LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Energy Systems
Degree Programme of Environmental Technology

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ASSESSMENT OF PELLET AND POLYMER POWDER EMISSIONS

Examiners: Professor Risto Soukka
M.Sc. (Tech.) Jenni Valonen

ABSTRACT

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Assessment of Pellet and Polymer Powder Emissions

Master's Thesis

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87 pages, 13 figures, 7 tables and 3 appendices

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Keywords: plastic production, environmental legislation, risk assessment, emission rate

Aim of this master's thesis is to research and find an appropriate measurement method and technique for determining pellet and polymer powder emissions from discharge waters. Aim is also to find out how the Finnish legislation could regulate these emissions in the plastic industry in the future. For future legislation, thesis will look at developments especially regarding environmental legislation. Since there is no precise and uniform legislation in Finland or in the European Union regarding pellet and polymer powder emissions, the thesis looks at how the pellet and polymer powder emissions are regulated and limited in other countries.

The thesis included a mapping of the emission sources to make the company easier to manage and reduce pellet and polymer powder emissions. The mapping of emission sources was carried out by means of risk analysis on all plastic plants in the industrial area. In the risk analysis, significant value is determined for each source of emission. With significance value the most significant emission sources for the company were found.

There are no standardized measurements methods or techniques for measuring pellet and polymer powder emissions. The studies conducted by other researchers have focused on measuring the amount of plastic particles from natural waters. Separate measuring methods had to be developed for pellets and powder due to their large difference on particle size. The developed measurement methods should be suitable for the company's needs. The obtained emission rate from the measurements are compared with the production capacity of the plants as well as with the results of previous research carried out in the European area.

TIIVISTELMÄ

Lappeenrannan Teknillinen Yliopisto
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Sini Hakala

Pelletti- ja polymeeripölypäästöjen arviointi

Diplomityö

2017

87 sivua, 13 kuvaa, 7 taulukkoa ja 3 liitettä

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Diplomityön tavoitteena on tutkia ja selvittää sopiva mittausmenetelmä pelletti- ja polymeeripölypäästöjen määrittämiseen poistovesistä. Tavoitteena on myös selvittää miten Suomen lainsäädäntö voisi tulevaisuudessa säädellä näitä päästöjä muoviteollisuuden yrityksissä. Tulevaisuuden lainsäädännön osalta työssä tarkastellaan ympäristölainsäädännön kehittymistä. Koska Suomessa tai Euroopan Unionissa ei vielä ole tarkkaa ja yhtenäistä lainsäädäntöä pelletti- ja polymeeripölypäästöihin liittyen, työssä tarkastellaan miten muissa maissa pelletti- ja polymeeripölypäästöjä on säädelty sekä rajoitettu.

Jotta yrityksen olisi tulevaisuudessa helpompi hallita ja vähentää pelletti- ja polymeeripölypäästöjä, työhön kuului tarkasteltujen päästölähteiden kartoitus. Päästölähteiden kartoitus toteutettiin riskianalyysin avulla kaikilla teollisuusalueen muovintuotantolaitoksilla. Riskianalyysissä jokaiselle päästölähteelle määritetään merkittävyysluku, jonka avulla löydetään yrityksen kannalta merkittävimmät päästölähteet.

Pelletti- ja polymeeripölypäästöjen mittaamiseen ei ole olemassa standardoitua mittausmenetelmää. Tehdyt tutkimukset ovat keskittyneet muovipartikkelien määrän mittaamiseen luonnonvesistä. Pellettien ja polymeeripölyn mittaamiseen tuli kehittää erilliset mittausmenetelmät niiden suuren partikkelikokoeron vuoksi. Kehitettyjen mittausmenetelmien tuli olla sopivat yrityksen tarpeisiin. Mittaukissa saatuja päästömääriä verrataan laitoksien tuotantokapasiteetteihin sekä aikaisemmin Euroopan alueella tehtyjen tutkimuksien tuloksiin.

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LIST OF ABBREVIATIONS

Abbreviations

BAT	Best available technique
BAT-AEL	BAT-associated emission level
BREF	Best available technique reference document
COD	Chemical oxygen demand
EU	European Union
FEM	European materials handling federation
FTIR	Fourier-transform infrared spectroscopy
GES	Good environmental status
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
HAZOP	Hazard and operability study
HELCOM	Baltic Marine Environment Protection Commission
IED	Industrial Emission Directive
OCS	Operation Clean Sweep
Pyr-GC-MS	Pyrolysis-gas chromatography-mass spectrometry
SEM	Scanning electron microscope
SYKE	Finnish Environment Institute
TOC	Total organic carbon
TSS	Total suspended solids
UNEP	United Nations Environment Programme

Compounds

H_2O_2	hydrogen peroxide
HCl	hydrochloric acid
NaCl	sodium chloride
NaI	sodium iodide
NaOH	sodium hydroxide

1 INTRODUCTION

Marine litter is a global problem, which has gained more and more attention recently. Marine litter consists of different solid materials like plastic, rubber, metal, paper, textiles and so on. (SYKE 2016a, 5.) Major part of floating marine litter is derived from plastic. Depending on the circumstances, litter can remain in the sea for a long time. Decomposition of marine litter is affected by the material of plastic piece and temperature conditions, amount of sunlight and particularly ultraviolet radiation levels, oxygen level and pH of the water. Also, the mechanical breakup influenced by factors such as surfing, sand, gravel and stones. (SYKE 2016a, 10.)

Problem with marine litter starting to accumulate to the oceans, were already found in 1970-1980 centuries. Extensive waste accumulations in surface layers of water, also called garbage gyres, are found from the Atlantic and Pacific Ocean. Garbage gyres do not have any fixed coherent, visible or detectable formations; the water is mixed with plenty of small powder like material, especially plastic, which resembles essentially a form of plastic soup. Today larger waste accumulations are found in five subtropical gyres, which are located in Northern and Southern Atlantic, Northern and Southern Pacific Oceans and Indian Ocean. Litter is carried long distances to these areas due to ocean currents. (SYKE 2016a, 9.) Also, near the coastline and in the coastline, can be seen areas where marine litter is accumulated. Marine litter is becoming a problem in Baltic Sea and also in Finland’s inland waters. (Lonkila 2016.)

Plastic litter and litter in general end up in the waters from diffuse sources. Therefore, litter management is complex and solving it requires a number of different parties and close international and regional co-operation. (Lonkila 2016.) According to Andrady (2011, 1597) about 80 % of marine debris is expected to be land-based. Rest about 20 % of debris is generated in activities which take place in sea such as transport, fish industry and aquaculture. Sources and pathways of plastic litter and debris are poorly managed landfills, stormwaters, rivers, sewage treatment plants, littering, illegal waste dumping, natural disasters and high population density near water bodies. (Lonkila 2016.) Also, important sources are road wear, abrasion of tyres and industry (Magnusson et al. 2016, 5). The major sources of plastic debris in 2010 are presented in figure 1. China is assumed to generate the greatest amount of ocean-bound litter. Highly developed garbage collection system is a key thing when actions for reducing the amount of waste entering sea are taken. China has dense populations near rivers and in addition for that ineffective garbage collections system increases the amount of plastic waste entering oceans. China is also one of the biggest global producers of plastics. (Parker 2015.)

Figure 1. Top 10 sources of ocean's plastic waste. In comparison the figure reflect the maximum overall amount plastic waste that flows into oceans each year, not the highest per capita amounts. (Parker 2015.)

According to Andrady (2011, 1597) the term microplastic and microlitter has been defined differently by various researchers. But in general litter sized less than 5 millimetres is called microlitter, if the particle is plastic then microplastic. Litter particles larger than 5 millimetres are called mesolitter. Currently microlitter of microplastics do not have a standardized definition to the size, but generally 5 millimetres is considered to be the limit between micro- and mesoparticles. Microplastics are not readily visible to the bare eye, but also mesolitter is relatively hard to detect. Microplastics are divided into two groups according to their origins; primary and secondary microplastics. According to Cole et al. (2011, 2589) and Crawford & Quinn (2016, 104) the primary microplastics are plastic particles that manufactured to be microscopic size. Usually these are used in cosmetics, personal care products and sandblasting shot. Pellets and powder from plastic raw material production are also counted to be primary plastic particles because of the size of them. Secondary microplastics are defined according to Cole et al. (2011, 2589) and Crawford & Quinn (2016, 109) to be result of degradation of larger piece of plastic. The shape of secondary microplastic is irregular while the shape of primary microplastic is typically spherical.

Problems caused by plastics and microplastics in waters are relatively new research area and it involves a lot of uncertainties. It is known that after reaching the marine environment, debris and litter may cause variety of problems to organisms. Micro sized plastic pieces may be caught up in organisms causing physical problems and deformities. Micro sized litter may also end up in food chain and lead to negative health effects. (SYKE 2016a, 37.) Plastic can contain harmful compounds, but they can also bind to various environmental toxins (SYKE 2016a, 32). In addition, a variety of social and economic impacts are caused due to litter such as littered beaches are no longer attractive to people and moreover floating debris can damage ships and damage the fish stocks or indirectly spoil the fish spawning areas. (SYKE 2016a, 37.) There are still disagreement and uncertainties about the extent and side effects of litter problems in marine environment. (Lonkila 2016.) As the argumentation about how to reduce and prevent marine litter and debris expands, the existing stage is an opportunity for actions. Some actions are taken internationally and in European Union level but also in the nearby area for example in Baltic Sea.

1.1 Background of the study

This company, as plastic producer, has committed to Operation Clean Sweep (OCS) and its five implementing steps. OCS is a voluntary programme for facilities that deals with plastic materials. The programme was established in 1991 and currently OCS is implemented in 23 countries around the world by several companies. OCS is designed to help facilities implement procedures that keep plastic materials out of waters and reduce the loss of plastic pellets, flake and powder. Operation Clean Sweep’s goal is to achieve zero pellet, flake and powder loss. (Gisagara 2016.)

The five steps of OCS are committing to make zero pellet loss as a priority, assessing company's situation and needs, making necessary upgrades in facilities and equipment as appropriate, raising awareness among employee's and follow up (Operation Clean Sweep 2016). Zero Pellet Loss –project has started in Porvoo location and within this project technical development, risk assessments and auditing has been made, but further assessment is required. Trainings and campaigns are held to raise the awareness of Zero Pellet Loss -projects and its goals. Follow up is made by using the help of different kind of reporting tools.

The overall assessment of pellet and powder losses for whole location is missing in this point. The amount of pellet and powder emissions are essential questions from environmental aspect but also from the aspects of production. There are no common approaches established to control pellets and powder in the production area as well as plants has different kind of equipment and standards for cleaning. Plastic pellets and powder are hard to control if it spreads to environment and access to the water collection system. Polymer powder is light material and it mixes well to water.

Awareness around different kind of emissions has raised a lot in past few years. Plastics and microplastics have been recognized as an emission from different sources and plastic raw material production is one of them. Plastics and microplastics are becoming a problem in water systems. (Lonkila 2016.) The raised awareness can lead to specific requirements in environmental permits to reduce pellet and powder emissions in plastic raw material production in the future.

1.2 Boundaries and structure

Only pellet and polymer powder emissions to discharge waters from plastic raw material production in Porvoo are included to this study. The emission rate is calculated for pellet and powder emissions in discharge waters. Powder in this thesis refers to polymer powder from plastic production. Pellet and powder are counted as emission if they without intention get out of the process and end up to the production area.

Master's thesis consists two parts. First the literature part reviews legal requirements and the future prospects of them as also the theory related to sampling and measuring pellets and powder from water. The experimental part includes measurement and determination of pellet and powder amount in discharge waters. Determination of possible emission sources in each plant is included to experimental part. Proposals and methods to reduce pellet and powder emissions are also presented based on the obtained results.

1.3 Objectives and research questions

This master's thesis is part of Zero Pellet Loss programme in Porvoo location. The objectives of theory part are to find out legislation requirements and best practices, which can be applied to pellet and powder emissions. Law perspective is viewed in national and European Union level. In theory section the purpose is also to find out possible sampling and measuring methods for pellet and powder emissions and choose the suitable method for Porvoo location to measure the amount of plastic in discharge waters.

In experimental part the objectives are to find out significant leaks and determine the emission rates in Porvoo location. Aim is also to do a risk assessment for the found leaks and assess the possibilities of them. The operators from the plants and the help of their knowledge of the processes are used to find the possible leaks. By knowing the leaks sources of pellets and powder, the further reduction actions are easier to implement.

The research questions of this study are presented in following list:

- Which places are the significant emitters in Porvoo location?
- What actions can be done to avoid pellet and powder emissions?
- What is the best possible way to measure these emissions?
- How much pellets and powder drifts to discharge waters in a year?

2 LEGISLATION, REQUIREMENTS AND BEST PRACTICES TO CONTROL PELLET AND POWDER EMISSIONS

In Finland industrial water conservation is guided in the Environmental Protection Act and Government Decree on Environmental Protection, EU regulations and also by the costumer and stakeholders requirements. Legislation guides industrial activity and sets the baseline for environmental protection actions. In EU countries national legislation is largely based on the international legislation and agreements. These all influence the company and its operations. In figure 2 is presented the broad and complex network, which is affecting the context of environmental legislation in national level and also the company's operating environment. (Teknologiateollisuus ry 2010, 8.)

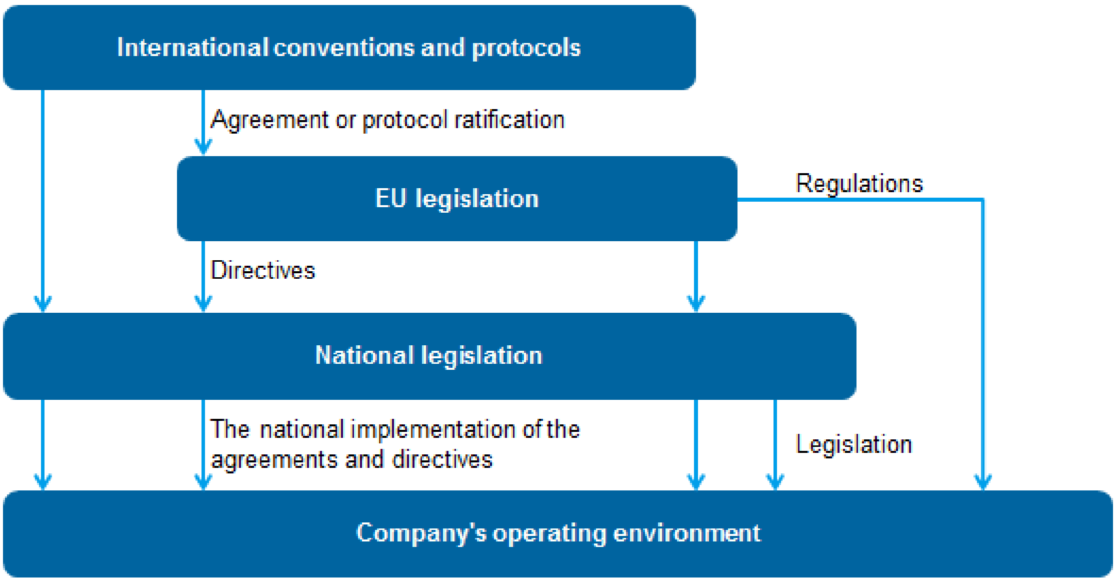

Figure 2. The business environment affecting environmental regulation from various groups (Teknologiateollisuus ry 2010, 9).

2.1 European Union based regulations

EU based regulations are given among other things in Reference Document on Best Available Technique (BREF), Directives and in Best Available Technique (BAT) Conclusions. BREFs are divided to into two groups according to their area of concern. BREFs related to particular industrial activities are vertical BREFs and BREFs dealing with cross-sectoral issues are horizontal BREFs. Horizontal and vertical BREFs are developed to be complementary for the purpose of setting permit conditions. Vertical BREFs may include information on techniques which can help technical working groups in deriving Best Available Technique (BAT) to other sectors. Horizontal BREFs contains information of a generic nature that can be used in many activities which fall under the scope of Directive 2010/75/EU, the Industrial Emission Directive (IED). Vertical and horizontal BREFs should not result in conflicting conclusions and in order to use both BREFs in complementary way. (2012/119/EU.)

Industrial production processes result in a substantial part of the total emissions in Europe. The largest emissions can be classified to be air pollution, waste water emissions and waste production. The Industrial Emission Directive is the EU's most important regulatory instrument for emissions from industrial installations. The IED was approved in November 2010, it entered into force in January 2011 and it had to be brought to the member states by January 2013. (European Commission 2016a.)

