



## **Rinsewater Reduction Calculator**

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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 (RRC), which uses a Microsoft Access database to model single, double counter current, and triple counter current rinse tanks. Implementing timer settings generated with the RRC in place of subjective practices has reduced rinsewater usage by more than 50%. Application of the RRC is discussed, and the tool (developed by Boeing chemical engineers) will be made available on the Boeing Company website.

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## Introduction

In a tankline 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<sup>1, 2, 3</sup>. 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<sup>4</sup>. 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<sup>5</sup> were previously developed 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 dragin, rinsewater dragout and evaporative losses. The Rinsewater Reduction Calculator (RRC), 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 RRC, which can be downloaded from the following website: <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:

$$F_t = (F_p (C_r - C_p) - F_e C_r) / (C_t - C_r) \quad (1)$$

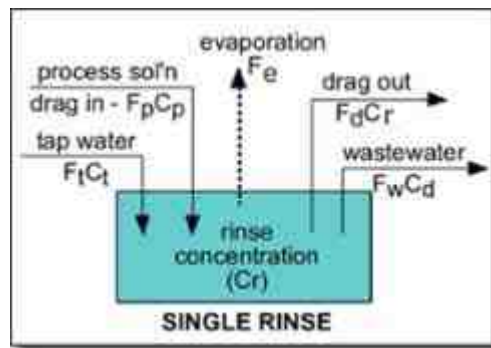


Figure 1. Model of Single Rinse

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

d (dragout)	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 than a single rinse. A mass balance performed over the DCCR results in a complex quadratic equation, with the following simplified solution:

$$F_t = [(F_d F_p C_p) / (C_2 - C_1)]^{1/2} \quad (2)$$

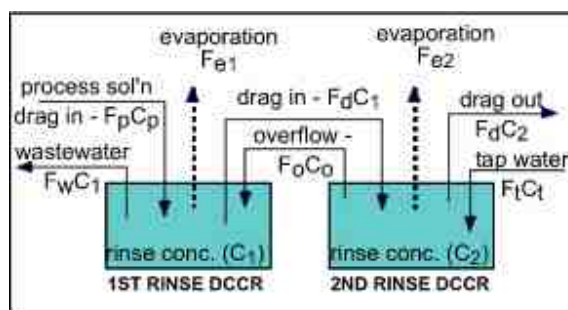


Figure 2. Model of DCCR

Additional subscripts in this figure are:

1 (First rinse) 2 (Second rinse) o (Overflow)

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

*TCCR Model.* This design (figure 3) is rarely used because the first rinse becomes highly concentrated, which 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 might use more water than a DCCR. For a TCCR, linear matrix algebra is required to simultaneously solve the mass balance equations around each of the rinses. To achieve the desired rinse concentration, the makeup water flow rate ( $F_t$ ) is determined by iterating the volume of water required per load.

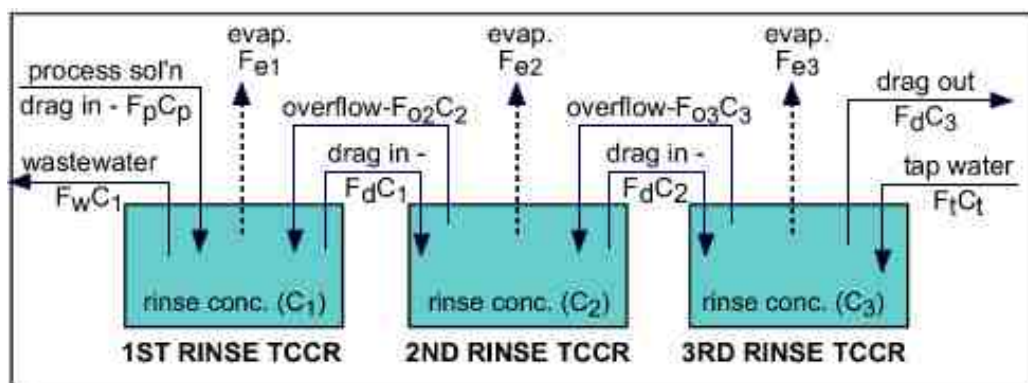


Figure 3. Model of TCCR (triple counter current rinse tank)

