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Content

Introduction	4
1 Lecture 1. Introduction in industrial ecology. Strategies for a better environment	5
2 Lecture 2. Environmental issues for the FDM sector (Food, Drink and Milk Industries)	22
3 Lecture 3. General techniques of environmental protection for the FDM sector	29
4 Lecture 4. Techniques for minimising air emissions for FDM	36
5 Lecture 5. End-of-pipe waste water treatment	59
Recommended sources	82

Introduction

Environmental protection is actual task for humanity. The most significant environmental issues associated with industrial enterprises, including Food, Drink and Milk sector, are water consumption and contamination; energy consumption; air pollution, and waste minimisation. Industrial solid wastes is an important part of all waste produced nowdays. To protect the environment industrial enterprises have to follow the principles of Industrial ecology.

The course aims at presenting the developments in research and application in the field of Industrial ecology and discussing the role of Industrial ecology in strategic sustainable development on a global scale as well as for strategies for manufacturing industries. Environmental problems and their solutions, mainly in the Food, Drink and Milk sector, are discussed in this course. The overall aim of the course is to provide theoretical and applied knowledge and understanding of strategies and technologies for a cleaner industrial production for the Food, Drink and Milk sectors.

The course of lecture covers themes such as “Introduction in Industrial Ecology. Strategies for a better environment”, “Environmental issues for the FDM sector (Food, Drink and Milk industries)”, “General techniques of environmental protection for the FDM sector”, “Techniques for minimising air emissions for FDM” and “End-of-pipe waste water treatment”. After each theme it includes study questions thanks to which Master's Students will able to check their knowledge.

The course of lectures has developed thanks to project Tempus IEMAST: «Establishing Modern Master-level Studies in Industrial Ecology».

LECTURE 1
INTRODUCTION IN INDUSTRIAL ECOLOGY. STRATEGIES FOR A BETTER ENVIRONMENT

Lecture schedule

1.1 Industrial ecology. History of Industrial Ecology.
1.2. Cleaner production.
1.3 Strategies for a better environment.

1.1 INDUSTRIAL ECOLOGY. History of Industrial Ecology.

Industrial ecology (**IE**) is the study of material and energy flows through industrial systems. Industrial ecology was popularized in 1989 in a Scientific American article by Robert Frosch and Nicholas E. Gallopoulos from General Motors. Frosch and Gallopoulos' vision was "why would not our industrial system behave like an ecosystem, where the wastes of a species may be resource to another species? Why would not the outputs of an industry be the inputs of another, thus reducing use of raw materials, pollution, and saving on waste treatment?".

The scientific field Industrial Ecology has grown quickly in recent years. The Journal of Industrial Ecology (since 1997), the International Society for Industrial Ecology (since 2001), and the journal Progress in Industrial Ecology (since 2004) give Industrial Ecology a strong and dynamic position in the international scientific community.

Industrial ecology can be considered the “production” component of sustainable development. The most important aspect of industrial ecology is the idea of industry as a system in which there is no waste at any step because all “waste” is a resource for another part of the industry network.

“Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a system view in which one seeks to optimise the total materials cycle from virgin material, to finished material, to product, to waste product, and to ultimate disposal. Factors to be optimised include resources, energy and capital.” [Graedel and Allenby, 1995].

Principles

1. One of the central principles of Industrial Ecology is the view that societal and technological systems are bounded within the biosphere, and do not exist outside of it. Ecology is used as a metaphor due to the observation that natural systems reuse materials and have a largely closed loop cycling of nutrients. Industrial Ecology approaches problems with the hypothesis that by using similar principles as natural systems, industrial systems can be improved to reduce their impact on the natural environment as well. The table 1.1 and figure 1.1 shows the general metaphor.

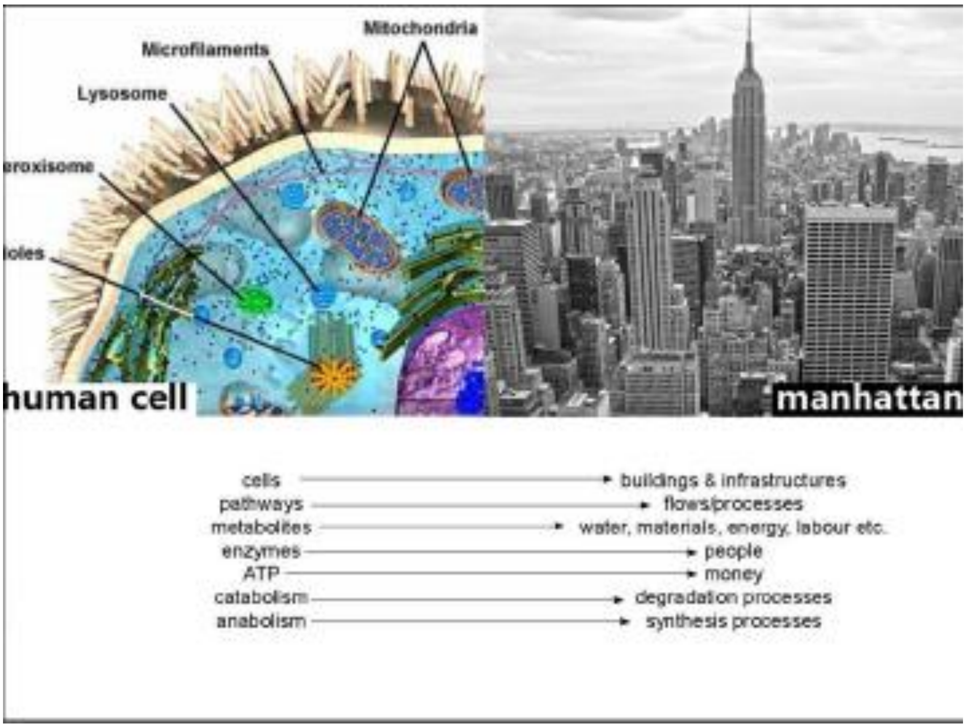

Figure 1.1 - A cell compared to a city

Table 1.1 - A comparison between biosphere and technosphere

Biosphere	Technosphere
• Environment	• Market
• Organism	• Company
• Natural Product	• Industrial Product
• Natural Selection	• Competition
• Ecosystem	• Eco-Industrial Park
• Ecological Niche	• Market Niche
• Anabolism / Catabolism	• Manufacturing / Waste Management
• Mutation and Selection	• Design for Environment
• Succession	• Economic Growth
• Adaptation	• Innovation
• Food Web	• Product Life Cycle

A notable example resides in a Danish industrial park in the city of Kalundborg (Figure 1.2). Here several linkages of byproducts and waste heat can be found between numerous entities such as a large power plant, an oil refinery, a pharmaceutical plant, a plasterboard factory, an enzyme manufacturer, a waste company and the city itself. This is one example of a system inspired by the biosphere-technosphere metaphor: in ecosystems, the waste from one organism is used as inputs to other organisms; in industrial systems, waste from a company is used as a resource by others.

Figure 1.2 - View of Kalundborg Eco-industrial Park

2. Moreover, life cycle thinking is also a very important principle in industrial ecology. It implies that all environmental impacts caused by a product, system, or project during its life cycle are taken into account. In this context life cycle includes

Raw material extraction
Material processing
Manufacture
Use
Maintenance
Disposal

3. Final and important principle of IE is its *integrated approach* or *multidisciplinarity*. IE takes into account three different disciplines: social sciences (including economics), technical sciences and environmental sciences.

Industrial ecology is a young but growing multidisciplinary field of research which combines aspects of engineering, economics, sociology, toxicology and the natural sciences.

1.2 CLEANER PRODUCTION

Industrial ecology can be considered the “production” component of sustainable development(Figure 1.3).

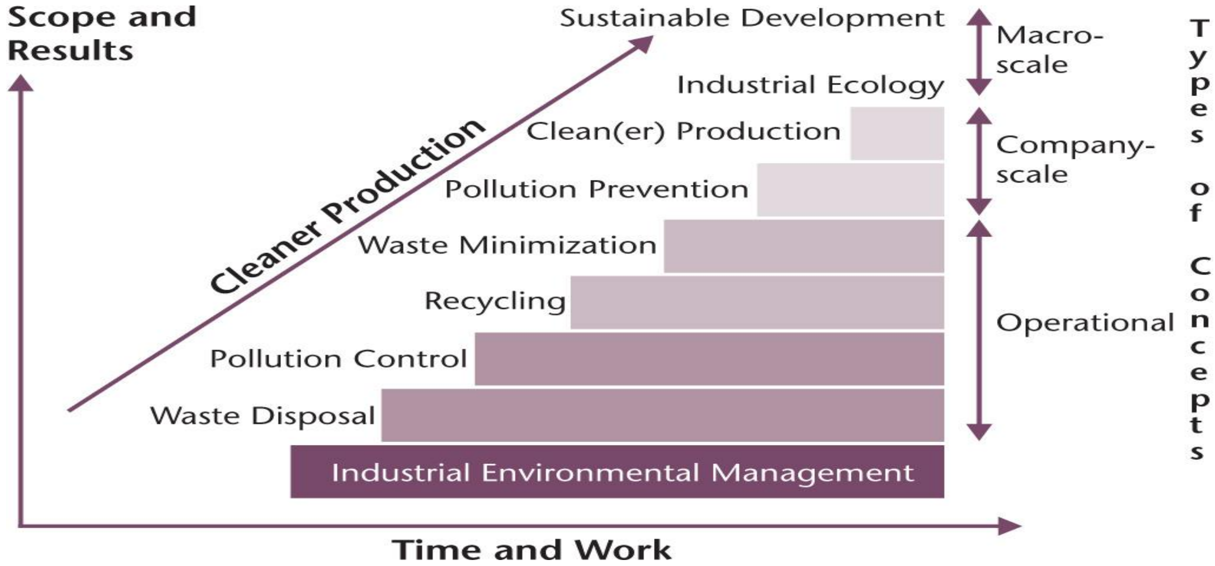

Figure 1.3 - Staircase of Concepts of Industrial Ecology

Throughout the second half of the 20th century a growing worldwide movement has attempted to change the way industry interacts with the environment. Governments and industry alike have contributed to this movement. The focus has been to reduce environmental impacts from industry through changes in industrial behavior and technology.

In the past, pollution control was seen as the key to a cleaner environment. Pollution control refers to the measures taken to manage pollution after it has been generated. One example is the extensive investment in the building of sewage or wastewater treatment plants, both in industries and in municipalities. This took place in Western Europe typically during 1960s and 70s, while in Central and Eastern Europe it was not until after the systems change around 1990 that WWTPs were built on a significant scale (Figure 1.4).

Figure 1.4- Pollution control. During the 1960s and 1970s wastewater treatment plants were built at all urban centers in Western Europe to save the recipients - rivers, lakes, and coasts

In recent decades we have witnessed a paradigm shift from pollution control to pollution prevention (sometimes referred to as P^2). Pollution prevention is the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the source. It includes practices that diminish the use of hazardous materials, energy, water, or other resources, and practices that protect natural resources through conservation or more efficient use (Figure 1.5).

Figure 1.5 - Changing technology. The chlor-alkali factory outside Skoghall in west Sweden once used the mercury electrode method to produce chlorine. In 1987 the new membrane-based technology was introduced, replacing all use of mercury. There has been a 100% change to this new technology in Japan, a partial change in Western Europe and USA, but no change has yet taken place in eastern and central Europe

Most recently, the concept of cleaner production (CP) has entered the global environmental arena. CP fits within P^2's broader commitment towards the prevention, rather than the control, of pollution.

Cleaner production refers to the continuous application of an integrated preventive environmental strategy to processes and products to reduce risks to humans and the environment. For production processes, cleaner production includes 1) conserving raw materials and energy, 2) eliminating toxic raw materials, and 3) reducing the quantity and toxicity of all emissions and wastes before they leave a process. For products, the strategy focuses on reducing impacts along the entire life cycle of the product, from raw material extraction to the ultimate disposal of the product. Cleaner production is achieved by applying know-how, by improving technology, and by changing attitudes.

P^2 is an approach which can be adopted within all sectors, whether it is a small service operation or a large industrial complex. CP, on the other hand, directs activities toward production aspects. Unlike in the past, when pollution was simply controlled, P^2 and CP programmes attempt to reduce and/or eliminate air, water, and land pollution. Therefore, the P^2 and CP approaches benefit both the environment and society.

Economically, P^2 and CP can actually reduce costs and in some cases, generate profit.

Cleaner Production (CP) begins with the insight that even if environmental technologies has lead to a significant reduction of emissions (at least per product) they are expensive and need further input of materials, energy and manpower. Environmental technologies therefore offer no economic incentives for industry. On the opposite they generally lead to higher production costs, and they include a regulatory approach. Industry may avoid environmental technologies by investing in countries with less strict regulations.

Cleaner Production, on the contrary, aims to reduce both the negative effects to the environment and the operating costs. Cleaner Production works with process integrated – preventive – methods instead of End-of-Pipe solutions. Cleaner Production is the conceptual and procedural approach to production that demands that all phases of the life cycle of a product or of a process should be addressed with the objective of prevention or minimisation of short and long-term risks to humans and to the environment.

Five Basic Principles of Cleaner Production

Cleaner Production requires that resources be managed efficiently. This consists both of careful use of resources, the closing of material streams, and resource substitution. It is possible to outline the general principles of Cleaner Production:

1. Input-Substitution

Use of less hazardous raw-, auxiliary- or operating materials. Use of operating materials with a longer lifetime.

2. Good Housekeeping

Increase the Material and Energy efficiency of actions in the process. Try to fetch the “low hanging fruits” first, e.g. reduce losses due to leakage. It is important to train employees.

3. Internal Recycling

- Close Material and Energy Loops for water, solvents, etc.

Cascading of Material and Energy streams.

4. Technological Optimisation/Change

- Implementation of new technologies.
- Improved process control.
- Redesign of processes.
- Change in or substitution of hazardous processes.

5. Optimisation of the Product

- Increasing the lifetime.
- Easier repair.
- Easier de-manufacturing, recycling or deposition.
- Use of non-hazardous materials.

How to implement CP actions in companies:

Start by getting to know the process. Important tasks are:

- Define the processes units, e.g. in electro-plating; degreasing, etching, bondering, rinsing.

- Understand the process with its chemical and physical connections.
- Draw a flow sheet with all (!) Input and Output-streams and all interrelationships (quantitative).
- Take a closer look at the most important material streams (qualitatively and economically, m^3/a, EUR/a).
- Look at existing cross-media effects.

Identify the weak points of the process: it is easier to convince companies to take actions if the economic benefits are clear at the start, so identify the low-hanging fruits, and define process optimisations.

In the longer term Cleaner Production will shift from being a process of continuous improvements to a process of redesign of production. The goal is to reach zero emission, that is a process in which all input material is turned into products, either to be sold or used in another process.

1.3 STRATEGIES FOR A BETTER ENVIRONMENT

The urgency to find solutions to the different environmental problems we are facing today is increasing, just as it is to avoid new environmental problems tomorrow. The media every day tell us about different environmental problems in forests, fields, lakes and rivers.

What possibilities are there to avoid, or at least reduce, the discharges of different pollutants to the air, water and soil from, for example, industrial processes? There are many different technical solutions to diminish the stress on our environment. The traditional methods are the technical waste stream treatment approaches, the so-called end-of-pipe solutions. But today strategies to address environmental problems using a process integrated approach, cleaner production, are coming to the forefront. Which alternative or alternatives one should choose depends on, of course, the nature of the problem, but also on a number of other factors, for instance economy, space limits in a factory, indirect effects on the environment etc.

Throughout this lectures the practices of the several concepts and strategies introduced here will be detailed and exemplified, on both a managerial and a technological level. The managerial level is concerned with motivating, planning, following up and evaluating a technology. The technological level is concerned with the practice and functioning of the techniques used. In all cases it will hopefully be clear that the techniques, with a focus on cleaner production, are realistic, highly profitable, and sometimes required, to follow legal requirements and permits.

STRATEGIES for a BETTER ENVIRONMENT

1. Dilution strategy.
2. Site Selection.
3. The End-of-pipe Approach (External Cleaning, The Filter Strategy).
4. Process Integrated Solutions (Changed Technology, The Substitution of Raw Materials, Integration and Environmental Audits).
5. Product strategy.

a) LCA

b) Environmental design

C) Recycling (Levels of Recycling, Organising Production to Decrease Emissions, Legal Measures).

6. The Long-term Solution – Reorganise Society (Products or Functions, Changing Production or Consumption?, Eco-development rather than Environmental Protection).

1 way - Avoiding the Problem – Let Nature Handle it (1, 2):

1. The Dilution Strategy

The original solution to the pollution problem was to ensure that the industrial waste was discharged in a recipient where it would be diluted enough to "disappear". Actually, only a generation ago, a red flag was shown every Saturday in a small river in Sweden. This was the signal for the women busy with their laundry downstream to stop the washing and take away their clothes from the water. The industry then dumped about 2 m^3 of "pickling liquor" into the water that flowed down the river as a brown plug, down to the nearest lake. After a while the washing was resumed again.

The solution to the pollution problem was thus to build a chimney high enough or an industry next to a big river with enough flow to ensure a good dilution.The industrial wastes gave disturbing effects for the waters and the organisms living there, but from a human point of view it wasn't considered so bad. The sewerage from toilets with its hygienic risks was of more urgent concern. But also here there is a history of neglect. For a long time the toilet waste was just emptied into the nearest water stream.

This way of handling waste relies on natural processes to clean it. Nutrients, such as toilet waste, are certainly taken care of by bacteria and the like. But if there is too much of it the natural processes are inadequate. This happens especially in cities and towns where many people are living together. Industrialism greatly increased the flows of waste and in early industrialised England the waste heaps gave rise to unbearable smells and was also the source of serious infections. Chimneys, to send the pollution far away, as mentioned, became the solution (Figure 1.6).

Figure 1.6 - Distribution of pollutants in the environment. Pollutants emitted to the air are often distributed over continental-scale distances and may even damage the global atmosphere. Most, however, are precipitated close to the point of emission

2 Site Selection

In the early stages of industrialism factories were located close to or in cities since that is where the workers lived. Industrial cities grew immensely as production increased. Classical examples are provided by e.g. Lodz in Poland or Manchester in England. When the pollution became too severe, in spite of high chimneys, an alternative was the selection of a site for the factory not too close to a city but where discharges could be handled. One of several reasons why there are many industries along coastlines is that the recipient (the receiver of sewerage) – in this case the sea – provides very much better dilution and therefore handles the emission better, compared to a small in-land river. By placing a combustion plant outside a city, as well as off the wind direction, the pollution situation can be considerably improved in the cities. Naturally, it is not common that production can be moved. Very often the plant is situated in a place chosen long before the environment became an issue.

A "proper" site selection, however, does not decrease the emissions but only redirects it and saves the neighborhood. In this way it is just the same as the dilution method. But sometimes the choice of a proper location can work. One example can illustrate this. A chemical industry handling a smelly chemical with a very low smell detection limit was situated in the wind direction to a high density urban area. When filling the chemical to storage tanks from trucks, small leakages were inevitable, and the inhabitants in the area were affected. The very simple solution was to fill the tanks at times when the wind came from other directions.

But Chimneys are Not Enough. The shortcomings of the method of dilution become obvious when we regard the rules for dimensioning and building a chimney for a combustion plant for heat production. The rules specify how high the chimney should be in order to maintain a low enough level of pollutants nearby the polluting source, so that people living and working in the area should not be affected.

By using a high chimney one solves the problems with too high a concentration in the neighborhood. But the total amount of pollutants emitted to the environment of course remains the same. The strategy relies on the environment to handle it. But we have numerous examples showing that the sea and the air space isn't large enough for the waste generated. For instance all nutrients discharged into the Baltic Sea have made the whole water body eutrophic, as can be seen from the ever larger algal blooms. A similar situation is found in many coastal areas in e.g. Southeast Asia and North America. The acid emissions from smoke stacks in England, Germany and Poland (and to some extent in Sweden) over many years have killed tens of thousands of lakes in Norway, Sweden and Finland. The amounts of carbon dioxide emitted from industries all over the world are so large that not even the entire global atmosphere can manage with it. The natural cycle, where carbon dioxide is dissolved in the oceans, is much too slow compared with the rate of emission. Dilution is obviously no solution.

3. The End-of-pipe Approach

External Cleaning

Yet another possibility to handle the pollution problem in an industrial plant is to take care of the waste in specially designed waste treatment facilities. The term

external indicates that the treatment measure is separated from the actual manufacturing process. There are a number of examples of this strategy in environmental technology. One is wastewater or sewerage treatment plants (WWTPs). During the 1960s and 70s extensive investments in the building of such plants, both for industrial and municipal wastewater, were made in Western Europe. The same investments were typically not made in Central and Eastern Europe until the 1990s. Industrial wastewater is often sent to the municipal treatment plants sometimes far away Some industries with discharges requiring special methods of treatment, however, have their own designated plants nearby.