IED aims to achieve a high overall protection level of human health and the environment by reducing harmful industrial emissions across EU, in particular through better application of BAT. Industrial Emission Directive is based on several pillars: an integrated approach, use of available techniques, flexibility, control and public participation. An integrated approach in IED means that the permits must take into account the whole environmental performance of the plant. The permit conditions including emission limit values must be based on the Best Available Techniques. In order to determine BAT and the BAT-associated environmental impacts at EU level, the Commission organises an exchange of information with experts from member states, industry and environmental organisations. Conclusions of the best available techniques aim at achieving a high-level protection of the environment, economically and technically viable circumstances. Flexibility in IED takes place in allowing environmental authorities to set less strict emission limit values in specific cases. IED includes mandatory requirements for environmental inspections, which should take place at least every 1 to 3 years, inspections should use criteria based on the risks. IED ensure that the citizen have right to participate in decision-making process. (European Commission 2016a.)

The Best Available Technique Conclusions for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector were published in May 2016. BAT conclusions are part of BAT reference documents resulting from the exchange of information carried out in technical working groups. These BAT conclusions address several issues relating to the IED enterprise of all chemical installations covered. The BAT conclusions for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector include 23 conclusions on BAT, of which six related to emissions to water with the total of nine BAT-associated emission levels (BAT-AELs) for direct discharges to a receiving waterbody. (European Commission 2016b.)

Reference Document on Best Available Technique in the Production of Polymers is the main BREF document for plastic industry. The document focuses on the main products of the European polymer industry both in production figures and in environmental impacts. Document was published in August 2007. (European Commission 2007, i.)

2.1.1 Compliance with Reference Document on Best Available Technique on the Production of Polymers

In BREF in the Production on Polymers occur three conclusions regarding the pellet and powder emissions from plastic production. First one is the BAT 5, where best available technique is to reduce dust emissions with the use of combination of different techniques. Techniques that can be used are, for example, reducing dust generation of conveying lines by surface treatment and forming proper alignment of the pipes or by using cyclones and/or filters in the air exhausts for dust removal units or by using wet scrubbers in the air exhausts of dust removal units. With these techniques reduction of dust emissions can be received. Pressure drops can be a limiting factor in the use of cyclones, filters and wet scrubbers. (European Commission 2007, 256.)

The BAT 9, in which best available technique is to prevent water pollution by appropriate piping and materials. To facilitate the inspections and repair of the pipes and pumps, these should be placed above the ground if available and installed accessible in waste water collection systems at new plants and retrofitted systems. (European Commission 2007, 256.)

BAT conclusion of separated water collection systems is presented in BAT 10. In this conclusion the best available technique is to use separated waste water collection systems. The contaminated process waste water, possibly contaminated water from leaks and uncontaminated water should be separated from each other. (European Commission 2007, 256.)

BAT 9 and BAT 10 aims to improve management and control of waste waters. These BAT conclusions are generally applicable for all processes of producing polymers. Retrofitting a separate waste water collection system in the old plant can be complicated and requires more planning than building new waste water treatment plants. (European Commission 2007, 256.)

2.1.2 Compliance with BAT Conclusions for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector 2016/902/EU

In BAT Conclusions for Common Waste Water/Waste Gas Treatment/Management Systems in the Chemical Industry exists some appropriate conclusions concerning pellet and powder emissions to water. The specific conclusions are BAT 4, BAT 8, BAT 9, BAT 10 and BAT-associated emission levels (BAT-AELs) for direct emissions of total organic carbon, chemical oxygen demand and total suspended solids to the receiving waterbody.

The scope for the BAT Conclusions for Common Waste Water/Waste Gas Treatment/Management Systems in the Chemical Industry concern chemical industry and BAT conclusions concern activities in specified sector. BAT-AELs are given as concentrations and refer to flow-weighted annual average values of 24-hour flow-proportional composite samples. The BAT-AELs apply at the point where the emissions leave the installation and also apply to the direct emissions of a receiving waterbody. (2016/902/EU.)

In BAT Conclusions for Common Waste Water/Waste Gas the BAT-AEL values for direct emissions of total organic carbon, chemical oxygen demand and total suspended solids to a receiving waterbody are specified. Values are presented in table 1. Either the BAT-AEL for TOC or the BAT-AEL for COD should be applied. The lower end of the TSS range is typically achieved using filtration, while the upper end of the range is typically achieved only by using sedimentation. If TOC, COD or TSS does not exceed the given BAT-AEL limit, BAT-AELs are not applied. (2016/902/EU.)

Table 1. BAT-AELs for direct emissions of TOC, COD and TSS to receiving waterbody (2016/902/EU).

Parameter	**BAT-AEL (yearly average)**	**Conditions**
Total organic carbon (TOC)	10-33 mg/l	The BAT-AEL applies if the emission exceeds 3,3 tons in a year.
Chemical oxygen demand (COD)	30-100 mg/l	The BAT-AEL applies if the emission exceeds 10 tons in a year.
Total suspended solids (TSS)	5-35 mg/l	The BAT-AEL applies if the emission exceeds 3,5 tons in a year.

The best available technique is to monitor emissions to water according to EN standards, but if EN standards are not available ISO, national or other international standards may be used instead. The minimum monitoring frequency for TOC, COD and TSS should be daily. The monitoring frequency can be adjusted if the data series clearly demonstrate a sufficient stability. The sampling point should be located at the point where the discharge leaves the installation. (2016/902/EU.)

BAT conclusions for waste water collection and separation are presented in BAT 8 and BAT 9. In BAT 8 the best available technique to reduce emissions to water is to separate uncontaminated water flows from the waste water flows that require treatment. In BAT 9 the best available technique for preventing uncontrolled discharges to water is to provide a suitable buffer storage capacity of waste water resulting from other than normal operating conditions based on the risk assessment. The risk assessment should take into account the nature of the pollutant, the effect on further treatment and the receiving environment. Separation is needed to storage contaminated rainwater. The separation of uncontaminated rainwater may not be applicable in the case of existing waste water collection systems. (2016/902/EU.)

BAT conclusions for waste water treatment are presented in BAT 10. In BAT 10 the best available technique for reducing emissions to water is to use an integrated waste water management and treatment strategy that includes appropriate combination of techniques. The suitable combination of techniques in order of importance is presented in table 2. (2016/902/EU.)

Table 2. Techniques in the order of importance for integrated waste water management and treatment strategy (2016/902/EU).

	Technique	**Description**
1	Process-integrated techniques	Techniques to prevent or reduce the generation of water pollutants.
2	Recovery of pollutants at source	Techniques to recover contaminants before their discharge to the waste water collection systems.
3	Waste water pre-treatment	Techniques to abate pollutants before the final waste water treatment. Pre-treatment can be performed in the source or in the combined streams.
4	Final waste water treatment	Final waste water treatment by, for example, preliminary and primary treatment, biological treatment, nitrogen removal, phosphorus removal and/or final solids removal techniques before discharge to a receiving waterbody.

2.2 Finnish legislation on environmental protection

In Finland the main control means in environmental protection are Environmental Protection Act (27 June 2014/527) and Environmental Protection Decree (4 September 2014/713). The main objectives of the Environmental Protection Act are listed below (Environmental Protection Act, 27 June 2014/527).

- To prevent environmental pollution and danger, to prevent and reduce emissions and to remove the adverse effects of pollution and prevent environmental damages

- To secure healthy, pleasant and ecologically diverse and sustainable environment, support sustainable development and combating climate change
- To promote the sustainable use of natural resources and reduce the amount and harmfulness of waste and prevention of adverse impact of waste
- To improve the assessment and consideration of the overall impact of polluting activities on the environment
- To improve citizens' opportunities to influence decision-making on the environment

Environmental Protection Act is applied in industrial and other activities that cause or may cause environmental pollution. The law requires that the operator to be aware of the environmental impacts and risks of their activities and to reduce harmful effects. The operator shall organize their activities so that environmental pollution can be prevented in advance. If the pollution cannot be completely avoided, it should be reduced to a minimum. The general principles of the law are prevention and harm minimization, precaution and diligence as well as use of the best available technologies. (Environmental Protection Act, 27 June 2014/527.)

Activities, which pose a risk of environmental pollution, the environmental permit is needed according to the Environmental Protection Act (27 June 2014/527). Practically all large-scale industrial activities require an environmental permit. In order permit can be granted, requires that the operations do not cause health damage or significant environmental pollution or risk thereof. Environmental Protection Act (27 June 2014/527) and Environmental Protection Decree (4 September 2014/713) sets out the risk of pollution causing activities for which permit is applied, as well as other requirements for the permit application and the permit decision. The structure of environmental permit is defined in Environmental Protection Decree (4 September 2014/713). The environmental permit is given the scope of the provisions, emissions and the reduction among other things concerning the operation. The environmental provisions will prevent all major industrial pollution to the environment caused by the operations. (Environmental Protection Act, 27 June 2014/527 & Environmental Protection Decree, 4 September 2014/713)

The permit provisions give the necessary provisions including measures to disturbance or in other exceptional circumstances. On this basis, the environmental provisions of the operator may be ordered to prepare for the environmentally harmful fires. Also, the collection and treatment of waste water quenching should be taken into account when preparing for the emergency situations.

2.3 Other requirements and proposals

2.3.1 The Marine Strategy Framework Directive 2008/56/EC

The aim of the Marine Strategy Framework Directive (2008/56/EC) is to strengthen the common objectives and principles between the member countries and to maintain marine ecosystems. The directive was adopted on 17 June 2008, and it was to be transposed into national legislation by 15 July 2010. The purpose of the directive is intended to protect more effectively and more comprehensively the marine environment in European Union and to achieve good environmental status (GES) in these areas by 2020. Directive outlines a transparent and legislative framework for an ecosystem-based approach to the management of human activities. According to Marine Strategy Framework Directive the European sea areas are divided in following areas the Baltic Sea, the North-East Atlantic, the Mediterranean and the Black Sea. Countries which are located in these sea areas along the coastline and are EU member states are responsible for the implementation of the directive. (2008/56/EC.)

Good environmental status is determined based on the qualitative descriptions. These descriptions are described in annex 1 of Marine Strategy Framework Directive (2008/56/EC). Descriptions consist vide range of indicators which measure the state of the sea area, but can be divided into two main groups to descriptions that characterise marine biodiversity and descriptions that are related to human-induced pressures. One of the descriptions concerns marine litter and the amount of it in coastal and marine environment. (2008/56/EC.)

In order to achieve GES, the states marine strategies take into account the special problems and needs of each sea area. Coastal states need to communicate and co-operate with others in order to bring each marine region as a harmonious whole in marine strategy. In Marine Strategy Framework Directive (2008/56/EC), it is recommended that member states exercise the coordination of the implementing of regional conventions dedicated to sea protection organizations. These organizations have already working interest, experience and skills in working with the seas. (2008/56/EC.) In Baltic Sea region the territorial sea protection commission is called Baltic Marine Environment Protection Commission (HELCOM), commission is also known as Helsinki Commission.

To achieve GES by 2020, each member state shall develop a strategy for its marine areas. The strategy should contain an initial assessment of the current environment status of Member State's marine waters, a determination of what GES means for those waters, targets and indicators designed to show whether a member state is achieving GES, a monitoring program to measure progress towards GES and a program of measures designed to maintain or achieve GES. The program of measures should have been developed by 2015 and it should be in operation by 2016. (2008/56/EC.)

2.3.2 HELCOM Regional Action Plan on Marine Litter in the Baltic Sea

HELCOM's goal is to protect marine environment of Baltic Sea from all sources of pollution and to maintain its ecological balance. HELCOM has noticed an issue with marine litter in Baltic Sea region. On 2013 HELCOM Copenhagen Ministerial Declaration compromises a clear commitment: to develop a Regional Action Plan on Marine Litter. The Action Plan was adopted in June 2015 after a broad consultation process with number of stakeholders. (HELCOM 2016.)

The two main objectives of the Regional Action Plan on Marine Litter are to reduce marine litter significantly by 2025 as compared to 2015 levels and to prevent further damage to coastal and marine environment. The action plan can be divided into different themes, main themes that are directly linked to plastic raw material production plants are actions to improvement of waste prevention and the question about micro sized particles, which include microplastics, entering water systems. Action plan has altogether 30 regional actions and voluntary national action tackling the marine litter problem in Baltic Sea. (HELCOM 2016.) Regional actions require common, large-scale and widespread actions of the Contracting Parties. Voluntary national actions are primary national concern and responsibility of the Contracting Parties. Contracting Parties may voluntarily select actions for implementation according to national significance. (HELCOM 2015, 6.)

In action plan there are two regional actions relevant to micro sized particles. The first one deals with the importance of the establishment of an overview of the primary and secondary particles from various sources as well as to evaluate if they are covered with by national legislation. For further specification an overall picture of what products and processes contribute to the input of microplastics to the Baltic Sea should be done by 2017 by Contracting Parties and by 2018 existing national legislation is assessed and necessary measures identified together with relevant stakeholders. Second regional action considers the best available techniques in waste water treatment plants for preventing micro sized particles entering to marine environment. In additions for this action HELCOM prepares a report of micro particle removal in waste water treatment plants by 2018. (HELCOM 2015, 8.)

2.3.3 Programme of measures for the development and implementation of the marine strategy in Finland 2016–2021

The programme of measures for the development and implementation of the marine strategy in Finland 2016-2021 was approved by the Finnish Government on 3 December 2015. This programme of measures is a national maritime strategy for Finland which was required in the Marine Strategy Framework Directive (2008/56/EC). The programme of measures gives an overview of the measures taken so far for improving the status of the marine environment, but it also sets 29 new measures for implementing the marine strategy. (Laamanen 2016, 9.)

The programme of measures reduces the impact and pressure caused by human activities for the marine environment and at the same time improves the stage of the marine environment. The aim is to maintain the good environmental status in the areas, which has reached it, and in the same time achieve good environmental status by the end of the year 2020 to areas, which are currently missing it. The programme examines the mitigation of eutrophication, reduction of hazardous and harmful materials, protection of biodiversity, combating invasive alien species, promoting the sustainable use of marine resources and management, the prevention of disruption caused by hydrographic changes as well as reduction of litter and underwater noise of the sea and beaches. (Laamanen 2016, 9.)

The purpose of reducing the sea and beach litter is to prevent further harm to the coastal and marine environment. Littering is now a new focus and status among good environmental status because of the data gaps earlier. Sources of litter have been recognized to be recreational use of the sea and beaches, maritime transport, waste water treatment plant spill overs and outfalls, stormwater and fishing. In 2015, HELCOM adopted the recommendation and the Baltic Sea Action Plan to reduce litter. This action includes the international agenda in the Baltic Sea to take action. The first phase of the operation carried out an extensive assessment of litter sources and the effects, the following action defines the objective and measures related to litter and the last stage of the measures implemented. (Laamanen 2016, 11.)

Actions planned to prevent further littering in sea area are divided into three stages. In the first stage of the action wider general description of the origins of the marine litter, the amount in different areas and assessment of the potentials for reducing litter. The report covers both visible litter and micro sized litter. In the second phase proposal for environmental objectives for littering are set based on the first phase. In the third stage proposals for reducing measures on sea and beach litter are suggested. When preparing suggestions the possibilities to reduce plastic litter is a key aspect. Measures will be launched and if possible be implemented by the end of 2021. (Laamanen 2016, 94.)

3 UPCOMING PROSPECTS RELATED TO PLASTIC HANDLING AND MANAGEMENT

Marine litter and microplastics are an environmental problem and litter is not limited to the borders of nations. Litter can be carried far away from the actual emissions sources. The emission sources variate and the possible sources can be landfills, poorly managed city waste management, industry, municipal waste water treatment plants or transportation. Among these sources the plastic industry is relatively small player causing microplastics compared to municipal waste water treatment plants or transportation. (SYKE 2016a, 45; Magnusson et al. 2016, 5; Sundt 2014, 37-38.)

The most important measures for the marine conservations point of view are the reduction and prevention measures. In particular, with the regard of microplastics the removal of them from marine environment is almost impossible. Meaningfulness of prevention and reduction measures should be taken into account when considering the lifecycle of plastics. Actions made in the beginning of the lifecycle are clearly cheaper than the environmental remediation measures and debris removal from the environment. (SYKE 2016a, 45.)

