MnTAP Intern Project Report
Hutchinson Technology Inc.
Luke Ehalt
2004

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Abstract

Luke Ehalt, an undergraduate chemical engineering student at the University of Minnesota, worked to reduce water waste and improve rinse water cleanliness at Hutchinson Technology Inc. over the summer of 2004. Below are estimated values of water usage at the start of the project, and estimated rates of use as per suggestions which were put forth by Luke Ehalt.

Water Consumption Reduction on Stripper Rinses 3, 6, and 9		
	May 2004 (Gallons/year)	Suggested Reductions (Gal/Year)(%)
Cookout Procedure*	54,000	19,000 (35%)
Sprayout Procedure*	550,000	220,000 (40%)
Sump Reduction*	N/A	415,000
	*These estimates are for individually implemented changes	
Total if all Changes Implemented Simultaneously		Savings
Gallons/Year		490,000
$/Year		$44,000

An airknife device was tested on the vertical stripping machines and if permanently implemented would cut down on chemical dragout into the rinse sumps by 30 – 40 %. The improved cleanliness of the rinse water would further warrant the changes in sprayout procedure and sump reduction. Additionally, it is possible that these changes would lead to chemical savings. Initial tests show that product quality would still remain within specification.

The ozone water purification system was investigated, possible options for ozone generator efficiency improvements were looked into. Ultimately, the current setup was the most cost effective option.

The HCl spike used to control the pH of the rinse water had its makeup water switched over from RO to DI. This change decreases the amount of contamination introduced to the water through this spike system.

Chemical sprayout created by water spraying from chamber to chamber in the cascading rinses was addressed previously by using a pinch roller. Testing was done to use a deflector instead of these pinch rollers. If implemented, the deflectors could possibly reduce the amount of chemical sprayout, and thus sump contamination. Additionally, the deflectors would decrease the likelihood of bends and other physical defect upon the parts which previously has been an issue with the current pinch roller apparatuses.

The final DI rinses were monitored to create a baseline for their water cleanliness. This baseline will be used in the future to evaluate permanent process changes.

The peroxide cookout procedure was monitored and evaluated. This preventative maintenance intended to control living matter in the cascading rinses, occurs at set intervals for each machine. Through testing it was determined that these intervals could possibly be lengthened to save on water and labor costs. If implemented, these changes would result in water savings of 19,000 gallons annually, or $1,700. Along with $2,400 in labor. Leading to a total annual savings of $4,200. Additionally, standpipe drain valves were installed to improve the efficiency of these cookout procedures.

The sprayout procedure is used to clean the cascading rinses at set intervals. Through sample collection and procedure testing, it was determined that these intervals could possibly be lengthened. This change, if implemented, would save on labor costs, decrease deionized water waste by nearly 220,000 gallons/year, and would save $6,600/year. Additionally, there would be a labor savings of $11,250/year and furthermore there would be less downtime for the machines, thereby increasing capacity for production.

Tests were conducted by reducing the size of the sumps temporarily to promote the possibility of cutting down on sump size permanently. This would save water during daily dumps of the sumps for cleaning during the sprayout process as well as during peroxide cookouts. Proposed size change would be a decrease of 70%. This would result in deionized water usage reduction of 415,000 gallons/year and a cost savings of $37,500/year.

Company Description
Hutchinson Technology Inc. Is an international leader in the field of precision manufacturing. By utilizing chemical, mechanical, and electronic technologies, the company is able to specialize in the design and manufacture of close tolerance products. The majority of Hutchinson's finished products are suspension assemblies for hard disk drives. Hutchinson Technology is truly an international company with offices in Tokyo Japan, Dongguan China, Bangkok Thailand, and Singapore. Also there are domestic manufacturing and corporate locations in Hutchinson Minnesota, Plymouth Minnesota, Sioux Falls South Dakota, and Eau Claire Wisconsin. This project deals only with the Hutchinson location which is home to over 1,700 employees alone, and operates 24 hours a day.

PhotoEtch Process

Suspensions are made primarily of high grade stainless steel. This steel is transformed into the desired suspension form by a multistep process. The metal is delivered to Hutchinson in large rolls, the metal department cuts these rolls into sheets which are then sent to the coaters. The coaters coat the metal sheets with a layer of photoresist before they are sent to the art department. In the art department, the sheets are exposed to a pattern of suspensions. Each sheet typically has three panels and each panel contains multiple strips of suspensions. After the part pattern has been exposed onto the sheet, it is sent to a developer. In the developer it is sprayed with a chemical to remove the developed photoreactive material, thereby leaving behind bare stainless steel. After this process has been completed, the sheets are sent to an etcher which sprays a ferric chloride onto the sheets to remove the unprotected stainless steel. Then the Sheet goes to a stripper which uses a caustic chemical to remove the photoreactive coating but which does not harm the stainless steel beneath it. After being rinsed and dried, the sheets are sent elsewhere to receive further processing in assembly.

Cascading Rinses

All of my work this summer was focused on the cascading rinses which are a part of the stripping machines. These rinses consist of six individual modules which spray deionized water onto the parts to remove all residual chemicals from them. Each module is progressively cleaner than the previous, this is accomplished by using a counter-current cascade flow of DI water. Thus, the water discarded from the cleanest module is immediately used by the second cleanest module and so on down the chain of modules. The water discarded from the final module goes to drain. Each module consists of a spray chamber mounted on top of a sump. The spray chamber is the part of the module that the part travels through on a conveyor, in this chamber the part is sprayed with water by a number of manifolds with spray nozzles. The sump is the collection tank for the chamber runoff as well as the reservoir from which the pumps pull water to be sprayed upon the parts in the spray chamber.
In all there are six vertical strippers in the photoetch portion of the Hutchinson plant, however two are rarely used and one of these is slated for demolition shortly. Another is

much older than the remaining three. Thus the improvements which I have suggested are intended for these three, vertical strippers numbered 3, 6, and 9.

Following each cascading rinse is an independent final DI rinse which is the cleanest of all but is separate from the cascading rinse.

Incentives for Change

The cost of producing deionized water is significant ($.03/gallon), and furthermore the cost of treating it after it has been discarded is even more ($.06/gallon). Because Hutchinson Technology uses a large amount of this commodity, there is a constant desire to reduce the quantity consumed. Furthermore, the plant was quickly approaching its capacity for the amount of deionized water that it could create each day. A reduction in deionized water usage would make it possible to avoid costly new machinery which would have been required to increase the production capacity.

Additionally the cleanliness of water used in the process is vital to the integrity of the parts produced. With tighter and tighter specifications each year concerning contamination, Hutchinson Technology was interested in improving the cleanliness of their deionized rinse water to meet these demands.

Another constant concern in the process machinery is the presence of mold bacteria which can cause contamination to the finished products. The company is always looking for ways to cut down on the amount of bacterial growth, and one idea has long been to cut down on the size of the sumps for the machines. The bacteria seems to proliferate in these sumps primarily because of their large surface area. By cutting down on the size of said sumps, the suitable habitat for the bacteria would be significantly decreased.

The modifications and improvements that I am developing and hope to implement are concerning the triple rinse modules on the vertical strippers. However, many of the changes that I will propose could easily be applied to other rinse modules on other machines that the process uses. Likely process steps to fit this criteria would be rinses on the vertical developers and/or etchers, as well as cascading chemical modules.

Intern Project:

My projects as an intern for the summer of 2004 were focused on water quality and waste reduction.

The objectives of this project were as follows:

1. Determine baseline levels for cleanliness of the sumps of the stripper rinses
2. Evaluate sump cleaning/maintenance procedures to increase rinse water cleanliness
3. Determine feasibility of chemical dragout reduction to reduce sump contamination and improve rinse water cleanliness; then implement improvements.
4. Evaluate possible designs/plans for sump size reduction, and/or to cut back on the amount of water consumed.

Dragout Reduction

As the parts proceed down the conveyor through the vertical stripper, there are first two strip modules used to remove photo-resist, followed by a clean module to remove as much of the residual photo-resist and stripping chemical as possible, and after the clean module comes the rinse module. The clean module uses a caustic chemical to actively remove as much chemical contamination from the part as possible. Ideally as the parts entered the rinse module they would be totally untainted, but inevitably some of this cleaning chemical is dragged into the rinse sumps. Minimizing this dragout is beneficial because any chemical dragged into the rinse sumps represents a loss of chemical in the clean module sumps. Additionally, this minimization is helpful because any dragout into the rinse sumps equates to dirtier rinse water.

In an effort to determine if the machines were operating as efficiently as possible, I examined an equation written by Pinkerton which would predict rinse sump concentrations. Although this formula gave us a general idea of what we could strive for it was not perfect in predicting the actual sump concentrations. This disparity was likely due to chemical sprayout losses, hydrochloric and sodium hydroxide interactions, and imperfect dragout measurements. This graph can be found as an appendix (graph 1).

By retrieving sheets immediately after they entered the cascade rinse module, Scott Brusehaver and I were able to measure the amount of dragout by massing it. Through calculations I was able to determine that there was an average dragout rate of .0028 gallons/minute or .168 gallons/hour. After initially determining the current level of dragout into the rinse sumps of vertical stripper 6, I set to work modifying a design which Scott Brusehaver had drafted some time ago for an airknife. This device works by creating a wall of air which each part must travel through, and in doing so much of the chemical which previously clung to the part and was dragged into the rinse sump is knocked off and will return to the clean module. I had some parts fabricated and once I had all of the necessary components I assembled and began testing the airknife.

With the current setup approximately 3,100 gallons of clean chemical are wasted annually because of dragout on VS (vertical stripper) 3, 6, and 9 collectively.

Dragout was identified as a problem to be addressed by myself because of its direct relation to rinse water cleanliness. As long as rinse water remains clean it need not be discarded, thus keeping the rinse water as clean as possible would enable me to make other changes concerning the consumption rates of the rinse water. Moreover, use of this apparatus could again potentially be extended into other areas of production throughout the corporation.

I recommend a change which would permanently implement the use of airknives between the clean and rinse modules on vertical strippers 3, 6, and 9. By implementing said airknives, a reduction of 30-40% dragout could be reached. This should translate into cleaner rinse water and thereby cleaner product. These changes would further warrant a lengthened sprayout cycle, and create the possibility for reducing the counter current cascade flow.

There would be an initial expenditure resulting from the parts and installation along with a recurring charge for the compressed air used consistently. The installation and fabrication costs would be approximately $300, and the compressed air costs would be approximately $120/year.

I have recommended this equipment modification and further testing will soon be conducted to solidify its feasibility. I made use of the analytical abilities of the chemical services lab here at Hutchinson Technology to prove that these airknives would not damage our parts. I tested product quality by collecting sample parts that ran through the machine one after another (one with the airknife on, one with the airknife off) and sending them to lab for FTIR (Fourier Transform Infrared) NVR (Non-Volatile Residue) and IC (Ion Chromatography). Each of these tests proved in a different way that the parts were clean to specifications which regulate them, though a full product order will likely be tested before permanent implementation.

Ozone System Improvement

To deter the growth of bacteria and thereby promote the cleanliness of the DI water in the sumps of the rinse modules, an ozone system has long been in use here at Hutchinson Technology. Ozone is a strong oxidizing agent which disinfects water when dissolved into it. There is an Ozone generator attached to each rinse module which creates gaseous ozone and sends it directly into the sump water where it is absorbed. These generators are linked into the machine program and thus run at all times that the machine is operating.

With the current setup approximately 550,000 cubic feet of compressed air are being consumed annually to feed the ozone generators. This translates into an expenditure of approximately $120/year.

I examined possible changes to the ozone system in hopes of optimizing it and its effectiveness. I looked at replacing the spargers which create small bubbles of ozone to be more readily dissolved into the water. I also looked into the ideal water temperature for ozone solubility in water. Moreover I looked at changing the feed to the generators from plant compressed air to either some sort of further filtered air or to bulk oxygen supply. However none of these options proved to be necessary or economically sensible. The spargers currently in use proved to be up to industry standards. The water in the sumps is relatively cold and in order to increase solubility that water would need to be further cooled, without any means to do this, it was discarded. The cost of bulk oxygen is nearly 35 times that of compressed air, and because these options were decidedly unfeasible or unnecessary, they will not be implemented.

HCl Spike

In order to control the pH of the rinse water in the cascading countercurrent rinses, there is a hydrochloric acid spike in the B, or second dirtiest, sump. The pH is automatically monitored in this sump and if it becomes too high, HCl is added to bring the value back within specification. This HCl is pulled from a bulk tank of very high concentration in the basement. The HCl is then mixed with RO water to dilute it to the correct normality.

Although this setup has shown no signs of causing problems, at the suggestion of Scott Brusehaver, I looked into the changeover of this makeup water from RO (reverse osmosis) to DI (deionized). This change would signify an increase in purity and thereby reduce possible sources of contamination to the rinse water and consequently the parts.

The changeover has begun and soon the HCl spikes for VS3, VS6, and VS9 will have makeup water that is deionized instead of reverse osmosis and thereby cleaner.

Chemical Sprayout

While the rinse modules are running and spraying water about in the spray chambers, some of that spray accidentally transfers from chamber to chamber. This sprayout is deflected or splashed from chamber to chamber, as opposed to dragout which travels while attached to the sheet. This is problematic because much like dragout, carryover contaminates sump water prematurely. Currently there are pinch roller apparatuses guarding the transitions between chambers. The pinch rollers operate very close to the actual part as it passes through the transition. This close proximity creates the possibility for contamination due to physical transfer between the rollers and the part. In addition to adding contaminant to the part, the roller can also cause physical defects in the parts such as bends. Another problem with these pinch rollers is their construction. They are made of polypropylene and poly vinyl chloride, both of which are very conducive to bacterial growth, especially in a wet environment such as a spray chamber. There is a constant bacterial problem within the construction of the pinch roller and in the crevices where the pinch roller is attached to the spray chamber wall because this area is relatively undisturbed during daily operation and sprayout maintenance. In an attempt to solve this problem I co-designed some stainless steel baffles with Scott Brusehaver to test possibly replacing these pinch rollers. Their stainless steel construction will greatly dampen the ability of bacteria to grow, additionally, in designing the baffles Scott and I made sure to minimize the amount of area that was not vigorously contacted by the spray water. Furthermore, the deflectors will reduce the possibility for physical defects because their opening is much wider than that of the pinch rollers. After the design was complete I had the baffles fabricated and when they were complete Scott and I tested their effectiveness in the rinse sumps of VS 6.

Without the aid of the counter current flow, the machine was able to run only until a certain amount of carryover had left the sumps, either to drain or up the chain to the next chamber. Scott and I turned off the counter current flow and monitored the amount of time it took to achieve such levels of chemical sprayout. Both the pinch roller and the baffle provided comparable times and concentrations when the testing was complete. By monitoring the conductivity, pH and normality of the sumps before and after the pumps were run we could track the chemical sprayout. These results are found in the appendix (graphs 2 – 9)Thus, the deflectors were a success because they are much less likely to allow the growth of bacteria. Furthermore, graph 8 shows promise because it suggests that with the baffles, sprayout is more likely to travel in the same direction as the counter current flow, and thus not contaminating the rinse water.

