Optimising spray nozzles

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Spray nozzles have an important role in chemical plants and there are multiple uses of nozzles in the cement and lime industry. Applications such as, gas cooling/conditioning, SNCR (Selective Non-Catalytic Reduction), dedusting, etc require nozzles to facilitate the production of droplets in an efficient way. There are different types of nozzles for different applications.

The selection of a nozzle should be based on intrinsic process variables. For example, the selection of droplet size is often determined by the available straight evaporation length in the vessel. Some other factors which may influence the droplet size requirement are gas velocity distribution, relative humidity and temperature gradient. Also selection of nozzle material depends on liquid properties and on the environment where the nozzle is going to be installed.

Energy is required to break liquid streams into small droplets. A solid stream has an overall higher surface energy than a spray with a fine mist. The universal principle of conservation of energy is applicable to sprays. Solid streams tend to break up into smaller droplets. The droplet size depends on the surface tension of the liquid and the drag forces acting on it. Drag shears the droplets and breaks them into small droplets. For bigger droplet sizes drag is higher and the surface tension cannot prevent the droplets from disintegrating into smaller droplets. But as the droplets sizes become smaller, drag has less effect and the surface tension keeps the droplet from disintegrating. Droplet size can also be decreased by providing additional external forces to overcome the surface tension. For a given spray volume it requires more energy to produce smaller droplets than larger ones.

Types of spray nozzle:

Hydraulic atomisation

In hydraulic atomisation, high-pressure liquid is forced to pass through a small opening. As the liquid comes out from the orifice it forms a liquid sheet which breaks down further into a liquid web. The shear forces resulting from interaction with ambient air help in breaking this web of liquid to form smaller droplets. An increase in pressure produces greater liquid film velocity which increases the relative shear, thus producing finer droplets.

Figure 1: clinker cooling spray injection

Air atomisation

In an air-assisted atomising nozzle, the air breaks the liquid into droplets. The droplet size depends on two factors air-to-water mass ratio and air- and water-pressure. Also the water can be directed into a mechanical device which can break the solid stream of liquid into webs and then the air will complete the atomisation.

There are other types of nozzle designs available but these two basic types are widely used in the cement industry.

Spray injection applications in cement plants

• Gas cooling system: The most visible use of a spray injection system in a cement plant is in the gas cooling and conditioning tower. The spray injection system is utilised to cool the gases to a relatively lower temperature for operational reasons. For example, current fabric or membrane filters can withstand temperatures of around 300°C. The outlet temperatures from the preheater tower is usually between 350-450°C. This requires injection of water sprays to cool the gas. Also, when gas cooling with water, the actual gas volume is reduced and the air-to-cloth ratio for the fabric/membrane filters is reduced, thus increasing the filtration capacity or reducing bag wear and tear. Some plants have dioxin and furan problems, which require very rapid cooling of the gas to avoid the formation of these pollutants. With new trends of cooling the gases inside the downcomer duct, twinfluid nozzles are the best choice for their narrow angle and relatively smaller droplet size. The spillback nozzle has a relatively larger droplet size and wider spray angle. They are often used in gas conditioning towers. The spray injection systems are also installed in the long dry and wet kilns to cool the gases. The sprays are installed on the feed end of the kiln, injecting coaxially.

• Gas cooling in cyclone: recently cyclone sprays are being set-up when the required straight length for evaporation in the downcomer is not sufficient either due to the duct orientation or an increased cooling water requirement. The nozzles used for this application are spillback nozzles, which are positioned from the sidewalls of the cyclone and angled in a way such that the spray is directed towards the centre. The pressure of water is around 30-35 bar at the nozzles.

