Rinsewater Reduction Calculator

By J.K. Unangst & W.J. Fullen*

*[**Technical Editor's Note:** For purposes of clarity and compatibility with the description given for the Calculator, this paper is being published without the usual English-Metric unit conventions.]*

Regulatory and cost drivers have increased the focus on rinsewater reduction at the Boeing Plant in Auburn, Washington. The first step in making reductions is to determine the amount of rinsewater required for a given process, taking into account requirements driven by health and safety, applicable specifications and part quality. This can be accomplished with the Rinsewater Reduction Calculator (Calculator), which is a Microsoft® Access database that models single, double counter-current and triple counter-current rinse tanks. Implementing timer settings generated with the Calculator in place of subjective practices has reduced rinsewater usage by more than 50%. Application of the Calculator is discussed, and the tool is available for download from the Boeing Company web site.

In a tank line that uses double counter current rinses (DCCR), two-thirds of the tanks contain rinsewater, which for purchase, treatment and discharge, costs around 2 cents per gallon. Even at that relatively low rate, the monetary savings are substantial when achievable reductions are in the millions of gallons. It is well known that most facilities use more water than necessary and reductions would provide significant environmental and economic benefit.[1, 2, 3] The first step in making reductions is to determine the amount of rinsewater required for a given process, taking into account requirements driven by health and safety, applicable specifications and part quality.[4] Aside from general inflation, the future cost of water might be influenced by fluctuating water supply, regional growth, salmon habitat protection and water de-regulation.

Mathematical models were previously developed[5] to determine the volume of water required to manage the levels and concentrations of single, double counter-current (DCCR) and triple counter-current (TCCR) immersion rinses. These models account for changes in rinsewater levels and concentrations due to process solution drag-in, rinsewater drag-out and evaporative losses. The Rinsewater Reduction Calculator (Calculator), a Microsoft® Access database, is used to adapt these mathematical models to real life applications. Although the mathematical models are briefly presented here, the focus of this paper is on the use of the Calculator, which can be downloaded, along with a help file, from the following web site: http://www.boeing.com/special/rrcalc/

Mathematical modeling

Single rinse model

Figure 1 illustrates the model for a single immersion rinse, the simplest of the three designs modeled and the most inefficient. A mass balance performed over the rinse results in the following steady-state general solution:

$$F_t = [F_p(C_p - C_r) - F_eC_r]/(C_t - C_r) \qquad (1)$$

The variables in the above equation are flow rate (F) and concentration (C) and are used with the following subscripts:

d (drag-out)	p (process solution)	t (makeup water)
e (evaporation)	r (rinsewater)	w (wastewater

DCCR model

Figure 2 depicts the model for a DCCR, which is the most commonly used design and substantially more efficient

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Nuts & Bolts: What This Paper Means to You

The battleground is heating up for fresh water and will probably be the next political hotbed. Conserving rinse water in plating shops will no doubt become a mandatory item in the future. This increased focus on rinsewater reduction requires the plater to know how much is being used. The authors have developed a Rinsewater Reduction Calculator (RRC), which uses a Microsoft Access database to model single, double counter current and triple counter current rinse tanks. This useful tool is available on the Boeing Company website and is described in detail here.

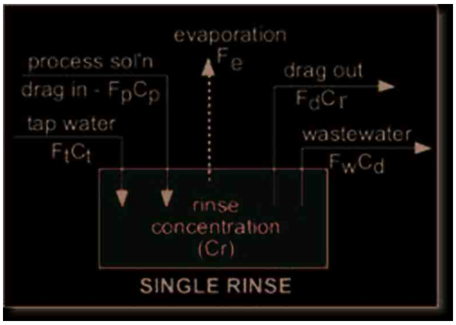


Figure 1—Model of a single rinse.

