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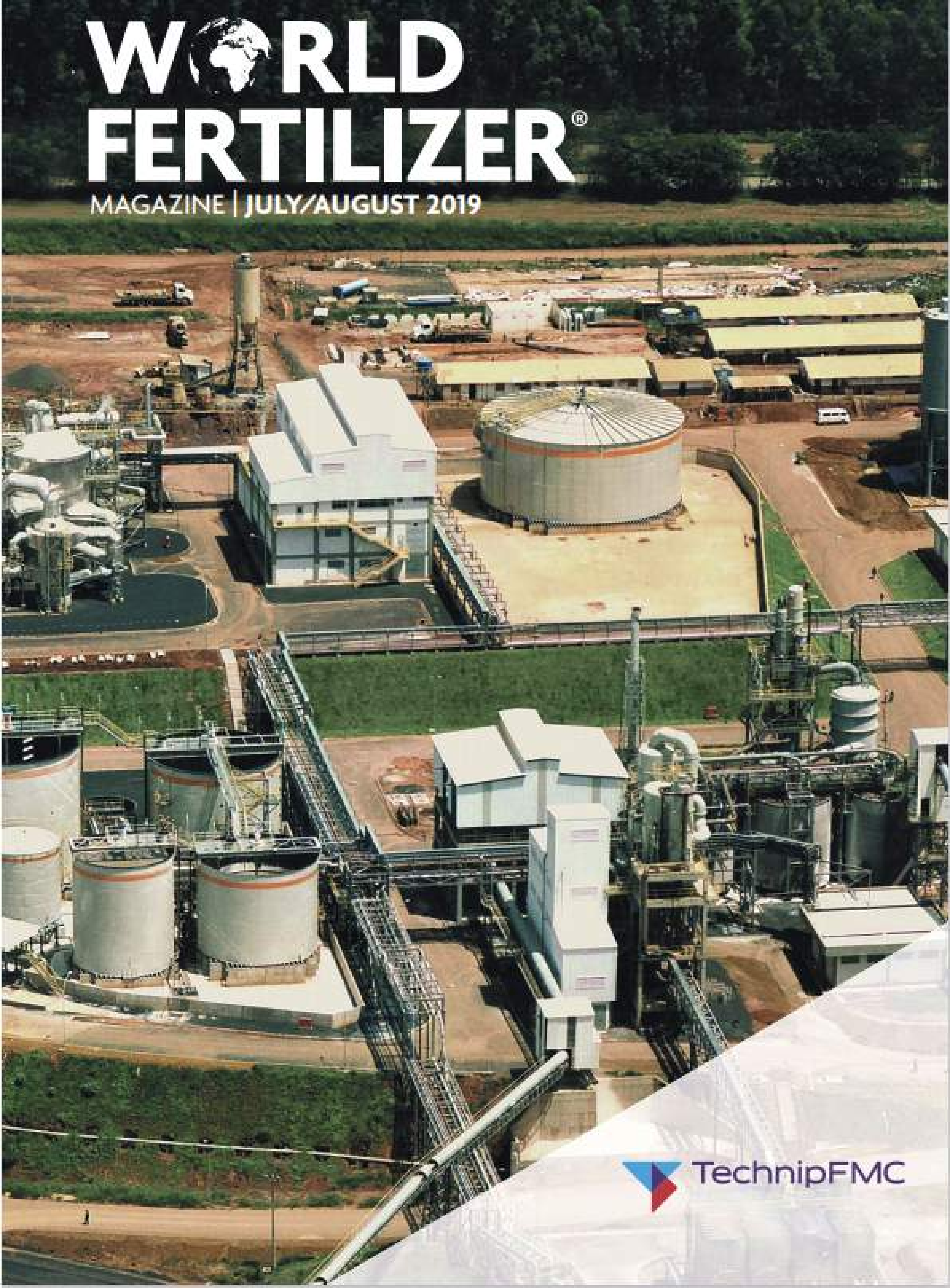
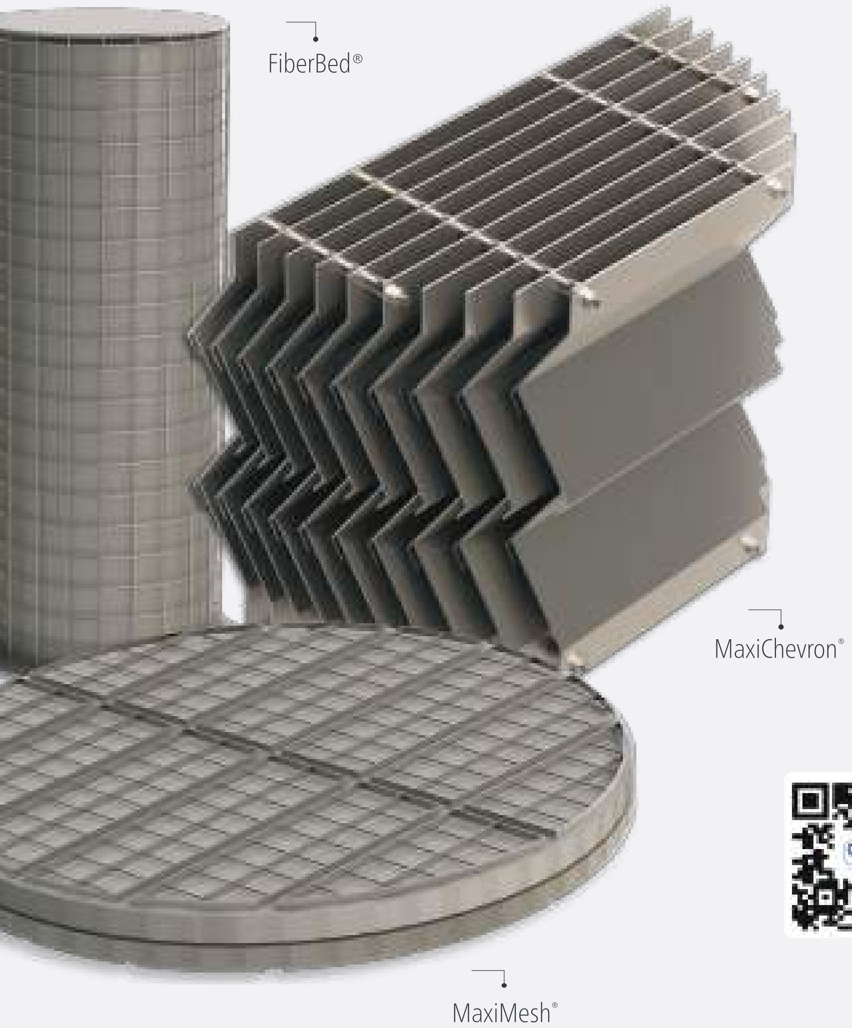