This change would necessitate cost in the fabrication of parts for modification of the machine. Additionally, there would be labor costs for the installation of said deflectors. In all these costs would amount to $40,00 for all three machines. This estimate was provided and created by Scott Brusehaver. Cost savings would appear indirectly due to less bends, and less contamination, thus leading to higher yields.

I believe that baffles would be a positive change for the rinse modules and I have recommended their implementation. More testing will need to be completed before further steps are taken. Product quality, as always, is an issue of concern.

Final DI Rinse Resistivity

After the countercurrent cascade rinse there is a final DI rinse which again sprays deionized water onto the parts, but this time at a maximum purity. Each of these final rinse modules are equipped with a digital readout of their sumps' resistivity. This can be used as a measure of cleanliness, the higher the resistivity, the more pure the water is. I monitored these values and developed a baseline which can be compared against to determine the effectiveness of future, permanent changes. The data collected can be found in the appendix (graphs 10-12).

Peroxide Cookout

The peroxide cookout is a preventative maintenance performed on all of the rinses at a set interval. For stripper rinses 3 and 6, the process is repeated every three weeks, while for stripper rinse 9 it is repeated every two weeks. This disparity is due to other maintenance scheduling. VS9 goes down on the two week schedule because it runs copper product which requires more frequent preventative maintenance in other parts of the machine. Because the machine is already down, the peroxide cookout is performed. The process consists of draining and manual sprayout cleaning of the sumps (this is accomplished by use of a hose with a spray nozzle and heated water), followed by filling them with clean deionized water and adding hydrogen peroxide. The counter-current cascade flow is turned off so that the peroxide is not diluted, and the amount of water and chemical lost to drain is minimized. Then the pumps are turned on and allowed to run for a period of time, thus cleansing the spray chamber, the sump, and the associated plumbing. After the pumps are done running, the sumps are drained, then filled again with deionized water. Once the sumps are full, the pumps are turned on and again allowed to run, followed by another draining. Then the machine is again manually spray-cleaned. Finally the sumps are filled one final time and the rinse modules are ready for use.

Currently approximately 2200 gallons of peroxide are used each year on rinses 3, 6, and 9. Additionally, during the cookout process 48,600 gallons of deionized water are consumed per year.

This operation was chosen to research for two reasons. First, it uses a significant amount of DI water and it was believed that a reduction might be possible. Secondly, we were unsure if this frequency was necessary to maintain the cleanliness of the machines. Additionally, peroxide cookouts are performed elsewhere within the plant here in Hutchinson, and at satellite plants in Eau Claire and Sioux Falls on similar machinery. Any savings which are possible on the rinse sumps of the vertical strippers might also be extended to other machines throughout the company.

I collected samples for baseline testing over a 4 week period (2 cycles). After determining that there was no significant decrease in water purity toward the end of the cycle I concluded that a process change might be possible to save water. In fact the water was the dirtiest immediately following the cookout procedure which occurred midday on 06/23/2004. The data collected can be found in the appendix (graphs 13 – 20).

The process change suggested for this procedure is twofold: reduce the frequency of these cookouts, as well as installing a standpipe drain valve to improve the cookout efficiency.

Cookout Cycle Extension

By extending the cookout cycle from three to four weeks on rinses 3 and 6, and from two weeks to four on rinse 9, the company will save 800 gallons of peroxide each year, along with a waste water reduction of 6,500 gallons/year. Additionally there will be a reduction of 55 labor hours. The resulting cost savings would be as follows, $3,100 in peroxide costs, along with $1,800 in DI water costs and $2,400 in labor.

This change would require no initial investment or increase in operating cost. Thus the net annual savings would be $7,300.

I have recommended this change and it is currently under review to determine whether or not it will be implemented. I used a battery of water quality tests to determine the feasibility of this change. By measuring the pH, conductivity/resistivity and ATP counts of the sumps during the peroxide cookout procedures I was able to determine that the water maintains a sufficient level of cleanliness even into the end of the cookout cycle. This change has not been implemented yet because further testing is required to ensure the quality of the product.

Standpipe Drain Valves

By installing a valve on the standpipe of the last rinse sump (which goes to drain), the company will be able to improve the efficiency of the cookout procedure. Without the valve, after the peroxide has been added and the pumps have been started, the level in the sumps decreases because at that time there is no water in the plumbing. This allows whatever bacteria/mold that had inhabited the sump walls at this high level to proliferate. By including this valve, the sumps can be overfilled, thus accounting for this bathtub ring of contamination, and hopefully will be able to increase the effectiveness of the cookout. The initial cost of this project is $900.

Through my discussions with Scott I have decided to recommend this change and it is currently being implemented. The valve has been installed on one of the three rinses, and the modification for the other two is slated for the near future. Additionally a program change is necessary and maintenance is currently working on that change.

Machine Sprayout

The machine sprayout is a preventative maintenance performed on all of the rinses at a set interval. It is repeated every twelve hours on rinses 3 and 6, while it is on a twenty-four hour cycle for rinse 9. The reasoning behind this difference comes from the fact that VS9 is much newer than VS3 and VS6, and the recent improvements have made it more efficient. The procedure calls for the sumps of the rinse to be drained, the machine components to be sprayed out manually using heated water and a hose with a spray nozzle, and then for the sumps to be refilled with deionized water. The operators are instructed to look for and try to remove any visible mold or bacteria of any kind. Once the sumps have been filled with DI water, the machine is again ready for use.

The current procedure and schedule produces approximately 550,000 gallons of waste DI water annually, as well as 37,000 gallons of waste heated water. Obviously this process consumes a great deal of water, it was chosen as a point of research because such a large quantity was being expended. There was much anticipation that this process could be refined to further minimize water loss. Furthermore, other machinery in other parts of the plants in Hutchinson, Eau Claire, and Sioux Falls undergo very similar sprayout procedures. Any success I might have with the vertical strippers in the photoetch area could possibly be extended to further reduce waste and save money elsewhere.

Again I collected samples to create baseline measurements for this procedure. This time I created a baseline for both VS6 and VS9 (for 12 and 24 hours respectively). Again, this process supplied evidence that there was no significant increase in the dirtiness of the water toward the end of the cycles, in other words, the cycle may be able to be extended. Graphs can be found in the appendix (graphs 21 – 36).

I suggest a process change which will reduce the amount of deionized water sent to drain significantly. By lengthening the sprayout cycle on rinses 3 and 6 from twelve to twenty-four hours Hutchinson Technology will save 220,000 gallons of deionized water per year, as well as 15,000 gallons of heated water. Also there will be a reduction of 730 labor hours. The resulting cost savings would be significant, $6,600 in DI water costs, $150 in heated water costs and $11,250 in labor. Furthermore the downtime for the machines would be decreased, resulting in an increased capacity.

Because this change would simply imply the removal of a sprayout each day there would be no initial investment involved, nor an increased operating cost. Overall the cost savings annually would be $18,000.

I have recommended this change, it is currently being considered for implementation. Before it is implemented, further testing will likely be necessary to prove that product quality will remain unaltered. I used four methods to monitor the purity of the water throughout my testing to support this suggestion: conductivity, resistivity, ATP counts and pH. Through my research, I believe that the sumps maintain a level of cleanliness throughout the twelve hour cycle and would continue to maintain that level of cleanliness through a longer twenty-four hour cycle.

During the summer I also looked at the hose water which is used to spray out the machines. It is currently heated, softened well water. I looked into having this changed to DI water or RO (reverse osmosis) water, but because of cost issues these options were not really viable possibilities. Simply put, the water being used is effective enough and the cheapest heated water source available.

Although, the hose water makeup was the best option available, there was no doubt that it was dirtier than we wanted the resulting sump water to be. Thus I evaluated the possibility of a process change to the sprayout procedure. I compared the resultant sump water after the current procedure to that of draining the sumps and filling them again without a sprayout. I found that the sumps were actually cleaner when they were not sprayed out by the hose. Results in appendix (graphs 37 – 46).

I have recommended changing the procedure to remove the sprayout. Before it is implemented, further testing will be necessary to prove that product quality will remain acceptable. I used conductivity, resistivity, ATP counts and pH to justify my suggestion. If implemented, the change would save HTI $450 in heated water costs and $7,000 in labor, for a total of $7,450 saved annually.

Sump Reduction

As previously stated, each rinse module consists of a spray chamber mounted over a sump. During sprayout and cookout procedures these sumps are drained and cleaned. With each consequent drain and fill there is a water consumption and water waste.

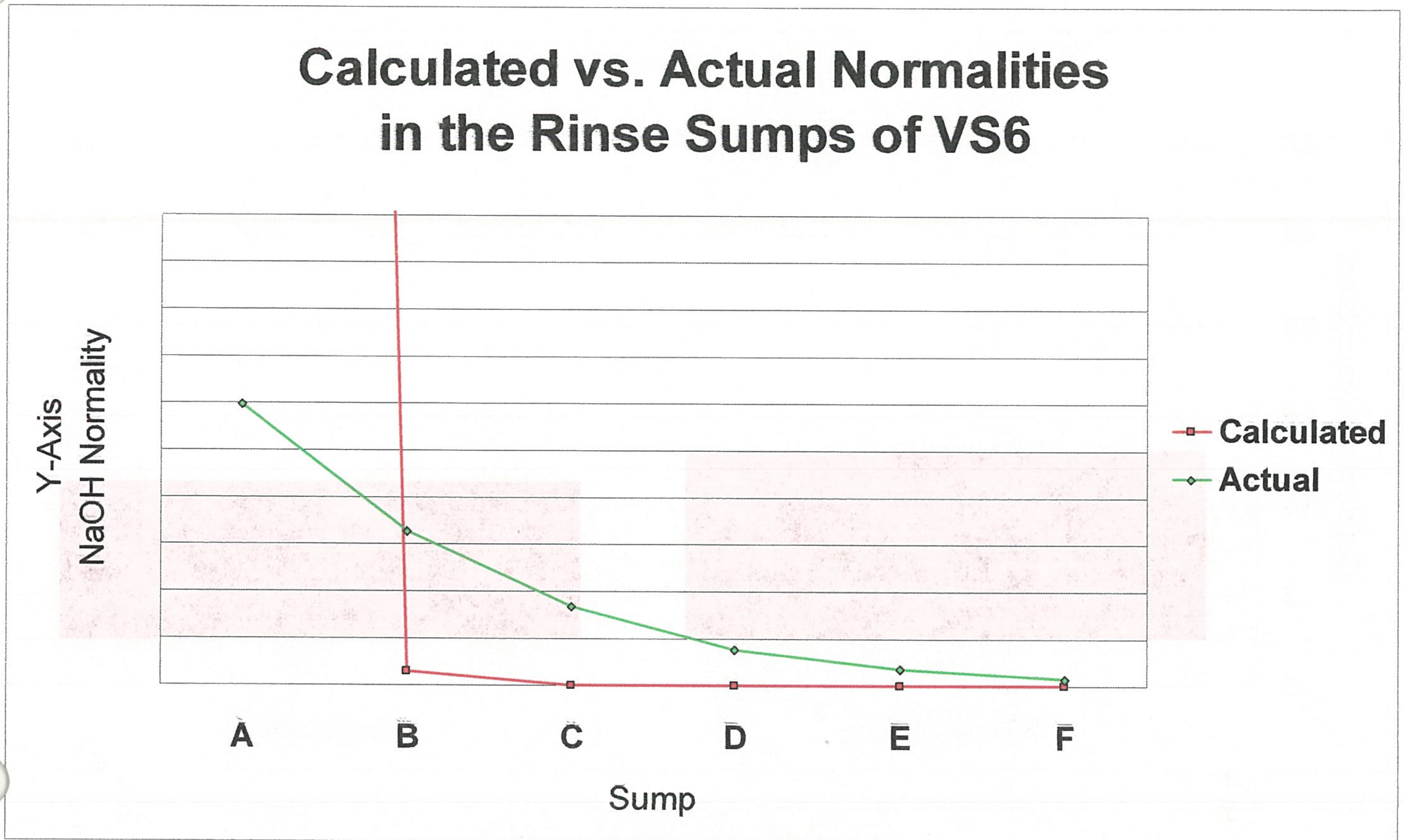
Currently, a combination of draining, for sprayout and cookouts use approximately 600,000 gallons of deionized water each year. There are additional times when the sumps must be drained (i.e. Engineering tests, machine modifications, etc.) However, they are blanketed under the fact that the 600, 000 figure is an approximation.

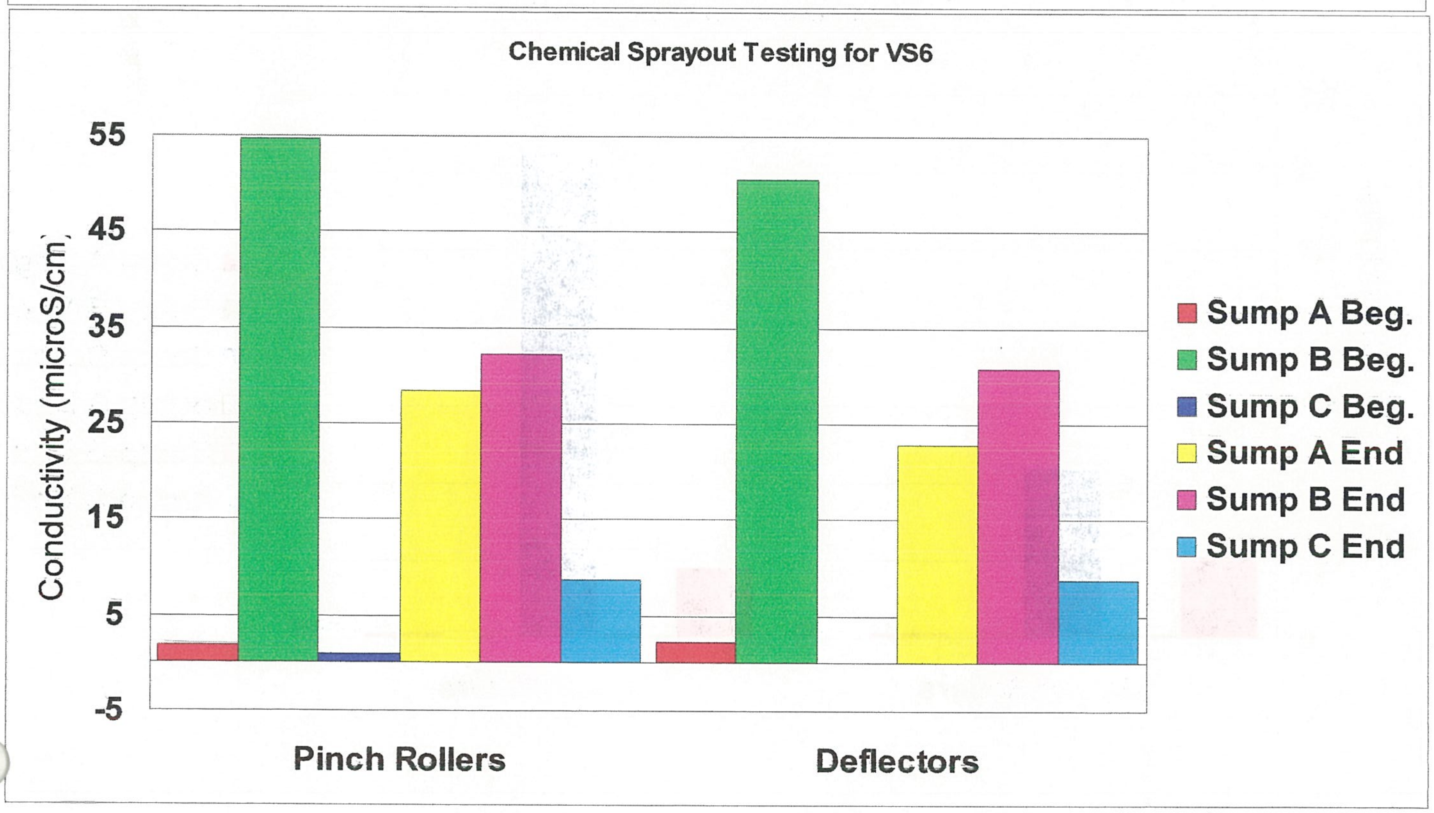
There is a large amount of water being consumed through the aforementioned processes. Because one of the main objectives for me to work on during the summer, this was waste water. By reducing the size of the sumps we would be able to cut back on the amount of water used each day during sprayout and cookouts. This sump reduction would be accomplished by blocking off part of the existing sump with a new divider made of polypropylene, just like the rest of the machine. Furthermore, we would be able to remount the pumps inside of the sumps which would cut down on the ambient noise in the production bay. With a 70% reduction of the sump size would therefore conserve 420,000 gallons/year, and a cost saving of approximately $12,500/year would also accompany these changes.