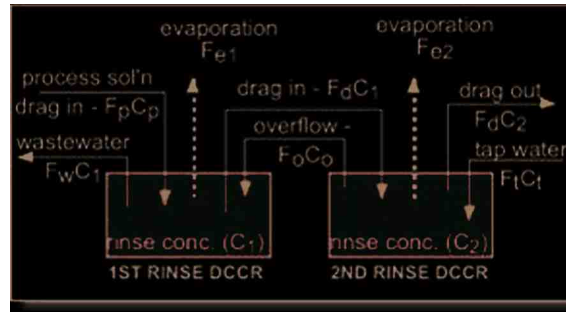


Figure 2—Model of a double counter-current rinse.

than a single rinse. A mass balance performed over the DCCR results in a complex quadratic equation, with the following simplified solution where the "1" and "2" subscripts refer to the first and second rinses. The "o" subscript refers to the overflow from the second rinse to the first.

$$F_t = [(F_d F_p C_p)/(C_2 - C_t)]^{1/2} \quad (2)$$

Equation (2) is similar to that found in other publications,[6] but if used, results in a loss of precision and accuracy. The Calculator uses the complex quadratic equation without simplifying assumptions.

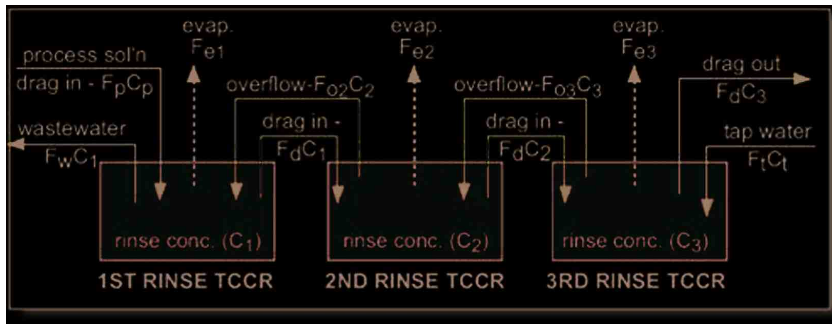


Figure 3—Model of a triple counter

TCCR model

This design (Fig. 3) is rarely used because the first rinse becomes highly concentrated and can have a deleterious impact on the process, equipment or wastewater pretreatment plant. If there are restrictions on the concentration of the first rinse, a TCCR could use more water than a DCCR. For a TCCR, linear matrix algebra is required to solve simultaneously the mass balance equations around each of the rinses. The makeup water flow rate (F_t) is determined by iterating the volume of water required per load until the desired rinse concentration is achieved.

Calculator (Rinsewater Reduction Calculator)

Purpose

The Calculator can be used to determine the amount of water required to properly maintain the level and concentration of a given rinse tank design and the length of time it takes to add the water if the water is only added when a load is processed. It is designed for applications where a timer is used to control the addition of water to a rinse tank. The timers are programmed with settings obtained from the Calculator (sec/load or min/load), and tank line operators are trained to press the timer button each time a load is processed. Strictly controlling the amount of water added to the rinse tanks in this manner results in more efficient rinsewater management.

Additionally, the Calculator can be used to compare the efficiencies of a single rinse, DCCR and TCCR. The impact of process parameters on water usage can also be evaluated (*e.g.,* rinse temperature, loads per day, air agitation level, water quality, drag-in and drag-out, etc.).

Getting started

Figure 4 shows the Calculator Data Input Form. The major sections are labeled in the figure and discussed below. The data fields labeled with blue-colored text are required fields.

Section 1. Data in this section are used to identify the process (*e.g.*, location, tank number) and is optional.

Section 2. Air temperature and relative humidity near the rinse tank are entered in this section. If not entered, the default values of 67 to 77°F and 30 to 70% relative humidity will be used.

Section 3. The following data are required: the average number of part loads per day (*e.g.*, baskets or racks of parts), process solution concentration (TDS) and drag-in rate (gal/load), rinsewater drag-out rate (gal/load), makeup-water concentration (TDS) and