Mist Elimination Solutions



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Mist Elimination and its Applications on the Phosphoric and Sulfuric Acid Manufacturing Process

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1. Introduction

There are two different processes using various raw materials to manufacture phosphoric acid (H_3PO_4): thermal and wet. Wet process represents the main line of production around the globe. There are three possible subgroups of wet processes depending on which acid is used for acidulation, i.e. nitric acid (HNO_3), hydrochloric acid (HCl) or sulfuric acid (H_2SO_4). The wet digestion of phosphate rock with H_2SO_4 is the preferred process in terms of volume [BREF, 2007].

Within the wet digestion using H_2SO_4, there are more specific categories of processes: dihydrate; hemihydrate; hemi-dihydrate recrystallisation with single-stage filtration; hemi-dihydrate recrystallisation with double-stage filtration; di-hemihydrate recrystallisation with single-stage filtration. In the hemihydrate process, it is possible to produce 40 – 46% P_2O_5 acid directly, enabling valuable savings in energy usage [BREF, 2007]. This acid tends to contain much less free sulphate and suspended solids and lower levels of aluminum and fluorine than evaporated dihydrate process acids of the same strength. Additionally, a satisfactory rate of reaction can be achieved from much coarser rock than in the dihydrate process, because of the more severe reaction conditions in the hemihydrate process.

Regarding sulfuric acid manufacture, H_2SO_4 is produced from sulfur dioxide (SO_2), which is derived from various sources, such as combustion of elemental sulfur or roasting of metal sulfides. The main source of producing SO_2 is elemental sulfur [BREF, 2007].

Both H_3PO_4 and H_2SO_4 are corrosive, toxic and valuable, raising interest in reducing carryover. Furthermore, calcium sulphate ($CaSO_4$) particles can also accumulate inside pipes and equipment in phosphoric acid plants. Solids presence raises pressure drop and lowers capacity of unit operations.

