Air Emissions from Dairy Processing and Energy Plants
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## Air Emissions from Dairy Processing and Energy Plants

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Air Emissions from Dairy Processing and Energy Plants

Foreword

The dairy sector has been giving environmental issues serious attention for many years, starting significantly before the global environment attracted as much public interest as it does today. This guide on air emissions is one contribution in support of the evolution of a sustainable dairy sector that strives continually to reduce its impact on the environment.

An Action Team was established to undertake the task under the auspices of the IDF Standing Committee on Environment. The work was accepted as a new work item by IDF National Committees in 2006. The members of the Action Team presented an overview of definitions, sources, legal requirements and technical solutions for air emission control in dairy processing and control of dust emissions from energy supply plants, submitting their final draft to the SC on Environment for approval in 2011.

The data presented in this publication are based on sources available until the year 2010. The paper focuses mainly on technical solutions to control dust emissions. IDF experts are aware that other solutions such as factory applied management processes and techniques exist (e.g. as described in BREF documents formally adopted in the European Union under the Directive on industrial emissions (IED) 2010/75/EU) and represent additional and influential means of controlling dust emissions. The scope of this publication does not cover the recovery and recycling of removed dust either. These issues may be covered in a future update of the present paper as dust emissions continue to be addressed by the dairy sector.

IDF wishes to thank the members of the Project Group for their efforts and the successful work: Mr. Rainer Bertsch (DE) - leader of the Action team, Dr. Jim Barnett (NZ), Ms. Karen Leov (NZ), Mr. Roeland H. Peters (CA) and Mr. Jan Turowski (PL).

Nico van Belzen, PhD
Director General of IDF

Brussels, July 2012
Air Emissions from Dairy Processing and Energy Plants

1. Introduction

Air quality can be influenced by the discharge of contaminants to air, either as point source or diffuse discharges. Diffuse sources of emissions are the major contributor of emissions to air. These include natural sources (sea spray, vegetation, land cover and farm animals) and human sources such as industries, homes and motor vehicles. Natural sources generally emit far greater quantities than human sources.

Point source emission, such as that from industry, is more obvious than diffuse source discharge. It is the dust component of point source emission which is the focus of this paper.

1.1 Definition of Dust

Dust comprises both suspended particles and inhalable particles, which collectively make up particulate matter and the terms ‘dust’ and ‘particulate’ matter can be interchanged in this context.

Particulate matter is defined in the 1987 National Air Quality Standard for Particulate Matter (so called PM-Standard) of the US Environmental Agency EPA (Environmental Protection Agency). This standard introduced a fundamental change in the evaluation of emissions, as previously focus had been on total emission rather than the identification of inhalable emission within that total emission.

Particulate matter is often described in terms of particle size, and the terms PM10 and PM2.5 are often referred to. Inhalable particulate matter or PM10 is particulate matter less than 10 microns in diameter. Sources of PM10 include smoke, mining, abrasive blasting, wind-blown dust and sea salt. PM2.5 is particulate matter less than 2.5 microns in diameter. These finer particles are also known as respirable particulate. The finer the particles, the more potential there is for inhalation and this is reflected in the emphasis placed on particulate according to particle size (100 % emphasis particle size< 0.5 µm; 50 % emphasis particle size ca. 2.5 µm, and 0 % emphasis particle size > 3.5 µm).

When particulate matter is being measured, it is important that consideration is given to the finer particles and the contribution they make to overall emission.

1.2 Effects of Dust for Human Health

While air pollution is caused by the discharge of contaminants from natural or human sources to air, the actual effects of these discharges on people or the environment will depend on a number of different circumstances. The quality of air at any given site will be determined by:

- The nature, proximity and rate of discharge of the relevant emissions.
- The state of the atmosphere, including wind, turbulence and temperature and the sensitivity of the receptor (e.g. person or plant) to emissions.

Fine particulate matter has the potential to pass through the mucous membranes of the lungs and cause irritation or damage. The effects of fine particulate are typically compounded for those people that may suffer allergy or asthmatic problems.

Figure 1. Route of fine particulate entry to the lungs (Source. Wikipedia)
1.3 Sources of Dust

As noted both natural and anthropogenic sources contribute to particulate matter (PM), and regional conditions will normally determine which source is dominant.

The following list identifies the main anthropogenic sources of particulate matter determined in Germany.

- Industry: 60,000 T/annum
- Private homes and small consumers: 33,000 T/annum
- Road traffic (exclusive of tyre, asphalt and brake abrasion contribution): 29,000 T/annum
- Power plants: 19,000 T/annum
- Other traffic: 16,000 T/annum
- Transfer bulk material: 8,000 T/annum
- Industrial power plants: 6,000 T/annum
- Rail traffic: 6,000 T/annum

Source: German Ministry of Environment

The above list excludes tyre abrasion from the road traffic contribution but this is estimated at 60,000 T/annum (10% of which is assessed as PM10). The abrasion of brakes causes 5,500 – 8,500 T/annum (almost all of which is PM10).

There are no known estimates for asphalt abrasion.

In a city environment the contribution of traffic to overall particulate emission is considered to be approximately 20%.

The rural sector also contributes to particulate emission and it is estimated that this contribution is about 9% (based on European PM10 emission data) and approximately 50% of the agricultural contribution is from livestock.

Natural dust sources include:
- Dust from deserts
- Protista and fragments of protista, pollen
- Erosion of stones (mainly caused by wind and water)
- Wood fires
- Volcanic eruptions
- Sea salt from sea spray

In some confined areas, cigarette smoke can be one of the major contributors to dust, although this is dependent on the restrictions placed on smoking in public areas throughout the world. A list of the most polluted cities, assessed from a particulate perspective is set out below:


<table>
<thead>
<tr>
<th>Rank</th>
<th>City</th>
</tr>
</thead>
<tbody>
<tr>
<td>169</td>
<td>Cairo, Egypt</td>
</tr>
<tr>
<td>150</td>
<td>Delhi, India</td>
</tr>
<tr>
<td>128</td>
<td>Kolkata, India (Calcutta)</td>
</tr>
<tr>
<td>125</td>
<td>Tianjin, China</td>
</tr>
<tr>
<td>123</td>
<td>Chongqing, China</td>
</tr>
<tr>
<td>109</td>
<td>Kanpur, India</td>
</tr>
<tr>
<td>109</td>
<td>Lucknow, India</td>
</tr>
<tr>
<td>104</td>
<td>Jakarta, Indonesia</td>
</tr>
<tr>
<td>101</td>
<td>Shenyang, China</td>
</tr>
</tbody>
</table>
Section 3 of this report sets out legal standards for air quality in different parts of the world, but a common thread appears to be a reduced emission concentration limit being permitted across a range of air contaminants. In Europe limits for emissions of particulate matter involved a staged reduction in order to bring about improved air quality i.e.:  
1. From 1 January 2005 to 31 December 2009 the compliance limit measured as a daily average for PM10 was 50 µg/m³ with 35 breaches allowed in the year  
2. From 1 January 2005 to December 2009 the allowed yearly average PM10 was 40 µg/m³  
3. From 1 January 2010 the allowed daily average for PM10 is 50 µg/m³ with only seven breaches allowed in the year  
4. From 1 January 2010, the allowed yearly average PM10 is 20 µg/m³  

2. Sources of Dust Emission in the Dairy Industry  

2.1 Dairy Manufacture Air Emissions  
Air emissions can be divided into ducted, diffuse and fugitive emissions. Only ducted emissions can be treated. Diffuse and fugitive emissions can, however, be prevented and/or minimised.  

