiency goes down, or that more efficient systems became available in the meanwhile. There will always be a trade off between the benefits of the energy consumption a new more efficient system versus the material and energy that goes into building the new system. Also maintenance will increase over the years for older systems.

This trade off is currently made with respect to the financial aspects of the issue. However, the same can be done for the environmental aspects of this issue using life cycle thinking. Unfortunately the emphasis in current business model lies on the financial aspect. This can result in a belt conveyor system with high environmental impact to stay in operation as it is financially still the most profitable option.

The impact of maintenance on the sustainability will not be the main focus of this survey. However it will be discussed briefly when it can contribute to more sustainable operation of the system. In the following chapters different impacts of belt conveyor systems are discussed, including preventative measures for negative side effects. Proper maintenance can sometimes be a viable solution, seen from the sustainability point of view. However, maintenance can be costly as it may interrupt operation, and often include manual labor. When the status of the current system does not propose direct danger to employees or the systems up time, the financial aspect is most of the time conclusive in the decision.

End of life

When a belt conveyor systems is no longer needed, or has to be replaced with a new systems it has reached its ed of life. At this point all the parts and materials in the belt conveyor will be taken away as it will not generate profit anymore. In the life cycle assessment the end of life stage is also included as the material can be a big burden to the environment. Many man-made materials do barley deteriorate in nature unless mankind breaks them down. Some materials used can release toxic chemicals, or propose other dangers to the environment. The impact of the afterlife is therefore important in life cycle thinking.

In the case of a belt conveyor system the afterlife is considered a small part of the entire cycle. Also the materials used are often not very toxic. However, most systems include a huge amount of material that is worth recycling. A lot of metal is used, and this can be recycled rather well while the rubber belt is probably

more challenging to recycle. Because belt conveyor systems are often upgraded instead of replaced entirely the afterlife is only a small aspect and will therefore not be included in the rest of this survey.

4.3. Environmental and social concerns during belt conveyor operation

From the previous section it became clear that the use or operational stage of the belt conveyor will be the focus of this survey. Also the focus of the survey will be on the social and environmental impacts of a belt conveyor system.

Operation of a belt conveyor systems also has effects that are less desirable. Some are inevitable as it is required for the systems functioning, others are side effects of operation. The side effects effects can differ per situation as the materials that are transported have different characteristics. Most of the regular side effects and other negative effects are mentioned and discussed regarding relevance for further research. The selected topics will be investigated further and evaluated in later chapters.

Energy consumption

Belt conveyors perform a task that requires a lot of energy. Usage of a belt conveyor for transport is most interesting in scenarios where a lot of material is to be transported. The energy consumption of a belt conveyor system does have an impact in various ways. Energy in the form of electricity must be produced and this energy can be produced using different energy sources. How this is done depends on the location of the belt conveyor and the available resources. Depending on the available energy source in the area the electricity can come from a renewable or fossil source. In most part of the world fossil fuels are the main source. The energy consumption could therefore be likened to emission of greenhouse gasses which contribute to climate change. Also energy consumption forms a major part of the operational costs of a belt conveyor system. Therefore it will be interesting to see what effects the power consumption of belt conveyor systems and what is being developed to reduce this.

Dust and spillage

Dust generation and the spillage of material often occur as negative possible side effects of the processes and equipment used in the material handling industry. The handling equipment continuously processes huge amounts of material. As the material consists of separate particles it is required to guide the material to the place it is supposed to go in order to prevent spillage of material. Spilled material can build up around the equipment possibly causing nuisances and problems. Due to the handling procedures smaller particles can be separated of the material and get airborne. The airborne particles, dust, is difficult to control as it can be picked up by the wind and deposited at any location. Both spillage and dust have negative effects on the equipment's life time and functioning as it can cause wear different components. When spillage occurs cleaning is required and wear results in more maintenance tasks. Both result in more labor and downtime of the system, increasing the operational costs, and decreasing profits.

Beside its effects on the equipment and the process, spillage and dust can also be a nuisance to nearby communities and create health risks to both the workers and inhabitants in the area. Especially dust is much more dangerous than was thought in the early years of the mining industry. Chapter 6 will be dedicated to the impacts dust and spillage can have on the sustainability of belt conveyor systems. The chapter includes insights in how and where dust is generated during operation of belt conveyor systems, what the dangers are to the environment and the people, and it will give an overview of what possible prevention and control methods are currently available to deal with dust and spillage.

Noise

Operation of a belt conveyor can generate lots of sounds. The conveyor is a large machine with many moving components. Especially loading and unloading of a conveyor can cause lots of noise generation, but also the belt running over the idlers is a possible source of noise. Noise generation is often continuous during operation, with maximum levels around transfer points. Subjection to loud noise can do damage to ones hearing

resulting in temporary discomfort or permanent damage. This is a real risk for people working in direct surrounding of a conveyor for longer times at once. But also surrounding neighborhoods can have nuisance from noise. High sound levels can lead to restlessness and insomnia. But noise generation is not only a problem to people. Wildlife can also be effected by the sounds generated. This is for example the case when the belt conveyor system is located near the feeding or breeding area of certain species.

Both seen from a social as well as from an environmental point of view the noise generation should be kept to a minimum. However, the impact on others can differ depending on the location of the belt conveyor system. Therefore also the preventative measures that are required can differ per situation. Both noise reduction as well as noise protection are option to consider. In chapter 7 the sources for noise generation during operation will be discussed, followed by effects noise can have on society and environment. Also techniques to minimize and prevent noise generation are included.

5

Energy consumption

For the transport of bulk solid material belt conveyors are frequently chosen as the mode of transport since it is an efficient and cost effective way of transport. As the word 'bulk' already suggests, the quantities of material to transport are large. Often the supply of material is more or less constant for a significant period of time. A belt conveyor system allows transportation over long distances to go continuously and automatically. However, the transport of such large quantities of material requires a lot of energy. And depending on the energy source it will have an impact on the global resources and the environment. How the power consumption has an impact on the environment will first be discussed in this chapter. The effects on the environment are likely to cause changes that will effect the society as well, as will be discussed in the following section. Next, the basic power consumption of a belt conveyor is investigated, to get some insight in what factors influence the power consumption. Finally recent improvements in the technology and promising new techniques are presented and explained.

5.1. Environmental impact

Energy can be found in many forms, but our modern society requires a lot of energy in the form of electrical energy. The same applies to belt conveyor systems as these most of the time are driven by an electrical motor. Electricity itself is not a natural recourse and can be produced in different ways. The conventional ways to produce electricity is via a power plant that is driven by a fossil fuel like coal or gas. In remote locations mobile generators can be used which can also be powered by gasoline or diesel. A newer energy source is nuclear power. These types of power generation create a lot of harmful emissions or wastes for the environment. The use of fossil fuels results in large quantities of green house gasses, which are a major contributor to global warming. Also the natural resources of fossil fuels are running out as the fossil fuels are being used at higher rates then it is regenerated by nature. Herman Daly stated the following three ... (voorwaarden) for a society to be physically sustainable [27]:

- The rate at which renewable sources are being used does not exceed the rate at which these sources are regenerated.
- The rate at which non-renewable source are being used does not exceed the rate at which sustainable renewable resources are being developed.
- The emission of harmful and polluting substances do not exceed the natural cleaning capacity of the environment.

Currently mankind does not meet the last two, if not all three, of these criteria.

The extraction of fossil fuels has large impacts on the environment. The oil industry has caused many oil spills over the last decades, destroying the living areas of many species. Waters and grounds have been polluted killing lots of animals and vegetation. Cleaning operations are very costly and only partially effective. Also coal mining has made deep scars in the earth's surface, again destroying nature.

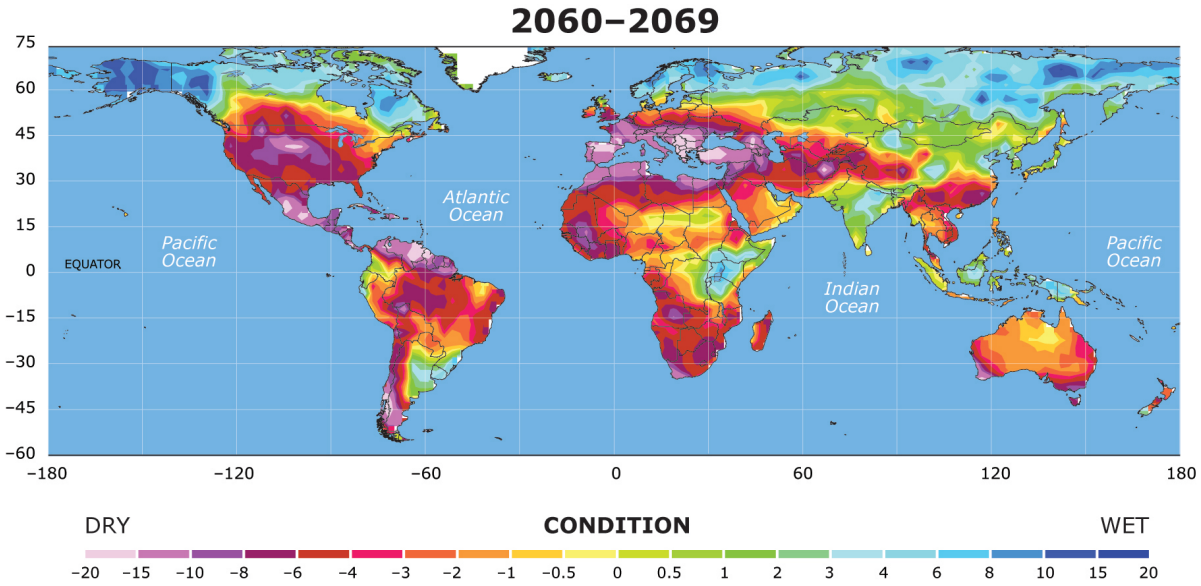

Figure 5.1: World map indicating the Palmer Drought Severity Index (DPSI) for the decade of 2060-2069 [30]

Also nuclear power has the disadvantage that it leaves behind nuclear waste which is very dangerous material. Operation of a nuclear power plant and storage of the waste is dangerous as the effects of a meltdown are enormous. Therefore these energy sources are undesirable to use in large quantities.