Because of mist formation during evaporation, air drying and absorption, liquid and solid particles can follow the gas stream. To solve this problem, mist eliminators are set before towers outlet. As a result, particles are retained and sent back to the liquid phase.

There are different approaches for retaining particles, each of which is dependent on the application. Clark Solutions conceived numerous products that meet the needs of many industrial applications, including those of phosphoric and sulfuric acid manufacturing.

2. Mist formation

The term mist generally refers to liquid droplets from submicron size to about 10 μm. If the diameter exceeds 10 μm, the aerosol is usually referred to as a spray or simply as droplets. Mists tend to be spherical because of their surface tension and are usually formed by nucleation and the condensation of vapors [VALLERO, 2014]. Inside an absorption tower in a contact H_2SO_4 plant, the diameter is very small, ranging from 0.1 to 30 μm [PERRY, 1984]. Different sources of mist and their respective particle sizes can be seen at Figure 1.

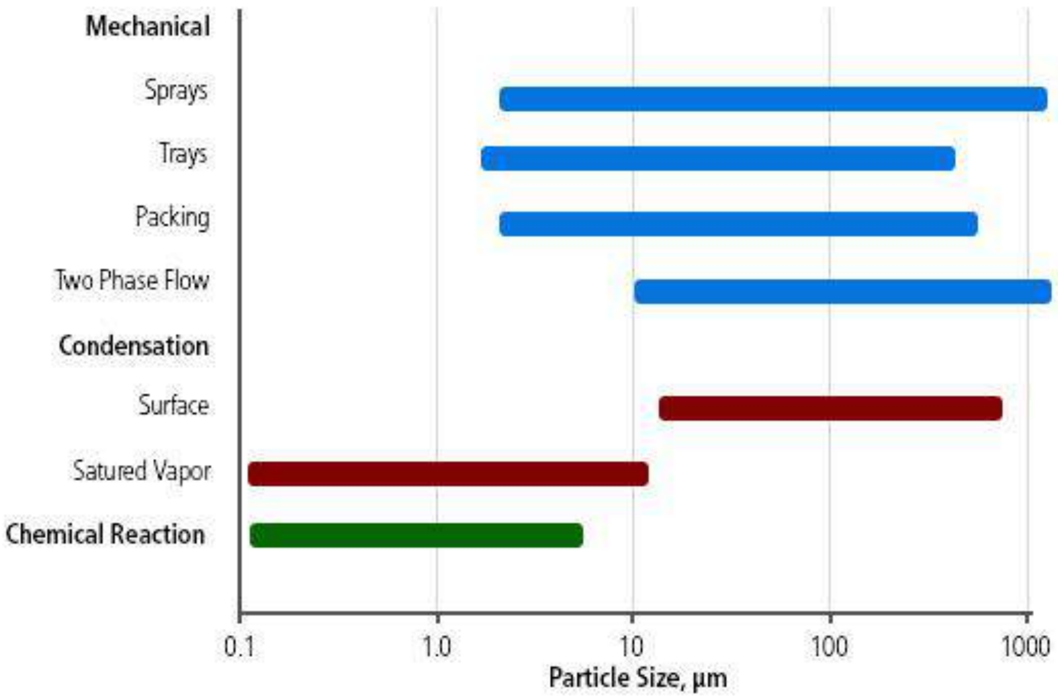

Figure 1: Mist sources and their respective particle sizes

3. Getting rid of mist

The method for mist elimination is dependent on particle momentum. In other words, its size and velocity define equipment type. This is more clearly visible at Figure 2.