## RRC (Rinsewater Reduction Calculator)

*Purpose.* The RRC can be used to determine the amount of water required to properly maintain the levels and concentrations of a given rinse tank 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 RRC (sec/load or min/load), and tankline 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 RRC 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, etc.).

*Getting Started.* Figure 4 shows the RRC Data Input Form. The major sections are labeled in the figure and discussed below. Text fields labeled with blue-colored text are required.

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

Section 2. 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.

The coefficients for the solutions were calculated using 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 in the RRC to calculate pH:

$$\text{pH} = \text{slope} * \ln[\text{TDS}] + \text{intercept} \quad (3)$$

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

Section 3. The data in section 3 are required and include average number of part loads processed per day (e.g., baskets or racks of parts), air temperature and relative humidity. Default values are provided for the air temperature (67-77°F) and relative humidity (30-70%).

Section 4. The following data are required: process solution concentration (TDS) and dragin rate (gal/load), rinsewater dragout rate (gal/load), and makeup water concentration (TDS) and flow rate (gal/min). The uncertainty data are used in the single rinse and DCCR models and are optional. The uncertainties should reflect your confidence in the data. If uncertainties are used, a safety factor will be added to the timer settings.

Figure 4. RRC Data Input Form

Section 5. These parameters are properties of the rinses and are used to calculate evaporative losses. The following are required: surface area (ft<sup>2</sup>), ventilation rate (m/sec), temperature (°F) and level of air agitation. Evaporative losses are usually significant for heated tanks and can also be important if the process solution concentration is low.

If only room ventilation is available, the range 0.1 – 0.2 m/sec can be used as an approximation for ambient air movement and is the default.

Rinse tank air agitation is described by one of the following levels and 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<sup>7</sup>.

Section 6. In this section, indicate the models that will be evaluated by checking the applicable boxes. A report summarizing the timer settings can be printed out from this section. For a model to appear on the report, its box must be checked.

Section 7. Single Rinse Design: To apply this model, enter the desired or target TDS for the clean rinse, which is usually controlled by the governing process specification. Press the “GO” button, and the timer settings are calculated. (You can also press the enter key twice.)

In figure 5, at a TDS of 350 PPM, the pH of the single rinse is shown as 11.3. The pH will only be calculated and displayed if regression coefficients are selected. Approximately 203 gallons of water need to be added to the single rinse each time a load is processed to maintain the proper level and concentration of that rinse. The makeup water flow rate is used to calculate a timer setting 9.2 min/load, as shown in figure 5.

**Single Rinse** [help](#)

Enter the desired TDS for the rinse (PPM); press GO.

	Single
pH:	11.3
TDS:	350

**GO**

Single Timer Settings:

202.7 gal/load

552.7 sec/load

9.2 min/load

Figure 5. Single Rinse

Section 8. DCCR Design: To apply this model, enter a target TDS for the second rinse as shown in figure 6. Click the “GO” button or press the enter key twice.

If regression coefficients are chosen, the pH of both rinses will be displayed as shown in the figure. If the TDS of the first rinse is too high, as is the case for some processes, decrease the target TDS until the first rinse TDS and pH are acceptable. Physically, the TDS of the first rinse cannot be less than the makeup water TDS or more than the process solution TDS.

For the DCCR model, 9.3 gallons need to be added each time a load is processed, which is substantially less than the 203 gallons needed for a single rinse. The timer setting is 25.5 seconds per load.

**DCCR** [help](#)

Enter the desired TDS for the 2nd rinse (PPM); press GO.

