De Dietrich Process Systems, Inc

THE THEORY AND BENEFIT OF MULTI-STAGE COUNTER-CURRENT RINSING

When asked what kind of rinse system is used after each plating tank in their process, surface finishing shop owners and operators alike will generally use one of the following phrases to indicate the hydraulic arrangement of the rinse tanks:

> "COUNTER-FLOW RINSES"
> "CASCADE RINSES"
> "COUNTER-CURRENT RINSES"

These descriptive phrases are typically used interchangeably without regard to what each phrase actually describes, or doesn't describe. These phrases do not mean the same thing and should NOT be used interchangeably.

The phrase "COUNTER-FLOW RINSING" is non-specific. It implies only that the two streams in question (dragged-in plating bath and rinse water) are flowing in generally opposite directions. The phrase "COUNTER-FLOW" is not informative. One cannot conclude or deduce from this phrase alone the effectiveness of the associated rinse water flow pattern or hydraulics (see Figure 1).

The phrase "CASCADE RINSING" is somewhat more descriptive. We know immediately that there are two or more rinse tanks involved (as shown in Figure 2) and that rinse water is most likely overflowing from the top of one tank onto the rinse water surface of a preceding tank. However, the effectiveness of this rinsing description is not readily quantifiable mathematically with regard to the degree of mixing or the efficiency of rinsing in each rinse stage or with regard to the amount of rinse water required to achieve acceptable rinsing.

The potential problems with cascade rinsing are: 1) dragged in plating bath is generally more dense than the incoming rinse water. The rinse tank can stratify; that is, the dragged-in bath can sink to the bottom of the tank unless the tank is strongly and continuously agitated either by a mechanical stirrer, by pumped recirculation or by an air sparging system. More often than not, the overflowing rinse from the succeeding tank <u>can</u> flow directly across the top of the water surface, mixing inadequately or little at all thereby requiring the use of more water than should theoretically be necessary to achieve adequate rinsing, and, 2) rinse mixing is potentially erratic. The concentration of principal metal ion in each stage is not easily modeled or mathematically computed. The result is that cascade rinse systems generally consume more rinse water than required to achieve effective rinse quality.

The COUNTER-CURRENT RINSE technique, properly implemented (as shown in Figure 4), uses rinse water more effectively and efficiently than either of the foregoing methods. Rinsing efficiency and the respective concentrations of drag-out in each rinse tank is more easily and dependably determined using simplified rinsing equations.

An important requirement of a multi-tank countercurrent rinse system is the hydraulic elevation of each subsequent tank in the system to permit gravity flow of a lower concentration (or lower specific gravity) rinse water against a more concentrated, higher specific gravity rinse water in each preceding rinse stage. Each succeeding rinse tank (E.g., Figures 3, 4 & 5) may require a hydraulic elevation of between 2 to 4 inches depending on the concentration of the plating bath involved, the bath drag-out rate, the number of rinse stages and the rinse water flow rate. If an automatic hoist is used, the hoist travel and rack design must accommodate the required hydraulic elevation of each succeeding rinse tank in the system.

Note that if plating bath recovery is being considered, the chosen recovery system - whether it is a vacuum evaporator or another suitable recovery system - will have to process the quantity of rinse water required by the rinse system excluding any free running rinse tanks or closed loop DI rinses which may also be used. So, using a scheme which minimizes rinse water consumption in a manner consistent with good rinsing not only reduces rinse water cost but the capital and operating cost of the recovery system as well (see Figures 3 & 4).

The more rinse tanks that can be used in a COUNTER-CURRENT RINSE system, the better. (Figure 4). It is typical to have at least three rinse stations or tanks. Every effort should be made to incorporate more tanks if possible. The reduction in rinse water required for a given rinsing quality, or effectiveness, is an inverse exponential function of the number of rinse tanks in the system, as will be shown later in this discussion.

To achieve good COUNTER-CURRENT hydraulics, each rinse tank in the system should be piped or plumbed in a very specific way. Clean city water or DI water is delivered through a siphon breaker to the bottom rear of the last tank in the rinse system and should flow diagonally upward and out of the tank through an overflow weir or discharge pipe located on the opposite or forward wall of the tank. This overflow stream is then directed through an overflow weir or discharge pipe connected to the bottom rear wall area of the preceding tank in the series.

This bottom-to-top, diagonal flow pattern is repeated in each rinse tank in the series. In most cases, the rinse water flow pattern is directly opposite to the direction of work flow through the rinse system. COUNTER-CURRENT rinse systems are usually referred to as two stage, three stage, four stage (and so on) COUNTER-CURRENT RINSE SYSTEMS.

The counter-current rinse water flow pattern will depend on the geometry of both the rinse tanks and of the work being plated. The most common flow patterns are depicted in Figures 3 & 4. However, to accommodate long, tubular products, some rinse tanks must be a long, narrow, rectangular design in which the work transfers across the narrow dimension or the width of the tank (Figure 5). Attempting to oppose the work flow with a directly opposing stream of rinse water by using long, overflow weirs on the long dimension of a tank can be problematic or impractical because of weir warpage and the potential for mal-distribution of rinse water overflowing the weir, or because of tanks and/or weirs that are not level.

