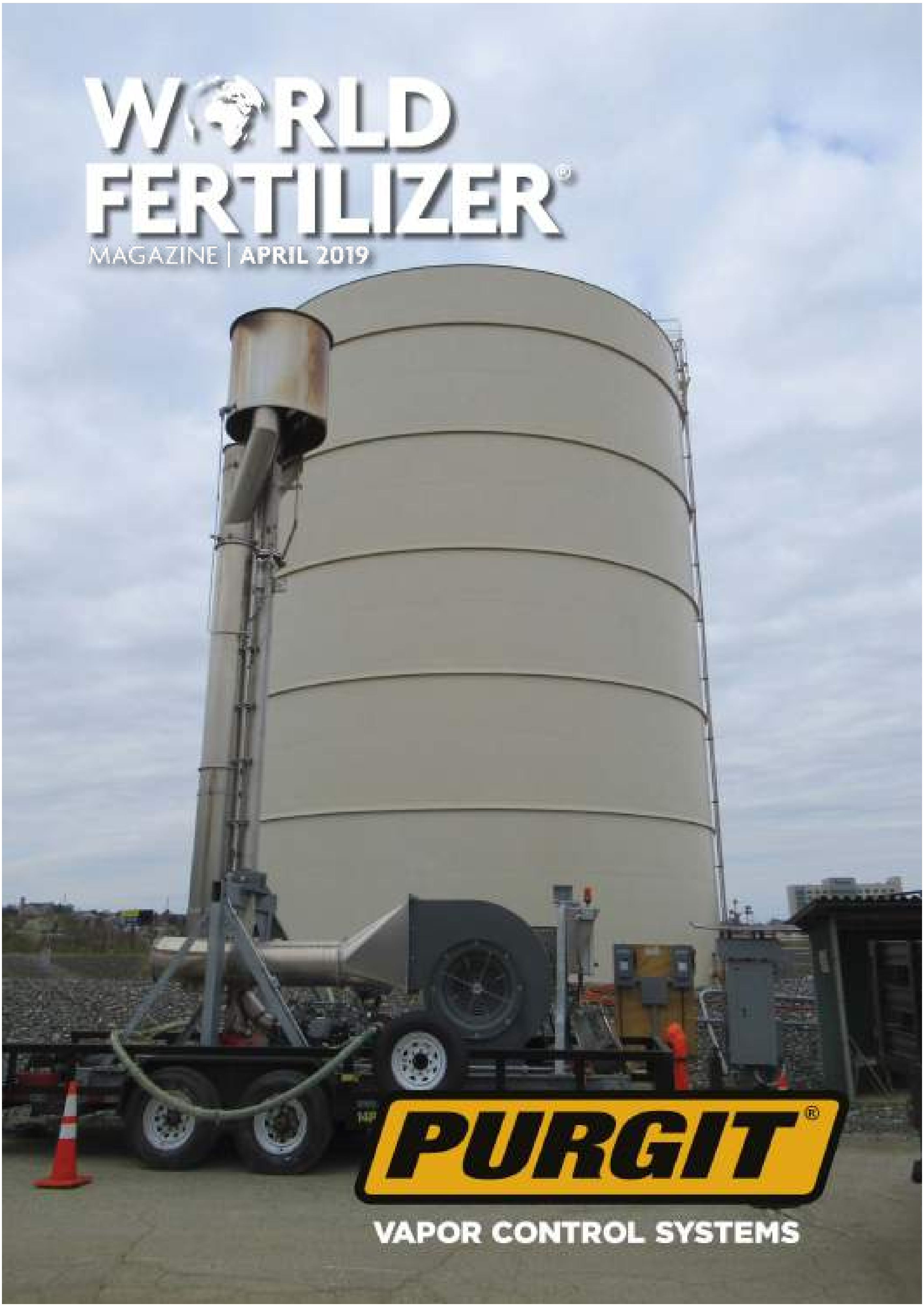
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