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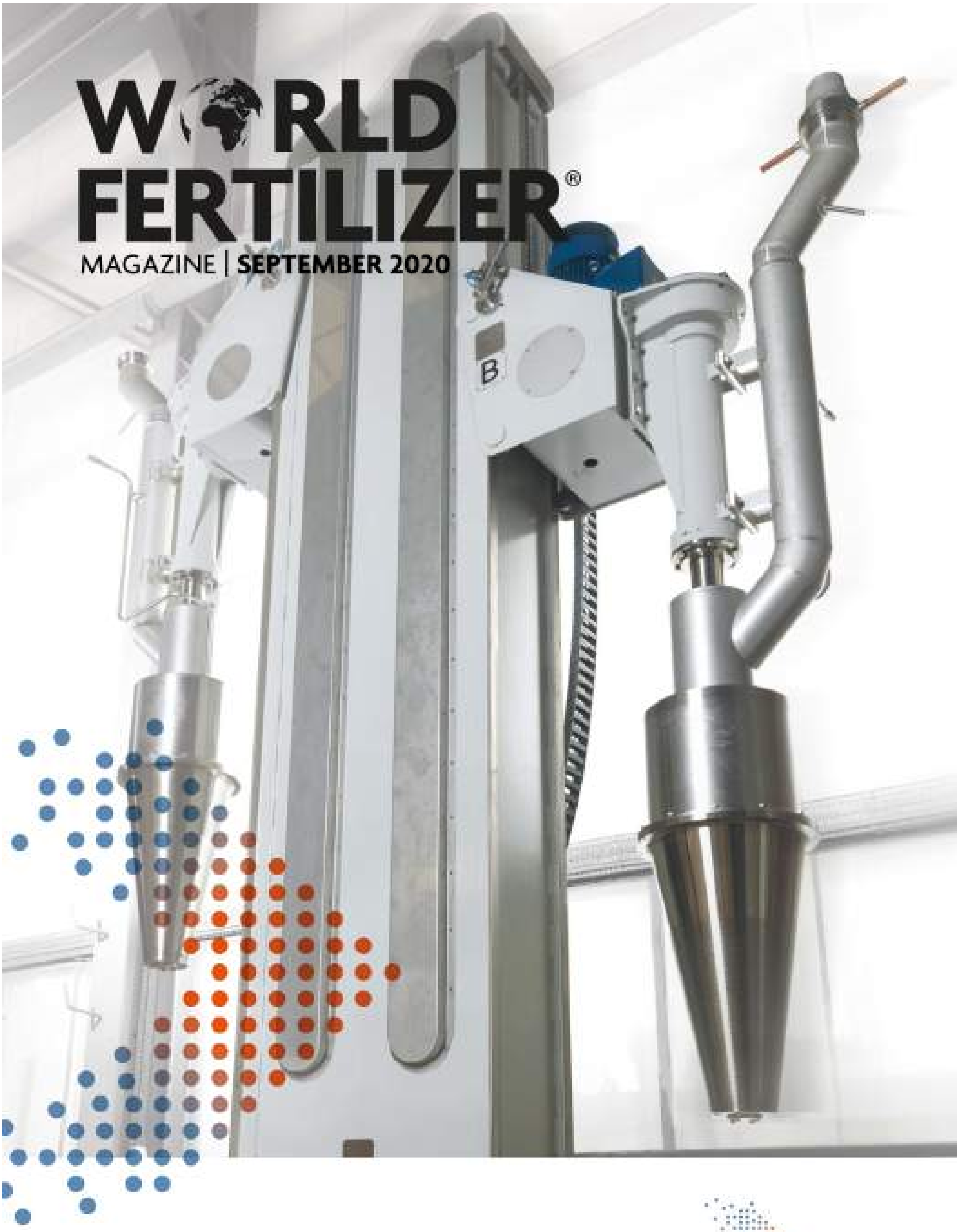

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FROM MIST ELIMINATORS TO FACE MASKS

Eduardo Almeida, Vitor Sturm, Nelson Clark, Victor Machida, and Bruno Ferraro, Clark Solutions, Brazil, provide an insight into aerosol elimination.