The sources of ducted emissions in the dairy manufacture sector are:  
• Process emissions, released through a vent pipe by the process equipment and inherent to the running of the plant, eg in frying, boiling, cooking operations  
• Waste gases from purge vents of preheating equipment, which are used only on start-up or shut-down operations  
• Emissions from vents from storage and handling operations, eg transfers, the loading and unloading of products, raw materials and intermediates  
• Flue-gases from units providing energy, such as process furnaces, steam boilers, combined heat and power units, gas turbines, gas engines  
• Waste gases from emission control equipment, such as filters, thermal oxidisers or adsorbers  
• Waste gases from solvent regeneration, eg in vegetable oil extraction plants  
• Discharges of safety relief devices, eg safety vents and safety valves  
• Exhaust of general ventilation systems  
• Exhaust of vents from captured diffuse and/or fugitive sources, eg diffuse sources installed within an enclosure or building  

The sources of diffuse emission in the dairy manufacture sector are:  
• Emissions by the process equipment and inherent to the running of the plant, released from a large surface or through openings  
• Emissions from storage equipment and during handling operations, eg filling of drums, trucks or containers  
• Emissions from flares  
• Secondary emissions, resulting from the handling or disposal of waste, eg volatile material from sewers, waste water handling facilities or cooling water  

The sources of fugitive emissions in the dairy manufacture sector are:  
• Odour losses during storage, filling and emptying of bulk tanks and silos  
• Stripping of malodorous compounds from a waste water treatment plant, resulting in releases to air and/or odour problems  
• Storage tank vents  
• Pipework leaks  
• Fumigation
- Vapour losses during storage, filling and emptying of bulk solvent tanks and drums, including hose decoupling
- Burst discs and relief valve discharges
- Leakages from flanges, pumps, seals and valve glands
- Building losses from windows, doors, etc
- Settling ponds
- Cooling towers and cooling ponds

The main air pollutants from dairy manufacture processes, not including the pollutants released in associated activities such as energy production, are:
- Dust
- VOCs and odour
- Refrigerants containing ammonia and halogen
- Products of combustion, such as CO₂, NO₂ and SO₂

Figure 2. Flow diagram of milk powder production and dust generation
2.2 Energy Supply Plants

Energy supply for dairy processing fundamentally relies on the burning of carbon in energy generation plants.

Different energy sources such as natural gas, fuel oil, oil, coal or wood result in different levels of black carbon production.

Black carbon (BC), (also known as carbon black, elemental carbon (EC), or soot), is composed of pure carbon clusters, skeleton balls and buckyballs, and is one of the most important absorbing aerosol species in the atmosphere. It should be distinguished from organic carbon (OC): clustered or aggregated organic molecules on their own or permeating an elemental carbon buckyball.

Table 1: European Environment Agency (EEA) gives fuel-dependent emission factors based on actual emissions from power plants in EU

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Hard coal</th>
<th>Brown coal</th>
<th>Fuel oil</th>
<th>Other oil</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 (g/GJ)</td>
<td>94600</td>
<td>101000</td>
<td>77400</td>
<td>74100</td>
<td>56100</td>
</tr>
<tr>
<td>SO2 (g/GJ)</td>
<td>765</td>
<td>1361</td>
<td>1350</td>
<td>228</td>
<td>0.68</td>
</tr>
<tr>
<td>NOx (g/GJ)</td>
<td>292</td>
<td>183</td>
<td>195</td>
<td>129</td>
<td>93.3</td>
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<tr>
<td>CO (g/GJ)</td>
<td>89.1</td>
<td>89.1</td>
<td>15.7</td>
<td>15.7</td>
<td>14.5</td>
</tr>
<tr>
<td>Non methane organic compounds (g/GJ)</td>
<td>4.92</td>
<td>7.78</td>
<td>3.70</td>
<td>3.24</td>
<td>1.58</td>
</tr>
<tr>
<td>Particulate matter (g/GJ)</td>
<td>1203</td>
<td>3254</td>
<td>16</td>
<td>1.91</td>
<td>0.1</td>
</tr>
<tr>
<td>Flue gas volume total (m3/GJ)</td>
<td>360</td>
<td>444</td>
<td>279</td>
<td>276</td>
<td>272</td>
</tr>
</tbody>
</table>


Natural gas therefore provides the cleanest form of primary energy (excluding renewable energy sources) for dairy plant energy needs.
3. Legal Requirements

Summary of Air Quality Standards

The following two tables detail the air quality standards that discharges to air from dairy manufacturing plants must meet.

Table 2A: Air Quality Standards: The statements in italics indicated permissible excesses

<table>
<thead>
<tr>
<th>Pollutant &amp; averaging</th>
<th>EU 2005</th>
<th>EU2010</th>
<th>US</th>
<th>Japan</th>
<th>WHO$^1$</th>
<th>China $^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SO$_2$ (μg/m$^3$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 hour average</td>
<td>350</td>
<td>24/year</td>
<td>262</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 hour average</td>
<td></td>
<td></td>
<td>1310</td>
<td>1/year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 hour average</td>
<td>125</td>
<td>3/year</td>
<td>365</td>
<td>1/year</td>
<td>104</td>
<td>125</td>
</tr>
<tr>
<td>Annual average</td>
<td>20 Annual and winter ave.</td>
<td>79</td>
<td>50</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NO$_2$ (μg/m$^3$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 hour average</td>
<td>200</td>
<td>18/year</td>
<td>200</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 hour average</td>
<td></td>
<td></td>
<td>75-113</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual average</td>
<td>40</td>
<td>100</td>
<td>40</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PM$_{10}$ (μg/m$^3$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 hour average</td>
<td></td>
<td></td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 hour average</td>
<td>50</td>
<td>35/year</td>
<td>50</td>
<td>150</td>
<td>100$^3$</td>
<td>50</td>
</tr>
<tr>
<td>Annual average</td>
<td>40</td>
<td>20</td>
<td>50</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PM$_{2.5}$ (μg/m$^3$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 hour average</td>
<td></td>
<td></td>
<td>65</td>
<td>98 percentile</td>
<td>50</td>
<td></td>
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<tr>
<td>Annual average</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
<td>40</td>
<td></td>
</tr>
<tr>
<td><strong>CO (μg/m$^3$)</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1 hour average</td>
<td></td>
<td></td>
<td>40000</td>
<td>1/year</td>
<td>30000</td>
<td>10000</td>
</tr>
<tr>
<td>8 hour average</td>
<td>10000</td>
<td></td>
<td>10000</td>
<td>1/year</td>
<td>22900</td>
<td>10000</td>
</tr>
<tr>
<td>24 hour average</td>
<td></td>
<td></td>
<td>11500</td>
<td></td>
<td></td>
<td>4000</td>
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<tr>
<td><strong>Ozone (μg/m$^3$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 hour average</td>
<td>180/240$^6$</td>
<td>240</td>
<td>120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 hour average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 hour average</td>
<td>120 - 25 days/year$^7$</td>
<td>160</td>
<td>120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AOT40$^7$</td>
<td>180000$^8$ May-July</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Benzene

