Recent Insights into Mechanically-Enhanced Evaporation of Mine Affected Waters

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CONFERENCE: 2017 World of Coal Ash – (www.worldofcoalash.org)

KEYWORDS: mine affected water, wastewater, water management, evaporation, mechanically-enhanced evaporation, ponds.

INTRODUCTION

Mine sites both produce and consume water. Significant water uses might include water for process and dust suppression, however, the volumes required for these uses often pale in comparison to the volumes produced by dewatering and/or surface run-off. As a result many mines experience a net accumulation of water, the volumes of which can be significant.

Once water has come into contact with any mine workings it is termed ‘mine affected water’ (MAW) and from a regulatory perspective is considered to be unclean and potentially contaminated. The primary risk associated with MAW is the uncontrolled discharge of water from site and is a product of both water quality and water quantity.

A common approach to reducing this risk is by environmental discharge, however, this typically requires some level of water treatment. The cost associated with the required water treatment can be prohibitively expensive and the rate at which this water can be discharged from site is limited by the capacity of the water treatment plant, which is generally fixed in nature.

Another common approach to reducing the risk associated with the uncontrolled discharge of water from site is evaporation ponds. Evaporation ponds present a number of benefits including very low operating costs, operator requirement and maintenance. However, evaporation ponds tend to require a substantial footprint, the evaporation rate is limited to ambient conditions which may not be sufficient and due to the fact that they are typically located in remote areas, capital costs can be high.

This paper presents the development of ‘Mechanically-Enhanced Evaporation’ as a means of addressing the disadvantages that are inherent in the use of evaporation ponds to reduce the risk associated with the uncontrolled discharge of water from site.

EVAPORATION

Evaporation is one form of vaporization, the other being boiling, which achieves a phase change from liquid to gas. While boiling is a bulk process in which the temperature of the liquid must be at the boiling point, evaporation is a surface process in which the liquid need only exhibit an appreciable vapor pressure under the given conditions.

Net evaporation can be calculated as the product of evaporation rate and surface area (Equation 1):

$$E = ER \times SA \qquad \text{(Equation 1)}$$

where E is net evaporation in m^3 or cuft, ER is evaporation rate in m or ft and SA is surface area in m^2 or sqft.

Accordingly, net evaporation (E) can be increased by increasing the evaporation rate and/or the surface area of the liquid. Typical evaporation pond design has inherent limitations with respect to these parameters thereby limiting net evaporation. The evaporation rate is limited to that provided by the ambient conditions measured as pan evaporation rate (PER). Additionally, the typical design of an evaporation pond permits evaporation from one face only.

EVAPORATION RATE

Evaporation rate (ER) can be estimated by a number of methods which typically fall into one of two categories, energy budget methods and mass budget methods[1,2].

Energy budget methods consider energy inputs and losses from a system. These methods are often modelled on an evaporation pan which can then be reduced to a simplified model (Figure 1).