In such cases, properly sized overflow piping can be used at alternating ends of such tanks to establish, as a minimum, what can be defined as a CROSS TANK, bottom-to-top, counter-current flow pattern where the rinse water flows at 90 degrees to the work flow path from, say, the bottom of the left end of the tank diagonally upward along the long dimension of the tank to overflow the opposite, right end of the tank at the top, and then to the bottom of the preceding tank . Thus the connecting overflow pipe loops will be installed alternately at opposite ends of the rinse tanks as shown in Figure 5.

If all the overflow pipe loops are installed at the same ends of the rinse tanks, mixing will be impaired and hydraulic short-circuiting of the rinse flow along the short end wall may likely occur depending on how these pipe loops are designed.

If floor space is available, the advantages of designing for true counter-current rinse water flow are as follows:

WATER ECONOMY: Substantially and exponentially reduces the quantity and cost of rinse water required to achieve quality rinsing. This in turn reduces the size, capital cost and operating cost of any bath and water recovery equipment applied to this rinse system.

The reduction in water demand decreases exponentially as the number of rinse stages in the system increases. In other words, the more counter-current rinse stages or tanks that can be applied to a rinse system, the less rinse water will be required.

PREDICTABLE PERFORMANCE: The PRINCIPAL METAL ion concentration in each respective rinse tank of a counter-current rinse system can be theoretically and easily estimated using the simplified algebraic equations that follow.

Four variables --- 1) bath concentration, 2) bath drag-out rate, 3) the number of CC rinse tanks being used and 4) the rinse ratio (GPH rinse water required divided by the GPH of bath dragged out) can be manipulated mathematically to achieve the desired principal metal ion concentration in the last rinse tank of the CC rinse system.

To determine if a given rinse ratio is adequate, the principal metal ion concentration in each rinse tank can be calculated for various rinse ratios by using the formula:

$$C_i = C_o \div R^i$$

where

C_i = Target concentration of the principal metal ion (ppm) in rinse tank i in a counter-current system;
C_o = Concentration of principal metal ion (ppm) in the plating bath; and
i = the number of Counter-Current rinse stages
R^i = Rinse Ratio (gal/h rinse water required per gal/h of bath dragged-out) raised to the power of i, as used in C_i.

For example, assume you wish to calculate the ppm of hexavalent chrome ($Cr^{=6}$) in the third rinse tank of a three tank system (i = 3). The plating bath concentration is 32 oz./gal. of CrO_3 which is equivalent to 16 oz./gal. Hexavalent chrome (the percentage of Cr^{+6} in CrO_3 is 50%) or 120,000 ppm hex chrome (multiply 16 oz./gal. by 7500 to convert to ppm).

If we select a rinse ratio of 25:1, the calculation then becomes

C_3 = 120,000 ppm ÷ 25^3 = 7.7 ppm theoretical hex chrome in the third rinse tank

To decrease this theoretical concentration value, we can either increase the rinse water flow rate (the Rinse Ratio) in the three-tank CC Rinse System, or, add a fourth rinse tank to the system. If a fourth rinse tank is added, i = 4 and Ci = C_4 and the calculation becomes

C_4 = 120,000 ppm ÷ 25^4 = 0.31 ppm theoretical hex chrome in the fourth rinse tank

Adding a fourth tank reduces the chrome concentration by a factor of **7.7 ÷ 0.31 or 25 times!** This demonstrates the power of <u>true</u> COUNTER-CURRENT rinse hydraulics.

Thus, the greater the number of true counter-current rinse tanks which can be physically and hydraulically accommodated in a COUNTER-CURRENT rinse system, the less water is required for adequate rinsing, and the lower the principal metal ion concentration will be in the last rinse stage in the system.

If the number of tanks cannot be changed, then the rinse rate, or gallons of rinse water used per gallon of bath dragged out can be increased as shown in Figure 3. Or perhaps measures to reduce drag-out can be taken.

The quantity of chrome in these examples that can be theoretically captured or recovered with a vacuum evaporation recovery system is calculated using the formula

$$\% \text{ capture} = [\ 1 - 1/R^i\ ]\ 100$$

With the assumptions of the preceding examples,

Where $i = 3$

$$\% \text{ capture} = [\ 1 - 1/25^3\ ]\ 100 = 99.994\%$$

and

Where $i = 4$

$$\% \text{ capture} = [\ 1 - 1/\ 25^4\ ]\ 100 = 99.9997\% \text{ theoretical}$$

So, it is demonstrated that in a three stage counter-current rinse system the theoretical percent capture rate is well over 99.99%, and, at that level, the rinse ratio is not as much a concern as the principal metal ion concentration in the last rinse tank of the system.

In order to illustrate as clearly as possible the simplicity, hydraulic effectiveness and economic impact on water usage of a well designed and operated multi-stage counter-current rinse system, the potential added benefit of incorporating additional rinse water economies such as over-tank sprays and/or rinse water removal devices such as air knives, have not been considered in the foregoing analysis.