Annual Average

5

3
Table 2B: Air Quality Standards: The statements in italics indicated permissible excesses

<table>
<thead>
<tr>
<th>Pollutant &amp; averaging</th>
<th>China II²</th>
<th>China III²</th>
<th>Switzerland</th>
<th>Australia⁴</th>
<th>New Zealand</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SO₂ (μg/m³)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 hour average</td>
<td>500</td>
<td>700</td>
<td>100</td>
<td>600</td>
<td>350</td>
</tr>
<tr>
<td>3 hour average</td>
<td></td>
<td></td>
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<tr>
<td>24 hour average</td>
<td>150</td>
<td>250</td>
<td>100</td>
<td>200</td>
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</tr>
<tr>
<td>Annual average</td>
<td>60</td>
<td>100</td>
<td>30</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td><strong>NO₂ (μg/m³)</strong></td>
<td></td>
<td></td>
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<tr>
<td>1 hour average</td>
<td>120</td>
<td>240</td>
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<td>240</td>
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<tr>
<td>24 hour average</td>
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<td>120</td>
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</tr>
<tr>
<td>Annual average</td>
<td>40</td>
<td>80</td>
<td>30</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td><strong>PM₁₀ (μg/m³)</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1 hour average</td>
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<td>250</td>
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<tr>
<td>Annual average</td>
<td>100</td>
<td>150</td>
<td>20</td>
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<tr>
<td><strong>PM₂.⁵ (μg/m³)</strong></td>
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<td>AOT40⁷</td>
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<td>Benzene</td>
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<tr>
<td>Annual Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. WHO values are guideline values.
2. China: Zone 1: residential areas; Zone 2: commercial areas; Zone 3: industrial areas
3. Suspended particulate matter
4. Values given for CO, NO₂, O₃, SO₂ in the Australian Standard as ppm were converted to μg/m³ using the formula to μg/m³ = ppmxM/22.71 where M is the molecular weight of the pollutant.
5. There is an information threshold of 180 μg/m³, and a warning threshold of 240 μg/m³. For a warning to be issued, the value must be exceeded during three consecutive hours.
6. Switzerland has also a limit for ½-hourly values: For each month, 98% of half-hourly values should be below 100 μg/m³.
7. 120 μg/m³ is a target value for 2010, to be understood in the following way: For each day, calculate the largest running 8-hour average during the day, and assign that value to the day. As an average over three years, there should be no more than 25 days per year with larger values that 120μg/m³. Further, as a long-term objective for 2020, this value of 120 μg/m³ should be exceeded no more than 1 day per year.
8. AOT40 is defined as the sum of the differences between hourly ozone concentration and 40 ppb for each hour when the concentration exceeds 40 ppb during a relevant growing season, e.g. for forest and crops. The limit value here is given in the unit μg/m³*hour. The EU has set a target value of 18,000 μg/m³*hour for 2010, and a long-term objective of 6,000 μg/m³*hour for 2020.
4. Air Emission Control Technology for the Dairy Industry

The following section describes the technologies that can be utilised by the dairy industry to reduce emissions from dairy manufacturing plants.

4.1 Cyclones

Description

Cyclones use inertia to remove particles from the gas stream by using centrifugal forces, usually within a conical chamber. They operate by creating a double vortex inside the cyclone body. The incoming gas is forced into circular motion down the cyclone near the inner surface of the cyclone tube. At the bottom the gas turns and spirals up through the centre of the tube and out of the top of the cyclone. Particles in the gas stream are forced toward the cyclone walls by the centrifugal force of the spinning gas but are opposed by the fluid drag force of the gas travelling through and out of the cyclone. Large particles reach the cyclone wall and are collected in a bottom hopper, whereas small particles leave the cyclone with the exiting gas.
Achieved Environmental Benefits

Reduction of air emission pollutants. Potential re-use of airborne materials.

Cross-media effects

Energy consumption

Operational Data

Cyclones are characterised by a simple and robust design, small space requirements and high operating reliability. Cyclones achieve better separation results than separators. Figure 3 shows the operational principle of a cyclone.

Cyclones are used to remove small particles in the exhaust air of the drier during the production of distillers dried grain and the efficiency of the cyclone is about 99.97%.

Applicability

Cyclones are used to control particulate material of primarily >10μm. There are, however, high efficiency cyclones designed to be effective even for particles as small as 2.5μm.

Cyclones used without other abatement techniques are generally not adequate to meet air pollution regulations, but they serve a purpose as precleaners for more expensive final control
devices such as fabric filters or ESPs. They are extensively used after spray drying operations and after crushing, grinding and calcining operations. Fossil-fuel-fired industrial fuel combustion units commonly use multiple cyclones which operate with greater efficiency than a single cyclone and can separate particles <2.5μm.

**Single-cyclone Separators**

They create a dual vortex to separate coarse from fine dust. The main vortex spirals downward and carries most of the coarser dust particles. The inner vortex, created near the bottom of the cyclone, spirals upward and carries finer dust particles.

**Multiple-cyclone Separators**

Also known as multiclones®, consist of a number of small-diameter cyclones, operating in parallel and having a common gas inlet and outlet, as shown in the figure. Multiclones® operate on the same principle as cyclones—creating a main downward vortex and an ascending inner vortex. Multiclones® are more efficient than single cyclones because they are longer and smaller in diameter. The longer length provides longer residence time while the smaller diameter creates greater centrifugal force. These two factors result in better separation of dust particulates. The pressure drop of multicone® collectors is higher than that of single-cyclone separators.

Multicone® dust collectors are found in all types of power and industrial applications, including pulp and paper plants, cement plants, steel mills, petroleum coke plants, metallurgical plants, saw mills and other kinds of facilities that process dust.

**Secondary Air Flow Separators**

This type of cyclone uses a secondary air flow, injected into the cyclone to accomplish several things. The secondary air flow increases the speed of the cyclonic action making the separator more efficient; it intercepts the particulate before it reaches the interior walls of the unit; and it forces the separated particulate toward the collection area. The secondary air flow protects the separator from particulate abrasion and allows the separator to be installed horizontally because gravity is not depended upon to move the separated particulate downward.

Cyclones are used for the removal of solid and liquid air pollutants. They are mainly used for separation of large particles only, ie >10 μm. They are suitable for use where:

- There are high levels of dust in the untreated gas
- There is no great requirement for the removal of fine particles
- There is a need for preliminary separation and/or protection and relief of downstream systems
- Pressures are high, eg high pressure dedusting
- Temperatures are high, eg high temperature dedusting

**Economics**

Low cost technique.

**Example Plants**

Cyclones are used during the production of animal feed; dried milk; dried soup; cake mixes; custard; distillers’ dried grains; dried sugar beet pulp; ice-cream mixes; coffee roasting; drying and blending; tea blending and malt blending. Generally, cyclones are used an as integral part of the process to recover dust from the extracted air for reprocessing. They are used...
in the vegetable oil subsector to remove fine impurities such as plant residues, dust and sand from raw oilseeds and wet dust emissions from refining.

4.2 Wet Separation

Description

In dynamic separation techniques, the effective mass forces, i.e., gravity, inertia and centrifugal forces, all fall off sharply with increasing particle size. Wet cyclones are high efficiency units, spraying water into the waste gas stream to increase the weight of the particulate material and hence also removing fine material and increasing the separation efficiency. Although, generally speaking, this merely shifts the pollution from the air into the water. Wet separators may be chosen for particular application, e.g., when there is an explosion risk associated with a dust. Different types of wet separators can be distinguished by classifying them in terms of their design features. Some examples are (also shown in Table 4):

- Absorption techniques, such as scrubber towers, spray scrubbers, parked bed adsorbers
- Injection scrubbers, e.g., high pressure/dual substance injection scrubbers
- Jet scrubbers
- Vortex scrubbers
- Rotary scrubbers, disintegrators (high performance)
- Venturi scrubbers (high performance)

Environmental benefits achieved

Reduction of air emissions, e.g., dust. Potential re-use of airborne materials. It can be advantageous if there is an in-plant opportunity to re-use the laden collecting liquid. Recovery of the product,
eg. in vegetable oil processing, the collected dust is recovered and can be added back to the meal. Prevention of fire risk.