Currently the usage of green energy sources is developing in the form of solar power and wind power. However, this industry is not mature jet and just a very small amount of the worlds energy consumption comes from natural renewable green resources. According to the International Energy Agency the worlds primary energy supply still consists for 81.4% of fossil fuel. [28]

5.1.1. Greenhouse gasses and climate change

Electricity generation has a big impact on the environment as it is a large contributor to the emission of green house gasses. These green house gasses are one of the main reasons for global warming. Joseph Romm published in 2011 a warning of the expected consequences of global warning if this continues at current rates, and the scenarios he predicted are mentioned in this section. [29] The earths temperatures will continue to rise, and this will continue at even faster rates if also energy consumption is not brought down. Results of the rising temperature are changing climates all over the planet. This includes melting of the polar ice which causes the sea levels to rise. If this continues the coastal areas will flood which would have major consequences as a larger percentage of the world population is living in the coastal regions. But strangely enough this problem with the sea levels does not ensure fertile and green land. The rising temperature will change large parts of currently fertile grounds into desserts. A landscape and climate like the one in Northern Africa can be expected the emerge up north as far as London, Paris, Berlin, Beijing or San Francisco. This will create shortages of fertile farmland increasing the food problems we have already in many parts of Africa. Also the hotter temperatures create climates where tornado's and heavy sand storms will occur more frequently with all their destructing effects. Scenarios like these are based on moderate climate change. These are not worst case predictions as these were made based on current emission levels, neglecting the increase in emissions that we are sill witnessing today. Scenarios like these can already be reality in the year 2060. Figure 5.1 shows a world map indicating the Palmer Drought Severity Index (PDSI) for the decade of 2060-2069. To give a comparison: In great parts of the United States the DPSI only briefly peeked at -6 during the 'Dust Bowl', but during the rest of that decade the measurements did barely indicated above a -3 drought level. This was already enough to abandon before fertile farm land on a large scale. [30]

5.2. Social impact

One can imagine that such effects on the environment also have a huge impact on society as well. As mentioned the rising sea levels endanger the living area a vast amount of the world population, and also fertile grounds can fall into decay because of rising temperatures. This will alter our modern society and endanger many communities. And all these effects can already be real in the year 2060 if we continue in this way. But also some effects are already noticeable as it directly effects societies. For example the heavy industry around Shanghai and Beijing in China contribute to lots of smog in the air. This limits visibility as these cities appear the be in a grey cloud most of the time and it is bad for the health of the people inhaling it. On days of heavy smog breathing the air can be compared to smoking cigarettes. An other example is the extraction of gas from the ground in Groningen, in the Netherlands. This causes regular earthquakes, and as the ground starts moving, many houses damage and walls tear. These effects directly influence communities as people are endangered, and living areas are being destroyed. And the ongoing environmental changes will only effect society more and more.

5.3. Basic power consumption

Belt conveyor systems are seen as a efficient way to transport large amounts of material, and compared with other modes of transport the systems are often already performing well in terms of energy consumption. Also the fact that belt conveyors run on electricity make that they have lots of potential to also the the sustainable mode of transport the future needs; when the electricity used comes from a green or renewable source. However, still further development is required to bring the energy consumption down. At this moment this will contribute to a more sustainable world, but also ensure the market position of belt conveyor systems in the future. This s because energy costs are currently the major contributor to the operational costs of belt conveyor systems. [31] [32]

In this section the focus lies on the energy consumption of belt conveyor systems. The goal is to find out what factors contribute to the energy consumption of the system. In chapter 3 the power consumption of a belt conveyor systems is already briefly discussed. From that chapter we learn that the power that is consumed by a belt conveyor is linked to the drive force. The drive force together with the pulley dimensions determine the required drive torque 3.5. Through the gearbox this drive torque is delivered by the motor torque 3.3. The motor torque directly determines the power consumption 3.1 for the entire system. So the drive forces, together with the efficiency of the drive chain components, directly influence the power consumption. As the drive train components are bought from external manufacturers these will not be discussed further. However, the combination of other components in the system will determine the drive force and these will be discussed in this section.

5.3.1. Drive force components

The drive force needed to make the conveyor run and keep it running is a combination of 4 different resistances in the systems. To accelerate the belt, or keep it running at a continuous speed, these resistances have to be overcome, leading to the power consumption of the motor as explained in the section about the drive chain. The four groups of resistances are listed below and add up to the total drive force F_t as shown in equation 5.1

- Main or primary resistances F_H
- Side or secondary resistances F_N
- Gradient or lift resistance $F_S t$
- Special resistances F_s

$$F_t = F_H + F_N + F_S t(+F_s) \tag{5.1}$$

Main resistances
The main resistance F_H is build up of the entire mass that is moving in the system and this includes the mass of the rollers that the belt is running over and the mass of the the belt as well. The different masses are calculated per meter length of conveyor and are defined as the mass of the rotating rolls m'_R, the mass of the belt m'_G and the mass of the material on the belt m'_L. In equation 5.2 the masses per meter length are added up. The total mass of the systems is defined as M, the length of the conveyor is defined as L and the inclination angle is defined as δ. Important to realize that the mass of the entire belt has to be taken into account, including the return side. Therefore the mass of the belt is also multiplied by 2.

$$M = L[m'_R + (2m'_G + m'_L)\cos\delta] \tag{5.2}$$

$$F_H = fMg \tag{5.3}$$

To calculate F_H equation 5.3 is needed were g is the gravitational constant, and f is the equivalent friction factor [33]. The norm for belt conveyors for loose bulk materials, DIN 22101, prescribes how this equivalent friction factor has to be calculated.

Side resistances
The side resistance is determined through experiments and appears to have a fixed relation with F_H. This relation is shown in equation 5.4. The coefficient C is a factor between 1 and 9, and declines as the length of the conveyor increases. For short conveyors this resistance is has a major contribution to the total resistance. As the length of the conveyor increases the effect diminishes and can almost be neglected for conveyors of considerable length.

$$F_N = (C-1)F_H \tag{5.4}$$

Gradient resistances
When a conveyor has a path that is inclining this will add dramatically to the required drive force. In order to move a load up to higher ground, it has to increase in potential energy resulting in high energy consumption. This resistance is calculated using equation 5.5.

$$F_S t = Hm'_L g \tag{5.5}$$

In this equation H elevation in meters that has to be reached. The contribution to the total energy consumption can clearly be seen in the comparison between conveyors with large differences in elevation as made by Alspaugh in 2004 [34]. As the elevation between the begin and end of a conveyor becomes larger, the effect of the lift resistance increases tremendously and the other resistances can diminish to only 10% of the total resistance. However, it is not possible to elevate a load without adding considerable energy to the load. This means that the lift resistance is inevitable. Using a more efficient conveyor will not influence the absolute energy that is required for the lift of the material [35].

Special resistances
So called special resistances can be specified in case other resistances occur that are not common on other conveyors. An example is for instance when the conveyor track includes turns which induced extra resistances that normally would not occur. With most through conveyors there would be limited to no special resistances to account for in the model.

Total drive force
When the previous equations are substituted in equation 5.1 the more specific equation 5.6 is found. This is excluding the special resistances as these are not applicable to every conveyor and have to be defined in case they occur.

$$F = CfL[m'_R + (2m'_g + m'_L)\cos\delta]g + Hm'_L g \tag{5.6}$$

5.3.2. Losses in the system

That a load will induce resistance and requires a certain force to be transported can be considered trivial. But when one looks to the conveyor in more detail, it is possible to point out what creates these resistances. This knowledge is important while designing more efficient conveyors. This section will discuss a few typical phenomena that occur within belt conveyors that cause energy losses in the system. [35]

Rubber indentation losses

Where the belt makes contact with a roller or idler the belt will dent under at the contact area. This happens constantly as the belt moves along and this happens at every idler. The effect of this is loss of power as it costs energy to dent the rubber. Using other types of material or higher belt speeds the losses from this phenomena can be reduced.

Material flexural losses

The through in the belt is created using idlers as they push the sides of the belt upwards. This allows more material to be loaded on the belt. But in the spaces between two sets of idlers the sides are not supported and the material will sag outwards. Also will the material sag downwards as an effect of gravity. When this material passes the next idler it is pushed back inwards and upwards as the idlers dictate a specific shape for the belt. The move the material back into the desired shape costs power and therefore induces losses again. This losses can be minimized by shortening the idler spacing and increase belt tension.

Idler losses

The idlers itself must be positioned perfectly relative to the belt in order to minimize losses. When the rotational axes of an idler is not precisely perpendicular to the belt also losses occur. The rolling direction of the idles is not the same as the movement for the belt and this causes the belt to partially slide over the roller, inducing more friction and therefor losses. This also may effect the life of the belt as the cover wears faster due to the sliding.

5.3.3. External influences

The energy consumption of a belt conveyor is not only determined by the efficiency of the components in the system. There is a considerable difference in power consumption between flat conveyors and inclined conveyors. Inclined conveyors lift the material up to an other height which requires a lot more power. This is inevitable as potential energy must be added to the material in order to lift it, and in this situation the main contribution to the energy consumption comes from this lift (figure 5.3). In the case of a flat conveyor the energy consumption is mainly dictated by the belt material flexure and idles resistance (figure 5.2) [35] [34].

When looking at the equipment, the power consumption is caused by several factors. As previously said, depending on the terrain the lift determines the power consumption for a great deal. Also the energy losses in the system contribute to the power consumption as resistances have to be overcome in order to keep the system running. In section 5.3.2 three examples are given of how components induce losses in the system. During start up peaks in the power consumption occur. Besides this, also the drive trains efficiency influences the power consumption as energy losses in the conversion of electricity to mechanical energy do occur. All of these are areas where possible improvements can be made to decrease power consumption.

Power consumption can be addressed on both the equipment level, as well as on operation level. On equipment the focus lies on using more efficient components that perform the operation using less electricity. This could be a motor or gear reducer that transform the energy more efficient, but it could also be a new belt or better idlers that induce less friction in the system. On operational level the occupancy of a belt conveyor system can be optimized focusing on power consumption. Theses will be discussed in this section.

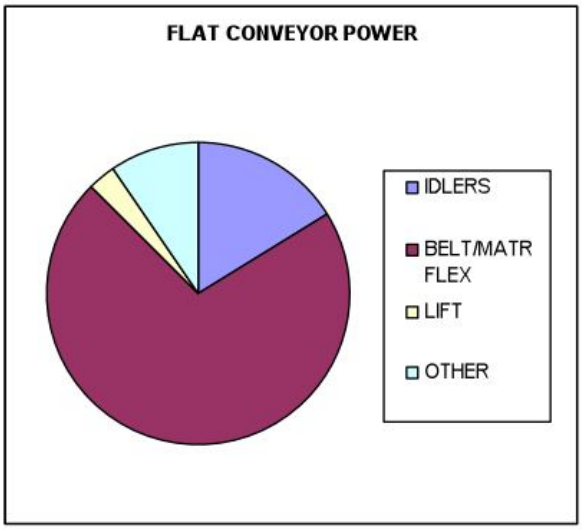

Figure 5.2: Flat belt power [35]

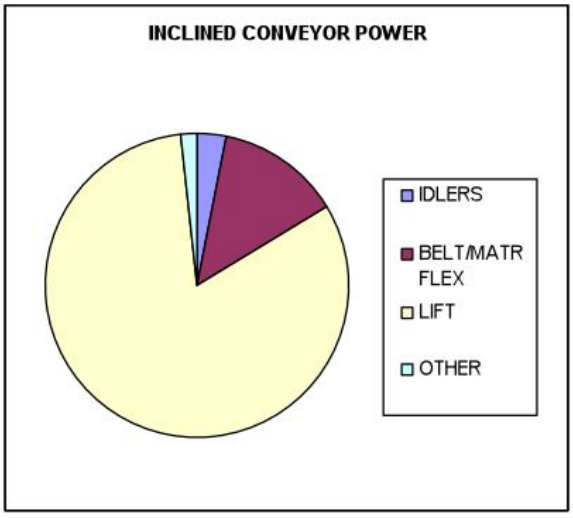

Figure 5.3: inclined conveyor power [35]

5.4. Technological innovations to minimize power consumption

The power consumption of belt conveyor systems is an aspect that receives a lot of attention from different manufacturers. Decreasing the power consumption is interesting for the operator as this brings down operational costs, and improves sustainability performance as well. Also more regulation concerning energy consumption is to be expected. All this makes it worth to invest in more efficient technologies and techniques to bring down energy consumption of belt conveyor systems. This is visible in the market as many companies advertise with new belt conveyor solutions on this issue. In the previous section several factors that influence the power consumption of a belt conveyor system were indicated. This section will show what technological innovations are available to minimize power consumption.