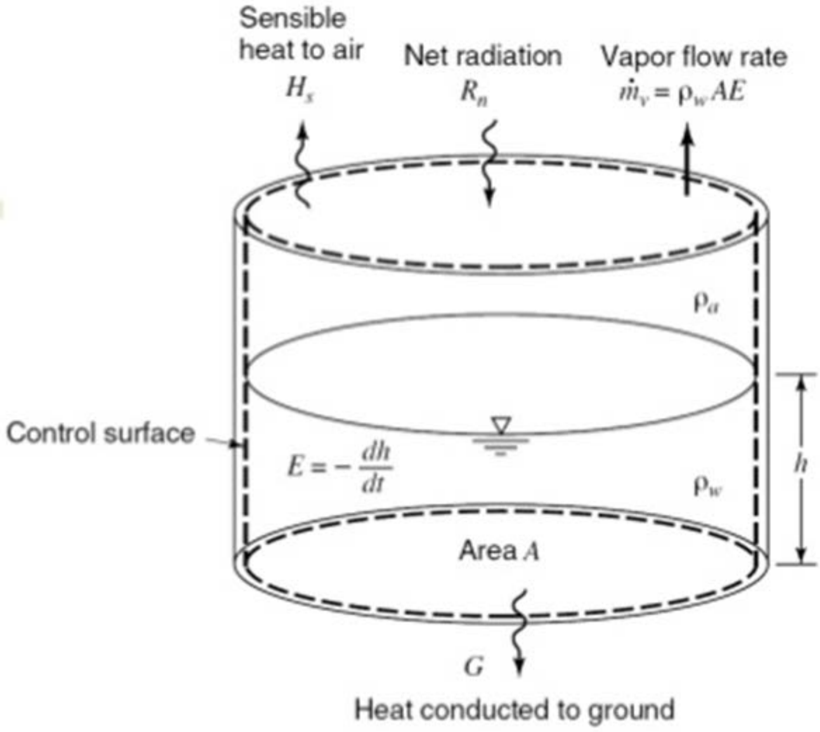

Figure 1 - Example of an evaporation pan model as applied to energy budget method of estimating evaporation rate[1]

For practical applications, such as when applied to evaporation ponds, several of the above factors can be excluded resulting in the simplified relationship:

$$E_r = R_n / l_v \rho_w$$

(Equation 2[1])

where E_r is the evaporation rate, R_n is the net radiation, l_v is the latent heat of vaporization and ρ_w is the density of water. It is worth noting that air and water temperatures are not direct inputs into evaporation rate when adopting this approach, however, both l_v and ρ_w do vary with respect to water temperature. R_n is therefore the only direct input when adopting an energy budget approach and to increase the evaporation rate one must increase R_n. Practically, this may not be achievable due to atmospheric and/or financial constraints.

Mass budget methods consider the transportation of water vapor away from the water surface. Primary factors affecting this transportation are wind velocity and humidity (Figure 2).

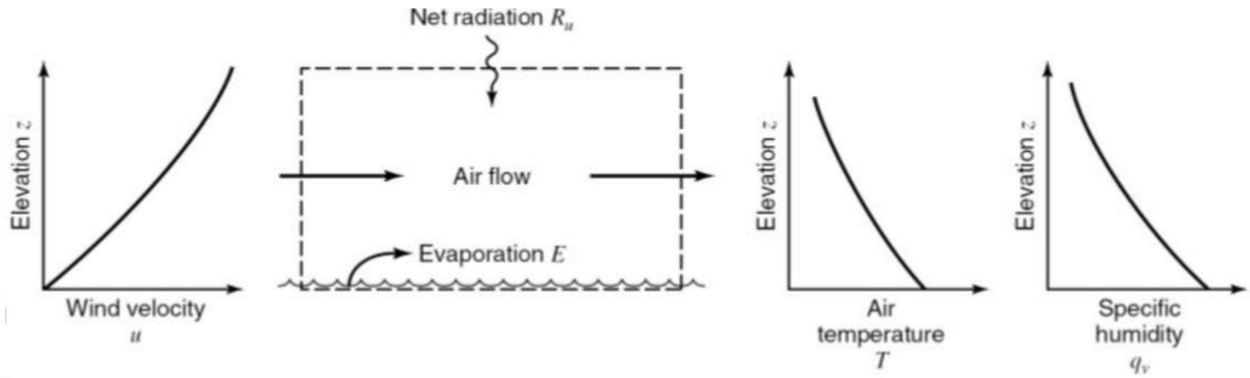

Figure 2 – Aerodynamic factors affecting evaporation of water from an open surface in relation to mass budget method of estimating evaporation rate[1]

The above factors can be utilised to estimate evaporation rate as expressed in the following equation:

$$E_a = B\,(e_{as} - e_a)$$

(Equation 3[1])

where E_a is the evaporation rate, B is the vapor transfer coefficient, e_{as} is the saturated vapor pressure, and e_a is the ambient vapor pressure. B incorporates wind velocity into the relationship (Equation 4) while humidity is represented by the difference between e_a and e_{as}.

$$B = 0.102u_2 / [\ln(z_2/z_0)]^2$$

(Equation 4[1])

where u_2 is the wind velocity, measured at height (z_2) and z_0 is the roughness height of the water. Air temperature does not affect evaporation directly, however, it does influence vapor pressures (e_{as} and e_a). Simplifying the relationship, increased wind velocity and reduced humidity will result in an increased evaporation rate.

SURFACE AREA

Increasing the surface area of the liquid to be evaporated increases net evaporation (Equation 1). Typical evaporation pond design exploits this relationship by maximizing the surface area of the water surface that is viable in terms of evaporation (Figure 3).