**Table 4: Dust Removal from Air – Overview of Wet Separators**

<table>
<thead>
<tr>
<th>Description</th>
<th>Scrubber tower</th>
<th>Injection scrubber</th>
<th>Jet scrubber</th>
<th>Vortex scrubber</th>
<th>Rotary scrubber, disintegrator</th>
<th>Venture scrubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbols according to DIN 30600/28004</td>
<td><img src="symbol1.png" alt="image" /></td>
<td><img src="symbol2.png" alt="image" /></td>
<td><img src="symbol3.png" alt="image" /></td>
<td><img src="symbol4.png" alt="image" /></td>
<td><img src="symbol5.png" alt="image" /></td>
<td><img src="symbol6.png" alt="image" /></td>
</tr>
<tr>
<td>Gas speed in contact zone in relation to free cross-section (m/s)*</td>
<td>1-5</td>
<td>20-60</td>
<td>5-15</td>
<td>8-20</td>
<td>25-70</td>
<td>40-150</td>
</tr>
<tr>
<td>Pressure difference over entire separator (bar)*</td>
<td>1-25</td>
<td>5-25</td>
<td>Pressure recovery of approximating 1-10</td>
<td>15-30</td>
<td>2-10^1</td>
<td>30-200</td>
</tr>
<tr>
<td>Energy requirements (kWh/1000m^3)</td>
<td>0.2-3</td>
<td>0.4-2</td>
<td>1.2-3</td>
<td>1-2</td>
<td>4-15^1</td>
<td>5-15</td>
</tr>
<tr>
<td>Collecting liquid/gas ratio l/m^3</td>
<td>1-5</td>
<td>0.5-5</td>
<td>5-50</td>
<td>No data possible due to process principle</td>
<td>1-3 per stage</td>
<td>0.5-5</td>
</tr>
<tr>
<td>Separation limit (µm)*</td>
<td>0.7-1.4</td>
<td>0.1-1</td>
<td>0.8-0.9</td>
<td>0.6-0.9</td>
<td>0.1-0.6</td>
<td>0.05-0.5</td>
</tr>
<tr>
<td>Separation rate (%)^2</td>
<td>50-85</td>
<td>90-95</td>
<td>90-95</td>
<td>90-95</td>
<td>92-96</td>
<td>96-98</td>
</tr>
</tbody>
</table>

* Approximate values, higher or lower variations are possible.
1 In didintegrators, the energy consumption is often considerably higher depending on the efficiency and the volume of gas handled. A pressure recovery of up to 25 bar is possible.
2 The separation rate shown in the table merely gives a rough idea of the possible working range. Although the separation rate is easy to measure, it only permits limited conclusions about the efficiency of a separator. For example, it is directly dependent on the particle size distribution of the input material. If the particle size distribution changes, so does the separation rate, even if the other parameters remain constant. A knowledge of the separation rate does, however, become important in the specific application. The fraction separation rate is a much more suitable parameter for assessing the efficiency of a separator.

**Cross-media Effects**

Energy consumption. Waste water production.

**Operational Data**

Using wet separation, it is possible to achieve separation rates of 80-99%. When using cyclones, wet dust emission concentration of <50mg/Nm^3 can be achieved.

Dust particles present in the untreated gas are brought into contact with, and become attached to, the considerably larger droplets of the collecting liquid and can then be removed together with the droplets. The relatively large dust-laden droplets, which have a diameter of 50-200µm are usually removed from the gas stream by means of cyclones or lamellar separators. Cyclones are used for heavy solid loads and small gas streams. Better separation rates and lower pressure losses are achieved by using lamellar separators in high performance separation units. These consist of vertically arranged metal or plastic plates. These can separate particles large than 10 µm.

Waste water is produced. The dust-laden collecting liquid can be treated and returned to the process, or concentrated by evaporation. Drying plants, in particular, give off vapours laden with water vapour which may contain not only particulate pollutants, but also odours and gaseous pollutants.
Applicability

Wet separators are used for the removal of solid and liquid air pollutants, eg.

- Flammable or sticky dust
- Where there is a risk of explosion
- For the simultaneous separation, or preliminary separation, of solid, liquid and gaseous pollutants
- For small dust particles (<0.1μm).

Scrubbers are used in the dairy manufacturing sector, eg to treat VOCs, ffa and odours from vegetable oil refining.

Economics

The cost of waste water treatment may be considerable, in some cases even higher than for measures to control dust emissions.

4.3 Filtration

Filter separators are typically used as final separators, downstream of preliminary separators, eg where the waste gas components have properties damaging to filters, such as abrasive dust or aggressive gases. This ensures adequate filter life and operating reliability.

In filter separators, the gas is fed through a porous medium in which the dispersed solid particles are held back as a result of various mechanisms. Filter separators can be classified on the basis of filter medium, performance range and filter cleaning facilities.
In a fabric filter, waste gas is passed through a tightly woven or felted fabric, causing particulate matter to be collected on the fabric by sieving or other mechanisms. Fabric filters can be in the form of sheets, cartridges or bags (the most common type) with a number of the individual fabric filter units housed together in a group. The dust cake that forms on the filter can significantly increase the collection efficiency.

Cleanable filters are among the most important types of filter separators used in industrial particulate removal. The practice of using a woven fabric filter material has largely changed to the use of non-woven and needle-felt materials. The most important parameters in cleanable filters are the air to cloth ratio and the pressure loss.

The filter material performs the actual separation and is the essential component of a filter separator. Woven fabrics have threads which cross at right angles. Non-wovens and needle-felts, by contrast, are flat three-dimensional structures that may be stabilised by the adhesion of the fibres or by alternating the insertion and removal of fibres. Non-wovens and needle-felts may also contain an internal supporting woven fabric, eg polyester or glass fibre fabric, to reinforce them. Needle-felts made of synthetic fibres are being increasingly used.

Non-wovens and needle-felts possess three-dimensional filtering characteristics. Dust particles are caught in the filter structure, forming an ancillary filter layer that ensures good separation of even the finest particles. One characteristic of this 'deep filtration' is a large effective specific surface area. Regular intensive cleaning removes the accumulated dust layer and prevents excessive pressure losses. Problems, however, may be caused by sticky, fatty, agglomerating, adhesive, abrasive and/or hygroscopic dust particles.

4.3.1 Tubular Filters

Description

In tubular filters, the filter medium consists of tubes up to five metres long with a diameter of between 12 and 20 cm. The gas flows from inside to outside or vice versa, depending on the cleaning method.

The equipment contains a round filter comprising a bank of vertical tubes mounted in a cylinder, similar in appearance to a cyclone, and which does not require significant space. The airstream is passed through the filter and the fines are deposited on the surface of the individual tubular filters. The tubular filters are cleaned by means of a fully automatic pulse-like reverse flushing system, using compressed air or other pressurised gases, with the aid of a multistage injector system. The tubes are cleaned individually, which ensures continuous cleaning of the tubular filters and dust removal.