Lastly, it is common practice to use drag-out or still rinse tanks as part of a rinse tank system. It should be evident from the foregoing discussion that drag-out and/or still tanks are acting as extensions of the plating bath in which no electroplating is taking place.

Converting drag-out or still rinse tanks to operate as additional stages of a true counter-current running rinse system has a more powerful and significant impact on reducing overall rinse water requirements without impairing rinsing effectiveness.

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DE DIETRICH PROCESS SYSTEMS

COUNTER-FLOW

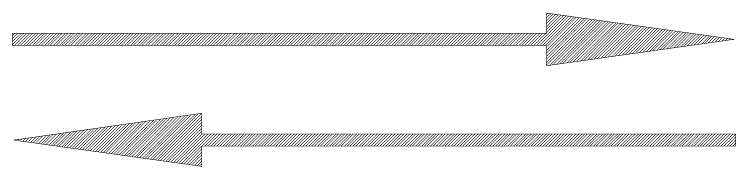

FIGURE 1

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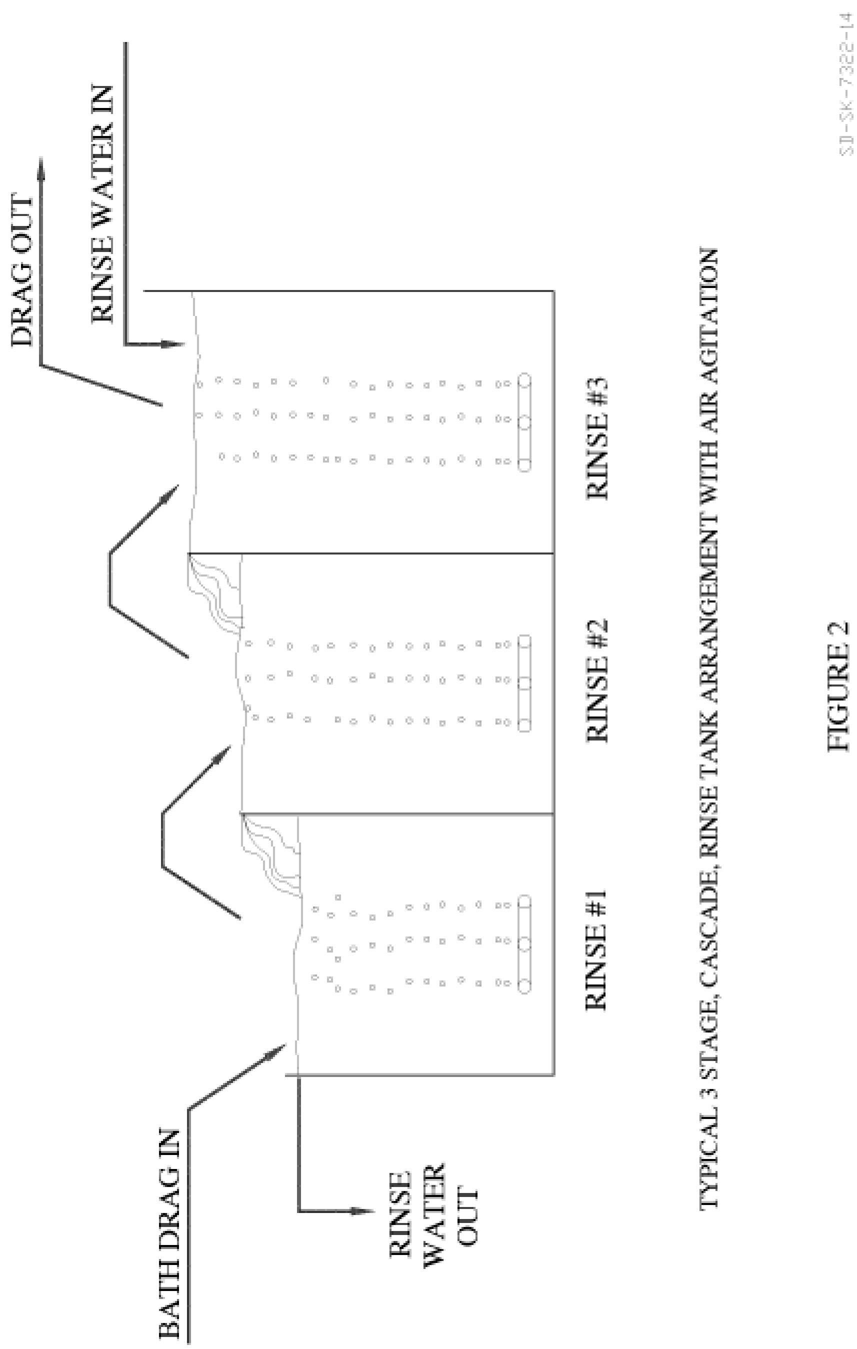
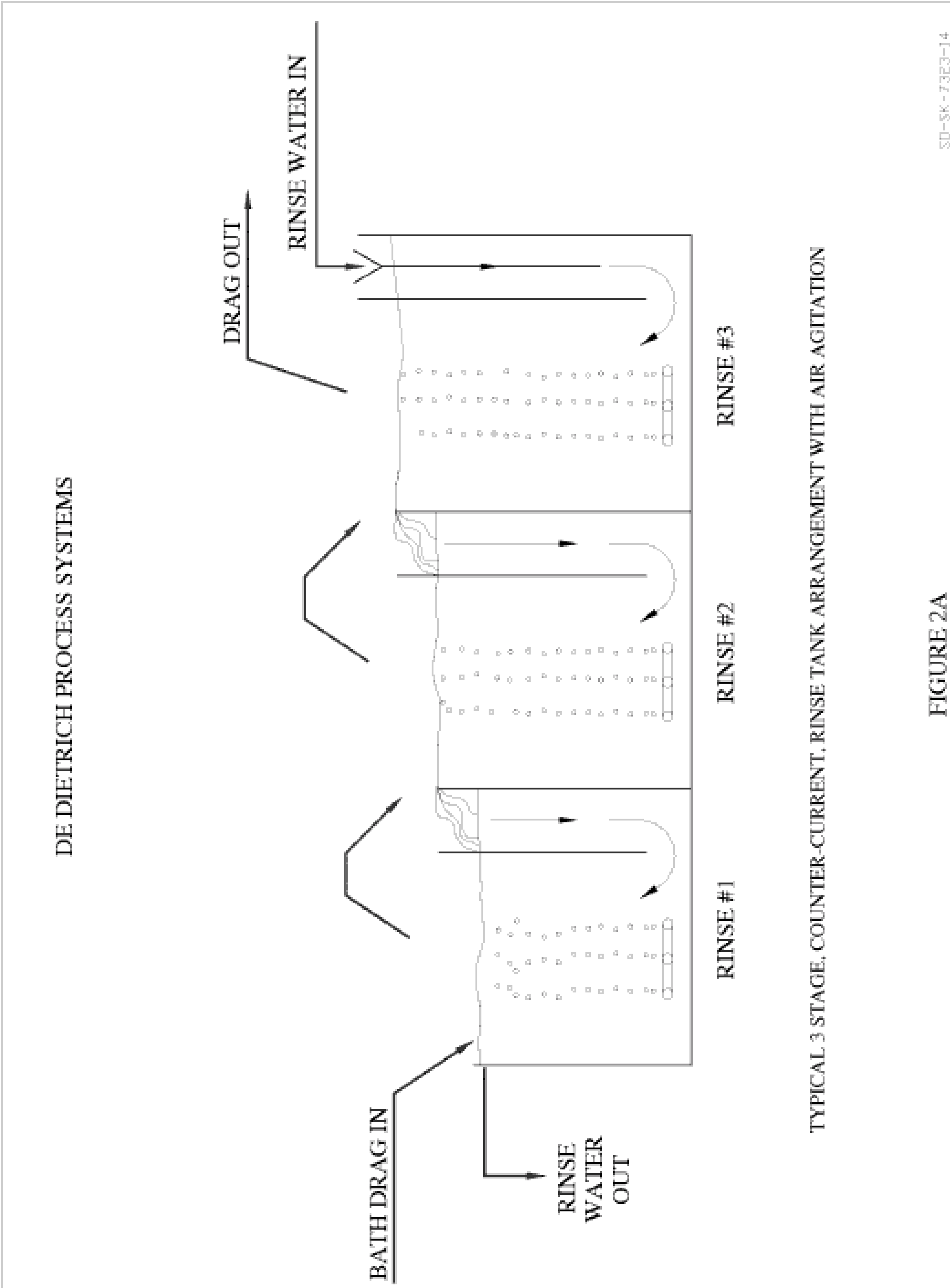