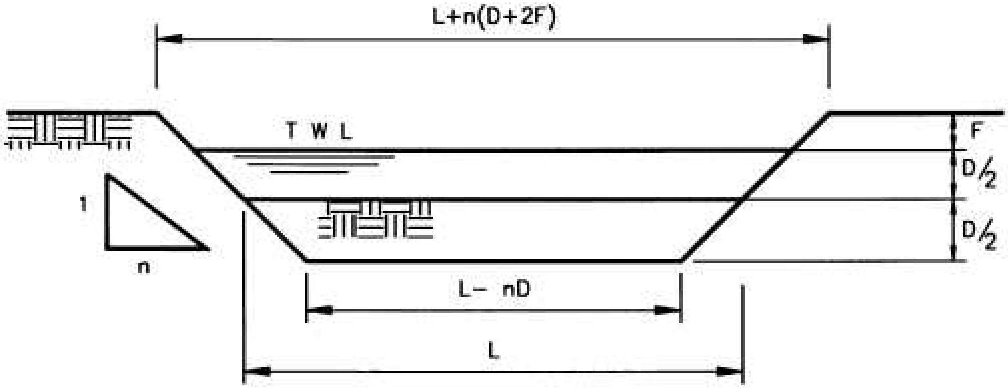

Figure 3 – Example of typical evaporation pond .design maximizing the top water surface[3]

This design approach results in an inverted truncated pyramid geometry but has two significant limitations when trying to achieve maximum evaporation. While a truncated pyramid has six surfaces, evaporation can only occur from one surface, the ‘active surface’. The pond design maximizes the area of the active surface, however, the remaining five surfaces are redundant with respect to evaporation. Additionally, as evaporation proceeds, the level in the pond drops reducing the surface area of the active surface, thereby reducing net evaporation.

MECHANICALLY-ENHANCED EVAPORATION

The evaporation pond has established itself as an industry leader in wastewater management. A complementary, rather than competitive approach was adopted in developing a new technology that could improve on the performance of the evaporation pond. A complementary approach was considered to offer several advantages including, increasing the ease at which the new technology could be implemented and not rendering existing infrastructure redundant upon implementation of the new technology.

Key drivers for the design needed to address the limitations/disadvantages inherent with evaporation ponds including, large footprint, evaporation rate being limited to the ambient PER, evaporation being limited to a single active surface only and evaporation decreasing with decreasing volume within the pond. This had to be provided at a capital cost that was less than the cost of an evaporation pond with equivalent evaporative capacity.

Increasing net radiation (Equation 2) was considered to be unfeasible for most applications unless waste energy in an appropriate form was readily available on site and could be harnessed sufficiently. Accordingly this approach was not pursued in terms of design.

To increase evaporation rate in accordance with the mass budget method, wind velocity must be increased and/or relative humidity reduced (Equation 3). Increasing air velocity can be easily achieved by mechanical means. Humidity reduction via absorption or condensation was also considered, but rejected on the basis of cost.

Increasing the surface area of the water was targeted as the primary driver for design. It was anticipated that this would be the simplest and most cost effective parameter to maximize.

DESIGN

The Minetek Evaporator consists of three key components; feed water pump, a plurality of fracturing nozzles and fan (Figure 4).

