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Spray Technology is Critical in Helping a Plant Achieve Optimal Performance

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ABSTRACT:

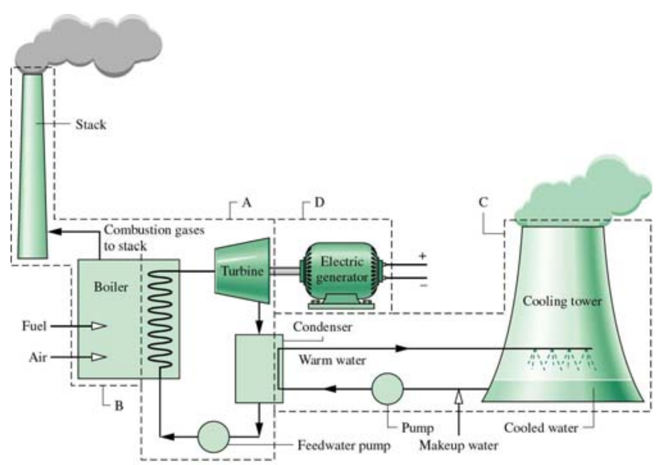
Spray nozzles are used in several locations inside a powerplant and have intimate contact with the processes in the plant. Nozzles are used for inlet fogging, humidification, Wet and Semi-Dry FGD (Flue Gas Desulphurization) applications using open spray towers, CFB (Circulating Fluidized Bed) and SDA (Spray Dry Absorber) scrubbers, NOx using SCR (Selective Catalytic Reduction) and SNCR (Selective Non-catalytic Reduction) technologies. As plants try to achieve optimum efficiency, spray nozzles need to be designed, installed, and maintained properly. In addition, operators and designers need to be aware when a spray nozzle needs to be cleaned or replaced. A defective spray nozzle will have an adverse affect on plant performance.

Several factors are to be considered in selecting the proper nozzle. These include material of construction, flowrate, spray angle, operating pressure, placement, droplet size, maximum free passage, spray angle, and many more. New developments in spray nozzle technology are allowing powerplants to have better control and achieve/maintain the tighter regulations on key emissions in the plants. Examples of nozzle type, their application, and recent installations/retrofits will be discussed.

OVERVIEW:

Powerplants (Graphic 1) are built for the sole purpose of power generation. When plants were originally built and operated, the plant's efficiency was the primary measure of how well the plant was run and maintained. Since that time, we have become aware of the environmental impact powerplants can have on the local environment and population. Environmental issues such as acid rain, ozone, water pollution, and opacity have been indentified and corrected to minimize its impact. Today, a plant's efficiency and effectiveness is determined by the political environment, the required emission control devices it supports, the parasitic loads to meet increased EPA requirements, its ability to recover heat, fuel sources, and financial gains/losses from the required cap and trade programs. Since the advent of the powerplant, great strides have been made in making electrical power clean, reliable, and abundant. Several improvements have been made to continually improve the efficiency of the process. These include improved control technology, engineered materials, streamlined processes, and years of operator experience.

Nozzles play an integral part in the process of power generation, from when the coal is mined from the ground to the final cleaning of the gas before it's emitted into the atmosphere. Nozzle technology has contributed to the improved performance of plants and the reduction of harmful pollutants emitted into the atmosphere.



Graphic 1[1]
Basic Rankine Cycle

NOZZLE MATERIAL:

Nozzle material is very important as applications in the powerplants have varying degrees of temperature, corrosion, and erosion aspects of performance. In addition, the nozzle material can not contaminate the process or process fluid being atomized. Depending on the application (Chart 1), nozzles can be made from relatively low cost brass, stainless steel, or polymers (plastic) to exotic high cost materials such as duplex stainless steels containing high levels of nickel and chromium, as well as ceramics.

