## Best Practices

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# Best Practices for Efficient and Effective Spray Rinsing: Part 1

In the June issue of *P&SF*, I discussed the importance of best practices in immersion rinsing. In that column, I presented ten rules for effective and efficient rinsing. Ultimately spray rinsing and immersion rinsing are more similar than different. Rinsing, whether by immersion or spray, is a dilution process. Next month, **Part 2** of this paper will present ten rules for effective and efficient spray rinsing.

To discuss spray rinsing effectively, it is necessary to define some terms:

**Spray rinse**: Spray rinses depend upon impingement of an aqueous stream on a work surface to wet the work surface and dilute the dragout film. If the work surface is moving through the spray, or the nozzles are moving across a stationary target, then the spray can also exert a shear force and effectively "blast" the dragout film. Spray rinsing is largely a line-of-sight process, and the efficiency and effectiveness of spray rinsing is limited on complex work surfaces.

**Spray rinse efficiency**: For our purposes, spray rinse efficiency (See **Fig. 1**) is defined as the percentage of dragout film reduction accomplished in a single, countercurrent or series spray rinse system. Spray rinse efficiency is a measure of the effectiveness of spray rinsing. The total countercurrent or series spray rinse efficiency ($\eta$) can be calculated as:

**[1- (*Conc. of dragout from the n^th rinse/Conc. of dragout from process*)]** (1)

The fractional spray rinse efficiency for any rinse can be calculated as:

**[1- (*Conc. of dragout from the n^th rinse/Conc. of drag-in to the n^th rinse*)]** (2)

The average fractional spray rinse efficiency ($\eta_n$) for multi-stage spray rinsing can be calculated as:

$$\eta_n = 1 - (C_p/C_{Dn})^{1/n} \quad (3)$$

where $C_p$ is the concentration of the process tank(s), $C_{Dn}$ is the dragout concentration from the n^th rinse, $\eta_n$ is the fractional spray rinse efficiency, and n is the number of rinse tanks.

**Example 1**:
If $C_p$ = 250 g/L and $C_{Dn}$ = 50 ppm, then $\eta$ = 99.98%.
If n = 3, then $\eta_n$ = 87.40%,
and $C_{D1}$ = 31.50 g/L and $C_{D2}$ = 3.97 g/L.

**Example 2:**
If $C_p$ = 250 g/L, n = 3 and $\eta_n$ = 50.0%.
$C_{D1}$ = 125 g/L, $C_{D2}$ = 62.5 g/L and $C_{Dn}$ = 31.3 g/L,
and $\eta$ = 87.5%.

**Example 3**:
If $C_p$ = 250 g/L, n = 3 and $\eta_1$ = 50.0%, $\eta_2$ = 85.0%, $\eta_3$ = 85.0%,
$C_{D1}$ = 125 g/L, $C_{D2}$ = 18.8 g/L and $C_{Dn}$ = 2.81 g/L,
and $\eta$ = 98.9%.

From these examples, it is clear that the fractional spray rinse efficiency must be high (> 85%), and/or the number of spray rinses must be high (≥ 3), and/or the acceptable n^th rinse dragout concentration must be relatively high, and/or the process concentration must be relatively low to utilize spray rinsing as a total replacement for immersion rinsing. Spray and immersion rinsing can often be combined to utilize the advantages of each for overall synergy.

**Rinse efficiency:** Rinse efficiency is a relative measure of the quantity of water, time and/or energy required for efficient spray rinsing. Rinse efficiency can be quantified by comparing spray rinsing to immersion rinsing. Rinse efficiency and spray rinse efficiency are almost always inversely related. Spray rinse efficiency or effectiveness can usually be improved with increased spray time and water usage, but rinse efficiency will be reduced.

**Spray efficiency:** Spray efficiency is governed by highly complex phenomena that govern droplet transport from the nozzle to the target. 100% spray efficiency would mean that 100% of the spray droplets are utilized effectively to rinse the target.