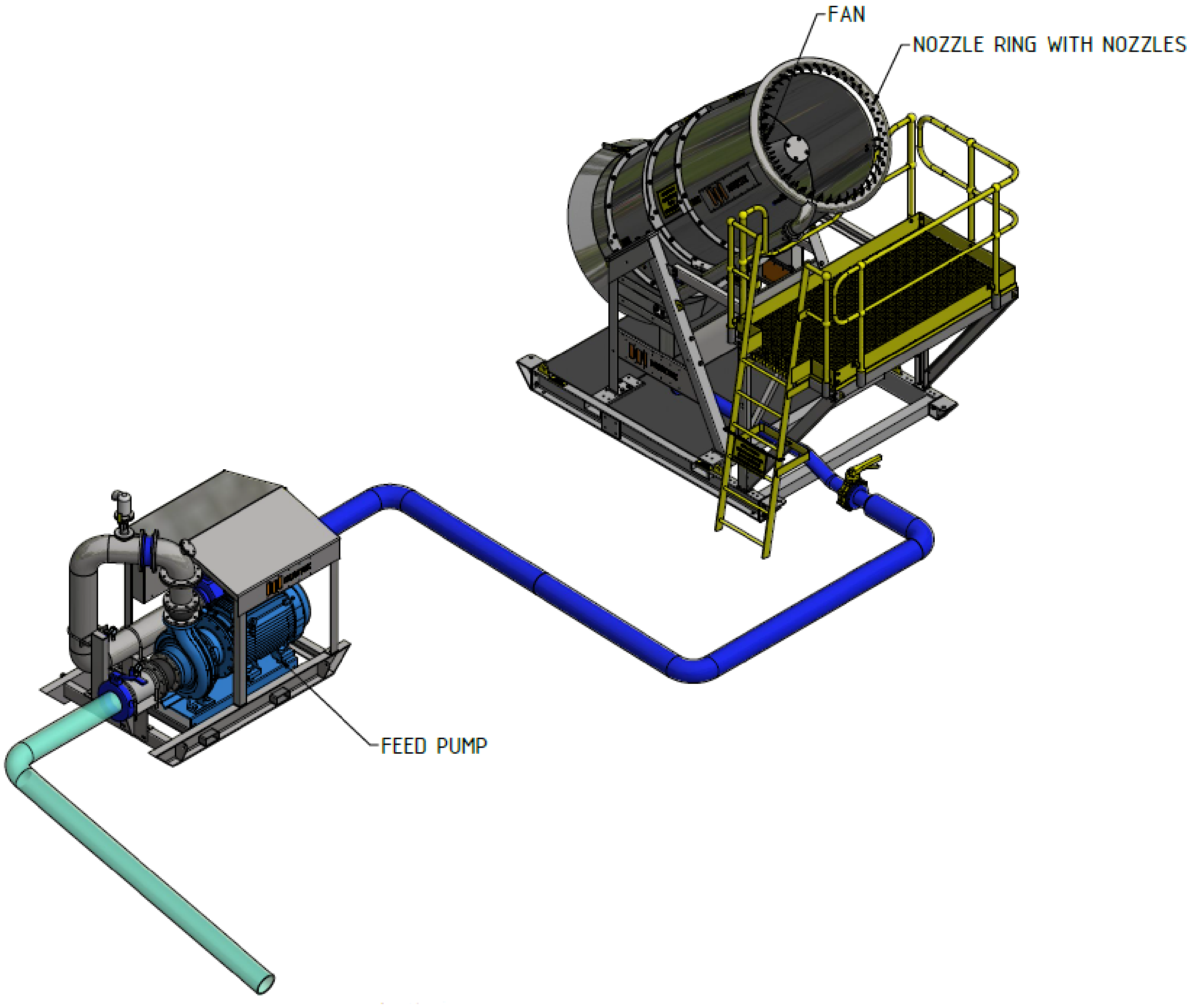

Figure 4 – The Minetek Evaporator

The feed water pump delivers the feed water to the fracturing nozzles at operating pressure resulting in fracturing of the water into a multitude of very small droplets. The volume mean diameter (VMD) of the droplets produced by the nozzles is inversely proportional to the operating pressure (Figure 5).

The fracturing of the water into many small droplets produces a massive increase in the surface area of the water volume. Large-bore nozzles were selected to maximize throughput and prevent blockages by entrained solids.