The product cleaned off the tubular filters falls on to the outlet base, where it is conveyed by air flowing through a special perforation system to the dust outlet. The gases cleaned in this way leave the filter as clean gas via a clean gas chamber.

The individual cleaning of the tubular filters reduces the quantity of dust cleaned from the filter at any given time, which means the potentially explosive dust-air volume in the filter chamber is correspondingly smaller compared with conventional filter systems. CIP filters have been used successfully in the food industries since 1995. If used in the dairy industry, the filter product is comparable to the spray drier tower product. Tubular filters may be used without a preliminary cyclone separator.

The cleaning system for the round filters is similar that used for cleansing the tubular filters installed as a CIP system. A stream of air is passed through the CIP nozzles in the base of the tubular filter and the other nozzles within the filter during operation, but not during CIP cleaning. This prevents the CIP nozzles from being blocked with dust from the process air.

Another important advantage is that the tubular filter base in the zone where the airstream is laden with dust is kept clean by air flushing. This means that even with very hygroscopic products the base is kept free of heavy deposits. This is a substantial advantage compared with other filter designs and extends the operational time between cleaning phases. The clean gas and dirty gas zones, the tubular filters, the filter wall and the other internal parts are intensively sprayed via carefully arranged nozzle groups.

Figure 5 shows a tubular dust filter used to remove fines, downstream of a spray drier in a large dairy.
Achieved Environmental Benefits

Reduced emissions of dust to air. Reduced energy consumption is also reported (no data provided).

Reduced waste production, e.g. due to the separation process being dry, it may, in principle, be possible to re-use separated particulate matter in the process, or as a by-product.

Filters use significantly less energy than cyclones and produce less noise. If filtering installations suitable for CIP are used for outgoing air it is not necessary to use cyclones, allowing huge energy savings and noise reduction to be achieved. Reduced consumption of water and cleaning agents, by using CIP.
Operational Data

Filter separators can achieve high separation rates, eg >99%, with even very fine particles being separated very efficiently.

The tubular filters need to be dried with warm air, with the tubular filter cleaning system switched off, to prevent operational problems due to moisture when it is used again.

Applicability

Tubular filters are widely applied in the dairy manufacture sector. They are used for the removal of solid and liquid air pollution.

4.3.2 Bag Filters

Description

Bag filters are made up of filter materials up to about 30mm thick and measure up to 0.5m high and 1.5m long. The filter bags are fitted with their open end towards the clean gas duct. The untreated gas stream always flows from outside to inside, usually in the upper region of the filter bag. Table 5 shows a comparison between different bag filter systems.

Achieved Environmental Benefits

Reduced emissions of dust to the atmosphere

Reduced waste production due to separation process being dry. It may be possible to re-use separated particulate matter in the process or as a by-product when CIPable systems are used.

Operational Data

Filter separators can achieve high separation rates (>99%) with even very fine particles being separated very efficiently. Bag filters can be used to reduce dust emissions to <5mg/m$^3$.

4.4 Spray scrubber

Description

A spray scrubber simply comprises a liquid spray which comes into contact with an airstream rising upwards within a vessel. The vessel contains no packing or plates or any device used to enhance gas-liquid contact. A typical spray tower configuration is shown in Figure 6.
Achieved Environmental Benefits

Removal of condensable vapours and dust from air.

Cross-media Effects

Waste water is generated. Likely to generate a visible plume at the flue-gas outlet.

Operational Data

The equipment is compact so it does not take up much space, but it may require space for the safe storage of chemicals.

Where the presence of particulates or condensables is a potential problem and gaseous pollution or odour removal is required in the same piece of equipment, this can give rise to considerable operational problems and downtime whilst the absorber is cleaned and put back into action. In this respect, a wave plate absorber may be a suitable installation. Here, the airstream entering the unit is forced through a series of wave bank plates, with a liquid spray positioned in front of each wave plate assembly. The wave plate assembly can be designed to be removed in situ, washed and replaced into the unit without the need to switch off the plant.
Applicability

A spray chamber is not generally suitable for the control of odour or gaseous substances, owing to the limitations in mass transfer. However, where the airstream to be treated contains a significant level of particulates or condensable material, then a simple spray tower may be used to remove them prior to treatment with an increased gas-liquid contact, such as a plate or packed bed absorbed.

Economics

Relatively low capital and operating costs.

4.5 Electric Static Filters

Electrostatic precipitators use electrostatic forces to separate dust particles from exhaust gases. A number of high-voltage, direct-current discharge electrodes are placed between grounded collecting electrodes. The contaminated gases flow through the passage formed by the discharge and collecting electrodes. Electrostatic precipitators operate on the same principle as domestic "ionic" air purifiers.

The airborne particles receive a negative charge as they pass through the ionised field between the electrodes. These charged particles are then attracted to a grounded or positively charged electrode and adhere to it.

The collected material on the electrodes is removed by rapping or vibrating the collecting electrodes either continuously or at a predetermined interval. Cleaning a precipitator can usually be done without interrupting the airflow.

The four main components of all electrostatic precipitators are:

- Power supply unit, to provide high-voltage DC power
- Ionising section, to impart a charge to particulates in the gas stream
- A means of removing the collected particulates
- A housing to enclose the precipitator zone

The following factors affect the efficiency of electrostatic precipitators:

- Larger collection-surface areas and lower gas-flow rates increase efficiency because of the increased time available for electrical activity to treat the dust particles.
- An increase in the dust-particle migration velocity to the collecting electrodes increases efficiency. The migration velocity can be increased by:
  - Decreasing the gas viscosity
  - Increasing the gas temperature
  - Increasing the voltage field.

Types of Precipitators

There are two main types of precipitators:

- High-voltage, single-stage - Single-stage precipitators combine an ionisation and a collection step. They are commonly referred to as Cottrell precipitators.
- Low-voltage, two-stage - Two-stage precipitators use a similar principle; however, the ionising section is followed by collection plates.

Described below is the high-voltage, single-stage precipitator, which is widely used in minerals processing operations. The low-voltage, two-stage precipitator is generally used for filtration in air-conditioning systems.

**Plate Precipitators**

The majority of electrostatic precipitators installed are the plate type. Particles are collected on flat, parallel surfaces that are 8 to 12 in (20 to 30 cm) apart, with a series of discharge electrodes spaced along the centreline of two adjacent plates. The contaminated gases pass through the passage between the plates, and the particles become charged and adhere to the collection plates. Collected particles are usually removed by rapping the plates and deposited in bins or hoppers at the base of the precipitator.

**Tubular Precipitators**

Tubular precipitators consist of cylindrical collection electrodes with discharge electrodes located on the axis of the cylinder. The contaminated gases flow around the discharge electrode and up through the inside of the cylinders. The charged particles are collected on the grounded walls of the cylinder. The collected dust is removed from the bottom of the cylinder.

Electric static filters are used in big coal fired boiler houses. Therefore this technology is less extensively used in the dairy industry.

### 5. Comparison of Emission Control Technology for Dairy Plant Discharges

The performance of the Emission Control Technology for discharges from dairy manufacturing plants is shown in Table 6.