Facilities for management of hazardous waste are also generally located outside the origin of the waste. They mostly incinerate the waste at very high temperatures. Such incineration plants may also use waste oil and solvent wastes from industries as fuel.

Landfills and composts may also be seen as places for waste treatment externally to the site of production.

The Filter Strategy

The strategy of separating pollutants from a water flow with a therefore designed cleaning facility constitutes a so-called filter strategy or “end-of-pipe” solution. Sometimes a particular component in a waste stream is separated by e.g. an ion exchanger or a membrane. The substance then has to be washed out regularly and is received as a concentrate. Flue gases are cleaned by end-of-pipe technologies. These include scrubbers to remove sulphur oxides by the addition of lime, electrostatic precipitators to remove particulates, and incinerators to remove hazardous organic pollutants at high temperature. Special measures are used to e.g. remove mercury from flue gases, or chromate from discharges from the tanning industry.

With the end-of-pipe technologies the pollutant is not dispersed in the environment. It is still there but now as a concentrate, for instance a mud. The most typical might be the sludge produced in a wastewater treatment plant. Other examples are the filter cakes from a flue gas cleaning equipment, and the residual ash received after incineration.

This concentrate is then often taken care of externally, and very often new problems arise. The question about how to handle the sludge from wastewater treatment can be used as an example for the discussion. The sludge is rich in water, and dewatering is the first problem to deal with. Secondly it may also be polluted with e.g. heavy metals, which makes it unsuitable as compost for agricultural use. Thus even if it may be useful, it is often sent to the landfill.

The result from the external cleaning technology does not always constitute a concentration of pollutants. Sometimes the pollutants may be transformed in the external cleaning step into less harmful products that subsequently can be handled by nature itself. One example of this is the destruction of cyanides in wastewater through oxidation to carbon dioxide and nitrogen gas.

Waste as a Resource

Concentrated waste may also be useful. The sludge that arises in a wastewater treatment plant was originally used directly as fertiliser on farmland. This is still possible if the contamination of e.g. metals and organic micro-pollutants is low enough, which is often the case today (Figure 1.7).

The capture of sulphur oxides in a desulphurisation scrubber also produces a useful residue. The sulphur is oxidised to sulphate which together with the lime forms gypsum, which can be used as building material. The success story of reduced acid rain from the power industry thus goes hand in hand with the invention of a new product, gypsum boards for the building industry.

Other residue from wastewater treatment or flue gas cleaning may be more difficult to turn into useful products. Ashes from combustion still mostly end up on landfill although it is also possible to mix them with asphalt to be used in road construction. Hazardous organic waste may be used as fuel in cement furnaces. But some pollutants filtered away cannot be used, the most typical being heavy metal residue, such as mercury. This has to be stored in safe places forever.

Figure 1.7 - Growing in sludge. Sludge that arises in a wastewater treatment plant can be used directly as fertiliser and to improve soil on farmland.

4. Process Integrated Solutions

a) Changes within the process

The third possibility of tackling the problem of pollution is to change the process itself and/or purify/exchange the raw material used in the process. This is the concept of process integrated measures.

By changing the process itself it is possible to reduce the formation and emissions of pollutants and the production of solid waste from the process. We may achieve this by changing the equipment used, the process conditions (temperature, pressure, chemical environment, etc.), or by installing a separation equipment inside the process itself. These are some of several different possibilities.

The pulp and paper industry is one industrial branch where many examples of integrated process solutions are found. This particular industrial branch started comparatively early with the integration of environmental protection solutions in their processes. One important reason for this was that the branch was rather homogeneous. This made it possible to find common solutions for many different plants. The costs for development could thus be shared between several companies.

A classic and illustrative example is the following. A major environmental problem was the huge discharges of fibres in the surrounding waters. A dramatic decrease in fibre discharges was achieved by installing strategically placed sieves to collect the fibres. The fibres, which used to go to waste, could now be recycled into production. As a result the yield of raw materials in the process increased considerably. The measure was very simple and at the same time very profitable.

Another example is the change of technology for bleaching pulp. A main environmental impact was due to the discharges of large amounts of chlorinated hydrocarbons, shown to be toxic to fish and waster ecosystems. It was caused by the use of chlorine to bleach the paper. By changing bleaching technology, e.g. using hydrogen peroxide instead of chlorine, these emissions virtually disappeared.

The most important step may however be the transition from sulphite to sulphate pulp technology. The sulphate process, also called the Kraft pulp process, is a recovery process, where the chemicals used in the cooking of the pulp are, generally, recycled. In addition so-called black liquor produced in the process may be incinerated and as such provide the industry with all energy needed.

Within the industry an extensive structural rationalisation has therefore taken place. A number of the smaller sulphite pulp and paper plants, causing rather big discharging problem, were closed down and instead investments were made in bigger sulphate units. Due to this the discharges of oxygen consuming compounds and sulphur etc., have been drastically decreased, in spite of a substantial increase in production. At the same time the industry is virtually self-sufmcient in energy. The result is overwhelming. The whole industry of paper production after 20 years of restructuring has turned from one of the worst environmental culprits to a clean, modern, efficient and very profitable industry.

Other examples include the textile industry, which has halved its emissions to water with respect to non-biodegradable compounds, basically due to closing down of inadequate plants. In the steel industry there has been a significant decrease of emissions of dust. This is basically due to the replacement of older martin furnaces with modern electro-steel furnaces, equipped with efficient dust separator systems.

b) The Substitution of Raw Materials

The substitution of raw materials in a process is an important process integrated measure. The raw materials and the process are closely connected. The process has to be designed with respect to the raw materials utilised. Exchange of process and raw materials often amounts to the same thing.

Raw materials may be exchanged because of legal constraints, made by authorities for environmental reasons. A well-known case is the drastic decrease of emissions of sulphur oxides, due to restriction on the allowed amount of sulphur in fuels. Other cases include taxes on emissions, e.g. sulphur oxides and nitrogen oxides, taxes on energy or emissions of carbon dioxides, and outlawing certain chemicals, e.g. freons or CFCs.

A strategy for the review of raw materials and support chemicals used includes the following steps:

1. Identify the substances causing problems in the effluent.

2. Localise this substance in the flow of raw materials or support chemicals.

3. Replace the substance with a better one, from an environmental point of view.

4. If an exchange is not possible, separate the substance causing problems with some suitable separation technology.

The strategy of replacing the raw materials by more environmental friendly ones has been very efficient and important in industrial environmental work, and there are many applications to illustrate this. To achieve this, many compounds have been banned by the authorities. The first legal measures were taken in the 1970s, concerned with POPs, e.g. certain biocides. Since the 1980s limitations on the use of CFC compounds have been introduced and it has today virtually ended. Several national and international institutions, chemical inspectorates, as well as individual industries have produced lists with compounds or groups of compounds which eventually will be banned. In 2001 the Stockholm Convention on hazardous chemicals was signed. In the near future we will see restrictions on the use of among others the metals lead, mercury, and cadmium as well as the solvents trichloroethylene, methylene-chloride and tetra-chloroethylene. The implementation of the REACH Directive of the European Commission will take chemicals control into a new phase where the responsibility of industry will increase. The list of banned chemicals will, most certainly, be longer during the coming years of environmental work.

c) Integration and Environmental Audits

To change the process and/or substitute the raw materials in the process is a rather drastic measure. A much simpler approach is to improve the existing process. Satisfying results, that is, a decrease in emissions, can often be achieved by bearing in mind that there are human beings involved in production, and they may make errors. It is very likely that one can prevent completely unnecessary discharges to the environment by regularly performing so-called environmental audits. This consists of proper inspection of all the different procedures in the activity, improvement of the process supervision and control, improvement in the maintenance of the equipment etc. and education of the staff. Every single separate discharge may be almost negligible when looking at the complete emission profile of an industry, but all various discharges taken together may add up to be very significant.

Yet another factor not to be forgotten is the manufactured product itself. By simple changes in the product it might be possible to eliminate those process steps that are doubtful from an environmental point of view.

5. Product strategy

a) LCA

b) Environmental design

C) Recycling

Levels of Recycling

Recycling has sometimes been regarded as “the solution” to many of our environmental problems. By a substantial increase in recycling we would get away from our environmental problems. The reality is, of course, never so simple. Naturally, it is important to get an increased degree of recycling, but we must also remember that there are limits for how far recycling can be taken. Recycling often needs substantial resources of different kinds. These include personnel, economic, energy as well as environmental resources.

Below we will differentiate between three levels of recycling. These are 1) recycling of a “consumed” product; 2) recycling carried out in, or in connection with, a manufacturing process, so-called internal recycling; and finally 3) recycling as an external recycling process carried out as a separate industrial activity.

Recycling of a “consumed” product can be subdivided, based on how far back in the production chain one looks. We have at least three different kinds:

- Reusing or regaining a product means that the product is reused after, for instance cleaning and check-up. A well-known example is the reuse of recycled glass bottles.
- Material recovery means that the material is utilised in a new life cycle after, for instance re-melting or some other treatment. An example is the recovery of recycled paper, glass or solvents.
- Recovery of the energy in the waste means incineration of the material for recovery of the energy content. The incineration of oil and domestic waste is an example.

Recycling carried out in, or in connection with, a manufacturing process, basically implies the establishment of feedback loops in a process, for instance, the separation and recovery of a valuable component within a process (Figure 1.8). The above mentioned recovery of fibres in the pulp and paper industry is an example of this. Another one is the use of so-called counter current rinsing in the metal plating industry. A third example is solvent recovery by means of adsorption, in connection to a de-greasing step in the manufacturing industry. The feedback of material in a process yields a higher degree of raw material utilisation and less solid waste. Also large volumes can be treated and fed back into the process after the removal of contaminants. One example is the complexation of manganese cations in process water in pulp and paper peroxide bleaching.

It leads to dramatically decreased discharges and water use.

Recycling can also be external to the original process. An example of external recovery is when an industry has a separate plant for solvent distillation. Solvent mixtures are transported from different process steps to the special plant for recovery. By distilling, the solvent mixture can be separated and most of the solvents recycled. There are several companies specialised in solvent recovery, as well as recovery of other types of wastes.

Figure 1.8- Bleaching towers in a Kraft Mill System. The sulphate process, also called the Kraft pulp process, is a recovery process, where the chemicals used in the cooking of the pulp are, generally, recycled. In addition so-called black liquor produced in the process may be incinerated and as such provide the industry with all energy needed

Organising Production to Decrease Emissions

Recycling and actions to increase recycling, although important for a better environment, are not regarded as preventive environmental protection measures. They are rather ways to organise production in such a way that environmental protection measures are less necessary.

The best thing is to avoid the concept of waste all together. This is the concept of zero waste. An important part of the zero waste strategy is to see the so-called waste as a resource to be used somewhere else in the production or in a different production. Comparing with nature always gives insight. In nature there is little waste. Most is used by some other ecosystem. Nature only supports cyclic flows, even if some of them are on a geological rather than biological time scale. Waste on the other hand is by definition perceived as the end point of a linear flow. This is what we have to avoid.

6. Further possibilities

The Long-term Solution – Reorganise Society

Products or Functions

Let us study the car as an example. From a product-oriented point of view the car is the fixed point of departure, and the discussion is focused on how this product can emit less exhausts, pollution, and noise and consume less energy and so on. From a functional point of view, however, the function of the car is the interesting and important issue. In this case the main point is to facilitate the transport of people and/or merchandise between different places. The product, i.e. the car, is then no longer a fixed condition. The discussion in this case concerns which alternative solutions there are to fulfil the transportation function, and the problems connected to these different solutions.

Public transport could in many cases constitute a more environmentally sound and resource saving solution. This is true in particular for track-bound traffic, railways. The merchandise should, from this point of view be transported not by trucks but by railway. Trains use only a fraction of the energy of the car per kilometer and amount of transported goods (ton-kilometer) and have almost no emissions.

Changing Production or Consumption?

Another example concerns our need for energy. Today a number of different methods are utilised to supply us with energy, mainly combustion of fossil fuels. When burning a fuel, the remains are generally various gases and a solid waste. Which the produced gases are and the amount of each depends on the fuel used, as well as the conditions during combustion. The emissions from a combustion plant may thus be diminished by the choice of a different fuel and improved conditions under which combustion takes place, i.e. process integrated measures. Another possibility is of course to use external cleaning technology. But we may also look at the function of the power station – to provide heat and electricity. Can it be done differently?

One measure which has proven to give large environmental gains in urban areas is to replace all small household heating systems, with a large power plant, that is, to turn to district heating. By building a central power plant with an improved process control, as well as cleaning equipment, and with an energy distribution net instead of a number of small household heaters, the amount of air pollutants drastically decreases.

Figure 1.9 - Housing. Insulation of a house as here may decrease energy demands considerably. Additional possibilities for reducing energy costs are installation of a heat pump, and use of solar panels.

Eco-development rather than Environmental Protection

There are also a number of other ways to economise produced energy, such as controlling the temperature in our flats and houses, using more energy efficient electrical equipment, etc. In many urban areas the local electricity companies can inform and encourage the inhabitants to buy and use more energy-saving products (lamps etc.), in order to lower the consumption of electricity.

Improved public planning of our societies may be seen as the highest level in the hierarchy of changes to protect the environment better. According to this radical perspective, the environmental and resource problem as well as a number of other difficult problems in society today are caused by the present developing pattern in our society. This development is basically characterised by increased consumption, considerable centralisation and specialisation etc. which, in this perspective, leads to more difficult problems.

Study Questions

1. What kind of environmental problems can be caused by an industrial process? List possible measures to reduce these impacts.
2. In what way have the strategies of environmental protection changed during the last 50 years?
3. What is the main strategy of environmental protection nowadays? Explain why. How is this strategy used to change industrial processes and substitute raw materials?
4. Compare the costs of remediation of polluted soil and water compared to the costs of pollution abatement. Give concrete examples.
5. Discuss the limitations of the dilution approach, and in particular the capacities nature has to absorb pollution; compare with e.g. eutrophication and acidification.
6. Give examples of how end-of-pipe technologies give rise to a concentrate of pollutant and what can be done with it.
7. How is it possible to decrease the production of pollutants and wastes? Explain the concept of "zero waste". What international and national agreements support this initiative?
8. How should the production and consumption in society, in your opinion, be changed, in your point of view, to meet the demand for sustainable development and environmental protection?
9. Explain how pulp and paper production has turned from being a culprit to a "best in class" industry.
10. Give examples of how a change of technology or raw material in an industrial process may give rise to reduced pollution.
11. Name three kinds of recycling, give typical examples.
12. Give examples of how a change from selling a product to a service, so-called servicizing, gives rise to less pollution.

LECTURE 2
ENVIRONMENTAL ISSUES FOR THE FDM SECTOR (FOOD, DRINK AND MILK INDUSTRIES)

Lecture schedule

2.1 Key environmental issues.
2.2 Water.
2.3 Air emissions.
2.4 Loss of materials.
2.5 Energy.

2.1 KEY ENVIRONMENTAL ISSUES

Water consumption is one of the key environmental issues for the FDM sector. Most of the water which is not used as an ingredient, ultimately appears in the waste water stream.

Typically, untreated FDM waste water is high in both COD and BOD. Levels can be 10 - 100 times higher than in domestic waste water. The SS concentration varies from negligible to as high as 120000 mg/l. Untreated waste water from some sectors, e.g. meat, fish, dairy and vegetable oil production, contains high concentrations of FOG.

The main air pollutants from FDM processes are dust, VOCs and odour. Refrigerants containing ammonia and halogen may be accidentally released. Odour is a local problem either related to the process or to the storage of raw materials, by-products or waste.

Noise may also be a problem for some installations, typically associated with vehicle movements and refrigeration.

The solid output from FDM installations is composed of by-products, co-products and waste. The main sources of solid output are spillage, leakage, overflow, defects/returned products, inherent loss, retained material that cannot freely drain to the next stage in the process and heat deposited waste.

The FDM sector is dependent on energy for processes required for freshness and food safety. Mechanical processing, e.g. raw material preparation and sizing, and thermal processing, e.g. dehydration, are the most commonly used techniques for food preservation and processing. Both require significant amounts of energy. Process heating uses approximately 29 % of the total energy used in the FDM sector. Process cooling and refrigeration accounts for about 16 % of the total energy used.

2.2 WATER

2.2.1 Water consumption

Water consumption is one of the key environmental issues for the FDM sector. Water has many different uses, e.g:

• for cooling and cleaning
• as a raw material, especially for the drinks industry
• as process water, e.g. for washing raw materials, intermediates and products

• for cooking, dissolving and for transportation
• as auxiliary water, e.g. for the production of vapour and vacuum
• as sanitary water.

The quality of water needed depends on the specific use. In 1998 in Germany, the total industrial water consumption was 8500 million m^3 of which 304 million m^3 was used by the FDM sector.

Of the 1730 million m^3 of water used by the German FDM sector in 1998, 834 million m^3, i.e. more than a half, was used as cooling water and 438 million m^3 was used as process water.

In the FDM sector as a whole, about 66 % of the total fresh water used is of drinking water quality. In some sectors, like dairies, soft drinks and mineral water manufacturing and breweries, up to 98 % of the fresh water used is of drinking water quality.

2.2.2 Wastewater

Although the FDM sector is an extremely diverse sector, certain sources of waste water are common to many of its sectors. These include:

• washing of the raw material
• steeping of raw material
• water used for transporting or fluming raw material or waste
• cleaning of installations, process lines, equipment and process areas
• cleaning of product containers
• blowdown from steam boilers
• once-through cooling water or bleed from closed-circuit cooling water systems
• backwash from regeneration of the WWTP
• freezer defrost water
• storm-water run-off.

2.2.2.1 Quantity of waste water

The FDM sector has traditionally consumes a large of water as an ingredient, for cleaning, means of conveyance and feed to utility systems. Large FDM processing installations need several hundred cubic metres of water a day. Most of the water which are not used as an ingredient, forms waste water stream.

Substantial reductions in the volume of waste water generated in this sector can be achieved through waste minimisation techniques. There is no simple relationship between the amount of water applied in cleaning and hygiene standards, and food safety legislation requirements prevent water use minimisation from causing unsatisfactory levels of cleanliness, hygiene or product quality.

Waste water flowrates significantly change on a daily, weekly or seasonal basis. The kind of waste water is largely dependent on production patterns and cleaning measures. In some sectors, for example sugar beet and olive oil production, processing takes place on a campaign basis and waste water can not be generated for part of the year.

2.2.2.2 Composition of waste water

2.2.2.2 Composition of waste water

There are a large of compounds of waste water in the FDM sector. Often it includes high in both COD and BOD, which levels can be 100 times higher in comparison with domestic waste water.

The SS concentration varies from negligible to as high as 120000 mg/l. High concentrations of edible fats and oils are sometimes contained in the waste water from the meat and dairy sectors.

Food processing waste waters can be very acidic, pH 3.5, or very alkaline (pH 3,5-11). Factors affecting waste water pH involve:

• the natural pH of the raw material;

• pH adjustment of fluming water to avoid raw material deterioration;

• utilize of caustic or acid solutions in processing operations;

• utilize of caustic or acid solutions in cleaning operations;

• acidic waste flows, for example acid whey;

• acid-forming reactions in the waste water, for example high yeast content waste water, lactic and formic acids from degrading milk content;

• nature of the source of raw water, either hard or soft.

Waste waters include few compounds that individually have an adverse effect on WWTPs or receiving waters. Possible exceptions involve:

• salt where large amounts are utilized, for example pickling and cheesemaking;

• pesticide residues not easily degraded during treatment;

• residues and by-products from the application of chemical disinfection techniques;

• some cleaning products.

The existence of pathogenic organisms in the waste water may be an issue, especially where meat or fish are being processed. The amount of plant nutrients may as well be an issue. For the biological waste water treatment of the waste water, the ideal BOD:N:P ratio is approximately 100:5:1. At this level, processing waste water in FDM sector would be too deficient in N and/or P to maintain biological activity during treatment. Excessive levels of P can also take place, particularly where large quantities of phosphoric acid are applied in the process, for example vegetable oil de-gumming, or in cleaning. If such waste water turns anaerobic during treatment then there is a risk that constituents which are contained phosphate could release phosphorus to the final discharge water. The application of nitric acid in the process produces a similar effect, thus increasing the nitrate levels in the waste water.

Some ordinary sources of fugitive and unscheduled emissions, i.e. accidental releases, are:

• contaminated storm-waters

• storage tank leaks

• pipework leaks

• spillages

• bund drains

• leakages from flanges, pumps, seals and valve glands.

2.3 AIR EMISSIONS

Air emissions are divided into ducted, diffuse and fugitive emissions. But only ducted emissions can be treated. Diffuse and fugitive emissions can, nevertheless, also be avoided and/or minimised.