Entrainment occurs whenever process gas suspends and carries liquid particles. This phenomenon commonly takes place in nature – as fogs – and in industrial plants where processes involves sprays, chemical reaction, condensation, and mass transfer – such as absorption and distillation – as well as many others.

Throughout daily life, humans also produce aerosols. Again, usually undesirable, breath, coughs, and sneezes can form different aerosols and may spread diseases.

Aerosols can have a myriad of different compositions, particle sizes and distributions and can be roughly classified depending on their mechanisms of formation (Figure 1).[1]

In many cases, aerosol formation is not intended and its generation can cause harmful consequences. Production loss, environmental contamination, equipment corrosion and damage, among others, are just some of the common issues fertilizer plants face.

Large enough aerosols deentrain by themselves after certain distances, such as in the industry, by action of gravity, while fine aerosols, also known as mist, are more stable and must be captured by special means.

Mist eliminators

Each type of aerosol will be captured by a distinct device. Therefore, there are many types of mist eliminators, each one specifically designed and built for best performance in a certain process.

In this article, Clark Solutions will analyse the MaxiMesh®, a commonly used type of mist eliminator. This mist eliminator is composed of a series of geometrically knitted layers of metal, glass, plastic, or a combination of these materials, which are laid one above the other in a certain path that will maximise the number of targets for particle collection, while minimising pressure drop and favouring collected liquid drainage.

The wire mesh pad mist eliminator is the standard separator for a wide range of applications – specific mesh, crimp, layout, number of layers as well as a broad range of materials will fit each process and conditions.

These devices are the main choice when droplets are mechanically generated since this type of entrainment contains droplet size distributions from few to dozens of micrometers.

Wire mesh pad mist eliminators are often the first de-entrainment devices to be considered as they will operate with nearly 100% efficiency in a broad particle size spectrum at a minimal energy cost – unless fouling is a primary concern or extremely fine mist is present (less than 2 µm).

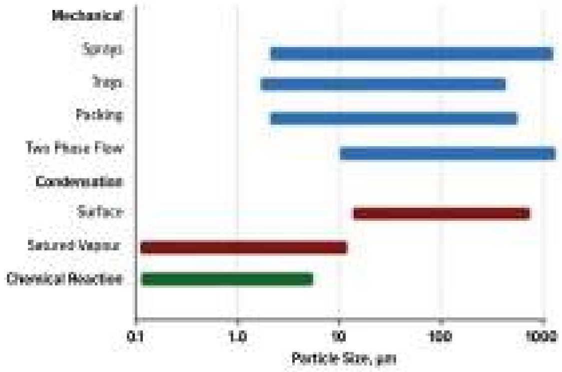

Figure 1. Mist sources and their respective particle sizes.

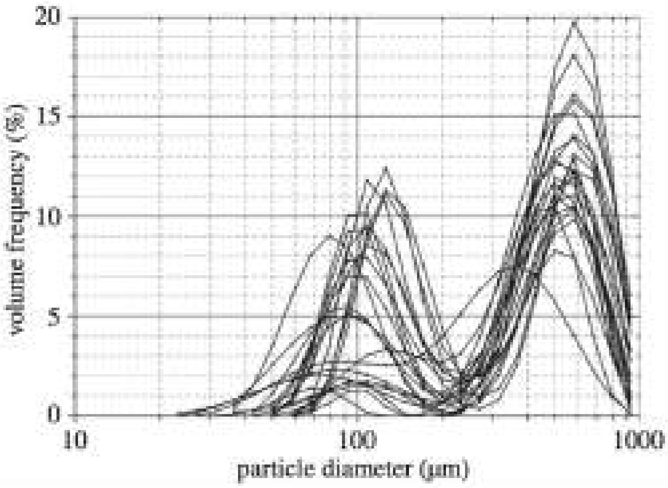

Figure 2. Bimodal distribution measured in experiment (23 sneezes of 10 subjects).[2]

Collection mechanism

Mechanical mist elimination can be achieved through three major collection mechanisms: direct interception, inertial impaction and Brownian diffusion.