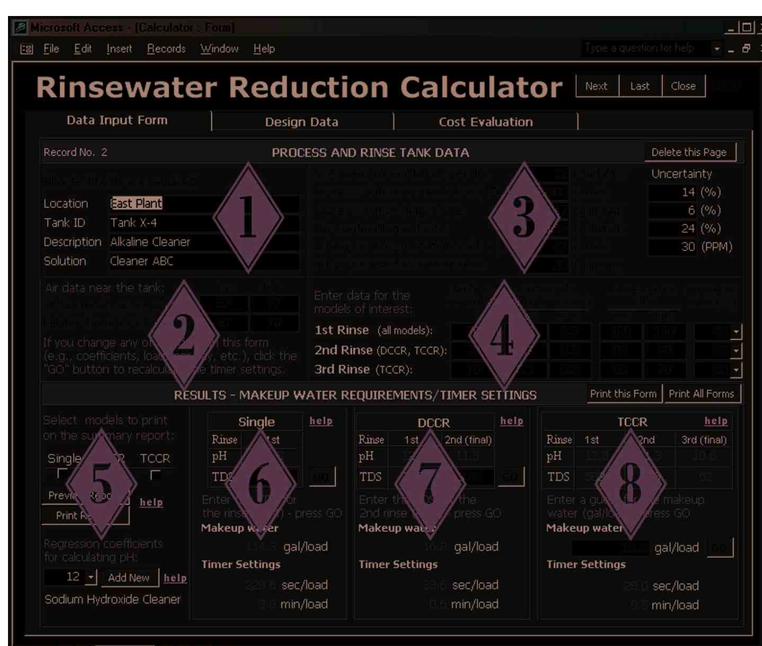


Figure 4—Calculator data input form.

makeup-water flow rate (gal/min). The uncertainty data are optional and are applied only to the single-rinse and DCCR models. The uncertainty values reflect confidence in the data and are used to buffer or increase the timer setting to safeguard the process.

Section 4. The following rinse tank properties are used to calculate evaporative losses and are required: surface area (ft^2), ventilation rate (m/sec), temperature (°F) and level of air agitation. Evaporative losses are usually significant for heated tanks and can be important if the process solution concentration is low.

If only room ventilation is available, the range 0.1 to 0.2 m/sec can be used as an approximation of ambient air movement and is the default. The level of air agitation in a rinse tank is selected from a dropdown menu: no-air, bubbling, moderate or rolling. Since air sparging increases the evaporation rate, the evaporation rate is multiplied by a preset factor based on the level chosen.[7]

Section 5. A report summarizing timer settings can be viewed or printed by selecting the checkboxes for the models desired and clicking on the appropriate button.

Regression coefficients, which are solution specific and used for calculating rinsewater pH, are chosen from a dropdown menu. If a representative solution is not available, choose "none" from the dropdown menu. Coefficients for additional solutions can be added by clicking the "Add New" button and adding the required information.

Coefficients for the solutions were determined from laboratory data, while those for the pure acids were calculated using published dissociation constants. For the solutions, the concentration (TDS) and pH of a series of sequentially diluted process solutions were measured and graphed. A linear regression analysis was performed to derive the regression coefficients (slope, intercept), which are used in the following equation to calculate pH:

$$pH = slope \times \ln[TDS] + intercept \qquad (3)$$

TDS is the concentration of total dissolved solids in units of ppm (parts per million).

Section 6. To evaluate the use of a single rinse, enter the desired or target TDS for the rinse, which is usually controlled by the governing process specification. Press the "GO" button or press the enter key twice to calculate the timer setting.

In Fig. 5, at a TDS of 350 PPM, the pH of the single rinse is calculated to be 11.3. The pH will only be calculated and displayed if regression coefficients are selected. Approximately 114 gal of water need to be added to the single rinse each time a load is processed to maintain the proper level and concentration. Using the flow rate of the makeup water, a timer setting of 3.8 min/load is calculated, as shown in Fig. 5.

Section 7. To evaluate the use of a DCCR, enter the desired or target TDS for the second or final rinse (Fig. 6). Click the "GO" button or press the enter key twice to calculate the timer setting.
If regression coefficients are selected, the pH of both rinses will be displayed. If the TDS or pH of the first rinse is too high, decrease the TDS of the second rinse until acceptable values are obtained. Realistically, the TDS of the first rinse cannot be less than that of the makeup water or more than that of the process solution.

For the DCCR model, 16.8 gal need to be added each time a load is processed, which requires a timer setting of about 34 sec/load. This is substantially less than the 114 gal needed for a single rinse.

Figure 5—Single rinse results.

Figure 6—DCCR results.

Figure 7—TCCR results.

Figure 8—TCCR results.