Nozzle Material(s)	Price	Application(s)
Brass, 303 SS, Plastics	$	Vehicle Rinsing Floor Wash General Cleaning Cooling Towers Mist Eliminators
304SS, 316 SS	$$	SCR/SNCR Inlet Fogging Dust Suppression Fuel Injection Steam Condensation Evaporative Cooling
Duplex Stainless Ceramics	$$$	Emergency Quench Flue Gas Desulphurization Coal Supply
$ - Low Cost $$ - Medium Cost $$$ - High Cost		

Chart 1
Typical Nozzle Materials Used at Powerplants

The nozzle material must be designed to withstand not only the fluid being atomized but also the process it is placed into service. Using an inferior nozzle material increases your overall operating costs due to shortened life, increased maintenance, and unforeseen repairs. Nozzle erosion affects a nozzle's flowrate, spray pattern, and droplet size. (See Photo 1 & 2)

Photo 1
Erosion of stainless nozzle after 5 weeks of service

Photo 2
No erosion of ceramic nozzle after 24 weeks of service

NOZZLE SPRAY PATTERNS:

The four primary spray patterns that are used in the industry are the solid stream, flat fan, full cone, and hollowcone:

The solid stream nozzle provides a solid column of water with no effective atomization of the fluid. This provides the largest impact force of the different patterns. It is used for cleaning of a small area. This pattern is seldomly used in the powerplants.

The flat fan nozzle distributes the water into a wide pattern with a constant minimal spray thickness across the spray. These nozzles create large droplets at high velocity and impact that are used for application of fluids on wide surfaces. This spray pattern also creates a push-broom effect on a surface when oriented at an angle to the surface being sprayed. Typical uses for these nozzles are for high pressure washing, and spraying of a moving surface such as a conveyor belt.

A full cone nozzle atomizes the droplets into a conical shape from the nozzle orifice. The droplets are dispersed throughout the full cross section of the spray and tend to have smaller droplet sizes and lower velocity in comparison to a similarly sized flat fan nozzle. This distribution can be created from twin-fluid and hydraulic nozzles. Typical uses for hydraulic fullcones are mist eliminator panel washing, steam condensing, inlet fogging, and packing rinsing. There are several more. Twin-fluid fullcones are used in aqueous ammonia injection for SCR as well as SNCR, and evaporative cooling.

Last, the hollow cone nozzle atomizes the droplets into a conical shape from the nozzle orifice as well. However, the droplets are dispersed along the circumference of the spray pattern with no droplets dispersed inside the cone of the spray. The droplets have a higher velocity and smaller droplet size in comparison to fullcone nozzle due to the reduced energy losses in the atomization chamber. Hollowcone nozzles are only able to be atomized hydraulically. Typical uses for these nozzles is evaporative cooling and gas scrubbing for flue gas desulphurization.

NOZZLE TECHNOLOGY:

There are two nozzle types that are typically installed in powerplants. They consist of the single-fluid (hydraulic) nozzles and twin-fluid (air-atomizing) nozzles (See Photos 3 & 4). These nozzles come in various materials, sizes, spray patterns, and quantities to perform the intended design function. Twin-fluid nozzles create the smallest droplet sizes (Chart 2) but require the highest amount of energy input in creating these droplets. In certain cases, hydraulic nozzles can be operated at extremely high pressures to create droplets that are comparable to twin-fluid droplet sizes.

Photo 3
Large Single-fluid Hollowcone Nozzle used for Wet Flue Gas Desulphurization

Photo 4
Twin-fluid Nozzle used for Semi-Dry Flue Gas Desulphurization OR Selective Catalytic Reduction