5.4.1. Motor technology

The motor plays a big role in the energy efficiency as this is where the power is consumed. Chapter 3 shows that the drive train converts the electrical power to mechanical power driving the motion of the belt conveyor. This conversion includes a electrical motor and a gearbox, both converting the energy with a certain efficiency. With higher efficiency of these components energy losses can already be decreased. Older components tend to have a lower efficiency, as after years of operation the efficiency of components can decrease because of wear. Also new developments in technology over the years might have improves efficiency overall. The investment in new and better electric motors has a very short payback time as the acquisition of a 3000 hour annual service life only accounts for less than 3% of the total costs for that motor. Yet 95% of the total costs come from energy consumption. Is it clear that a more efficient motor can pay itself back in a short period of time and is therefore interesting from both an economical and the sustainable point of view [36].

As electric motors have a much larger application than in belt conveyor systems alone it is an active research field for along time already with multiple industries investing in it. The belt conveyor industry often purchases the specific motor for a belt conveyor system from a specialized motor manufacturer as they have the know how to provide state of the art products. Since electric motors are applied in various industries it is possible to choose form a wide range, and enough motors that suit belt conveyor systems are available. Over the last decades the conventional electric motor have been replaced with a new generation of energy efficient electric motors that is up to nearly 5% more efficient resulting in considerable reduction of the energy costs [37]. New belt conveyor systems can be equipped with efficient motors, but also older belt conveyor systems can be easily updated with more efficient motors. This is an interesting option when motors are burnt out, but it can even be profitable to replace older motors before they stop functioning. Because of the expected energy savings such an investment can pay itself back in a short period of time. Off course the local energy price has to be taken into account.

5.4.2. Speed control

The energy consumption of Belt conveyor systems can be reduced by improving the operation efficiency trough coordination of its belt speed and feed rate [38]. Coordination of belt speed and feed rate is often mentioned as variable speed drive of speed control, and attempts to load the conveyor to its rated capacity. The rated capacity of a belt conveyor is the capacity that the manufacturer guarantees for that specific conveyor. Depending on the feed rate the conveyor is slowing down or speeding up. For example the conveyor slows down when less material is fed to the belt. This allows the conveyor to be filled up to rated capacity. The lower speed of the conveyor costs less energy, while the amount of material that is transport per time unit stays the same since this is determined by the feed rate. Using simulation it is shown that variable speed control can indeed safe energy, although it is not applicable in every scenario. Speeding up the belt conveyor requires and additional acceleration, which requires extra energy. If the feed rate changes constantly, the conveyor has to sow down and speed up for short instances of time. Since this costs energy it is not profitable to do this for every small change in feed rate. Only when the feed rate stays constant for a longer time, it can be profitable in terms of energy savings.

A conveyor can be stationed in line with a feeder, or and other conveyor to feed material. In figure 5.4 the situation with two conveyors in series is illustrated. The first conveyor runs at a certain speed v_r with a small amount of material on the belt, as can be seen at its cross section area of material on the belt A. The second

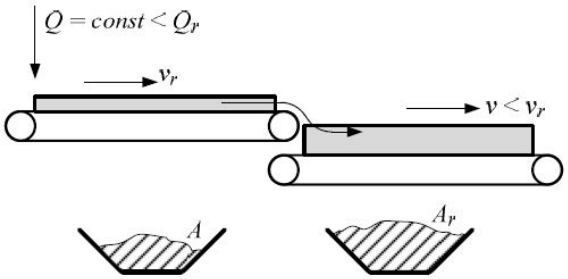

Figure 5.4: Cross section of belt conveyor at different speed [39]

conveyor runs at a lower speed $v < v_r$ so that more material per length unit is loaded on the second conveyor. This can be seen in the cross section area of material on the second belt A_r. If a conveyor operates on less than rated capacity, there are multiple possible combinations of belt speed and cross section area of material to transport the same amount of material [39]. The two conveyors in figure 5.4 transport the same amount of material in the same time, and this amount is dictated by the feed rate.

Adjusting the belt speed to maximize the cross section area of material on the belt should result in energy savings, according to DIN22101 [33]. The proposed resistance model in DIN22101 assumes that the coefficient of friction f is constant. This indicates it is not a function of belt load or velocity resulting in the conclusion that adjusting the belt speed or belt load has no influence on the friction. Therefore it is theoretically possible to save energy using speed control on conveyors, to reduce belt speed and maximize belt load, or cross section area of material on the belt. Currently several researches are dedicated to the development fuzzy speed control for belt conveyor systems to improve the energy efficiency, and make this applicable in the field. [40] [39]

5.4.3. Low loss conveyor belts

Technology concerning the belt itself has also improved. Belts consists of a carcass, in between a cover to make it durable and strong enough. As the carcass performs as the structural part of the belt is has to be tough and able to withstand high stresses. Therefore a common type belt carcass is steel cables. However, this can increase the weight of the belt tremendously and all that weight has to be pulled around, costing energy. To bring down the weight of the belt, the carcass has been researched and an alternative for the rather heavy steel cords has been found in the form of Aramid [41]. This material at the same strength, is 5 times lighter than steel and 4 times lighter than polyester [42]. This saves considerable weight of the belt compared with the conventional reinforcement, resulting is lower belt induced resistances. In the cases tested in [42] energy savings of 40% up to 60% are expected which would be enormous. The payback time of such belt is very short; only two to three months. This shows how much can be gained from the use of smart materials in belts, both from and environmental as from an economical point of view.

Over the past years several low loss conveyor belts have been developed. As material knowledge grew, and more synthetic materials became available there was a lot of choice for net belt material. Now the quick gains in this area have been picked and significant improvements have been made. The improvements that are still to be made are smaller and require more research.

The locations where natural materials are extracted spread as former mines are running out. This leads to a question from the market for longer belt conveyors, so called overland conveyors. As technology advances such overland conveyors have become possible, also crossing more challenging terrains. A longer conveyor also means the increase of the belt weight in the system, increasing the resistance in the system. In overland conveyors this additional resistance in significant because of the length of the belt. This asks for the design of lighter belt covers and carcasses.

6

The impact of dust generation and spillage

This chapter is dedicated to the impact of dust generation and spillage of material during operation of belt conveyor systems transporting bulk solid materials to the environment and social communities and individuals. The goal is to gain insight in what causes dust generation at different stages of the process, and what causes spillage of material during operation. After this the impact of dust and spillage on the environment and the society will be discussed, including a brief overview of possible financial consequences. After this strategies and technologies will be discussed to give an overview of possible solutions to the problem.

6.1. Sources of dust generation and spillage

Different kinds of bulk material are moved in great quantities by belt conveyor systems. When the material contains light enough particles, dust generation will be a problem during different stages of the handling process. The constant moving of the material creates the risk of spillage and particles becoming airborne. In the case of belt conveyor systems the loading and unloading of the conveyor a transfer points creates additional movements of the material as it changes direction, comes in contact with multiple part of equipment and decelerates and accelerates. Also dust can be shaken from the belt as it passes over the idlers. Further a high velocity of ventilation air, or winds in the open, can assist the release dust by drying the material and releasing settled particles [43]. However, especially during loading and unloading of the belt conveyor huge amounts of dust are generated, as the material is shaken up the most. (figure6.1).

During loading of a conveyor belt the material falls down and is directed onto the belt. To do so a chute is used, which directs the material in the right direction to prevent spilling and create an even load distribution across the conveyor belt. During this process the material can make contact with the chute or with other particles of the material, possibly causing more dust particles to emerge. The material falls of the conveyor and this lands in a designated area. Dust pollution at the transfer station is primarily caused by the air entertainment and shock waves [44]. The falling material takes air with it, causing additional airflow around the material, and on impact shock waves occur. This causes particles to be blown away, creating dust. The effects of unloading a belt conveyor are comparable to the loading since the material is changing direction and speed, causing the entrainment of air and dust generation. The unloading is usually done at the head pulley where the belt follows the pulley to return, and the material continues in more or less the direction it had because of its inertia. The material falls of the belt and lands in a chute or a sort of container, or on top of a stockpile, and is also vulnerable for spillage and dust generation as is described before.

Depending on the final usage of the material it is desired not to break it into smaller particles during processing. This would also create more dust and possible spillage. Therefore the handling equipment is often designed to minimize impact on the material, in order to minimize damage to the particles. When the handling equipment causes dust generation it is important to include dust prevention and dust control measures in the process. This is often required at transfer points, although in the case of material that is more likely to become airborne, dust prevention might have to be included all along the route of the conveyor.

Figure 6.1: Dust generation during unloading [45]

The type of material influences the amount dust generation. Only small and light material particles can become airborne resulting in dust, as the particles are often less than 500 micron in size [46]. Material that has larger and heavier particles will create less dust. Also moist material is not likely to cause dust as the moist makes the small particles heavier, and stick together or to the equipment making it less likely to get airborne. The weather conditions influence the dust generation as well. Rain will prevent particles from becoming airborne during open air operation, and the rain also prevents the dust from spreading over a great distance. Depending on the material that is transported and the weather conditions dust generation can be a problem during operation as some material loose functionality or value when they get wet.

6.2. Safety hazards

Most people know that airborne dust can irritate the respiratory ducts and the eyes, but that is only the tip of the iceberg. In fact, airborne dust is a serious hazard for workers at a plant, inhabitants in the neighborhood, and the vegetation and wildlife in the area as it can cause diseases, explosions and fire. Also dust can do damage to the equipment and cause premature wear. In the beginning of industrialization these hazards were unknown, but currently these are acknowledged by most governments and regulation agencies. Appropriate legislation is set up in a lot of countries to protect employees, inhabitants and the environments from the hazards that airborne dust can oppose.

6.2.1. People and health

The World Health Organization warns for the dangers of airborne contaminants, and in particular airborne dust as these are associated with widespread occupational lung diseases [47] [48]. Inhaling the particles can cause a wide variety of problems, such lunch diseases like pneumoconioses, systemic intoxication, cancer, asthma, allergic alveolitis and irritation. Also non-respiratory diseases may occur, even at much lower exposure levels. When people inhale airborne dust, they are at risk of occupational disease. Effects of a disease can be temporarily or permanent disabilities, as well as death. Many materials transported using belt convey-

ors, among which also many can generate dangerous dust clouds. For example silica, asbestos and coal are commonly known to cause lung diseases and lung function impairment [49]. Coal has been mined in great volumes for a long time already and in the beginning the safety regulations were very minimal. Currently coal dust is known as serious hazard as it is proven to cause 'black lung' or pneumoconiosis and obstructive pulmonary disease when inhaled frequently. The risks have now been largely controlled by dust suppression, ventilation and respiratory protection. Vigilance is, however, to maintain effective control [50].