This article will focus solely on inertial impaction, which is the main mechanism for the MaxiMesh wire mesh mist eliminator.

Inertial impaction occurs when a gas stream carrying liquid particles passes through an obstacle. While, the gas will deviate from the interference, particles above the inertia threshold will be projected from the gas flow and impact on the obstacle. Inertial impaction presents as a pronounced increase in the gas velocity, as the liquid to gas density ratio increases and as target gets smaller (i.e. the gas trajectory change is steep to avoid the interference).

This formal definition within the collection mechanism can be at times hard to visualise. As the collection of entrained droplets in a mist eliminator is similar to the collection of projected saliva or sneeze aerosols in a face mask, a comparison of the two technologies can help explain the science behind wire mesh mist eliminators.

Aerosol collection efficiency estimation

The current global pandemic, COVID-19, is creating massive challenge to every day life all over the world. In an effort to combat the virus, the World Health Organization (WHO) has released recommendations for countries and individuals on how to wear face masks in a safe manner.[1]

As a disclaimer, this article does not intend to offer real efficiency of face masks, but only illustrate one of many mechanisms with which they operate.

The operating mechanism of face masks is, in much aspects, the same as mist eliminators. To nearly illustrate how mist eliminators operate, this article presents a comparison to help provide an understanding and theoretical analysis which more tangible to the reader.

Both wire mist eliminators and face masks are an entanglement of fine filaments offering obstacles to the liquid carried over by the gas phase, turning aerosols into cleaner gas (Figure 2).

The following calculations consider some simplifications (cotton wires considered with constant diameter and equally spaced) and standardised tests must be undertaken to evaluate efficiency.

Typical mist sources that mist eliminators encounter are displayed in Figure 1, alongside their respective particle size. Meanwhile the distribution of sneeze particles encountered by face masks is shown in Figure 2.

However, each mist eliminator application uses different strategies: wire mesh mist eliminators have a less superficial area but thicker pads, while face masks have more superficial area but are usually thinner (normally two layers of fabric) (Figure 3).

There are dozens of different correlations to calculate mesh pad mist eliminators efficiency. For the MaxiMesh, Clark Solutions employs a proprietary method, but to calculate the efficiency of face masks, this article will use Langmuir and Blodgett's correlation for a single wire efficiency[4] in addition to the Carpenter and Othmer correlation to convert a single wire to the mesh-pad efficiency.[5]

The first step required to calculate a face mask's efficiency is to consider the flow parameters, known as 'Stoke's number' (Stk):

$$Stk = \frac{(\rho L - \rho G) \times (D_p^2) \times V_G}{18 \times \mu_G \times D_w} \tag{1}$$

With:

- ρL – liquid density.
- ρG – density.
- D_p – particle diameter.
- V_G – gas velocity.
- μ_G – gas viscosity.
- D_w – wire diameter.

After which, the Langmuir and Blodgett correlation is applied:

$$E_w = \frac{-0.105 + 0.995 \times Stk^{1.00493}}{0.6261 + Stk^{1.00493}} \tag{2}$$

Where E_w is the single-wire removal efficiency.

Finally, the overall mesh pad efficiency is calculated using the Carpenter and Othmer correlation:

$$E_{PAD} = 1 - e^{-0.238 \times S \times T \times E_W} \tag{3}$$

Where:

- E_{PAD} – total removal efficiency for a droplet of diameter DP.
- S – pad specific surface area.
- T – pad thickness.

For this analysis, water droplets and ambient air are considered. For this, the liquid density is 1000 kg/m³. Gas is essentially air at ambient conditions, which consequently implies a gas density of 1.2 kg/m³ and gas viscosity of 0.02 cP.

According to the Food and Agriculture Organization of the United Nations, cotton fibre diameters average typically range from 11 to 22 µm.[6] Therefore, in this case the D_w was selected as 20 µm. This is a conservative assumption, since the higher the diameter, the lower the specific surface are and consequently lower efficiency.

A gas velocity calculation demands certain assumptions, such as:

- Condition of breath: rest.