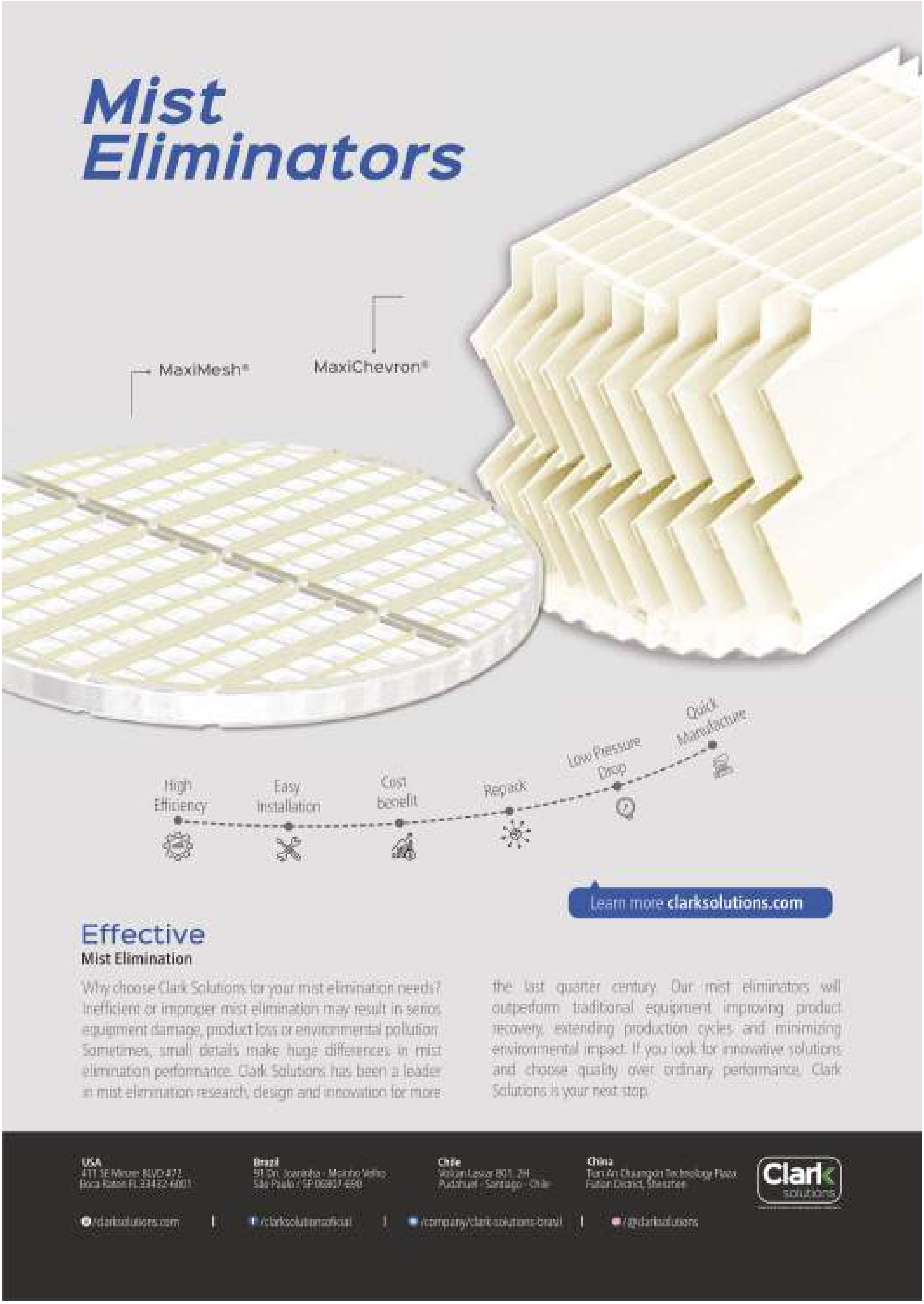
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