This change would require extensive modifications to the machines, these modifications would incur a onetime $80,000 start-up cost.

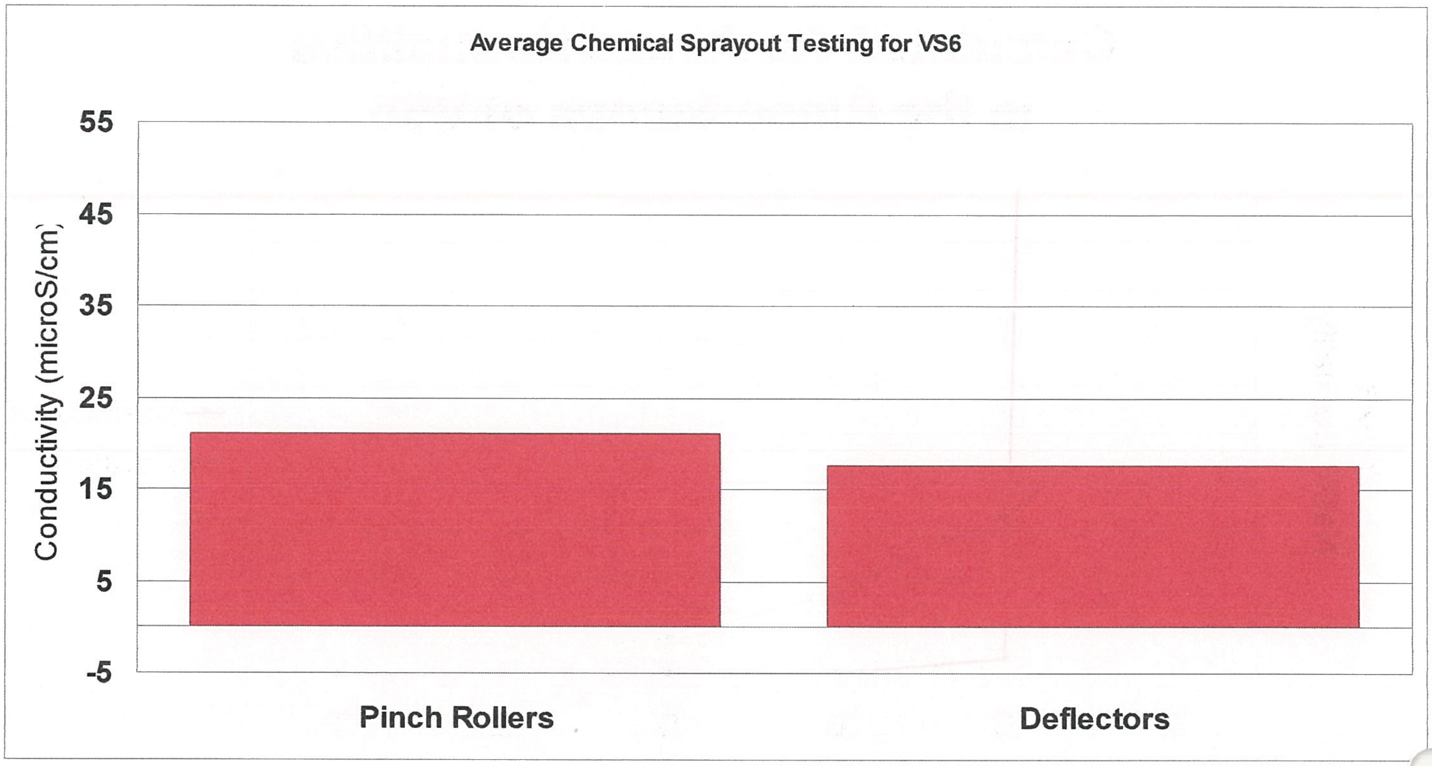
I have recommended this change, and it is currently being considered for implementation. To test the feasibility of this reduction I, along with the help of Scott Brusehaver, filled up approximately 70% of the rinse sumps on vertical stripper 2 (which has the same design as VS 3 and 6). We used large inflatable vinyl balls manufactured as children's toys to occupy the space in the sump. After doing so I used pH, conductivity, resistivity, normality and ATP counts to monitor the sump water cleanliness while Scott and I ran sheets through the machine to mimic normal operation. These tests showed that the water cleanliness levels were very similar to those found during baseline measurements of VS6 and VS9, thus implying that the sump reduction did not correspond to a decrease in water quality. In fact, the ATP counts decreased throughout the testing timeframe, this is likely due to the higher turnover rate in the sumps. Because there is less water in each sump, the water remains stagnant for far less time, thus, the mold/bacteria have less chance of surviving. These results can be found in the appendix (graphs 47 – 56). Additionally, I collected sample sheets for NVR, FTIR and IC evaluation in the chemical services lab. This change has not been implemented yet because further testing, such as a full product order, will be necessary to ensure product quality.