Section 9. To evaluate the use of a TCCR, enter an estimate of the makeup-water required per load (gal/load). Press the "GO" button or press the enter key twice to calculate the timer setting. The makeup-water requirement obtained from the DCCR evaluation can be used as a starting point. For example, 16.8 gallons per load from the DCCR model are entered as shown in Fig. 7. Iterate either up or down, as required, to obtain the desired pH and TDS (Fig. 8).

Comparing the three models depicted in Figs. 5 thru 8, the DCCR and TCCR provide substantial water savings over the single rinse, but the TCCR provides meager savings over the DCCR. For a given process, if the first and second rinses of a TCCR are controlling (*e.g.*, pH or TDS limitations) or heated, it is likely that the TCCR will use more water than a DCCR.

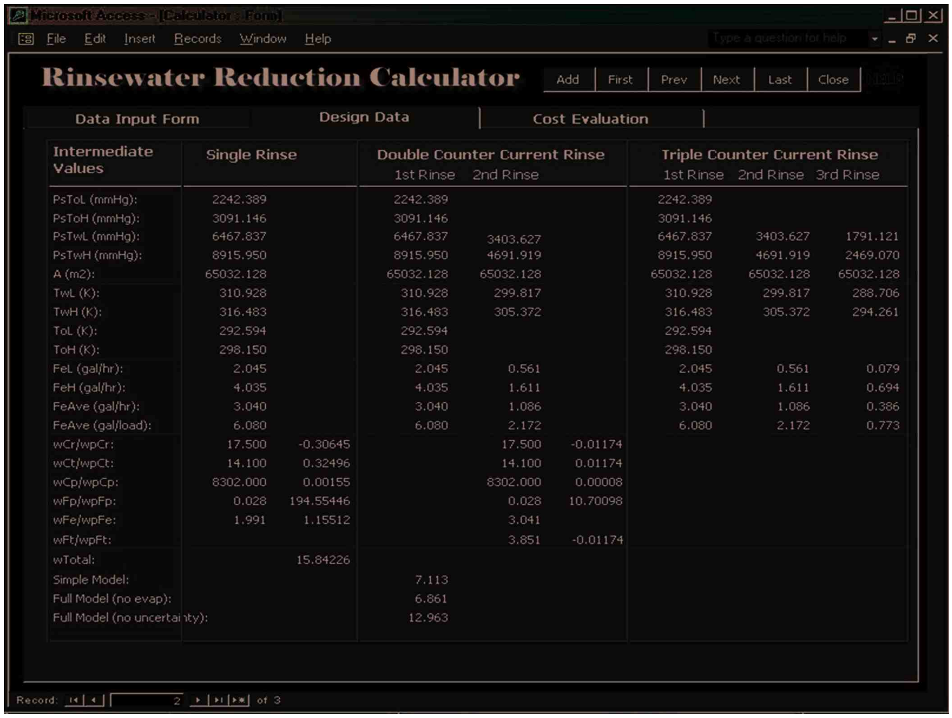
Design data – Intermediate calculations

The second tab on the Calculator Data Input Form displays the values of intermediate calculations, as shown in Fig. 9. These values are not stored but can be reproduced by pressing the "GO" button for each model. The intermediate calculations are explained in detail in the help file that accompanies the Calculator.

Application of the Calculator–A case study

The following fictitious example is presented to give the user a better understanding of how to use the Calculator. The XYZ Chemical Company would like to reduce its water usage but has almost no capital budget to spend on equipment. As a first step, the process engineer has decided to use the Calculator to determine how much water is actually needed to maintain the concentrations and levels of the currently installed DCCR tanks within company specifications. The process engineer will collect data and complete a Data Input Form for each process in the tank line. The form can be printed out for use in data collection in the field.

The XYZ Chemical Company has a chemical laboratory (Chem Lab), which performs analytical testing and can provide some of the data required on the Data Input Form. Currently, water is added to maintain a clean appearance in the DCCR tanks and, according to Chem Lab records, the total dissolved solids (TDS) in the rinse tanks never approach the maximum values allowed in the specification.