**Multi-stage spray rinsing:** Spray rinsing efficiency and rinse efficiency can often be improved with multi-stage spray rinsing. **Figures 2 and 3** illustrate multi-stage spray rinsing. Multi-stage spray rinsing can configure with countercurrent or series sprays sequences. A multi-stage series spray rinse uses fresh water feeds, whereas a countercurrent system utilizes a cascading feed from the n^th rinse toward the first rinse. Both multi-stage series and countercurrent spray rinses are often utilized effectively on conveyor-

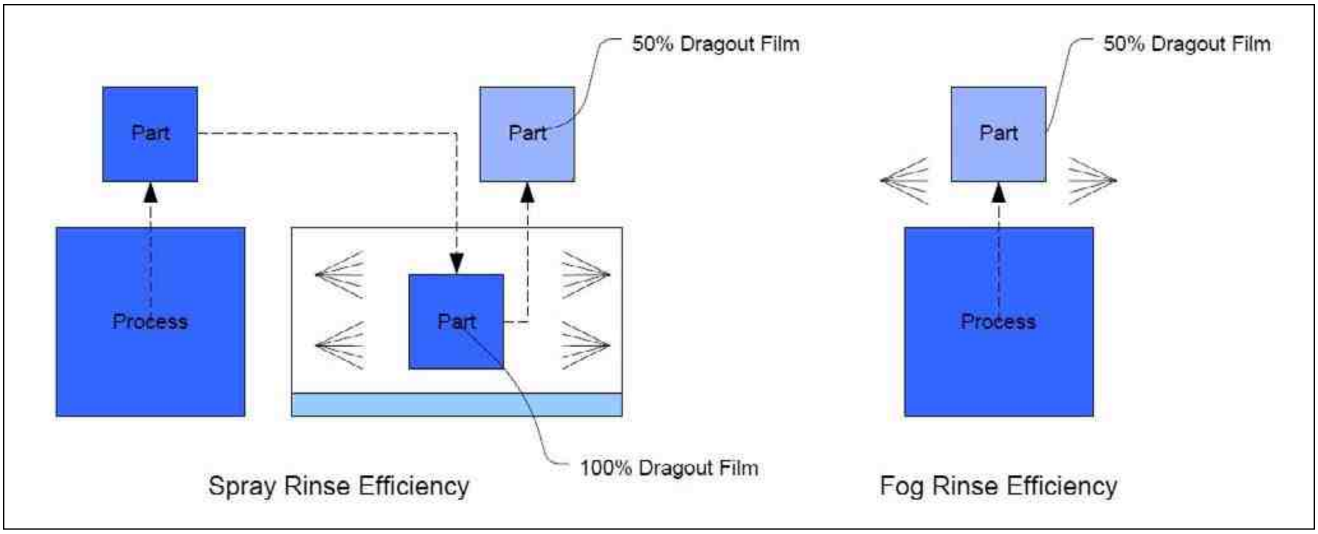


***Figure 1**—Spray rinse efficiency schematic.*

ized systems. Stationary spray rinse tanks can normally be optimized with a single station. A single tank utilizing equivalent spray volume and time is equivalent to multi-stage spray rinses unless the added tanks are configured with different spray configurations. Countercurrent spray rinse tanks can improve rinse efficiency and facilitate dragout recovery.

**Fog rinse:** A fog rinse is a finely atomized spray of very low capacity which is normally utilized over a process tank to reduce dragout, and/or to reduce the concentration and reaction rate of reactive films (*i.e.*, aluminum etch), and/or to prevent rapid drying of the dragout film during transfer of parts from high temperature process tanks.

**First rinse:** A first rinse may be designed as both a rinse and a secondary process step. Cleaners and pickling solutions may loosen soil or scale, and a high impact spray can be used to blast off the residue. Pickling and stripping operations often create loosely adherent metallic smuts, and spray rinsing can be effective for removing the smut.

**Air knife:** Air knives can be used, with or without aqueous sprays, to reduce dragout or as an air curtain to manage over-spray.

**Spray wand (or Hand-held spray):** A spray wand is a hand held spray which can be used by operators to direct sprays into recesses on complex parts which are difficult to reach with spray manifolds.