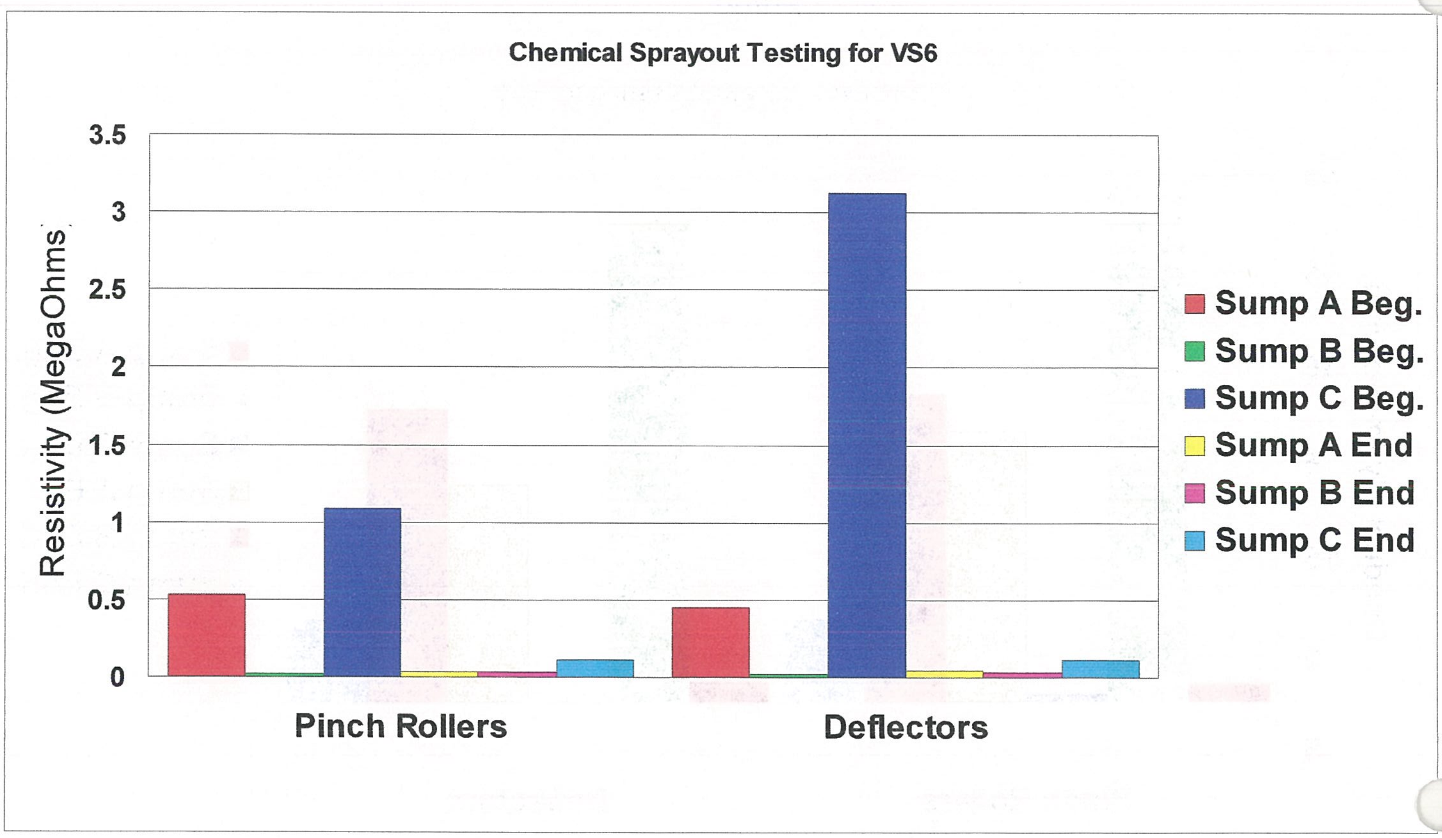
Graphs 1 and 2



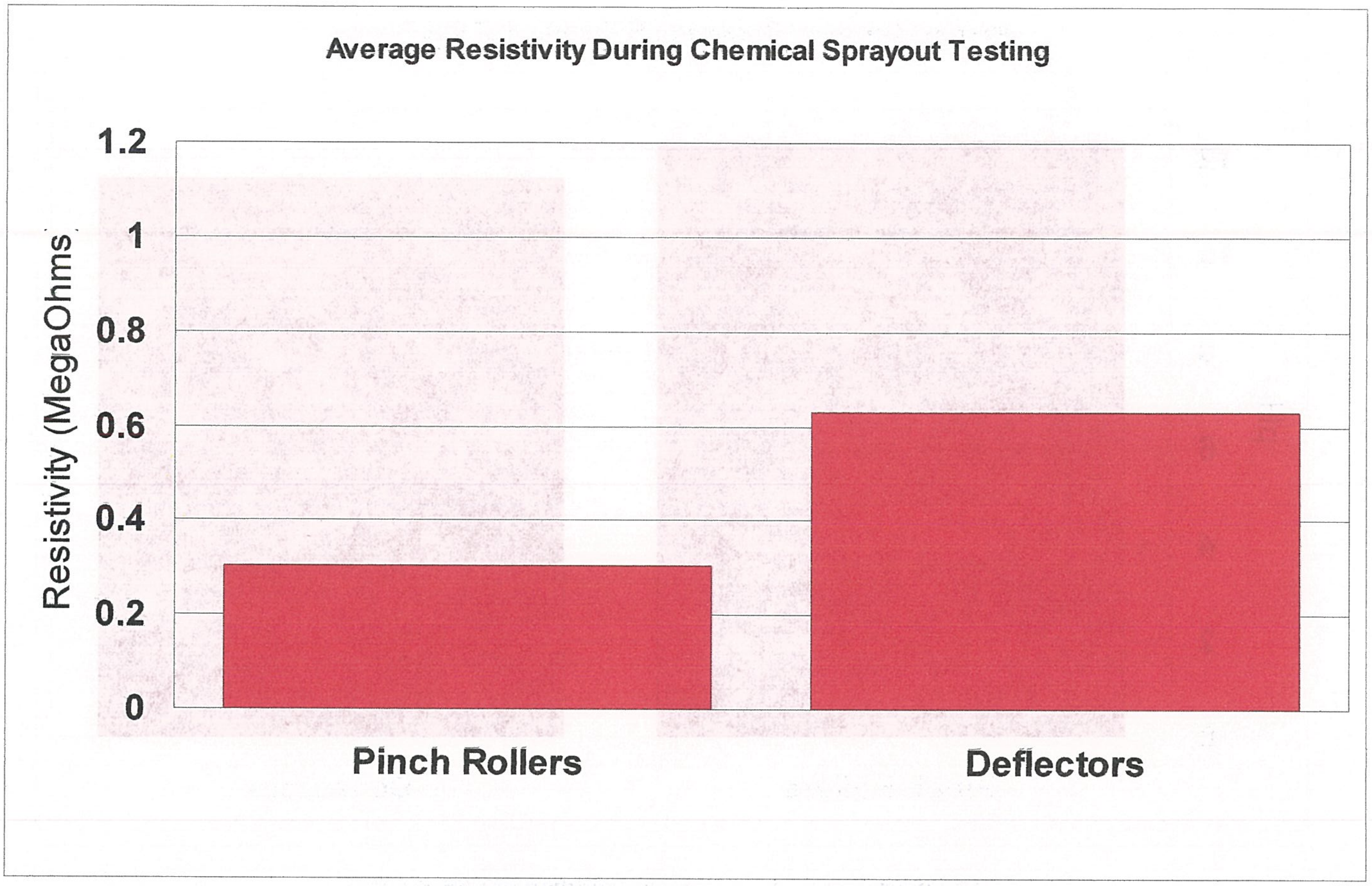


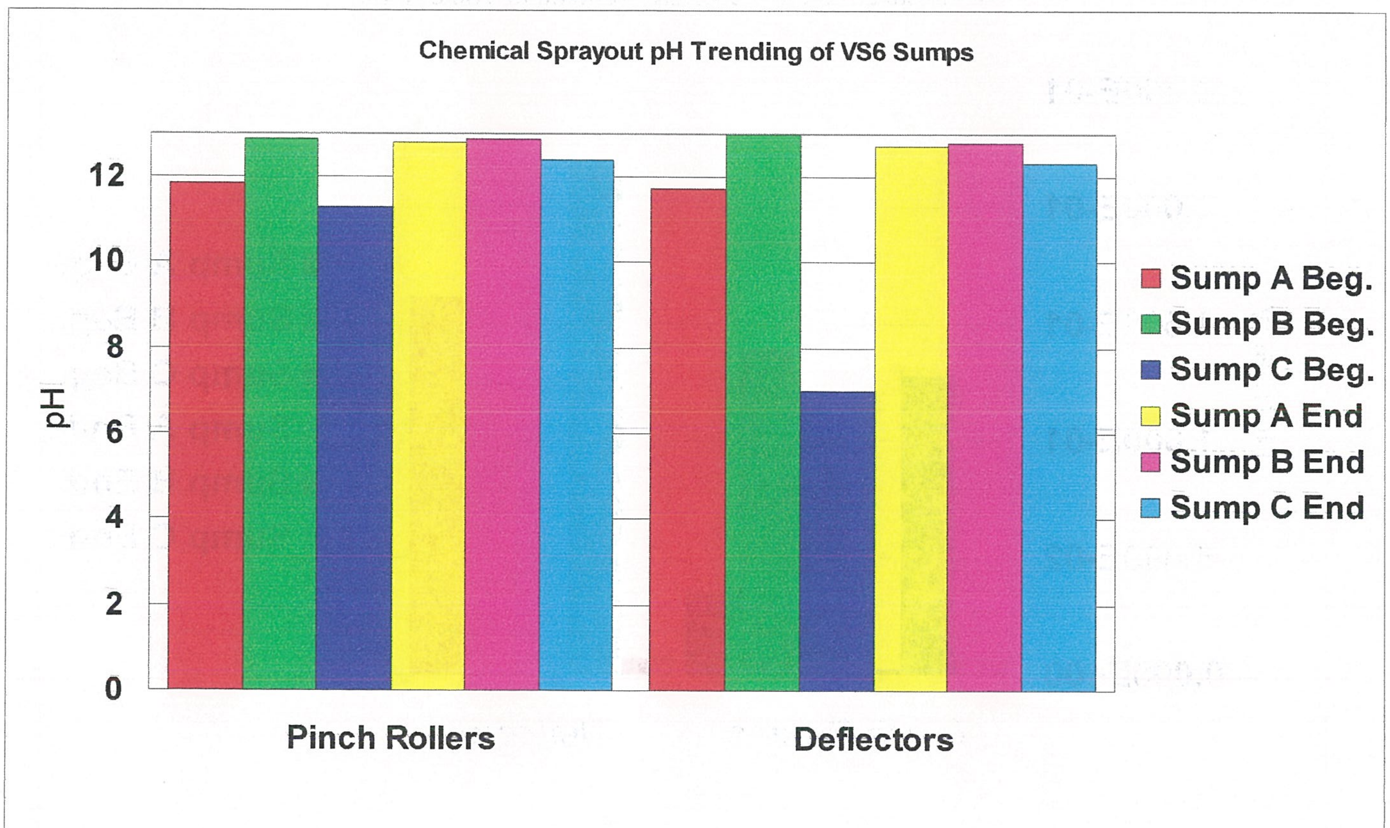
Graphs 3 and 4



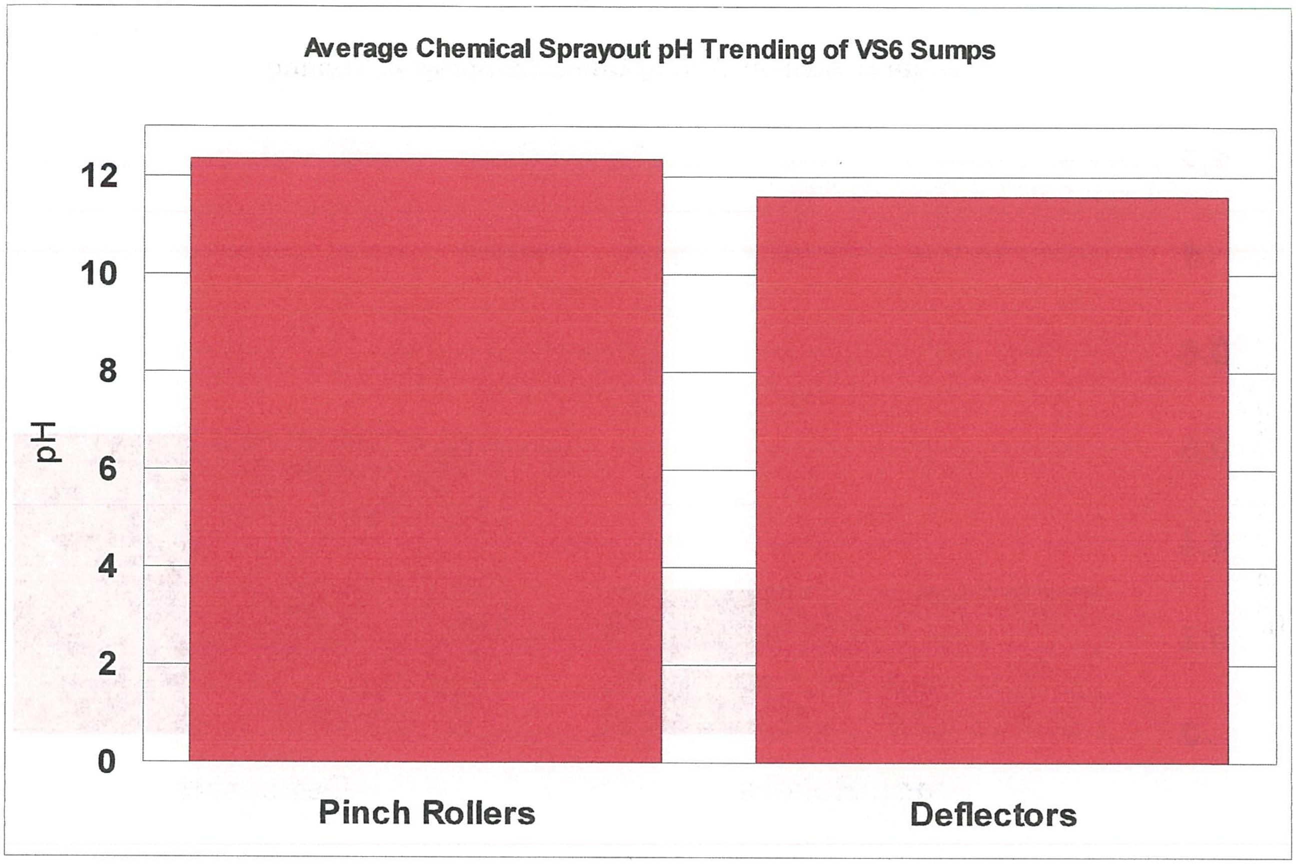


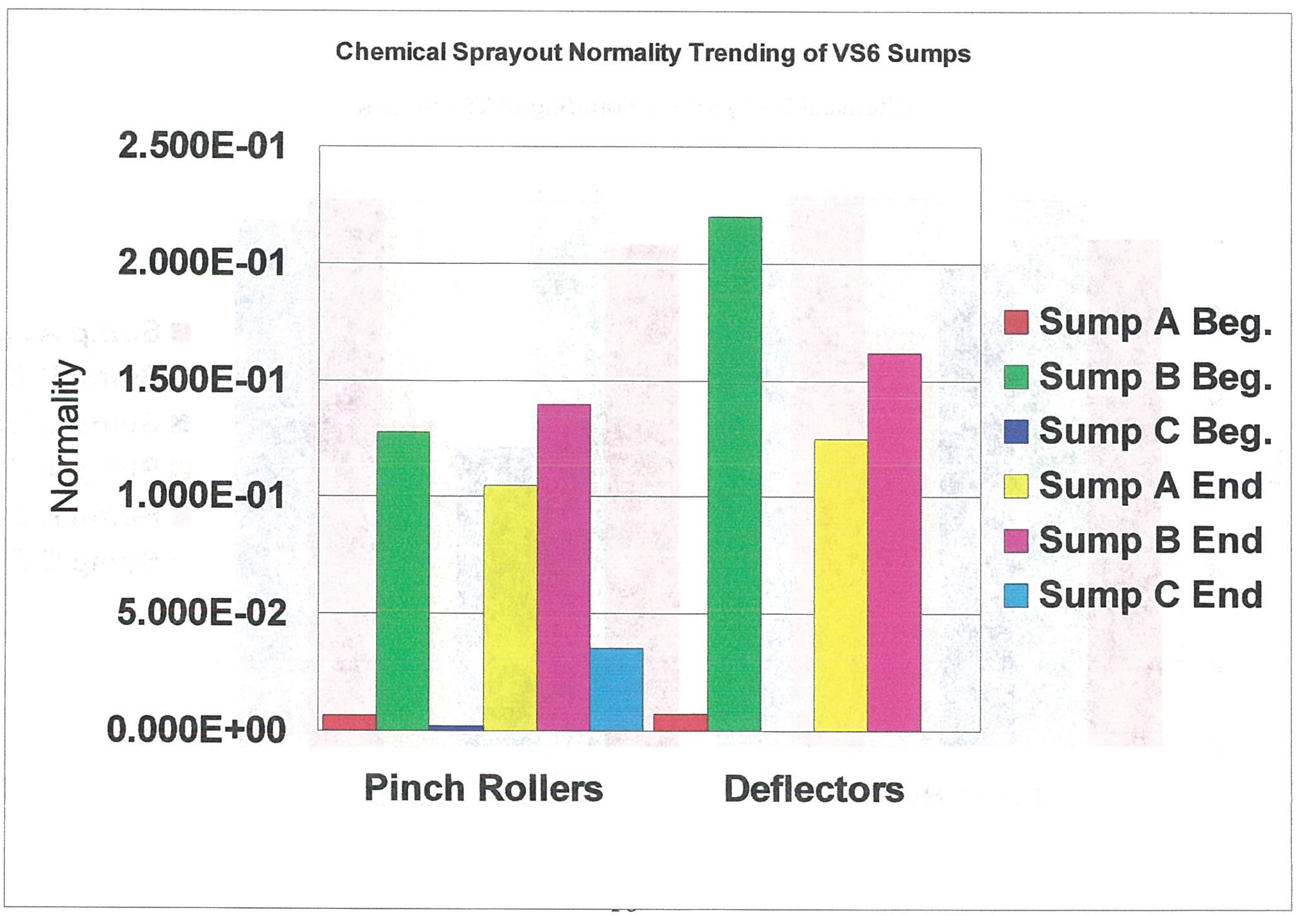