Depending on the particle size that is inhaled it will be deposited at some point in the respiratory duct. Typically particles of more than 30μm diameter are deposited at the nose and upper airways, while smaller particles are able to reach the lungs. The concentration of the dust in the air is an important factor in the risk the dust proposes, as well as the composition of the dust particles and the material. Therefore it is important to examine the possible dust generation at a plant, so that appropriate measures can be taken.

In well developed countries the work conditions are valued and unsafe work environment or workers conditions are seen as unethical. Besides that it can lead to dangerous situations for the employee it can also lead to citations from authorities. Also the costs of occupational diseases can come back to the employer, leading to high financial costs. Although inhabitants of the area have less risks of being subjected to high concentrations of dusts, the company should also guarantee safety for those.

6.2.2. Explosion and fire

The material that is thrown into the air creates the danger of an explosion. Depending on the characteristics of the material it can ignite with a single spark. Not all materials are flammable enough to cause such problems, but it is a real threat in some cases. Not only chemicals propose this danger as harmless looking material can also incinerate explosively. For example coal dust proposes this danger when it gets airborne in the right concentrations of the right particle sizes [51]. Dust in closed areas can build up to dangerous levels more easily, but also in open air explosive combustion of dust is a hazard that has to be dealt with. Large buildups of dust deposits form an additional danger in the case of an explosion or a fire. Such an event causes additional air movement that can easily stir up dust piles. This can cause more explosive ignitions and accelerate the spreading of fires. Also for this reason it is important to keep the work area free of dust deposits.

6.2.3. Social impact of dust and spillage

These safety hazards can have a negative social impact when they are not dealt with properly. When employees get sick because of their occupation it is considered a decrease in welfare as the quality of life for those individuals will decrease. But also for the society as a whole this would increase the costs of the health care system. The employee will have to contribute financially as well to the heath care of its employees so it is also beneficial for him to minimize occupational risks.

Occupational deceases and accidents is not the only way the society can be effected by dust. Also communities in the neighborhood of a dust source can experience nuisances from the dust formation. This can vary from dust that irritates the eyes and respiratory tracts, to the more serious diseases. Also the deposit of dust in and around houses is a negative effect that can cause bad publicity, or even law suits in extreme cases. All these can have financial consequences as well for the company.

6.2.4. Environmental impact of dust and spillage

One can imagine that not only humans can be effected by dust particles in the air. Wildlife is likely to react more or less similar when exposed the sufficient concentrations of dusts. In addition the dust particles will eventually settle somewhere in the area. The material on the ground from spillage or spread as dust is likely to be end up in the ground when it rains. The water seeps into the ground, taking the material with it, contaminating the ground, surface waters and ground waters [52]. This can effect the vegetation and the wildlife in the area as their living ground gets polluted. The severity of this risk partially depends on the chemicals and material in the dust, but can have major effects on the environment as well as on the society as resources like drinking water can become polluted. Depending on the material that gets airborne these effects should be considered as well.

6.2.5. Monitoring dust levels

As different types of material in the air propose different dangers to the workers, the residents and the surrounding environment it is important to know what has to be dealt with. The sort of material, the particle size composition and the concentration determine the possible effects, and the possible measures that can be taken to counter those effects. Measuring what type of dust composition is dealing with can therefore be of great importance. In areas where dangerous chemicals are processed the workers are often equipped with personal tags that measure the air quality around the breathing area. The tags can possibly warn the worker is levels increase dangerously so they can evacuate. It also provides an overview of at which steps in the process dust is generated. Knowing this gives the possibility to attach the problem at the source, for instance by changing the equipment used, or introducing extra safety precautions.

6.3. Equipment wear

Besides the effects dust can have on humans, it can also effect the functioning of equipment. As the tiny particles are able to penetrate through tine openings they can enter the equipment used in a plant. Equipment with rotation or moving parts is vulnerable for dust particles as they can cause wear when they get stuck between moving components. One can think of an electric motor. The components inside are made with high precision which can be damaged easily. This may reduce the efficiency of the machine or the life time of the components, leading to higher maintenance costs and costs for new components or machines. Also dust that settles creates unwanted piles of material on the equipment and the work area. This has to be cleaned as well to keep the equipment in good condition. Cleaning includes the risk of settled dust particles to become airborne again, with all its dangers for the employee and others. And in addition cleaning also introduces addition labor costs, decreasing the profitability of the operation.

6.4. Dust and spillage control

It is clear that dust proposes a threat to the health of workers and the environment, which can result in high cost for health care and negative public attention. In addition dust and spillage can increase operational costs as it increases wear of equipment and requires more cleaning and maintenance. Preventing dust generation and spillage should be main priority as this is the best way to eliminate all hazards and costs. If this is not possible, dust control should have highest priority of the management and the workers. Conveyor transfer points have been identified as areas that may produce high amounts of dust. Also these areas are prone to spillage of material as it changes transport mode. Although spillage itself proposes other dangers it also generates dusts and requires unwanted cleanup of systems. There is an overlap between how spillage and dust generation must be handled, which will be included in this section. There are several ways to control this, typically categorized as containing, suppression or collection methods.

It is important to already include dust control and spillage prevention in the focus during the conveyor design phase. In this way it can be kept to a minimum, and the control techniques can be applied most efficient and at lowest costs. Next it is important to take measures in the following order. To exclude most hazards efficiently one should start with proper containment, so that the dust is kept in a specific area and all workers outside of that area are not at risk. As the dust is contained it makes it possible to focus on how to suppress and collect the dust so that is will not interfere with the machinery and can be fed back into the process line, or eliminated in an other way. [53] [43]

6.4.1. Containing dust

The principle of containing dust particles is important to keep control over where dust occurs and where protective measures might be required. Containing is the mechanical control and confinement of material on the conveyor or load zone. There are multiple methods developed to achieve the confinement of dust particles and prevent other types of spillage. The difficulty is that it is preferred to restrict the confinement of dust to a mall area to keep installation costs low, and create a large safe area for workers. However, as the

Figure 6.2: Fully enclosed conveyor in urban area. [54]

material moves in and out a load zone or a conveyor, a supply of material is required. This can only be done by creating an opening in the borders of the confinement, giving an opening where the airborne dust particles can escape. Also it might be required to reach into the confinement for maintenance. This makes it more difficult to confine the dust to a confined area.

Confining the dust generated at transfer points can be done in different ways. First of all, a transfer point can be enclosed entirely using some sort of building or structure around it. The material comes into the area on a conveyor, and leaves on an other one. This leaves two openings in the confinement of the transfer point. These openings can be closed of for dust using a spray or a curtain. This may not be enough to contain the dust when large quantities of dust are generated. In that case ventilation and a dust collector can be used to suck in air via the openings, preventing dust from escaping. This also requires proper dealing of other opening in the barriers [43]. However, this is not always an option. This solution requires regular cleaning of the transport point area, as lost of the dust will settle in the large space that is used to enclose the area. This puts the cleaning workers in the enclosure in danger and results in additional operational costs. The concentration of dust in the closed of area can become dangerous for explosive combustion as well. And in addition, the equipment in the enclosure is exposed to all the dust, which can cause wear to this equipment. Therefore it is preferred to keep the dust contained to a much smaller area. The following paragraphs will discuss all aspects that have to be addressed to succeed in containing the dust and spillage to a minimum, and focusing on keeping it on the belt.

In residential areas it is often required to keep dust to an absolute minimum. Therefore it is common to enclose the entire conveyor all along the route, to keep the dust from escaping the conveyor. For example at a building site in the city center of Stuttgart, Germany, this is done on the conveyors carrying the tunneling material off. These conveyors cross part of the streets and walkways overhead as is visible in figure 6.2. In this case spillage should be prevented at all times as this can create dangerous situations.

Carryback

Material particle can adhere to the surface of the conveyor belt. This result in so called *carryback* as the material is transported past the discharging point at the head pulley. The carryback mostly consists of fine particles that come loose later on and form spillage. It also adds weight to the conveyor on the return path which is unfavorable for operation. Also, the finest particles can become airborne. To minimize spillage, dust generation and smooth operation the carryback must be removed from the belt in the head pulley area.

The carryback can often be scrapped of brushed off the belt. A cleaner is positioned against the belt to take the adhering material off. As this device makes contact with the belt it is important to make sure that the cleaner does minimal damage to the belt. The cleaner can increase belt wear, with the risk of the belt failing prematurely. This can be very dangerous and will cause a long standstill of the operation. The downtime of the machine is costly as well as replacing a broken or damaged belt.

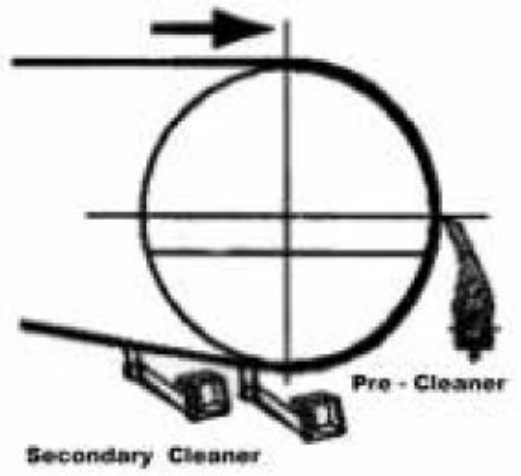

Figure 6.3: Setup belt cleaner system [53]

In modern belt cleaner systems often multiple belt cleaners are used in one set. A pre-cleaner is used first in line to remove the most of the material, which contains the bigger particles. Next the belt will run past one or more secondary cleaners to clean the smaller residue before the belt returns. This is illustrated in figure 6.3. Depending on the material and how easily it can be removed from the belt surface a more thorough method can be applied. For maximum cleaning wash boxes can be used. These first wet the belt and then remove the water and fines. [53]

Skirt spillage

During loading of material on a belt conveyor often side skirts are used to create a smooth transition between the chute and the conveyor belt. This helps make sure that the material can not end up besides the belt, preventing spillage and dust. The skirt is a strip of material, often a bit flexible, that is placed on the sides of the belt to keep material from falling over the edge (figure 6.4). Setting up the side skirt correctly is crucial to make sure it functions effectively and does not cause additional wear and damage to the belt. Three focus points to ensure proper skirt design are listed below [53]:

- Proper belt support to minimize belt sag
- Wear liners inside the chute to protect the sealing system
- Multiple-layer edge seals to contain any escaping fines

Belt support

The belt and the skirt should make contact to ensure a good seal, preventing material to escape. This requires a proper belt support and belt tension the prevent belt sag. Belt sag creates open spaces under the skirt that can entrap material, as is illustrated in figure 6.5. This material is likely to spill out, or get stuck between belt and skirt. If it gets stuck between the moving belt and the stationary skirt it can start to grind causing wear to the belt. A belt moving over idlers can easily sag. This can be minimized using more idlers spaced closer together, together with the proper belt tension.