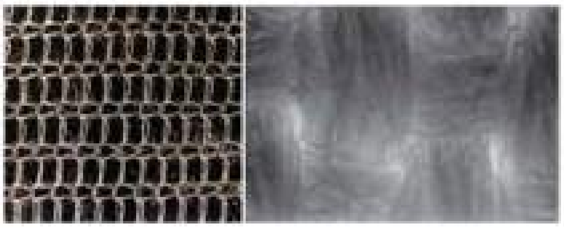

Figure 3. Left: One of MaxiMesh wires pattern. Right: a cotton fabric woven pattern.[3]

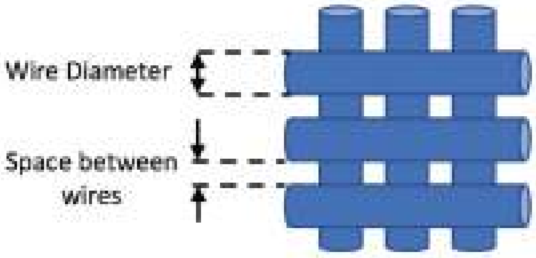

Figure 4. Region to define specific surface area.

- Inhales per minute: 20.[7]
- Exhales per minute: 20.[7]
- Time for one breath: 1.5 seconds.
- Tidal volume for each breath: 0.5 litres.[8]
- Volumetric flowrate of each breath: 1.2 m³/hr.

These assumptions have been based on an average human at rest. Not all lung volume is used when breathing and the tidal volume is the air volume inhaled and exhaled at each breath. Volumetric flowrate is calculated dividing tidal volume by breath rate.

$$\frac{60 \left[\frac{\text{Seconds}}{\text{Minute}}\right]}{20 \left[\frac{\text{Breaths}}{\text{Minute}}\right]} = 1.5 \left[\frac{\text{Seconds}}{\text{Breath}}\right] \tag{4}$$

$$\frac{0.5 \left[\frac{\text{Litres}}{\text{Breath}}\right]}{1.5 \left[\frac{\text{Seconds}}{\text{Breath}}\right]} = 20 \left[\frac{\text{Litres}}{\text{Minute}}\right] = 1.2 \left[\frac{m^3}{h}\right] \tag{5}$$

The average velocity of breath is calculated with another estimation considering the mask area. When a human is at rest, not all of the mask's superficial area is used, so a diameter slightly larger than the nose is estimated. The almost arbitrary value selected is 40 mm, which results in 1260 mm² area and an average velocity of 0.27 m/s.

$$\frac{\pi \times (40\,[mm])^2}{4} = 1260\,[mm^2] \tag{6}$$

Table 1. Impact of different parameters

Parameter	Unit	Base scenario	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Wire diameter	μm	20	10	40	20	20
Specific surface area	m^2/m^3	306 500	598 400	155 140	306 500	306 500
Fabric layers	-	2	4	1	3	1
Pad thickness	μm	40	40	40	60	20
Collection efficiency of 50 μm particle	%	96.78%	99.88%	82.19%	99.42%	82.05%

Table 2. Analysis of Table 1

Base scenario	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Wire diameter	Smaller	Larger	Same	Same
Specific surface area	Larger	Smaller	Same	Same
Pad thickness	Same	Same	Larger	Smaller
Collection efficiency	Better	Worse	Better	Worse

Table 3. Product comparison

Base model - 431	Model 421	Model 326	Model 931
Surface area	46% more	97% more	39% Less
Number of layers	17% more	67% more	40% Less
Service	High mist content	Fine particles	Viscous mist

$$\frac{1.2\left[\frac{m^3}{h}\right]}{1260\,[mm^2]} = 0.27\left[\frac{m}{s}\right] \qquad (7)$$

This average velocity calculation is similar to the calculations used in industrial cases. The process has a volumetric flowrate and the vessel a specified diameter. The average velocity is calculated by dividing the volumetric flowrate by the cross-sectional area.

The last two parameters remaining to be determined are specific surface area and pad thickness.

For the former, a small region of three vertical filaments and three horizontal filaments will be considered, and are illustrated in Figure 4.