**Table 6**: Comparison of the performance and some separation techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Particle size µm</th>
<th>% collection efficiency at 1µm</th>
<th>Maximum operation temperature °C</th>
<th>Range of achievable emission levels mg/Nm³</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclone</td>
<td>10</td>
<td>40*</td>
<td>1100</td>
<td>25-100</td>
<td>Coarse particles. Used to assist other methods</td>
</tr>
<tr>
<td>Wet separation</td>
<td>1-3</td>
<td>&gt;80-99</td>
<td>Inlet 1000 Outlet 80</td>
<td>&lt;4-50</td>
<td>Good performance with suitable dust types. Acid gas reduction</td>
</tr>
<tr>
<td>Dry ESP</td>
<td>&lt;0.1</td>
<td>&gt;99</td>
<td>Depending on design</td>
<td>&lt;5-15 (pre-abatement &gt;50)</td>
<td>4 or 5 zones. Usual application is pre-abatement</td>
</tr>
<tr>
<td>Wet ESP</td>
<td>0.01</td>
<td>&lt;99</td>
<td>80</td>
<td>&lt;1-5 (optically clear)</td>
<td>ESP with 2 zones in series. Mainly mist precipitation</td>
</tr>
<tr>
<td>Filtration - i.e.</td>
<td>0.01</td>
<td>&gt;99.5</td>
<td>220</td>
<td>&lt;1-5</td>
<td>Good performance with suitable dust type</td>
</tr>
<tr>
<td>ceramic filter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filtration - i.e.</td>
<td>0.01</td>
<td>99.5</td>
<td>900</td>
<td>0.1-1</td>
<td>Very good performance with suitable dust types</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* For larger particle sizes an high efficiency cyclones, collection efficiencies around 99% can be achieved.
6. Dust Emissions in Energy Supply Plants

The choice of fuel/energy source can have a significant influence on dust/particulate emission from energy generating plant post combustion. Through use of appropriate emission control systems, suited to the fuel source used, the dust/particulate emission levels can be substantially reduced.

Coal, fuel oil and natural gas are the main fossil fuels used by dairy processing in energy generation plants globally. For example, these fuel types account for 95% of the total thermal energy consumed in the USA.

The fuel sources considered in this paper are:
- Coal - bituminous and sub-bituminous.
- Coal - anthracite.
- Natural gas.
- Wood residue
- Waste oil.
- Fuel oil.
- LPG.

6.1 Coal – Bituminous and Sub-bituminous

Emissions from coal combustion depend on the rank of the coal (which in turn is determined by volatile matter, fixed carbon, inherent moisture and oxygen), and the composition of the fuel, the type and size of the boiler, firing conditions, load, type of control technologies and the level of equipment maintenance. Particulate matter can be a major pollutant from bituminous and sub-bituminous coal combustion. Particulate matter composition and emission levels are a complex function of boiler firing configuration, boiler operation, pollution control equipment and coal properties. Uncontrolled particulate emissions from coal fired boilers include the ash from combustion of the fuel as well as unburnt carbon resulting from incomplete combustion. In pulverised coal systems, combustion is almost complete thus the emitted particulate matter is primarily composed of inorganic ash residues.

Coal ash may either settle out in the boiler (bottom ash) or be entrained in the flue gas (fly ash). The distribution of ash between the bottom ash and fly ash fractions directly affects the particulate matter emission rate and depends on boiler firing method and furnace type (wet or dry bottom). Boiler load also affects the particulate matter emissions as decreasing load tends to reduce particulate matter emissions. However the magnitude of the reduction varies considerably depending on boiler type, fuel and boiler operation. Soot blowing is also a source of intermittent particulate matter emissions in coal fired boilers. Steam soot and air soot blowing is periodically used to dislodge ash from heat transfer surfaces in the furnace, convective section, economiser and air pre-heater.

Particulate emissions can be categorised as either filterable or condensable. Filterable emissions are the particles that are trapped and generally considered to be greater than 0.3 microns. The condensable particulate emitted from boilers fuelled on coal or oil is primarily inorganic in nature.

The principal control techniques for particulate emission are combustion modifications (applicable to small stock-fired boilers) and post combustion methods (applicable to most boiler types and sizes). Uncontrolled particulate emissions from small stoker-fired and hand-feed combustion sources can be minimised by employing good combustion practices such as operating within the recommended load ranges, controlling the rate of load changes, and ensuring steady, uniform fuel feed. Proper design and operation of the combustion air delivery systems can also minimise particulate emissions. The post combustion control of particulate emissions from coal-fired combustion sources can be accomplished by using one or more of the following particulate control devices:
- Electrostatic precipitator (ESP),
• Fabric filter (or baghouse),
• Wet scrubber,
• Cyclone or multiclone collector, or
• Side stream separator

Electrostatic precipitation technology is applicable to a variety of coal combustion sources. The modular design enables ESPs to be applied to a wide range of system sizes and should have no adverse effect on combustion system performance. The operating parameters that influence ESP performance include fly ash mass loading, particulate size distribution, fly ash electrical resistivity, and precipitator voltage and current. Other factors that determine ESP collection efficiency are collection plate area, gas flow velocity, and cleaning cycle. Data for ESPs applied to coal-fired sources show fractional collection efficiencies greater than 99% for fine (less than 0.1 micrometer) and coarse particles (greater than 10 micrometers). These data show a reduction in collection efficiency for particle diameters between 0.1 and 10 micrometers.

Fabric filtration has been widely applied to coal combustion sources since the early 1970s and consists of a number of filtering elements (bags) along with a bag cleaning system contained in a main shell structure incorporating dust hoppers. The particulate removal efficiency of fabric filters is dependent on a variety of particle and operational characteristics. Particle characteristics that affect the collection efficiency include particle size distribution, particle cohesion characteristics, and particle electrical resistivity. Operational parameters that affect fabric filter collection efficiency include air-to-cloth ratio, operating pressure loss, cleaning sequence, interval between cleanings, cleaning method, and cleaning intensity. In addition, the particle collection efficiency and size distribution can be affected by certain fabric properties (e.g. structure of fabric, fibre composition, and bag properties). Collection efficiencies of fabric filters can be as high as 99%.

Wet scrubbers, including venturi and flooded disc scrubbers, tray or tower units, turbulent contact absorbers, or high-pressure spray impingement scrubbers are suitable for particulate emission control on coal-fired combustion sources. Scrubber collection efficiency depends on particle size distribution, gas side pressure drop through the scrubber, and water (or scrubbing liquor) pressure, and can range between 95% and 99% for a 2 micron particle.

Cyclone separators can be installed singly, in series, or grouped as in a multicyclone or multiclone collector. These devices are referred to as mechanical collectors and are often used as a pre-collector upstream of an ESP, fabric filter, or wet scrubber so that these devices can be specified for lower particulate loadings to reduce capital and/or operating costs. The collection efficiency of a mechanical collector depends strongly on the effective aerodynamic particle diameter. Although these devices will reduce particulate emissions for coal combustion, they are relatively ineffective for collection of particles less than 10 micron (i.e. PM10). The typical overall collection efficiency for mechanical collectors ranges from 90% to 95%.

The side stream separator combines a multicyclone and a small pulse-jet baghouse to more efficiently collect small-diameter particles that are difficult to capture by a mechanical collector alone. Most applications for side-stream separators have been on small stoker boilers.

Atmospheric fluidised bed combustion (AFBC) boilers may tax conventional particulate control systems. The particulate mass concentration exiting AFBC boilers is typically 2 to 4 times higher than pulverised coal boilers. AFBC particles are also, on average, smaller in size, and irregularly shaped with higher surface area and porosity relative to pulverised coal ashes. The effect is a higher pressure drop. The AFBC ash is more difficult to collect in ESPs than pulverised coal ash because AFBC ash has a higher electrical resistivity and the use of multiclones for recycling, inherent with the AFBC process tends to reduce exit gas stream particulate size.