Plastic industry is not the biggest polluter when it comes to microplastics. Plastic industry in turn is relatively compact and easy to control and it is controlled by the same environmental legislation than any other industrial sector. Restrictions, which are relate to maintain and protect the stage of environment, are for example restrictions for air emissions, demand on waste handling and requirement for the treatment of waste water.

Policy-makers in public and private sectors need guidelines on how to target the plastic and microplastic issues. Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), United Nations Environment Programme (UNEP) and Finnish Environment Institute (SYKE) has given recommendations on actions that could be suitable for actions of the nations. GESAMP (2015, 66) has recommended to identify the main sources and categories of plastic and microplastic sources entering the water systems and seas. Also, HELCOM has this kind of actions in its' Marine Actions

Plan on Marine Litter in Baltic Sea. HELCOM's aim is to make a review on what products and processes contribute to the input of microplastics to the Baltic Sea by 2017. (HELCOM 2015, 8.) The management of marine litter is only possible if the sources are mapped comprehensively (SYKE 2016b, 289).

California has passed a law which include the best management practices for companies that manufactures, handle and transport plastic pellets in 2007 (California Water Code - Section 13367). Law covers particularly raw material production facilities of plastic. The minimum best practices are determined specifically for manufacturing and transportation actions and the anticipation has great value on that. It requires facilities to have appropriate containment systems for all storm drain discharge locations that are downgradient of the areas where plastic pellets are present in production or transportation manners. The containment system can be a device or series of devices that captures all plastic particles at least diameter of one millimetre. The capacity should be designed enough to handle peak loads for example during heavy rains. (UNEP 2016, 22-23.)

California has also regulations concerning the durability of containers and cleaning equipment in the plant area. At all points of plastic raw material production sealed containers should be durable enough so as not to break under typical loading and unloading activities. This regulation also affects to storage of plastic. All the conveying equipment shall have conveying valves and devices used in the case of loading, unloading or other conveying actions. California Water Code also demands that facilities shall make a vacuum cleaners and vacuum type systems available to its employees for quick clean-ups of fugitive plastic pellets. (UNEP 2016, 23.)

Two main sources of microplastics are the gradual fragmentation of larger pieces of plastic and microbeads in home and personal care products. Canada and seven states in United States have launched regulations concerning the microplastics and the use of them in products. The Government of Canada has added microbeads to the List of Toxic Substances under the Canadian Environmental Protection Act. As a result, the government could develop regulations that prohibit the manufacture, import, sale and marketing of products containing microbeads. Maryland, Illinois, Maine, New Jersey, Colorado, Indiana and California have adopted a legislation restricting the use of microbeads in personal care products. (UNEP 2016, 25.) In 2015 Cosmetics Europe gave a recommendation for cosmetic industry to abandon the fixed, non-biodegradable plastic particles in personal care product and in cosmetics by 2020. The recommendation was based on the fact that microbeads have caused public concern as a part of marine litter and as alternative raw materials are available also companies have already taken voluntary business action to phase out the use of microbeads. (Teknokemian yhdistys ry 2017.) In Finland SYKE (2016a, 46) has pointed out that usage of microbeads should be reduced and be replaced with other degradable material. Potential action in Finland would be to ban the use of microbeads in consumer products such as personal care products and cosmetics.

Landfills set a risk for plastic leaks to environment. European Commission has announced that it has adopted proposals including a landfill ban for recyclable materials by 2025. The aim of this proposal is to boost Europe to turn more towards into circular economy and enhance recycling in member countries. (Millet 2016.) Action to prevent possible plastic leakages from landfills is to place landfills far enough from coastline and rivers and to prevent emergence of illegal waste dumps. Also, the transportation and collection bins can leak plastic debris to environment. For this reason recycling bins should be closable and have appropriate emptying schedule to prevent overfilling. (SYKE 2016a, 45.)

One of the most common legal mechanisms to deal with plastic litter is to regulate or ban the use of plastic bags in retail and consumer end-user level. More than 100 national and subnational governments have prohibited or otherwise regulated the use of plastic bags. The provisions relating to the thickness of the plastic bags, taxes or fees on end-user bags or some combinations of these two including band of plastic bags are assumed to be the most effective ones. (UNEP 2016, 27.) The ban is a clear control means in those countries where litter caused by plastic bags is a significant problem because the lack of waste management. The use rate of plastic bags is relatively lower in Finland than the average use rate in other EU countries and in addition plastic bags in grocery stores are payable in Finland. In order to further reduce the consumption of plastic bags in Finland, there were a proposal for extending the payable plastic bags in special retail and variety of services with voluntary agreements. (SYKE 2016a, 47.)

Raising awareness of the impacts of plastic and microplastic is determined as a recommended action by GESAMP (2015, 67) and SYKE (2016a, 47). When consumers are more aware what kind of risks plastics and microplastics can cause to the environment and in the environment, consumers start to demand actions to reduce risks from decision-makers. Consumer demand guides the industry to produce products that consumers desire. In HELCOMs' (2015, 13) Marine Action Plan on Marine Litter in the Baltic Sea educations and raising public awareness of the harms of marine litter is proposed voluntary national action. Raising awareness, especially among children and youth, of the threats that marine litter causes to environment will have positive effect of reducing the amount of litter in seas.

Ecolabelling takes a stand on the use of microplastics and microbeads in consumer products. In Nordic countries the Nordic Ecolabels' Swan label demonstrates that the product is a good environmental choice. The Nordic Swan label checks that product fulfils certain criteria and the criteria are verified by samples analysed in independent laboratories, certificates and control visits. EU ecolabel is similar to the Swan label. In order to obtain EU ecolabel, the criteria must be met and maintained in audits. Criteria of the Swan label and the EU ecolabel bans the use of microbeads in rinsed off cosmetic products. (SYKE 2016a, 46.)

BREF on the Production of Polymers is the vertical BREF for plastic and plastic raw material production. Last BREF on Production of Polymers was published in 2007. During this time many best available techniques have changed and improved compared to the 2007 published BREF document. Plastic industry is currently missing at the moment comprehensive and common guidelines for all institutions for production techniques and environment protection. Recently published BAT Conclusions for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector is a horizontal BREF for plastic and plastic raw material production. It has some restrictions which can be assumed to concern plastic industry in some extent. On the other hand this BREF does not comment directly on the emissions from plastic raw material production. Requirements are more or less general and related to waste water treatment. Either BREF on Production of Polymers or BAT conclusions for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector does not directly take a stand on the microplastics or measuring the amount of them in waste waters. In BAT Conclusions for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector the yearly average of total suspended solids is determined if the emission exceeds 3,5 tons in a year.

One of the objectives in Finnish environmental protection laws is to prevent environmental pollution and danger and as well as to remove the adverse effects of pollution and prevent environmental damages. Littering is counted as pollution and source of pollution in environmental laws. Littering and litter leakages are mainly problems related to waste management and are controlled with other laws and regulations. Emissions from industrial and processing plants are controlled with environmental permits. Environmental permit gives limits to the amount and quality to the emissions. SYKE (2016a, 46) points out that, in the future industrial and processing plants should pay closer attention to the possible plastic emissions. This could lead to new environmental permit requirements considering specifically plastic emissions and preventions of them. New requirements in environmental permits might come to prominence after the new vertical BREF for plastic raw material production has been published.

3.1 Possible environmental permit requirements in the future in Finland

Environmental protection actions are focused on preventive measures and a comprehensive environmental management system. The trend of environmental permit restrictions is likely to get more and more stringent in the near future. For plastic raw material production environmental permit restrictions will be likely to be added with a limit for plastic pellet and powder emissions to waste and discharge water as well as regulation for better handling for powder that drifts into the air. Environmental authorities may impose new requirements for environmental permits if they consider that new measures will increase the efficiency of environmental protection. Authorities can also impose new environment reporting requirements for companies without actual emission limits. Authorities may see a lack of control in plastic pellet and powder emission as an environmental risk. Restrictions for microplastics and plastic emissions as well as requirements and limitations for emissions from plastics may need regulation or decisions of the Commission of European Union before the restrictions can be set at the national level.

New potential environmental regulations in environmental permits can be related to process waste waters, stormwaters and the treatment and handling of them. Plastic residues in discharge waters are typical emissions in plastic raw material production plants. Stormwaters from process areas can contain pellets and powder, which are spread to production area unintentionally. Process waters may also contain reductions of plastics if the collection device is not working properly or there have been some technical problems. The amount of plastic in waste water is a part of total suspended solid in waste waters among organic matter. Related to this it is possible that amount of total suspended solids is included to future environmental permit decisions.

In BAT Conclusions for Common Waste Water/Waste Gas Treatment/Management Systems in the Chemical Sector the frequency on waste water measurements has been presented to be once in a day, but it can be fewer if sufficient stability can be demonstrated in the quality of waste water. In waste water monitoring plan the operating company suggests, how they would monitor waste waters and the frequency of monitoring. Environmental authority can demand changes to presented plan, if they see gaps and areas of development.

In addition to measurements of total suspended solids environmental authorities may add limits only to the amount of plastic in waste waters. Currently the effective way of measuring plastic amount in waste water continuously is missing. One-time measurements are possible, but it is challenging to achieve a representative result from it. Possible measuring techniques and methods need to be invented and standardized before the requirement can be set to environmental permits. In the future techniques and methods for measuring will be improve and after that requirements for plastic amount in waste water can be set. As earlier said plastics in waste waters are contained in waste water solids. Total suspended solids are easier to define and the result gives an indicative result of the amount of plastics in waste waters. The ratio between plastic and other solids is however difficult to define.

One aspect to reduce plastic entering water systems is to make structural changes to the facilities where production and transportation of pellets and powder happens. Structural changes can be for example improving the conditions of the yard areas and tarmacking all the yard areas or build structures that lead stormwaters to the desired position and prevent the diversion of them. Authorities may require that the yard areas are improved due to a more effective cleaning.

In exceptional cases, a fire or heavy rain, a lot of unwanted compounds and material is likely to flow out of production area without purifying or neutralization. For these kinds of situations collecting ponds should be large enough to be able to store fire waters and heavy rains.

The requirement to clean all stormwaters and waste waters before being discharged into the waterbody is possible. Purification targets can be set in environmental permits. These targets should be achieved with purification steps before waste waters are lead to waterbody. Targets can be set for the minimum purification size of plastic particles and the purification level which should be achieved with each particle size. Purification target for suspended solids in waste water can also be set. To reduce the amount of solid matter is waste water. Filters can be installed to reduce the amount of solids in waste waters. These targets can be applied for stormwaters and process waste waters.

Plastic pellets and powder can also be a problem outside of the production area if pellets and powder gets to the environment. It is possible that requirement of cleaning these areas is added to the environmental permit. The Finnish Environmental Protection Act already has clear expression that pollution of the environmental is prohibited.

In Finland it is also possible that microplastics can be added to environmental quality standards as Canada has done. Environmental quality standard refers to an aquatic concentration of harmful and hazardous substances in surface water, sediment or biota, which should not be protect human health or the environment beyond. When adding microplastics to environmental quality standards, government has the ability to develop regulations that would restrict the use of microplastics in products. However, in order to microplastics could be set as environmental quality standards, more research into their effects on the aquatic environment, to humans and food chain are needed.

Currently Finnish environmental legislation does not take microplastics into account as an emission or hazardous subject. There are possibilities to pose restrictions related to plastic and microplastic emissions as some countries have already done. Possible environmental permit requirements and additions to national legislation in the future are listed below:

- Limits for total suspended solid in waste water
- More frequent sampling frequency or continuous sampling of suspended solids
- Measuring the amount of plastic in waste waters and reporting it to environmental authorities
- Structural changes to prevent plastic getting to the environment
- Preparedness for emergency situations with basin or basins for gathering area waters in these situations for cleaning prior to discharge to waterbody
- All waters from the area should be lead to controlled purification before discharge
- Purification targets for the size of plastic particles in waste water and targets for the amount of plastic in waste water
- Requirement for cleaning pellets and powder outside the production area if they appear and the cause can be traced back
- Adding microplastics to environmental quality standards

4 SAMPLING AND MEASURING METHODS FOR PLASTICS IN ENVIRONMENT

Microplastic sampling and analysing methods vary considerably and there is a need for standardisation. In sedimentary environments the majority of work has been done from sandy beaches with sample taken from different tidal levels using varying methods and equipment. Sea surface and water column samples are mostly taken by plankton nets with different mesh sizes at varying depths and speeds. (Hidalgo-Ruz et al. 2012, 3060.) There is a general lack of specific sampling protocols for sampling of microplastics in water and sediment (Rocha-Santos & Duarte 2015, 48).

Most of the studies that have been done to determine the amount of plastic particles are carried out in the marine environment and beaches. Current sampling and analysing methods of plastic particles have been developed for these environments. Plastic production facilities are different environment to do sampling and measurements of plastic particles. However, the same sampling techniques can be applied in production facilities with some changes as in environment sampling. Analysing plastic particles from the samples does not differ from the sample whether the sample is taken from production facilities or from environment. Only difference might be in the concentration of plastic in the sample. The quality identification techniques of plastic particles are the same in environmental samples as in samples taken from production facilities.

4.1 Sampling and sample handling

There is no generally accepted or standardized procedure for sampling of plastic particles from aquatic, solid fractions or biological samples (Crawford & Quinn 2016, 179). In sampling the physical environment varies a lot and some consideration need to be done before sampling. It is important to carefully consider the type of sample to be collected and the sampling method to be applied. Since the chosen sampling method can greatly influence the obtained result. (Crawford & Quinn 2016, 184.) The plastic concentrations in waters and aquatic environment can vary dramatically between regions.

The concentration can be relatively low in aquatic environment but in plastic raw material production the concentrations of plastics in discharge waters might be a bit higher. (Crawford & Quinn 2016, 185; Löder & Gerdts 2015, 204.) The nature's physical forces such as wind and water currents can influence the diversion and accumulation of microplastics in marine environment. Nature forces can affect to spatial and temporal differences in plastic particle distribution. (Crawford & Quinn 2016, 185.) The low concentrations of plastic particles lead to the requirements for large sample volumes. (Crawford & Quinn 2016, 185; Löder & Gerdts 2015, 204.)

Used sampling strategy depends on the purpose of the study, is it qualitative or quantitative. If the purpose of the research is qualitative, the goal is to quickly gather non-numerical information about the types of plastic particles in the environment. In quantitative research, the goal is to gather numerical data regarding the distribution and abundance of plastic particles in environment. (Crawford & Quinn 2016, 185.) Sampling of microplastics and plastic particles in the marine environment may require different approaches. General sampling methods in marine environment can be divided into three groups (Hidalgo-Ruz et al. 2012, 3061; Crawford & Quinn 2016, 181):

- Selective sampling: items visible to bare eye are collected directly from the environment, such as on the surface of the water or sediment
- Bulk sampling: extracting microplastics from the entire volume of sample in the laboratory
- Volume reduced sampling: the volume of the bulk sample is reduced until only the specific items of interest remains for further analysis

The selective sampling is more time-consuming and may lead to an underestimation of abundance of microplastics because all the microplastic pieces are not located at the surface of the water. This collection method is sufficient in situations where different microplastics of similar shape features and a size greater than 1 millimetre are present. The main disadvantage of selective sampling method is that, when microplastics are mixed with other debris or have no characteristic shapes, then there is a risk of overlooking. (Hidalgo-Ruz et al. 2012, 3061; Crawford & Quinn 2016, 181.)

Bulk samples are the most suitable approach when plastic particles cannot be easily visually recognized because they are covered with sediment or the abundance of plastic particles is small and requires filtering of large volumes of water or plastic particles are too small to be identified with bare eye. Practical limitations with this method are the amount of sample that can be collected, stored and processed. In theory, the advantages of this method is that all the microplastics in the sample can be collected, regardless of their size or visibility. (Hidalgo-Ruz et al. 2012, 3061; Crawford & Quinn 2016, 181.)

In volume reduced sampling the volume of bulk sample is reduced until only the specific items of interest remain in sample. The volume of the bulk sample is usually reduced during the sampling. As a reason of that the majority of the sample is discarded. This method is typically utilised to collect samples from surface water because it has the advantage that large areas or quantities of water can be sampled. The disadvantage of volume reduced sampling is that discarding the clear majority of the sample introduces the risk of underestimate the abundance of microplastics in the sample due to the potential loss of microplastics in the sample. (Hidalgo-Ruz et al. 2012, 3061; Crawford & Quinn 2016, 181.)