Graphs 5 and 6



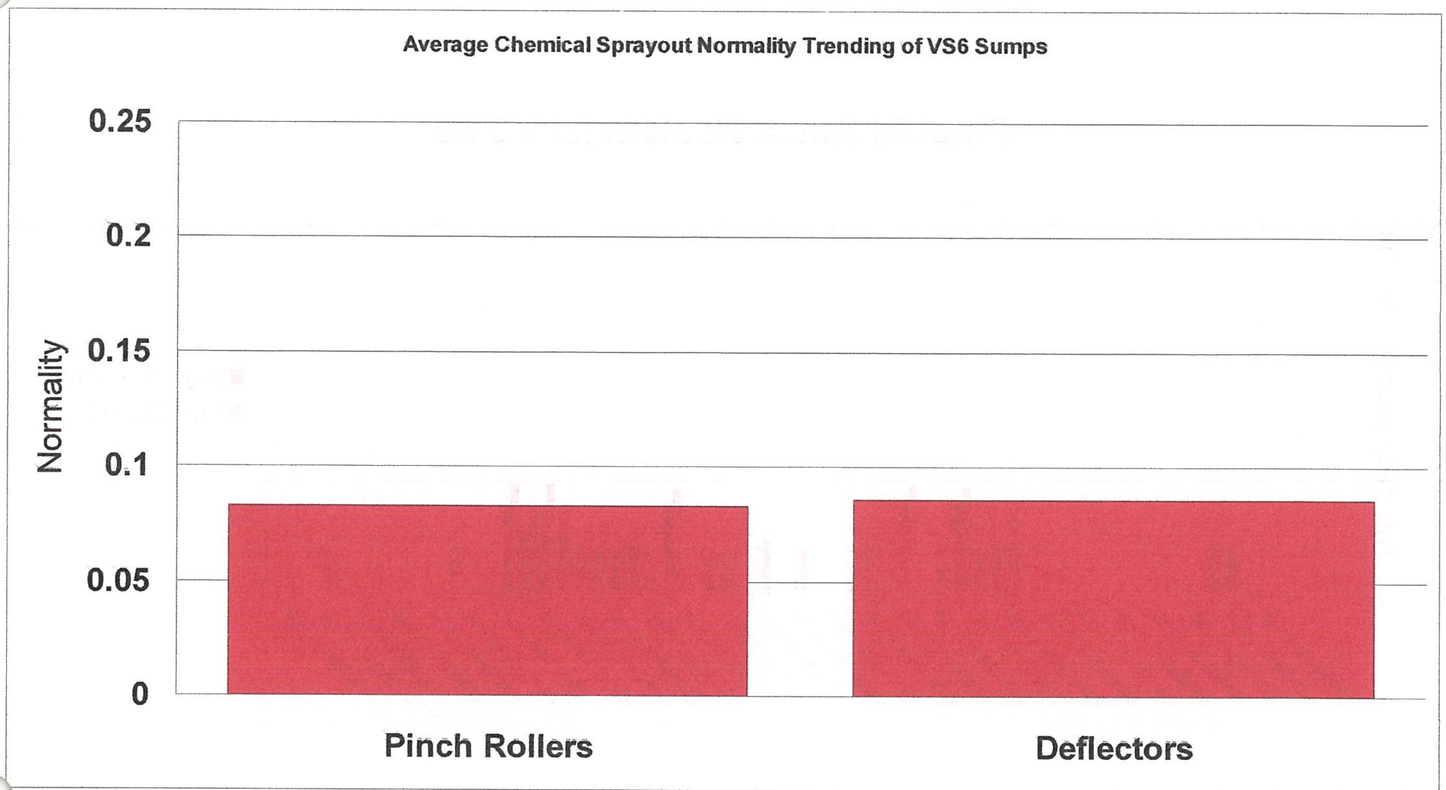


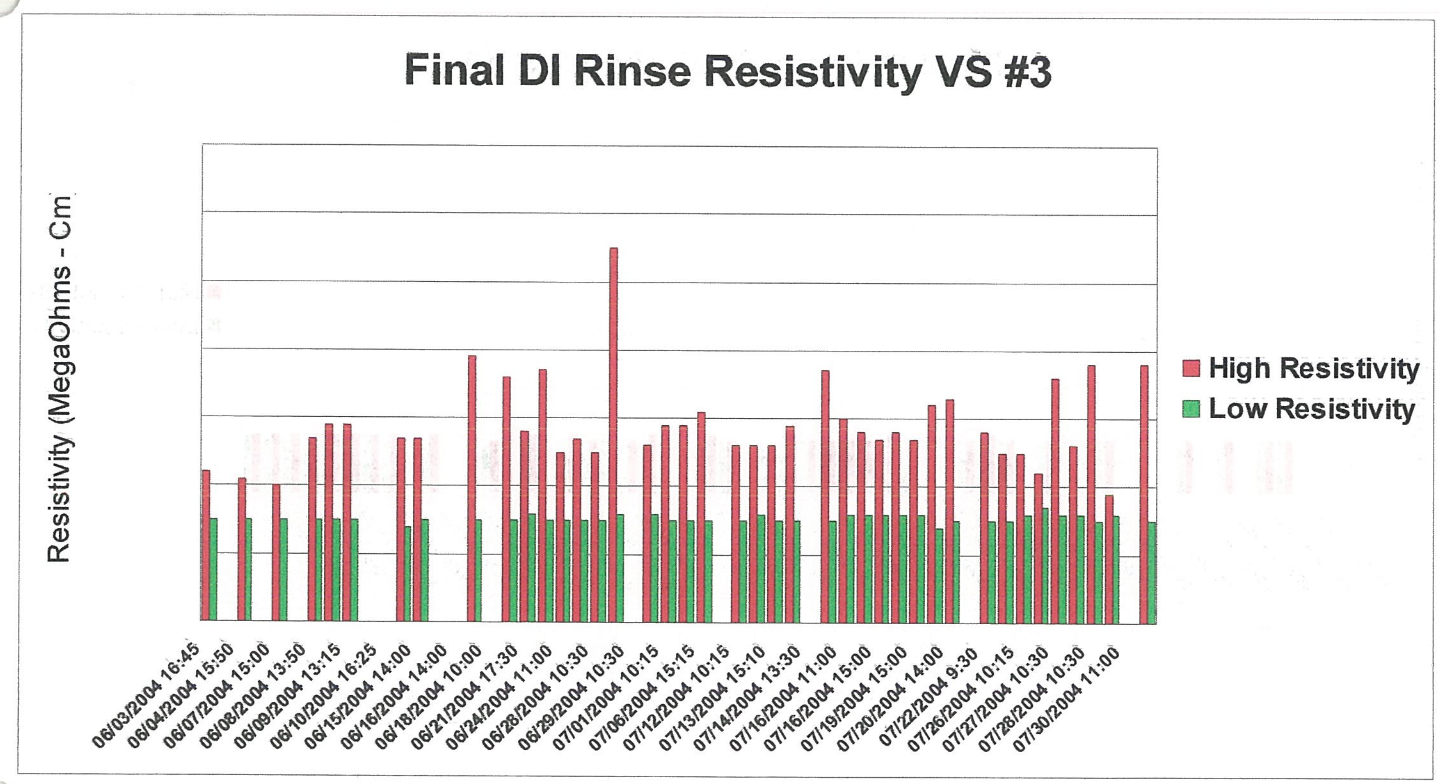
Graphs 7 and 8



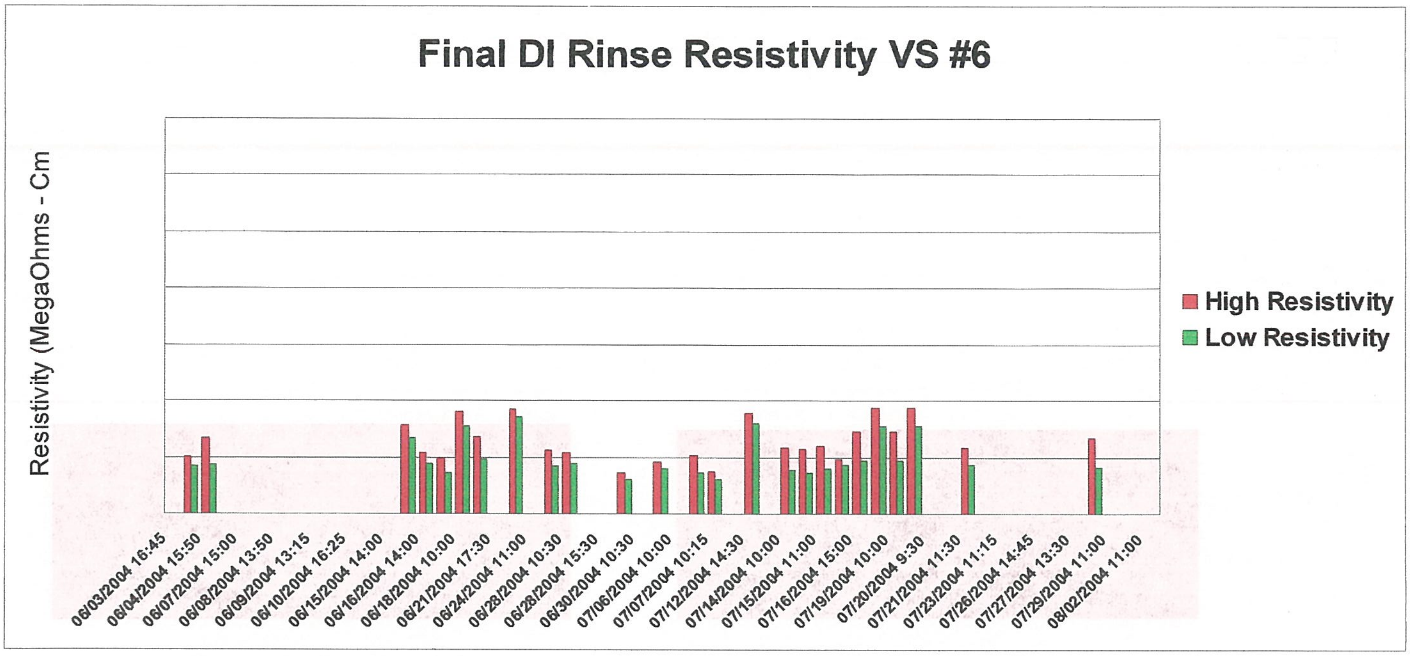


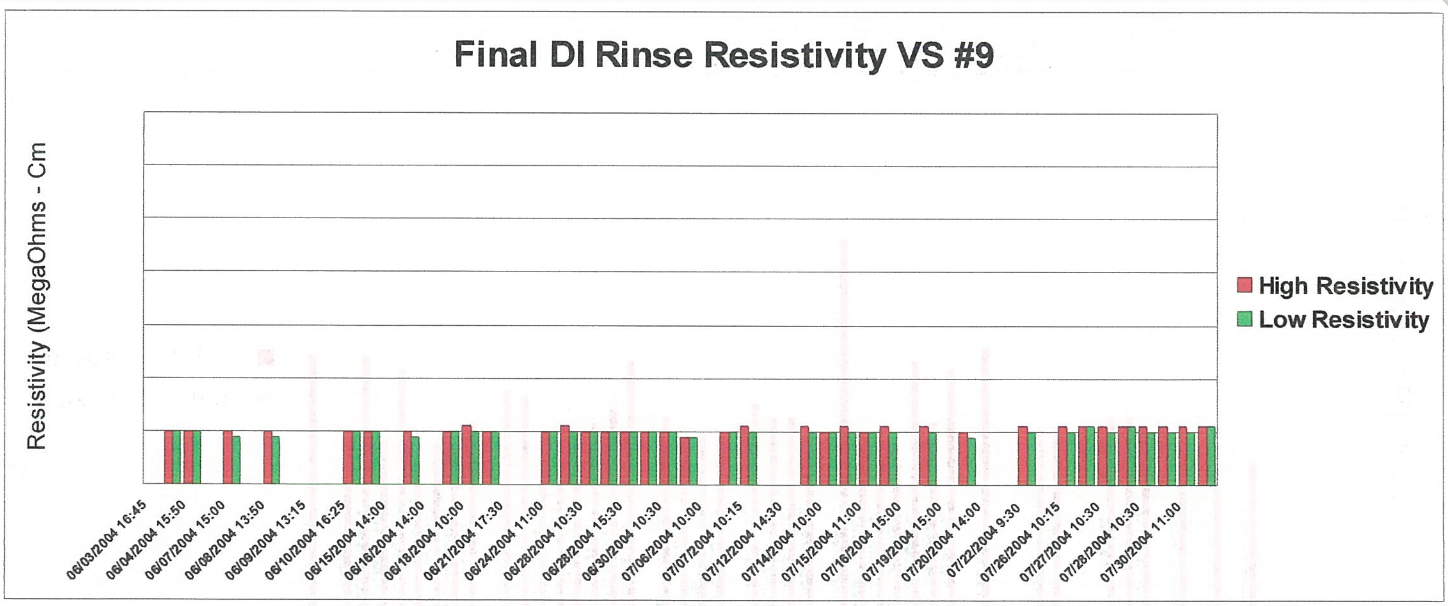
Graphs 9 and 10