The sources of ducted emissions in the FDM are listed below:

• process emissions, emitted through a vent pipe by the process equipment and inherent to the running of the installation, for example in boiling, frying, cooking operations;

• waste gases from purge vents or preheating equipment, which are applied only on start-up or shut-down operations;

• emissions from vents from storage and handling operations, for example transfers, the unloading and loading of products, raw materials and intermediates;

• flue-gases from units providing energy: steam boilers, process furnaces, combined heat and power units, gas engines, gas turbines;

• waste gases from emission control equipment: filters, thermal oxidisers or adsorbers;

• waste gases from solvent regeneration, for example in vegetable oil extraction installations;

• discharges of safety relief devices, for example safety vents and safety valves;

• exhaust of general ventilation systems;

• exhaust of vents from fugitive sources and/or captured diffuse, for example diffuse sources installed within an building or enclosure.

The sources of diffuse emissions in the FDM sector are listed below:

• process emissions due to the process equipment and inherent to the running of the installation which are released from a large surface or through openings;

• breathing losses and working losses from storage equipment and during handling operations, for example filling of drums, trucks or containers;

• flare emissions;

• secondary emissions which are resulted from the handling or disposal of waste, for example volatile material from sewers, cooling water or waste water handling facilities.

The sources of fugitive emissions in the FDM sector are listed below:

• losses of an odour during storage, filling and emptying of bulk tanks and silos;

• stripping of malodorous substances from a WWTP resulting in releases to air and/or odour problems;

• vents of storage tanks;

• pipework leaks;

• fumigation;

• losses of a vapour during storage, filling and emptying of bulk solvent tanks and drums, involving hose decoupling;

• burst discs and discharges of relief valves;

• leakages from flanges, seals, pumps and valve glands;

• building losses from doors, windows, etc.;

• settling ponds;

• cooling ponds and cooling towers.

The main air contaminants from FDM processes, not including the contaminants released in associated activities such as energy production, are:

- dust;
- VOCs and odour (some of them are caused by VOCs);
- refrigerants including ammonia and halogen;
- combustion products, such as CO_2, NO_x and SO_2.

Odour

Odour is mainly a local problem. Some harmful emissions into the atmosphere can also be malodorous. For two identical plants that produce the same products and use the same raw materials and process operations, one can be subject to significant complaints, and for another - the emission of an odor can not be a problem. There are many cases where installations formerly located in rural areas on the outskirts of a town or city are now facing odor problems as new housing estates have been constructed near the site as the town has grown.

In the vast majority of countries, odor emissions are regulated in accordance with the laws of nuisance. In some countries there is quantified legislation. This quantified legislation can relate to either the amount of malodorous emission, or, alternatively, to the maximum concentration of a component or group of components that are known to cause malodorous emissions. The internationally accepted odor units are "odor units per cubic meter" (OU/m^3). Instrumental odor measurements exist, but the quantification of odour is still based on olfactometry to a large extent.

The Netherlands Emissions Guideline for Air, states that the national goal is the prevention or reduction of odour nuisance. It sets an upper limit of 5 OU/m^3 as 98 % for installations used and suggests that a limit of 0.5 OU/m^3 as 99.5 % schould be satisfied for new equipments; the latter is not an upper limit.

2.4 LOSS OF MATERIALS

2.4.1 Exceed weight/volume specification

Product loss by overfilling takes place even with the most accurate filling equipment. Operating to average filling weight legislation, the packaged product will unavoidably include marginally more than the nominal package contents. Due to its economic significance, overfill is as usual very closely controlled by check-weighing on a sampling or continuous basis. Such loss of material is as usual of no environmental significance. It is, however, very significant when conducting a mass balance, to accurately quantify the overfill amount, so that this can be allowed for in the equation of a mass balance.

2.4.2 Spillage

Spillage of the product, for example onto the floor, leads to the product being unfit for human consumption and must be defined as loss and waste, if not rightly recovered. Routinely occurring spillage indicates poor equipment design, poor maintenance or poor operation, for example of a packaging line. This usually causes a significant loss of product and packaging material. When spillage takes place during manual handling, the working procedures may be at fault.

2.4.3 Leakage/overflow

Liquid product leakage from pipe joints and overflow from tanks may be an important source of loss of waste and material, if not properly recovered. These problems can be caused, for example by obsolete gaskets or faulty high level alarm switches.

2.4.4 Product defects/returned product

Products not meeting the required specification, whether identified prior to dispatch or returned by customers, can be a major source of loss of materials and waste, although some may be recovered. This group also involves over-produced fresh products, for example in cases where order fluctuations lead to too much product being produced which cannot then all be sold in time because of shelf-life considerations.

2.4.5 Inherent loss

Some process equipment, even with the most appropriate technique, can cause a loss of materials and waste which is unavoidable by design. An example of inherent loss is the self-desludging centrifugal separator, where solids from the bowl, and inevitably some product, are flushed to waste during desludging.

A similar situation exists where the product is purged through the equipment with water at the end of production or at product change-over, e.g. in CIP systems. Inevitably the interface between the product and the water will not be sharp and depending on what measures are taken to minimise this, a greater or lesser quantity of a mixture of the two is produced.

2.4.6 Retained material

Retained material occurs when liquid products or ingredients cannot freely drain to the next stage in the process. This can, e.g. be caused by dips in supposedly continuously falling pipelines, which trap the product and prevent it from draining either way. Another example is where the product rises in the pipelines and any trapped product will then not drain away, thus leading to a loss of material. If the product cannot drain, then it must be purged with gas, water or a pigging system.

Also, with very viscous products, e.g. yoghurt, adhesion to the pipeline and tank walls is a significant source of retained material. Unless mechanically removed, e.g. by pigging, prolonged pre-rinsing is likely to be required.

2.4.7 Heat deposited waste

Whenever liquid products are heated, there is a likelihood of deposition of the product onto the heat-exchange surface. Deposits on the plates or tubes in heat-exchangers, and on batch kettles may not rinse off and when removed with detergents is lost in the waste water. In many sectors, these sources of loss are contained and recycled or recovered back into the process.

2.5 ENERGY

The FDM sector depends on energy for processing, storage, to maintain freshness and to ensure food safety. Process heating uses approximately 29 % of the total energy used in the FDM sector. Process cooling and refrigeration accounts for about 16 % of the total energy used.

In Germany, the FDM sector consumed about 54500 MWh/yr in 1998, representing 6.7 % of the total German energy consumption making it the fifth largest energy consumer among all industrial sectors. The energy was produced using 49 % gas, 23 % electricity, 21 % oil, and 7 % coal. The energy consumption doubled in 30 years from 1950 to 1980. There was a slight decrease in the 1980s and 1990s.

Study Questions

1. List the key environmental issues for different FDM sectors.
2. What are the main air pollutants emitted into the environment from FDM processes?
3. List the most common sources of waste water in the FDM sector.
4. Describe the composition of waste water in the FDM sector.
5. Give examples of the sources of ducted emissions in the FDM sector.
6. List the sources of diffuse emissions in the FDM sector.
7. What the sources of fugitive emissions are in the FDM sector.
8. Explain why odour is a local problem and name the internationally accepted units of odour.
9. Describe the loss of materials during the processes in the FDM sector. Why it has, in your view, environmental significance.
10. Describe the energy consumption in the FDM sector. Give an example.

LECTURE 3
GENERAL TECHNIQUES OF ENVIRONMENTAL PROTECTION FOR THE FDM SECTOR

Lecture schedule

3.1 Environmental management tools.
3.2 Optimise operation by providing training.
3.3 Equipment design.
3.4 Installation design considerations.
3.5 Maintenance.
3.6 Methodology for preventing and minimising the consumption of water and energy and the production of waste.
3.7 Production management techniques.
3.8 Process control techniques.

3.1 ENVIRONMENTAL MANAGEMENT TOOLS

Within the European Union, many organizations have decided on a voluntary basis to implement environmental management systems based on EN ISO 14001:1996 or the EU Eco-management and audit scheme EMAS.

An environmental management system (EMS) for an IPPC installation can contain the following components:

(a) definition of an environmental policy
(b) planning and establishing objectives and targets
(c) implementation and operation of procedures
(d) checking and corrective action
(e) management review
(f) preparation of a regular environmental statement
(g) validation by certification body or external EMS verifier
(h) design considerations for end-of-life installation decommissioning
(i) development of cleaner technologies
(j) benchmarking.

According to a Swiss study, the average cost for building and operating ISO 14001 can vary:

• for a company with between 1 and 49 employees: CHF 64000 (EUR 44000) for building the EMS and CHF 16000 (EUR 11000) per year for operating it

• for an industrial site with more than 250 employees: CHF 367000 (EUR 252000) for building the EMS and CHF 155000 (EUR 106000) per year for operating it.

3.2 OPTIMISE OPERATION BY PROVIDING TRAINING

Giving staff at all levels, from management to shop floor, the necessary training and instruction in their duties can help to improve the control of processes and minimise consumption and emission levels and the risk of accidents.

Numerous examples exist for environmental benefits, including the prevention of accidents, that result from optimised operation through training, e.g.

• avoiding spillage when disconnecting pipes and hoses, e.g. during the bulk delivery of milk; cleaning chemicals, such as caustic and organic solvents, such as hexane for vegetable oil refining

• preventing product losses or spillages in warehouses by ensuring workers, e.g. forklift truck drivers, are trained

• ensuring that vessels and hoses are drained before disconnection

• discharging malodorous liquids below the liquid level in a vessel or back venting raw material deliveries into the delivering road tanker are both relatively easy and cost effective to initiate and can control odour emissions

• ensuring that noisy equipment, for which the noise levels cannot be reduced sufficiently at source, is operated for the minimum time necessary and that noise reduction measures to protect the environment, such as closing doors and windows, are always applied.

3.3 EQUIPMENT DESIGN

3.3.1 Design equipment to minimise consumption and emission levels

Description

Careful design of pumping and conveying equipment can prevent solid, liquid and gas emissions.

Examples of ways of minimising air emissions through design of equipment include fitting tanks with floating roofs, or pumps with double mechanical seals. Refrigeration plants and other equipment, e.g. boilers and cooling towers, can be adequately sized for the maximum expected demand and adequately controlled to always supply the required demand.

Conveyors can be completely enclosed and sealed, or fitted with hoods with local exhaust ventilation designed to trap emissions, when enclosure is not feasible. Minimising the length of conveyors and the number of transfer points can reduce emissions. Conveyors can be self-emptying, without dead spaces and provided with drainage to facilitate cleaning.

3.3.2 Selection of efficient and quiet fans

3.3.3 Selection of fans with low numbers of blades

3.3.4 Designing pipework to minimise noise emissions

Pipes can be enclosed within walls or laid in special ducts to reduce noise immission levels. Optimum results are achieved by either lining or filling cavities with sound absorbing material. Sound insulation can be improved by:

• selecting pipe material with sound insulating properties, e.g. cast iron instead of plastic

• increasing the thickness of the pipe wall

• insulating the pipe.

3.3.5 Sound insulation of equipment

3.3.6 Position equipment to direct noise away from neighbors

3.4 INSTALLATION DESIGN CONSIDERATIONS

Exp., Designing rooms with smooth walls and rounded corners that are easy to clean can also optimise the recovery of materials for use or disposal. This can also reduce water and detergent use for cleaning and consequently also waste water volumes and loads.

- Sound insulation of buildings
- Shielding buildings from noise immission sites
- Application of a spiral turbulence generator to a chimney to minimise noise emissions.

3.5 MAINTENANCE

Description

The effective planned preventive maintenance of vessels and equipment can minimise the frequency and size of solid, liquid and gas emissions, as well as water and energy consumption. For example, tanks, pumping and conveying equipment, compressor seals, valves and process drains can be major sources of leaks. Faulty process control equipment can lead to leaks, overflow and loss through dripping.

3.6 METHODOLOGY FOR PREVENTING AND MINIMISING THE CONSUMPTION OF WATER AND ENERGY AND THE PRODUCTION OF WASTE

Prevention and minimisation requires the adoption of a systematic approach. A successful

methodology usually consists of the steps:

• step 1: obtaining management commitment, organisation and planning
• step 2: analysis of production processes
• step 3: assessment of objectives
• step 4: identifying prevention and minimisation options
• step 5: carrying out an evaluation and feasibility study
• step 6: implementing the prevention and minimization programme
• step 7: ongoing monitoring by measurement and visual inspection.

The importance of preventing and minimising the consumption of water and energy, and waste production is described below.

Water pollution control can be achieved by:

• reducing the volume of the waste water generated
• reducing the strength of the waste water generated
• eliminating or decreasing the concentration of certain pollutants, particularly the priority pollutants
• recycling or re-using water
• waste water treatment.

Preventing and minimising energy consumption

In many of the FDM sectors, energy consumption is an important cost factor. Depending on the nature of the production activities, energy costs may vary from less than 1 % to more than 10 % of the production costs. Taking a systematic approach to reduce energy consumption is an important issue, both from the point of view of the environmental impact, e.g. greenhouse effect, and also due to cost savings.

Preventing and minimising waste production

For example, the use of materials originally intended for use in food products, but which do not meet the customers specification but are otherwise fit for consumption, may be suitable for use in animal feed.

It is reported that some transport/washing/process water, surplus biomass from biological WWTPs and other solid residues are sometimes spread on land. For example, potato fruit water, wheat solubles and the sludge from the waste water treatment in the starch industry and sugar beet transport water, possibly after settlement, can potentially be sent for landspreading.

3.7 PRODUCTION MANAGEMENT TECHNIQUES

3.7.1 Apply production planning, to minimise associated waste production and cleaning frequencies

Exp., If an installation produces several different products or the same product, but with different flavours or colours, then depending on the difference between the product specifications and the risk of cross-contamination, equipment and installation cleaning is required between products. This may be important for food safety reasons, e.g. when changing from using ingredients which people may be allergic to, such as peanuts when making ready meals. Also, for flavour and or colour reasons, e.g. when changing yoghurt flavours from blackberry to peach.

3.7.2 Receive materials in bulk

Many FDM raw materials are delivered by bulk tanker and stored in silos for direct use in the process. These include, e.g. grain, for milling, brewing and animal feed production; flour, for bread and confectionery manufacturing; semolina, for making pasta; sugar for confectionery manufacturing and milk for producing milk, milk powder, butter, cheese, yoghurt and other dairy products. Silo storage is designed so that solid materials received first and fed through the top of the silo are used first from the bottom of the silo. Liquids such as milk are used batch wise. Problems with shelf-life can thereby be avoided by managing the control of receipt, storage and use.

3.7.3 Minimise storage times for perishable materials

3.7.4 Transport solid materials dry

Many raw materials, co-products, by-products and wastes can be transported without using water. This reduces the entrainment of organic matter into water, which would consequently have to be treated in either an on-site or MWWTP, or sent for landspreading.

3.7.5 Use a waste management team

3.7.6 Segregation of outputs, to optimise use, re-use, recovery, recycling and disposal (and minimise water use and waste water contamination)

Accurately positioned splash protectors, screens, flaps, drip trays and troughs can be used to contain individual materials separately. They can be fitted at processing, filling/packing and transfer lines and next to workstations, such as peeling, cutting and trimming benches. The position and design of, e.g. a tray or trough, the means of preventing mixing with water and the transportation of the liquids or solids depend on the unit operation, the degree of segregation of different materials desired or required and their ultimate intended use, or disposal route.

3.7.7 Use of by-products, co-products and residues as animal feed

3.7.8 Segregation of water streams to optimise re-use and treatment

3.7.9 Minimise heating and cooling times

3.7.10 Optimise start-up and shut-down procedures and other special operating situations

Start-up and shut-down procedures and other special operating situations can be optimised. For example, by minimising the numbers of start-ups and shut-downs, waste gases from purge vents or preheating equipment, can be minimised. The emission peaks associated with start-up and shut-down can be avoided and consequently, the emissions per tonne of feedstock are lower. This also applies to the operation of abatement equipment.

3.7.11 Good house keeping

Enforcing a system to maintain the installation in a clean and tidy manner can improve the overall environmental performance. If materials and equipment are kept in their allocated place then it is easier to ensure that use-by dates are respected and less waste is generated. It is also then easier to clean the installation and reduce the risk of infestation by insects, rodents and birds. Spillages and leaks can be actively minimised and spilled materials can be collected dry immediately.

3.7.12 Manage on-site vehicle movements

By controlling the times when vehicles enter and leave the installation and the location and times of on-site vehicle movements, noise emissions off-site can be reduced at sensitive times, e.g. at night during the hours when neighbors, in residential areas, normally wish to sleep. This may be optimised further by the selection of quiet vehicles, including those that are well maintained and providing road surfaces with low noise transmission qualities.

3.8 PROCESS CONTROL TECHNIQUES

The benefits of improved process control include an increase in saleable product, improved quality and reduced waste.

3.8.1 Control temperature, by dedicated measurement and correction

Raw material waste and waste water generation can be reduced by controlling the temperature, e.g. in storage vessels, processing vessels and transfer lines. Possible benefits from this include reduced deterioration of materials, reduced out-of-specification products and less biological contamination.

In confectionery manufacture, temperature sensors can be used to minimise the temperature drop during product transfer, thereby minimising product deterioration.

3.8.2 Control flow or level, by dedicated measurement of pressure

Pressure or vacuum may be applied in several operations, e.g. in filtering, drying, fermenting, autoclaving.

In an example dairy, pressure measurement is used in monitoring and controlling flow velocities in pipelines, via pump controls, to avoid friction damage to the product.

3.8.3 Level measurement

The two main categories of level sensors are level-detecting sensors and level-measurement sensors. Level-detecting sensors indicate whether or not a fluid is present at a specific point in a vessel (usually a high or low point). Most applications are connected to a visual indicator, a visual or audible alarm, or on-off control of flows in or out of the vessel. Level-measurement sensors allow continuous monitoring of actual fluid levels, with associated variable controls, e.g. increasing or slowing pumping rates.

3.8.4 Flow measurement and control

In an example dairy processing 3000 m^3 of raw milk a week, 0.2 % of waste milk was saved by optimising the water/milk interface through flow-meters and conductivity probes. The final site waste water COD reduced from 3100 to 2500 mg/l.

A confectionery manufacturer found that there was considerable variation in the weight of chocolate coating on its products. A number of measures were implemented to improve the control of chocolate addition. These included installation of an electromagnetic flow-meter and a control valve to control the chocolate feed rate accurately. Consumption was reduced by 10 t/yr.

3.8.5 Analytical measurement

To minimise wastage and to check the quality of materials, the pH, conductivity and turbidity of a range of fluids are commonly checked in-line.

pH measurement

pH probes measure the acidity or alkalinity of a liquid. pH is important in many applications, e.g. controlling milk quality; monitoring cream and cheese ripening; fermentation processes; the production of baby foods and treatment of both water and waste water.

Conductivity measurement

Conductivity meters were installed to help reduce detergent use. The conductivity probe detects whether water or detergent is in the line and, if detergent is present, it diverts the flow to a detergent recovery tank. The result was recycling of rinse-water, reduced use of detergent and a consequent reduction in COD in the waste water.

The Example dairy reported savings of GBP 10000/yr and a payback period of 4 months on the investment.

Turbidity measurement

Economics

The food manufacturing company referred to reported lower waste water treatment costs and savings of over GBP 100000/yr.

Use automated water start/stop controls

Use of control devices

At an example chicken processing company, excessive water consumption was identified. Flow regulators were installed to fix the water supply to particular processes at the rate required by the process, thereby saving on water consumption.

At the chicken processing installation, the introduction of flow regulators cost less than GBP 1000 and resulted in water savings worth over GBP 10000/yr.

Use of water nozzles

Selection of materials

Selection of raw FDM materials which minimise solid waste and harmful emissions to air and water

Exp., The selection of fresh materials and those which meet the quality standards required for processing at the installation, before the materials are received at the installation, can minimise the amount of waste due to disposal of, e.g. over-ripe fruit and vegetables or fish that has started to decompose and is unsuitable for processing. This can be helped if agreements are made with the grower/supplier about, e.g. time of harvesting, harvest production and harvest processing. Additionally, agreements can be made about the use of pesticides, e.g. about ceasing their use sufficiently in advance of harvesting to minimise the contamination of waste water from washing fruit and vegetables.

Study Questions

1. Explain how the training of the staff can optimise operation for environmental benefits.
2. In what ways can improve equipment design to minimise consumption and emission levels including noise emissions?
3. List the main steps for the successful methodology for preventing and minimising the consumption of water and energy and the production of waste.
4. Explain how production planning can minimise associated waste production and cleaning frequencies.
5. How is it possible to avoid problems with shelf-life by managing the control of receipt, storage and use of materials in the FDM sector?
6. Give examples of materials which can be collected separately for optimal use or disposal in the FDM sector.
7. Explain how raw material waste and waste water generation can be reduced by controlling the temperature.
8. Describe how a pressure control can be applied to minimize of waste in FDM sector.
9. Give examples of use of level sensors in FDM processing.
10. Describe the typical applications of flow measurements in the FDM sector.