Samples are usually taken from open waters with plankton nets of different mesh sizes. The sea surface may be sampled for floating plastic particles with manta trawls or neuston nets, presented in figure 3. The volume of filtered water by the nets is usually recorded by a flowmeter mounted at the net opening. This enables the calculation of concentration of plastic particles per unit of water volume. (Löder & Gerdts 2015, 204.) Manta trawls and neuston nets or variations of them are also useable when sampling in rivers. When sampling in rivers the flowrate of water can be measured with flowmeter mounted at the net opening. The mesh size has to be determined according to particle size which is wanted to be collected.

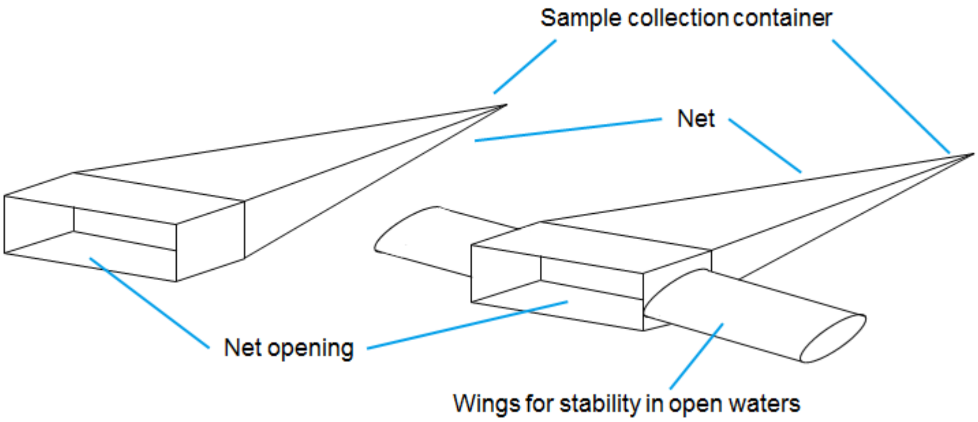

Figure 3. Principles of neuston trawl (left) and manta trawl (right) (Crawford & Quinn 2016, 188).

4.2 Contamination of samples

Assessing the amount of microplastics the sample can easily be contaminated during the sampling and analysis in the laboratory from variety of sources. Possible contamination sources are sampling and analysis equipment, clothes and gloves or airborne particles. Fibres from clothing and gloves have ability to hoover in the air and can cause a high contamination potential and problems during the analysis. (Löder & Gerdts 2015, 203.) While analysing the samples, possible contamination sources might be poorly cleaned equipment or improperly sealed samples.

According to Rocha-Santos & Duarte (2015, 48) plastic particles in the sample may stick to the wall of the containers when moving samples to another dish. This may lead to the possibility of losing a part of sample during the analysis. To prevent losing a part of sample the dishes must always be rinsed on the filter or sieve carefully. (Hidalgo-Ruz et al. 2012, 3064.) Contaminations and losing part of sample can lead to overestimation or underestimation of concentrations of microplastics in the sample and distort the results (Löder & Gerdts 2015, 203).

During the sampling and analysing, special attention should be paid to the prevention of contamination. Potential sources of contamination could be avoided by replacing plastic devices in laboratory ware with non-plastic material. Also, the use of control samples is highly recommended. Analysis of the control samples helps to identification of the source of contamination if the contamination has occurred. (Löder & Gerdts 2015, 204.) Hidalgo-Ruz et al. (2012, 3064) recommends that for example sealing of filters in Petri dishes during drying of the samples reduces the risk of contamination during the procedures.

4.3 Sample purification

Various methods have been proposed for purify suspected microplastic items and clean the surface of any biofouling organism. Sample purification step takes place usually after the microplastic separation step. The methods proposed for purifying include freshwater rinsing, ultrasonic cleaning and treatment with various chemicals including hydrochloric acid, sodium hydroxide and hydrogen peroxide. When using chemicals for the separation of microplastics from biological material, similar caution must be exercised when attempting to remove biogenic material, since the chemicals could potentially alter the characteristics of the microplastics. (Crawford & Quinn 2016, 219-220.)

Any surface exposed to the marine or freshwater environment will be subject to some form of fouling, particularly biofouling, where layer of microorganisms accumulates on the surface. The change in surface appearance can greatly impact how the items are identified and may result in the underrepresentation of microplastics in the sample. (Crawford & Quinn 2016, 219-220.) If the samples are taken from unproductive waters, samples usually contain small amounts of biological material. Identifying and isolating any plastic particle may be done without the need for any sample purification and cleaning. With sediment samples, plastic particles can be separated according to the density difference by using low-density salt solutions (NaCl or NaI solutions). (Cole et al. 2014, 1.)

According to Cole et al. (2014, 2-3) acid (HCl), alkaline (NaOH) and enzymatic (Proteinase-K) are possible to use in digestion treatments of plankton rich seawater samples. With these chemicals, the digestion efficiencies range from 54,0 % to 97,7 %. In the study from Cole et al. (2014) the alkaline treatment resulted in the partial destruction of nylon fibres and melting of polyethylene fragments.

Treatment with hydrogen peroxide (30 %) is found to be an effective method in removing biogenic organic matter from samples. However, it was found to alter the characteristics of the polymer making it difficult to identify and in some cases even dissolving it. As a result hydrogen peroxide (30 %) has the possibility of altering the characteristics of the polymer. Because of this purification step should only be undertaken if there is a high degree of organic matter present and it is hindering visual selection of the microplastics. Other possible way to separate microplastics from sediment is subjecting solids to wet peroxide oxidation in the presence of a Fe(II) catalyst to digest liable organic matter. (Crawford & Quinn 2016, 219-220.)

4.4 Methods for separation of plastics

Plastic particle in samples need to be separated from all the organic and inorganic material which is present in water, sediment and biological samples. Separation ensures that the plastic particles can be quantified by counting or weighing and identified accurately. The sample may have had some sort of separation or sample reduction on-site, such as filtration through a net or sieve, but also the whole sample processing can happen in laboratory. Several techniques are used in the laboratory for separation of plastic particles from organic and inorganic matter: visual sorting, filtration, sieving, density separation and flotation. (Crawford & Quinn 2016, 203.)

4.4.1 Visual sorting

Visual sorting is an essential step when analysing plastic particles from the sample. This step is recommended to be used in all sample forms (water, sediment and biota). The aim in visual sorting is to remove other materials, such as shell fragments, wood and anthropogenic contaminants from the sample. These unwanted contaminants are typically present in bulk samples and commonly found in volume reduced samples. Visual sorting is done by direct examination of the sample by bare eye or with the support of microscope. (Hidalgo-Ruz et al. 2012, 3064; Crawford & Quinn 2016, 203.)

Use of visual sorting in plastic particle sampling can be controversial because of its potential for misinterpretation. In order to avoid misidentifications and underestimation of plastic particles it is necessary to harmonize the plastic particle selection and set criteria to ensure proper and uniform identification. There is no better method of detecting and separating plastic materials from other debris than human operator. (Hidalgo-Ruz et al. 2012, 3064; Crawford & Quinn 2016, 204.)

To aid the positive identification of plastic particle by visual examination, the strict criteria are suggested. Criteria could contain some limitations for the structure, colour and shape of the particle. With the smaller and indistinct particles, high-magnification microscopic examination should be undertaken. (Crawford & Quinn 2016, 220-221.)

4.4.2 Sieving

Plastic particles can be separated from the sample by using sieves of variable mesh sizes. The sieve physically captures the plastic particles and allows the water to be lost from sample. A different mesh sizes allow separating plastic particles into different size categories. The size of the mesh is usually chosen by the size of plastic particle desired to be collected. (Hidalgo-Ruz et al. 2012, 3064; Crawford & Quinn 2016, 206.) According to Crawford & Quinn (2016, 206) most commonly used mesh size varies between 38 micrometres to 4,75 millimetres. The mesh size should not be greater than 5 millimetres otherwise the size of collected plastic particles would be outside the size-range of microplastics.

To ensure that all desired particle sizes are collected, sieving should be repeated several times with different mesh sizes or use multi-tier sieving. Multi-tier sieving involves separating material of different sizes by passing through a series of sieves with decreasing mesh size. The principle of multi-tier sieving is presented in figure 4. (Crawford & Quinn 2016, 206.)

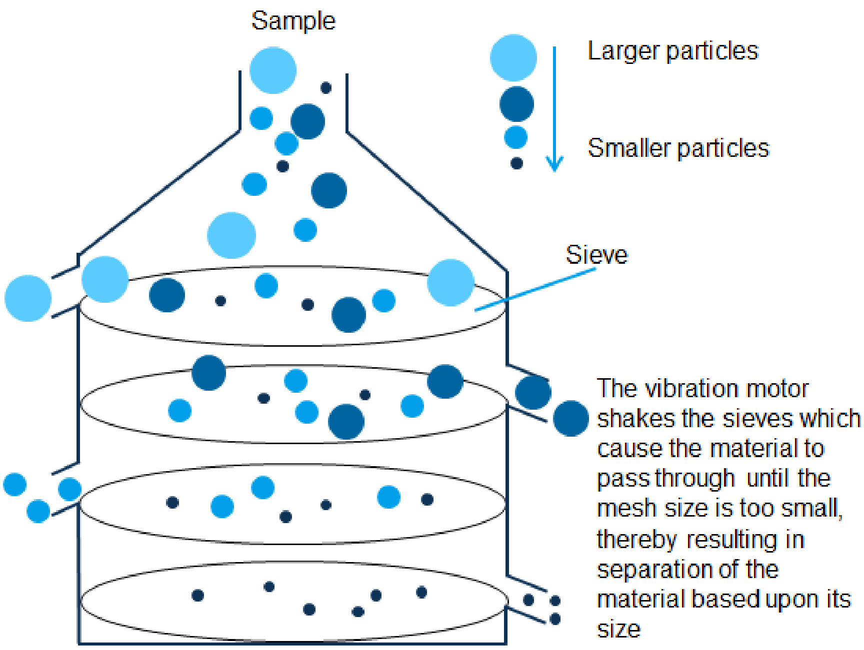

Figure 4. Principles of multi-tier sieving (Crawford & Quinn 2016, 206).

4.4.3 Filtration

Filtration is effective physical or mechanical methods used to separate solids from fluids by using a filter that only fluid can pass and the solids are left in the filter paper. Usually filtration is aided by vacuum. The size and amount of solids left in the filter depends on the pore size of the utilized filter paper. (Hidalgo-Ruz et al. 2012, 3063; Crawford & Quinn 2016, 204.) The process of separating plastic particles is normally undertaken physically using a funnel, a filter paper and a vacuum system. After filtration plastic particles are retained in the filter paper. In figure 5 is presented the fundamental filtration system aided by vacuum. (Crawford & Quinn 2016, 204.) According to Hidalgo-Ruz et al. (2012, 3064) and Crawford & Quinn (2016, 205) the pore size of used filtration paper usually varies between 1-2 micrometre. Crawford & Quinn (2016, 205) recommends that in filtration qualitative filters should be utilised.

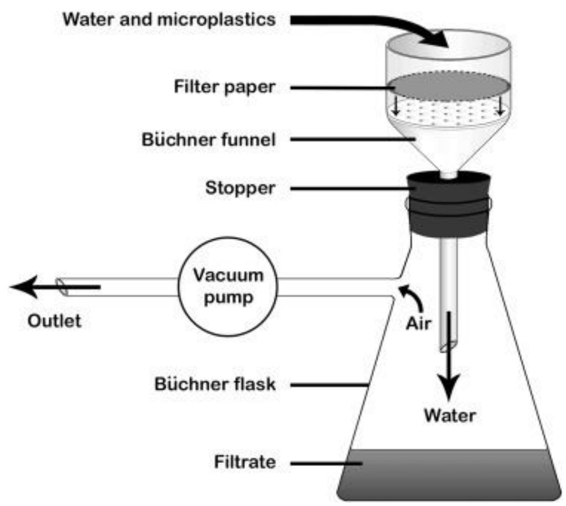

Figure 5. A vacuum filtration system (Crawford & Quinn 2016, 205).

Filtration is relatively simple process, but complications often arise when the water sample is contaminated with a lot of particulate matter or other debris. This might cause clogs to filter paper and reduces the effectiveness of filtration in separating plastic particles from water and often leads to complete clogging of the filter. Blockages can be prevented with reducing the volume of liquid to be filtered or adding a pre-cleaning step for the sample. Cleaning steps typically includes settling the liquid to allow separation of heavier solid fractions, pre-filtering with larger pore size, employing the density separation technique and/or encouraging flocculation of the solid fractions by adding chemicals to the liquid. Disadvantage of pre-cleaning is the risk of losing plastic particles from the sample to be analysed. This can lead to underestimation of concentrations of microplastics in the sample. (Crawford & Quinn 2016, 205.)

4.4.4 Density separation

Density separation is a process that takes advantage of the fact that plastic materials have a range of different densities. Density separation is commonly used for sediment samples. The density of plastic ranges from 0,9-1,4 g/cm^3 and the typical density for sand or other sediments is approximately 2,65 g/cm^3 (Hidalgo-Ruz et al. 2012, 3063). The different densities of plastics are presented in table 3 (Hidalgo-Ruz et al. 2012, 3064; Crawford & Quinn 2016, 211). According to Crawford & Quinn (2016, 208) density separation has become the most reliable and commonly used method for the separation of microplastics and plastic particles, because the density of the liquid can be adjusted to allow certain plastic materials to float on the surface of the liquid.

Table 3. The density ranges of common plastics (Hidalgo-Ruz et al. 2012, 3064; Crawford & Quinn 2016, 211).

Plastic	**Density [g/cm^3]**
Polyethylene	0,917-0,965
Polypropylene	0,9-0,91
Low-density polyethylene	0,917-0,94
High-density polyethylene	0,94-0,97

When a mixture of materials with varying densities, such as sediments and plastic particles, are placed in a liquid of intermediate density (water or salt solution), the material with a lower density than that of the liquid will float, while material with greater density will sink to the bottom of container. The floating plastic particles can be collected by decanting the liquid that lies above the layer of sediment. Density separation will not work if the sample contains much organic matter that has relatively same density than the plastic particles. The main aspect of density separation is presented in figure 6. (Crawford & Quinn 2016, 207.) Mixing of sediment sample with a saturated solution and shaking it for a certain period of time will speed up the density separation of the lighter plastic particles from the heavier sediment grains. The sample mixing time can vary between 30 seconds to 2 hours and the settling time ranges between 2 minutes to 6 hours. (Hidalgo-Ruz et al. 2012, 3063.)

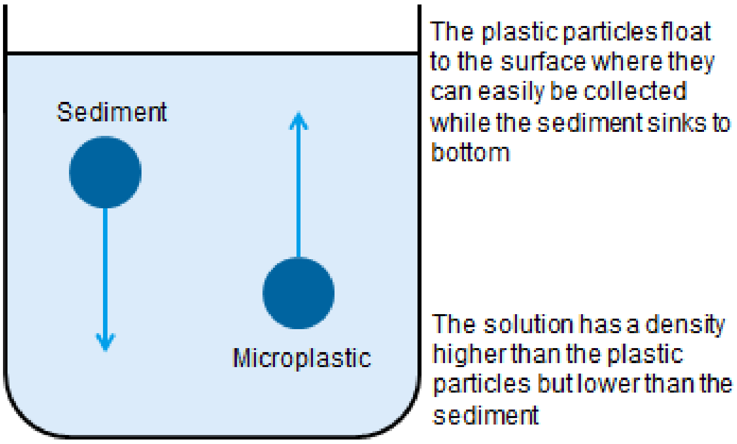

Figure 6. Density separation of plastic particles and sediment (Crawford & Quinn 2016, 208).

Most commonly used liquid in density separation is saturated sodium chloride (NaCl) solution. Particles lighter than the density of liquid will float. Other salt solutions can also be used for separation of plastic particles from a sample. Using NaCl solution in density separation is advantageous because NaCl solution is cheap, widely available and environmentally friendly. Disadvantage with NaCl solution is that it has specific density and it will only allow items to float that possess a density below that value. NaCl solution can be substituted with ethanol if a low-density solution is desired. (Hidalgo-Ruz et al. 2012, 3063; Crawford & Quinn 2016, 208-209.)