A much seen design of belt support at the loading side of the conveyor is the cradle. The cradle is a section of belt support designed to absorb impacts during loading and helps eliminate the possibility of belt sag at the loading section. Such an impact absorbing cradle is shown in figure 6.6. Instead of idlers perpendicular to the direction of the belt, this type of cradle is equipped with bars placed along the direction of the belt. This makes sure that the belt can not sag where the skirt is located, and the bars create a larger area at which the belt is supported. This also spread impact of the material loading better. The bar is covered with a layer of

Figure 6.4: Side skirt setup at a conveyor [55]

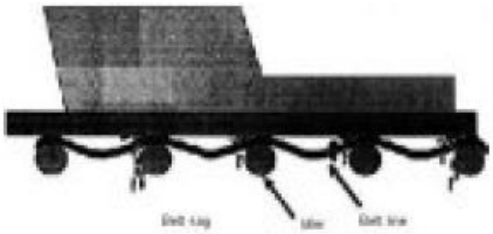

Figure 6.5: Side view of skirt and conveyor assembly [53]

low friction material so the belt can slides over it. However, this still creates more friction compared to idlers. This may cause more wear to the belt, and will increase the power consumption for the system.

Also combinations of the bar cradle are used where the the middle of the belt is still supported by idlers, while the sides are supported by bars. An example can be seen in figure 6.7. This type does increase the friction in the systems less, but increases the support for the belt at the sides where the skirt makes contact. The extra support is only given where this is required, however, the impact of the loading of the material is not absorbed and spread over as much area as with the previous cradle design. Therefore the belt can still sag a bit. The full bar cradle is probably more interesting with heavier materials,while this combination cradle offers advantages for lighter material.

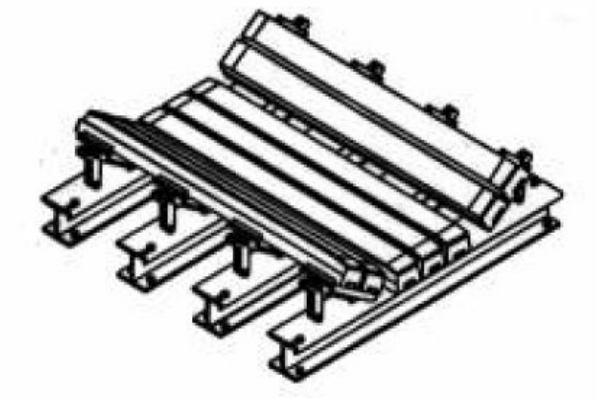

Figure 6.6: Impact absorbing belt support cradle [53]

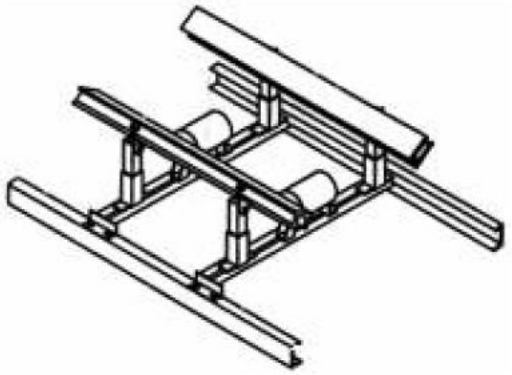

Figure 6.7: Side seal belt support cradle [53]

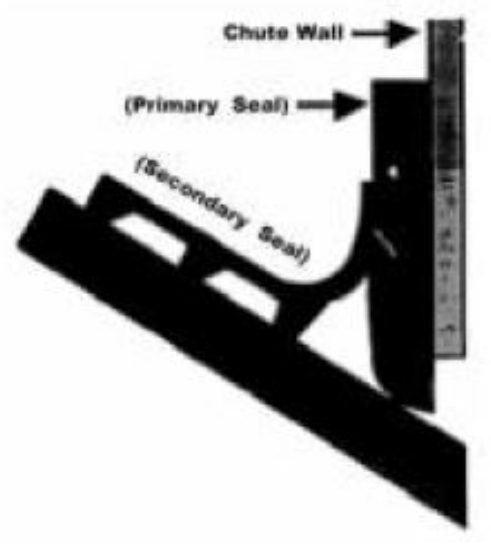

Figure 6.8: Cross section of skirt and skirt seal configuration [53]

Skirt board seal

The skirt is used to make a connection between the belt and keep material on he belt during loading. This skirt is the first line of defense against spillage and dust, but the impacts on the skirt can be large as bug chunks and large amounts of material make contact. The requires a rigid connection, but this is difficult to do without risking damage and wear to the belt. Because of this the skirt often is capable of stopping the majority of the material from falling of the belt, but smaller particles and dust tend to get through this first line of defense. Therefore the skirt board seal is introduced as a second line of defense. The skirt board seal is a more flexible layer of rubber like material attached to the back of the skirt as illustrated in figure 6.8. This layer is meant to trap fine particles and dust that have gone past the skirt. This secondary line of defense is made of a less wear resistant and more flexible material than the skirt itself, making it vulnerable for bigger impacts of material. Because of the setup as secondary line of defense this is unlikely to happen, and the advantage of its extra flexibility is that it is better capable to follow irregularities of the belt, creating a better seal. In figure 6.8 it is also visible that by creating ridges on the surface of the skirt seal multiple barriers for the material are created increasing the efficiency of the seal. [53]

Entry and exit area sealing

Using the skirts, proper support and the skirt board seal keep material and dust escaping over the sides. However, this does not close of the opening where the belt enters the loading area, the entry area. Through this

opening the material is able to roll back, and end up beside the belt. Also dust can easily escape this way as it is not in contact with the moving belt. This can partially be solved with a good chute design. Also to minimize wear to the belt it is best to make sure that material has the same speed as the belt during loading. The decreases the the risk of material rolling back tremendously. If roll back is a problem the area where the belt enters must be sealed of.

The area can be sealed of using a sealing strip. However, if the strip is placed to tight against the belt, it starts acting as a scraper and residue on the belt will build up behind it, eventually spilling the material. It the strip is not making enough contact with the belt it does not provide a good seal. To create a one way seal a flexible strip must be used and deflected in the direction of the belt movement. In this way the strip is easily pushed up when there is some material attached to the belt, but roll back will push down the strip more creating a tight seal. This should be installed far enough from the actual lading zone to eliminate the problem of sealing the high-pressure corners of the impact zone [53]. The side skirts should start where the entry seal is placed to create a total enclosed environment for the loading.

Sealing the exit area is also required to create a total enclosed loading zone. The belt full with the loaded material should be able to leave the loading zone without disturbing the material that has just settled on the belt. This can be done with rubber curtains placed at the end of the skirt board. These curtains consists of dubber drapes. The height of the material on the belt can differ and the drapes are able to be pushed aside when the material is higher than normal. This ensures that the material is always able to leave the area, while most of the dust is stopped at the curtain. To make sure dust in the air can settle a dead area must be created using a set of 2 curtains, placed roughly 450 mm apart [53].

Air flow
It is difficult to create a perfect seal between a moving and a stationary component. To prevent dust escaping from small breaches in the boundaries air flow can be used. Research has effectively weakened or guided air entrainment by utilizing a chute, enclosure, or the design of adequate ventilation facilities in transfer stations to reduce dust emissions during the transfer process [56]. For example by creating a negative pressure within the confined area air is sucked in via any small opening, making it more difficult for dust to escape. A precipitator is used to remove air flow from the transfer section to create a negative pressure, making sure no dust escapes, while the precipitator removes dust from the air [57]. Using CFD simulation the dust emissions are evaluated even further to create an even better understanding of the air flows during loading and unloading of a belt conveyor. This will lead to more effective measures to eliminate dust emissions at transfer points.

Various different configurations of partial solutions have been tested by Chen et al. [58] resulting is a drastic decline of dust emissions. The so called *restrictor* structures can be used to limit the air that is entrained with the material falling down a chute, and has proven to be very successful as it reduced dust emissions by approximately 71%, and a *stilling chamber* reduces dust emissions by approximately 75% [58]. A stilling chamber is box around the loading area of the belt that contains multiple vertical plates to reduce the movement in the air, letting the dust settle.

6.4.2. Suppressing dust

Dust suppression is preventing fine particles from becoming airborne. Techniques to suppress dust particles are often focused on using some sort of additional substance or chemicals to make sure the particles loose the ability to become airborne. This is not possible for all materials as it may degenerate the properties of that material. One can think of coal used for burning, loosing flammability if it becomes moist.

Water spray

Water is a widely available fluid that can help to suppress dust generation. It can easily be spread in small quantities over the material keeping the dust down. This is achieved as the moist material has increased mass and increased cohesiveness, making it more difficult for particles to become airborne. This is a relative low tech solution that can easily fitted on the material. However, getting it right can be difficult. The amount of water required depends on different parameters, some better predictable than other. The weather plays an

Figure 6.9: Water spray to suppress dust while discharging material [59]

important role as on a sunny day the material can dry on the conveyor, while on a cloudy day the material might stay moist longer. Therefore it might be required to change the amount of water sprayed depending on the conditions. Also the material characteristics itself play a role in this.

Water sprays can easily be used in different stages of the operation. For example on a long conveyor it might be required to spray water on the belt every set distance to make sure the material stays moist enough. Also the material can be spayed during discharging as it shown in figure 6.9. This shows the use of water sprays to create a tube like enclosure during discharging making sure the dust can not escape.

A difficulty in the effectiveness of water for dust suppression is the air movement. When the air velocity is to high, a water spray can loose its effectiveness. This is because of a 'slip stream' like effect [53]. What happens is that the dust particle is pushed aside by the water particles because if its high velocity. This can best be described as a motorcycle on the highway that is pushed away away from a semi-truck. One way to overcome this problem is to add more water, but this has several negative side effects and is therefore not favorable. An other solution is to reduce the air velocity by for example increasing the size of the enclosure, as air velocity can now dissipate.

Using water also has some disadvantages. For example, not all material are suited to become wet. Also the water can cause the material to rinse away across the terrain and sink into the soil, possibly causing pollution of the ground, or waters. Furthermore excessive wetting can result in sticky residue on the belt. This is difficult to remove and when it is carried back, it likely dries on the way and falls off, increasing spillage and belt dust [43]. A wet belt is more likely to slip, and the wet material may increase in mass causing higher stresses on the system and an increase in power consumption. Typically the water volume added to the material lies in the range of 0.5% to 4% [53] Although spraying water is a low tech solution, it can be difficult getting it right as there are may possible pitfalls.

Figure 6.10: Foam sprayed on a conveyor to suppress dust [63]

Fog

Fog suppression systems are a recent improvement on water sprays [53]. Fog is water in extremely small droplets, creating a mist of water and dust particles are captured in this mist. The dust particles will bind to the small water droplets in the air, increasing the weight causing the dust to settle. The droplets should be the same size as the dust particles to work effectively. As the water droplets are much smaller and the mist stays in the air longer the water use can be reduced enormously compared to conventional spray systems. As fog is only effective against airborne dust, nozzles must be placed at every location where dust can become airborne. This makes it less attractive to use along the length of a conveyor as this requires a large installation all along the way. In such a case, a water spray to wet the material could be more effective as one spray station can guarantee dust suppression for a long distance after the station.