LECTURE 4
TECHNIQUES FOR MINIMISING AIR EMISSIONS FOR FDM

Lecture schedule

4.1 Air emissions control strategy.
4.2 Process-integrated techniques.
4.3 End-of-pipe air treatment.

This lecture is divided in three main sections. Section 1 describes a systematic approach to air emissions control, from the initial definition of the problem to how to select an acceptable solution. Section 2 describes process-integrated techniques that are used to prevent or minimise air emissions. Finally, Section 3 describes end-of-pipe abatement techniques used after process-integrated measures.

4.1 AIR EMISSIONS CONTROL STRATEGY

Step 1: Definition of the problem

Information is gathered about legislative requirements for emissions into the atmosphere. Local configuration, for example. weather and geographical conditions, can also be important in determining the problem, for example, for odour.

Step 2: Inventory of site emissions

The inventory covers normal and abnormal operational emissions. The characteristic of each emission point allows subsequent comparison and ranking with other points of site emission.

A systematic way to determine normal operational emissions into the atmosphere is to work through each process and determine all potential emissions. For example, this study may include the following site operations:

- delivery of raw materials;
- storage of bulk raw materials;
- minor raw material storage, for example. drums and sacks;
- production;
- packaging;
- palletizing or warehousing.

Step 3: Measurement of major emissions

Emissions to the atmosphere are quantified to determine priorities for prevention and treatment. The measurement will allow to regulate emissions in terms of the magnitude of their impact.

Step 4: Selection of air emission control techniques

4.2 PROCESS-INTEGRATED TECHNIQUES

Process-integrated procedures to minimize emissions to the atmosphere usually have other environmental benefits, for instance optimizing the use of raw materials and minimizing generation of waste.

4.3 END-OF-PIPE AIR TREATMENT

Table 4.1 lists some widely used end-of-pipe air treatment techniques.

Table 4.1 - Treatment processes

Treatment processes	
Solid and liquid pollutants	Gaseous pollutants and odour/VOCs
Dynamic separation Wet separation Electrostatic precipitation Filtration Aerosol/droplet separation*	Absorption Carbon adsorption Biological treatment Thermal treatment Non-thermal plasma treatment Condensation* Membrane separation*
*Not described as an air emission minimisation technique in this document	

4.3.1 Optimal use of air abatement equipment

The need for pollution control equipment can vary depending on the prescription, for example, in the case of odor.

When the example of installing a moist canned food factory that operated without the emission of fetid substances began to produce another product, odour became a serious problem, as existing odor control measures were unsuitable for a new recipe. Changes in the recipe also led to fluctuations in odors in animal feed mills, where fish oils or molasses are added on a batch basis. These examples demonstrate a different need for abatement, even in some separate installations.

4.3.2 Collection of air emissions at source – local exhaust ventilation

Enclosure of sources of emissions into the atmosphere and use of local exhaust ventilation uses much less energy than treating the whole volume of room. Emissions to the atmosphere include, for example, odors that often arise thanks to VOC emissions and dust, such as grain and flour. To be effective, the suction capacity must be adequate, and characteristics such as guide plates and hoppers with swing flaps and lids can help minimize dust and gas emissions.

4.3.3 Transport of ducted emissions to the treatment or abatement equipment

Ducted emissions are transported to the treatment. There are three main factors to consider when designing equipment for transporting emissions to treatment plants: transport velocity, the design of ventilation ducts and discontinuous flows.

The transport of emissions from the ducts to treatment facilities requires careful consideration to minimize any operational problems. In particular, the particle deposition potential and the potential for condensation of water and other contaminants in the air can lead to serious contamination, which requires frequent cleaning and can lead to problems with hygiene.

4.3.4 Selection of end-of-pipe odour or VOCs abatement techniques

When choosing odor control methods, the first step is to analyze the flow, temperature, humidity and concentration of particles and contaminants of the malodorous emissions. Odors often arise from VOC emissions, in which case the abatement technique used must take into account of both toxic and flammable hazards.

4.3.5 Techniques of dynamic separation

The basis used for the separation and removal of particles in dynamic separators is the field forces, which are proportional to the particles mass. Consequently, gravity separators, deflectors or inertial separators and centrifugal separators, such as cyclones, multiclone and rotary flow cleaners, are dynamic separators. They are mainly used for the separation of large particles (> 10 am) or as an initial stage before the removal of small dust by other methods.

4.3.5.1 Separators

The stream of waste gas is passed into a chamber in which the dust, aerosols and/or droplets are separated from the gas thanks to the influence of gravity/mass inertia. The effect is increased by reducing the velocity of gas by design means, for example baffles, lamellae or metal gauze.

The design should ensure a good uniform speed distribution within the vessel. Preferential flows adversely affect on efficiency. The use of internal obstructions in the inertial separator makes it possible to operate at higher speeds, which is a decrease in the volume of the separator compared with the settling chamber.

Separators have follow characteristics: a simple and reliable design, small space requirements and high operational reliability.

Deflection or inertia separators provide effective dust removal. Because of their inertia, larger particles can not follow the repeatedly deflected gas flow and are separated. With an appropriate design, a separation rate of 50% can be achieved for particles in excess of 100 am.

Applicability.

Separators can be use where:

• in the untreated gas there is a high level of dust;

• there is no special requirement for the removal of small particles;

• there is a need for preliminary separation and / or protection and relief of downstream systems;

• high pressures, for example, high-pressure dust extraction;

• high temperatures; high temperature dedusting.

Economics.

Low cost of using.

4.3.5.2 Cyclones

Cyclones use inertia to remove particles from a gas stream using centrifugal forces, usually inside a conical chamber. They work by creating a double vortex inside the cyclone. The incoming gas is forced into a circular motion down the cyclone near the inner surface of the tube of cyclone. At the bottom, the gas turns and spirals through the center of the tube and comes out of the top of the cyclone. The particles in the gas flow are forcedly directed to the walls of the cyclone due to the centrifugal force of the spinning gas, but they counteract the force of the hydraulic flow of gas passing through the cyclone and emerging from it. Large particles reach the wall of cyclone, after that they are collected in the bottom hopper, while the fine particles leave the cyclone with the outgoing gas.

Cyclones are characterized by a simple and reliable design, small space requirements and high operational reliability.

The operational principle of a cyclone see in Figure 4.1.

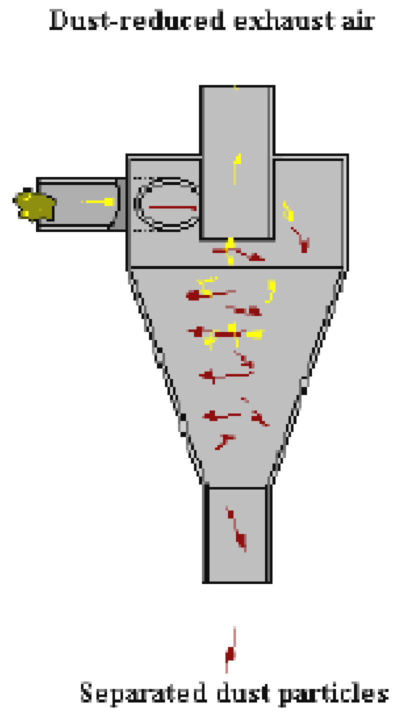

Figure 4.1 - Operational principle of a cyclone

It is reported that cyclones are used to remove fine particles in the exhaust air of the dryer, during the manufacture of distillers dried grains, and the efficiency of the cyclones can reach 99.97%, depending on process conditions and particle sizes. Applicability:

Cyclones are used to control the material in particulate form, preferably> 10 µm. Nevertheless, cyclones with high efficiency are effective even for particles as small as 2.5 µm in size.

Cyclones used without other methods of pollution control are generally not suitable for observing air pollution regulations, but they serve a purposes as precleaners for more expensive final control devices, such as fabric filters or ESPs. They are often used after spray drying operations and after crushing, grinding and calcining operation. Fossil fuel-fired industrial fuel combustion units usually use several cyclones that operate with greater efficiency than one cyclone, and can separate particles <2.5 µm.

Cyclones are used to remove solid and liquid air pollutants. They are mainly used to separate only large particles, for instance > 10 am. They are suitable for use where:

• there is a high level of dust in the untreated gas;

• there is no special requirement for the removal of small particles;

• preliminary separation and / or protection and relief of downstream systems are needed;

• high pressures, for example high-pressure dust extraction;

• high temperatures; de-dusting of high temperature.

Economy:

Low cost.

Examples of plants:

Cyclones are used in the production of animal feed; powdered milk; dried soup; cake mixes; custard; distillers of dried grains; dry sugar beet; starch; ice cream mixes; coffee roasting, drying and blending; tea blending and malt blending, as a rule, cyclones are used as an integral part of the process to extract dust from extracted air for reprocessing. They can be used in the vegetable oil sector to remove small impurities, such as plant residues, dust, sand and emissions of moist dust from crude oilseeds.

4.3.5.3 Wet separation

In methods of dynamic separation, effective mass forces, for instance gravity, inertia and centrifugal forces, sharply decrease with increasing size of particle. Wet cyclones are highly efficient units, spraying water into the waste gas stream to increase the mass of the particulate material, and therefore also to remove the thin material and improve the separation efficiency. Although it simply carries pollutants from the air into the water. Wet separators can be selected for specific applications, for example, when there is a risk of explosion associated with a dust.

Different models of wet separators can be distinguished by classifying them in terms of their design characteristics. Here are some examples:

• absorption methods, such as scrubber towers, spray-scrubbers, packed bed absorbers;

• injection scrubbers, for example, high pressure injection scrubbers;

• jet scrubbers;

• vortex scrubbers;

• venturi scrubbers.

Achieved environmental benefits:

Reduction of air emissions, for example, dust. Potential re-use of airborne substances. This can be advantageous if it is possible to reuse the laden collecting liquid. Product recovery, for example, when processing vegetable oil, the collected dust is extracted and can be added back to the flour. Prevention of fire hazard.

4.3.6 Electrostatic precipitators

Electrostatic precipitators can be used to separate solid or liquid particles from off-gases. The particles distributed in the gas are electrostatically charged, then they adhere to the collecting plates.

The main components of the electrostatic precipitator are listed below: the filter housing; discharge, collection electrodes; source of power; gas guides or baffles, a system to clean the collecting plates. The process of separation can be divided into the following stages:

• charging of the particles in the ion field;

• transport of the charged particles to the collecting plate;

• collection and film formation on the collecting plate;

• deletion of the dust film from the collecting plate.

There are dry and wet electrostatic precipitator. They can have a horizontal or vertical gas flow. Dry electrostatic precipitators are mainly constructed with collecting electrodes in the form of a plate; they can be also called as plate electrostatic precipitators. In wet electrostatic precipitators, the collecting electrodes often take the form of tubes, where the gas flow is often vertical; they can be also called as tubular electrostatic precipitator.

Electrostatic precipitators provide separation rates of up to 99.9%, efficient separation of particles even below 0.1 am, and treatment of off-gas volumes above 1000000 m^3/h.

Electrostatic precipitators have relatively low losses of pressure, for example, from 0.001 to 0.004 bar; low energy consumption, for example, from 0.05 to 2 kWh / 1000 m^3 and a long service life. Wet electrostatic precipitators can provide higher separation rates than dry electrostatic precipitators. In particular, they can release fine dust, aerosols and to some extent, heavy metals and gaseous substances.

Using of electrostatic precipitators lead to producing of waste water. The dust-laden collecting liquid can be also treated and returned to the electrostatic precipitators or concentrated via evaporation. Dry plants, in particular, emit vapors laden with water vapor, which may contain particulate pollutants, odors and gaseous pollutants.

4.3.7 Filters

Filter separators are usually used as final separators after using of preliminary separators, for example, where the waste gas has components with properties destroying the filters, for example, abrasive dust or aggressive gases. This ensures a long filter life and reliable operation.

In filter separators, the gas passes through a porous medium in which the dispersed solids particles are retained as a result of different mechanisms. Filter separators can be classified based on the medium of the filter, the performance range and filter cleaning facilities, as shown in Figure 4.2.

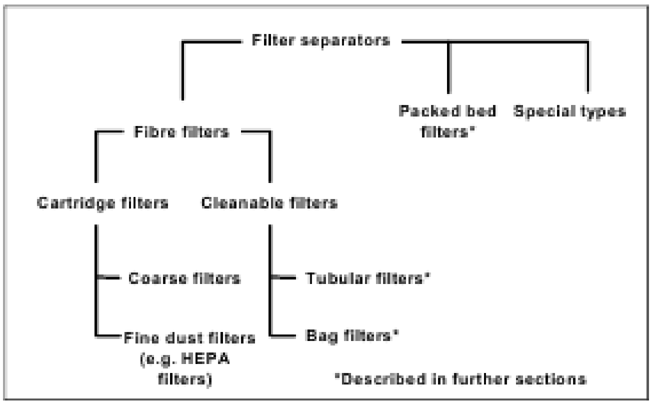

Figure 4.2 - Types and classification of filters

In the fabric filter, the off-gas passes through a tightly woven or felt fabric, causing the dust to collect on the fabric due to sieving or other mechanisms. Fabric filters can has a form of sheets, cartridges or bags (it is the most common type) with several individual fabric filter blocks placed together in a group. The sediment formed on the filter can significantly improve the collection efficiency.

Cleanable filters are among the most significant models of filter separators used in the deletion of solid particles. The practice of the use a fabric filter material has significantly changed to the use of non-woven materials or needle-felt materials.

The most great characteristics in cleanable filters are the air to cloth ratio and the loss of pressure.

The filter material executes the actual separation. It is an significant component of the filter separator. Woven fabrics have threads that intersect at right angles. In contrast, nonwovens materials and needle-felt are flat three-dimensional structures that can be stabilized by adhering fibers or alternating insertion and removal of fibers. Nonwoven materials and needle felt may also comprise an inner supporting woven fabric, for example, polyester or fiberglass fabrics to strengthen them. At present, needle felts made of synthetic fibers are being increasingly used.

Nonwoven materials and needle felt have three-dimensional filtration features. Particles of dust fall into the structure of the filter, forming an auxiliary layer for the filtration, which ensures a good separation of even the thinnest particles. One of the features of this "deep filtration" is a wide efficient particular surface area. Regular intensive cleaning removes the accumulated layer of dust and prevents excessive loss of pressure. However, problems can be caused by some dust particles such as sticky, fatty, agglomerating, adhesive, abrasive and hygroscopic.

4.3.7.1 Tubular filters

In tubular filters, the medium of the filter consists of tubes up to 5 meters in length with a diameter of 12 to 20 cm. The gas flows from the inside outwards or vice versa, depending on the used method.

The equipment contains a round filter consisting of a bank of vertical tubes installed in a cylinder, similar in shape to a cyclone and not requiring significant space. The flow of gas passes through the filter, and fine particles settle on the surface of the individual tubular filters. Tubular filters are cleaned with a fully automatic pulse backwash system using compressed air or other gases under pressure using a multi-stage injector system. Tubes are cleaned individually, which ensures continuous cleaning of tubular filters and removal of dust.

The product cleaned off the filters falls onto the outlet base where it is transported by air flowing through a special perforation system to the dust outlet. The gases leave a filter in the form of clean gas through a chamber of clean gas.

Individual cleaning of the tubular filters reduces the amount of dust that is cleaned from the filter at any time, which means that the potentially explosive volume of dust air in the filter chamber is correspondingly smaller compared with conventional filtration systems. This type of filters have been used successfully in the food industry since 1995. When used in the dairy industry, the filter product is comparable to the product of a tower sprayer. Tubular filters are applicable without a preliminary cyclone separator.

The round filter cleaning system is similar to the cleaning used to clean tubular filters installed as a CIP system. The air flow passes through the CIP nozzles at the base of the tubular filter and other nozzles inside the filter during operation, but not during CIP cleaning. This prevents clogging of CIP nozzles with dust from the process air.

Another significant advantage is that the base of the tubular filter in the area where the airflow is loaded with dust is maintained by clean air. This means that even with very hygroscopic products, the base does not contain heavy precipitation. This is a significant advantage over other filter designs and extends the operating time between cleaning phases. The clean gas and dirty gas zones, tubular filters, filter wall and other internal parts are sprayed intensively through carefully arranged groups of nozzles.

A tubular dust filter used to remove fines, downstream of a spray drier in a large dairy are shown in Figure 4.3.

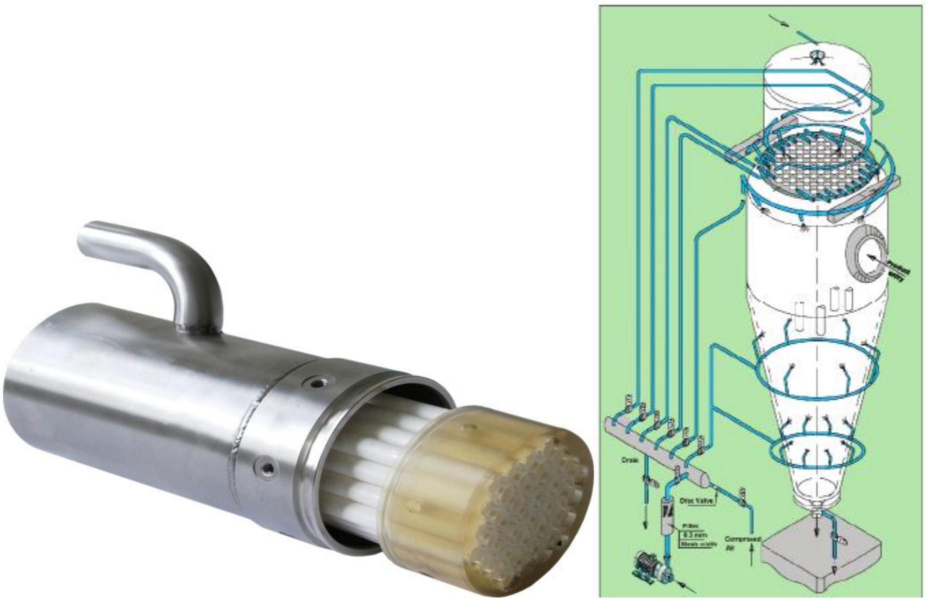

Figure 4.3 - Tubular filter system of a large dairy

Achieved environmental benefits:

Reduce waste production, for example because the separation process is dry, it can, in principle, be possible to reuse individual particles in the process or as a by-product. Filters use significantly less energy than cyclones, and create less noise. If filtering plants suitable for CIP are used for outgoing air, there is no need to use cyclones to achieve huge energy savings and noise reduction. Reducing the consumption of water and cleaning products with CIP.

Operational data.

Filter separators can achieve high separation rates, for example > 99%, and very fine particles are separated very efficiently.

In the example with dairy products, the dust emissions from drying were 534 kg / year after filtration, giving 28 mg of dust / ton of dried product. It is also reported that the emission level of 10 mg / Nm^3 is reached.

Example plants:

A milk powder manufacturer in Germany.

4.3.7.2 Bag filters

Bag filters consist of a filtering material up to 30 mm thick and have a length of up to 0.5 m and a length of 1.5 m. The filter bags are provided with an open end towards the clean gas channel. The untreated gas flow always goes from outside to inside, often into the upper part of the filter bag. Figure 4.4 shows an industrial baghouse.

Figure 4.4 - Picture of an industrial baghouse

Achieved ecological benefits:

Reduction of dust emissions to the air and energy consumption. Reduced waste production, for example, because of the separation process is dry, it can, in principle, be possible to reuse separated particles in the process or as a by-product.

Filters consume significantly less energy than cyclones, and create less noise. If filters suitable for CIP are used for outgoing air, there is no need to use cyclones to achieve huge energy savings and noise reduction. Reducing the consumption of water and cleaning products with CIP.

4.3.7.3 Packed bed filters

The filter material used in packed bed filters is usually a granular layer of sand, gravel, limestone or coke in a particle size range of 0.3 to about 5 mm. During the filtration, the dust particles are attached to the granular layer. A dust layer which helps the separation process is formed at the surface of the bed. The penetration of the dust to be separated can be prevented via using fine particles (<0.5 mm) and low flow speeds (<0.1 m/s). Though, there is a risk of bridging, which can lead to a reduction in the rates of separation.

The packed bed can reach several meters. Cleaning is carried out by countercurrent washing, mechanical shaking in combination with rinsing air or with the help of moving nozzles during cleaning. Using the design of a multi-compartment filter provides continuous cleaning.

Applicability:

To ensure the simultaneous separation of dust and gases, packed bed filters can be used. Packed bed filters are suitable to an essential requirement for dedusting in the case of high temperature or hot gas, namely the use of the thermal energy of the cleaned gas flows at level of high temperature. Packed bed filters can be used for dust removal, when:

• dust is hard or abrasive;

• there is a temperatures higher than 1000 ºC;

• dust is mixed with chemically aggressive gases;

• combustible and when a risk of sparks are higher;

• dust is mixed with mists;

• mixed with different gaseous pollutants, e.g. SO_2, HCl and HF, when it is possible to achieve simultaneous separation with suitable packing.