	1st	2nd (final)
pH:	11.8	11.3
TDS:	1849	350

**GO**

DCCR Timer Settings:

9.3 gal/load

25.5 sec/load

0.4 min/load

Figure 6. DCCR Results



Section 9. TCCR Design: To apply this model, a value is entered for the gallons of makeup water required per load, and the “GO” button is pressed. Run the DCCR model first and use the value obtained from that model as a starting point. For example, start with 9.2 gallons per load from the DCCR model (figure 6) and iterate downward until the TDS of the rinses are acceptable.

The target TDS of 350 PPM can’t be attained because the TDS of the first rinse is higher than that of the processing solution. Even with a TDS of 298, the TDS of the first rinse approaches that of the processing solution (53900 PPM) and could be deleterious to the parts or equipment.



Figure 7. TCCR Results



Figure 8. TCCR Results

Slightly increasing the makeup water to 8.9 gallons per load dramatically decreases the first rinse TDS. It is important to understand how sensitive the process is if a high concentration in the first rinse is impacting.

A comparison of the three models depicted in figures 5-8 shows the DCCR provides substantial water savings over the single rinse, while the TCCR provides meager savings over the DCCR. If the first and second rinses of a TCCR are controlling (e.g., pH limitations) or heated, it is likely that a TCCR will use more water than a DCCR.

*Design Data – Intermediate Calculations.* The second tab on the RRC Data Input Form displays the values of intermediate calculations, as shown in figure 9. These values aren't stored but can be reproduced by pressing the “GO” buttons for the models.

The intermediate calculations are explained in detail in the help file that accompanies the RRC.

Rinsewater Reduction Calculator						
First Prev Next Last New Entry RRC HELP Close Form						
Data Input Form Design Data - Intermediate Calculations						
Intermediate Values	Single Rinse	Double Counter Current Rinse		Triple Counter Current Rinse		
		1st Rinse	2nd Rinse	1st Rinse	2nd Rinse	3rd Rinse
P <sub>s</sub> T <sub>OL</sub> (mmHg):	2242.389	2242.389		2242.389		
P <sub>s</sub> T <sub>OH</sub> (mmHg):	3091.146	3091.146		3091.146		
P <sub>s</sub> T <sub>WL</sub> (mmHg):	8915.950	8915.950	1791.121	8915.950	1791.121	1791.121
P <sub>s</sub> T <sub>WH</sub> (mmHg):	15336.626	15336.626	4691.919	15336.626	4691.919	4691.919
A (m2):	204386.688	204386.688	204386.688	204386.688	204386.688	204386.688
T <sub>WL</sub> (K):	316.483	316.483	288.706	316.483	288.706	288.706
T <sub>WH</sub> (K):	327.594	327.594	305.372	327.594	305.372	305.372
T <sub>OL</sub> (K):	292.594	292.594		292.594		
T <sub>OH</sub> (K):	298.150	298.150		298.150		
F <sub>EL</sub> (gal/hr):	5.595	5.595	0.206	5.595	0.206	0.206
F <sub>EH</sub> (gal/hr):	15.784	15.784	4.425	15.784	4.425	4.425
F <sub>Eave</sub> (gal/hr):	10.689	10.689	2.316	10.689	2.316	2.316
F <sub>Eave</sub> (gal/load):	21.378	21.378	4.631	21.378	4.631	4.631
w <sub>Cr</sub> /w <sub>pCr</sub> :	37.500 -23.68690	37.500	-0.44821			
w <sub>Cp</sub> /w <sub>pCp</sub> :	0.720 23.68156	0.720	0.44821			
w <sub>Cp</sub> /w <sub>pCp</sub> :	43555.000 0.03667	43555.000	0.00099			
w <sub>Fp</sub> /w <sub>pFp</sub> :	2.500 641.29794	2.500	17.19029			
w <sub>Fp</sub> /w <sub>pFp</sub> :	10.189 1.10619	14.408				
w <sub>Fp</sub> /w <sub>pFp</sub> :		77.467	-0.44821			
w <sub>Total</sub> :	2437.02371					
Simple Model:		607.768				
Full Model (no evap):		594.873				
Full Model (no uncertainty):		610.762				

Figure 9. Design Tab displaying Intermediate Calculations

## Application of the RRC - A Case Study

The following fictitious example is presented to give the user a better understanding of how to use the RRC.