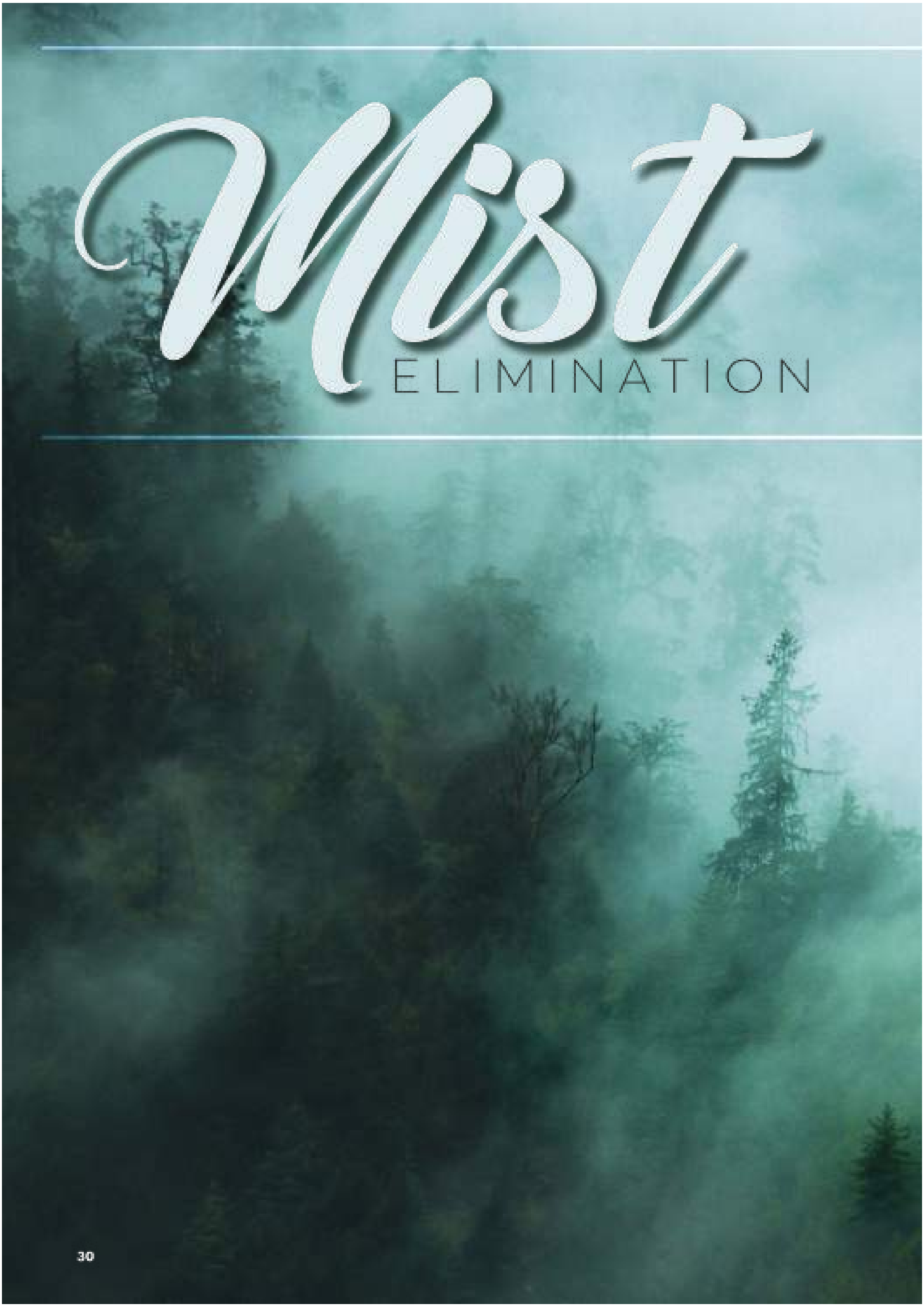
Mist ELIMINATION