4.3.8 Absorption

The use of the words “absorber” and “scrubber” sometimes can cause confusion. Absorbers are usually used to remove trace gases while scrubbers are used to control particulate abatement. This difference is not always so significant that the odour and gaseous components in the air can also be removed with dust due to using vapour condensation or wet scrubbing.

The purpose of absorption is to obtain the maximum possible surface of the liquid and to provide a good counter current stream of gas and liquid. The absorption process is based on the preferred solubility of the contaminants present in the exhaust flow in the absorption medium. There are several different kinds of absorber design and many options with removal efficiency performances when contacting gas and liquid. Three types of absorbers are reported; packed bed absorber, plate absorber, and spray scrubber.

This method includes transferring the mass between the soluble gas and the liquid solvent in the gas-liquid contacting device.

The effective distribution of liquid and air is a great requirement in all type of absorbers.

Absorbing reagents:

The absorption efficiency can be improved if the absorbing liquid includes a reagent that reacts with the substances present in the air flow. This effectively decreases the concentration of airborne components on the surface of the liquid and thus maintains the driving force for absorption without the need for a large amount of absorbing liquid. There are different specific reagents that can be used in absorption systems for removing malodorous or other organic substances from the air flow. These reagents are usually oxidising solutions.

The most commonly used agents include hydrogen peroxide, sodium hypochlorite, ozone and potassium permanganate. Using of acids and alkalis as absorbing media is also quite widespread, and often the acid- alkali system is used in combination with an oxidizing absorbent. Thanks to the large number of substances that can be present in air emissions from a food processing installation, multi-stage absorbers are usually applied. Hence, the absorbent system can consist of an initial water scrubber, followed by an acid or alkaline stage and an oxidation stage.

Hypochlorite of sodium is a very widely used oxidizer, primarily because of its high reactivity. It was found that hypochlorite is particularly useful in installations with emissions containing a large amount of sulfur and nitrogen based malodorous substances.

Hypochlorite is usually applied at an alkaline pH to avoid dissociation into free chlorine. Hydrogen peroxide is usually less effective than hypochlorite, because of its lower oxidising power. However, it has the advantage that its product of reaction is water and can be applied for applications where aromatic compounds are present.

Hydrogen peroxide is commonly applied in acidified conditions, mainly to control its decomposition rate.

Ozone is also a powerful oxidizer, although its oxidative capacity is more significant in the liquid phase than in the gas phase.

A number of absorbing solutions based on surfactants have been applied in recent years, thought there is limited information on their effectiveness. In particular, a non-ionic surfactant system with reduced foaming, such as a material used for rinsing agents for dishwashers, has been used successfully.

4.3.8.1 Packed bed absorber

Packed bed systems are the most commonly applied absorber, which given the advantages of a maximum surface area per unit volume and a comparatively low drop of pressure. A packed bed absorber system layout is represented in Figure 4.5.

The air flow to be treated is directed in a countercurrent fashion to the flow of the recirculated liquid. The area of the packed bed includes a large number of packaging parts, usually made of plastic, which allow a large surface area for contacting gas and liquid with each other. A liquid system can contain anything from a simple recirculation pump assembly to a complex chemical dosing station together with pH control dosing/control facilities. It is reported that the distribution of the liquid is most effectively achieved by means of a number of nozzles arranged symmetrically along the surface area of the device. The treated airflow is discharged through a mist eliminator to remove any trapped droplets before discharging.

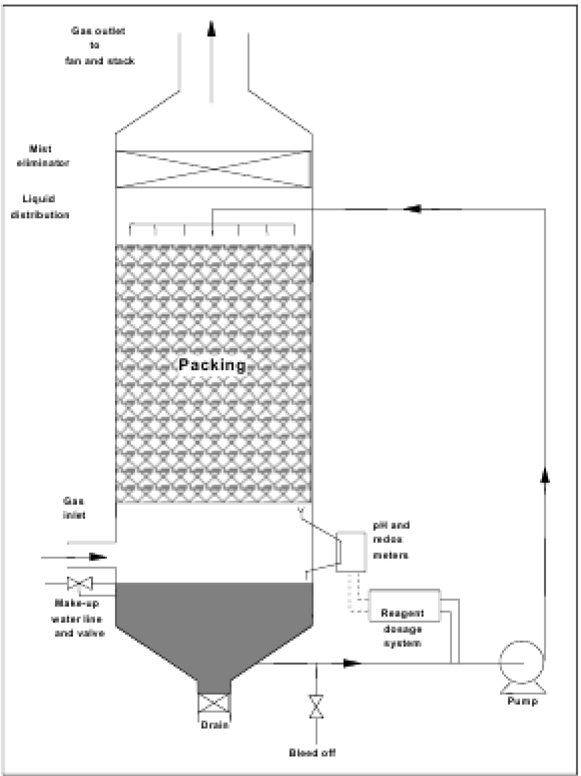

Figure 4.5 - Packed bed reactor layout

Economics:

Relatively inexpensive, compared other end-of-pipe odour control methods. Comparatively low capital and operating costs. Their economic efficiency is reduced if the exhaust gas to be treated are characterized by a high moisture content because of their preferential absorption of water vapor.

4.3.8.2 Plate absorber

Plate absorbers comprise a vertical tower with several horizontal perforated trays or sieve plates stacked in it. Baffles are located a short distance above the holes in the plates. Scrubbing liquid enters the top of the tower and passes successively along each of the trays. The air flow to be treated enters the lower part of the tower and flows upward, passing through the perforations in the plates. The speed of the air flow is sufficient to avoid liquid seeping through the perforations. The air flow that needs to be treated is guided through the falling curtains of the liquid that transfuses the trays. There are many changes in the design of the plate and the positioning of liquid nozzles. The plate absorber system is represented in Figure 4.6.

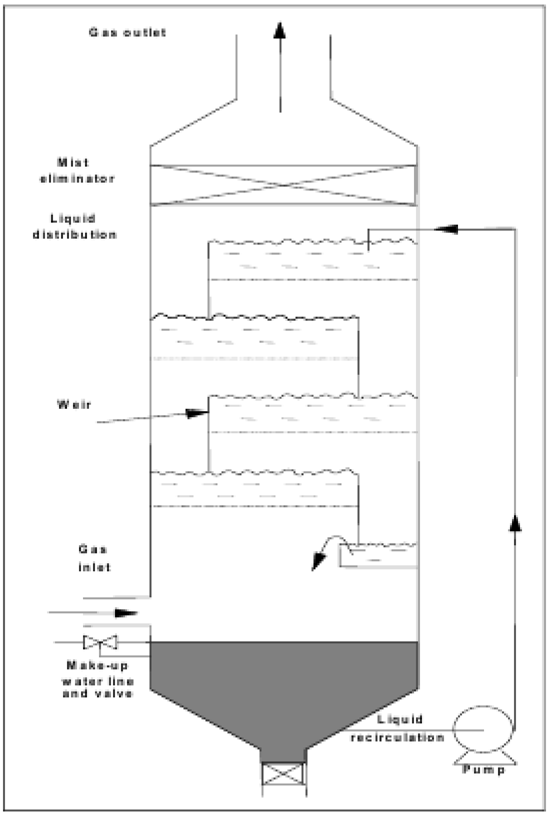

Figure 4.6 - Plate absorber layout

Plate absorber is compact, so it do not take up much space, but they may need space for the safe storage of chemicals.

Applicability:

In general, the absorbers are applicable for a wide range of volumetric air streams that contain gases and / or odors in comparatively low concentrations.

Economics:

Comparatively inexpensive than other end-of-pipe odour control techniques. Comparatively low capital and operating costs.

4.3.8.3 Spray scrubber

Spray scrubber simply contains a liquid spray that comes into contact with the rising airflow inside a vessel. The vessel does not contain packing or plates or any device used to improve gas-liquid contact. A typical configuration of the spray tower is shown in Figure 4.7.

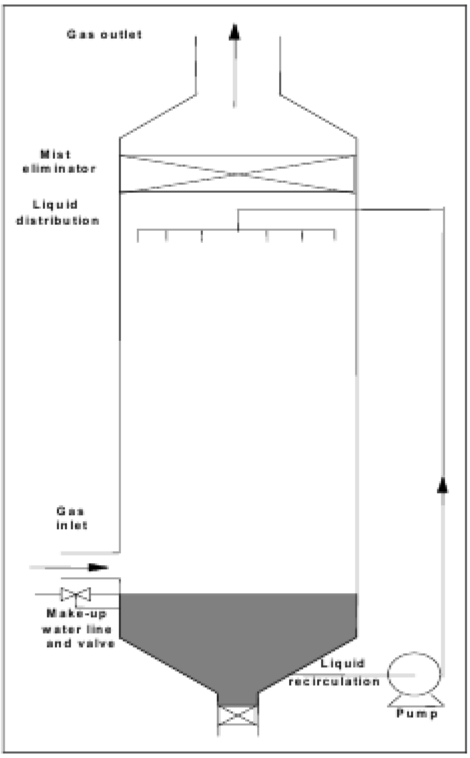

Figure 4.7 - Spray chamber layout

4.3.9 Carbon adsorption

Adsorption is a unit process, which involves the capture of airborne components onto a fine particulate active surface. There are a number of possible active materials that are used for general applications, including zeolites, silicas, polymeric resins and activated carbon. Currently, activated carbon is the most commonly used absorbent in the FDM sector, and therefore the term "carbon adsorption" is commonly used.

Carbon adsorption represents a dynamic process when vapor molecules collide with the surface of the solid and remain there during a period before desorbing again into the vapor phase. An equilibrium is established between adsorption and desorption, for example, the specific concentration of the compound on the carbon surface corresponds to the concentration or partial pressure of this compound in the gas phase.

The adsorption process can be either physical (the adsorbed molecules are retained on the surface by Van der Waals forces) or chemical (chemical bonds are formed between the adsorbed molecules and the surface). Both of these processes produce heat, the latter more than the former.

Activated carbon can be made from various carbonaceous materials, including wood, coal, peat, nut shells, lignite, bones and oil residues. Shell and coal-based products are commonly used in the vapor phase. The production process consists of the dehydration and carbonization of raw materials, which distills the volatile matter and forms a rudimentary pore structure. Thermal or chemical activation follow after that.

Carbon layers can either be used, or disposed of, or regenerated. Regenerative systems are usually used in installations where recovery of captured material is economically attractive. Most often, a single-adsorption system with a fixed layer is used. Regenerative systems are usually designed for several beds, so adsorption and desorption can be carried out simultaneously. It is usually necessary to increase the temperature of the adsorbent bed to release the adsorbate, with steam being the most commonly used medium. Therefore, the regenerative system requires an additional capture mechanism for materials desorbed during the regeneration process.

The fixed bed system comprises an activated carbon bed through which the gas stream to be treated is passed. The carbon is either in a simple compacted bed, or in the form of carbon filters. Filters are paper or carton cartridges containing powdered activated carbon. In general, the cartridge device is used for general ventilation of premises, while a packed bed system is used to control the odour from process exhausts. Once activated charbon has expired, for example, as judged by the increased outlet odour level, it is necessary to replace carbon or a cartridge. The packed bed system has the follow advantage – in most cases it can be returned for regeneration , while the cartridge filters are typically removed by the user.

Table 4.2 shows the principles of operation of the three major types of adsorbers.

Table 4.2 - Principle of operation of the main types of adsorbers

Adsorber	Principle of operation
Fixed bed unsteady state adsorber	The contaminated gas passes through a stationary bed of adsorbent
Fluidised bed adsorber	The contaminated gas passes through a suspension of adsorbent
Continuous moving bed adsorber	The adsorbent falls by gravity through the rising stream of gas

Applicability:

Carbon adsorption is generally suitable for low air productivity of less than 10,000 m^3/h and where the contaminant being removed is present in a low concentration, for example less than 50 mg/Nm^3. From the point of view of odor control, the main fields of application of carbon adsorption are the purification of ventilated air and the treatment of malodorous process emissions.

The presence of dust in the processed gas stream can seriously affect the efficiency of the carbon bed, as well as increase the drop in working pressure. Therefore, carbon adsorption is not applicable where dust or even condensable material is present. Dust and condensable materials can be removed in the pre-filtering device, although this will add complexity and cost to the device, and will add operational problems in the requirements for cleaning and dust breakthrough.

As a rule, the lower the temperature, the greater the amount adsorbed and, therefore, the longer the penetration time or bed life. As a guideline, carbon adsorption is not applicable at temperatures above 40 ºC. In addition, the efficiency of the activated carbon is reduced at a relative humidity above 75%, with the exception of water-soluble compounds such as lower amines and hydrogen sulphide. This preferred water adsorbent can lead to condensation in the bed, which makes the carbon inactive. Then the bed had to dry before it could be reused.

Economics:

This method has relatively low capital costs. The operating costs are high, for example carbon costs about 2,400 euro / t. Regeneration is usually not economical, so the carbon layer should be completely renewed when its adsorption efficiency begins to fall, which can occur only after a short period of time, depending on the rate of odor emission and odorant concentration.

4.3.10 Biological treatment

The process of using microorganisms for the emission of odour into the atmosphere is very widely used. The reaction rate of the biodegradation process is relatively low, and optimization of operating conditions can have a decisive influence.

There are two types of biological treatment. These types include biofilters and bioscrubbers. The most popular type of biological treatment can be considered a biofilter.

There are a number of constructive considerations that need to be considered to ensure effective work; this is the residence time, temperature, humidity, the effect of dust and fat on the filter, as well as the design and characteristics of the filter material.

Advantages and disadvantages of biological treatment methods are shown in Table 4.3.

Table 4.3 - Advantages and disadvantages of biological treatment

Advantages	Disadvantages
Relatively low capital cost	Restricted to wet bulb temperatures <40ºC
Relatively low operating costs	High land area requirements
Potentially high odour removal ~ 90 – 99 %	Potential for visible plume formation
Simple design and operation	Requires control of pH and water content
	Slow adaptation to fluctuating concentrations

Principle of operation.

A biofilm is a layer of water that predominates around individual particles of the filter material, in which microorganisms are present. When the air stream to be treated flows around the particles, a continuous mass transfer occurs between the gas phase and the biological layer. The volatile components present in the exhaust gases together with oxygen partially dissolve in the liquid phase of the biological layer. The second stage of the reaction is the aerobic biological degradation of the components in the liquid phase. Thus, a concentration gradient is created in the biological layer, which maintains a continuous mass flow of components from the gas to the moist biological layer.

Transport along the phase boundary and diffusion into the biological layer provides food for microorganisms living in the biological layer. Nutrients necessary for cell growth are provided from the filter material.

4.3.10.1 Biofilter

In biofilters, the cleaning occurs as the gas stream passes directly through a filter containing micro-organisms located on a fixed filter medium that degrade the pollutants in the gas stream. The biofilter material is arranged in the form of a packed bed. It is very important that the gas to be moistened in order to reach a high humidity. To avoid clogging of the filter it is necessary to remove dust before the biofilter in the case when waste gases has high dust levels.

This type of filters can be operated in either downflow or upflow fashion. The relative merits of each mode not clear and it is most likely that operational efficiency is the same in each situation. The pressure drop over a filter is low, typically in the range of 10 to 25 mm/m of packed height. The low pressure drop infers that proper design of the air distribution for either downflow or upflow installations is one of the most important design parameter. A typical layout of a such filter is illustrated in Figure 4.8.

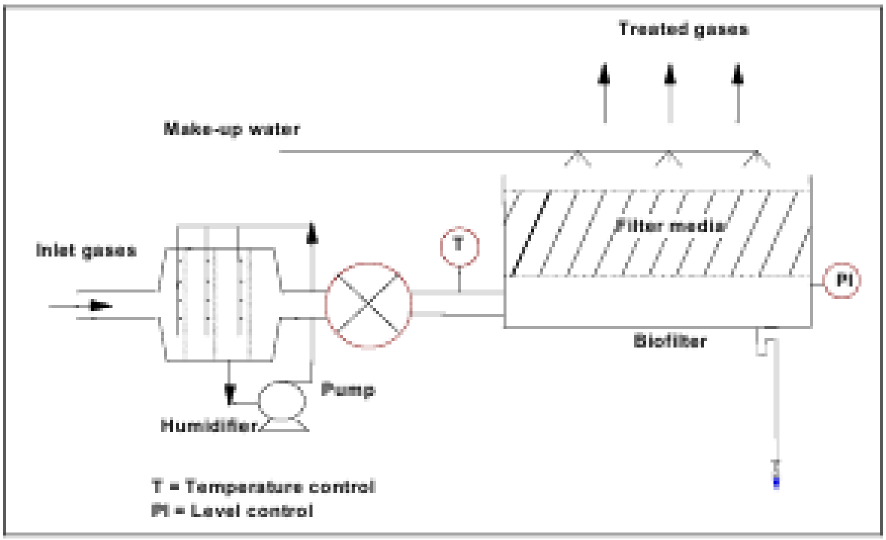

Figure 4.8 - Biofilter layout

To reach high level of humidity the waste gas is directed initially into a humidifier, where it meets with recirculating water. After humidifier the waste gas is directed to the biofilter.

In biofilters are used variety of filter materials. The filter is characterized by material with a high specific surface area, e.g. 300 – 1000 m^2/m^3, a high water bearing capacity, limited compaction characteristics and a limited resistance to flow. It often consist of fibrous peat mixed with heather in a 50 % proportion.

Microorganisms are active within the peat whilst the heather provides a stiffening agent to prevent compaction, thereby extending the operating life of the bed.

A variation of the peat/heather mixture represent the mushroom compost in which polystyrene spheres with 5 mm diameter are added for support, in a 50 % proportion. Rootwood is typically consist of tree roots, branches and loose twigs. The rootwood is split into lengths of typically 15 cm by a tearing apart action rather than straight cuts. This action is necessary to provide the maximum surface area and does not require supporting material.

The such filters can be subdivided into soil and non-soil based biofilters. The soil based biofilter or soil bed, has a layer of porous soil under which network of pipes are placed through which the airstream to be treated is passed.

An open structured soil is important to keep the pressure drop across the bed to a minimum.

Achieved environmental benefits:

Reduced air emissions, e.g. odour/VOCs.

Cross-media effects:

Generation of acidic by-products, necessity of disposal of the filter material, recycling of condensation water.

Applicability:

The biofilter are used in order to eliminate biodegradable gaseous air pollutants, such as organic pollutants and odours. It can be usually used in the fish sector, coffee processing and WWTPs. It are applicable for the purification of room and process air in beer yeast drying and in oil mills; cleaning of roasting gases in cocoa production and cleaning of cooling air in production of animal feed.

The biofilter can not be used in the case when temperatures of airborne in excess of 40 ºC. If temperatures above 40 ºC during a lot of time the micro-organisms present in the filter die and the bed of biofilter requires reseeding. If temperatures below 10 ºC, the rate of biological degradation are тoo low. This technique is not used when the humidities lower than 95%.

4.3.10.2 Bio-scrubber

A bio-scrubber are absorbers which includes two parts: an absorption column and a biological water treatment step, usually in the form of an activated sludge facility. Thus, in the bio-scrubber there are two separate processes that have to interact. First the pollutants are transferred from the treated gas to a water phase thanks to absorbtion. Then the scrubber fluid is regenerated when the micro-organisms degrade the pollutants to carbon dioxide and water. It is necessary to control pH and other parameters if the pollutants are acidic or alkaline.

The micro-organisms used in the bio-scrubber require a range of different nutrients in building up their cells. Hence, it is important to add nutrients. It is also necessary to add a fresh water.

The bio-scrubber essentially comprises a packed bed absorber containing a bacterial population within the packing and the sump. The polluted gas is cleaned in the tower when it passes through a flow of water in which are a population of bacteria. A construction of a bio-scrubber installation is shown in Figure 4.9.

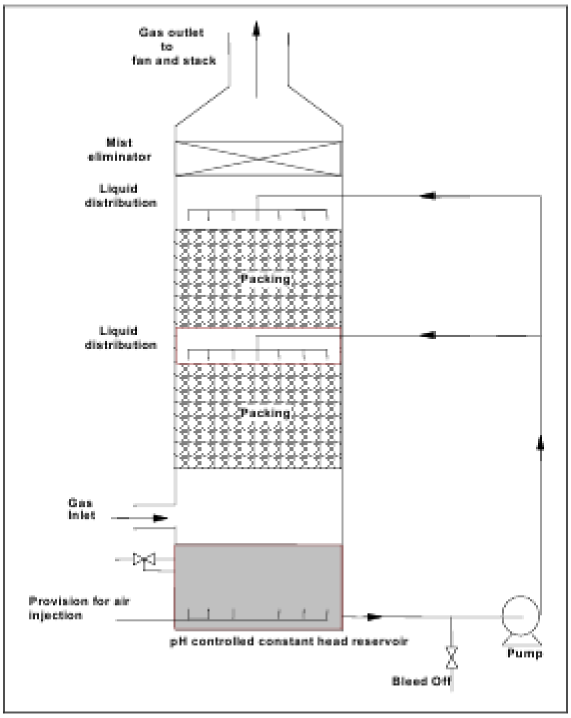

Figure 4.9 - Bioscrubber layout

The process of cleaning of the contaminated gas requires has relatively high investment costs. The bio-scrubber need more energy than the biofilter. One of the advantages of bio-scrubber is that it requires a much smaller land area than biofilters.