4.5 Methods for identification of plastics

After sample collection and separation, the final stage in the assessment of microplastics in the environment is the identification of those items suspected to be composed of plastic. The precise chemical composition of plastic particles is potentially very broad and depends for example on the additives and co-polymers used. But in the other hand each plastic quality has its own specific physiochemical properties. Several techniques are available for microplastics identification, ranging from a simple visual identification to analytical techniques based on the chemical composition of the polymer. Identifications techniques are typically carried out on special instruments such as scanning electron microscope, Fourier transform infrared spectroscopy, Raman spectroscopy and pyrolysis-gas chromatography-mass spectrometry. (Crawford & Quinn 2016, 219.)

4.5.1 Scanning electron microscope

A scanning electron microscope (SEM) is used to create an image of a small surface of a sample by firing a high intensity beam of electrons at the samples surface and scanning it with a zig-zag pattern. Using electrons to image the sample levels of detail lower than 0,5 nanometre resolutions are achievable at very high magnifications. Achieved resolution with SEM is much higher compared to standard optical microscopes. In this technique electrons can be generated in two ways by a hot filament source or field emission. (Crawford & Quinn 2016, 232.)

Scanning electron microscope can be used to analyse the physical characteristics of microplastics recovered from environmental samples, as well as to determine their physical size and specific dimensions of any surface features. SEM can also help to distinguish plastic items from non-plastic items providing high-resolution images. SEM is not normally used for identifying the type of plastic particles. (Crawford & Quinn 2016, 234.)

4.5.2 Fourier-transform infrared spectroscopy

Fourier-transform infrared spectroscopy (FTIR) is the most popular and widely used technique for the identification of the types of plastic that microplastics in environmental samples are composed of. Reasons for the popularity are the straightforwardness and reliability of the technique. FTIR is highly accurate in identifying the type of plastic present by producing highly specific infrared spectra which contain distinct band patterns. The technique relies on the reality that most of the molecules absorb light in the infrared region of the electromagnetic spectrum. In figure 7 is presented the basic set-up of FTIR microscopy. (Crawford & Quinn 2016, 241.)

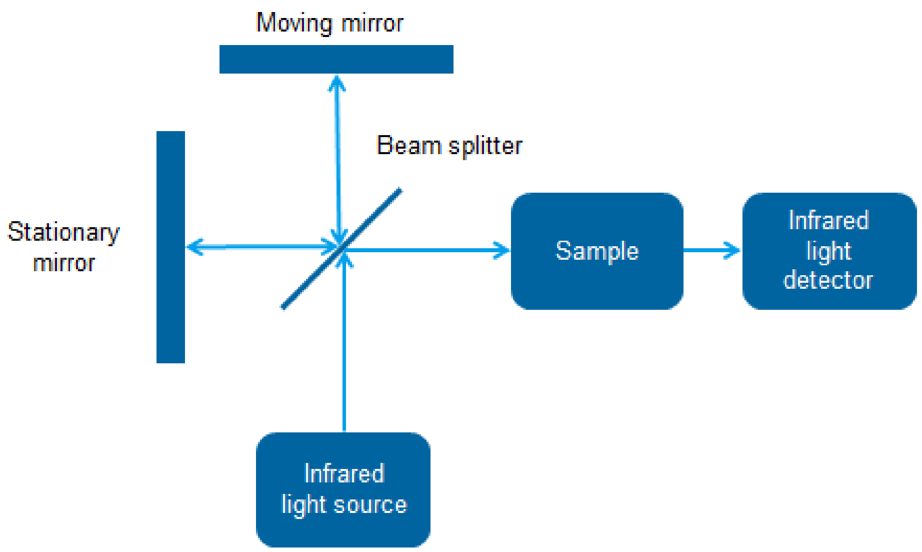

Figure 7. The basic set-up of a Fourier-transform infrared (FTIR) microscopy (Crawford & Quinn 2016, 247).

By measuring the amount of absorption of infrared radiation at different frequencies it is possible to generate an absorption spectrum that can provide insight concerning the molecular structure of the sample. The infrared spectrum contains a series of absorption peaks which corresponds to the different frequencies of vibration between the bonds of the atoms in the molecule sample. FTIR spectrums are unique for each plastic type and can be used to positively identify the type of plastic that plastic particle is composed of. (Crawford & Quinn 2016, 244.) The FTIR does not require sample preparation. Although sample clean-up may be needed if sample contains a lot of other particles. (Rocha-Santos & Duarte 2015, 50.)

4.5.3 Raman spectroscopy

Raman spectroscopy is used to identify plastic particles and the quality of them. The laser beam falling on an object result in different frequencies of back-scattered light depending on the molecular structure and atoms present, which produce a unique spectrum for each polymer. Raman uses the inelastic scattering of monochromatic light usually coming from laser. The interaction of laser light with the molecules and atoms of the sample results in difference in frequency of the backscattered light when compared to the irradiating laser frequency. This so-called Raman shift can be detected and lead to substance-specific Raman spectra. The basic principles of Raman spectrometry are presented in figure 8. Raman spectroscopy identifies the plastics and also provides profiles of the polymer composition of each sample similar to FTIR microscopy. Raman spectroscopy is sensitive to the additive and pigment chemicals in microplastics, which interfere with the identification of polymer types. Raman spectroscopy can be easily separated from the molecules of chemicals that are very similar to each other. (Crawford & Quinn 2016, 255-256; Löder & Gerdts 2015, 213.)

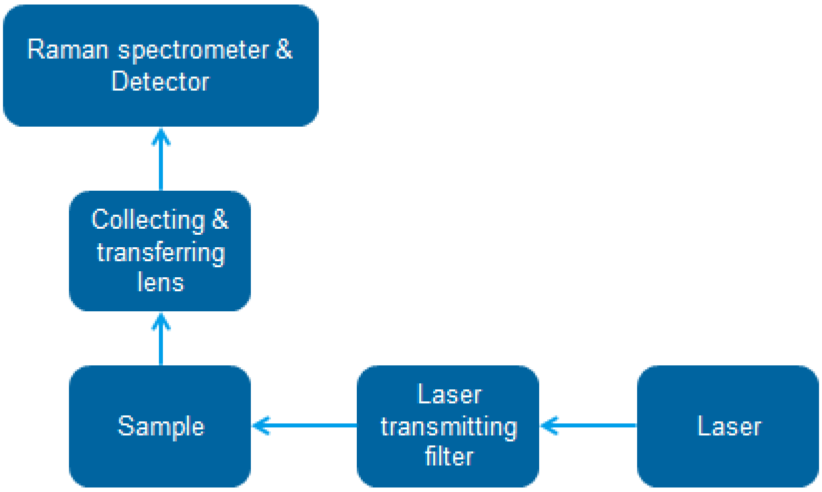

Figure 8. The basic set-up of a Raman spectrometry (Crawford & Quinn 2016, 256).

The energy changes in the incident photons is characteristic of the type of bonds that they are interacting with and provides precise information about the molecular structure of the sample. Raman spectrum is produced with characteristic peaks at wavelengths associated with different vibrations and bonds by collecting Raman scattered light by a detector upright to the incident beam. The spectrum can be interpreted and compared to Raman reference spectrums to identify the type of plastic in sample. (Crawford & Quinn 2016, 258.)

Raman spectroscopy is a straightforward technique to determine the composition of plastic in sample. It is also efficient and reliable technique which requires minimal sample preparation, but to achieve more reliable result extraction and visual sorting of the sample should be done. Raman spectroscopy has been successfully used for the identification of microplastics that have been separated from environmental samples. (Crawford & Quinn 2016, 259.)

4.5.4 Pyrolysis-gas chromatography-mass spectrometry

Pyrolysis-gas chromatography-mass spectrometry (Pyr-GC-MS) is a technique which thermally decomposes the large high-molecular weight molecules of a sample by heat mediated cleavage in the presence of an inert atmosphere or a vacuum to create a suite of smaller low-molecular weight moieties. (Crawford & Quinn 2016, 235.) In Pyr-GC-MS the plastics are analysed by the thermal degradation of a product. (Rocha-Santos & Duarte 2015, 50.) The composition of moieties is subsequently determined by mass spectrometry. Mass spectrometry provides characteristic information as to the structural composition of the samples large high-molecular weight molecules, thereby allowing the sample composition to be identified. (Crawford & Quinn 2016, 235.) Pyrolysis of plastic features in characteristic programmes, which facilitate the identification of the polymer type (Löder & Gerdts 2015, 212).

Pyr-GC-MS thermally decomposes the sample and further analysis of the plastic particles is precluded. This might be a limiting factor in some cases. The advantage of Pyr-GC-MS is that the technique utilises direct introduction of the sample with minimal pre-treatment, only extraction and visual sorting is needed for the sample. (Crawford & Quinn 2016, 235; Löder & Gerdts 2015, 212.) Pyr-GC-MS is also able to analyse polymer type and organic plastic additives at the same time without use of solvents. (Rocha-Santos & Duarte 2015, 50.)

5 PLANT LEVEL PELLET AND POWDER EMISSION SOURCES AND RISK ASSESSMENT

In this section the plastic pellet and powder emission sources are mapped in each production plant. The assessment of emission sources includes a risk assessment where the significance of each risk is assessed.

5.1 Risk assessment in general

Risk assessment is the overall process of risk identification, risk analysis and risk evaluation. The way the risk assessment is applied depends not only on the risk management context but also the methods and techniques used for risk assessment. Risk identification is a process of finding, recognizing and recording the risk that the company may have. (SFS-EN 31010:2013, 21.) Risk analysis is about developing understanding of the risks and it also consists of determining the consequence and probabilities of the risks (SFS-EN 31010:2013, 23).

Risk management is part of all the activities what industry has. The importance of risk management emphasizes when the scale of activities increase. In environmental aspect the emissions prevention in the production is in a large extent risk management. When the operation scale grows the risk assessment and the precautions gets more difficult. However, the risks and necessary measures for management of them are identified and evaluated as a part of risk analysis. (SYKE 2006, 18.)

Risk analysis is a procedure where information is used to identify risks and the significance of risks. In figure 9 presented the content of risk analysis. Risk assessment is an essential part of risk management and it includes assessment of the magnitude and probability of the risk. (SYKE 2006, 18.)

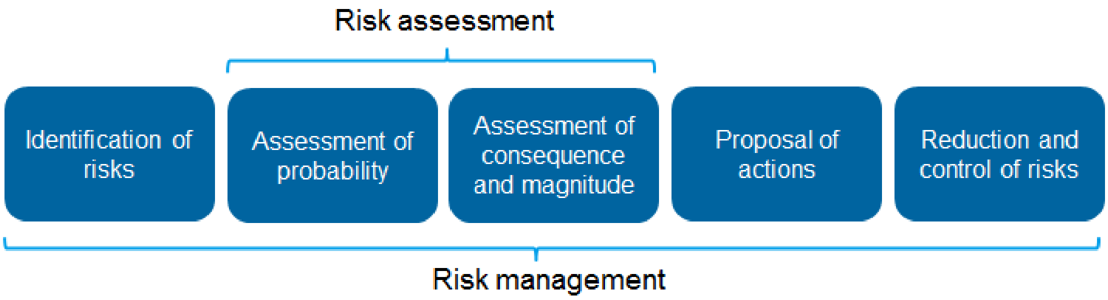

Figure 9. Content of risk analysis and its relation to risk management and risk assessment (SYKE 2006, 18).

According to SFS-EN 31010 (2013, 25-27) the assessment of the probability of the risk is usually done by using one or more approaches. One of these approaches is to use relevant historical data to identify events or situations that have occurred in the past and may therefore have a probability to happen again in the future. When historical data is not available or it is insufficient, the probability can be predicted using predictive techniques, such as fault tree analysis and event tree analysis. The third option is to use expert's opinion. The opinion should be based on all relevant available information including historical, system-specific, organization-specific, experimental and design data.

The risk assessment may be carried out with varying degrees of depth and detail as well as using one or more assessment techniques ranging from simple to more complex ones. How the assessment is done and what kind of output is desired should be consistent with the risk criteria as a part of establishing the context. In general, a suitable technique should be justifiable and appropriate to the situation, provide result that will improve understanding of the nature of the risk and can be treated as well as the technique should be traceable, repeatable and verifiable. (SFS-EN 31010:2013, 31-33.)

Possible suitable risk assessment techniques for this thesis might be brainstorming, structured or semi-structured interviews, hazard and operability study (HAZOP) and consequence/probability matrix. When choosing the most suitable technique for undertaken risk assessment, the criteria in previous paragraph should be taken into account as well as the purpose for what reason the risk assessment is done.

5.1.1 Brainstorming

Brainstorming encourages skilled group of people for free discussion to identify possible failure modes and related hazards and risks as well as criteria for decision and treatment options. Brainstorming can be used with other risk assessment methods or as a single technique. Technique encourages imaginative thinking at all stages of the risk assessment process and it can be used when discussing matters in general, detailed surveys or details of specific problems. (SFS-EN 31010:2013, 48-51.)

Outputs from brainstorming depend on the stage of risk management process at which it is applied. For example, outputs may be a list of risks and existing controls of them. Brainstorming is a relatively quick and easy to set up and it also involves key operators and aids communication overall. Brainstorming is relatively unstructured method, and therefore it is difficult to demonstrate that the process has been extensive and all potential risks have been identified. (SFS-EN 31010:2013, 48-51.)

5.1.2 Structured or semi-structured interviews

In a structured interview or individual interviews a questionnaire is asked for a set of ready questions. This encourages the interviewee to look at the situation from a different point of view and thereby identify risks from this point of view. A semi-structured interview is similar, but gives more freedom of discuss the issues that emerge. These two types of interviews are useful when it is difficult to get people into one session or if a free-flowing discussion in a group is not suitable for the situation. (SFS-EN 31010:2013, 51.)

The essential questions are set to guide the interview. Questions should be open-ended, simple and cover only one issue where possible. Possible follow-up questions for clarification should also be prepared. Outputs from interview are the stakeholder’s view in the issue which are the subject of the interview. (SFS-EN 31010:2013, 51-53.)

5.1.3 Hazard and operability study

Hazard and operability study (HAZOP) is a structured and systematic study of a planned or existing product, process, procedure or system. It is a technique to identify the risks to people, devices, environment and/or organizational objectives. HAZOP process is a qualitative process based on the use of guide words that question how the design intention or operating conditions might not be achieved at each stage in the design, process, procedure or system. It is generally carried out by a multi-disciplinary team during a set of meetings. (SFS-EN 31010:2013, 59.)

The HAZOP technique was originally developed to analyse the chemical process systems, but has been extended to other types of systems and complex operations. The technique can handle any kind of deviation from design intent due to shortfall design, component, planned procedures and human activity. (SFS-EN 31010:2013, 59.)

HAZOP study examines processes, procedures and systems and reviews every part of that to discover what deviations may occur from the intended performance, what the potential causes are and what are the likely consequences of deviations. This is achieved by systematically examination and using guidewords on looking at how the process, procedure or system responds to change in the key parameters. Guidewords can be customized for a particular process, procedure or system but also generic words can be used that cover all types of deviation. (SFS-EN 31010:2013, 61.)

HAZOP provides the means to examine the process, procedure or system systematically and thoroughly in very detailed way. In the other hand, HAZOP is very detailed analysis of risks and it can be very time consuming and therefore expensive. (SFS-EN 31010:2013, 59.)

5.1.4 Consequence/probability matrix

The consequence/probability matrix is a way to combine qualitative or semi-qualitative ratings of consequence and probability of the risk and form a level of risk or risk rating.

This technique is used for classification of the risk, source of the risk or risk treatment based on the risk. It commonly used as a screening tool when a number of risks have been identified, for example to determine what risks need further or more detailed analysis. (SFS-EN 31010:2013, 149.)

Consequence/probability matrix needs customized scales for the consequence and probability and a matrix that combines these two. The consequence scale should cover the range of different types of consequences, such as financial loss, safety, environment or other parameters, depending on the context. The scales of consequence should extend from the maximum consequence to the lowest possible consequence. Definitions for probability must be selected in such way as to be as clear as possible and be appropriated for the situation to be assessed. The scales may have any number of points, but most commonly used are 3, 4 or 5 point scales. The matrix is drawn with consequence on one axis and probability on the other. The risk levels are addressed to the cells depends on the definitions for the probability and consequence for the risk. The matrix may be set up to give extra weight to consequences or to probability, or it can be symmetrical, depending on the application. (SFS-EN 31010:2013, 149.)

The output of consequence/probability matrix is an importance rating for each risk or a ranked list of risks with significance levels defined. This technique is relatively easy to use and it also provides a quick ranking of risks into different significance levels. Limitations for this technique may be the difficulty to define the scales unambiguously and the use of this technique is very subjective and there tends to be differences between reviewers. (SFS-EN 31010:2013, 153-155.)