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 RRC 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 fill out a RRC Data Input Form for each process in the tankline. 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 by the RRC. Currently, water is added to maintain a clean appearance in the DCCR tanks. And, according to Chem Lab records, the TDS in the rinse tanks never approaches the maximum values allowed in the specification.

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

1. The location, ID, description and solution name are entered on the form.
2. 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.
3. The average number of loads per day is 15.

4. 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.
5. Humidity has an inverse relation with evaporation. Low humidity will result in a higher evaporation rate than a high humidity. The default values are used.
6. 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 time period is 8.7 oz/gal with a sample standard deviation of 0.6. The MSDS lists the specific gravity of the cleaner as 1.1. The concentration of the process solution can now be calculated:

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

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

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

8. Process solution dragin and rinsewater dragout are somewhat difficult to measure. Several methods can be used: gravimetric, tracer element and conductivity. The last two involve comparing dilutions of the process solution to minor changes measured in a stagnant rinse tank. These two methods involve extensive lab work and inevitably result in large uncertainties. It is more accurate to weigh a representative load when it's wet, weigh it again when it's dry and then subtract the dry weight from the wet weight. The difference is either the process solution dragin or the rinsewater dragout, depending on which one is being measured. Multiple measurements are made and then averaged to obtain the values for dragin, dragout and standard deviations.

For the sodium hydroxide based cleaner, the average dragin rate is measured at 0.12 gal/load, while the average dragout rate of the rinsewater is measured at 0.23 gal/load. You would expect liquids with similar rheology to have nearly equivalent dragin and dragout 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 than that of water, which results in more dragout of rinsewater than dragin of process solution. Expect fairly large uncertainty values because even measured dragout values 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 brevity).

9. The average makeup water concentration is calculated in the same manner as the concentration of the process solution, using Chem Lab data. The result here 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 for the uncertainty in this example.
10. 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 inches and a width of 42 inches. It takes 8 minutes for the water to rise 4 inches in the tank. The makeup water flow rate is calculated to be 22 gal/min as follows:

$$(240 \text{ in}) \times (42 \text{ in}) \times \left( \frac{4 \text{ in}}{8 \text{ min}} \right) \times \left( \frac{\text{ft}^3}{1728 \text{ in}^3} \right) \times \left( \frac{7.47 \text{ gal}}{\text{ft}^3} \right) = \left( \frac{22 \text{ gal}}{\text{min}} \right) \quad (6)$$

11. Surface area is calculated to be 70 ft<sup>2</sup> based on the dimensions above.

12. Average air speed across the surface of the tank (m/s) - If the tank isn't ventilated, a default value of 0.1-0.2 m/sec can be used to represent ambient air movement. 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 figure 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 (42in).

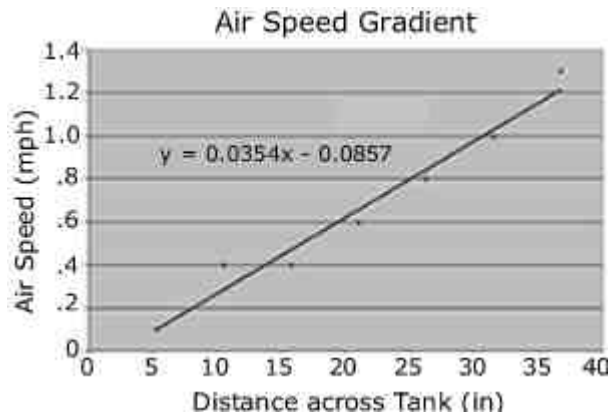


Figure 10. Graph of data obtained with a vane anemometer

$$\text{Average air speed} = \int_5^{37} \frac{0.0354 X - 0.0857}{42} = 0.50 \text{ mph} = 0.22 \text{ m/sec} \quad (7)$$