Eduardo H. R. A. de Almeida, Vitor A. Sturm, Bruno B. Ferraro, and Nelson P. Clark, Clark Solutions, Brazil, discuss the use of mist eliminators during continuous spray washing for heavy fouling processes.

In phosphoric acid plants, mist eliminators downstream from evaporators can affect capacity and uptime if not properly designed. Vane-type mist eliminators are usually chosen for this process. This type of low pressure drop mist eliminator consists of spaced blades offering an undulatory stream pathway. The alternating path direction promotes droplet inertial impaction, a collection mechanism where density and viscosity differences between vapour and liquid causes droplet disengagement, as the latter's higher inertia makes it unable for a set of droplets to rapidly respond to abrupt changes in trajectory. Therefore, entrained liquid collides with mist eliminator walls and are collected and drained.

Many processes operate with saturated solutions that will precipitate solids due to pressure and thermal effects. Wide spacing and good capability for solid handling does not mean mist eliminators are immune to fouling. For this reason, a properly designed spray washing system for fouling processes,

Figure 1. Inertial impaction in MaxiChevron® Model 3.11.30.

such as

Figure 2. MaxiChevron in plastic material.

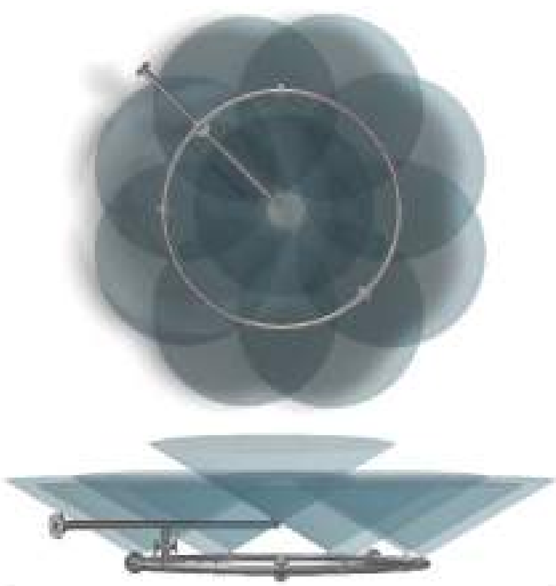


Figure 3. Example of spray arrangement of the MaxiWash™.

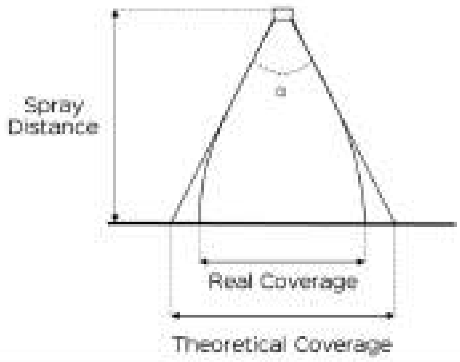


Figure 4. Pulverisation angle and spray distance considerations.

phosphoric acid mist elimination was developed by Clark Solutions (Figure 1).

Precipitation and fouling

Solids carried by vapour stream are basically calcium sulfate ($CaSO_4$), which results in the first stages of the plant, in which phosphate rock is attacked by sulfuric acid. Some of the $CaSO_4$ bypass the filters and get to mist eliminators. This solid has a high fouling aspect and is difficult to remove, since it forms plaster.

Calcium sulfate has a solubility around 7 g/l in 30% phosphoric acid, which means that this component can be carried in solid as well as diluted form.[1] The amount of entrained solid can be evaluated by empirical or theoretical means:

- Intervals for equipment removal for cleaning.
- Estimates of entrained liquid flow and therefore solid content (Table 1).

Fouling can occur by two means:

- Evaporation of saturated droplets collected on vane-type mist eliminator walls due to equipment pressure gradient.
- Solids accumulation on blades by direct impact against an existing fouling layer.

Solids accumulation decreases the active cross-sectional area of the mist eliminator, causing velocity profile changes and pressure drop increase. Pressure drop increase 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 could damage the blades, decreasing equipment lifespan.