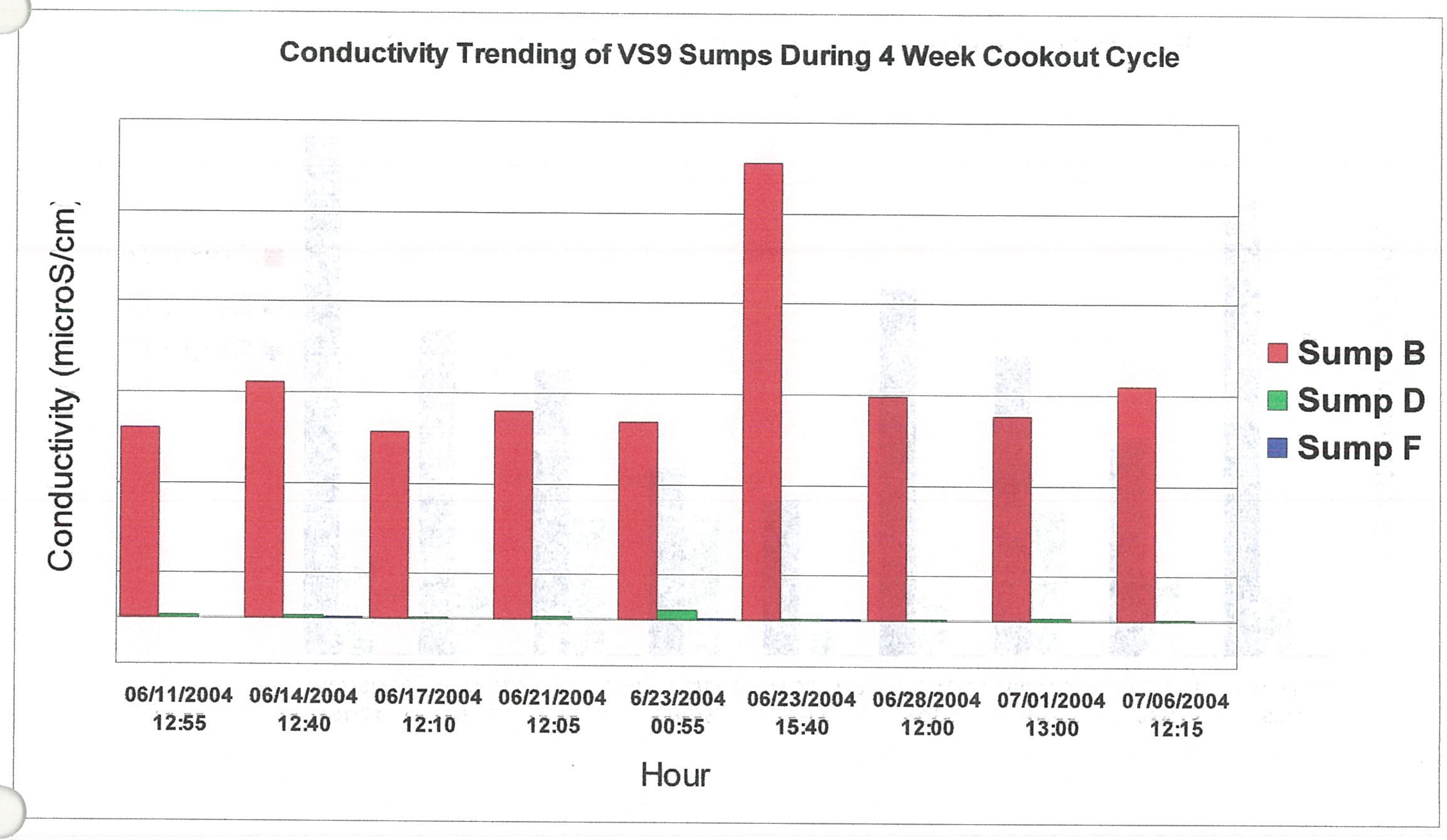


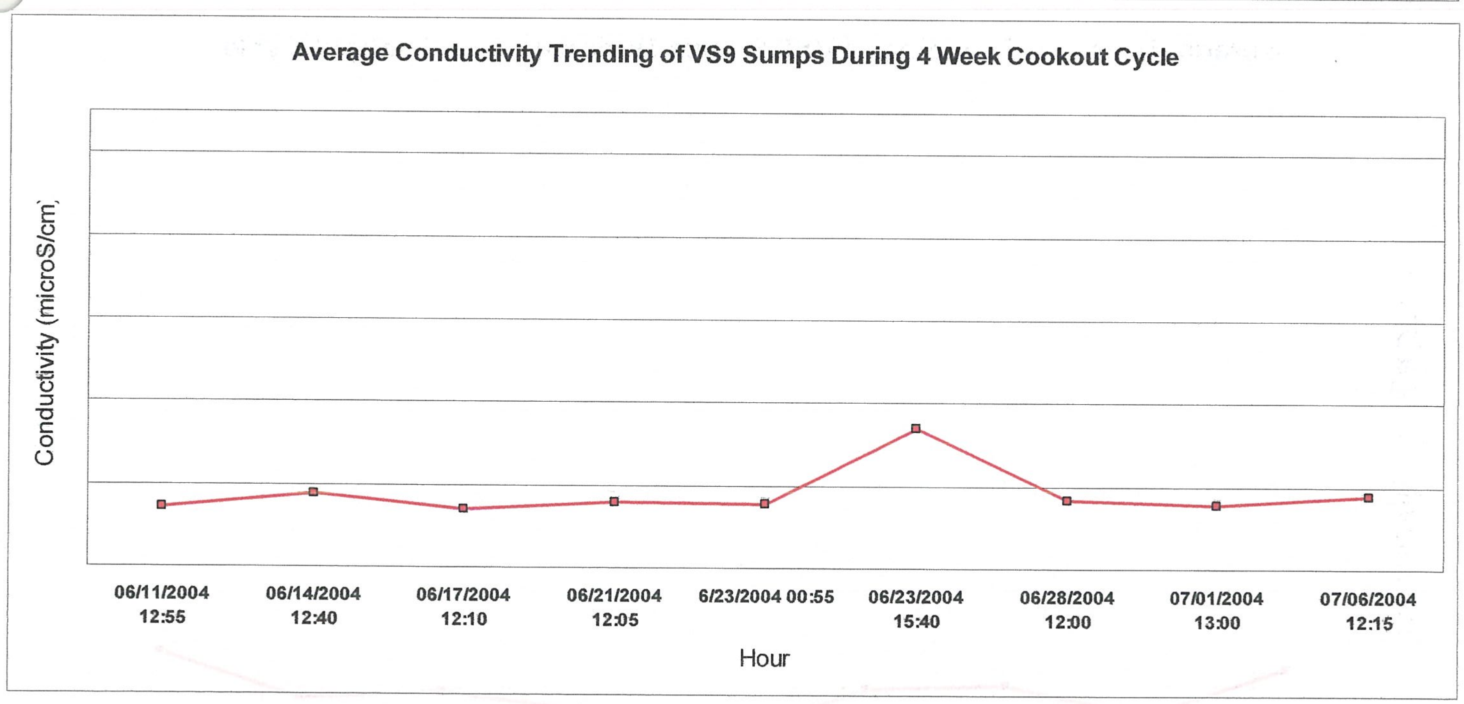
Graphs 11 and 12



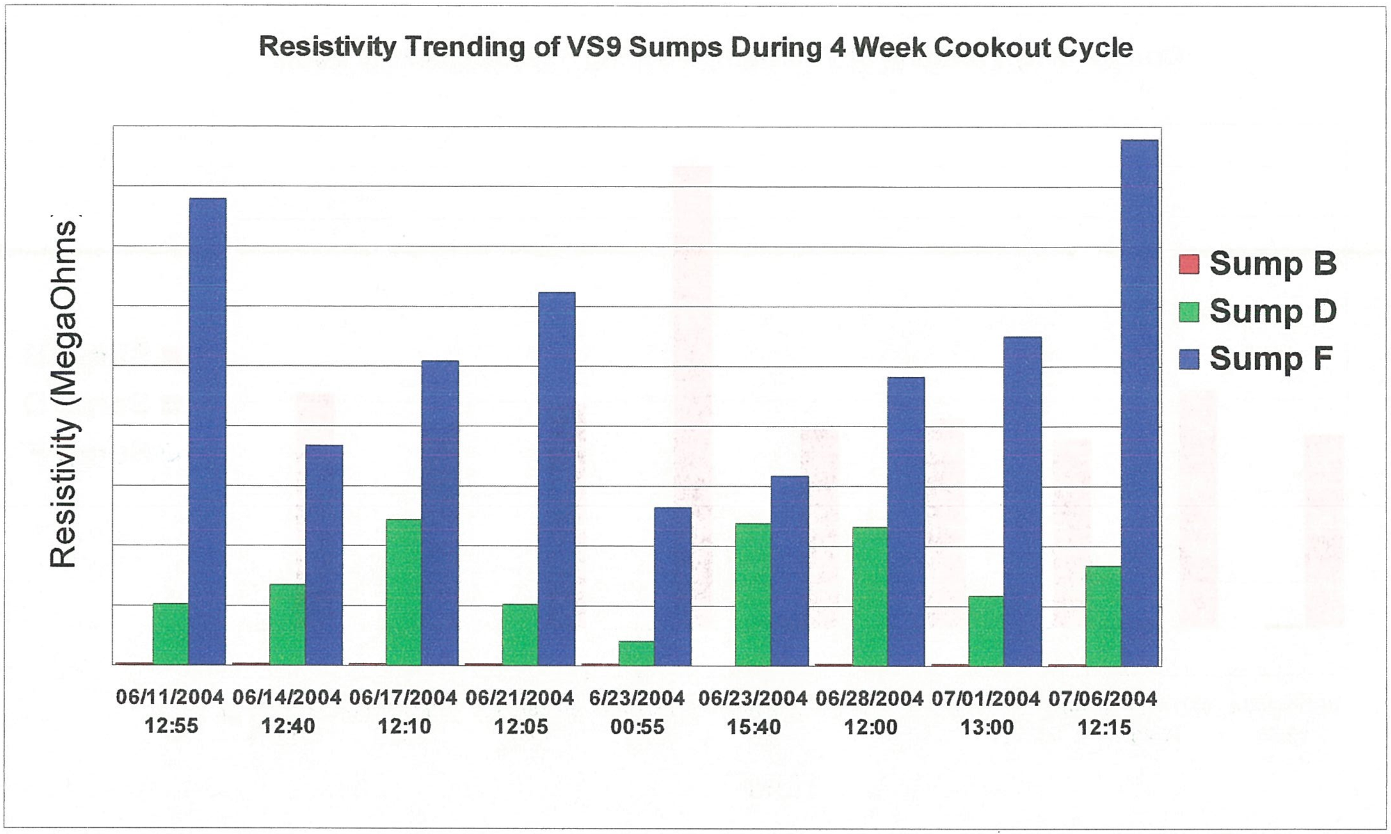


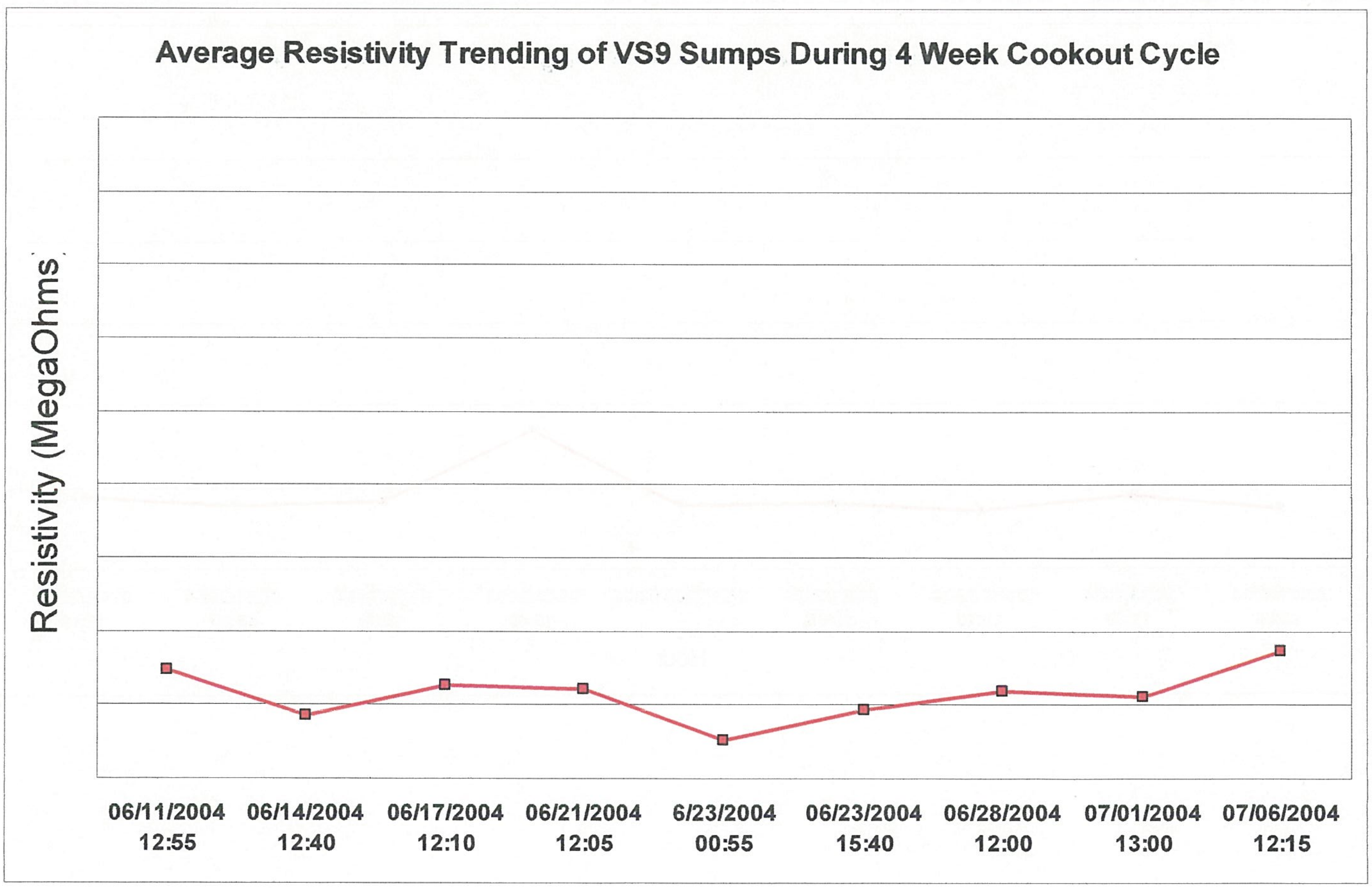
Graphs 13 and 14



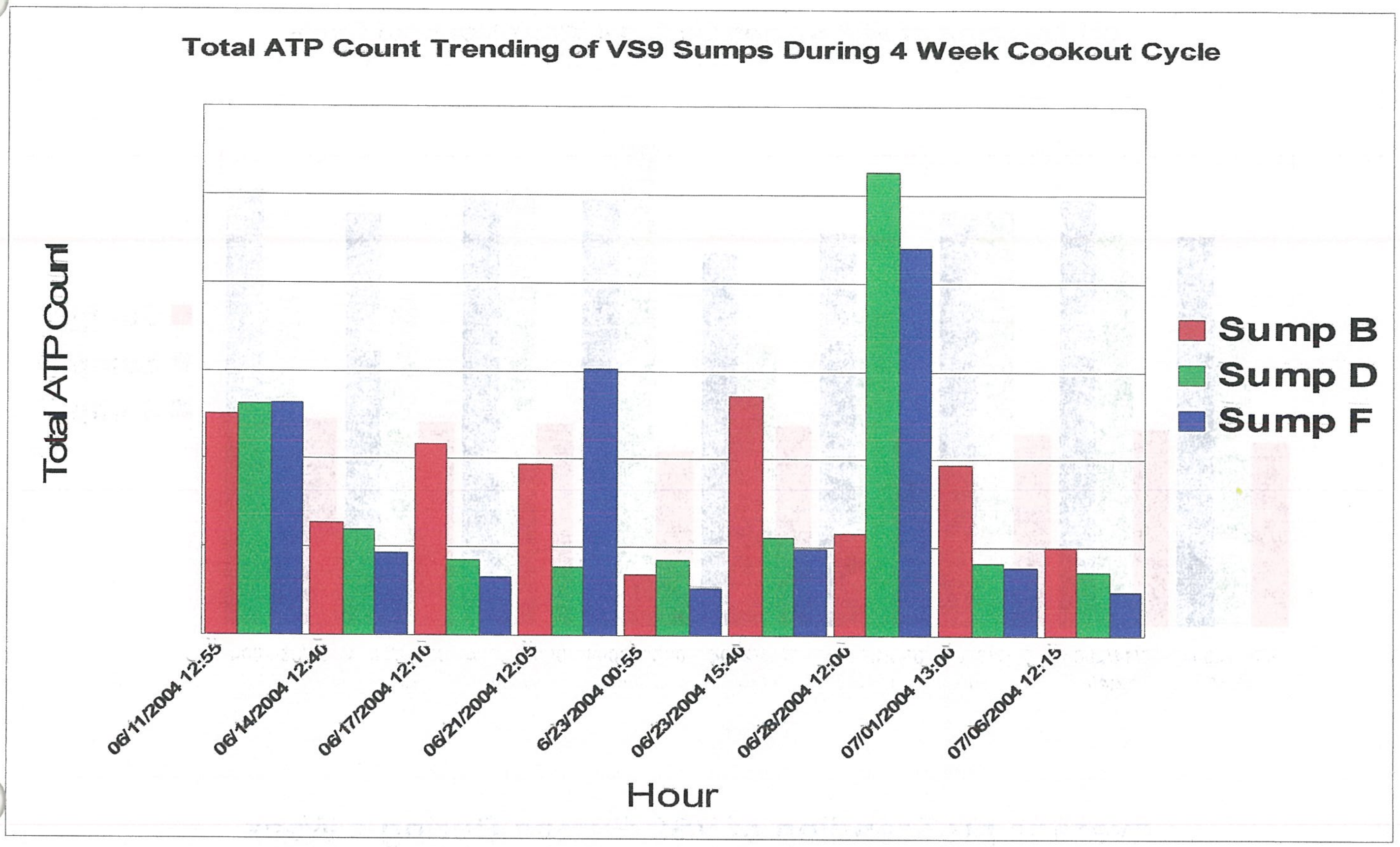