6.2 Coal - Anthracite

Anthracite coal is a high ranking coal with more fixed carbon and less volatile matter than bituminous, sub-bituminous or lignite varieties.
Emissions from coal combustion depend on coal type and composition, the design type and capacity of the boiler, the firing conditions, load, the type of control devices, and the level of equipment maintenance.

Particulate emissions from anthracite coal combustion are a function of furnace firing configuration, firing practices (boiler load, quantity and location of underfire air, soot blowing, fly ash reinjection, etc) and the ash content of the coal. Pulverised coal fired boilers emit the highest quantity of particulate matter per unit of fuel because they fire the anthracite in suspension, which results in a high percentage of ash carryover into exhaust gases. Travelling grate stokes and hand-fired units produce less particulate matter per unit of fuel fired, and coarser particulates, because combustion takes place in a fuel bed without significant ash carryover into the exhaust gases. In general, particulate emissions from travelling grate stokers will increase during soot blowing and fly ash reinjection and with higher fuel bed underfeed air flowrates. Smoke production during combustion is rarely a problem, because of anthracite's low volatile matter content.

Controls on anthracite fired boilers have mainly been applied to reduce particulate emissions. The most efficient particulate controls – fabric filters, electrostatic precipitators (ESP), and scrubbers – have been installed on large pulverised anthracite fired boilers. In fabric filters (baghouses), particulate laden dust passes through a set of filters mounted inside the collector housing. Dust particles in the inlet gas are collected on the filters by inertial impaction, diffusion, direct interception, and sieving. The collection efficiencies of fabric filters on coal fired boilers can exceed 99%.

Particulate collection in an ESP occurs in 3 steps: suspended particles are given an electrical charge; the charged particles migrate to a collecting electrode of opposite polarity while subjected to a diverging electric field; and the collected particulate matter is dislodged from the collecting electrodes. Removal of the collected particulate matter is accomplished mechanically by rapping or vibrating the collecting electrodes. When applied to anthracite coal fired boilers, ESPs are only 90 to 97% efficient because of the characteristic high resistivity of low sulphur anthracite fly ash. It is reported that higher efficiencies can be achieved using larger ESPs combined with flue gas conditioning.

The most widely used wet scrubbers for anthracite coal fired boilers are venturi scrubbers. In a typical venturi scrubber, the particle-laden gas first contacts the liquor stream in the core and throat of the venturi section. The gas and liquid streams then pass through the annular orifice formed by the core and throat, atomizing the liquid into droplets which are impacted by particles in the gas stream. Impact results mainly from the high differential velocity between the gas stream and the atomized droplets. The droplets are then removed from the gas stream by centrifugal action in a cyclone separator and (if present) a mist eliminator section.

Particulate matter collection efficiencies of 90% or greater have been reported for wet scrubbers. Gaseous emission may also be absorbed to a significant extent in a wet scrubber. Operational problems can occur with wet scrubbers due to clogged spray nozzles, sludge deposits, dirty recirculation water, improper water levels, and unusually low pressure drops. Mechanical collectors, or cyclones, use centrifugal separation to remove particulate matter from flue gas streams. At the entrance of the cyclone, a spin is imparted to the particle laden gas. This spin creates a centrifugal force which causes the particulate matter to move away from the axis of rotation and toward the walls of the cyclone. Particles which contact the walls of the cyclone tube are directed to a dust collection hopper where they are deposited. Mechanical collectors typically have particulate collection efficiencies up to 80%.

6.3 Natural Gas

Natural gas is one of the major combustion fuels used for dairy processing energy requirements. Because natural gas is a gaseous fuel, filterable particulate emissions are typically low. Particulate matter from natural gas combustion has been estimated to be less than 1 micrometer in size and has filterable and condensable fractions. Particulate matter in natural gas combustion is usually larger molecular weight hydrocarbons that are not fully combusted. Increased particulate matter emissions may result from poor air/fuel mixing or maintenance problems. Controls are
not normally installed specifically for particulate matter but for other pollutants that may be contained in the fuel source and require control measures.

6.4 Wood Residue

The burning of wood residue in boilers is mostly confined to those industries where it is available as a by-product.

Particulate matter is the major emission of concern from wood boilers. These emissions depend primarily on the composition of the residue fuel burned, and the particle control device. The composition of the wood residue and the characteristics of the resulting emissions depend largely on the industry from which the wood residue originates. Pulping operations, for example, produce great quantities of bark that may contain more than 70% by weight of moisture, sand and other non-combustibles. As a result, bark boilers in pulp mills may emit considerable amounts of particulate matter to the atmosphere unless they are controlled.

Furnace operating conditions are particularly important when firing wood residue. For example, because of the high moisture content that may be present in wood residue, a larger than usual area of refractory surface is often necessary to dry the fuel before combustion. In addition, sufficient secondary air must be supplied over the fuel bed to burn the volatiles that account for most of the combustible material in the residue. When proper drying conditions do not exist, or when secondary combustion is incomplete, the combustion temperature is lowered, and increased particulate matter emissions may result from any boiler type. Significant variations in fuel moisture content can cause short term emissions to fluctuate.

The four most common control devices used to reduce particulate emissions from wood fired boilers are mechanical collectors, wet scrubbers, electrostatic precipitators (ESP) and fabric filters. The use of multtube cyclones (or multiclon) mechanical collectors provides particulate control for many wood fired boilers. Often, two multiclones are used in series, allowing the first collector to remove the bulk of the dust and the second to remove smaller particles. The efficiency of this arrangement varies from 25% to 60%. The most widely used wet scrubbers for wood fired boilers are venturi scrubbers, and particulate collection efficiencies of 85% or higher have been measured.

ESPs are employed when collection efficiencies above 90% are required. When applied to wood fired boilers, ESPs are often used downstream of mechanical collector pre-cleaners which remove larger sized particles. Collection efficiencies of 90–99% for particulate matter have been observed for ESPs operating on wood-fired boilers.

A variation of the ESP is the electrostatic gravel bed filter. In this device, particulate matter in flue gases is removed by impaction with gravel media inside a packed bed; and collection is augmented by an electrically charged grid within the bed. Particulate collection efficiencies are typically 80% or higher.

6.5 Waste Oil

The emissions from burning waste oils reflect the compositional variations of the waste oils. Particulate matter includes ash and trace elements. Ash levels in waste oils are normally much higher than ash levels in either distillate oils or residual oils. Waste oils have substantially higher concentrations of most of the trace elements relative to concentrations found in virgin fuel oils. Without air pollution controls, higher concentrations of ash and trace metals in the waste fuel translate to higher emission levels of particulates than is the case for virgin fuel oils.

Emissions can be controlled by the pre-treatment of the waste oil to remove the pollutant precursors or with emission controls to remove the air pollutants. Reduction of emission levels is not the only purpose of pre-treatment of the waste oil, as this also improves combustion efficiency. The most common pre-treatment scheme uses sedimentation followed by filtration. Water and large particles (greater than 10 microns in diameter) are removed. Other methods of pre-treatment involve clay contacting; and demetallisation by acid, solvent or chemical contacting.

Blending of waste oil with a virgin fuel oil is practised frequently and has the same effect as some of the other pre-treatment processes.
6.6 Fuel Oil

The two major categories of fuel oil are known by combustion sources i.e. distillate oils and residual oils.