Foam

Water can also be used to create a foam to keep the dust down. Foam has a similar advantage as fog, since it requires much less water. For dust control, foam works better than water. It provides dust reductions of 20% to 60% compared to water. Foam also can produce similar results at lower water use. The amount of water needed to make the foam is less than the equivalent water spray. High-expansion foam, when compared to water sprays at a belt transfer point, averaged an additional 30% dust reduction [60]. For these reasons it is often used around heavy equipment [61]. As it requires less water the ground will not get muddy, witch is favorable for operating conditions, and puts less pressure on water as a recourse. Foam is created using a foaming additive in the water. This creates a layer of foam that does not directly soak the material, like water, and stays on the material for a longer time. It can be applied simply using a spray over the conveyor at a transfer point 6.10, or along the way of a conveyor. This creates and impenetrable layer for dust particles keeping them down. The disadvantage is that some sort of additive is required which can have its effect on the equipment or on the environment. It might also influence the characteristics of the material transported as it will leave residue after drying. Because of this, and financial reasons it is desired to administer only small quantities of foaming agent to the water, resulting in the development of new foam agents adding devices [62].

Wetting agents

Besides foaming agents there are other chemical additives available on the market to increase the effectiveness of water as dust suppressor. The additives vary in application and effect on the material and environment. In selecting such a chemical its effects on the material and environment must be carefully looked at to be sure the effects are only positive. The idea of such wetting agents is that is makes the water even "wetter" which means that is increase the ability to attract, bind and hold dust particles. Most of the interest has been in coal mining because of the hydrophobic nature of coal. The effectiveness of wetting agents has been the subject of considerable research over the years, without much of a definitive answer on how well they work. [60]

6.4.3. Collecting dust

When despite attempts to prevent dust generation and dust suppression dust still gets airborne it might be necessary to collect the dust from the air. This prevents spreading of the dust and dust deposits in unwanted areas. Also when the dust is successfully contained in a certain area collection might be desirable, to prevent high concentrations that for example propose the danger of explosive combustion. Also when the dust is not collected form the air the dust will settle in the confined area, which at one point requires manual cleaning introducing additional costs.

To collect dust the air that carries the particles must be taken to some sort of filter. This air must be pulled through the filter system. The capacity of the filter system must be adequate for the volume of moving air with dust. If the capacity of the filter is to low, the air will find other paths to escape the area, taking the dust with it. The air that has to be included in these calculations are the so called 'displaced air', the 'induced air' and the 'generated air'. The displaced air is the air that is move by the volume of material that flows through the area. This material takes a certain volume pushing the air away that was there first. Induced air is the air that is surrounding the materials particles during flight. On landing the material particles will com closer together again, forcing the entrapped air away. Generated air is the air that is set in motion by moving components in the machine. When all these are known the capacity of the dust collection system can be determined. [53]

There are three basic methods to collect dust from the air; 'central', 'unit' and 'integrated'. When central dust collection is used, all dust sources are connected together via means of air ducts. At a central location a large filter station is installed to filter all the air. The unit method uses a filter installation for individual or small conveniently grouped dust sources. The integration method is an extension of the unit method, as the filters are integrated whithin the dust generation point itself. Depending on the scale of the system, and the quantity of air to filter different solutions are viable. [53]

6.5. Conclusive

Dust can have mayor consequences and proposes a real danger to the people that work in a dusty environment. Health issues like respiratory diseases are proven to be related to the inhalation of dust. The exact type of material and particle size seem to be of influence on the risk, as well as the quantity of material inhaled. Besides the health risks, dust also proposes the immediate danger of explosive combustion. Again risk depends on the material type and concentration in the air.

Besides the risks to the people working in a dusty environment, there is also the negative effects on dust on the functioning of the equipment. Dust, as well a spillage of material during the operational processes can do damage to components of the system and speed up the wear of the system. When spillage occurs this has to be cleaned often in a manual way and also dust that settles has to be removed. This is not only labor intensive, but also proposes additional dangers to the employee as cleaning itself is a dusty operation, and often puts the employee in a dangerous position close the the moving heavy equipment.

Dust in the air can be carried over great distances causing nuisances to nearby neighborhood inhabitants. It can have physical consequences of irritation to the respiratory tracts and the eyes, as well as the danger of diseases depending on the material type. Also the dust can settle in the houses and surroundings.

Also dust and spillage can have a negative impact on the environment as toxic materials can end up in nature. This can pollute ground waters, open waters and soils creating problems for the vegetation and wildlife in the area. Also sources of drinking water for humans can become useless because of contamination.

All these negative effects can have financial consequences for the system operator. Cost on cleaning or addition maintenance are directly visible, but the health care costs that can occur on an longer time scale can also be enormous. Negative publicity liked the this can do damage to the brand and even cause shut down of operation in extreme cases. These are all additional reasons to keep dust and spillage under control.

There are various techniques available on the market to prevent dust form taking off and prevent spillage of material. Key is to asses possible dust generation and spillage already in the design phase of the belt con-

veyor system to deal with possible sources adequately. This ensures the most effective methods can be installed keeping the costs of prevention and control as low as possible. When additional systems have to be installed later, or current systems must be replaced higher costs will be the result.

7

The impact of noise generation

Belt conveyor systems for the transport of bulk solid materials can be a source of noise. Noise is defined as undesirable sound and is also a by-product of operation of the system as all the moving components tend to generate sounds of different levels. Although noise from a belt conveyor is not very dangerous it can still do harm to ones hearing, and continuous loud noise in the neighborhood is considered annoying. In the report on our common future by the world commission on environment and development noise is also noise pollution of the world is acknowledged as a growing concern during development of the world [7]. This chapter will focus on noise generated by belt conveyor systems, and how this effects its surroundings. Also possible measures that can be taken to reduce the noise generation and spreading will be included in this chapter.

7.1. Sources of noise

Sounds are vibrations in the air and an ear can pick up these vibrations so that a human can hear the sound. These vibrations in the air can easily be initiated by moving components of, for example a belt conveyor system. Different components can all contribute, and the end result can be a constant rumbling of such magnitude that is can damage a humans hearing. Noise is almost ubiquitous in mining. It is generated by drilling, blasting, cutting,materials handling, ventilation, crushing, conveying and ore processing.Controlling noise has proven difficult in mining and noise-induced hearing loss remains common [50]. As conveying is one of the sources of noise in a mining environment this is interesting to investigate. Also conveying in for example a bulk terminal can be a problem. The following sections indicate components of a belt conveyor that are known to contribute to the entire noise generation of the system.

Noise generation of a belt conveyor has different sources. A case studies shows several sources of noise during mining and indicates different aspects of conveyor use as source for noise, and indicates that a conveyor can produce 83-84 dBA. The transfer point where material is loaded and/or unloaded on a conveyor can even impose higher sound levels of about 91-92 dBA. [64]. Noise levels of above 75 dBA can cause damage to one hearing [65]. Especially subjection to such noises for longer periods of time propose a risk to occupants.

Depending on the location some noise regulations are imposed for industrial operation, and exceeding these can result in heavy fines. Commonly the regulations set a maximum of 70-80 dB for in industrial areas [66]. In other situations the limits may even be lower, for example the restriction to noise levels in residential areas being 65dB [67]. To avoid the risk of heavy fines, and to decrease the risks of hearing damage for occupants it is important to prevent noise generations as much as possible.

7.1.1. Idlers

The idlers support the belt all along the way, and many of them are used in a conveyor. The interaction between belt and idler is the most dominant noise source in belt conveyor systems. The idler roll surface profile is shown to be a major input to excitation of vibration and noise radiation for most conveyors, according to Brown [68]. Brown has tested several idler types and constructed the idler roll surface profile parameter and

found a strong correlation with the conveyor noise generation. An important factor that influences the noise generation is the outer material of the idler rollers [69].

7.1.2. Transfer point

At a transfer point the material is thrown around and redirected in such way that is ends up on the desired place. This can include a chute to catch the material, resulting in an impact of the material on the walls of the chute. This can obviously generate a lot of vibrations in the air resulting in noise as a by-product of operation. The noise generated depends on the materials that is transported, as harder and heavier material will generate more noise. It also depends on the design and the material of the chute. Some material do muffle the sounds on impact, while other materials create an extra echo. The design itself is of influence, as the chute can be aligned better in the trajectory of the material, minimizing the impact of the material. This also keep the noise generation down.

7.1.3. Parameters for noise generation

Previous paragraphs already indicate several sources for noise. But also the operating conditions include several parameters that influence the noise. A parameter of influence is the belt speed. Noise levels generally increase with increasing belt speed [67].

7.2. Social and environmental impact of noise

Noise is always a concern, especially when it is realized near a residential area. Noise pollution gets more critical as a belt conveyor is located closer to residential areas. [70]. The noise are an inconvenience for people living nearby. Especially at night noise can cause nuisances to inhabitants of the area. In some cases this has resulted in different restriction levels for day, evening and night.

The problems noise can cause can be harmful to society. First of all, longer subjection to loud noise can cause temporarily of permanent hearing impairment. Load noises form a occupational hazard, as workers can easily be subjected to loud noises as they might work close to the machines. This is to be prevented by the employer, who can supply workers with protective gear against the noise. This measure does not sole the risk for all that can be effected.

The noise can also spread over an greater area and cause nuisances to surrounding residential area's. This can be a problem when the magnitude of the sound does not decrease enough before reaching communities. Depending on the distances and the terrain the noises can be carried across long distances. The problems noise can cause for a community mainly come from personal discomfort. In extreme cases also hearing impairment can occur, but often this risk is only small. However, the noise can cause stress concentration problems for individuals. Also insomnia can be caused when a residential area is subjected to certain noise levels. This can also lead to physical effects like raised blood pressure and risks linked to that. [71]. Also ecosystems are effected by noise, as animals can be scared away as a result of the noises.

7.3. Preventing and muffling noise

Noise can be difficult to prevent, as it is often a by-product of certain components. With the design of components, focused on decreasing noise emissions the noises can be decreased. For example the design of idler rollers that produce less noise receives attention from multiple researchers and companies [72] [73] [69]. These all focus of reducing the vibrations in moving components, or in the interaction between components. In this research the struggle often is to find and apply materials that do reduce the noise, but still are durable for longer operation. If the use silent components results in an increase of maintenance, it can result in unprofitable operation.

Besides the development of silent components for the construction of belt conveyor systems also muffling noises to prevent it from reaching nearby communities is a technique seen often. when a belt conveyor

runs through a populated area this is often done by enclosing the entire conveyor. The advantage is that this can also exclude the possibilities of dust spreading through the area.

An other technique is to use so called baffle banks. This is a bank of earth that blocks the noises from reaching the other side. Often a baffle bank is also covered in natural vegetation. The natural vegetation, like trees and bushes, is made from organic material and helps to absorb and block sounds. [52]

7.4. Conclusive

Noise emissions are often inevitable during operation of belt conveyor systems. Depending on the material transported and the size of the conveyor the noise levels can differ. Also the design of the components used for construction, and the belt speed of the conveyor have an influence on the noise levels emitted.

The effects of noise can be harmful especially to workers exposed to higher sound levels for longer period of time. The result can be hearing impairments. As the noise levels decrease further away from the source the health risks for nearby communities are less. however, insomnia and concentration problems can cause stress and result in physical complaints like high blood pressure. Also wild life can be driven our of the area when noises are to high.

The government often restricts the amount of decibels that can be produced by industry, and thus by the conveyor. The maximum levels differ all over the world, and often the location is included as well. If there are no residential areas nearby the limits ca be higher. Exceeding the limits can result in high fines for the operating company.