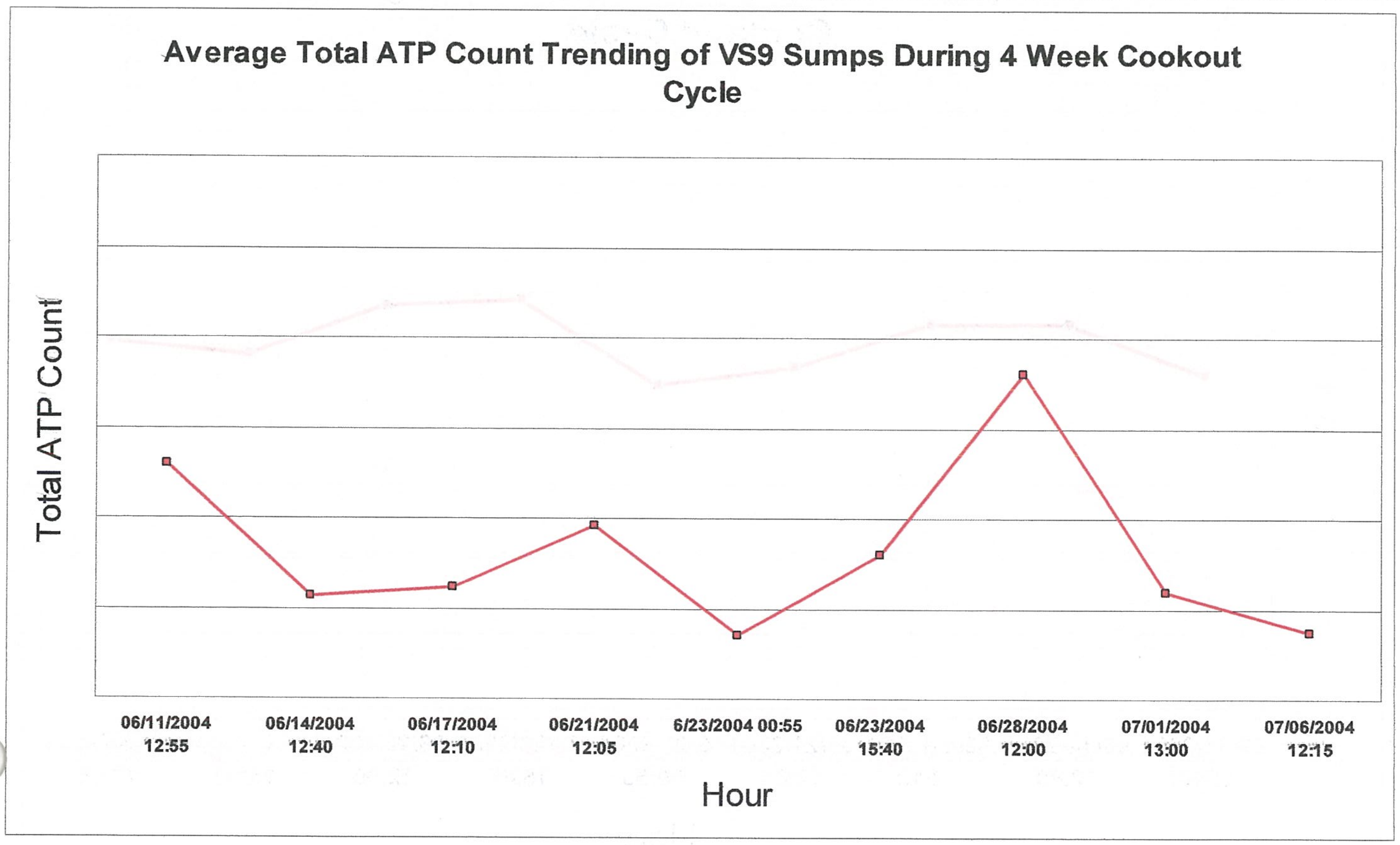
Graphs 15 and 16



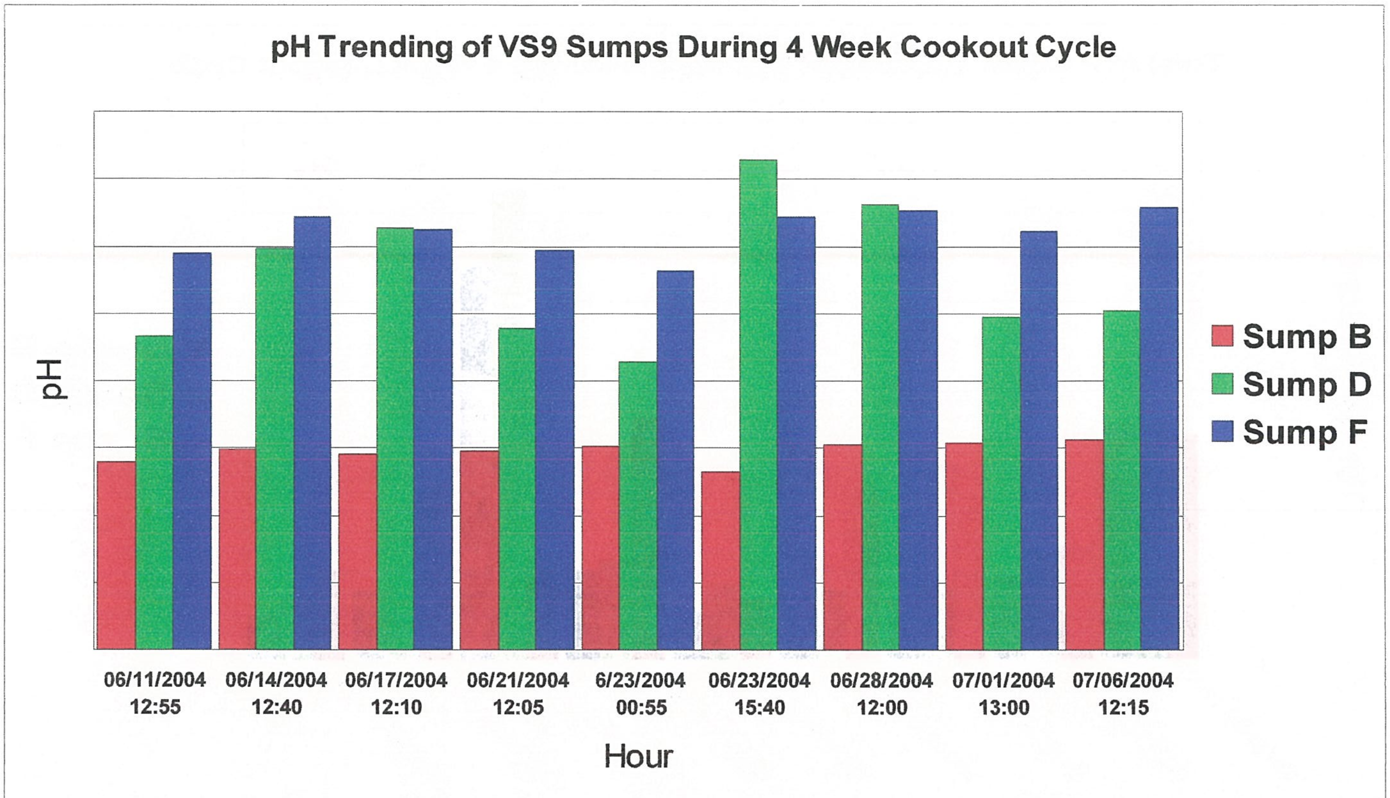


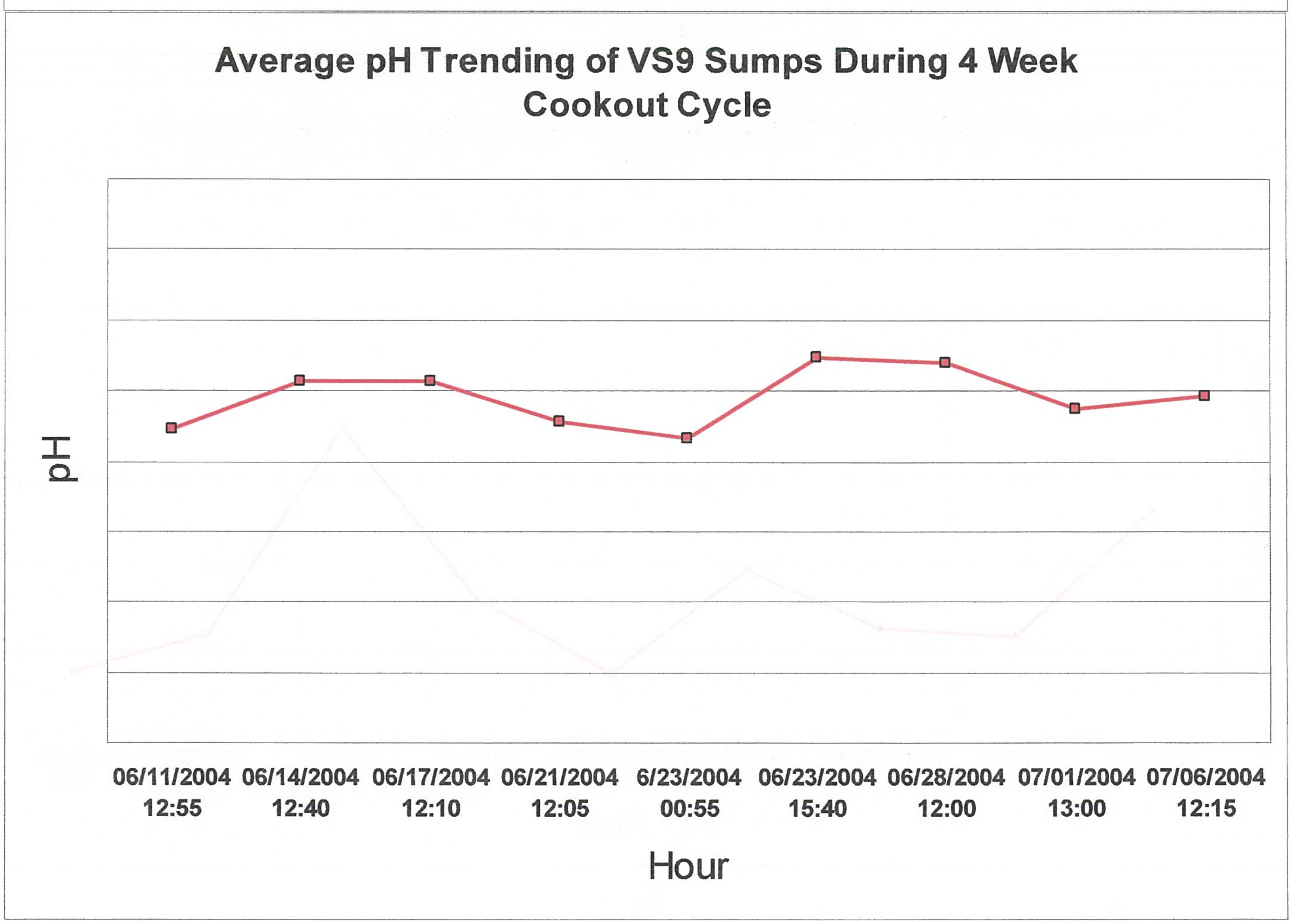
Graphs 17 and 18



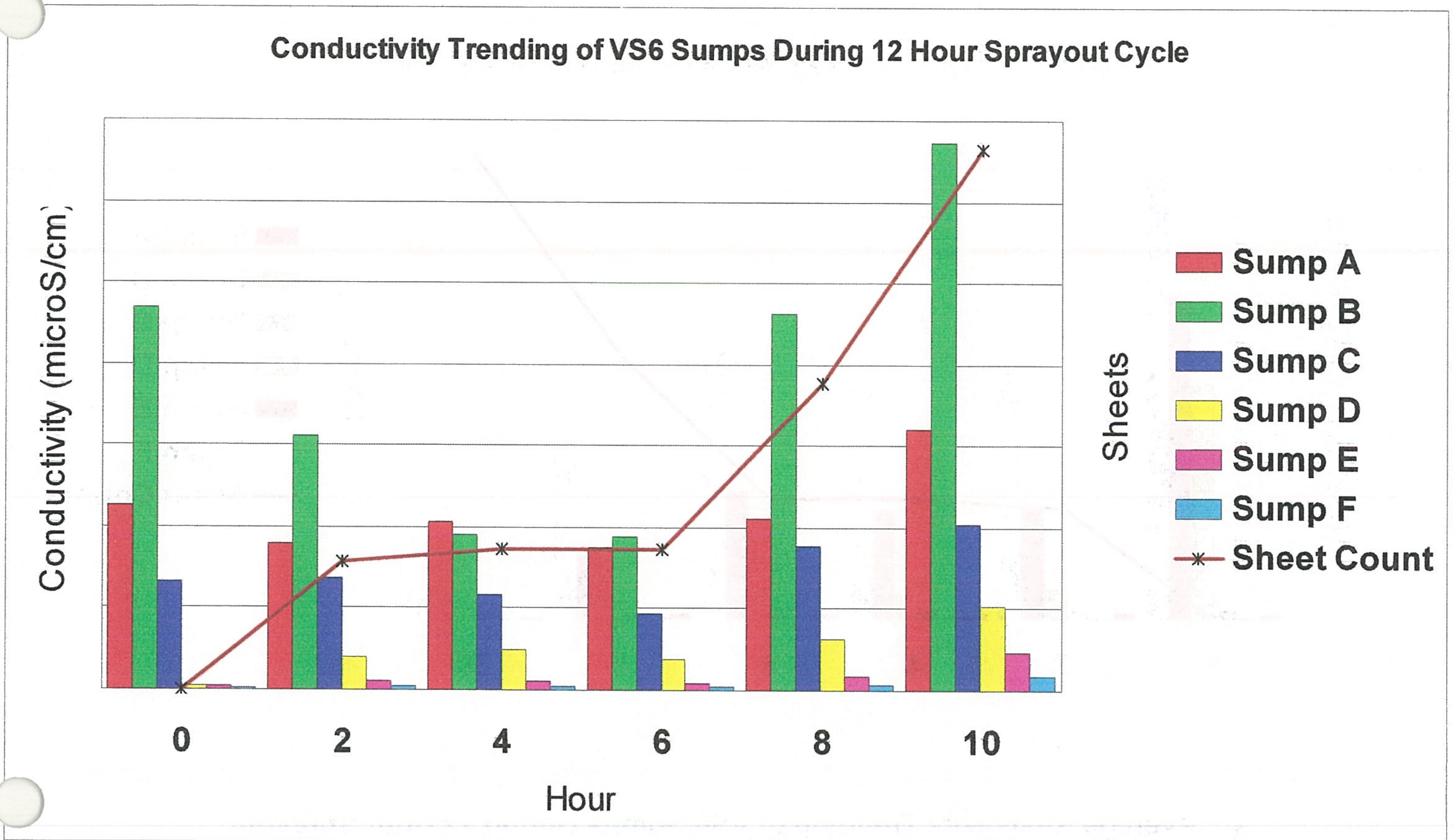


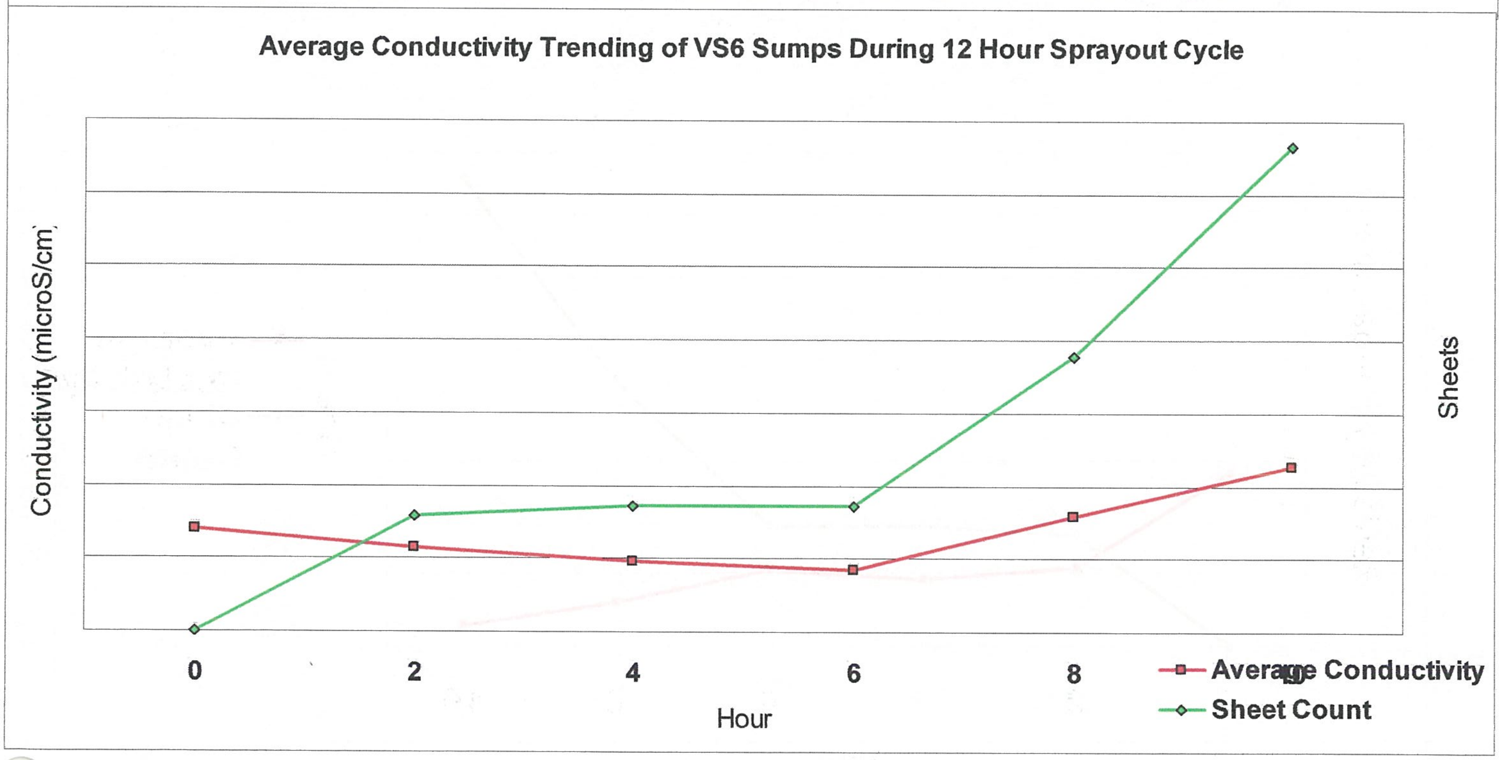