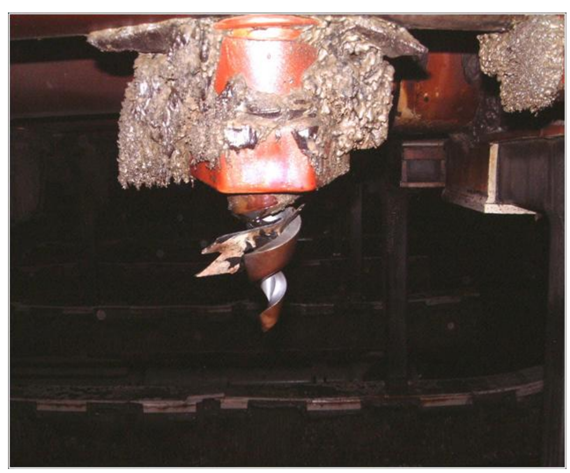
Typical Droplet Sizes	
Nozzle Type	Droplet Range (μm)
Twin-fluid	25 - 100
Single-fluid (small)	50 - 500
Single-fluid (medium)	500 - 1,500
Single-fluid (large)	1,500 - 3,000

Chart 2[2]
Droplet size range (Sauter Mean Diameter) produced by different nozzles (Ref. 1 in. = 25,400 μm)

For most applications requiring relatively large droplets for surface cleaning, hydraulic nozzle technology utilizing feed pressure to atomize the fluid sprayed is adequate. Control technology to monitor the process is relatively straight-forward with a pressure gauge and flowmeter to monitor pressure and flowrate respectively and valves to adjust flow and pressure. Nozzles used in these applications require minimal maintenance. Typical issues with these nozzles are pluggage caused by internal debris or particles in the supply fluid that have not been properly filtered (See Photo 5). In order to design a proper strainer system for your nozzle, the mesh size of the strainer should be ⅓ to ½ of the free passage of the nozzle in use. The free passage area is defined as the largest particle that may pass through the nozzle without clogging.

Twin-fluid nozzles are also heavily used in powerplants. Their use is for the gas conditioning/cleaning of NOx, SO_2 (~ 100 MW or smaller plant), SO_3, and mercury in the flue gas. The nozzles and systems, their material, and spray performance are critical in order to successfully remove the pollutants in the flue gas. Control technology is more complex as two fluids (typically the chemical solution and compressed air) need to be monitored and adjusted and kept in balance to maintain spray performance. Twin-fluid nozzles, due to their critical function in a plant's APC (Air Pollution Control)

Photo 5
Hydraulic spiral nozzle used in Wet Flue Gas Desuphurization plugged with internal debris



system, require a high degree of reliability, maintenance, and control. The process gas these nozzles get placed into service is laden with moisture, dust, and ash which promote buildup on the nozzle surface and walls. Nozzle spray degradation (See Photo 6) increases droplet size, affects the spray pattern, and can vary the flowrate, thereby affecting the entire APC system of the plant. It can cause emissions from the plant to exceed limits. Poorly maintained nozzles cost the plant money in increased maintenance, increased operating expenses, and reduced income potential from the cap and trade programs.

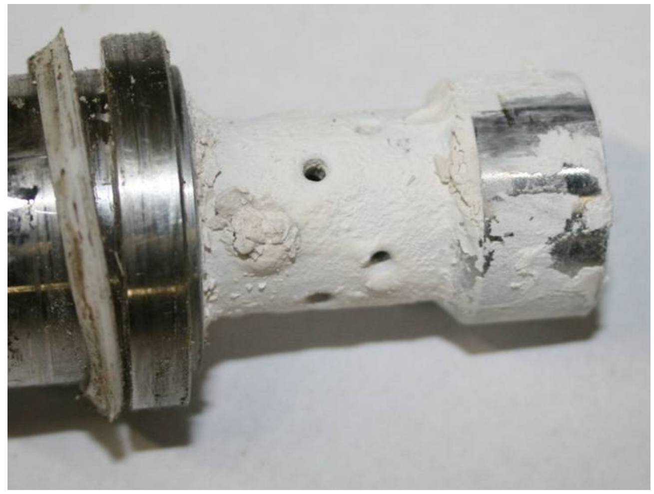
Photo 6
Buildup around nozzle orifice of twin-fluid nozzle

SPRAY TECHNOLOGY DEVELOPMENTS:

Nozzle designs and their applications have continuously evolved to help powerplants meet increasingly stringent emission requirements. New nozzle designs have helped improve spray performance through better atomization (smaller droplet size), reduced energy requirements, improved spray patterns, and less maintenance costs. New corrosion and erosion resistant materials are now in the marketplace to withstand the extreme environments nozzles are placed into. In most cases, the payback period for improved nozzle technology is quite short. The savings they generate over their 24 hour, 365 day typical service time quickly pays for their initial cost outlay.