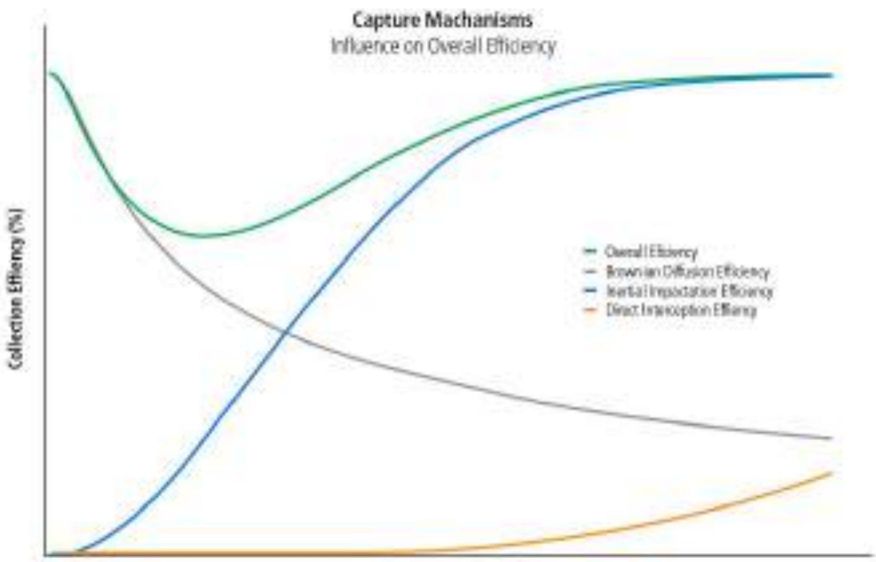

Figure 2: Collection efficiency for different capture mechanisms. (Curves are resized for illustration purposes)

A. Inertial impaction and direct interception

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

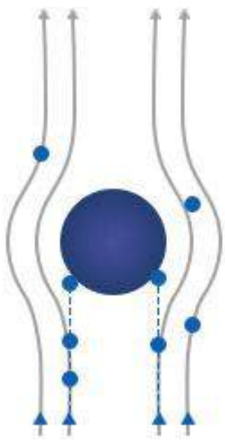

Figure 3: Inertial impact mechanism

Direct interception occurs when particle diameter is small enough to follow gas streamlines, but big enough to collide on obstacles edges. This effect will increase as target gets smaller and mist eliminator void fraction is reduced. Mechanism schemes for inertial impact and direct interception are found on Figure 3 and Figure 4, respectively.

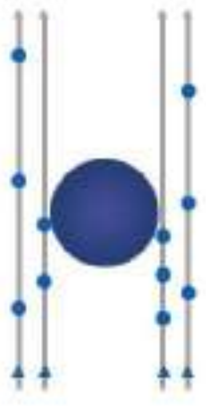

Figure 4: Direct interception mechanism

- Vane type mist eliminator

Vane mist eliminators remove entrained liquid primarily by inertial impact. In these eliminators, curved vanes (shaped plates) cause the gas to move in an undulatory manner. Liquid drops cannot follow these changes due to higher inertia, impinging and adhering on blades surface.

When liquid content is sufficiently high it forms a film, which drains away under gravity. For vertical vanes, where gas flows upwards, this drainage is countercurrent to gas flow. If gas flows horizontally, drainage is perpendicular to it [NARIMANI, 2010].

These devices bring lower efficiency than other mist eliminators, but also lower pressure drop and higher liquid drainage capacity. They are usually the best option for high fouling operations as blades support higher drainage and allow simple washing when plugged.

Figure 5: MaxiChevron® made with plastic

This is the case with phosphoric acid evaporators. During first stages, phosphate rock is attacked by sulfuric acid. This reaction produces the main product, H_3PO_4, and calcium sulfate ($CaSO_4$), and they are separated by solid-liquid filters (BREF, 2007). After filtering $CaSO_4$, evaporation is often employed to yield higher concentrations of H_3PO_4. Calcium sulfate have a solubility around 7 g/L in 30% phosphoric acid (TABER, 1905) which means that this component can be carried in solid as well as diluted form. This salt has a high fouling aspect and is difficult to remove, since it forms plaster.

Solids accumulation decrease mist eliminator free cross-sectional area, causing pressure drop increase. Higher pressure drop reduces evaporation capacity. Therefore, the mist eliminator is removed for cleaning and installed again – or replaced in extreme cases. Besides downtime, which is costly, cleaning with high pressure water can damage the blades, decreasing equipment lifespan.

In this situation, MaxiChevron® coupled with MaxiWash™ is recommended, since they will remove both $CaSO_4$ plasters, particles and H_3PO_4 solution.

MaxiChevron® is a vane type mist eliminator, it consists of a series of vane modules appropriately spaced, either horizontally or vertically positioned. The material can be made of alloy, thermoplastic or composite. It is ideal for systems that work with high solid content or viscous fluids that foul other equipment, reducing effective area, leading to its wearing. Figure 5 has a MaxiChevron® made of plastic.