TYPICAL 3 STAGE, CASCADE, RINSE TANK ARRANGEMENT WITH AIR AGITATION

FIGURE 2

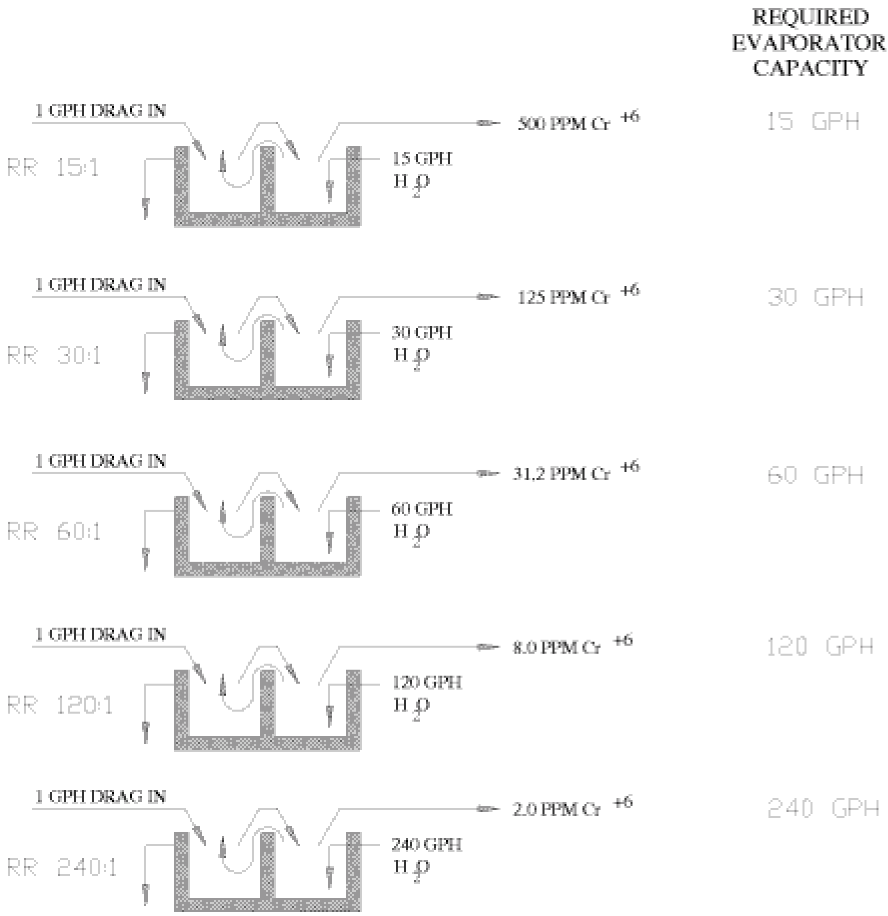


TYPICAL 3 STAGE, COUNTER-CURRENT, RINSE TANK ARRANGEMENT WITH AIR AGITATION

FIGURE 2A

DE DIETRICH PROCESS SYSTEMS
FIXED NUMBER OF RINSE TANKS
VS. RINSE RATIO (EVAPORATOR SIZE)

GIVEN:
- DECORATIVE CHROME BATH
  30 OZ/GAL CrO_3
  15 OZ/GAL Cr^{+6} (112,351 PPM)
- DRAG-IN: 1 GPH
- TWO CC RINSE TANKS
- RINSE RATIO VARIABLE



ASSUMES TRUE COUNTER-CURRENT FLOW AND 100% MIXING

FIGURE 3

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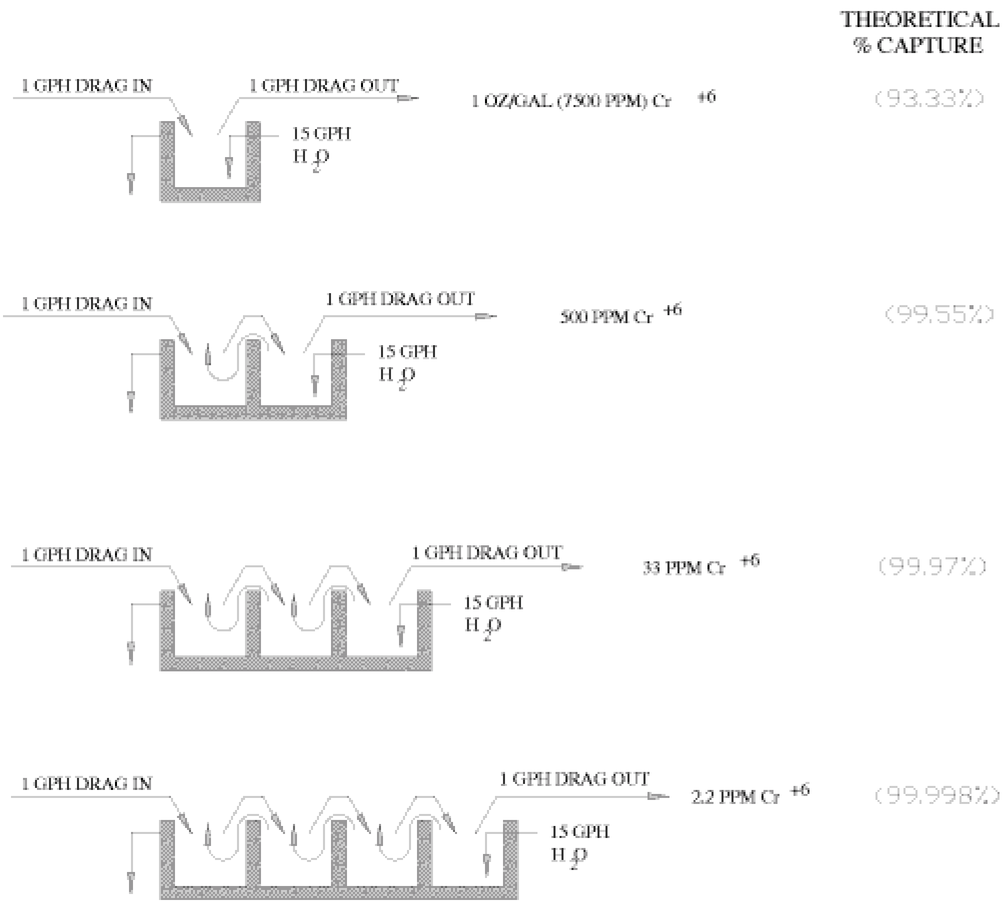
DE DIETRICH PROCESS SYSTEMS
FIXED RINSE RATIO (EVAPORATOR SIZE)
VS. NUMBER OF RINSE TANKS