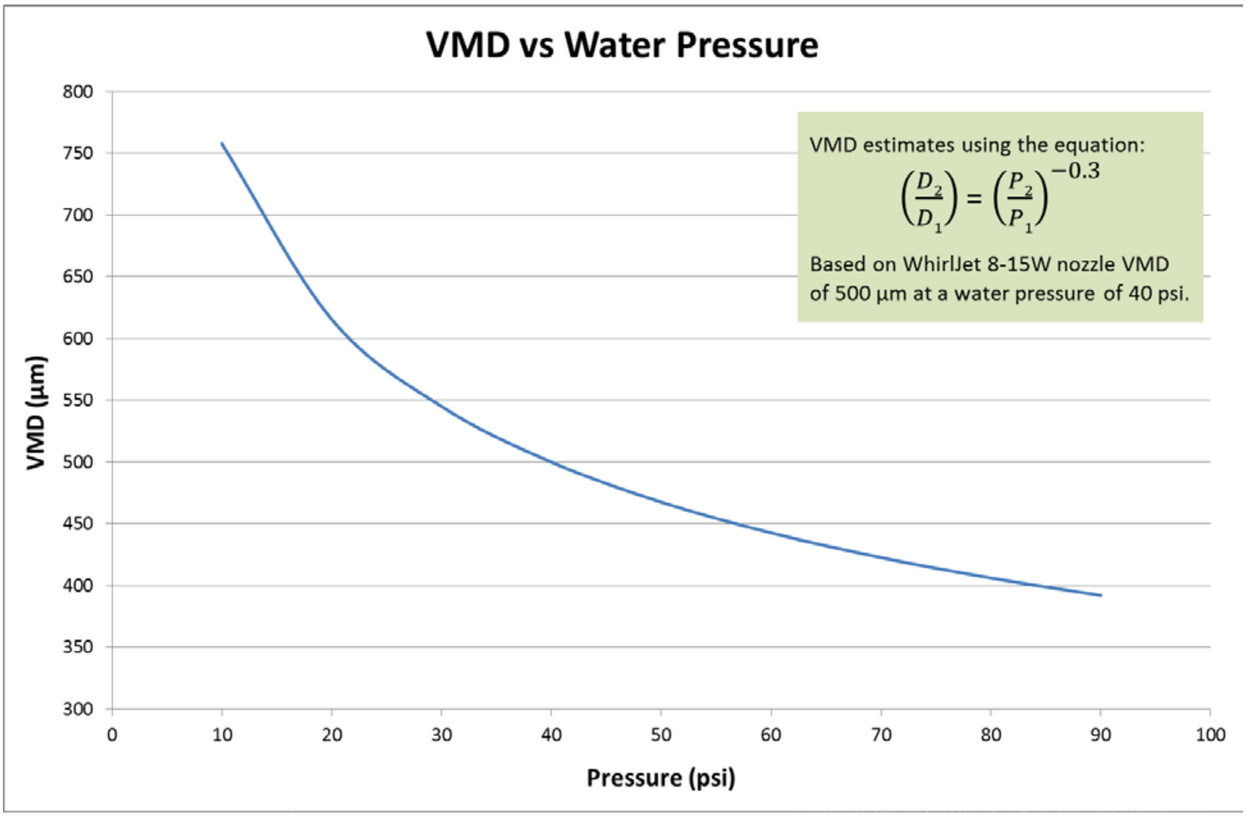

Figure 5 – Relationship between operating pressure vs droplet volume mean diameter (VMD) for WhirlJet 8-15W spray nozzle[4]

The fan provides forced induction of air into the system yielding several benefits to evaporation. Forced induction of air provides approximately 2000 volumes of air for each volume of water, preventing saturation of the air during the evaporation process. The increased air velocity of 160 km/h (100 mph) ejects the produced droplets more than 45 m (150 ft) into the air extending the ‘hang time’ and the duration of the increased surface area. Finally, the increased air velocity also greatly increases the evaporation rate in accordance with Equation 3.

OPERATION

The large increase in surface area produced by the fracturing nozzles results in an increase in net evaporation in accordance with Equation 1 with the plurality of large-bore nozzles offering throughputs of up to 136 m^3/h (600 gpm) for a single unit.

Based on an ambient wind speed of 16 km/h (10 mph) the 160 km/h (100 mph) air velocity produced by the fan results in a 10-fold increase in evaporation rate (Equation 3) relative to the ambient environment within the immediate vicinity of the evaporator. In terms of net evaporation this effect is compounded by the increase in surface area produced by the fracturing nozzles. The air velocity produced by the fan also has the advantage of being constant and is not subject to diurnal fluctuation as is observed with ambient wind speeds.

The Minetek Evaporator achieves an evaporation efficiency of approximately 50% in a single pass, i.e. of the 136 m^3/h (600 gpm) pumped through the unit approximately 68 m^3/h (300 gpm) is evaporated. To date, evaporation rate measurements have been largely anecdotal being based on observed reductions in water volumes. Accurate measurement of the evaporation rate is complicated by the absence of any standard measurement procedures, the magnitude of the area required to operate the evaporator at full-scale and difficulty in establishing a controlled environment of the required area in which to conduct the measurement. The evaporation efficiency achieved by the Minetek Evaporator is subject to ambient conditions such as relative humidity. However, as described above it achieves net evaporation greater than that based on the ambient PER due to its design.