One application of nozzles is the atomization of lime slurry into the flue gas for semi-dry flue gas desulphurization. During this process, compressed air atomizes pump-fed lime slurry into small droplets. The small droplets create a large surface area for the flue gas to interact with and maximize mass transfer of the SO_2 and SO_3 out of the flue gas. Inside the nozzle chamber, the pressure differential between the compressed air supply and slurry supply is in constant flux. This allows for temporary penetration of lime slurry into the air supply. The water in the slurry quickly evaporates leaving a deposit of slurry on the holes. Over time this buildup begins to restrict air flow and affects nozzle performance and droplet size. (See Photo 7).

Photo 7
Fouling of twin-fluid nozzle spraying slurry after 1 week of service



The continuous buildup of slurry required maintenance of removing the lance, removing the nozzle, cleaning the nozzle in a solution to dissolve the lime and re-assembling the nozzle and lance to put back into service. Several of these lances are typically required to achieve the required emission targets which creates a high degree of maintenance time and cost.

Two steps were taken to decrease the maintenance frequency on these nozzles. The first improvement was a redesign of the air inlet holes. The air inlet holes were modified to create a larger pressure drop between the air supply and the mixing chamber. This created a larger resistance to backflow of slurry into the air holes. The second modification consisted of a flushing sequence that injected an acid solution into the air supply and through the air inlet holes to dissolve any lime buildup. This created a more dependable, low maintenance solution for the powerplant (See Photo 8).

Photo 8
Modification of twin-fluid nozzle after 1 week of service and cleaning cycle.

SPRAY TECHNOLOGY DEVELOPMENTS (CON'T):

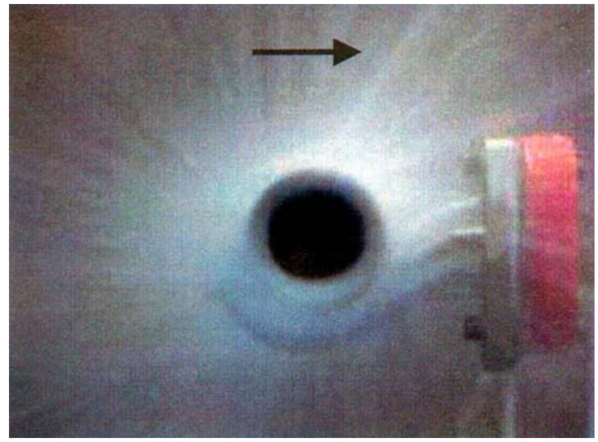
Another issue facing twin-fluid nozzle lances operating in the powerplant is buildup on the exterior surfaces (See Photo 6). The causes for this include flue gas flow around the nozzle creating eddies, bad design of the nozzle orifice, erosion/corrosion of the nozzle material, and condensation on the nozzle lance. The twin-fluid lance has two fluids that have a lower temperature relative to the flue gas and can be below saturation temperature of the flue gas. The velocities in the lance are high, which create a high heat transfer coefficient of the outer surface of the lance exposed to the flue gas. To help alleviate this problem, the two fluids could be heated to above saturation temperature. This creates additional energy input into the system and can create more problems than it solves. A solution to this problem is the addition of a second annulus around the lance and pipe. (See Photo 9). The annulus between the lance and the outer pipe is fed with low pressure (less than 1 psig) blower air that allows the outer skin surface of the outer pipe to remain closer to the flue gas temperature.