GIVEN:
- DECORATIVE CHROME BATH
  30 OZ/GAL CrO_3
  15 OZ/GAL Cr^{+6} (112,351 PPM)
- DRAG-IN: 1 GPH
- UP TO FOUR CC RINSES AVAILABLE
- RINSE RATIO @ 15:1



ASSUMES TRUE COUNTER-CURRENT FLOW AND 100% MIXING

FIGURE 4

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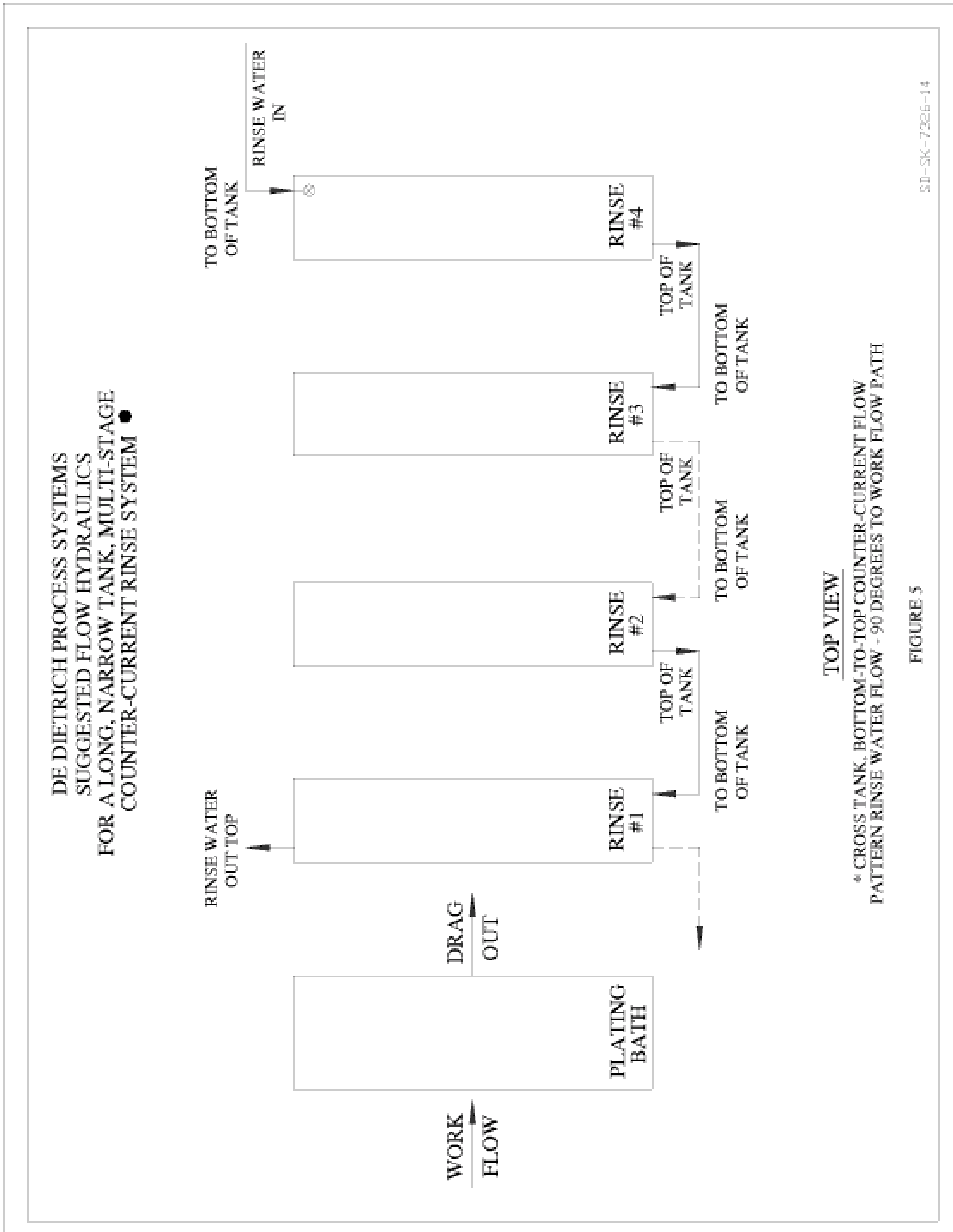
DE DIETRICH PROCESS SYSTEMS
SUGGESTED FLOW HYDRAULICS
FOR A LONG, NARROW TANK, MULTI-STAGE
COUNTER-CURRENT RINSE SYSTEM
RINSE WATER IN
TO BOTTOM OF TANK
RINSE #4
TOP OF TANK
TO BOTTOM OF TANK
RINSE #3
TOP OF TANK
TO BOTTOM OF TANK
RINSE #2
TOP OF TANK
TO BOTTOM OF TANK
RINSE #1
RINSE WATER OUT TOP
DRAG OUT
PLATING BATH
WORK FLOW
TOP VIEW
* CROSS TANK, BOTTOM-TO-TOP COUNTER-CURRENT FLOW
PATTERN RINSE WATER FLOW - 90 DEGREES TO WORK FLOW PATH
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FIGURE 5