An evaporation efficiency of 50% is beneficial in terms of mitigating potential environmental impacts. The evaporation efficiency of 50% refers to the reduction in volume but is often incorrectly interpreted as a reduction in the total number of droplets. Reducing the volume of a spherical droplet of diameter 200 µm (4.19×10^{-12} m^3) by 50%, results in a droplet of diameter 159 µm. This is because the volume of a sphere reduces in a cubic manner in relation to the reduction in radius (where d = 2r). Importantly, the droplet does not evaporate to dryness which is significant in determining the fate of dissolved species in the feed water.

In a typical closed-loop (Figure 6) or semi-closed loop application the dissolved species are concentrated in the partially evaporated droplets and returned to the feed pond. This is due to the fact that the dissolved species exhibit a greater affinity for water over air (i.e. are non-volatile) and have a tendency to stay dissolved in the droplet. This results in a measurable increase in the total dissolved solids concentration/conductivity of the water in the feed pond over time.

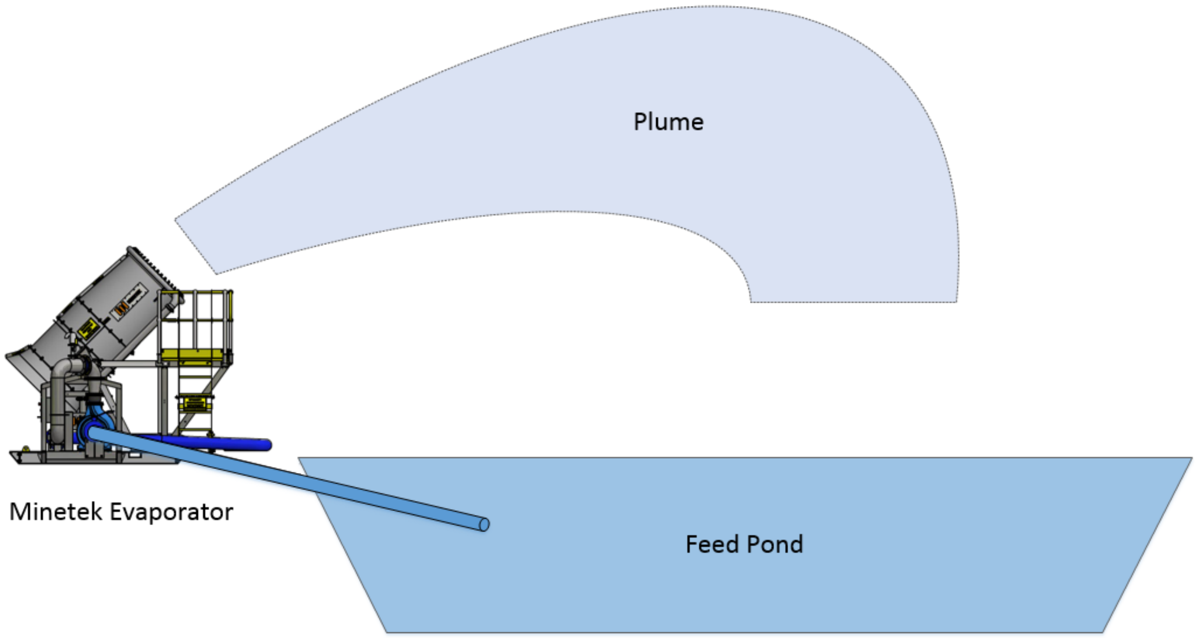

Figure 6 – Example of Minetek Evaporator operated in Closed –Loop configuration

Additionally, the droplets that are only partially evaporated act in a suppressing manner with respect to any particulate matter present. While it is possible that particulate matter could be produced from the dissolved species due to the complete evaporation of smaller droplet this particulate matter is subject to bombardment by the multitude of non-evaporated droplets.

FUTURE WORKS

Additional works are underway to develop a greater understanding of the mechanically-enhanced evaporation process. These works include measurement of droplet size distribution, measurement of evaporation efficiency and determination of spray drift in response to meteorological conditions. Results of these works will be communicated in subsequent publications.

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