Table 1: Benefits of MaxiChevron®

Benefits
• **High efficiency** Efficiency is guaranteed at mid pressure levels
• **Very low pressure drop** Gas trajectory is barely affected
• **Flexibility** Projects are custom-made
• **Cost-benefit** Dimensions are substantially reduced
• **High resistance to fouling** Operates even with liquids containing high solid content

MaxiWash™ is a continuous spray washing system with the goal of maintaining blades wet. The used liquid is typically the system solution, such as phosphoric acid.

Two objectives are achieved simultaneously by keeping a continuous liquid film on vane-type walls:

- Evaporation of liquid due to pressure gradient turns irrelevant, since liquid is provided by the sprays at the rate it is evaporated, maintaining solids diluted
- The film prevents free solids to accumulate on walls, carrying down impinged solids alongside liquid draining

Continuous washing will collect solids in a slow and enough pace avoiding its accumulation on walls, substantially increasing maintenance intervals and mist eliminator lifespan.

- Wire mesh mist eliminator

(Co-)Knitted wire mesh pads mist eliminator devices collect droplets primarily via inertial impaction and are the standard separator for a wide range of applications – with adaptations on mesh, crimp, thickness and co-knitted materials to specifically fit each condition. 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 pads are the first de-entrainment devices to be considered – unless fouling is a primary concern or extremely fine mist is present.

Wire mesh mist eliminator, in most general sense, is a simple porous blanket of metal or plastic wire. It retains liquid droplets entrained by gas. The separation process includes three steps.

The first step is inertial impaction of liquid droplets on wire surface. As gas phase flows past or around wires surface in the mesh pad, streamlines are deflected, but kinetic energy of liquid droplets associated with gas stream may be too high to follow gas streamline and they impinge on the wires. The second stage in the separation process is the impinging droplets coalescence on wires surface. In the third step, droplets detach from the pad. In vertical flow installations, captured liquid drains back as large droplets that drip from the upstream face of the wire mesh pad. In horizontal flow systems, collected liquid droplets drain down through the vertical axis of the mesh pad in a cross-flow manner [EL-DESSOUKY, 1999].

Figure 6: MaxiMesh® model 738

Wire mesh are applicable inside drying towers for sulfuric acid process. Air drying is located at the very beginning of the sulfuric acid process. A recirculating concentrated solution of H_2SO_4 is used to remove humidity.

If acid mist is not properly removed, downstream equipment could be severely damaged. This could lead to plant shutdown or even accidents.

Taking this into account, a mist eliminator must be placed inside the drying tower. A properly designed and assembled MaxiMesh® will virtually eliminate all acid carryover in the tower, protecting both blower and furnace. MaxiMesh® is a knitted mesh demister manufactured by Clark Solutions, model 738 is pictured at Figure 6.

Table 2: Benefits of MaxiMesh®

Benefits
• **High efficiency** Collects about 100% of particles with diameters above 2 μm in moderate liquid flow
• **Low pressure drop** Suitable to processes in which pressure drop is a primal feature to proper operation
• **Easy assembly** Delivered in modules, allows passage through manhole and comes with assembly instructions
• **Quick manufacture** 1. Own manufacture, undertaking urgency cases 2. The mesh can be repacked, reusing grids when capex is lower

B. Brownian diffusion

Brownian diffusion occurs with extremely small particles which acquire a Brownian movement. These submicrometric objects follow gas trajectory, defining residence time. They also move randomly by colliding with gas molecules, determining mean path and probability. They eventually reach an obstacle and form a liquid film. The lower the particle velocity, the higher the residence time and the higher the probability of collection. The mechanism is represented at Figure 7.

$$Collection\ efficiency \cong function(Time, Probability)$$

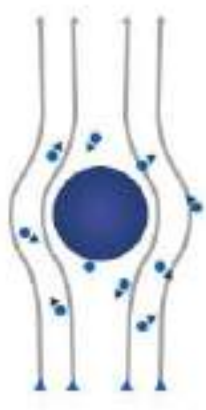

Figure 7: Brownian diffusion mechanism

- Candle filter mist eliminator

Candle filter eliminators make use of Brownian diffusion mechanism to collect particles. These candles consist of metallic or plastic open cartridges with compacted fibers, such as fiberglass or polymers. Extremely fine droplets are bounced between gas streamlines until they impact on a thin fiber, thus coalescing and draining along the casing.