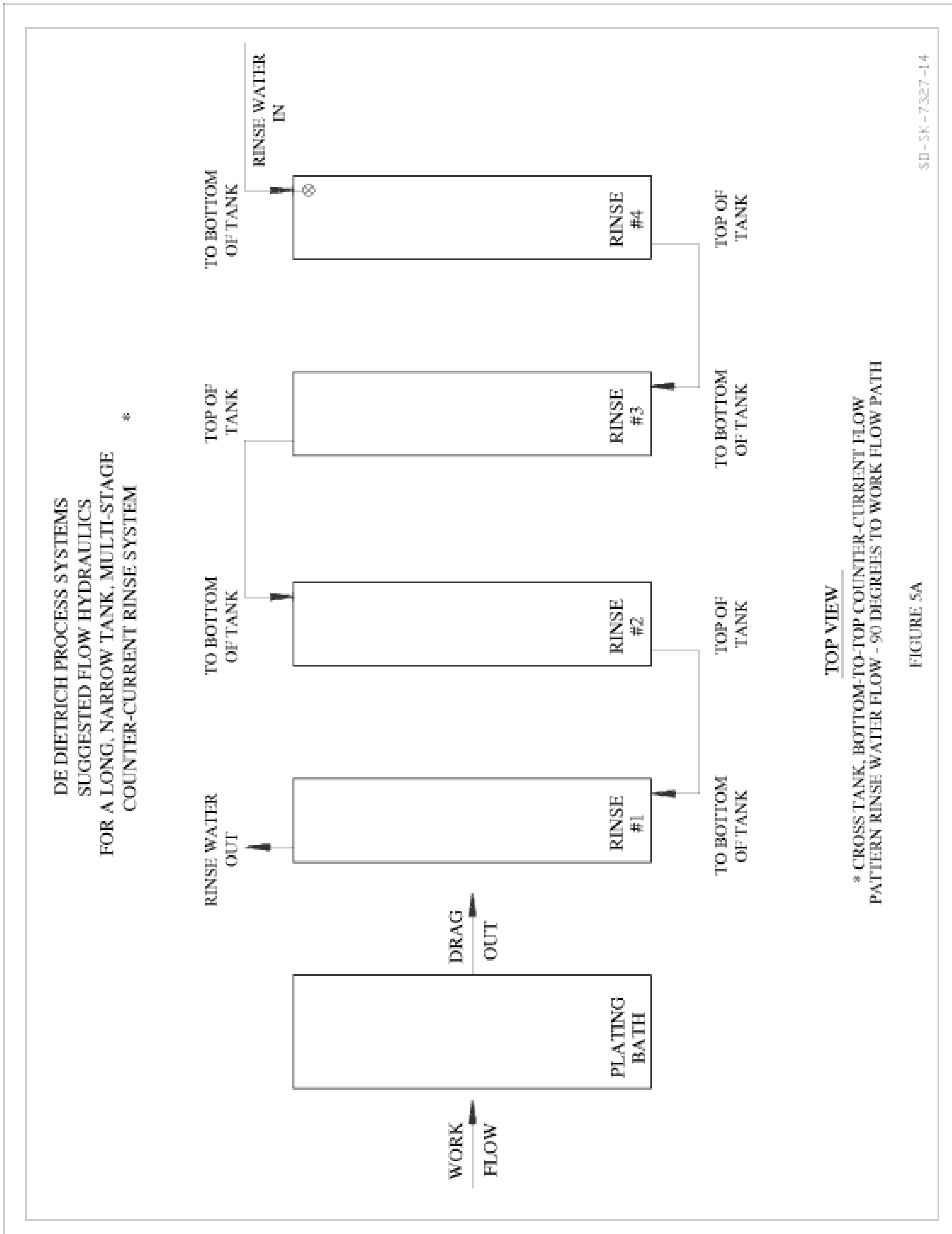
DE DIETRICH PROCESS SYSTEMS
SUGGESTED FLOW HYDRAULICS
FOR A LONG, NARROW TANK, MULTI-STAGE
COUNTER-CURRENT RINSE SYSTEM
*
WORK FLOW
PLATING BATH
DRAG OUT
RINSE WATER OUT
RINSE #1
TO BOTTOM OF TANK
TO BOTTOM OF TANK
RINSE #2
TOP OF TANK
TOP OF TANK
RINSE #3
TO BOTTOM OF TANK
TO BOTTOM OF TANK
RINSE #4
TOP OF TANK
RINSE WATER IN
TOP VIEW
* CROSS TANK, BOTTOM-TO-TOP COUNTER-CURRENT FLOW
PATTERN RINSE WATER FLOW - 90 DEGREES TO WORK FLOW PATH
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FIGURE 5A