Research is done in attempts to decrease the noise emission of certain components. Especially the idler rollers are topic of research as these contribute a lot to the noise emissions. If prevention is not possible, the spreading of the sound should be prevented. This is often done by enclosing the entire conveyor. In more remote locations also a baffle bank and vegetation can be enough.

8

Conclusion and Recommendations

8.1. Conclusion

Sustainability is a growing concern for the world and its inhabitants. This is acknowledged by the world leaders and in most other layers of western societies. However, action taken on the issues at hand is only slowly taking shape. There are lots of initiatives and plans to increase the sustainability of mankind and its man made systems. However up until this point these have booked only limited results when it comes to turning around the damaging phenomena that threaten our planet, like global warming and decreasing biodiversity.

The step to translate the policies into practical results has to be taken by the corporate powers and the industrial players themselves. To achieve the global plans, all small systems and subsystems have to assess their own sustainability and increase this where required. Therefore the sustainability of belt conveyor systems is of importance. In this conclusion the research questions will be answered, giving an overview of the sustainability of belt conveyor systems.

8.1.1. The definition of sustainability

Sustainability is a broad concept and can be applied in many different contexts. The main aspect of sustainability is the ability to *continue over a period of time*, or to *be maintained at a certain rate or level*. Defining the context is important when attempting to assess the sustainability of an object or system. This also applies to belt conveyor systems.

The public has become more aware of sustainability issues for the world. This has lead to an increase in value for sustainable products and processes, and also the economy has started to act on this. When sustainability is mentioned in advertisements or in corporate policies it often refers to both environmental and social aspects of the product or the production process. However, still only a limited amount of people are willing to pay more for sustainable products. Therefore sustainability has to be stimulated more by policies ad regulations.

Economy, society and environment are identified as the three main pillars of the modern world. These three overlap and multiple relations between then can be found. The interests form these three areas often conflict. Sustainable development provides a framework bringing the different parties together and opening the discussion on how to satisfy all.

Sustainable development is also applicable to belt conveyor systems as further development of the systems desired for the development of industry and economy. However, this can not be at achieved at any costs as this can do harm to society and environment.

Legislation provides additional stimulation for the industry to become of sustainable. This is required since the industry serves the economy and this is mainly driven by the financial aspects of an operations. Legislation can provide addition criteria to comply with.

Assessment of the sustainability of a product or system is difficult as many different aspects can be of influence, while many of those aspects are not yet quantified properly. In addition there are limited target values available for industry. This is because currently only the obvious causes are being addressed. To assess the entire impact of a system an in depth analysis is required. Life cycle assessment provides a framework to do so, evaluating all life stages of the subject.

The context of belt conveyor systems can be seen as the economy since this is where the most belt conveyors operate. However, as we learn from chapter 2 the interests of the economy interacts with, and might conflict with the interests of the society and the environment. Therefore the context in which the sustainability of belt conveyor systems will be assessed is defined as the society and the environment.

8.1.2. Operational side effects and by-products

To determine the context of belt conveyor systems in which its sustainability can be assessed, all life stages where briefly considered. The operational stage was chosen to focus on during this report as during this phase many side effects and by-products occur that can impact the environment and society.

Three effects of operation where selected as these were expected to have big impacts on the environment and the society. These are the high energy consumption due to the heavy labor the system has to perform. The dust generation and spillage that can occur because of the rough material handling and material characteristics. And the noise generated by the handling equipment and material interaction.

8.1.3. Impact of belt conveyor system operation

In this subsection the last two research questions will be answered for each side-effect or by product mentioned above. Both the possible impact as well as preventative measures are described. These preventative measures can include both currently available techniques as well as new developments in that field.

Energy consumption

Energy consumption of belt conveyor systems has a negative effect as it contributes to global warming. This can translate into negative effects on society as well. The high energy consumption is effected by the terrain and the equipment. The terrain can often not be addressed to minimize the energy consumption. The equipment can be improved on this issue and this is one of the focuses during development of new belt conveyor systems. The goal of recent and ongoing research is to improve the components to minimize the drive force required. This mainly results in minimizing friction of moving components. Also the control of the conveyors is being researched as theoretically energy savings can be achieved by ensuring optimal loading of the conveyors. Energy consumption can not be eliminated but minimizing it is important to decrease the contribution of belt conveyor systems to the environmental issues. This also gives a financial advantage to the operator and ensures the market position of belt conveyor systems.

Dust and spillage

Dust and spillage are by-products of belt conveyor operation that cause problems. The type of material is a variable that effects dust generation, and the transfers stations are major sources for spillage and dust generation. The hazards of dust include health issues and the danger of explosive combustion. Also the equipment can wear out faster under the influence of dust and spillage. legislation is often used to restrict the levels of dust in the air. Several techniques to counter these effects are available. Some focus on the prevention of particles becoming airborne, while other techniques focus on the containment and collection of dust. What technique is suitable for a specific operation depends mainly on material type, and scale of the problem. Overall dust and spillage is well manageable with proper design and setup of the conveyor.

Noise generation

The noise generated by belt conveyors can damage the hearing of workers and cause discomfort to people living in the area. Therefore the noise generation is limited by legislation in most locations. The noise is generated by the different moving components of the belt conveyor. There are many sources of noise on a single

generator, which makes control difficult. The focus of research lies on the creation of more silent components. The problem is that wear of components does significantly increase noise generation. Therefore also regular maintenance is a good tactic to minimize the problem. Enclosing the conveyor or creating a muffling barrier to stop the noise from spreading is used to stop noise from spreading to nearby communities. Workers often have to use protective gear when working near noise sources.

8.2. Recommendations

This survey has identified the need for further development of energy efficient belt conveyor systems. The public, as well as governments desire a more sustainable society. Belt conveyor systems are large energy consumers so there is a lot of potential for more efficient systems. In this section some recommendations that can improve belt conveyor systems even further will be mentioned.

This survey gives a general understanding of the sustainability of belt conveyor systems. However, only limited data on sustainability of belt conveyor systems is quantified. Creating a standard for this can provide a better insight in what areas, components or life stages have the most potential to improve in terms of sustainability. To quantify this, more research is required. Such research should include the entire life of a belt conveyor system, and life cycle assessment can provide the framework to achieve this. Therefore a proper LCA of belt conveyor systems would be recommended.

Through conveyors are applied on large scale, however there are many more types of conveyors available that probably have different characteristics concerning dust, energy and noise. It would be interesting to see the differences from a sustainability point of view, combined with the operational and financial advantages. It could well be that other types of conveyor are more efficient in specific situations. Therefore comparison of the different types of belt conveyor systems, focusing on their sustainability is recommended. This would make it easier for operators to select the most sustainable conveyor for their operation.

In the process of assessing the impact of belt conveyor systems the effects of different components have to be known. A database with the characteristics and possible impacts of separate component of suppliers would help the make assessment quicker. If the assessment of a belt conveyor can be done quickly operators are more likely to performs such assessment and take is into consideration when designing a net belt conveyor. This can have a large effect on the industry when it becomes standard during the design phase. By providing insight in also the sustainable performance of components, this can be taken into account during the selection of different components. This also stimulates manufacturers of components to develop more sustainable products. Eventually this will lead to more sustainable belt conveyor to be build, decreasing the overall impact of belt conveyor systems on the environment and the society.

List of Figures

Bibliography

[1] Habasit, "Belt conveyor history." [Online]. Available: http://www.habatec.net/HNet/HabaTEC.nsf/vwWebContent/B3AFDB9C92909C37C12578BE002BB553?OpenDocument." [Accessed on: 2016-06-24]

[2] PHC, "Belt conveyor history." [Online]. Available: http://www.phcfirst.com/words-in-motion/2014/6/30/the-history-of-conveyors." [Accessed on: 2016-06-24]

[3] Cambridge Dictionary, "sustainable Meaning in the Cambridge English Dictionary." [Online]. Available: http://dictionary.cambridge.org/dictionary/english/sustainable." [Accessed on: 2016-05-10]

[4] Oxford Dictionary, "sustainable - definition of sustainable in English from the Oxford dictionary." [Online]. Available: http://www.oxforddictionaries.com/definition/english/sustainable." [Accessed on: 2016-05-10]

[5] R. Costanza and B. C. Patten, "Defining and predicting sustainability," *Ecological Economics*, vol. 15, no. 3, pp. 193–196, 1995.

[6] D. L. Gadenne, J. Kennedy, and C. McKeiver, "An empirical study of environmental awareness and practices in SMEs," *Journal of Business Ethics*, vol. 84, no. 1, pp. 45–63, 2009.

[7] G. H. Brundtland, "Our Common Future: Report of the World Commission on Environment and Development," *Medicine, Conflict and Survival*, vol. 4, no. 1, p. 300, 1987.

[8] B. B. A. Lietaer and J. Matthieu, *Geld en duurzaamheid : van een falend geldsysteem naar een monetair ecosysteem*. Van Arkel, 2012.

[9] a. Azapagic and S. Perdan, "Indicators of sustainable development for industry: a general framework," *Trans IChemE*, vol. 78, no. July, pp. 243–261, 2000.

[10] B. Ness, E. Urbel-Piirsalu, S. Anderberg, and L. Olsson, "Categorising tools for sustainability assessment," *Ecological Economics*, vol. 60, no. 3, pp. 498–508, 2007.

[11] R. W. Kates and W. Clark, *Our Common Journey, a transition toward sustainability*. National Academy Press, 1999.

[12] R. W. Kates, T. M. Parris, and A. a. Leiserowitz, "What Is Sustainable," *Policy*, vol. 47, no. 3, pp. 8–21, 2005.

[13] United Nations, "The Paris Agreement," 2015. [Online]. Available: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

[14] R. Meyer, "A Reader's Guide to the Paris Agreement: Climate Finance, Global Stocktaking, and Common But Differentiated Responsibility." [Online]. Available: http://www.theatlantic.com/science/archive/2015/12/a-readers-guide-to-the-paris-agreement/420345/." [Accessed on: 2016-05-24]

[15] Nederlandse Emissieautoriteit, "Rapport-voortgang-emissiehandel-2015.pdf," Tech. Rep., 2015.

[16] Y. J. Zhang and Y. M. Wei, "An overview of current research on EU ETS: Evidence from its operating mechanism and economic effect," *Applied Energy*, vol. 87, no. 6, pp. 1804–1814, 2010. [Online]. Available: http://dx.doi.org/10.1016/j.apenergy.2009.12.019

[17] Nederlandse Emissieautoriteit, "Missie Nederlandse Emissieautoriteit." [Online]. Available: https://www.emissieautoriteit.nl/over-de-nea/missie." [Accessed on: 2016-06-26]

[18] Het Milieuloket EU, "Europees milieubeleid." [Online]. Available: http://www.milieuloket.nl/9353000/1/j9vvhurbs7rzkq9/vhurdyxqxfmi{#}p2." [Accessed on: 2016-06-26]

[19] Het Milieuloket NL, "Nederlands Milieubeleid." [Online]. Available: http://www.milieuloket.nl/9353000/1/j9vvhurbs7rzkq9/vhurdyxq65wm." [Accessed on: 2016-06-26]

[20] Internationale Organisatie voor Standerdesatie, "ISO 14001," 2016.