## Rinsewater quality

See previous column, "Rinsewater Quality in Immersion Rinsing."[1]

## Water quality

Water quality effects spray rinsing in the same way that water quality effects immersion rinsing, (See previous citation, ***P&SF*** June 2009). However, water quality also impacts spray nozzle performance. Hard water will cause

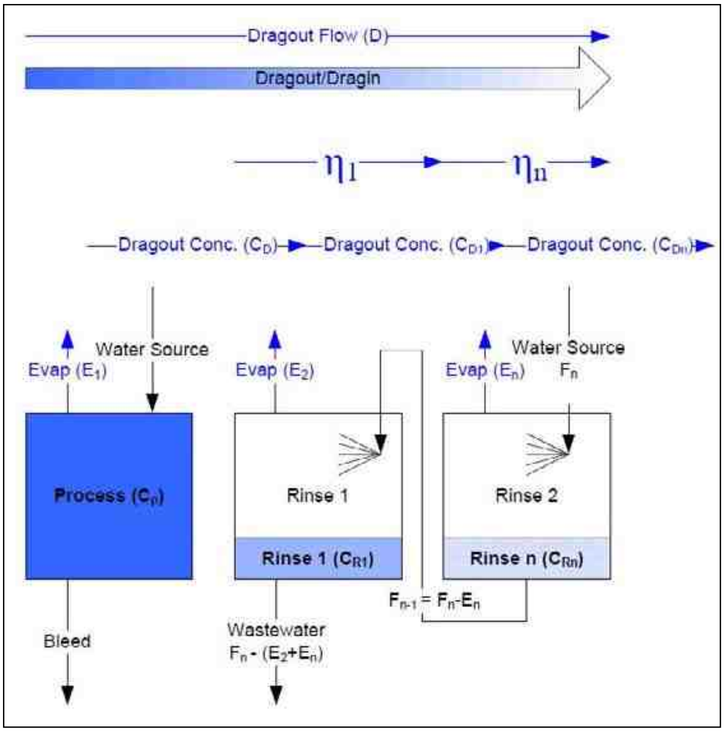


***Figure 2**—Countercurrent spray rinse.*

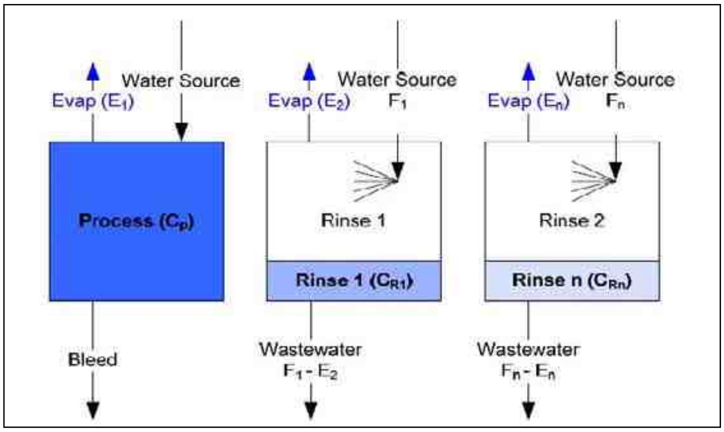


***Figure 3**—Parallel or sequential spray rinse.*

1 P. Gallerani, *Plating & Surface Finishing*, **96** (5), 16-20 (June 2009).

scale build-up, and particulates will clog spray nozzles. Deionized or softened water is recommended for spray rinsing, and strainers and/or filters should be installed in all spray systems.

## Basic spray rinse expression

The basic expressions which define the calculation of single and countercurrent spray rinse parameters are shown in Equations 3 and 4. **Figure 2** illustrates a simple process with two countercurrent rinses (n = 2).

$$C_{rn} = \eta_n \times C_{Dn\text{-}1} \times D/F_n \tag{4}$$

Where $F_n$ is the feed water flow rate to the n[th] rinse, $D$ is the dragout flow rate, $C_p$ is the concentration of the process tank(s), $C_{Dn}$ is the dragout concentration from the n[th] rinse, $C_{Dn\text{-}1}$ is the dragin concentration to the n[th] rinse, $C_{rn}$ is the rinse concentration in the n[th] rinse tank, $\eta_n$ is the fractional spray rinse efficiency, and n is the number of rinse tanks. The rinse equation calculates concentration of the n[th] rinse tank. The spray rinse efficiency and required water flow must be determined experimentally, as both are dependent upon part complexity.