5.2 Used risk assessment technique

Risk assessment is used to assess the possible pellet and powder leaks in plastic raw material production plants and make a comprehensive listing of the found leaks. The used risk assessment technique is a mixture of few standardized risk assessment techniques. Baseline when creating usable risk assessment technique is to find out what kind of assessment techniques is already used in company and how well those would suit to this situation.

Consequence/probability matrix and HAZOP study are been used in the company in different situations. Consequence/probability matrix has been found out to be effective and useful tool in risk mapping and assessment environmental aspects. All the risks are assessed according to the consequence and probability and the risks are given a significance value. According to the gained value the risks are ranked in order and necessary actions are taken to reduce the significance value. The HAZOP study is used to find out risk that might happen in production process and also when production processes are operated. HAZOP studies are strongly related to safety aspects of production plants and in HAZOP studies all the situations are thought through safety.

The desired result of this risk assessment is to find out as many risks as possible and rank them according to the significance. The output of consequence/probability matrix is a list of possible risks. The possible risk are recommended be found with the help of plant operators or engineers, who have the knowledge of the plant. Already done HAZOP studies might help if the aspects of pellet and powder leakages are taken into account. HAZOP studies can also be used to supplement the identified risks.

The consequence/probability matrix is used to list and rank the risks according to their significance. The probability of the risk is assessed in scale 1 to 5 where 1 refers that the risk is unlikely to happen and 5 the risk happens repeatedly. The consequence of the risk is assessed with the same scale. In this assessment 1 refers to a very small leak and 5 refers to very large leak. The consequence can also be assessed also with the time consumed in cleaning the leak or the amount of released pellets in the leak. The scales and definitions for probability and consequence are presented in table 4.

Table 4. Used probability and consequence scales for the risks.

Probability		**Consequence**	
1	Unlikely to happen	1	A very small leak
2	Possible to happen	2	Small leak
3	Happens time to time	3	Moderate leak
4	Probable to happen	4	Large leak
5	Happens repeatedly	5	Very large leak

Equation 1 shows the mathematical definition of the significance of the risk, where the significance of the risk is obtained by multiplying the probability and consequence of the risk. (Juvonen et al. 2005, 8.)

$$Significance = Probability \cdot Consequence \qquad (1)$$

This equation for assessing the significance of the risk can distort the true significance of the risk. The probability and consequence are equal and this gives the same significance rate for two very unequal risks. Risk which is probable to happen and has a small consequence is valued same as the risk which is unlikely to happen and has a high consequence. (Juvonen et al. 2005, 8-9.) The more sophisticated mathematical equation for significance of the risk is presented in equation 2 (Juvonen et al. 2005, 10).

$$Significance = Probability \cdot Consequence^2 \qquad (2)$$

Equation 2 highlights the effect of the consequence of the risk and makes it more valuable to the significance than the probability of the risk. Therefore, the probability is given a lower weighting because the consequence is more effective to the company if risk occurs. The significance of the risk can be estimated with equation 1 or equation 2 depending on the company desires to value the significance of the risk. (Juvonen et al. 2005, 10.)

In this risk assessment the equation 1 is used for estimation of the significance of the risk. The significance of the risk can be presented as a risk matrix. The risk matrix gives a visual sight where the risk is valued to place in probability and consequence. Risk matrix can be used in conjunction with the equation 1 to help identify the same valued significances of the risks. The used risk matrix for the significance of risk is presented in figure 10.

Probability

5	10	15	20	25
4	8	12	16	20
3	6	9	12	15
2	4	6	8	10
1	2	3	4	5

Consequence

Figure 10. Risk matrix for the significance of the risk.

The listing of risks is done with one or more persons from the productions plants. These persons are familiar with production plant area and process as well as have the best knowledge how the plant works. The structured or semi-structured interview could be suitable technique to interview operators of the risks but the all the production plants are different in size, operation, production technique and also the produced product is different. There is a risk of something to be missed out if only questions made beforehand are followed. Therefore, brainstorming is also used to find out the possible risk. When it comes to plastic production plants, every plant has the pelletizing where is some degree risk of pellet leakage and also the dust removal devices might have powder or dust leakages. These possible leakages are already known among operators and are likely to be listed but also the interviewer should point out these aspects if there are not otherwise pointed out.

5.3 Pellet and powder emission sources

The used form for locating and assessing the pellet and powder leaks is presented in appendix I. The form guides how the mapping should be done and helps to list the right things from found leaks as well as helps to achieve same kind of result from all the plants. The form is used in Finnish so that it is easy and simple to fill and use with the plant operators. The found leaks are rated to their significance by assessing the probability and consequence. The aim of the form is to be informative and a tool to enhance the handling of pellets and powder.

The assessment of pellet and powder emission sources is done in places where it is possible to have pellet, powder or dust leakages. Assessed places are listed below:

- Plant 1
- Plant 2
- Plant 3
- Plant 4
- Plant 5
- Plant 6
- Laboratory

In risk assessment the possible leaks are located to places where the pellet, powder or dust gets to a place where it does not belong like out of the process pipelines. Openings of process devices are common sources of leaks. Usually these risks are known and some preparations are done in these kinds of situations to avoid unintentional pellet or powder spreading to environment. All the leaks in this risk assessment are divided into two categories: normal operation and disturbance situations. Disturbance situations are usually unexpected and difficult to foresee and the consequence of leakage is generally greater than in leakages during normal operation. Leaks during normal operation are often smaller in consequence but the probabilities of these kinds of leaks are higher.

5.3.1 The most conventional pellet leaks

As a result of mapping pellet leaks, several leaks were found from all of the different production plants. All the production plants had some similar leaks but also special leaks for each production plant were found. Many leaks occurred during normal operation, but some leaks occur during disturbance situations. Usually leaks that happen during disturbance situation have low probability rates and high consequence rates. Leaks that happen during normal operation have a high probability rate but the consequence rate varies between different leaks. Most conventional pellet leaks were caused by loading and unloading manners, silo washing and trucks, pellet sampling and transferring of sample or product bags. Other leak sources were also found in this leak mapping. Pellet leaks related to operational devices and possible failures or openings of them are placed in pelletizing area. One major pellet leak found in this assessment is caused by disturbance is a failure of conveying line. Also, one big source of pellets, which is common to all production plants of the plant area, are possible pellets at snow collection sites.

All the wells in the area have screens that capture pellets that migrate into the water collection system with stormwaters. Screens in wells are simple and effective solution to prevent pellets to flow forward to water collection system. The screens operate well, but the edges of the wells must be intact and in good condition. Also, the proper maintenance and cleaning of the wells must and should be done regularly. With these aspects taken into account screens in wells work well in the purpose and reduce the amount of pellets in discharge waters.

In many cases of found pellet leaks, the pellets are cleaned before they can reach the water collection system. All of the production plants have some kind of cleaning instructions and manners how often cleaning have to be done. Brushes and shovels are placed around the plant area. Many production plants have also installed central vacuum cleaners to facilitate and speed up the cleaning when leaks occur. Brush machines are used to clean yard areas, especially in loading area brush machines are used regularly for cleaning.

Sampling is also issue with pellets. The found significance level for sampling is placed in the blue and yellow (significance value 1-12) area in risk matrix (figure 10). Sampling of pellets happens often and in regular basis during production. Samples are taken to a bag, which are carried to laboratory to be tested. When taking the sample there is a risk of pellets to spread to production area. It depends on the person who is taking the sample and also from the place where sample is taken, how much pellets are possible spread to production area. The process areas equipped with basins, as a precaution against damage that may be caused by leaking liquids, and they are in many cases surrounded by walls. These itself limits the spreading of the pellet to the production area and away from the production area.

When transferring pellet bags outside, there is always a risk of breaking the bag. The significance level of transferring pellet bags is placed in the blue area (significance value 1-8) of the risk matrix (figure 10). In this kind of cases the amount of pellets is relatively small and in many cases these are easy to clean from the tarmac. Bags are most likely to break from the seam. All the packaging lines have detectors to identify the broken bags and seams. After broken bag is noticed it is removed and repaired. Also, forklift trucks can break the bags or bags can fall of the forklift or load may crash during transfer inside the production area.

Unloading and loading manners are one of the biggest events in the production area where pellet leaks occur almost always but the quantities are usually small. The significance of the loading and unloading is placed in the blue and yellow (significance value 1-12) area in the risk matrix (figure 10). The significance level varies between production plants. In production plants the loading and unloading situations are done by service providers or by own operators. There is no difference in loading or unloading quality or the amount of pellets spread to ground between these two. Both have had the same instructions about the loading devices and the cleanliness of the loading surroundings. Cleaning equipment are also placed near all the loading and unloading stations. In loading area, the brush machine has routine cleaning schedule to avoid pellets to spread around the production area.

The most significant disturbances situation, which cause pellet leakage, is the failure of conveying line. Usually this kind of situation has the highest points in consequence. The probability of breakage of conveying line is relatively low and these will not necessary happen even annually. Significance level of the risk is placed in the blue (significance value 1-8) are in the risk matrix (figure 10) because the probability is low for this to happen. If the conveying line breaks it is important to be quick on termination the transfer and in this way reduce the amount of pellets in the ground. Same kind of situation with breakage of conveying line is over filling the product silos. All the silos have devices that prevent the over fillings. From time to time these however happen and most often the reason for this is the operation error and bypassing the prevention device in the silo. Over filling product silos is a disturbance situation and these happen only rarely.

The washing waters are also an issue in pellet leak perspective. The significance level of washing waters is found to be in the yellow area (significance value 9-12) in the risk matrix (figure 10). Washing waters always contain some amount of pellets and powder. Washing waters are lead through a filtration system in many cases. Problems may occur when filtration system gets clogged or junction breaks after that there is a risk of washing waters to flow straight to the sewer system. Silo washings are normal operation actions in production area and silos are washed between product and colour changes. All the wells in silo area have screens that capture pellets.

During winter months snow has to be plowed and piled at snow collection sites. Service provider, who takes care of snow plowing, is instructed to pile snow that contains pellets to another area, where pellets can be easily collected after the snow is melted, and the snow that does not contain pellets is piled to another snow collection site. The production area is roughly divided into areas where snow is likely to contain pellets and areas where snow is unlikely to contain pellets. Despite these limits pellets may also be spread to areas where they are not supposed. The significance level of this risk is in the yellow area (significance value 9-12) in the risk matrix (figure 10). With snow melting waters pellets can flow to nearby ditches and flow away from the production area.

In HAZOP studies carried out in different production plants do not take into account pellet leaks but if safety risks are related to pellet leakage or there are for example hydrocarbons presents then they are considered in HAZOP studies. Operational studies have been carries out in different production plants to determine whether there are leaks related to operational risks. But in HAZOP studies and operational studies there are similar types of leakage situations than found in pellet leak mapping

5.3.2 The most conventional powder leaks

As a result of mapping powder leak mapping, number of leaks were found from all of the production plants. All the production plants had similar kind of leaks but also plant-specific leaks were found. Many of the leaks occurred during normal operation, but some leaks occur in disturbance situations. Usually leaks that happen during disturbance situation have low probability rates and high consequence rates. Leaks that happen during normal operation have usually high probability rate but low consequence rate. Most conventional powder leaks were caused by washing of silos and trucks, powder sampling, replacement of bags in dust removal system and conveying lines. Also, other leak sources were found in this leak mapping. All the found powder leaks were small in size and amount. Challenge in handling powder is that it mixes easily with water and wind blows it away effectively. Powder is also very light material and it has low density, because of this it is hard to estimate the amount of powder in kilograms.

All the wells in the area where pellets or powder are handled have screens that capture pellets, but they will not prevent the powder from being transported. Screens cannot be replaced to denser ones that would capture also dust because after that the wells would not pull fast enough and waters would start flooding in the area.

The small leaks from conveying lines usually occur from gaps in flange or from other very small gaps. The significance level for small leaks from conveying lines according to risk assessment are in the blue area (significance value 1-8) in the risk matrix (figure 10). Powder is formed in pneumatic conveying when pellets are conveyed to storage silos at high speed. There can also be some powder on the surface of pellets after production. Some of the products are slightly dusty than others. In whole plastic raw material production area, there are several hundred meters of conveying lines for pellets.

When silos and trucks are washed, the washing waters usually contain some amount of pellets and powder. The found significance level for this risk is placed in yellow area (significance value 9-12) of the risk matrix (figure 10). In many situation waters go through a filter or filtration system where pellets are caught and major part of the powder is also caught. In cases of filter clogging or junction breakage, there is a risk that washing waters get straight to the sewer system. All the sewer lines are lead to one of the two flotation basins where pellets and powder can be caught if some gets to a sewer system.

In most of the cases the sampling of powder happens in the middle of the process area. The significance level for powder sampling is low and in the risk matrix (figure 10) the risk is place in the blue and yellow (significance value 9-12) area depending on the production plant. The process areas are equipped with basins, as a precaution against damage that may be caused by leaking liquids, and they are in many cases surrounded by walls. These itself limits the spreading of the powder to the production area and away from it. But in the production area there is gravel from which the powder is already considerably more difficult to clean than from smoother tarmac. The amount of powder spreading to environment is very small, but samples are taken many times during shifts so the total amount can be large over the long run.

HAZOP studies made for production plants do not take powder leaks into account but if safety risks are related to powder leaks or there are for example hydrocarbons presents then they are considered in HAZOP studies. In different production plants operational studies have been made to find out if there are any leaks related to operational risk. But in HAZOP studies and operational studies, same kind of powder leak situations arises as found in powder leak mapping.

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6 WATER MANAGEMENT SYSTEM AND DETERMINATION OF EMISSION RATES

Recently few studies have estimated the quantity of pellets lost in Germany, Norway Denmark and there is also study available about pellet loss estimation for Europe. The reports make an estimate of the pellet losses in plastic raw material production based on the best available information. Often the lack of available data and the quality of available data is poor. (Cole & Sherrington 2016, 33.) Estimates are summarised in table 5 with references.

Table 5. Summary of estimates of pellet loss form different studies.

Estimate of pellet loss	Area of study	Basic estimate	Reference
0,1-1,0 % of total plastic production Germany	Germany	Estimate is based on the resource efficiency comparing how much raw material is needed to produce a tonne of plastic.	(Essel et al. 2016, 28)
0,9 % of total plastic production. During transportation is lost 0,5 % and 0,4 % is lost during production.	Norway	The estimate is based on Norwegian plastic producers and Norwegian Environmental Agency.	(Sundt et al. 2014, 25)
0,001-0,01 % of raw material consumption at plastic raw material production facilities	Denmark	Data is collected via the Danish Plastic Federation from companies that have joined OCS.	(Lassen et al. 2015, 15 & 115)
0,1-1,0 % of total plastic production in Europe	Europe	Estimate is based on the resource efficiency comparing how much raw material is needed to produce a tonne of plastic.	(Essel et al. 2016, 28)

The values in table 5 are rough estimates of pellet loss in plastic production and values are ranging from 0,001 % to 1,0 %. In each study the basic estimate is different and also the entities from whom the information is obtained varies. Individual companies are reluctant to provide data about the actual production volumes and amount of lost pellets for public (Cole & Sherrington 2016, 33). The company’s unwillingness to provide this kind of data also complicates the estimations of the amount of pellet lost. Therefore, these studies are not directly comparable with each other, but give a rough estimate of the quantity of the loss of the pellets in these countries.

In this section the water management system in the production area is described and the emission rates for plastic pellets and powder are determined. Before the determination and measurements can be done a suitable measuring techniques for pellets and powder has to be invented. To achieve reliable and describing results of the situation the measuring points has to be planned as well. A carefully designed and implemented sampling strategy is in key role to obtaining reliable and representative result.

6.1 Water management system

In the production area all of the process, washing and stormwaters are lead through several basins before they are lead to discharge tunnel. In settling basins the possible plastic powder and dust rises to the surface and can be removed from the water. In figure 11 is presented principles of the water management system in this plastic raw material production area.