The volume and superficial area are calculated using the following equations:

$$Volume = (3 \times wire\ diameter + 3 \times space\ between\ wires)^2 \times wire\ diameter) \qquad (8)$$

$$Superficial\ area = \pi \times wire\ diameter \times (3 \times wire\ diameter + 3 \times space\ between\ wires) \qquad (9)$$

Wire diameter was already selected as 20 μm, and the space between wires is assumed to be 0.5 μm.[9] Using equations 7 and 8, a specific area of 306 500 m^2/m^3 is calculated.

Finally, pad thickness is considered as a double layer of fabric, which equates to 2 D_w.

Therefore, now all parameters required to calculate the approximate efficiency of a face mask have been either been calculated or estimated. Using equations 1 to 3, it is possible to calculate a collection efficiency for a specified particle diameter. Moreover, by analysing Figure 2 it is possible to conclude the mask only needs to collect particles larger than 50 μm.

$$Stk = \frac{(1000 - 1.2) \times (0.00005^2) \times 0.27}{18 \times 0.00002 \times 0.00002} = 92 \qquad (10)$$

$$E_w = \frac{-0.105 + 0.995 \times 184^{1.00493}}{0.6261 + 184^{1.00493}} = 98.73\% \qquad (11)$$

$$E_{PAD} = 1 - e^{-0.138 \times 306\,497 \times 0.0004 \times 0.9956} = 96.78\% \qquad (12)$$

Even when examining this oversimplified analysis, it is clear that the overall efficiency of face masks is high.

The most important aspect of this analysis is the impact of surface area and pad thickness, since those are the strategies for particle collection used in industrial scenarios (Table 1).

Table 1 compares quantitatively the base scenario, shown in equations 10 to 12, with four additional scenarios. Meanwhile, Table 2 compares qualitatively.

As Table 2 reveals, higher specific surface areas or pad thickness overall provide a better collection efficiency.

Comparison

Against the backdrop of COVID-19, discussions of the most effective number of layers and face mask material are common. These parameters correspond conversations of pad thickness and specific surface area in mist eliminators, which are main aspects to aerosol collection efficiency. Defining whether a mask will be of one or two layers and if the material will be cotton or polyester are crucial to effectiveness. Defining thickness and pad compositions are important parameters in MaxiMesh applications as well.

In an industrial environment, wire specific surface area is increased using a knit method. MaxiMesh products offer a range of different knit patterns, with filaments spaced further apart or closer together depending on process demands. As this article has calculated, decreasing space between wires increases superficial area, which increases the overall efficiency of particle collection. Also, a mesh can be co-knitted with materials such as fibreglass. This material's filaments partially occupies voids between metal wires, which also contributes to specific surface area.

Regarding pad thickness, MaxiMesh models usually have a size of 6 in., which could be adapted depending on process specifications. In Table 3, the 431 model is used as a base case for comparison.

The 421 model is recommended to high mist contents. Although it requires an increased surface area, no significant change in the number of layers is necessary.

Type 326 application is best used for fine particles. Since the main goal is high collection efficiency, the required surface area is almost the double and more layers need to be employed.

Finally, model 931 is used for more viscous liquid services. This way the mist eliminator must be more open than the standard 431, which corresponds to less surface area and number of layers, since fouling is an important aspect.

These are just a few of the available MaxiMesh models. Some are co-knitted with different materials which substantially increases surface area, others have a composition of sections with different surface areas and number of layers to increase mist eliminator gas capacity.

The design of mist eliminators considers similar aspects discussed in this article: fluid properties must be specified, calculated, or estimated. Gas velocity is calculated by the volumetric flowrate and the cross-sectional area (for conditions of well distributed gas flow). Once these calculations have been made, the correct model can be easily selected to collect the required particle diameter, whilst offering the lowest pressure drop.

Conclusion

By contextualising particle collection through a comparison of face mask design, this article has aimed to explain how mist eliminators work with an inertial impaction mechanism, which parameters are relevant and how they contribute to mist elimination design and operation.

These results displayed for face mask should not be construed as factual, since a lot of simplifications were made. Notwithstanding, scenario comparison is an interesting perspective on protection evaluation. **WF**

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