Solution in keeping the solution

With these issues in mind, Clark Solutions offers the MaxiWash™ concept coupled with MaxiChevron® mist eliminators in a wide range of materials and designs to address process specific restraints. The MaxiWash is a spray washing system with the goal of maintaining a continuously-flowing thin liquid film on the blades of the mist eliminator surfaces. The liquid solution used is typically the process solution, such as phosphoric acid (Figure 2).

The specially-engineered and designed spray nozzles generate droplet size distribution that will properly penetrate the MaxiChevron blades, which can collect up to 99.9% in the 10 μm range. Thus, the sprayed liquid will be collected by the mist eliminator in its various passes, instead of first pass only.

Two objectives are achieved simultaneously by keeping a continuous liquid film on the walls:

- Evaporation of liquid due to pressure gradient is irrelevant, since liquid is provided by the sprays at the rate it is evaporated, maintaining solids diluted.

- The film prevents free solids from accumulating on walls, carrying down impinged solids alongside liquid draining.

A continuous system has the following benefits over intermittent operation:

- Lower water consumption: intermittent washing requires high pressure and liquid flowrates, due to the difficulty of mechanically removing fouled $CaSO_4$. On the other hand, for continuous washing, the flowrate and pressure can be set as to be minimum, just enough to maintain a thin film and guarantee saturation.
- No clogging: intermittent washing operates after solid accumulation. Using high-pressure, intermittent washing could cause blocks of $CaSO_4$ to detach and clog drain pipes. A continuous washing would entirely prevent block formation.
- Solid pre-collection: A continuous washing system maintains a liquid curtain. In the continuous scenario, all carried free solids pass through a liquid cone formed by the sprays, which helps in solids collection and particle growth.

Table 1. Solubility of calcium sulfate on phosphoric acid[2]

Grams P_2O_5/l	Grams $CaSO_4$/l	Density of solutions 25°/25°
0.0	2.126	-
5.0	3.138	1.002
10.5	3.734	1.007
21.4	4.456	1.016
46.3	5.760	1.035
105.3	7.318	1.075
145.1	7.920	1.106
204.9	8.383	1.145
312.0	7.965	1.221
395.7	6.848	1.250
494.6	5.573	1.344

Table 2. Limitation of the aspects in consideration

Parameter	Lower limit	Upper limit
Number of sprays	Possibility of failure	Cost
Pulverisation angle	Dead zones	Excess superposition Spray against walls
Spray distance	Too wide a pulverisation angle requirement	Jet deformation

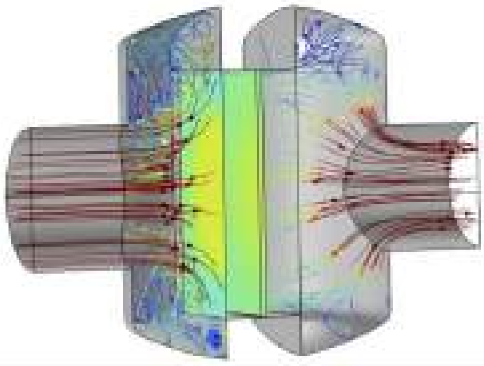


Figure 5. Vane-type mist eliminator without washing system.

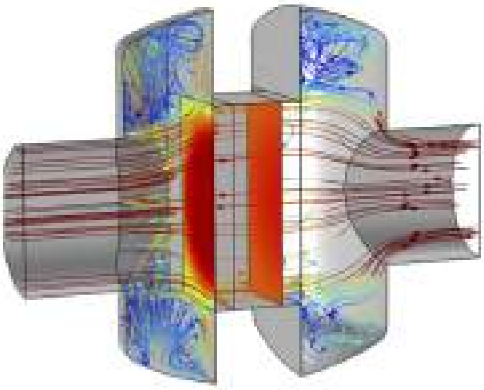


Figure 6. MaxiChevrons with space for MaxiWash.