Photo 9[3]
Cross section cutout of Twin-fluid lance with outer barrier pipe to minimize material buildup on lance

Wet flue gas desulphurization technology was introduced into the United States in 1970s. These are commonly known as WetFGD scrubbers. In their infancy, scrubbers were able to achieve 70-80% removal of the sulfur in the flue gas. Currently, scrubbers are now able to achieve 99%+ removal with the proper design and L/G (Liquid to Gas) ratio. Nozzles are a crucial part in achieving these levels while minimizing limestone requirements and pumping power. The primary nozzle that was utilized in the scrubbers is the single orifice hollowcone nozzle (See Photo 3). These nozzles were placed at several spray levels in the scrubber to help achieve a high L/G ratio and maximize the surface area of the droplets for mass transfer removal of pollutants in the flue gas.

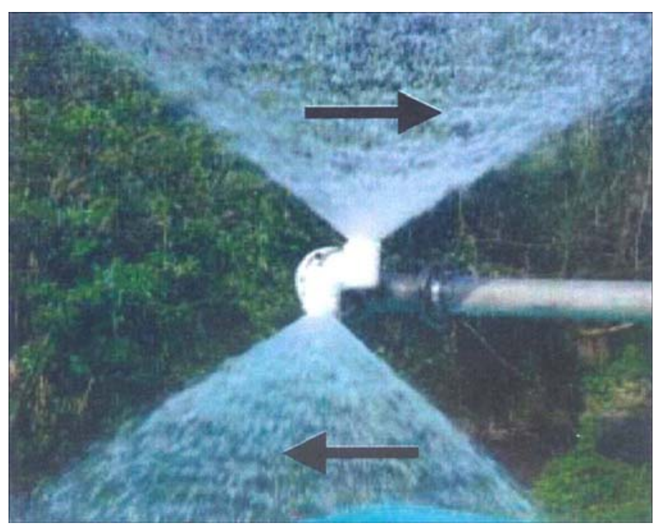
One design aspect of these nozzles is that the fluid entering the nozzle is tangentially fed. As the liquid leaves the orifice, the rotational momentum of the spray is transferred into an angular momentum as it leaves the nozzle (See Photo 10). This angular momentum is then transferred to the gas.

Photo 10
Droplets exiting from hollow cone nozzle orifice



To increase the residence time of the droplet in the flue gas and to counteract this angular momentum, a new nozzle was designed with separate spray chambers that are located on opposite sides of the nozzle supply inlet. This nozzle is typically described as a dual hollowcone nozzle (See Photo 11). It can be designed to have a fullcone or hollowcone spray pattern. The benefits of this technology when compared to single orifice nozzles include: smaller droplet sizes as the fluid is being atomized into two sprays, increased mass transfer with flue gas due to increased residence time and larger surface area, and counter-acting angular momentum transferred to the gas. This nozzle design is widely used in Europe and is installed in several coal fired powerplants in the United States.

Photo 11
Dual hollowcone nozzle spraying



SPRAY TECHNOLOGY DEVELOPMENTS (CON'T):

Another nozzle development for WetFGD scrubbers is a dual hollowcone nozzle that only sprays downward against the gas flow. This nozzle is typically described as the dual-down hollowcone (See Photo 12) and is designed to utilize all of the design features of the dual orifice nozzle but could be placed on the top level spray header inside a scrubber. This nozzle can also be designed with a fullcone or hollowcone spray pattern. Any slurry spraying upward into the mist eliminator panels would cause fouling and plugging. These nozzles are used in Europe and are installed in several coal fired powerplants in the United States. The use of the dual orifice technology has helped powerplants reach near 100% removal of the sulfur in the flue gas.

Photo 12
Dualdown hollowcones spraying inside scrubber

CONCLUSION:

Nozzles play an integral part in a plant's performance and must be designed for their intended service and performance. It has been demonstrated that keeping nozzles clean and operating as designed has a direct effect on a plant's performance. As plants are required to emit less pollutants, new nozzle technologies need to be developed to meet these requirements.

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