• Clinker gas cooling: spray injection systems are also fitted in the clinker gas cooling system for controlling temperature spikes in the gases. The spray injection system works as a safety feature to prevent the bags from burning, but it also reduces the gas volume and decreases the load on the bags. For this application both spillback/hydraulic and twinfluid nozzles

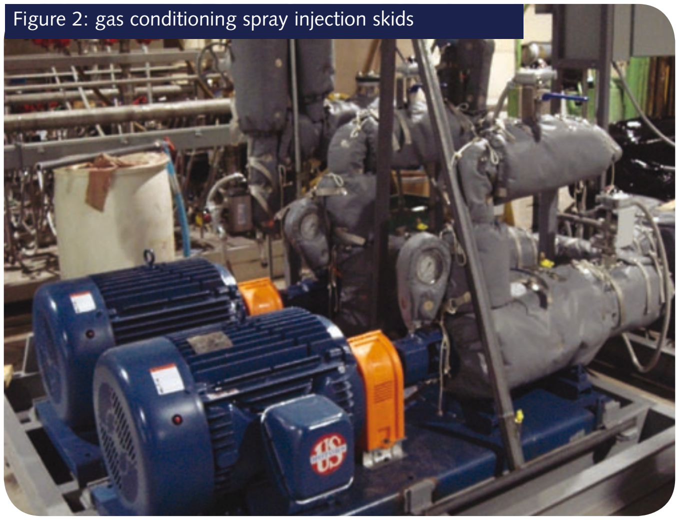


Figure 2: gas conditioning spray injection skids

Figure 3: Lechler gas conditioning system

are used, depending on the conditions and cooler design. Again spillback systems pose a benefit over twinfluid systems because they require no atomising air, thus giving them an advantage in both operational and running costs. This system is preferred in Europe and Asia for its simplicity and lower energy consumption compared to twinfluid systems. The biggest cost benefit for spillback systems is that it does not require expensive compressors.

- **Finish mill spray application:** Sprays are also used in the finish mill to reduce the temperature of finished product. The increase in temperature due to the mechanical friction between particles poses quality problems. Elevated temperature can alter cement properties and is detrimental to its quality. To keep the temperature under control, hydraulic spray nozzles are used in the mills.
- **SNCR and SCR ammonia/urea injection system:** to comply with newer, more stringent emission standards, cement plants have to install additional NO_x abatement systems. Existing low NO_x burner technology may not be able to meet these lower limits by themselves. SCR and SNCR systems have been well studied and evaluated in the plant to achieve the new targets and these technologies are capable of lowering the NO_x emission below the target. Both the SCR and SNCR systems generally use hydraulic or twinfluid reagent spray systems, but twinfluid systems are preferred over hydraulic systems for their superior turndown ratio. This is especially important during start-up and shut-down or periods of shifting production load.
- **SO_2 removal:** some plants have problems with SO_2 emissions. These plants have to inject lime slurry to overcome this problem. Usually a lime slurry spray injection system is tied into a gas cooling and conditioning system. Therefore the equipment cools the gas and also reacts and evaporates the lime slurry particles concurrently. Unreacted dry lime and gypsum particles are collected on the fabric filter or ESP.

Another way to scrub SO_2 from the gases is to install a wet scrubber downstream of the particulate filter using hydraulic nozzles. The latter is more expensive to install and operate but has a very high removal efficiency.

Power requirement calculation

Here is an example of how energy consumption plays an important role in selecting the best type of nozzle system for a cooling process.

A cement plant in North America decided to install a clinker gas cooling spray system. The goal was to inject water to reduce peak temperature. But the plant decided to run water sprays continuously in the clinker cooler to reduce hot air velocity in a downstream cyclone separator and to improve air-to-cloth ratio in the bag house. It chose to install a twinfluid spray injection system in the cooler. The gas flow rate before the cyclone inlet was measured 362,760am^3/h at 360°C. They wanted to reduce the gas temperature down to 232°C before the cyclone inlet. The amount of water required to achieve this outlet temperature was 170lpm.