Intermediate Values	Single Rinse		Double Counter Current Rinse			Triple Counter Current Rinse		
			1st Rinse	2nd Rinse		1st Rinse	2nd Rinse	3rd Rinse
PsToL (mmHg):	2242.389		2242.389			2242.389		
PsToH (mmHg):	3091.146		3091.146			3091.146		
PsTwL (mmHg):	6467.837		6467.837	3403.627		6467.837	3403.627	1791.121
PsTwH (mmHg):	8915.950		8915.950	4691.919		8915.950	4691.919	2469.070
A (m2):	65032.128		65032.128	65032.128		65032.128	65032.128	65032.128
TwL (K):	310.928		310.928	299.817		310.928	299.817	288.706
TwH (K):	316.483		316.483	305.372		316.483	305.372	294.261
ToL (K):	292.594		292.594			292.594		
ToH (K):	298.150		298.150			298.150		
FeL (gal/hr):	2.045		2.045	0.561		2.045	0.561	0.079
FeH (gal/hr):	4.035		4.035	1.611		4.035	1.611	0.694
FeAve (gal/hr):	3.040		3.040	1.086		3.040	1.086	0.386
FeAve (gal/load):	6.080		6.080	2.172		6.080	2.172	0.773
wCr/wpCr:	17.500	-0.30645		17.500	-0.01174			
wCt/wpCt:	14.100	0.32496		14.100	0.01174			
wCp/wpCp:	8302.000	0.00155		8302.000	0.00008			
wFp/wpFp:	0.028	194.55446		0.028	10.70098			
wFe/wpFe:	1.991	1.15512		3.041				
wFt/wpFt:				3.851	-0.01174			
wTotal:		15.84226						
Simple Model:			7.113					
Full Model (no evap):			6.861					
Full Model (no uncertainty):			12.963					

Figure 9—Design tab displaying intermediate calculations.

Filling out the Data Input Form

The first tank in the line is a sodium hydroxide based cleaner. The outline below describes how the Data Input Form should be filled out for this process:

1. The *location, ID, description and solution name* are entered on the form.
2. The average number of *loads per day* is 12.
3. The *air temperature* (°F) is the average range throughout the year or just the season of interest. In this case, the default values are used.
4. *Humidity* has an inverse relation to evaporation. Low humidity will result in a higher evaporation rate than a high humidity. The default values are used.
5. The *process solution concentration* must be calculated in ppm, so the quantity of chemicals dragged over to the first rinse can be determined. The Chem Lab records contain the concentrations (oz/gal) of the sodium hydroxide cleaner for the last 14 months: 8.3, 8.1, 8.2, 8.4, 8.2, 8.9, 9.2, 8.8, 9.7, 9.2, 9.5, 9.0, 8.9, and 7.6.

The average concentration of the cleaner over this period is 8.7 oz/gal with a sample standard deviation of 0.6. The MSDS (Material Safety Data Sheet) for the cleaner lists the specific gravity of the cleaner as 1.1. The concentration of the process solution can now be calculated:

Process Solution Concentration =

$$\left(\frac{8.7\text{ oz}}{\text{gal}}\right)\times\left(\frac{\text{lb}}{16\text{ oz }(1.1)}\right)\times\left(\frac{\text{gal}}{8.345\text{ lb}}\right)\times 1{,}000{,}000 = 59{,}300\text{ PPM} \quad (4)$$

6. The *uncertainty of the process solution concentration* is not required, but can be used to provide a safeguard during the calculation of the timer setting. A common engineering statistic for uncertainty analysis is two times the sample standard deviation. The uncertainty is calculated below:

$$\text{Uncertainty} = \frac{2 \times (0.6\text{ oz/gal}) \times 100\%}{8.7\text{ oz/gal}} = 13.8\% \quad (5)$$

7. *Process solution drag-in and rinsewater drag-out* are somewhat difficult to measure. Several methods can be used: gravimetric, tracer element or conductivity. The last two methods involve extensive lab work and inevitably result in large uncertainties. It is more accurate to weigh a representative load when wet, weigh it again when dry and then subtract the dry weight from the wet weight. The difference is either the process solution drag-in or the rinsewater drag-out, depending on which one is being measured. Multiple measurements are made and then averaged to obtain the values for drag-in, drag-out and standard deviations.