$$CD_n = \eta_n \times Cr_n + (1\text{-}\eta n) \times C_{Dn\text{-}1} \tag{5}$$

$C_{Dn\text{-}1}/C_{Dn}$ is the fractional dilution ratio, $C_p/C_{Dn}$ is the total dilution ratio and $F_n/D$ is the rinse ratio. Effective rinsing requires control of the total dilution ratio. Efficient rinsing requires effective control of dragin and the rinse ratio. Countercurrent spray rinsing, like countercurrent immersion rinsing, is a useful technique used to minimize the rinse ratio.

## Part Geometry

Part geometry and work configuration impacts spray rinse effectiveness and efficiency. Spray rinsing can be more efficient than immersion rinsing if part geometry is relatively simple and spray rinsing equipment is properly designed. Spray rinsing is essentially a line-of-sight process, and spray efficiency can approach 100% with well-designed spray rinse equipment. However, spray rinse efficiency will always be influenced by part geometry and work configuration. Effective spray rinse design and practices can overcome most limitations due to part geometry. However, immersion rinsing will always be more efficient for some work.

## Physics of spray rinsing

Spray efficiency is largely dependent on droplet size, impact velocity and the angle of impingement. The aerodynamics of the spray is impacted by the nozzle design, pressure and the distance from the nozzle to the target. Target complexity impacts the ability of the spray to cover the target effectively and the goal of nozzle selection and spray manifold design is to achieve 100% target coverage. Further, the hydrodynamics of the dragout film will also impact the spray efficiency, since another goal of the spray rinsing is to achieve 100% coalescence of spray droplets in the target dragout film. The physics of droplet coalescence is complex. The figures below are greatly simplified. However, they illustrate some of the physics behind sprays and droplets. **Figure 4** illustrates droplet collision with a solid surface. **Figure 5** illustrates droplet-droplet collisions which can impact spray efficiency.

**Figure 4A** illustrates a droplet colliding with a solid surface and breaking up into smaller droplets which rebound off the surface. **Figure 4B** illustrates a droplet colliding with the surface and rebounding with preservation of the original droplet characteristics. **Figure 4C** illustrates partial rebound of the droplet. **Figure 4D** illustrates a droplet colliding with the solid surface and splashing, resulting in both the generation of small droplets and surface wetting. **Figure 4E** illustrates a droplet colliding with the surface and jetting along the surface. **Figure 4F** illustrates droplets colliding with the surface and coalescing with the surface.

**Figure 5A** illustrates two droplets colliding and coalescing to form a larger droplet. **Figure 5B** illustrates two droplets colliding, temporarily coalescing and then separating. **Figure 5C** illustrates the aerodynamics of a small droplet and large droplet collisions. If the velocity of the large droplet is high, the wake of the large droplet will cause the small droplet to avoid colliding with the large droplet.