Economics:

A bio-scrubber has high level of odour removal and relatively low cost when compared with alternative treatment techniques.

4.3.11 Thermal treatment of waste gases

Some gaseous contaminants and odor can be oxidized at high temperatures. The reaction rate increases exponentially with temperature.

Oxidizing contaminants include all organic substances, as well as inorganic compounds, such as carbon monoxide and ammonia. With complete combustion, carbon and hydrogen react with oxygen to form CO_2 and water. Incomplete combustion can lead to the appearance of new pollutants, such as carbon monoxide, and in fully or partially unoxidized organic compounds.

If the exhaust gas includes elements such as nitrogen, sulfur, halogens and phosphorus, combustion results in the formation of inorganic contaminants, such as sulfur oxides, nitrogen oxides and hydrogen halides, which must then be removed by other methods for cleaning exhaust gases if concentrations are too high. This limits the possibility for the combustion of pollutants.

There are a number of security requirements, in particular:

• the need for protection from the flash flame between the thermal oxidant and the gas flow to be treated. This can usually be achieved with a flame arrester or a water seal;

• on start-up, before the burner ignites, the thermal oxidizer must be purged with air by a volume equivalent to five times the volume of the installation. Any reignition of the burners during operation require burner purge period;

• when air is rich in solvents, risk assessment to be done.

4.3.11.1 Thermal oxidation of waste gases

Thermal oxidants of direct flame usually operate at temperatures from 700 to 900 °C. The reaction temperature connects with the nature of the pollutant; it can be lower, but for less easily oxidized compounds, such as organohalogen substances, it can exceed 1000 ºC. For malodorous substances, a temperature of 750–800 °C is usually taken. A typical scheme of a thermal oxidizer is shown in Figure 4.10.

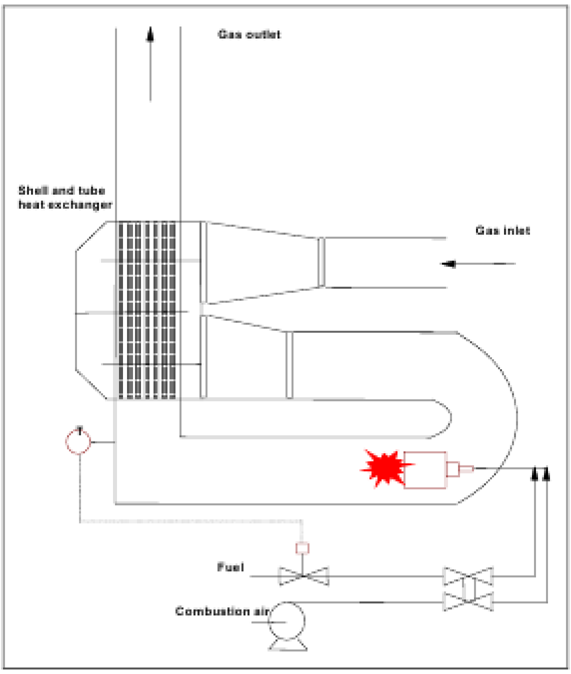

Figure 4.10 -Thermal oxidiser layout

Some form of heat recovery is almost always necessary to reduce operating costs and fuel consumption. Heat recovery is usually carried out in a shell and tube heat-exchanger, which allows the continuous transfer of heat to preheat the incoming gas flow. This type of system is called a recuperative system, with 70 – 80% of the heat recovery being a typical design level.

Heat recovery can also be reached in a regenerative system that uses two sets of ceramic heat-exchangers. There one bed is heated making a direct contact with the exhaust gas, and the other is used to preheat the incoming gases. The system works so that the beds alternate between heating and cooling. The potential of the heat recovery of this system is higher than the recuperative system, while the thermal regeneration of 80 – 90% is a typical design basis. Using of thermal fluids can become an alternative to this type of system.

A properly designed and controlled thermal oxidizer can provide an odor removal efficiency approximately 100%. The productivity of this method does not depend on the intensity of odor emissions.

Applicability:

Used to remove VOCs / odor. Thermal oxidation has the advantage that it is practically universally applicable as an odor control method, because most malodorous substances can be oxidized to non-malodorous substances at a high temperature, while the use of other methods is more restrictive.

Thermal oxidation is usually used for the processing of small volumes of less than 10,000 Nm^3/h, the driving factor is the increase in the cost for heating large volume of air streams. It is suitable for malodorous flows with varying concentrations of pollutants and is capable of treating a variable volumetric throughput.

If alkali metals are included in the soil in vegetable drying plants, they can cause premature failure of the ceramic media applied for regenerative heat recovery.

Economics:

This method requires high capital investment, but the main consideration in assessing the applicability of thermal oxidation is operating costs in terms of the fuel requirements. Using of recuperative or regenerative heat recovery systems can increase the efficiency of the technology and reduce operating costs. Modification is possible for all types of smoking kilns at different prices. Smoking kilns are applicabble with integrated equipment for thermal oxidation.

Example plants:

This method are used in at least one smokehouse in Germany and in smokehouses in the Nordic countries.

4.3.11.2 Oxidation of waste gases in an existing boiler

It may be possible to send malodorous gases to an existing boiler in place. This has the advantage of using existing equipment and preventing the costs of investing in an additional treatment option. The principle of operation is essentially the same as for thermal oxidation on a specially constructed plant.

A malodorous flow of exhaust gases is sent to the combustion airflow fan of the boiler or boilerhouse, and then to the boiler. It provides oxygen to the combustion process, and the malodorous substances are destroyed.

4.3.11.3 Catalytic oxidation of waste gases

Catalytic oxidation is a process analogous to thermal oxidation with the fundamental difference that the oxidation reaction carries out in the presence of a catalyst, rather than without it. The main advantage of catalytic oxidation is that much lower operating temperatures are required, for example, from 250 to 500 ºC.

As with adsorption, the reagents for the heterogeneous gas reaction must first be transported to the internal surfaces of normally porous catalysts. Since there is a general lack of adequate data on substances, such as the reaction rate constant and diffusion coefficient, reactors are usually developed on the basis of empirical data.

The main parts of the system of a catalytic combustion are auxiliary a heat-exchanger, firing equipment, and a reactor with a catalyst. A typical layout of a catalytic incinerator is represented in Figure 4.11.

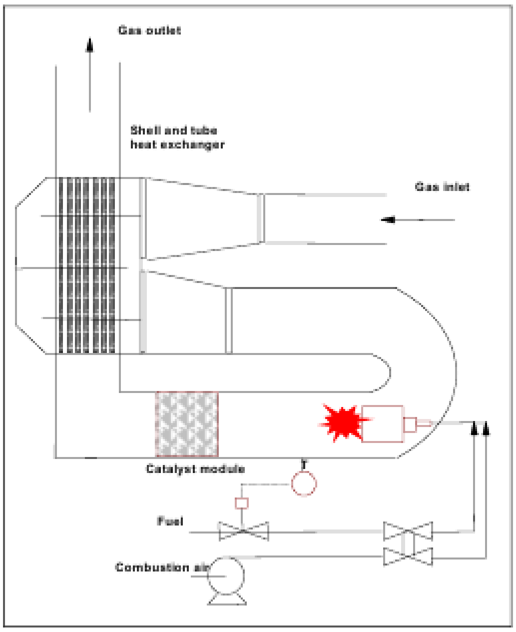

Figure 4.11 - Catalytic incineration layout

The air flow enters the unit and is preheated in a conventional shell and tube heat-exchanger.

Then, the preheated inlet flow is further heated by the burner to the desired temperature of oxidation before passing it to the catalyst. Pollutants present in an malodorous air flow together with oxygen diffuse onto the surface of the catalyst. Oxidation occurs and the oxidation products are desorbed back into the gas flow. These transport processes require a finite time in the catalyst, and the reaction rate depends strongly on the operating temperature. The treated gas flow then is directed through the heat-exchanger, heating the incoming malodorous airflow.

The most significant characteristic of the catalyst bed is the ratio of surface area and therefore the available area which are necessary for the reaction.

The active components commonly applied comprise platinum group metals and metal oxides Co, Cr, Cu, Fe, Mo, Ni, Ti, V and W. The support materials are generally metals in the form of plates, woven materials or nets, oxides of metals, for example, Al_2O_3, SiO_2 and MgO, and minerals, for example, zeolite and pumice, in molded forms.

Catalytic incinerators require less space than waste gas incinerators.

Economics:

Lower fuel costs with comparison to incineration. The cost of replacing the catalyst is an significant parameter in the calculation of operating costs.

4.3.12 Non-thermal plasma treatment

Non-thermal plasma treatment is a method for controlling odor, based on the creation of a zone with high reactivity in waste gases, in which malodorous molecules are destroyed. The way of creating this reactive zone can differ.

Plasma is a gas state in which the molecules of the gas are divided into a collection of ions, electrons, charge-neutral molecules of gas and other species in varying degrees of excitation. Corresponding to the amount of energy added, the resulting plasma can be called as thermal or non-thermal.

Equipment for non-thermal plasma treatment of odors has a modular design with a light and compact construction. One module processes air volumes of 20000 – 25000 Nm^3/h. When more processing is required, several modules can be installed in parallel. The technique does not require any technological additives and consumables for the operation, except for energy. It is characterized by a low pressure drop in the range of 30 – 180 Pa. It can be used both on the suction side and on the pressure side of the main fan of air extraction.

Applicability:

Non-thermal plasma treatment can be used as an end-of-pipe solution to malodorous waste gases in the FDM sector. This includes, for example, emissions from extruders, coolers, driers, and hammer mills. This method is used to various types of off-gas, which also can include dust, although dust removal may be required. The most odorous waste gases include a mixture of organic and inorganic substances. The plasma process has a high productivity for organic components, but is less effective when removing some inorganic components, for example, NH_3 and H_2S. This is because of the fact that at the present time achievable energy densities have insufficient power to destroy these substances. The equipment must be protected from a significant amount of water condensation on the equipment.

Because of changes in the conductivity of the waste gas, the technology of non-thermal plasma is less effective at temperatures of waste gases exceeding 80 ºC.

Economics:

According to the technology supplier, one module (treating between 20000 and 25000 Nm^3/h) will cost about 117000 euros. This includes the necessary equipment, electromechanical maintenance and commissioning from the supplier, but excludes the mechanical installation. Annual maintenance costs are approximately 3-5% of the investment costs. Consumables comprise power and minor amounts of rinsing water.

4.3.13 Physical dispersion of odour/VOC emissions

Dispersion is sometimes applied by existing installations on the site, for instance using a high discharge boiler stack.

The dispersion of an exhaust emission is in the air, and consequently its resultant ground level odour concentration, will correspond to a variety of factors, some of them are listed below:

• the prevailing conditions of the climate;
• discharge height;
• positioning of nearby buildings or structures;
• stack temperature (thermal buoyancy);
• velocity of a stack discharge;
• discharge stack configuration.

4.3.13.1 Extending the height of the discharge stack

The effect of buildings or structures in the immediate vicinity of the stack discharge can often lead to poor dispersion and, in some cases, to a phenomenon known as a plume grounding, where the exhaust is pulled downwards under the influence of neighboring structures. Air dispersion models can take into account of the potential impact of these structures.

4.3.13.2 Increasing stack discharge velocity

The magnitude of the discharge rate used to the final emission into the air can have a important effect on the resultant ground level impact of a malodorous emission. The increased discharge rate will lead to an increased momentum or buoyancy of the emission. This means that the discharge will have an increased elevation, thereby providing a greater potential for airborne dispersion and therefore lower ground level concentrations.

Study Questions

1. Describe four different measures for decreasing dust emission from solid materials handling by process integration.
2. What are the major process integration measures to reduce emissions of solvents and other organic liquids?
3. Give short descriptions of condensation, adsorption, absorption, membrane separation and biological methods to control air pollutants in the FDM sector.
4. What differences are there between the unit operations adsorption and absorption for separating pollutants from a gas flow?
5. List the four major principles which can be used for separating particulate pollutants from a gas flow?
6. How does an electrostatic precipitator work?
7. Describe the function of a cyclone for separation of particulate pollutants from a gas stream.
8. Why is water as an industrial solvent normally not considered the ultimate “clean” solvent?
9. How does the strategy of Cleaner Production effects the qualitative and quantitative pollutants profile of an industrial plant in the FDM sector?
10. Describe the function of biofilter.

LECTURE 5
END-OF-PIPE WASTE WATER TREATMENT

Lecture schedule

5.1 Discharge of waste water from installations.
5.2 Primary treatments.
5.3 Secondary treatments.
5.4 Tertiary treatments.
5.5 Natural treatments.
5.6 Sludge treatment

5.1 DISCHARGE OF WASTE WATER FROM INSTALLATIONS

When choosing a discharge option many factors are considered, including but not necessarily limited to:

• whether the waste water is clean or contaminated
• the availability of suitable space for on-site treatment
• the proximity and capacity of off-site WWTP(s)
• the proximity and characteristics of potential receiving waters
• the availability of other off-site treatment or disposal facilities
• on-site treatment costs versus off-site treatment/disposal costs
• the relative effectiveness, e.g. based on reduction of load, of on-site and off-site treatment
• the assessment of environmental risks associated with each option
• the disposal of secondary wastes arising from on-site treatment
• the ability to operate and maintain on-site treatment facilities
• negotiations with the permitting authority and/or WWTP operator and likely permit conditions
• projected trends in waste water volume and composition
• proximity of local residents.

The main options for discharging waste water from an installation are:

• to off-site, e.g. MWWTP without treatment
• to off-site, e.g. MWWTP after partial treatment
• to watercourse after full on-site WWTP
• off-site re-use of certain waste water streams, e.g. as a feed stream in another industry, or for irrigation
• off-site land application.

5.1.1 Waste water treatment techniques applied

Waste water in the FDM sector has the following typical characteristics:

• solids (gross and finely dispersed/suspended)
• low and high pH level
• free edible fat/oil
• emulsified material, e.g. edible fat/oil
• soluble biodegradable organic material, e.g. BOD
• volatile substances, e.g. ammonia and organics

• plant nutrients, e.g. phosphorus and/or nitrogen
• pathogens, e.g. from sanitary waters
• heavy metals
• dissolved non-biodegradable organics.

Waste water treatment techniques described and Table 5.1 summarises their typical application in the FDM sector.

Primary treatments

T1 Screening
T2 Fat trap for the removal of FOG and light hydrocarbons
T3 Flow and load equalisation
T4 Neutralisation
T5 Sedimentation
T6 DAF
T7 Diversion (emergency) tank
T8 Centrifugation
T9 Precipitation

Secondary treatments

T10 Activated sludge
T11 Pure oxygen systems
T12 SBR
T13 Aerobic Lagoons
T14 Trickling filters
T15 Bio-towers
T16 RBC
T17 BAFF – SBAF
T18 High rate filters
T19 Anaerobic lagoons
T20 Anaerobic contact processes
T21 Anaerobic filters
T22 UASB
T23 IC reactors
T24 Hybrid UASB
T25 Fluidised and expanded bed reactors
T26 EGSB
T27 MBR
T28 Multistage systems

Tertiary treatments

T29 Biological nitrification/denitrification
T30 Ammonia stripping
T31 Phosphorus removal by biological methods
T32 Dangerous and priority hazardous substances removal
T33 Filtration
T34 Membrane filtration
T35 Biological nitrifying
T36 Disinfection and sterilisation

Natural treatments
T37 Integrated constructed wetlands
Sludge treatments
T38 Sludge conditioning
T39 Sludge stabilisation
T40 Sludge thickening
T41 Sludge dewatering
T42 Sludge drying

Table 5.1 - The typical application of some waste water treatment techniques in the FDM sector

Emission type	Technique
Soluble organic material (BOD/COD)	T10, T11, T12, T13, T14, T15, T16, T17, T18, T20, T21, T22, T23, T24, T25, T26, T27, T32, T37
Total SS	T1, T5, T8, T9, T33, T34, T37
Acids/alkali	T3, T4
FOG (free)	T1, T2, T5, T6[1], T8[1], T9
FOG (emulsified)	T10, T12, T13, T14, T19, T20, T21, T28
Nitrogen[2]	T10, T11, T12, T13, T14, T15, T16, T29, T30, T35, T37
Phosphorus	T9, T10, T12, T14, T15, T16, T31, T37
Dangerous and priority hazardous substances	T5, T9, T10, T14, T32
1 Enhanced by using chemicals 2 Includes ammonia removal	

5.2 PRIMARY TREATMENTS

The term primary treatment is utilized to describe what is sometimes described as primary treatment, preliminary treatment or pretreatment.

5.2.1 Screening (T1)

After the solids are removed with in-process techniques and excluded from entering the waste water, for example the use of catchpots placed at drainage points inside the installation; further solids can be deleted from the waste water utilizing screening. Large quantities of non-emulsified FOG are removed if screening is carried out together with technical and operational measures to prevent clogging.

A screen is a device with holes, usually of the same size, which is used to retain coarse solids found in waste water. The screening element involves parallel bars, rods or wires, grating or a wire mesh or perforated plate. The holes may be of any shape, but are usually circular or rectangular slots. The distance between bars to remove very coarse materials prior to a finer screening, may be of from 60 to 20 mm. In order to remove smaller particles, such as pieces of vegetables and, for example, peas and beans in a canned food factory, the distance between the bars usually does not exceed 5 mm. The holes in the automatic screens range from 0.5 mm to 5 mm with holes of 1 – 3 mm in wide use. It is reported that smaller holes (1 – 1.5 mm) are less susceptible to blockage than larger ones (2 – 3 mm).

The basic types of screens utilized are static (coarse or fine), rotary and vibrating screens.

Static screens, brushed or run-down, can contain vertical bars or a perforated plate (Figure 5.1). This type of static screen needs manual or automatic cleaning.

In order to be effective vibrating screens need rapid motion. They are typically applied for primary treatments associated with the recovery of by-products, in particular solids with a low moisture content and preferably where the waste water does not include fats. Vibrating screens operate from 900 to 1800 rpm; the motion can be either circular, or rectangular, or square, changing from 0.8 – 12.8 mm total travel. The speed and motion can be chosen in accordance with a specific application. Priority in choosing the proper fine vibrating screen is the use of the correct combination of wire strength and the percentage of open area. The capacities of vibration screens are based on the percentage of the open area of the media of screen.

Figure 5.1 - Static screens

Rotary or drum screens get waste water at one end and discharge the solids at the other (Figures 5.2, 5.3). The liquid is transferred to the outside through the screen to the receiving box for forward transfer. The screen is often cleaned by continuous spraying through external spray nozzles that are inclined toward the end of the solids discharge. This type of screen is effective for flows containing a comparatively high solids content. Microscreens mechanically separate solid particles from the waste water using microscopically fine fabrics.

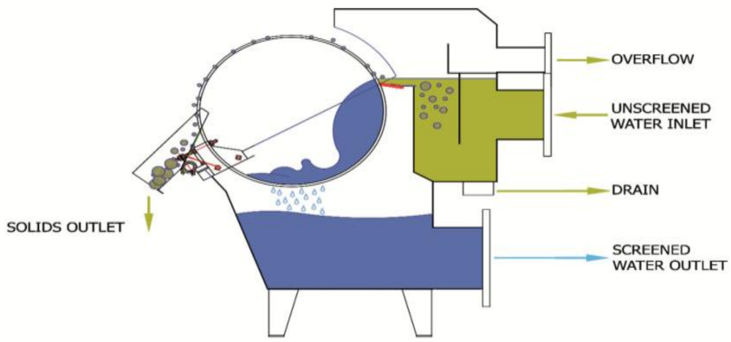

Figure 5.2 - Rotary screen

Figure 5.3 - Rotary screens

Achieved environmental benefits:

SS, FOG and BOD/COD levels reduced. Recovery of products, for example pulp in the fruit and vegetable sector.

Rotary or drum screens are applied in the fruit and vegetable, meat, fish, drinks and vegetable oil sectors.

5.2.2 Fat trap for the removal of FOG and light hydrocarbons (T2)

If FOG is not removed before aerobic biological treatment, it may hinder the operation of the WWTP because it is not easily destroyed by bacteria. Free FOG may be separated from water applying a fat trap (grease interceptor) (Figure 5.3). Similar device is utilized to separate light hydrocarbons.