For the sodium hydroxide based cleaner, the average drag-in and drag-out rates are measured at 0.47 gal/load and 0.55 gal/load, respectively. It is expected that liquids with similar rheology will have nearly equivalent drag-in and drag-out values. This is the case with acids and water but not necessarily with soap or other alkaline solutions. The rheology of an alkaline cleaner is much different from that of water, resulting in more rinsewater drag-out than process solution drag-in. Sizable uncertainty values are also expected because the measurement values of drag-out will vary significantly. The uncertainties are calculated as before and are 6% for the process solution and 24% for the rinsewater (actual data is not given here for the sake of brevity).

8. The *average makeup-water concentration* is calculated in the same manner as the process solution concentrated, using Chem Lab data. The result is 47 ppm. The *uncertainty* can be calculated or can be chosen. Based on the known fluctuation of the makeup-water concentration, 30 ppm is used to represent the uncertainty.
9. The *makeup-water flow rate* can be determined by installing a meter on the incoming water line, or more simply, by dropping the level of the rinse tank and timing how long it takes to fill it back up again. The rinse tank for the sodium hydroxide cleaner has

a length of 240 in. and a width of 42 in. It takes 13 min for the water to rise 9 in. in the tank. The makeup-water flow rate is calculated to be 30 gal/min as follows:

$$(240 \text{ in}) \times (42 \text{ in}) \times \left(\frac{9 \text{ in}}{13 \text{ min}}\right) \times \left(\frac{1 \text{ ft}^3}{1728 \text{ in}^3}\right) \times \left(\frac{7.47 \text{ gal}}{1 \text{ ft}^3}\right) = \left(\frac{30 \text{ gal}}{\text{min}}\right) \quad (6)$$

10. *Surface area* is calculated to be 70 ft^2 based on the above dimensions.

11. If the tank is not ventilated, default values of 0.1 to 0.2 m/sec can be used to represent ambient air movement or *average air speed across the surface of the tank* (m/sec). If forced-air ventilation is used, the air speed can be measured across the width of the tank with a vane anemometer and graphed as a function of tank width, as shown in Fig. 10. The resulting equation can then be integrated, using the first and last data points for the limits, and then divided by the entire tank width (42 in.).

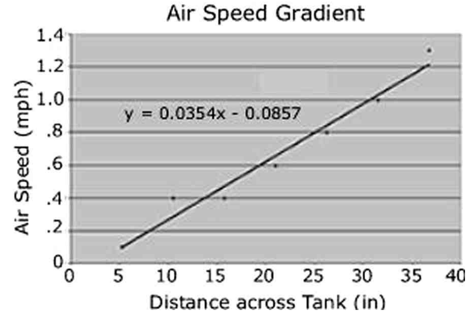


Figure 10—Graph of data obtained with a vane anemometer.

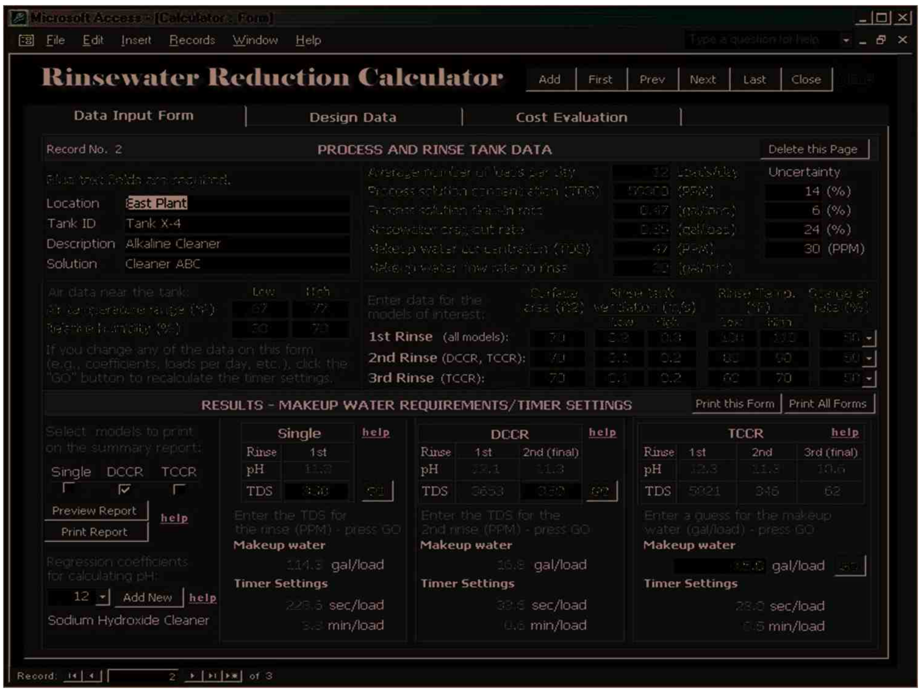


Figure 11—Calculator Data Input Form for a sodium hydroxide cleaner.