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

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

14. A moderate level of air sparging 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: 4.8 gallons of water per load of makeup water are required and a timer setting of about 13 seconds. 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 RRC is a starting point and may have to be adjusted either up or down based on process performance.

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

**Rinsewater Reduction Calculator** Fast Prev Next Last New Entry **RRC HELP** Close Form

Data Input Form | Design Data - Intermediate Calculations |

Record No. 2 **PROCESS AND RINSE TANK DATA** Delete this Entry

Blue text fields are required.

Location		Process solution concentration (TDS)		Required Data		Uncertainty (optional)	
East Plant		S9300 (PPM)		0.12 (gal/load)		13.8 (%)	
Tank ID: Tank X-1		Process solution drag-in rate		0.23 (gal/load)		6 (%)	
Description: Sodium hydroxide based cleaner		Rinsewater drag-out rate		47 (PPM)		24 (%)	
Solution: XYZ Cleaner		Makeup water concentration (TDS)		22 (gal/min)		30 (PPM)	

Choose Regression coefficients: **help**

Add New 12 Sodium Hydroxide Cleaner

	Loads/day	Air temperature range (°F)		Relative humidity (%)	Surface area (ft <sup>2</sup> )	Rinse tank ventilation (m/s)		Rinse Temp. (°F)		Sparge air rate (%)
		Low	High			Low	High	Low	High	
1st Rinse (all models):	15	67	77	30	70	0.17	0.27	60	70	50
2nd Rinse (DCCR, TCCR):					70	0.17	0.27	60	70	50
3rd Rinse (TCCR):					70	0.17	0.27	60	70	50

**RESULTS - TIMER SETTINGS** Print this Form Print All Forms

Select the models to be evaluated for this process:

Single DCCR TCCR

☐ ☐ ☒

If you change any of the data on this form (e.g., coefficients, loads per day, etc.), click the "GO" button to recalculate the timer settings.

Preview Report **help**

Print Report

Single Rinse <b>help</b>		DCCR <b>help</b>		TCCR <b>help</b>	
Enter the desired TDS for the rinse (PPM); press GO.		Enter the desired TDS for the 2nd rinse (PPM); press GO.		Enter a guess for the makeup water (gal/load); press GO.	
Single		1st 2nd (final)		1st 2nd 3rd (final)	
pH: 11.3		pH: 11.9 11.3		pH: 12.2 11.4 10.8	
TDS: 350 <b>GO</b>		TDS: 2436 350 <b>GO</b>		TDS: 5161 596 97	
Single Timer Settings:		DCCR Timer Settings:		TCCR Timer Settings:	
200.4 gal/load		4.8 gal/load		3.7 gal/load	
546.6 sec/load		13.2 sec/load		10.1 sec/load	
9.1 min/load		0.2 min/load		0.2 min/load	

Figure 11. RRC Data Input Form for Sodium Hydroxide Cleaner

## Implementation

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



Figure 12. Standard Rinse Tank Signage

Because the Auburn, WA tanklines 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 (figure 12). If the process is followed, the addition of water will be uniformly and efficiently managed.

## Summary

For any tankline 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 RRC. The timer settings generated by the RRC are a starting point and might have to be adjusted either up or down after implementation.

The results generated by the RRC 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. In practice, there has only been one application where the timer setting had to be increased due to a TDS overshoot.



Figure 13. Operator presses timer button after lowering basket into second rinse

The RRC is available on the Boeing Company website at the following address:  
<http://www.boeing.com/special/rrcalc/>

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