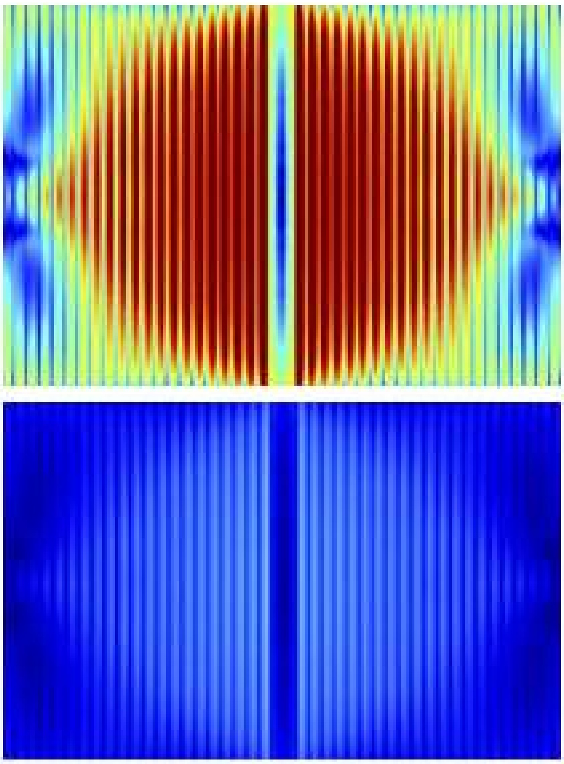


Figure 7. A bad distribution on mist eliminator entrance (top) and a good distribution (bottom).

- Uptime: Keeping a clean mist eliminator will avoid pressure drop build-up, debottlenecking evaporation production.

Continuous washing will collect the solids at a slow enough pace, avoiding accumulation on walls, substantially increasing maintenance intervals and mist eliminator lifespan (Figure 3).

System considerations

As mist elimination is downstream from phosphoric acid evaporators, the vapour phase is saturated. The mist eliminator equipment represents a pressure drop, causing a difference in pressure between saturated vapour flow and collected liquid throughout the mist eliminator. This de-entrained solution tends to vaporise and precipitate solids.

Liquid is added to the mist eliminator by continuous spraying to replace solution evaporation and prevent precipitation. Added liquid flow is calculated by comparing mist eliminator pressure drop and system absolute pressure. Estimation of vaporised liquid depends on liquid and vapour compositions and solutions vapour pressures, pressure changes, and total vapour mass flow along the mist eliminator area. An amount, slightly higher than the vaporised liquid on the mist eliminator surface, is added in the form of spray solution to keep continuous washing at minimum rate.

Once the spray liquid flowrate is calculated, other aspects must be considered:

- Spray distance to avoid jet deformation.
- Pulverisation angle (α).
- Number and position of sprays (Figure 4).

The number, position, and pulverisation angle must be adjusted in a way to avoid dead zones, as well as provide proper excess superposition.

Application

Phosphoric acid mist elimination vessel design sometimes consists of a sequence of mist eliminators; the first stages collect larger droplets and promote high drainage, while the last stages collect smaller ones as a polishing stage. First stages are typically wider, whereas last stages are tighter.

If the MaxiWash system is considered at the design stage, then the vessel size calculation should consider the cross-sectional area required for MaxiChevrons, as well as the space for the spray washing setup (mist eliminators placed between 500 – 1000 mm apart depending on nozzles setup).

Otherwise, in configurations without a washing system, the mist eliminators are normally close to each other and close to the inlet and outlet nozzle to get the minimum possible vessel size.

For a system upgrade with a washing system, Clark Solutions conducts an engineering study to evaluate a MaxiWash configuration, without the necessity of a new vessel. If possible, increasing the space between the

MaxiChevron sometimes requires a decrease in the cross-sectional area of the mist eliminators – especially for horizontal setups. MaxiChevron's design is based on the company's proprietary methodology, which is accurate enough to refine the design and check whether the new area is adequate.