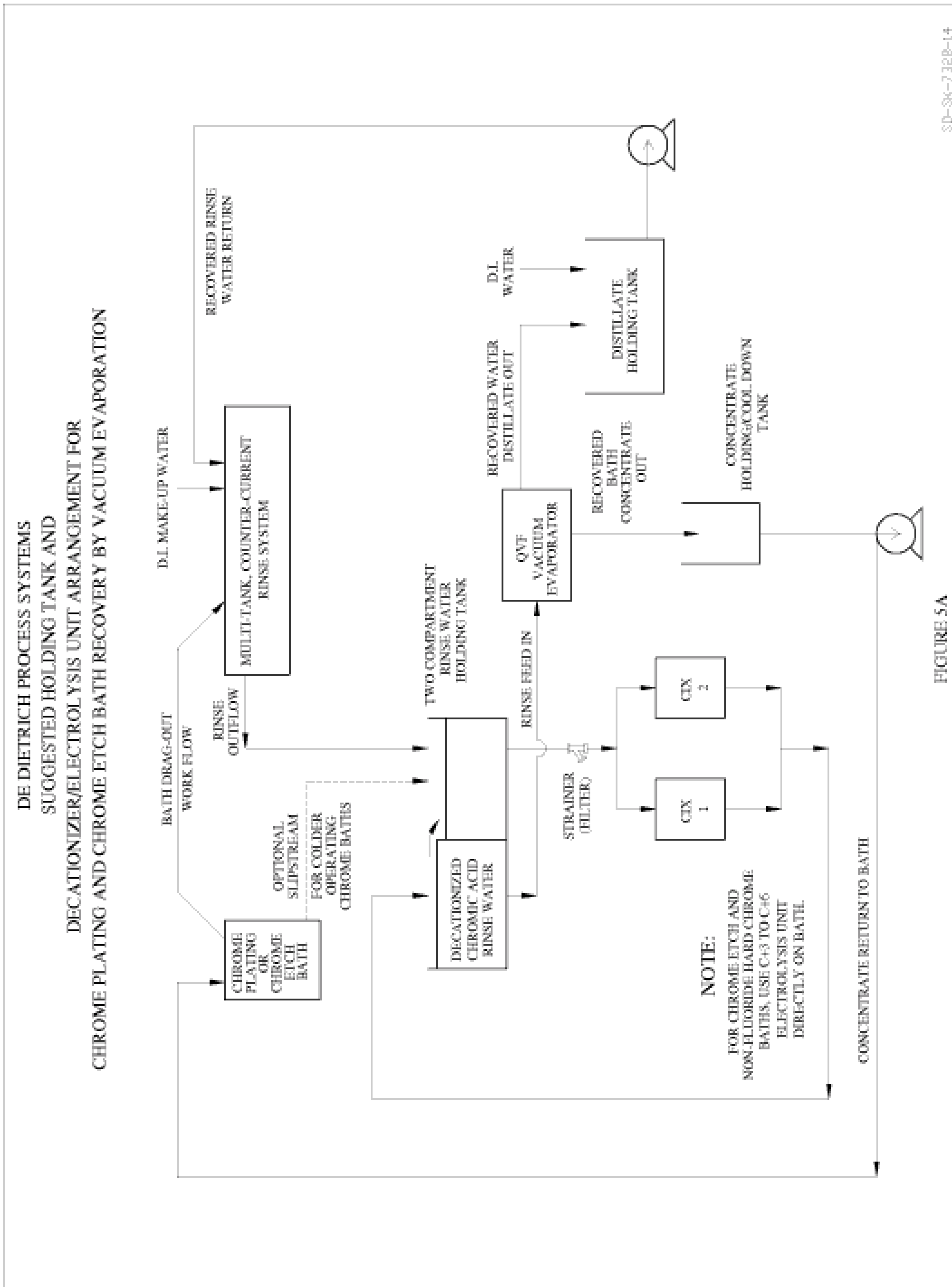
DE DIETRICH PROCESS SYSTEMS
SUGGESTED HOLDING TANK AND
DECATIONIZER/ELECTROLYSIS UNIT ARRANGEMENT FOR
CHROME PLATING AND CHROME ETCH BATH RECOVERY BY VACUUM EVAPORATION
D.I. MAKE-UP WATER
RECOVERED RINSE WATER RETURN
MULTI-TANK, COUNTER-CURRENT RINSE SYSTEM
BATH DRAG-OUT
WORK FLOW
RINSE OUTFLOW
CHROME PLATING OR CHROME ETCH BATH
OPTIONAL SLIPSTREAM
FOR COLDER OPERATING CHROME BATHS
TWO COMPARTMENT RINSE WATER HOLDING TANK
DECATIONIZED CHROMIC ACID RINSE WATER
RINSE FEED IN
QVF VACUUM EVAPORATOR
RECOVERED WATER DISTILLATE OUT
D.I. WATER
DISTILLATE HOLDING TANK
RECOVERED BATH CONCENTRATE OUT
CONCENTRATE HOLDING/COOL DOWN TANK
STRAINER (FILTER)
CIX 1
CIX 2
NOTE:
FOR CHROME ETCH AND NON-FLUORIDE HARD CHROME BATHS, USE C+3 TO C+6 ELECTROLYSIS UNIT DIRECTLY ON BATH.
CONCENTRATE RETURN TO BATH
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FIGURE 5A