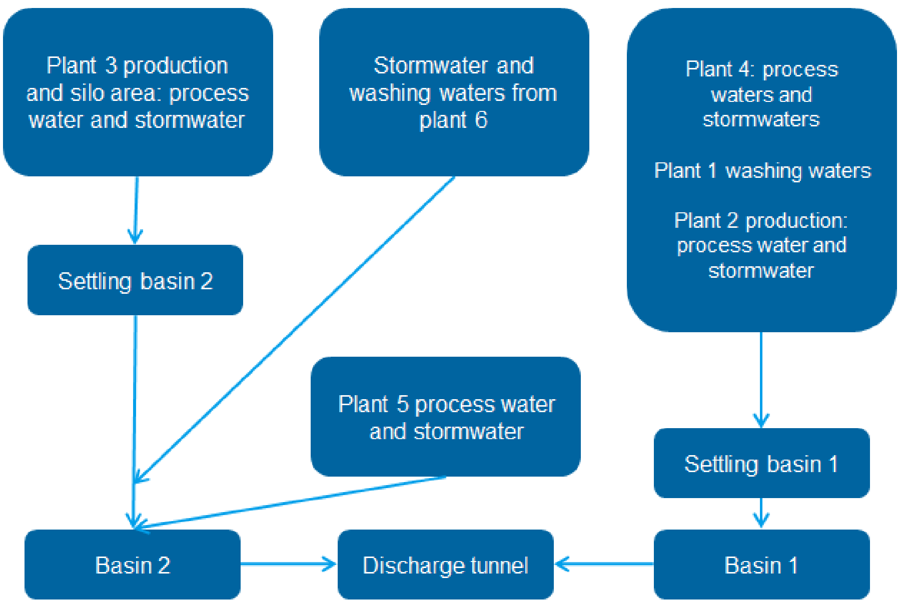

Figure 11. Description of water management system in the production area.

In the area all the wells have screens, which remove possible plastic pellets from the process, washing and stormwaters. The plastic powder and dust are removed in settling basins. Basins 1 and 2 are used to balance the water flow into the discharge tunnel and to increase the residence time of the water in the area.

6.2 Selection of measuring and determination technique or techniques

The size difference between pellet and powder is huge. Plastic pellets are cylinder shaped plastic pieces, generally about 2-3 millimetres in length. Powder in turn is fine powder with a particle size much smaller than the plastic pellets. According to European materials handling federation (FEM) particle size less than 500 micrometres is counted as powder or dust (FEM 2482:1999). Plastic powder cannot be seen by bare eye when it mixes to water or air. Pellets and powder mixes well to the flowing water because the density separation between these and water is small.

Because of the size difference between pellets and powder, own measurements techniques should be developed for both. The theory part also supports the idea of the pellets and powder amount been determined in different time. Also, the determination the emission rate of pellets might require much bigger sample size than the determination of powder. This also sets challenges when choosing the measuring technique.

It is expected that the plastic raw material production discharge waters have higher concentration of plastic than natural waters. Therefore, the sample size in plastic pellet and powder determination does not have to be as big as in assessing natural waters to achieve a representative sample of the situation.

The chosen technique to determine the plastic amount in waters should simple and safe to carry out to the employee. Safety factors are important in this company and this also limits the use of chemicals. If this kind of determination can be done without chemicals, technique and method is quite likely preferred.

In this case the only target is to determine the amount of plastic in discharge waters. The quality of the found plastics is not the needed because it is quite likely known where the plastics are coming from.

6.2.1 Technique used to determine the amount of pellets in discharge waters

According to European materials handling federation (FEM) particle size less than 500 micrometres is counted as powder or dust and particle size more than that are likely to be pellets or their blanks (FEM 2482:1999). Plastic pellets are done in extruders where the plastic mass is processed and cut to pellets. Cutting does not always work and deformed pellets form for one reason or another. These deformed pellets can be bigger or smaller and have different shape compared to the desired pellets.

In theory part different kind of trawls have been used when assessing the amount of plastic particles in natural waters. The suitable sampler for pellet amount determination would be something like a net or trawl. The suitable sampler is designed in a way that it can be placed in the sewer line for a certain period of time and it should be also strong enough not to break in the flow.

The mesh size is determined according to the FEM 2482 standard (1999). And it is something between 250-500 micrometres. The mesh size should be chosen so big that the water flows through and pellets in the water remains.

The sampling device is planned to be placed for 4-12 hours so the obtained result would be as realistic as possible. After that the number of pellets in the sampling device are calculated or weighted. Key factor with this sampling technique is to know water flow during the measurement. The obtained result in this measurement is number of pellets in cubic meter of water or mass of pellets in cubic meter of water.

This sampling technique has many opportunities for errors. One of these could be in case the water flow is too big and the sampling device cannot handle the water flow and the sampling device breaks. It is also possible that during the measurement pellets flows past the sampling device, especially if the water flow is too large. Clogging of the sampling device is also possible to happen.

6.2.2 Technique used to determine the amount of powder in discharge waters

In theory part filtration is described as a possible technique to determine the amount of plastic in water. Filtration is most commonly used technique for determination suspended solids in water. Plastic particles are counted to suspended solids in water. Filtration is an effective method to separate solids from fluids by using a filter that only fluid can pass and the solids are left in the filter paper. Filtration is also a standardized method in standard SFS-EN 872 (2005) and widely used for determination of suspended solids in waters. In itself the technique of filtering is simple and already used in the company as a part of waste water analysis.

The challenge with filtration is the purification of the sample. The purification need should be as small as possible because there is always a risk of losing a part of the sample to be analysed. In theory the preparation and purification of the sample could be done with peroxide but there is a risk for losing or destruct plastic particles from the sample to be analysed. Purification actions can lead to underestimation of concentrations of plastic particles in the sample. In ideal situation the sample should not contain much other solid matter than plastic.

The amount of other solid matter is difficult to determine with bare eye and after the filtration is done the amount of plastics and other solids is difficult to define from the filter paper. The amount of other solid matter can be minimized in the sample by choosing a suitable the place for sampling. It can be assumed that if the sample is taken as near as possible to the production plant, there should not be much other solids than plastic involved.

During filtration there is also a risk for losing a part of sample. Part of the sample can for example stick to the edges of used dishes. To avoid this analysis should be done carefully and all the used dishes has to be rinsed to the filter paper carefully. This way, it is possible to ensure that as much as possible solid matter is deposited in the filter paper.

The used sample size is 100-1 000 millilitres, but the according to the SFS-EN 872 (2005) the filtration time should not be more than 1 minute. The risk of filtration through glass fibre filter is that the sample contains more other organic matter or suspended solids than plastic. In this case the obtained result does not give reliable estimate of the amount of plastic is discharge waters. The amount of other solid matter could also clog the filter. The determination rate of SFS-EN 827 (2005) filtration method is 2 mg/l, results under that contain uncertainty and are reported as “below 2 mg/l”. The sample size should that big that the amount of solid matter is greater than the weighting accuracy of the balance. In these measurements the obtained result can be below the determination rate and still the result can be reliable enough for this purpose.

The samples should be analysed as soon as possible after the sample is taken, preferably within 4 hours. If the samples cannot be analysed within 4 hours, samples should be stored in dark between 1 °C to 5 °C. Freezing of samples should be avoided. (SFS-EN 827:2005, 6.)

The analysis of plastic particle content in discharge waters can be made according to the SFS-827 (2005) standard because the method is functional and has clear instructions. Standard defines high-quality sample handling and how to make the analysis in high-quality way. However, the result can be slightly applied, as the goal is not an official result but an approximate estimate of the amount of plastic in discharge waters.

6.3 Sampling and measuring points and timing of measurements

The desired result of these measurements is to achieve a sample from the discharge waters from the all the plastic production plants. Chosen sampling and measuring points are greatly influenced by the existing water management system. All the discharge waters are lead separately to the basins and samples and measurement required by the authorities are taken and from these waters. Plant 6 makes exception in this and discharge waters from these facilities are lead together to one of the basins. The measurement timing has also influence on the success of the made measurements.

It would be ideal to have same sampling and measuring points for both pellet and powder rate determinations. In the same time chosen sampling and measuring points has to be suitable in the safety aspect but also the installation of possible measuring equipment should be possible. When measuring the amount of pellets on discharge waters the sampling device should be there approximately 6 hours so that the obtained result corresponds to the plant's operations as well as possible.

As seen in figure 11 the discharge waters from plant 4, plant 1 and plant 2 are lead to the settling basin 1. Discharge waters from plant 4 are lead to another channel in basin 1 and discharge waters from plant 2 are lead to another channel in basin 1. Samples from plant 3 are ideally taken after the settling basin 2 if there is a well available in suitable place for measurements. The discharge waters from plant 6 are passed directly into basin 2 but in the basin 2 there are separate discharge pipes for plant 6 and plant 5. When measuring the amount of pellets in discharge waters the flow meters are required, because of this the measuring points should be planned to ensure that existing flow meters can be used in these measurements. In table 6 the planned and ideal measuring points in water management system are described. Finding suitable sampling point for powder samples is a bit easier than the finding suitable measuring points for pellet rate determination. However, sampling and measurements are made from the same point in order to obtain clear and easily interpretable results.

Table 6. Planned sampling and measuring points.

Pellet		**Powder**	
Plant 1	Settling basin 1	Plant 1	Settling basin 1
Plant 2	Settling basin 1	Plant 2	Settling basin 1
Plant 3	After settling basin 2	Plant 3	After settling basin 2
Plant 4	Settling basin 1	Plant 4	Settling basin 1
Plant 5	Before basin 2	Plant 5	Before basin 2
Plant 6	Before basin 2	Plant 6	-

Measurements for plant 4 waters and plant 1 area waters are made in settling basin 1. Plant 2 is measured together in one sample in settling basin 1. The samples for powder determination are taken from same points. Measurements for plant 3 are taken from settling basin 2; also the sample for powder amount determination is taken from the same point. Pellet and powder samples for plant 5 are taken before basin 2. Also pellet sample for plant 6 is taken before basin 2. Basin 2 has two inlet pipes one for plant 5 and other for plant 6. Powder sample is not taken from plant 6 because there is no suitable well for that.

The have good and representative powder samples from discharge waters the samples should be taken near the processes. This will ensure that there is as little as possible other solid matter in the water and the solid matter consist essentially of plastic. But there is always a possibility that samples contain some amount of other solid matter than plastic. With taking the sample close to the process minimizes the risk of other solid matter than plastic, but it does not completely eliminate it. The sewer system in this production area is relatively old and accumulation of other solids has happed over the years in sewer system.

The timing of the measurements made is essential. If the production plants have some kind of failures in installations and this increase the amount of water in sewer system, the obtained results do not reflect the correct plastic amount in discharge water. The measurements should be taken during normal operation state.

6.4 Average emission rates

The instructions for determination of powder rate and pellet rate are presented and explained in appendices II and III. In these appendices the required equipment and the used methods step-by-step are explained. The aim of these measurements is to achieve results for emission rates for both pellets and powder in discharge waters.

6.4.1 Pellet emission rate

For determination of pellet emission rate special sampling device had to be designed and build. The planned sampling points were possible to accomplish. For safety and difficulty reasons sampling point for two plants had to be abandoned. In case of the other plant the well was too deep and the sampling device would have been impossible or very challenging to install safety. In second case the diameter of the pipe in planned measuring point was too big and it was too far from the edge of the basin. Therefore, the measurement results are not completely give the whole picture about the amount of pellets in discharge waters.

The sampling devices were designed only for these sampling points. The mesh size in the sampling devices were 0,43 millimetres. There is a possibility that all the particle sizes have not been caught in these measurements. Smaller particles than 0,43 millimetres will pass the net and in suspended solid analyses pellets are removed from the sample if there have been some. Figures of built sampling devices are presented in appendix III.

The measurement time had to be changed from the planned 6 hours. In one sampling point there was a high risk for sampling device to clog. As a result of clogging the measurement fails and in these situations there is a risk for breaking the sampling device. For this reason the measurements had to be supervised and followed carefully, to avoid clogging, especially in one measuring point. In other sampling points the sampling device could be kept for the intended time. Shortening the measurement time have effected to the obtained results in this particular sampling point.

The obtained results are greatly influenced with the current production situations in the production plants. If there are silo washings on going during measurement, the number of pellets in sampling device is higher. The amount of flowing water during the measurements is influenced by the production but also by the prevailing weather. Stormwaters from the production area are lead to the measured water flows. To reduce the influence of the production and weather, measurements are repeated several different days and different times of day.

Pellets are collected from the sampling device with bare eye. Because of this there is always a possibility that some pellets are not noticed. The size range of pellets varies between plants and there is also small plastic chopping that is hard to see and collect with bare eye. Also seams in the sampling device make the collection pellets challenging. So that all the pellets are detected from the sampling device, it is advisable to rinse the captured pellets from the sampling device into bucket. Pellets will float, because of the density separation between water and plastic, and they are easier to collect.

The obtained results are presented in table 7. The measurement could be carried out in four measuring points with variable number of measurements. The results are presented as a share of total production in the production in production plants. One production plant has two discharge water flows, because of this the results of these plants are combined.

Table 7. Results from measurements of pellet amount in discharge waters.

	Number of measurements	**% of nominal capacity**
Plant 2	7	$4{,}4 \cdot 10^{-8}$ %
Plant 5	3	$4{,}0 \cdot 10^{-9}$ %
Plant 1 and 4	5	$1{,}0 \cdot 10^{-9}$ %

The total emission rate for pellets in discharge waters is calculated according to obtained results in table 7 and reported amount discharge waters. The total amount of pellets in discharge waters is $1{,}0 \cdot 10^{-8}$ % of the total nominal capacity of the production plants in the area. The result does not give a realistic estimate of the amount of pellets in discharge waters because not all plants have been measured. The measuring points are not the last points where the discharge waters leave the production area and some amount of pellets is caught from the discharge waters leave the production area. But compared to recently made studies presented in table 5 the gained results in these measurements are well below these estimates.

6.4.2 Powder emission rate

For determination powder rate in discharge waters suspended solid filtration is used. The used glass fibre filter was Whatman GF/A with pore size of 1,6 micrometres. The obtained results are presented in figures 12 and 13. According to these figures the emission rate for suspended solids can be calculated. The results had to be divided into two figures because of the difference in concentrations between production plants. The share between powder and other suspended solids is hard to estimate. For determination the ratio between powder and other suspended solids needs another analysis technique.

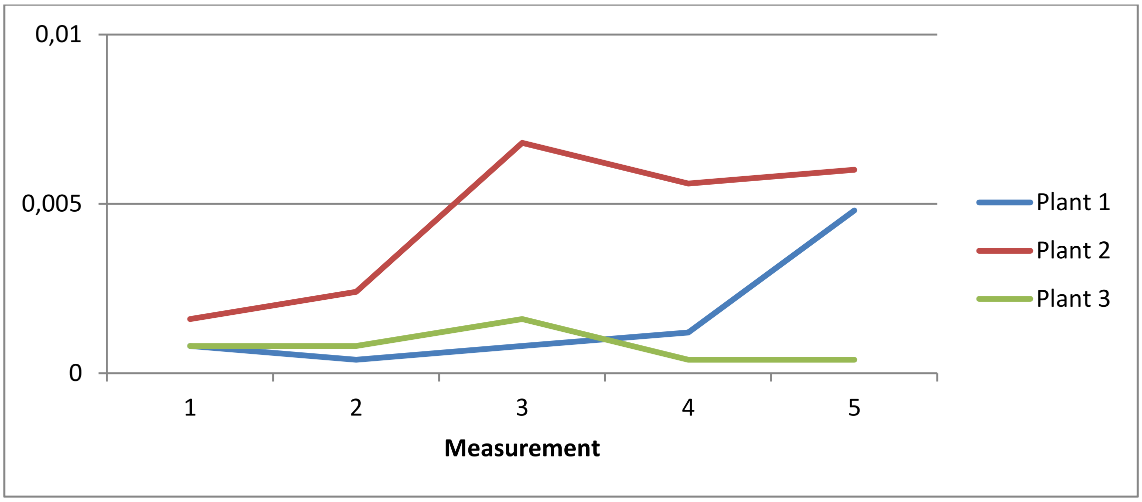

Figure 12. Results are presented in grams per unit of volume for plants 1,2 and 3 in filtration of suspended solids.