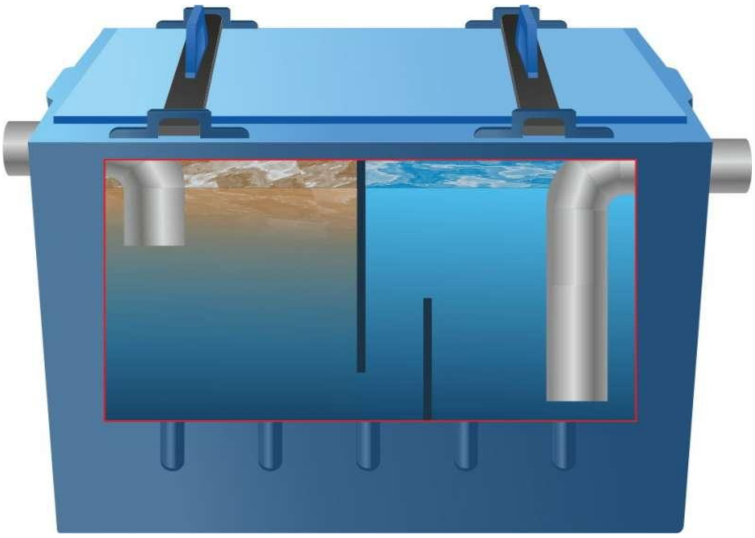

Figure 5.3 - Fat trap

A further improving of the fat trap is the parallel-plate separator where the separator chamber includes plates inclined at an angle of 45°.

In depend on the type of fat trap, for example without continuous fat removal, there may be emissions of odour, in particular during emptying.

Example plants:

The equipment are used in the meat and vegetable oils and fats sectors.

5.2.3 Flow and load equalisation (T3)

Typically, equalization tanks or buffer storage are provided to cope with the overall variability in flow and composition of the waste water, or to ensure corrective treatment, for example pH control or chemical conditioning. It may be necessary to take into account the need for equalization of waste water discharges to ensure that the flow and composition of waste water correspond to the design parameters of WWTP.

5.2.4 Neutralisation (T4) and self-neutralisation

The aim of neutralisation is to prevent the discharge of strongly acid or alkaline waste water. Neutralisation is applied to protect downstream waste water treatment processes.

The following are normally utilized to neutralize waste water which is characterized by low pH:

• limestone, limestone slurry, milk of lime (hydrated lime $Ca(OH)_2$);

• caustic soda (NaOH) or sodium carbonate (Na_2CO_3);

• ion exchangers (cationic).

The following are usually applied to neutralize waste water with high pH:

• introduction of CO_2, for example flue-gas and gas from fermentation processes;

• sulphuric acid (H_2SO_4) or hydrochloric acid (HCl);

• ion exchangers (anionic).

The term self-neutralization is applied when, in some cases, the size of the equalising tank, in combination with appropriate changes in the pHs of the waste water flows, means that no addition of chemicals is required. This can happen, for example in some dairy plants where both acidic and alkaline cleaning solutions are applied, and both are sent to the neutralization tank.

5.2.5 Sedimentation (T5)

Sedimentation is the separation from water, via gravity settling, of suspended particles that are more heavy than water. The settled solids are removed in the form of sludge from the bottom of the tank or periodically after the water removal.

The equipment applied for sedimentation can be either:

• rectangular or circular tanks equipped with the suitable scraper gear (top scraper for removing FOG, and a bottom scraper for solids removal) and sufficient capacity to ensure sufficient residence time for separation (Figure 5.4).

• laminar or tube separators in which plates are applied to increase the surface area for separation.

Figure 5.4 - Circular settling tanks

5.2.6 Dissolved air flotation (DAF) (T6)

The separation of materials which are lighter than water, for example edible oil/fat, can be intensified by utilizing flotation. In the FDM sector, dissolved air flotation is mostly applied. This method decreases the retention time but does not enable the separation of emulsified FOG from water and, consequently, is applied widely in the FDM sector to remove free FOG.

The main mechanism of DAF is the introduction of fine air bubbles into the waste water which includes the suspended solids to be floated. The fine air bubbles surround the chemically conditioned particles. Then they rise to the surface and the solids float to the surface with them.

The air is dissolved at pressure in 300 – 600 kPa (3 – 6 bar). The air is normally directed into a recycle flow of treated waste water which has already passed through a DAF equipment. This supersaturated mixture which are consisted of air and waste water flows to a large flotation tank in which the pressure is released, thus generating numerous fine air bubbles. In this tank they are accumulated, thickened and removed thanks to mechanical skimming or suction withdrawal. Chemicals, for example polymers, aluminium sulphate or ferric chloride, can be utilized to intensify flocculation and hence, the adhesion of bubbles. DAF unit is similar to that used for sedimentation (Figure 5.5).

Figure 5.5 - DAF equipment

5.2.7 Diversion (emergency) tank (T7)

Contingency measures can be provided to avoid accidental discharges from processes damaging the WWTP and/or the operation of the MWWTP, by them getting a sudden high load. A diversion tank which is able to receive typically 2 – 3 hours of peak flow can be established. The waste water flows are controlled upstream of the WWTP so that they can be automatically sidetracked to the diversion tank if it is need.

The diversion tank is connected with the equalisation tank or primary treatment stage so that out-of-specification liquors can be gradually introduced back into the waste water flow. As an alternative, provision can be made to allow the removal of the diversion tank contents off-site. Diversion tanks are also used in the case of absence of the separate drainage system for surface water and it could enter the on-site WWTP.

5.2.8 Centrifugation (T8)

There are four basic types of centrifuge approachable. The basket centrifuges and solid bowl dewater in a batch process. The solid bowl configuration relies on the supernatant liquors which have to either be scraped from the surface or over-top a weir arrangement at the centrifuge top. The basket system utilized a perforated mesh, so that the liquid phase gets through the screen medium during centrifugation. The disc-nozzle centrifuge is primarily applied for liquid/liquid separation. Finally, the decanter centrifuge is a conventional technology widely applied for activated sludge separation. Centrifuges can be applied for separating particles too fine to sediment, due to the greater gravitational forces used.

5.2.9 Precipitation (T9)

When solid particles cannot be disposal by simple gravitational methods, for example when they are too fine, their density is too similar to that of water or when they form colloids/emulsions, precipitation can be applied. This method transforms the substances dissolved in the water into insoluble particles through a chemical reaction. Precipitation may also be applied for phosphorus disposal.

This process includes three major stages. Its first stage is coagulation, which is used to destabilize the colloidal/emulsion system by reducing the potential responsible for the stability of the system. This is in general undertaken by dosing with inorganic chemicals among them are aluminium sulphate, ferric chloride, or lime. The next stage is the flocculation of fine particles into larger ones, which can be easily settled or floated. This may include the addition of polyelectrolytes in order to form bridges to produce large flocs. Besides coagulation-flocculation some precipitation of metal hydroxides takes place and these hydroxides adsorb particles of fat. After precipitation, sludges are removed by either sedimentation or DAF.

Economics:

This technique produces solid waste which is expensive to remove of.

Example plants:

Precipitation are used in the fruit and vegetable, fish, soft and alcoholic drinks and vegetable oils and fats sectors.

5.3 SECONDARY TREATMENTS

Secondary treatment is directed principally towards the disposal of biodegradable organics and SS using biological techniques. Adsorption of pollutants to the organic sludge produced will also dispose of non-biodegradable materials, for example heavy metals. Organic nitrogen and phosphorus can also be partly disposed of from the waste water. Secondary treatment options can be applied alone or in combination, depending on the features of the waste water and the requirements before discharge.

There are substantially three types of metabolic processes, i.e. aerobic processes, utilizing dissolved oxygen; anaerobic processes, without oxygen supply and anoxic processes, utilizing biological reduction of oxygen donors.

5.3.1 Aerobic processes

Aerobic processes are only generally useful and cost effective when the waste water is easily biodegradable. Micro-organisms in the mixed liquor receive the oxygen input from either the surface or from diffusers which are submerged in the waste water. Surface injection of oxygen is carried out through either surface aerators or oxygenation cages.

Advantages:

Aerobic processes lead to degradation into harmless compounds.

Disadvantages:

Large quantities of sludge.

Stripping results in fugitive releases that can result in odours/aerosols.

Bacterial activity is decreased at low temperatures.

5.3.1.1 Activated sludge (T 10)

Activated sludge technique creates an activated mass of micro-organisms that can stabilize a waste aerobically (Figure 5.6). The biomass is aerated and maintained in suspension inside a reactor vessel. Plants can utilize air, oxygen or their combination. When they utilize oxygen, they can be called pure oxygen systems.

The most ordinary problem associated with activated sludge is that of bulking. This term is used to describe biological sludge of poor settling features. Typically, this is due to the presence of filamentous bacteria and/or excessive water bound within the biological floc. One important and fundamental point to accent regarding bulking sludge is that prevention is better than a cure.

It is known that the typical cure for bulking is the use of chemicals, i.e. chlorination, the utilize of other oxidative chemicals or precipitation chemicals, to destroy all filamentous organisms that are not protected by active silt flakes. It is reported that these methods of curing are not very selective and can destroy all biological activity.

Bulking can be prevented by, for example, providing an optimal balance of nutrients to be add is maintained, minimizing as well as the release of nutrients and the oveproduction of filamentous bacteria. Procedures to deal with bulking when this occurs, involves reducing the load. The presence of ammonia as a breakdown product, indicates the levels and shows whether denitrification is needed. The hydraulic residence time, the age of sludge, and operating temperature are the most significant parameters for consideration. The parameters should be justified in terms.

Figure 5.6 -Aerotanks

It is widely used in the FDM sector. This technique is used to treat high or low BOD waste water, but will treat low BOD water most efficiently and cost effectively. The application of this method can be limited due to space requirements.

5.3.1.2 Pure oxygen systems (T11)

Pure oxygen systems are, in fact, an intensification of the activated sludge process, i.e. the introduction of pure oxygen into the existing conventional aeration plant. This is often done after increasing or changing plant production, which made the aeration installation ineffective, at least for some part of its operational cycle.

Pure oxygen systems in comparison with conventional activated sludge, have the ability to improve the process by operating at a higher MLSS level. In addition, this method uses less energy, since in conventional activated sludge, 70% of energy is lost due to nitrogen occupying 70% of the volume of the air.

5.3.1.3 Sequencing batch reactors (SBR) (T12)

The SBR is a variant of the process of an activated sludge. It is operated on the fill and draw principle and usually includes two identical reaction tanks. Different stages of the activated sludge processes are carried out in the same reactor.

5.3.1.4 Aerobic lagoons (T 13)

Aerobic lagoons are large shallow earthen basins that are applied to treat waste water due to natural processes. They include the use of bacteria, algae, sun and wind. Oxygen, besides that produced by algae, enters the liquid through atmospheric diffusion. The contents of lagoons are usually periodically mixed utilizing pumps or surface aerators.

The variant of the aerobic lagoon is the facultative lagoon, where stabilization is carried out by a combination of anaerobic, aerobic, and facultative bacteria. Oxygen is maintained in the upper layer of the facultative lagoon by surface re-aeration.

Disadvantages of the method are potential odour nuisance, soil deterioration and groundwater contamination.

5.3.1.5 Trickling filters (T14)

In aerobic processes with a fixed film, such as trickling filters, biomass grows as a film on the surface of the packaging medium, and waste water is distributed so as to pass through it evenly.

The trickling filter media usually includes rocks or various types of plastic. The treated liquid is collected under the medium and sent to a settling tank from which part of the liquid can be recycled for dilution of the strength of the incoming waste water. Variations involve alternating double filtration or permanent double filtration.

5.3.1.6 Bio-towers (T 15)

Waste water from FDM processing often has too high an organic strength for conventional aerobic treatment. Therefore, treatment is necessary to reduce the BOD to an acceptable level before further treatment, for example at a MWWTP. Bio-towers or roughing filters are specially projected trickling filters that operate at high organic loading rates that can provide high BOD removal levels.

In the technique, aboveground tanks containing plastic media with a high surface area are used. The microbial film adheres to the medium and consumes organic material. The waste water can be recycled over the bio-tower to achieve a further treatment. Then, the waste water from these units is discharged to a common biological process.

5.3.1.7 Rotating biological contactors (RBC) (T16)

An RBC comprise a series of round disks which are closely located and made of polystyrene or polyvinyl chloride. The disks are immersed in waste water and slowly rotate through it.

In operation, biological growths attach to surface discs and eventually form a layer of slime on the entire surface of the wettable surface of the discs. Rotating the discs puts biomass in contact with the organic material in the waste water, and then with the atmosphere for the oxygen adsorption alternately. Rotation is also a mechanism for removing excess solids from the discs so that they can be transferred from the unit to a sedimentation tank.

5.3.1.8 Biological aerated flooded filters (BAFF) and submerged biological aerated filters (SBAF) (T17)

Submerged biological aerated filters (SBAF) and biological aerated flooded filters (BAFF) are hybrid suspended/attached growth systems that are best described as active sludge plants that include highly voidage media to stimulate bacterial growth (Figure 5.7). As a rule, they also allow certain physical filtering within the same structure.

Figure 5.7 - BAFF

5.3.1.9 High rate and ultrahigh rate aerobic filters (T18)

Aerobic filters with high rate and ultra-high rate give the potential for higher, than ordinary loading rates to aerobic systems. This process uses a high rate of waste water recirculation directed through an integral nozzle assembly. Air is injected through the nozzle, providing a high shear force on the bacteria and an intense turbulence/oxygenation. It is this force undergone by the bacteria that makes this process so different from other aerobic methods, i.e. microorganisms pass through the nozzle, which leads to the existence in the system of only very small bacteria, which differs from other systems in which bacteria do not undergo such a shear and where there are also higher forms of life.

5.3.2 Anaerobic processes

When the oxygen is absence, organic matter is destroyed, producing methane (CH_4) as a by-product, which is applied to heat the reactors. In standard anaerobic processes, the reactors are generally unheated, but in high rate anaerobic processes, the reactors are in general heated. In both cases, the temperature of the reactor should be maintained at around 30 – 35 ºC (mesophylic) or 45 – 50 ºC (thermophylic), and whether heat is required depends, in essence, on the temperature of the feed.

Although anaerobic growth is slower than in an aerobic process, higher BOD loadings are reachable with an anaerobic technique (in terms of kg BOD/m^3 of reactor volume) for high strength waste water. Anaerobic techniques are in general used in those industries where there is a high level of soluble and readily biodegradable material which is organic and the strength of the waste water, expressed in COD, is in general high than 1500 – 2000 mg/l. For the FDM sector, the applying of anaerobic waste water treatment is largely limited to comparatively heavily polluted waste water with a COD between 3000 and 40000 mg/l, for example in the starch, sugar, fruit, vegetable and alcoholic drinks sectors. There has recently been some success in applying certain anaerobic systems even for less heavily polluted waste water with a COD between 1500 and 3000 mg/l, for example in dairies, breweries and in the fruit juice, mineral water, the soft drinks sector. Where there are large fluctuations in volume and strength, for example for waste water in the fruit and vegetable sector, this treatment is less effective.

One of the most fundamental aspects of anaerobic treatment of waste water is that the vast majority of organic carbon associated with the influent BOD is transformed to methane, and not for new cell growth. The opposite is true with aerobic processes, which transform most of the organic carbon to new cells which finally form waste biosolids that need either further treatment or off-site disposal. In anaerobic processes, much less waste is generated. Also the methane produced are characterized by a high calorific value and as such can be re-used as fuel, for example in another place of installation.

Anaerobic system alone will not achieve the final quality of waste water high enough for discharge to the watercourse. Consequently anaerobic installations are usually followed by aerobic ones.

5.3.2.1 Anaerobic lagoons (T19)

Anaerobic lagoons are resembling to aerobic lagoons, with the difference that the anaerobic lagoons are not mixed. They can cause odor problems due to H_2S emissions.

In the soft and drinks sector it was reported that anaerobic lagoons have a depth of more than 2 m.

5.3.2.2 Anaerobic contact processes (T20)

The anaerobic contact process can be compared with the process of aerobic activated sludge, as the separation and recirculation of biomass are included into the design. The untreated waste water is mixed with recycled sludge solids and then digested in a reactor isolated from the entry of air.

5.3.2.3 Anaerobic filters (T21)

In the anaerobic filter, the gain of anaerobic bacteria is established on the packaging material. The packaging retains biomass in the reactor, and also helps in separating the gas from the liquid phase. Anaerobic filter can be operated in the upflow or downflow mode.

5.3.2.4 Upflow anaerobic sludge blanket (UASB) (T22)

In the UASB system, waste water passes to the bottom of the reactor for monotonous distribution (Figure 5.8). The waste water is directed through a blanket of naturally formed bacterial granules with good settling features, so that they are not easily washed out of the system. The reactions are carried out by bacteria, and then natural convection raises a mixture of gas, treated waste water and sludge granules to the reactor top. Patented three-phase separator arrangements are applied in order to separate the final waste water from solids (biomass) and the biogas.

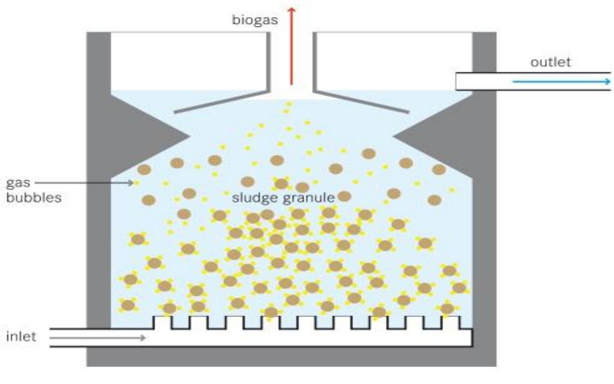

Figure 5.8 - UASB

5.3.2.5 Internal circulation (IC) reactors (T23)

There is a special configuration of the UASB process, i.e. the IC reactor, in which two UASB reactor parts can be put on top of each other, one of them high loaded and one – low loaded. The biogas collected in the first step drives a gas-lift resulting in an internal recirculation of the waste water and sludge, therefore the process name.

5.3.2.6 Hybrid USAB reactors (T24)

The hybrid process is a modification of the conventional UASB. This incorporates a packed media zone above the basic open zone. This allows to collect and retain non-granulated bacteria which, in ordinary UASB reactors, would be lost from the process. The lower sludge zone acts in accurately the same way as within a ordinary UASB reactor and is responsible for the majority of the biodegradation of the organic material. The function of the micro-organisms and media in the packed zone is to ensure a certain amount of polishing treatment, to keep biological solids in reserve, and to avoid the biomass from washing out of the reactor.

Achieved environmental benefits:

Reduced BOD/COD levels.

Operational data:

Anaerobic hybrids are high rate systems with typical loading speeds in the region of 10 – 25 kg COD/m^3 per day.

Applicability:

It is widely applicable in the FDM sector.

5.3.2.7 Fluidised and expanded bed reactors (T25)

These reactors are close to the anaerobic filters. If the particles and biomass are entirely mixed, the process is known as a fluidised bed, while a partly mixed system is known as an expanded bed. In the UASB system, the waste water is sent to the bottom of the reactor for uniform distribution (Figure 5.9).

Figure 5.9 - Fluidized bed reactor system

5.3.2.8 Expanded granular sludge bed reactors (EGSB) (T26)

EGSB reactors apply granular sludge of the type found in UASB reactors but they function with a much greater depth of granular sludge and a higher rate of water rise. The digester utilizes recirculated treated water and is fitted with a three-phase (solid, liquid, gas) separator.

5.3.3 Aerobic/anaerobic combined processes

5.3.3.1 Membrane bio-reactors (MBR) (T27)

An MBR is a variation on ordinary activated sludge whereby a several of membrane modules, or cartridges, are placed within the body of the reactor vessel (Figure 5.10). After biological treatment, the mixed liquor is pumped by static head pressure to the membrane unit in which the solids and liquids are divided, the clean waste water is discharged, and the concentrated mixed liquor is directed back to the bio-reactor. The MBR can be used in aerobic and anaerobic mode, thereby increasing the range of suitable chemicals, for example applied for membrane cleaning in biological treatment.

MBR can be used in all FDM installations. This method has the advantage of having low space requirements. This technique is ideal for higher strength, lower volume waste water. It is especially attractive in the cases where a long solids retention time is required to reach the necessary biological degradation of the pollutants. In addition, waste water containing not readily degradable compounds, for example, pesticides, phenols, chlorinated solvents and herbicides, and high organic pollution can be treated with MBR.

This technique requires high operating costs.