Fiber candles are applicable when H_2SO_4 reaction takes place. Condensed acid mist with diameter lower than 3 µm form inside the absorption towers, requiring a method for separating smaller droplets.

Hot gases containing SO_3 exit the catalytic bed reactor and – after transferring heat – enter absorption towers, where SO_3 exothermically reacts with water present on concentrated H_2SO_4 solution.

SO_3 absorption produces a considerable amount of fine mist. Which can severely damage downstream equipment and piping. Therefore, this mist must be eliminated, and the most suitable product is a FiberBed®, which can be seen at Figure 8.

Figure 8: FiberBed BD

The FiberBed® BD is a submicronic particle separator, composed by a bed of micro fiberglass. It is carefully designed and dimensioned to capture and drain liquid particles (<1 µm) from the gas flow. It minimizes waste and protects gas-gas heat exchangers, economizers and gas pipes.

Table 3: Benefits of FiberBed®

Benefits
• **High efficiency** Guarantees liquid recovery and security on adjacent operations
• **Cost-benefit** High durability and efficiency
• **Repacking** By reusing the grids, prices and deadlines are lower
• **Material variety** Many options for plastic and metallic materials for cages and different fibers to fit process chemical attack conditions

4. Typical applications

Three applications were already mentioned: MaxiChevron® are used on phosphoric acid evaporators due to fouling potential; MaxiMesh® on sulfuric acid drying towers to remove the most acid carryover as possible; FiberBed® on sulfuric acid absorption towers, since the SO_3 reaction produces a fine mist that also must be eliminated.

Besides these three, some sulfuric acid plants apply MaxiMesh® or FiberBed® at the end of gas lines. On the phosphoric acid process side, there are other applications in which MaxiMesh® or MaxiChevron® are selected depending on solid content and operation.

Most phosphate rocks contain fluoride between 2 – 4 % w/w. This fluoride is released during acidulation in the form of hydrogen fluoride and reacts readily with excess silica forming fluorosilicic acid (H_2SiF_6) [BREF, 2007].

A proportion of the fluoride is released in the vapor, this amount depending on reaction conditions. Volatile fluorine compounds are also present at evaporators outlet [BREF, 2007].

There are scrubbers that recover fluorine, phosphoric acid or SO_2 before releasing to stack, both for product recovery and emission control. Normally, a mist eliminator is applied in the last stage of this scrubbing system and on granulation scrubbers. MaxiMesh® can sometimes be applied on absorption towers and tail gas scrubbers, as well as more specific phosphoric acid applications.

Table 4 - Typical applications of mist eliminators on their corresponding processes

Acid Process	Application	MaxiMesh®	MaxiChevron®	FiberBed®
Sulfuric	Drying tower	Co-knit metallic[1]	-	-
	Absorption towers	Co-knit metallic[1]	-	Fiberglass[1,3]
	Tail gas scrubbers	Co-knit metallic[1]	-	Fiberglass[1,3]
Phosphoric	Evaporators	Plastic[1,2,3]	Plastic[1,2,4]	-
	Granulation scrubbers	Plastic[2,3]	Plastic[2,4]	-
	Last stage scrubbers	Plastic[2,3]	Plastic[2,4]	-
On line washing		Seldom[5]	Yes	No
Typical design pressure drop (mm W.C.)		25 to 50	< 25	> 250

[1]Equipment protection and reduced maintenance costs; [2]Product recovery; [3]Higher efficiency; [4]Higher uptime;

[5]MaxiMesh in sulfuric acid applications does not require washing system, but is recommended in some phosphoric applications

Phosphoric acid process sometimes employs washing system for mist eliminator, whereas sulfuric acid typically cannot. A table containing all the applications mentioned can be found at Table 4.

MaxiChevron® operates at best conditions when coupled with MaxiWash®, since it continuously removes solid accumulation on blades. This arrangement reduces excessive amount of equipment shutdown necessary for cleaning, which can be costly.

5. Conclusion

Both phosphoric and sulfuric acid operations generate mist in different stages and conditions. Different solutions or set of solutions can efficiently retain fine liquid and solid particles, reducing impacts of both corrosion and solid fouling on process downstream, as well as recovering product and reducing emission. Proper equipment selection is readily available to satisfy each process demand.

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