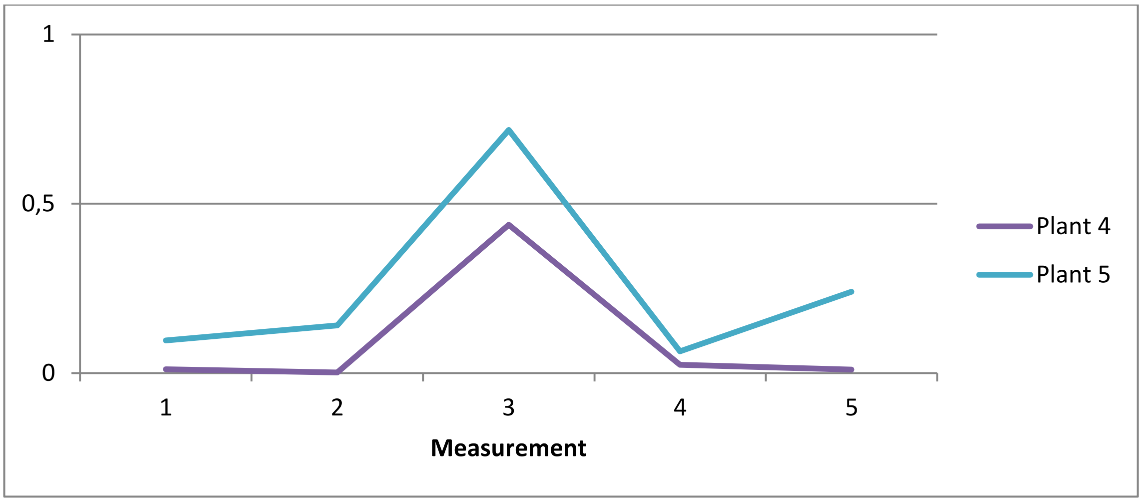

Figure 13. Results are presented in grams per unit of volume for plants 4 and 5 in filtration of suspended solids.

The achieved result for powder rate in discharge waters contains some amount of uncertainty. To achieve more reliable result the measurement should be repeated at least eight times instead of five. But still the obtained result can be considered as an indicative result, which shows the total emission rate per year. The chosen measuring points are not the last points where discharge waters leave the production area. For this reason all the measured suspended solids does not leave the production area, but some remain in the basins, drainage lines or are removed from the settling basins.

As seen in figure 13 plant 5 has the highest results compare to other plants. Sample from plant 5 have contained some amount other suspended solids than plastic when examining the colour from the filter paper. The obtained results are affected by the stage of production plants and what kind of actions there has been done when the sample is taken. In figure 12 plants 1,2 and 3 had quite similar and low concentrations compared to plants in figure 13. The total emission rate for powder in discharge waters is calculated according to obtained results in figures 12 and 13 and reported amount discharge waters. The total amount of suspended solids in discharge waters is 0,002 % of the total nominal capacity of the production plants in the area.

7 CONCLUSIONS, PROPOSALS AND METHODS TO REDUCE PELLET AND POWDER EMISSIONS

Microplastics are currently under discussion in society, politics, business and science. The interest between these mentioned parties differ greatly and all of these have different kind of approaches to deal with this topic. Business might be interested in the opportunity for value creation in this new field and in the other hand society is more concerned about the environmental impacts and risks. Many studies are ongoing in the field of microplastics in Finland and also in Europe.

There are many problems involved when it comes to microplastics. The first one is that the size of microplastic is not clearly defined. In recent studies 5 millimetres is used to be the limit between mesolitter and microlitter. Micro sized litter can also be microplastics if the quality of litter is plastic. Also, the definition of primary and secondary particles needs more clarifying. In this study the subject was pellets and powder in discharge waters from plastic raw material production. Pellets and powder are defined to be primary microplastics, despite pellets are further processed into plastic objects and pieces.

Future legislation and actions are influenced by many things and actors. One aim at moment is to guide the public to a different consumption pattern, which would not include so much plastic products and products containing microplastics. Raising awareness of microplastics among all age groups of the population has an important role. However, raising awareness is not the enough to eliminate and reduce the problem of littering and microplastics. Actions form both at EU and national level are needed. HELCOM has an important role in improving the state of Baltic Sea as well as Finnish programme of measures for the development and implementation of the marine strategy. In the aspect of plastic industry the Production of Polymers BREF in the future will reduce the emissions from plastic industry. The new Production of Polymers BREF will also offer new best available techniques for the plastic industry.

Preparing for the changing and tightening legislation in the aspect of plastic emissions and microplastic is reasonable in plastic industry. Despite the plastic industry is not the only source for plastic emissions, but it might be one of the easiest sector to make regulations to reduce plastic emissions. All the plastic raw material production plants will face the tightening legislation. Currently there is no comprehensive and uniform legislation around managing and reducing plastic emissions in Finland or in Europe. With new legislation the plastic emissions will be reduced effectively but in the same time to accomplish new regulations, investments and actions are needed. The most probable way to tighten the regulations in plastic raw material industry is to add permit provisions to environmental permits.

In these plastic raw material production plants actions have been taken to reduce plastic emissions. Company has joined to Operation Clean Sweep and made own project from it called Zero Pellet Loss. The aim of this project is to improve the knowledge of employee's on pellet emissions as well as to improve the actions to reduce pellet emissions. Trainings and fact sheets have an important role in this project. So that pellet emissions can be reduced effectively in this location, it is very important to know the leak sources and for this the leak mapping is needed. Significant leak sources for pellets and powder were found in leak mapping.

7.1 Proposals and methods to reduce the amount of pellets and powder

The mapping was done in all the production plants and in the laboratory. Many of the found leaks could be eliminated or the amount can be reduced with suitable actions. In all the cases big investments are not needed. Leaks can also be prevented with careful planning and actions as well as with anticipation. It also important to be aware of the possibility pellet or powder leaks. Operators how work closely to production plants, have the best knowledge of the leaks.

In this production area wells that are located to places where pellets are handled are equipped with screens. These screens are the most important device to prevent pellets to flow to the water management system. Screens have a relevant and important role in this production to reduce the amount of pellets in discharge waters. For this reason it is important the all the wells are undamaged and the screens are not clogged. To prevent the clogging the wells should be maintained and cleaned regularly. Also some kind of sealant would enhance the reduction of pellets in discharge waters. With the sealant pellets cannot pass between the edge and the screen.

Tarmacking the whole production area would ease the cleaning in the yard area. In the same time the amount of stormwaters will increase in the area. Pellets are easier to clean from tarmac than from gravel. But in the tarmac pellets are more likely to spread to wider area, the gravel limits the spread of pellets to wider area effectively. If power spreads to yard area it is always difficult to clean because powder is so fine-grained and spreads in the wind effectively.

Loading and unloading manners are significant leak points in plant areas. In many cases pellets are left over truck and containers. When trucks leave the plant area, pellets drop to the side of the road. In this way pellets can drift surprisingly far from the plant area. When pellets are dropped to the side of the road, there is a chance that pellets can be drifted with stormwaters to ditches and waterways. This kind of problem occurs especially in loading manners and this kind of drifting can be prevented with careful cleaning before truck and containers leave the plant area. Cleaning can be done for example with blowing. In unloading manners pellet leaks may occur from junctions and/or from careless handling.

Almost all production plants had leaks occurred in pellet and/or powder sampling. In all plants samples from product streams are taken several times during shifts. In these situations leaks are always small but the probability leak to happen is high. Due to this amount of pellets and powder to leaks can be significant in yearly base. In order to prevent spreading of pellets and powder to bigger area, sampling places should be modified. For example, sampling places could build a closer system with some kind of walls. Also vacuum cleaners should and could be installed nearby to ease and speed up the cleaning of possible leaks.

Truck and silo washing waters are also a problem almost in every plant. With washing waters pellets and powder drifts to water management system. Silo and truck washing waters are mainly filtered through filters that catch pellets. Major part of these pellets and powder is removed in two flotation basins in water management system. If some reason the water flows are too rapid in these basins the powder does not float and mixes to water. Also, the capacity of the basin is limited and in some cases there is a risk for it to flood. In this production area flotation basins are effective measures to reduce the amount of powder in discharge waters. To reduce the total amount of pellets and powder in discharge waters, it is essential to filter washing waters before being discharged to water management system. A quick solution for filtering would be use of big bags that pass water effectively and pellets and powder remains in big bags.

From snow collection site it is possible pellets to drift to nearby diches with melting waters. In this location it would be appropriate to change the snow collection site to place where melting waters are easily handled. In the snow collection site there is always a lot of sanding gravel after winter, and there is some amount of pellets mixed into the gravel. When the snow collection site is changed to more proper site pellets can be collected before they are flushed into ditches.

Cleaning of the yard and production areas plays an important role in preventing the spread of pellets and powder. At the moment a lot of cleaning happens with brushes and shovels, but it could be more efficient by for example brush machines. From gravel cleaning of pellets and powder is more challenging than from smooth tarmac. Brush machines are effective and quicker than brushes when pellets are cleaned from the tarmac.

7.2 Average pellet and powder emission rate determination

A lot of uncertainties is involved in the measurements. In powder rate determination there is a risk that samples contain a lot other suspended solids than plastic. But it was assumed that all the suspended solids in the chosen measuring points where plastic powder. Other suspended solids and plastic is hard to separate from each other. This risk was known and was reduced by selecting measuring points close to production plants.

In these measurements the sample purification was kept in minimum. Only pellets and bigger plastic particles where removed from the sample, but in many cases nothing have been removed from the sample. The filtration technique was suitable for this location. The filtration technique is not the only possible technique to determine suspended solids from discharge waters. During the analysis there were also a possibility lose a part of the sample, but this risk was reduced by careful rinsing.

The pellet amount measurements were challenging due to uneven flow in measured discharge waters. Also, some clogging happened during measurements and that lead to the rejection of few measurement times. The sampling devices were suitable for these measuring points, but probably different kind of measuring devices has to be designed for different kind on measuring points.

All in all the desired plant level emission levels were achieved with these measurements from most of the production plants. All the measuring points were not suitable for these measurements, despite the careful planning, and the comprehensive emission rate was not achieved from whole location. The done measurements were suitable for this plastic production plant.

8 SUMMARY

Plastic litter is a problem when it accumulates into oceans. Plastic litter can be accessed to waterways from diffuse sources; the biggest sources are poorly managed landfills, stormwaters from road areas, littering and aquaculture. The microplastic can be formed from bigger plastic pieces as a result of their degradation or microplastics can be produced for rinsed off cosmetic products. Plastic particles that have the size less than 5 millimetres are counted as microplastics, but there is no standardized specification for the size of microplastics.

Plastic industry is regulated among many different regulations example by Production of Polymers BREF document, the national legislation and environmental permits. At the moment in Finland there is no legislation related straight to microplastics but in Environmental Protection Act (27 June 2014/527) and Environmental Protection Decree (4 September 2014/713) forbids the polluting the environment. Some countries around the world have already imposed restrictions on the use of microplastics in consumer products and also prohibited the production of microplastics. It is likely that Finland among other EU countries will have restrictions for the use and production of microplastics in the future. It is possible that all the industry sectors, not only plastic production, will have stricter emission permit regulations concerning emission monitoring in the future.

For determination microplastics many variable techniques can be used. Several studies have been made where the amount of microplastics is determined from natural waters. Many measurements have been made where microplastics are determined from plastic production discharge waters in the production area. There no standardized techniques to measure the amount of microplastics on waters or even how to take representative sample. Separation techniques used in microplastic analysis are visual sorting, sieving, filtration and density separation. To identify the quality of the found plastic particles scanning electron microscope, Fourier-transform infrared spectroscopy, Raman spectroscopy and pyrolysis-gas chromatography-mass spectrometry can be used. Depends on the situation what are the things that are wanted to be analysed which technique would be the most suitable one.

In experimental part of this work leak mapping and measurement the emission rate in discharge waters was made. In leak mapping the aim was to find the pellet and powder leaks from the production plants. Leak mapping was done with the help of risk assessment and already done HAZOP studies. Leaks were rated according to the significance of them. With significance value leaks are easier to compare with each other and it also helps to find the most significant ones that need actions. Most conventional powder leaks found in leak mapping were washing waters from silos and trucks, powder sampling, replacement of bags in dust removal system and conveying lines. Most conventional pellet leaks found in this mapping were loading and unloading manners, washing of silos and trucks, pellet sampling and transferring of sample or product bags as well as snow collection site. Many of these leaks occurred during normal operation, but some leaks occur during disturbance situations. Usually leaks that happen during disturbance situation have low probability rates and high consequence rates. Leaks that happen during normal operation have a high probability rate but the consequence rate varies between different leaks.

The amount of powder from discharge waters was determined with filtration of suspended solids through glass fibre filter. This technique was found most promising one because sample preparation is not need and the technique is already used in the company. In this technique, there was a risk that sample contain more other solids than plastic. But it was assumed that with choosing sampling points near the production plants there would not be much other solids present and major part of the suspended solid in the samples are plastic powder. The amount of sustainable solids in the samples was strongly influenced by the stage of production, the type of produced product and weather. The total amount of suspended solids in discharge waters is 0,002 % of the total nominal capacity of the production plants in the area. The result does not give a realistic estimate of the amount of powder in discharge waters because not all plants have been measured.

The amount of pellets in discharge waters was determined with sampling device built for these measuring points. The measuring points had to be reduced from the planned because there would have been problems to install sampling devices safely in those measuring points. The amount of pellets in discharge water was strongly influenced by the stage of production plants and the discharge water flow. The total amount of pellets in discharge waters was 0,000001 % of the total nominal capacity of the production plants in the area. The obtained results in these measurements are much less than result gained in several studied made in some European countries where the amount of leaked pellets is estimated. The result does not give a realistic estimate of the amount of pellets in discharge waters because not all plants have been measured.

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Used Excel-sheet for mapping the pellet and powder leaks in plant area

Leak mapping
Pellet & Powder

Plant
Date
Participants

Evaluation of significance

Probability	Consequence
1 = Unlikely to happen	1 = A very small leak
2 = Possible to happen	2 = Small leak
3 = Happen time to time	3 = Moderate leak
4 = Probable to happen	4 = Large leak
5 = Happens repeatedly	5 = Very large leak

5	10	15	20	25
4	8	12	16	20
3	6	9	12	15
2	4	6	8	10
1	2	3	4	5

Nr.	Pellet/Powder/ Dust	Description	Place	Disturbance/Normal situation	Evaluation of significance			Current preparedness	Preventative measures	Comment
					Probability	Consequence	Total			
1							0			
2							0			
3							0			
4							0			
5							0			
6							0			
7							0			
8							0			
9							0			
10							0			
11							0			
12							0			
13							0			
14							0			
15							0			
16							0			
17							0			
18							0			
19							0			
20							0			

Instructions for powder rate determination in laboratory

Equipment

- Equipment for vacuum filtration
- Glass fibre filters
- Drying oven 105 °C ± 2 °C
- Analytical balance

Method

1. Allow the samples to attain room temperature
2. Remove any bigger particles, for example pellets, from the sample
3. Weigh the filter to the nearest 0,1 milligrams using the balance
4. Place the filter, the smooth side down, in the funnel of the filtering device
5. Shake the sample bottle vigorously and immediately measure the desired sample volume to a measuring cylinder in one stroke
6. Before the filtration, rinse the filter with distilled water
7. Filtrate the sample
8. After the filtration, rinse the measuring cylinder and funnel with distilled water
9. Release the vacuum, when the filter is almost dry
10. Place the filter on the drying support and dry it in the oven at 105 °C ± 2 °C for at least 1 hour
11. Remove the filter from oven and allow the filter to attain balance in desiccator for at least 30 minutes
12. Weigh the filter to the nearest 0,1 milligrams using the balance

Calculation

Calculate the content of suspended solids from the expression

$$\rho = \frac{1000 \cdot (b - a)}{V}$$

ρ = the content of suspended solids [mg/l]

b = the mass of the filter after the filtration [mg]

a = the mass of the filter before the filtration [mg]

V = the volume of sample [ml]

Figure 2.1. Vacuum filtration system.

Figure 2.2. Drying oven.

Figure 2.3. Analytical balance.

Figure 2.4. Glass fibre filters.

Instructions for pellet rate determination in plant area

Equipment

- Pellet sampling device (appropriate for the chosen measurement point)
- Analytical balance
- Container for the collected pellets

Method

1. Place the sampling device to sewer line for approximately 6 hours, remember safety aspects of your work
2. Observe the sampling device time to time during the measurement, for breakage or overcapacity
3. After approximately 6 hours lift the sampling device off from the sewer line
4. Separate pellets and bigger plastic particles from other solids
5. Calculate the number of pellets and/or weigh the pellets to the nearest 0,1 milli-grams using the balance

Figure 3.1. Pellet sampling device, mesh size 0,43 mm.

Figure 3.2. Pellet sampling device, mesh size 0,43 mm.