One typical assumption is that vapour velocity at the mist eliminator entrance is an average, which means it considers the volumetric flow divided by the cross-sectional area. This information is only true when there is a good enough distribution of the velocity profile at the equipment entrance.

Since it is considerably complex to estimate the behaviour of the gas trajectory inside the vessel, the company undertakes computational fluid dynamics (CFD) studies to analyse this parameter with precision and combine with the calculation methodology for the MaxiChevron's design.

CFD analysis

Study complexity is an important aspect, which means some assumptions must be made. In other words, several geometry details result in more computational time or convergence obstacles. This means that simplifications are applied to achieve faster results, while maintaining verisimilitude:

- Screws, hooks, and fixation parts are neglected.
- Boundaries do not have thickness.

Also, some assumptions regarding the flow include the following:

- The flow is incompressible (global pressure drop is less than 1% of total pressure).
- Isothermal simulation.
- Steady state.

Once the assumptions are made, the simplified vessel is built in the CFD software and a turbulent flow physics model is applied with the operational conditions to analyse the velocity profile at the entrance surface of the two vane-type mist eliminators.

In Figure 5, there is a configuration without space for the washing system (blocks representing vane-type mist eliminators are close to each other), while in Figure 6 the configuration includes the proper space (blocks are set apart). Using the velocity profile colour scale (higher velocities in red), it can be observed that the distribution is better at the second vane-type mist eliminator, for both configurations. The velocities in Figure 6 are higher, as there is less cross-sectional area. The impact on pressure drop and collection efficiency is analysed by Clark proprietary methodology.

The coloured plot allows a qualitative analysis; a more solid result is accomplished by a quantitative one. The approach is to split the entrance surface area of each MaxiChevron in regions under different

Table 3. Example of quantitative analysis of velocity profile distribution

Velocity groups (m/sec.)	Cross-sectional area pecentage					
	Vessel dia. = 2.6 m		Vessel dia. = 2.8 m		Vessel dia. = 3.5 m	
	1st vane	2nd vane	1st vane	2nd vane	1st vane	2nd vane
36 to 38	5%	0%	0%	0%	0%	0%
34 to 36	16%	8%	8%	8%	0%	0%
32 to 34	12%	16%	17%	16%	0%	0%
30 to 32	10%	19%	19%	19%	0%	0%
28 to 30	9%	13%	12%	13%	0%	0%
26 to 28	10%	9%	9%	9%	0%	0%
24 to 26	7%	7%	7%	7%	0%	0%
22 to 24	5%	6%	5%	6%	0%	0%
20 to 22	5%	5%	5%	5%	41%	0%
18 to 20	4%	4%	4%	4%	24%	0%
16 to 18	3%	3%	3%	3%	27%	49%
14 to 16	3%	3%	3%	3%	8%	49%
12 to 14	3%	3%	3%	3%	0%	2%
10 to 12	2%	2%	2%	2%	0%	0%
<10	6%	4%	4%	4%	0%	0%

groups of velocities. In other words, the velocity profile is divided in groups of 1 – 2 m/sec. from the lowest to the highest velocity and the percentage of the entrance surface area of the mist eliminator with flow at those velocities is observed.

A good distribution is represented by a scenario in which almost all of the area is in a small range of velocities. This means that there is little variation of velocity over the entrance of the mist eliminator and the assumption of average velocity is accepted.

In Table 3, three configurations of vessel diameter are shown. The first two arrangements offer an inadequate distribution in comparison with the third option. In the latter, more than 90% of the area is under a very uniform velocity profile, which is considered an adequate distribution.

Conclusions

MaxiWash spray washing system is a concept for processes involving mist elimination with heavy fouling components. The solution is simple and considerably increases equipment uptime and lifespan. This concept can be applied either for new vessels or existing vessels with foulling issues. For the latter, an engineering study that combines Clark design methodology and CFD analysis is realised. **WF**

References

1. TABER, W. C., 'The Solubility of Calcium Sulphate in Phosphoric Acid Solution', *J. Phys. Chem.* (January 1905) pp. 626 – 629.