Emissions from fuel oil combustion depend on the grade and composition of the fuel, the type and size of the boiler, the firing and loading practices used, and the level of equipment maintenance. Because the combustion characteristics of distillate and residual oils are different, their combustion can produce significantly different emissions.

Particulate emissions may be categorised as either filterable or condensable. Filterable emissions are generally considered to be the particles that are trapped and are greater than 0.3 microns. Vapours and particles less than 0.3 microns pass through the filter. Condensable particulate matter is material that is emitted in the vapour state which later condenses to form aerosol particles. The condensable particulate emitted from boilers fuelled on oil is primarily inorganic in nature.

Filterable particulate matter emissions depend predominantly on the grade of fuel fired. Combustion of lighter distillate oils results in significantly lower particulate matter formation than does combustion of heavier residual oils.

In general, filterable particulate matter emissions depend on the completeness of combustion as well as on the oil ash content. The particulate matter emitted by distillate oil-fired boilers primarily comprises carbonaceous particles resulting from incomplete combustion of oil and is not correlated to the ash or sulphur content of the oil. However particulate emissions from residual oil burning are related to the oil sulphur content.

Boiler load can also affect filterable particulate emissions. At very low load conditions (approximately 30% of maximum rating), proper combustion conditions may be difficult to maintain and particulate emissions may increase significantly.

Large industrial boilers are generally well designed and well maintained so that soot and condensable organic compound emissions are minimised. Particulate matter emissions are more a result of emitted fly ash. Therefore, post combustion controls (mechanical collectors, ESP, fabric filters etc) or fuel substitution/alteration may be used to reduce particulate matter emissions from these sources.

Mechanical collectors, a common control device, are primarily useful in controlling particulates generated during soot blowing, during upset conditions, or when a very dirty heavy oil is fired. For these situations, high efficiency cyclonic collectors can achieve up to 85% control of particulate. Under normal firing conditions, or when a clean oil is combusted, cyclonic collectors are not nearly so effective because of the high percentage of small particles (less than 3 micrometers in diameter) emitted.

Electrostatic precipitators (ESP) are commonly used in oil-fired power plants. Older precipitators, usually small, typically remove 40 to 60% of the emitted particulate matter. Because of the low ash content of the oil, greater collection efficiency may not be required. New or rebuilt ESPs can achieve collection efficiencies of up to 90%.

In fabric filtration, a number of filtering elements (bags) along with a bag cleaning system are contained in a main shell structure incorporating dust hoppers. The particulate removal efficiency of the fabric filter system is dependent on a variety of particle and operational characteristics including particle size distribution, particle cohesion characteristics, and particle electrical resistivity. Operational parameters that affect collection efficiency include air-to-cloth ratio, operating pressure loss, cleaning sequence, interval between cleaning, and cleaning intensity. The structure of the fabric filter, filter composition and bag properties also affect collection efficiency. Collection efficiencies of baghouses may be more than 99%.

Scrubbing systems have also been installed on oil fired boilers to control particulates (and sulphur oxides). These systems can achieve particulate control efficiencies of 50 to 60%.

Fuel alteration of heavy oil by mixing with water and an emulsifying agent has reduced particulate matter emissions significantly in controlled tests.
6.7 Liquefied Petroleum Gas

LPG is considered a clean fuel because it does not produce visible emissions. Particulate matter emissions are very low and result from soot, aerosols formed by condensables emitted or boiler scale dislodge during combustion.

There are no known controls developed specifically for LPG particulate emissions owing to their very low level.

6.8 Comparison of Energy Source Emission Controls

The following table summarises the particulate emission removal efficiency for the energy types considered in this section.

**Table 7**: Summary of the particulate emission removal efficiency for various energy types

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Particulate control systems</th>
<th>Particulate removal efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous and sub-bituminous coal</td>
<td>ESP</td>
<td>99%+</td>
</tr>
<tr>
<td></td>
<td>Fabric filtration (baghouse)</td>
<td>99%</td>
</tr>
<tr>
<td></td>
<td>Wet scrubber</td>
<td>95-99%</td>
</tr>
<tr>
<td></td>
<td>Mechanical collectors (cyclones)</td>
<td>90-95%</td>
</tr>
<tr>
<td>Anthracite coal</td>
<td>Fabric filtration (baghouse)</td>
<td>99%+</td>
</tr>
<tr>
<td></td>
<td>ESP</td>
<td>90-97%</td>
</tr>
<tr>
<td></td>
<td>Wet scrubbers</td>
<td>90%+</td>
</tr>
<tr>
<td>Wood residue</td>
<td>Mechanical collectors (cyclones)</td>
<td>25-60%</td>
</tr>
<tr>
<td></td>
<td>ESP</td>
<td>90-99%</td>
</tr>
<tr>
<td></td>
<td>Wet scrubbers</td>
<td>85%+</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>Mechanical collectors (high efficiency cyclones)</td>
<td>Up to 85%</td>
</tr>
<tr>
<td></td>
<td>ESP</td>
<td>Up to 90%</td>
</tr>
<tr>
<td></td>
<td>Fabric filtration (baghouse)</td>
<td>99%+</td>
</tr>
<tr>
<td></td>
<td>Wet scrubber</td>
<td>50-60%</td>
</tr>
</tbody>
</table>

7. Conclusion

This paper highlights that, while the dairy industry is a contributor of dust emissions, it is not a significant source.

Nevertheless technological solutions have been demonstrated to be able to reduce these emissions from powder drying plants and energy production plants.

There are different statutory requirements in different countries which will determine the emission standard necessary. Emission control solutions are therefore not only based on the fuel type and plant design, but also need to reflect local statutory standards.

Furthermore an economic assessment would be expected to accompany a decision on dust control systems, with relative energy costs and supply also taken into account.

The selection of dust control technology is multi-faceted, but technology is available to reduce dust emission levels and, importantly, the finer particulate levels, where this is required.
8. References

AIR EMISSIONS FROM DAIRY PROCESSING AND ENERGY PLANTS

ABSTRACT

The report presents an overview of definitions, sources, legal requirements, and technical solutions for air emission control in dairy processing and control of dust emissions from energy supply plants in dairy production.

This paper highlights the fact that, while the dairy industry contributes to dust emissions, it is not a significant source in global terms.

Furthermore, the report demonstrates the capacity of technological solutions such as cyclones, wet filters and tubular filters to reduce these emissions from powder drying plants.

The report also shows that the choice of fuel/energy source can have a significant influence on dust/particulate emission from energy supply plants and illustrates the different influences resulting from such choices.

Keywords: Environment, emissions, dust, dairy.

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± -------------------------------------Half-space before and after
microorganisms ----------------------Without a hyphen
Infra-red ----------------------------With a hyphen
et al.---------------------------------Not underlined nor italic
e.g., i.e.,.-----------------------------Spelled out in English - for example, that is
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skimmilk--------------------------------One word if adjective, two words if substantive
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AOAC International-------------------Not AOAC
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Decimal comma-------------------------in Standards (only) in both languages (as agreed by ISO)
No space between figure and % - i.e. 6%, etc.
Milkfat-------------------------------One word
USA, UK, GB--------------------------No stops
Figure-------------------------------To be written out in full
1000-9000--------------------------No comma
10 000, etc.-------------------------No comma, but space
hours-------------------------------0 h
second--------------------------------0 s
litre---------------------------------0 l

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