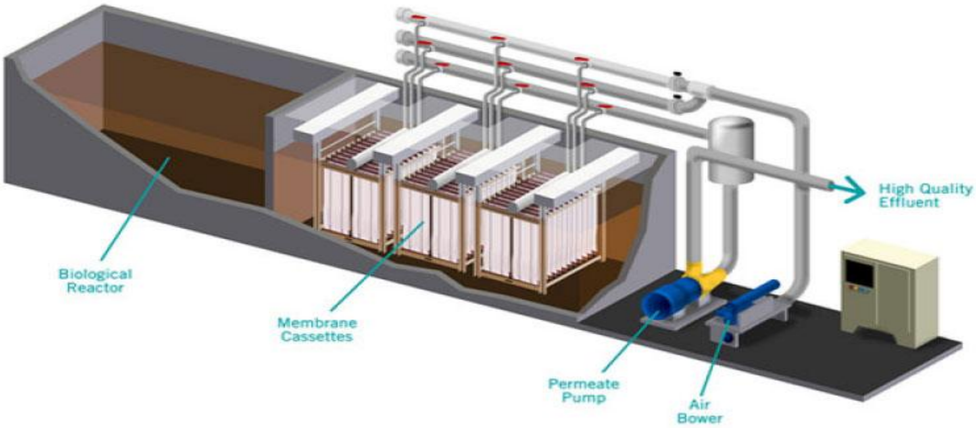

Figure 5.10 - Membrane bio-reactors

5.3.3.2 Multistage systems (T28)

The different aerobic and anaerobic waste water treatment processes can be used alone or in combination. When they are used in combination arranged in series, the technique is known as multistage systems. Waste water treatment occurs successively in individual stages, which are kept separate from each other through separate sludge circuits.

5.4 TERTIARY TREATMENTS

After secondary treatment, further treatment may be required either to allow the water to be re-used as low grade wash-water or process water, or to meet requirements of a discharge. Tertiary treatment belongs to any process that is considered a “polishing” step, up to and involving disinfection and sterilisation systems.

5.4.1 Biological nitrification/denitrification (T29)

This method is a variant of the activated sludge process. Here, four types of processes are described.

In preceding denitrification, the incoming waste water first are directed the denitrification basin.

NH_4-N comes through the basin unchanged, whereas organic N is partly hydrolysed to NH_4-N. In the subsequent nitrification basin, the hydrolysis is finished and the ammonium in particular is nitrified. The nitrate formed is transported through the return sludge and also through intensive recirculation from the nitrification basin outlet to the denitrification basin, in which it is reduced to nitrogen.

In a system with simultaneous denitrification, anoxic and aerobic zones are created on a targeted basis thanks to control of the input of oxygen into the basin. Simultaneous denitrification systems are mainly constructed as circulation basins or carousel basins.

In intermittent denitrification, completely stirred activated sludge basins are serially aerated. In the activated sludge basin, anoxic and aerobic processes occur successively in the same basin. The extent of nitrification and denitrification can largely be regulated to the feed conditions by varying the operating times.

In cascaded denitrification, several basin compartments including anoxic and aerobic tones (preceding denitrification) are located in series without intermediate sedimentation. The untreated water is directed into the first cascade to provide optimum utilisation of the substrate present in the waste water. The return sludge flow is directed into the first basin. Here, there is no need for internal recirculation within the individual stages.

5.4.2 Ammonia stripping(T30)

In addition to biological processes, some physico-chemical processes can be used for the purification of nitrogen loaded waste water flows. In the FDM sector, condensate, which includes high concentrations of ammonium, can be cleaned from ammonia in a two-step system. The system includes a desorption and an absorption column, which are both filled with packaging material for increasing the water-air interface.

The desorption column is filled by an alkalised condensate from the top, to shift the NH_4+ - NH_3 equilibrium towards NH_3, which subsequently drops downwards in the column. At the same time, air is entered at the base of the column. In the countercurrent process, a transfer of ammonia, therefore, occurs from the aqueous phase into the gaseous phase. Subsequently, the air enriched with ammonia is directed into the adsorption column, in which the removal of the ammonia from the stripping air is carried out by an acidic solution, approximately 40 % ammonium sulphate, being circulated in the desorption column. The air now cleared of ammonia is finally re-used for stripping.

The condensate, which are characterized by a low ammonium content after stripping, is partly re-used as service water and the remaining condensate surplus is sent into the aerobic biological purification process.

5.4.3 Phosphorus removal by biological methods (T31)

FDM waste water may include significant amounts of phosphorus if the cleaning agents applied have phosphate ingredients. 10 – 25 % of the phosphorus entering the system can be removed by primary or secondary treatment. If further removal is necessary, biological treatment methods can also be applied. The principle of the methods are based on stressing the micro-organisms in the sludge so as to they will take up more phosphorus than is needed for normal growth of cells.

The proprietary A/O process for mainstream phosphorus disposal is applied for combined carbon oxidation and phosphorus removal from waste water. This process is a single-sludge suspended growth system that connects anaerobic and aerobic sections in sequence.

In the proprietary phostrip process for side-stream phosphorus disposal, a portion of the return activated sludge process is directed to an anaerobic phosphorus stripping tank.

5.4.4 Dangerous and priority hazardous substances removal (T32)

Organic solvents, pesticide residues, and toxic organic and inorganic chemicals may be included in waste water.

The disposal of many of these pollutants can be implemented through the appropriate utilize of some treatments, such as precipitation, sedimentation, filtration and membrane filtration. Further removal can be implemented utilizing tertiary treatments such as chemical oxidation and carbon adsorption.

Carbon adsorption is an advanced waste water treatment technique. Granular-medium filters are commonly applied upstream of the activated carbon contactors in order to remove the soluble organics associated with the SS present in secondary effluent. Both granular and powdered carbons are applied and appear to have a low affinity for polar organic species of a low molecular weight. Granular activated carbon operates by adsorbance of the contaminants onto and within the carbon granules. These types of filtration media are also applied in order to remove some chemicals, tastes and odours.

Chemical oxidation can be utilized in order to remove ammonia, to decrease the concentration of residual organics, and to reduce the bacterial and viral content of waste waters. The oxidants used involve chlorine, chlorine dioxide and ozone.

5.4.5 Filtration (T33)

Filtration, for example fast filtration, slow filtration, surface filtration (microscreening), deep-bed filtration, biofiltration and coagulation filtration, can be applied as a waste water polishing step for removing solids. In contradistinction to sedimentation or DAF, filtration does not require any difference in density between the particles and liquid. The separation of liquid and particles is brought about by a difference of a pressure between the two sides of the filter which ensures the passage of water through the filter. Thereby, the particles are held back by the filter medium.

Filters may be either pressure filters or gravity filters. Depending on the nature of the solids, a standard sand or dual media filter (sand/anthracite) can be applied. At the present time there are a number of constantly self cleaning sand filters available which are highly efficient at polishing suspended solids from the final waste water.

5.4.6 Membrane filtration (T34)

Membrane filtration processes utilize a pressure driven, semi-permeable membrane to reach selective separations. A significant part of the selectivity is established by designations relative to size of pores. The pore size of the membrane is comparatively large if precipitates or suspended materials are being removed or very fine to remove inorganic salts or organic molecules. During operation, the feed solution flows across the membrane surface, clean water permeates across the membrane, and the pollutants and a portion of the feed remain in the solution. The treated or clean waste water is referred to as “the permeate or product water flow”, while the flow including the pollutants is named “the concentrate, brine or reject”.

Cross-flow microfiltration (CFM) is cross-flow filtration applying membranes with sizes of a pore in the range of 0.1 – 1.0 μ (Figure 5.11). The feed flow does not require extensive primary treatment, while the membrane is relatively resistant to contamination and can be easily cleaned.

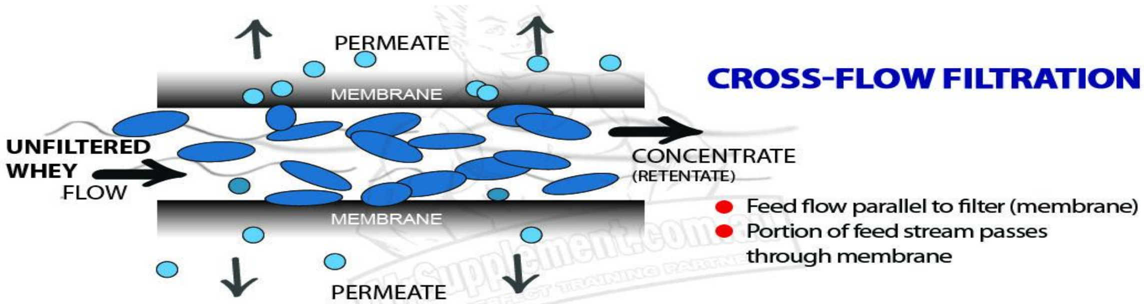

Figure 5.11 - Cross-flow microfiltration

Ultrafiltration (UF) is close to CFM, but the UF membranes have more fine pores, 0.001 – 0.02 μ (Figure 5.12). The smallest pore size ultrafiltration membrane has the capacity to reject molecules with diameters higher than 1 nm or nominal molecular weights higher than 2000. Some primary treatment may be necessary to avoid membrane fouling. For most UF designs, the introduction of flocculants or adsorbents to the feed flow is not recommended because they may plug the membrane module.

Figure 5.12 – Ultrafiltration designs

Reverse osmosis filtration (RO) has the ability to remove dissolved organic and inorganic molecules. Water is separated from dissolved salts by filtering through a semi-permeable membrane at a pressure exceeding the osmotic pressure caused by the salts. The advantage of RO is that dissolved organics are less selectively separated than in other methods. The purified solution permeates across the membrane.

Nanofiltration (NF) is a relatively new method that combines the characteristics of UF and RO with a high selectivity. Its name are occurred from its approximate cut-off size of some nanometres or more exactly molar masses of 200 – 1000 g/mol. This is achieved with the help of special nanofiltration membranes which still have pores of a certain size, but their retention depends on the electrostatic charge of the molecules which have to be separated. The membranes have selective penetrability for minerals, i.e. high penetrability for monovalent cations and anions and lower penetrability for bivalent cations. Nanofiltration systems are applied at medium pressures in the range of 1 – 5 MPa.

Electrodialysis allows ionic separation by applying an electrical field as a driving force as opposed to a hydraulic force. The membranes applied are adapted to make them ion-selective (for cations and anions). To make up the complete electrodialysis unit, a number of cells are required. Chemical precipitation of salts on the surface of the membrane and clogging by the residual organic colloids can be avoided through pretreating the waste water with activated carbon, or chemical precipitation or through some sort of multimedia filtration.

Economics:

The operating cost associated with the applying and cleaning of membranes can be very high. There are also high costs of energy.

5.4.7 Biological nitrifying filters (T35)

Ammonia is often removed during secondary biological treatment by allowing for extended sludge periods of time to facilitate the proliferation of nitrifying bacteria. However, it is also general to install separate tertiary biological nitrifying filters. These are often variations on the conventional percolating or high rate aerobic filters. They may be followed by attached growth systems or activated sludge plants.

5.4.8 Disinfection and sterilisation (T36)

The disinfection and sterilisation methods all operate on the same main principle. They affect the structure of a cell within bacteria and do not allow them to replicate themselves. Disinfectants applied for FDM production are within the scope of Directive 98/8/EC. Several types of treatment can be used. This includes the use of oxidising biocides, UV radiation and non-oxidising biocides. Steam is also applied for disinfection, to destroy thermo-resistant micro-organisms.

5.4.8.1 Biocides

Oxidising biocides work by oxidising the walls of bacterial cells to prevent replication. This depends on the use of strong oxidising agents such as chlorine/bromine, hydrogen peroxide and ozone. The use of chlorine compounds, for example chlorine dioxide, chlorine gas, sodium or calcium hypochlorite, depends on the formation of hypochlorous acid (the active biocide) in aqueous solution. Bromine based biocides are becoming more common in industrial applications because the hypobromous acid species dissociating at a higher pH than the equivalent chlorine based compounds.

Ozone can be created from air or pure oxygen when a high voltage is used across the gap of narrowly spaced electrodes. Ozone dissipates quickly after generation, so no chemical residual persists in the treated waste water but its content of a dissolved oxygen is high. No halogenated compounds are produced. Ozone is also applied as an oxidising agent.

Non-oxidising biocides operate by chemically altering the cell structure in order to prevent a replication of bacterial cells. They are being applied increasingly in the FDM sector; some examples are quaternary ammonium salts, formaldehyde and glutaraldehyde.

When using chlorine compounds, organic substances present in the waste water may react with chlorine to form toxic compounds, for example chloramines and other organic halogen substances. Moreover, this reaction can decrease the effective chlorine dose rate. Chlorine can also be very aggressive towards construction materials including stainless steel. The organic halogen substances can impair subsequent biological waste water treatment, after waster re-use. When utilizing ozone, carcinogenic or mutanogenic substances may be formed and ozone is known as a respiratory irritant, so occupational exposure needs to be controlled.

Ozonation is used in deep and covered contact chambers. It is effective without the necessary for further chemicals. Ozone will naturally convert to oxygen after a few hours.

The applying of ozone has a moderately high cost. The use of other biocides has comparatively low capital and operating costs.

5.4.8.2 UV radiation

Ultraviolet radiation, perhaps, is the most considerable achievement in the field of disinfection technologies over the past 10 years. Ultraviolet light at 254 nm is easily absorbed by cellular genetic material inside bacteria and viruses and excludes the cell from replicating. The rate of a dose is measured in milliwatts per square centimeter multiplied by the contact time in seconds. The actual dose depends on the transmittance, i.e. related to the presence of other compounds that can absorb and reduce the effectiveness of the UV radiation, of the wastewater stream.

Treated waters with UV radiation are susceptible to reinfection, so they must be used quickly and hygienically.

The important advantages of UV disinfection in comparison with other methods include: the lack of storage and the absence of the need for the use of hazardous chemicals and the absence of harmful by-products. On the other hand, the significant disadvantage of UV disinfection is that there should be direct visibility between the lamp and the bacteria/virus. Any appreciable levels of suspended solids or turbidity (which reduce transmitivity) will protect the bacteria and prevent their disinfection. Waste water with high-transmittance compounds requires higher doses of UV radiation. Ozone and UV radiation are unstable and should be generated as used.

5.5 NATURAL TREATMENTS

In the natural environment, physico-chemical and biological processes take place when water, soil, plants, micro-organisms and the atmosphere interact. Natural treatment systems are designed in order to take advantage of these processes, to ensure waste water treatment. The processes involved include many of those used in conventional waste water treatment systems, such as sedimentation, filtration, precipitation and chemical oxidation, but occur at “natural” rate. They are slower than common systems. The soil-based systems mainly apply the complex soil purification mechanism and uptake by crops and other vegetation. In the aquatic-based systems, for example, natural and constructed wetlands and aquatic plant systems, vegetation ensures a surface for the growth of bacteria.

Natural treatments are prohibited by law in some MSs, because of concerns about hazards to groundwater.

5.5.1 Integrated constructed wetlands (ICW) (T37)

The integrated constructed wetlands design simultaneously uses primary, secondary and subsequent treatment levels in its “free surface water flow”. This is achieved by the construction of a series of shallow interconnected basins or lagoons planted with a large of the species of aquatic plants (Figure 5.13). The waste water is directed at the highest point in these lagoons and is gravity fed through the lagoons. These sequentially located lagoons are individual ecosystems which are self contained. With each step, a treatment level of waste water is reached. The relationship of the waste water volume to the area of wetland in the overall ICW design defines the outflowing water quality.

The macrophytic vegetation applied in the ICW design carries out a variety of functions. Its primary function is the support of biofilms (slime layers), which performs the principal cleansing functions of the wetland. It also facilitates the nutrients sorption and acts as a filter medium, and by the use of appropriate emergent vegetation, can have control over odours and pathogens. Whereas the vegetation has the capacity to filter suspended solids it also increases the hydraulic resistance, thereby increasing the residence time.

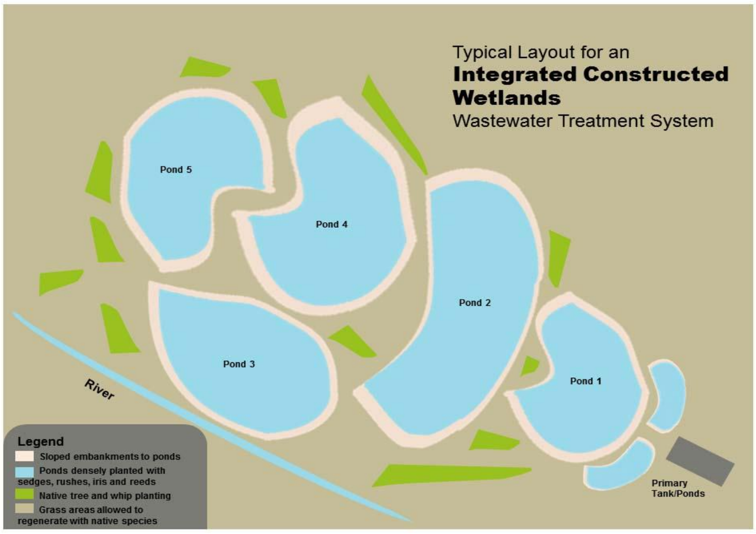

Figure 5.13 - Integrated constructed wetlands

An instance cheese plant in Ireland produces 85 tonnes of cheese per day using 800000 litres of milk and generating up to 1300 m^3 of waste water. The plant has an ICW involving 8 hectares of lagoons occupying 20 hectares which treat a waste water in volume of 1.1 million litres of per day. The waste water is directed to the wetland about half a mile from the plant and fed in at the highest point. The lagoon system progresses downwards along the contours of the land and the cleaning is achieved progressively as the waste water passes through the system.

Cheese plant which has been described above has reported that its ICW system cost EUR 120000, which is reported to be comparable to EUR 3.175 million for a conventional plant.

5.6 SLUDGE TREATMENT

This section focuses on the treatment of waste water sludge. The choice of treatment of sludge may be influenced by the utilize and disposal options available to the operator. These involve, for example landspreading, disposal by landfill, utilize as a sealing material, incineration, wet oxidation, co-incineration, pyrolysis, gasification and vitrification.

The capital and operating costs which are associated with sludge treatment can be high compared with other WWTP activities.

5.6.1 Waste water sludge treatment techniques

Sludge treatment methods typically either reduce the volume for disposal, or change its nature for disposal or re-use. Typically, volume reduction with the help of dewatering can occur on-site, while further sludge treatment is usually carried out off-site. Reducing the volume of sludge for disposal results in reduced transport costs and, if going to landfill, decreased landfill charges. The treatment techniques commonly used in the FDM sector are described in detail below.

5.6.1.1 Sludge conditioning (T 38)

The aim of conditioning is to improve the sludge characteristics so that it is easier to thicken and/or dehydrate. The techniques commonly applied are chemical or thermal. Chemical conditioning helps in the separation of the entrained and bound water from within the sludge. Thermal conditioning includes heating the sludge under pressure for short time periods.

5.6.1.2 Sludge stabilisation (T39)

The sludge is stabilized by chemical, thermal, anaerobic and aerobic processes for improving sludge thickening and/or dewatering and reducing odour and pathogens.

5.6.1.3 Sludge thickening (T 40)

Thickening is a procedure applied to increase the solids content of sludge through removing a portion of the liquid fraction. The techniques commonly applied for sludge thickening are centrifugation, sedimentation and DAF. The simplest method of thickening is to ensure the consolidation of a sludge in sludge sedimentation tanks.

Sludge thickening can be suitable to both primary treatment sludge and secondary treatment sludge. Primary treatment sludge includes inorganic material and/or primary organic solids. They are commonly able to settle and compact without chemical supplementation, as associated water is not overly “entrained” within the sludge. The water in secondary treatment sludge is connected within the flocs and is commonly more difficult to remove.

5.6.1.4 Sludge dewatering (T41)

The aim of sludge dewatering is the same as that of thickening with the difference that the solid content is much higher. There are a number of processes for sludge dewatering, and the choice will depend on the nature and frequency of the solids produced, and the sludge cake required. Typically, the dewatering methods used are centrifugation, filter press, belt filter press and vacuum filters.

Study Questions

1. In what ways can the amount of pollutants in a waste stream be reduced? List the most important strategies.
2. Give an example of how the substitution of raw materials in a process can reduce the amount of pollutants being emitted from that process.
3. List and discuss briefly different measures for modifying a production process in the FDM sector.
4. In what way can improved process control reduce the emissions of pollutants in the FDM sector?
5. In what way can the equalisation of wastewater flow reduce the emissions of pollutants?
6. Describe the principle of the unit operation adsorption and which types of separations can be done with adsorption.
7. Describe the principle of the unit operation ion exchange and which types of separations can be done with ion exchange.
8. Describe the principle of the unit operation membrane separation and the different types of membrane separations.
9. Describe the principle of the unit operation extraction and which types of separations can be done with extraction.
10. List advantages and disadvantages of anaerobic waste water treatment processes, compared to aerobic processes.

Recommended sources

1. Graedel, T. E. and Allenby, B. R. Industrial Ecology, 2nd ed, Prentice Hall, 2003.
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4. Williams, Paul T. Waste treatment and disposal. Second edition / T. Paul Williams. – West Sussex: Jonh Wiley & Sons Ltd, 2005. – 348 p.
5. Integrated Pollution Prevention and Control Reference Document on Best Available Techniques in the Food, Drink and Milk Industries. European Commission. August 2006. – 638 p.
6. UNEP (2002) Global status 2002: Cleaner Production http//www.uneptie.org/pc/cp/library/catalogue/regional_reports.htm#cpgs2002.