Figure 12—Cost savings analysis form.

$$\text{Average air speed} = \frac{\int_{5}^{37} 0.0354\,X - 0.0857}{42} = 0.50 \text{ mph}$$

$$= 0.22 \text{ m/sec} \quad (7)$$

The above equation is often more complicated than a simple linear expression. It is recommended that the range be determined by adding ± 0.05 to the calculated air speed. The range for the air speed is then 0.22 m/sec ± 0.05, or 0.17 to 0.27 m/sec.

12. The *rinse tank temperature* should be measured 2 to 3 in. beneath the surface and, in this case, ranges from 60 to 70°F.

13. A moderate level of *air sparging* is selected (*e.g.*, 50%).

14. Next, *regression coefficients* are chosen, so the pH of the rinses can be calculated for feedback. There is a sodium hydroxide cleaner in the dropdown menu, so it is selected.

Getting the Results

The company specification allows the final rinse to have a maximum TDS of 350 ppm. So, 350 is entered for the target TDS for the DCCR model, and the "GO" button is pressed. The results are as follows: 16.8 gal of water per load of makeup-water are required and a timer setting of about 34 sec. The timer on the rinse tank will have to be reset to the new setting, and the operator will have to be trained to press the button each time a load is processed. The timer setting generated by the Calculator is a starting point and may have to be adjusted up or down based on process performance.

A single rinse and a TCCR can also be evaluated for this application. The Calculator Data Input Form with the results of this case study is shown in Fig. 11.

Cost evaluation

The Cost Evaluation Form on the third tab of the Calculator (Fig. 12) can be used to calculate the return on investment (ROI) that will be realized when converting to a different rinse design or when designing a new facility. A Cost Evaluation needs to be filled out for each comparison. Multiple forms can be filled out for a given application. The ROI takes into account the cost for utilities, new equipment, and waste treatment or disposal.

Implementation

To date, seven tank lines at the Boeing plant in Auburn, WA are using timer settings generated by the Calculator to manage their water usage. The tanks in these lines range in volume from 600 to 3500 gal, and there are three to seven process solutions in each line. Approximately 7M gal of water is being saved each year, resulting in a cost savings of $155K for purchase, treatment, discharge, maintenance and energy (for heated tanks).

Because the Auburn, WA tank lines already had programmable timers installed on the tanks, no capital costs were incurred. Operators were trained to use the timers at crew meetings, where the phrase "press the button for every load" was heavily emphasized. Signs are posted on the tanks to remind the operators to press the timer button each time a load is processed (Fig. 13 & 14). If the process is followed, the addition of water will be efficiently managed.

Figure 13—Standard rinse tank signage.

Summary

When starting a tank line rinsewater-reduction effort, the first task is to determine the volume of water required to maintain the levels and concentrations of the rinse tanks. This can be accomplished with the use of the Calculator. The timer settings generated by the Calculator are a starting point and might have to be adjusted either up or down after implementation.

The results generated by the Calculator are only as accurate as the data used. The uncertainty analysis, which is only available for the single and DCCR designs, cushions the timer setting to ensure the specification requirements are met.

The Calculator and a help file are available on the Boeing Company website at the following address: http://www.boeing.com/special/rrcalc/

Figure 14—Operator presses timer button after lowering basket into second rinse.

Acknowledgements

Martin Chan–Boeing Chemical Process Manager
Nancy Fleener–Boeing Chemical Materials & Processes Engineer
Darren Sarver–Boeing Chemical Process Manager
Paul Siebenaler–Boeing Chemical Process Engineer
Alan Thompson–Boeing Chemical Engineer, Environmental Affairs
Paul Thompson–Boeing Chemical Process Management Engineer
Bert Vick–Boeing Chemist

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