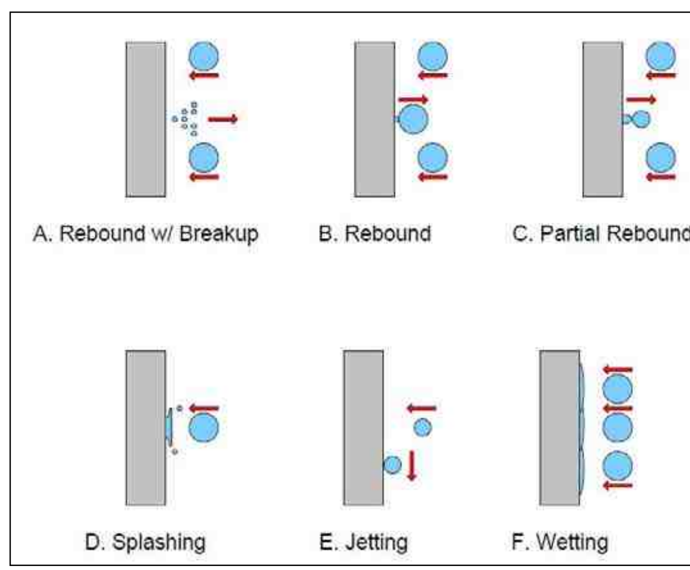


***Figure 4***—*Droplet collision with a solid surface.*

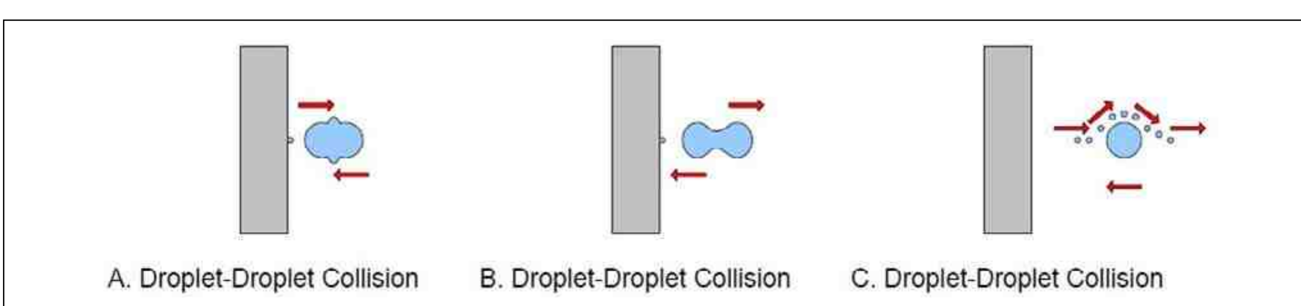


***Figure 5***—*Droplet-droplet collision.*

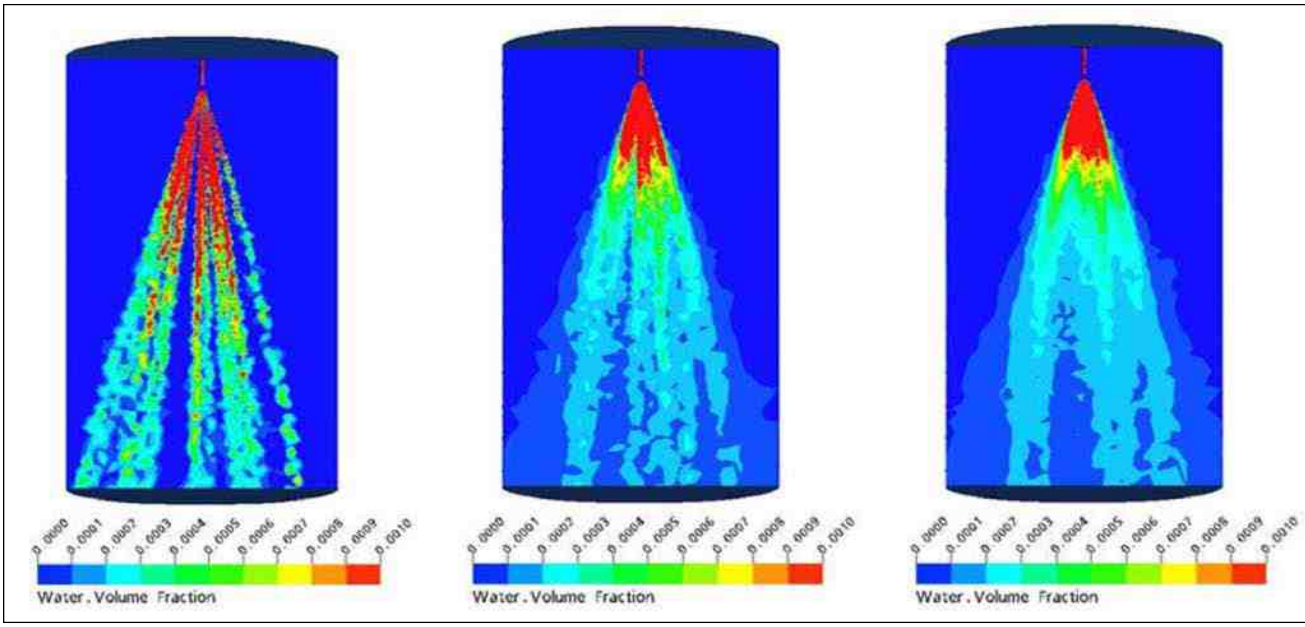


***Figure 6**—CFD characterization of water volume contours with (from left to right) 100, 500, 2000 particles.*[2]

Figures 6 and 7 illustrate computational fluid dynamics (CFD) models of spray patterns.