The current equipment was pumping 170lpm water at 4.5 bar pressure with a total atomisation air requirement of 800nm^3/h at 4.7 bar pressure. The plant wanted to run the clinker cooler sprays for continuously instead of only peak cooling. It realised that even though the process was running without any issues, it was using significant energy to meet the process requirements.

The plant has two 125hp (93.25kW) compressors with one running and one as backup. The water pumps are rated for 5hp (3.73kW). The total power consumption for the system is 130hp (96.98 kW). The approximate running cost for this system for 335 days of operation will be around US$47,500 per year, with an electricity cost of US$0.061/kWh.

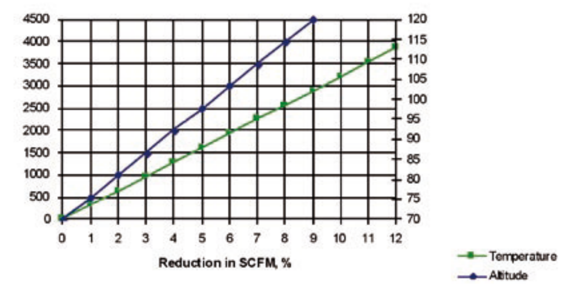
The plant is considering retrofitting the clinker cooling system with a hydraulic spillback system, pumping 170lpm water at 35 bar pressure for atomisation. The twinfluid lances will be replaced with similar capacity spillback nozzles. A 40hp (29.84kW) pump will be required on the skid for the system. The energy cost to run this hydraulic system for 335 days will be approximately US$14,500 per year. As electricity prices rise further, this saving will also increase. A summary of the running cost comparison for the two systems is shown in Table 1.

This cost study clearly shows the benefit of the more energy efficient system. The cost of running an air atomised system is not only high but it also requires more capital to buy the compressor and the receiver tank. Also, if the plant is at a higher elevation (see Figure 6), the compressor has to be oversized to deliver the same air output, which would result in even higher

Figure 4: spray nozzle for SNCR and SCR emissions control

Figure 5: reagent spray system

Figure 6: effects of altitude and ambient air temperature on compressor performance



operational costs. Although the use of hydraulic nozzles is often a better choice, it also has limitations. The liquid turndown ratio for simple hydraulic nozzles is much less compared to an air atomised nozzle and the droplet sizes are relatively bigger than what air atomising nozzles can achieve.

However, spillback nozzles address this turndown problem while still maintaining a very fine droplet size. The turndown from a spillback nozzle is more than enough to meet the demands of cement plants. But the turndown from a simple hydraulic nozzle is not enough to meet the industry requirement and are used in a cascade control system, where the turndown is a step function and not continuous.

Table 1: summary of cost comparisons

Summary	
Energy cost	0.061 US$/kWh
System running	100%
Number of days of operation	335
Spillback power consumption	29.84kW
Twinfluid power consumption	96.98kW
Running Cost	
Spillback system	US$14,500
Twinfluid system	US$47,500
Running cost difference	US$33,000
Cost of two additional compressors (if required)	US$85,000 (estimate)
Investment costs	
Spillback system	Twinfluid system
110%	100% plus ompressors

Conclusion

There are benefits to be gained from both types of nozzle systems. From a cost efficiency standpoint the spillback system is often less expensive to operate and requires less capital to purchase as it does not need expensive compressors. Twinfluid nozzles are the preferred option in cases of narrow duct applications or small diameter vessels. They are also the best option for slurry sprays, due to their larger free passage, which is less prone to plugging. As energy costs are rising rapidly, the cost of running compressors will make spillback systems much more favourable in the future. With the cost of carbon trading scenarios looming on the horizon, cement plants will need to minimise energy usage to reduce their carbon footprint.

In North America hydraulic spray systems have not gained popularity as cement plants are still concerned about droplet size.

However, the technology has improved and has been shown to be a cost effective with long-term use. Spillback systems have been successful all over the world where energy concerns have been an issue. As North American plants face higher energy costs they will want to carefully review all of their options for spray nozzle systems.