[21] K. Awuah-Offei and A. Adekpedjou, "Application of life cycle assessment in the mining industry," *The International Journal of Life Cycle Assessment*, vol. 16, no. 1, pp. 82–89, 2011.

[22] D. Khanda, "Application of Lice Cycle Assessment (LCA) in coal mining," in *6th Asian Mining Congress*, no. February. The Mining Geological and Metallurgical Institute of India (MGMI), 2016.

[23] M. Gómez, "Life Cycle Assessment Consultacy Services." [Online]. Available: http://www.marcelgomez.com/eng/?page{_}id=1604." [Accessed on: 2016-06-25]

[24] G. Lodewijks, "Characteristics and Handling of Bulk Solid Material," pp. 1–35, 2013.

[25] Samson Aumund Group, "Samson Flexible Hopper." [Online]. Available: http://samson-mh.com/en/samson/industries/ports{_}and{_}terminals." [Accessed on: 2016-06-25]

[26] G. Bierie, R. T. Swinderman, and A. D. Marti, "Loading chute." [Online]. Available: http://www.powermag.com/conveyor-upgrades-increase-plant-availability-reduce-airborne-dust/?pagenum=2." [Accessed on: 2016-06-25]

[27] H. E. Daly and J. B. Cobb, *For the Common Good: Redirecting the Economy Toward Community, the Environment, and a Sustainable Future*. Beacon Press, 1989.

[28] International Energy Agency, "Key World Energy Statistics 2015," Tech. Rep., 2015.

[29] J. Romm, "Desertification: the Next Dustbowl," *Nature*, vol. 478, pp. 450–451, 2011.

[30] A. Dai, "Drought under Global Warming: A Review," *Climate Change*, vol. 2, no. 1, pp. 45–65, 2011.

[31] S. Zamorano, "Reducing energy consumption on overland conveyors," *Engineering & Mining Journal*, no. June, pp. 58–62, 2009. [Online]. Available: http://www.osti.gov/scitech/biblio/21262022

[32] Habasit America, "How to reduce energy costs on conveyor systems." [Online]. Available: http://www.mhi.org/media/members/14161/130458690663034193.pdf

[33] Deutsches Institut für Normung, "DIN 22101," 2002.

[34] M. a. Alspaugh, "Latest Developments in Belt Conveyor Technology," *MINExpo 2004*, p. 11, 2004. [Online]. Available: http://www.overlandconveyor.com/pdf/LatestDevelopmentsinBeltConveyorTechnology.pdf

[35] R. dos Santos, A. Souza, and A. de Soares, "Conveyor energy consumption is getting attention," 2014. [Online]. Available: http://www.ppipella.com/media/documents/PPI{_}ConveyorEnergyConsumptionIsGett{_}92BA820D47F63.pdf

[36] W. A. Günthner, C. Tilke, and S. Rakitsch, "Energy Efficiency in Bulk Material Handling," *Bulk Solids Handling Vol. 30 No. 3*, pp. 138 – 142, 2010. [Online]. Available: http://www2.fml.mw.tum.de/fml/images/Publikationen/G{%}C3{%}BCnthner{_}Tilke{_}Rakitsch{_}BulkSolidsHandling{_}03-10{_}EnergyEfficiency.pdf

[37] M. Akbaba, "Energy conservation by using energy efficient electric motors," *Applied Energy*, vol. 64, no. 1-4, pp. 149–158, 1999.

[38] S. Zhang and X. Xia, "Modeling and energy efficiency optimization of belt conveyors," *Applied Energy*, vol. 88, no. 9, pp. 3061–3071, 2011. [Online]. Available: http://dx.doi.org/10.1016/j.apenergy.2011.03.015

[39] L. B. Ristic, M. Z. Bebic, D. S. Jevtic, I. D. Mihailovic, S. Z. Statkic, N. T. Rasic, and B. I. Jeftenic, "Fuzzy speed control of belt conveyor system to improve energy efficiency," *15th International Power Electronics and Motion Control Conference and Exposition, EPE-PEMC 2012 ECCE Europe*, pp. 1–7, 2012.

[40] Y. Pang and G. Lodewijks, "Improving enegry efficency in material transport systems by fuzzy speed control," *3rd IEEE International Symposium on Logistics and Industrial Informatics (LINDI)*, pp. 159–164, 2011.

[41] Teijin Aramid B.V., "Aramids in conveyor belts: a strong, energy-saving alternative, Product Brochure," 2014.

[42] G. Lodewijks, "the Next Generation Low Loss Conveyor Belts," *IMHC International Materials Handling Conference*, vol. Beltcon 16, no. via D, pp. 1–16, 2011.

[43] F. N. Kissel, "Handbook for Dust Control in Mining (IC 9465)," pp. 1–131, 2003. [Online]. Available: http://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/2003-147.pdf

[44] L. Xiaochuan, W. Qili, L. Qi, and H. Yafei, "Developments in studies of air entrained by falling bulk materials," *Powder Technology*, vol. 291, pp. 159–169, 2016. [Online]. Available: http://dx.doi.org/10.1016/j.powtec.2015.12.021

[45] Dust-A-Side, "Dust solutions." [Online]. Available: http://www.dustaside.com/services/material-handling/high-pressure-mist-system." [Accessed on: 2016-06-25]

[46] NSSGA AGG1 Academy, "Best Practices for Belt Conveyor Dust Control Best Practices for Dust Control," 2015. [Online]. Available: http://www.mapyourshow.com/MYS{_}Shared/woaagg115/handouts/W53.pdf

[47] World Health Organization, "Hazard Prevention and Control in the Work Environment: Airborne Dust - WHO," 2016. [Online]. Available: http://www.who.int/occupational{_}health/publications/en/oehairbornedust3.pdf

[48] T. Huy, K. De Schipper, M. Chan-Yeung, and S. M. Kennedy, "Grain dust and lung function," 1991.

[49] M. H. Ross and J. Murray, "Occupational respiratory disease in mining," *Occupational Medicine*, vol. 54, no. 5, pp. 304–310, 2004.

[50] A. M. Donoghue, "Occupational health hazards in mining: An overview," *Occupational Medicine*, vol. 54, no. 5, pp. 283–289, 2004.

[51] K. L. Cashdollar, "Coal dust explosibility," *Journal of Loss Prevention in the Process Industries*, vol. 9, no. 1 SPEC. ISS., pp. 65–76, 1996.

[52] P. L. Younger, "Environmental impacts of coal mining and associated wastes: a geochemical perspective," *Geological Society, London, Special Publications*, vol. 236, no. 1, pp. 169–209, 2004.

[53] L. Goldbeck and A. Marti, "Dust control at conveyor transfer points: containment, suppression and collection," 2012. [Online]. Available: http://www.ckit.co.za/secure/conveyor/troughed/transfer{_}points/transfer{_}ponits{_}dust{_}control.html

[54] O. Binneveld, "Photo of conveyor hauptbaanhoff, Stuttgart, Germany."

[55] C.C.Components, "Side skirt solution." [Online]. Available: http://www.cccomponents.com.au/products/conveyor-components/." [Accessed on: 2016-06-25]

[56] V. Minko and I. Logachev, "OPTIMIZATION OF ASPIRATION SYSTEMS FOR," *Chemical and Petroleum Engineering*, vol. 32, no. 3, pp. 65–67, 1996.

[57] M. A. Yun-dong, J. I. A. Hui-yan, and Z. Da-ming, "Airtight negative pressure dust-control technology and application of transpersite in the coal conveyer belt system," vol. 14, no. 4, pp. 562–566, 2008.

[58] X. L. Chen, C. A. Wheeler, T. J. Donohue, R. McLean, and A. W. Roberts, "Evaluation of dust emissions from conveyor transfer chutes using experimental and CFD simulation," *International Journal of Mineral Processing*, vol. 110-111, pp. 101–108, 2012.

[59] Reinhard H. Wëhlbier, "Dust solutions." [Online]. Available: http://forum.bulk-online.com/showthread.php?23616-Innovative-Dust-Suppression-Device." [Accessed on: 2016-06-25]

[60] L. Langmaack, B. Grothen, and P. D. Jakobsen, "Anti-wear and Anti-dust Solutions for Hard Rock TBMs," 2010. [Online]. Available: http://www.therobbinscompany.com/wp-content/uploads/2010/09/Anti-weardust{_}WTC{_}2010.pdf

[61] H. Wang, D. Wang, W. Ren, X. Lu, F. Han, and Y. Zhang, "Application of foam to suppress rock dust in a large cross-section rock roadway driven with roadheader," *Advanced Powder Technology*, vol. 24, no. 1, pp. 257–262, 2013. [Online]. Available: http://dx.doi.org/10.1016/j.apt.2012.06.012

[62] H. Wang, D. Wang, X. Lu, Q. Gao, W. Ren, and Y. Zhang, "Experimental investigations on the performance of a new design of foaming agent adding device used for dust control in underground coal mines," *Journal of Loss Prevention in the Process Industries*, vol. 25, no. 6, pp. 1075–1084, 2012. [Online]. Available: http://dx.doi.org/10.1016/j.jlp.2012.07.023

[63] Best-Chem, "Chemical Dust Solutions." [Online]. Available: http://www.best-chem.co.uk/dust-supression/what-is-foam-dust-suppression/." [Accessed on: 2016-06-25]

[64] C. Sensogut, "Occupational Noise in Mines and Its Control – A Case Study," *Polish Journal of Environmental Study*, vol. 16, no. 6, pp. 939–942, 2007.

[65] NIDCD, "Noise-Induced Hearing Loss," *National Institute of Health Publication*, no. 99, 2014. [Online]. Available: http://www.nidcd.nih.gov/staticresources/health/hearing/NIDCD-Noise-Induced-Hearing-Loss.pdf

[66] Flexco, "Noise and Your Rollers." [Online]. Available: http://www.flexco.com/filebase/en/log/File3188

[67] G. Lodewijks, "The design of high speed belt conveyors," *International Materials Handling Conference (Beltcon) 10*, 1999.

[68] S. Brown, "Conveyor noise specification and control," *Acoustics 2014*, no. November, pp. 269–276, 2014.

[69] M. Haines, "Development of a conveyor belt idler roller for light weight and low noise," BSc, University of New South Wales, 2007.

[70] G. Lodewijks, D. Schott, and J. Ottjes, "Modern Bulk Terminal Design," *Bulk Solids Handling*, vol. 27, no. 6, pp. 364–376. [Online]. Available: http://www.beltcon.org.za/docs/b1413.pdf

[71] Het Milieuloket, "Geluidshinder." [Online]. Available: http://www.milieuloket.nl/9353000/1/j9vvhurbs7rzkq9/vhurdyxq2n7t." [Accessed on: 2016-07-27]

[72] Forbo Siegling, "Amp Miser ™ Energy-saving conveyor belts." [Online]. Available: http://www.forbo-siegling.com/pages/brochures/special/download/238-fms{_}amp{_}miser{_}energy-saving{_}en.pdf

[73] P. Mills, M. Bridges, and E. Juillerat, "Noise reduction in new open-cut coal mines, coal handling and preparations plants," 1993. [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.138.4449