## Droplet size

Droplet size can be best understood by thinking of droplets in our natural environment. Table 1 provides a summary of typical droplet sizes in nature.

### Table 1: Droplet size

| Droplets in Nature | Droplet Size | Atomization |
|---|---|---|
| Dry fog | < 10 μm | Ultra-fine atomization |
| Fine mist | 10 - 100 μm | Fine atomization |
| Fine drizzle | 100 -300 μm | Semi-fine atomization |
| Light rain | 300 - 1000 μm | Semi-course atomization |
| Heavy rain | > 1000 μm | Course atomization |

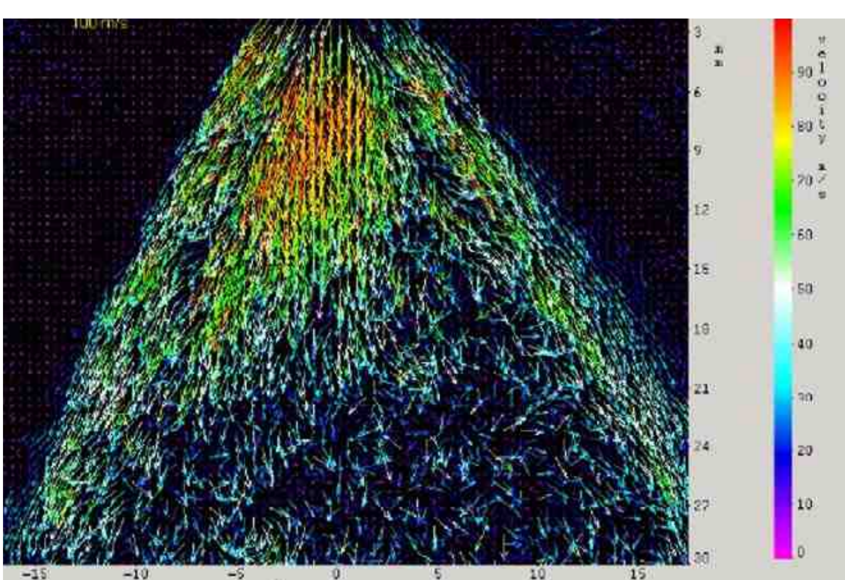


***Figure 7**—Model of the Velocity Field in a Hollow Cone Spray (80 Bar, Spray Nozzle = 0.8 mm).*[3]

Small droplets have higher total surface area for a given flow rate and can improve rinsing effectiveness and efficiency through improved surface wetting and reduced droplet collisions. Small droplets are also more effective for rinsing complex shapes, as small droplets can flow around the target and coalesce on non-line-of-sight surfaces. Large droplets have higher impact velocity and can improve rinsing on viscous films or after cleaning, pickling and stripping operations, where impingement can help remove loosely adherent soils or smuts.

**Part 2** of this ***Best Practices*** column will present practical considerations for spray rinsing, including performance specification development, spray rinse configurations, spray nozzle basics and ten rules for efficient and effective spray rinsing.

2 S.E. Gant, *"CFD Modeling of Water Spray Barriers, HSL/2006/79", Health and Safety Laboratory,* Harpur Hill, Buxton, Derbyshire, UK, 2006); http://www.hse.gov.uk/research/hsl_pdf/2006/hsl0679.pdf; last accessed 08/27/09.

3 Bjarne Paulsen Husted, et al., *"The Physics Behind Water Mist Systems," Proc. IWMA Conference 2004,* Rome, Italy, ; http://en.dbi-net.dk/media/Physics_behind_water_mist.pdf, last accessed 08/27/09.