Graphs 19 and 20



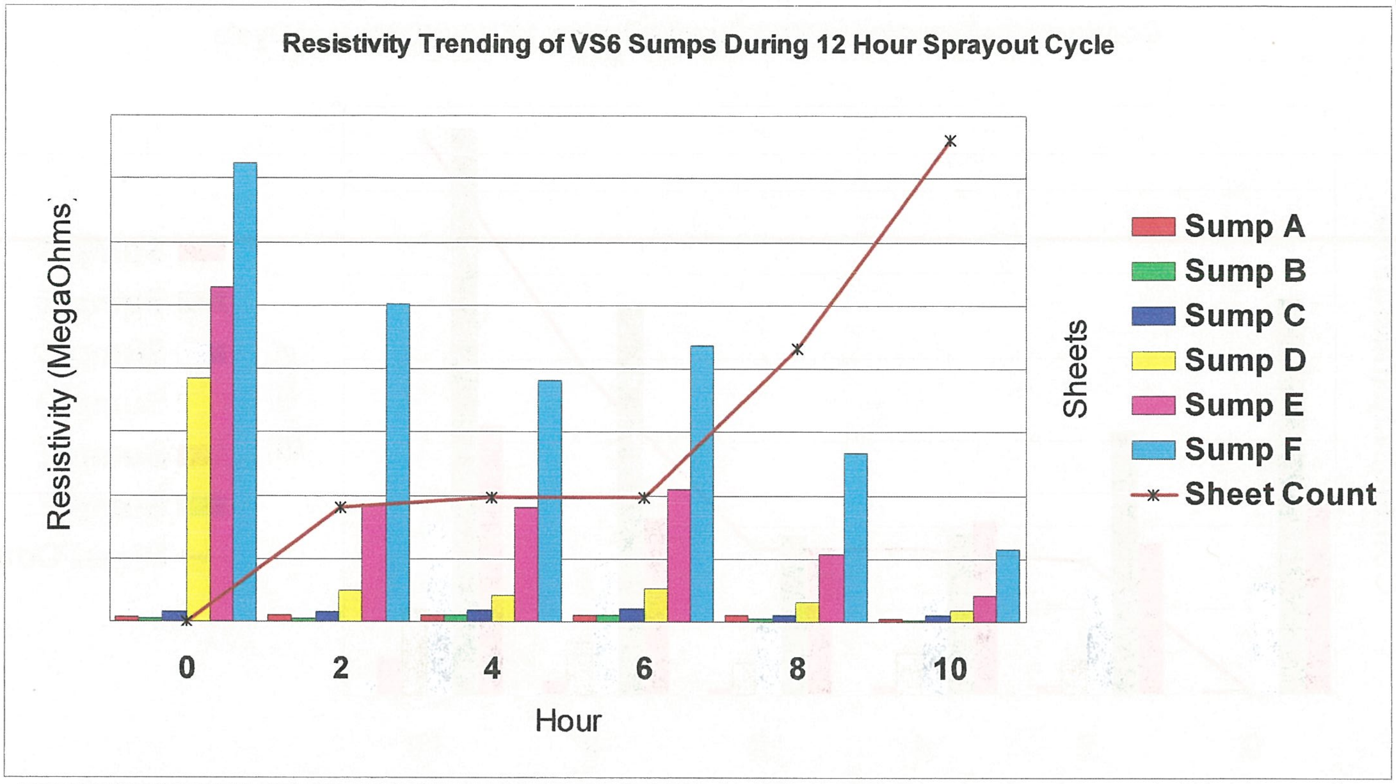


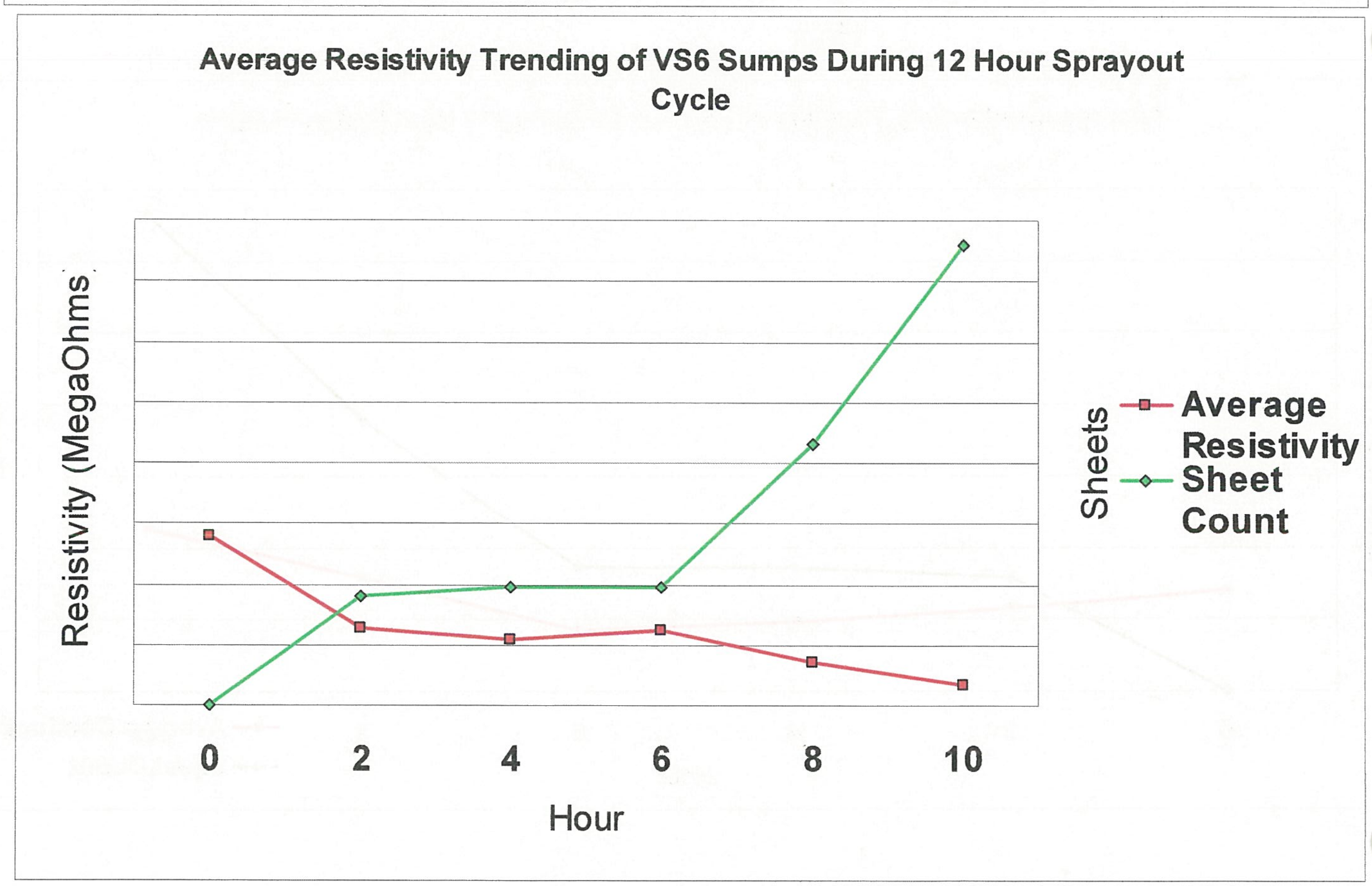
Graphs 21 and 22



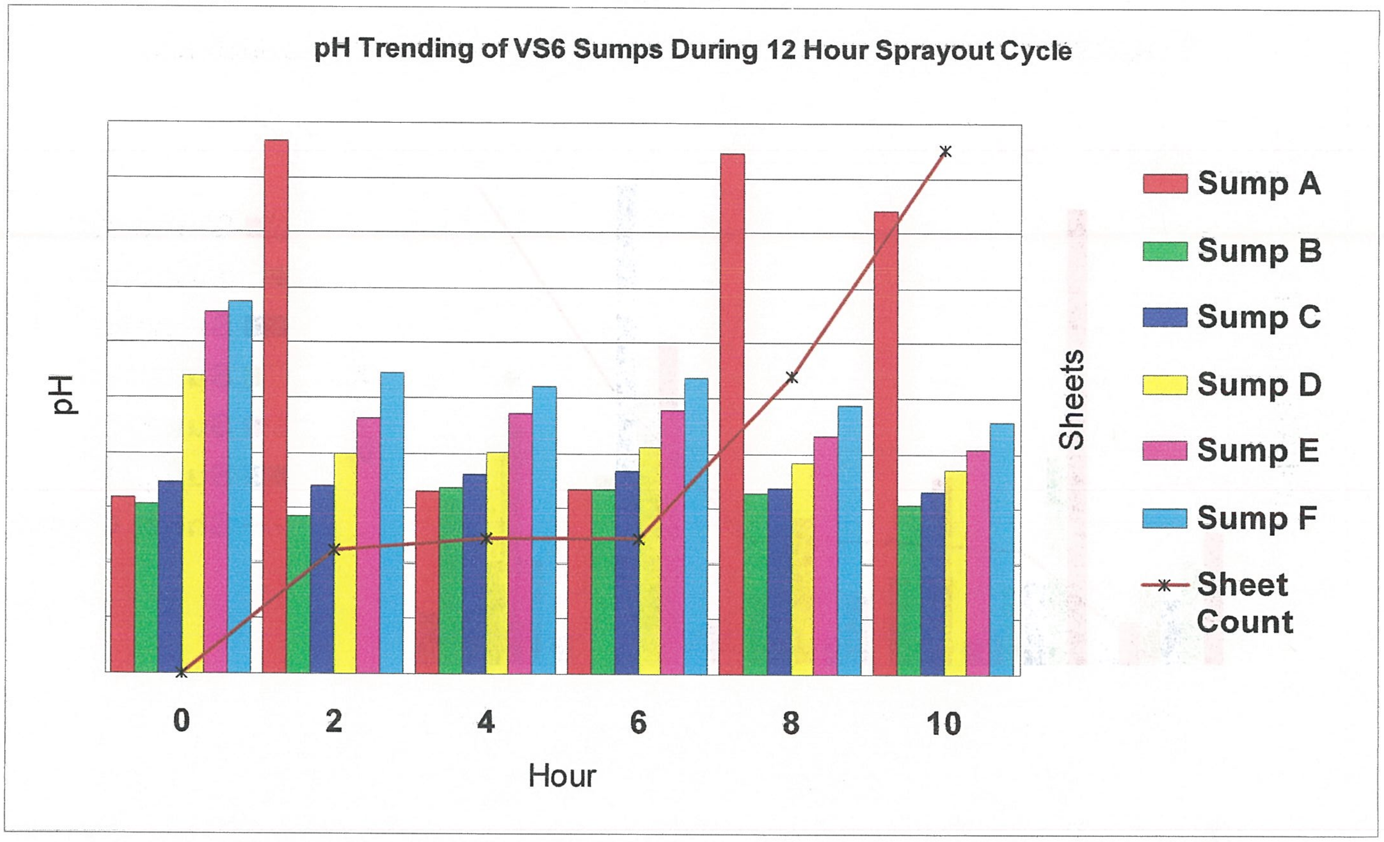


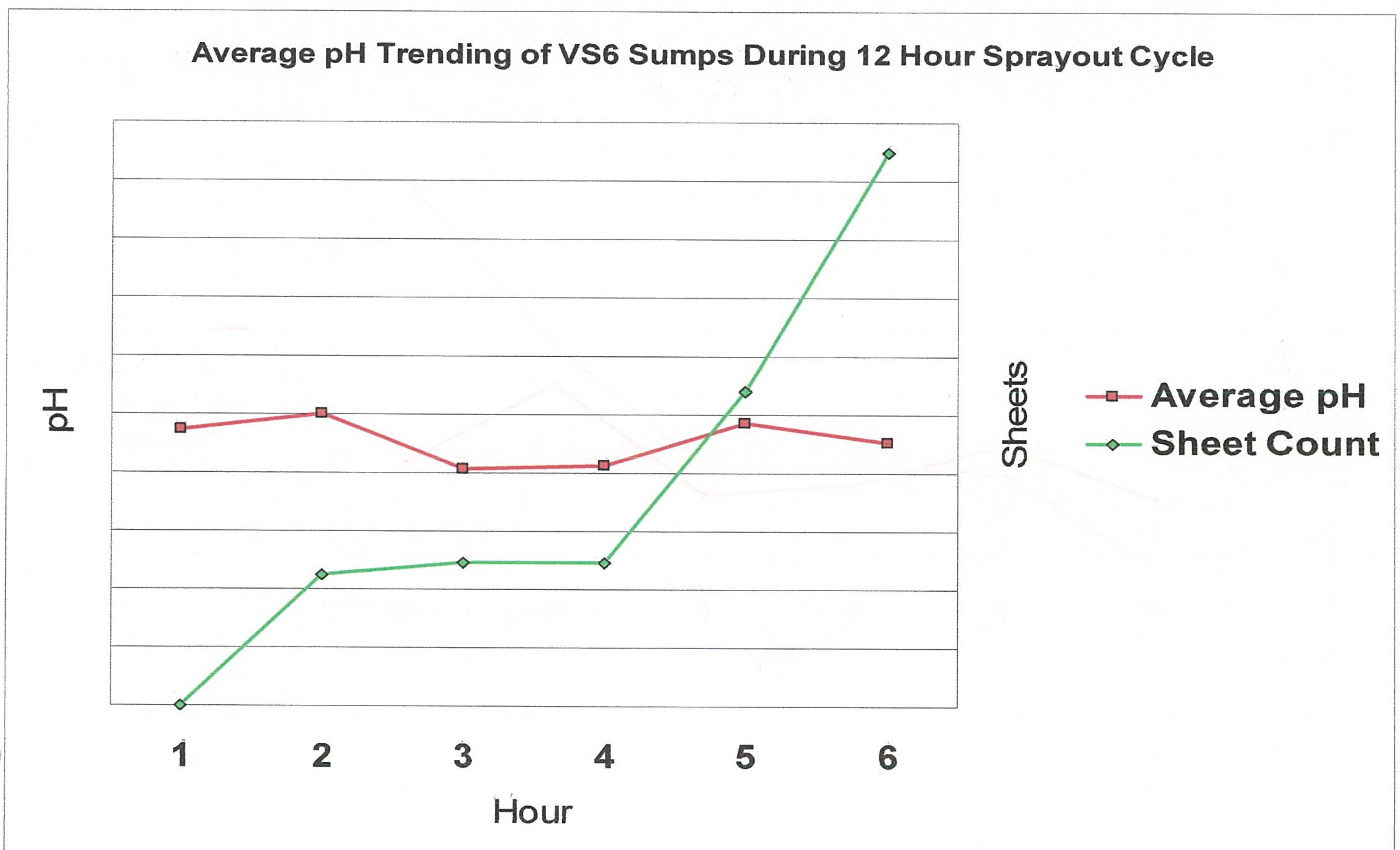
Graphs 23 and 24



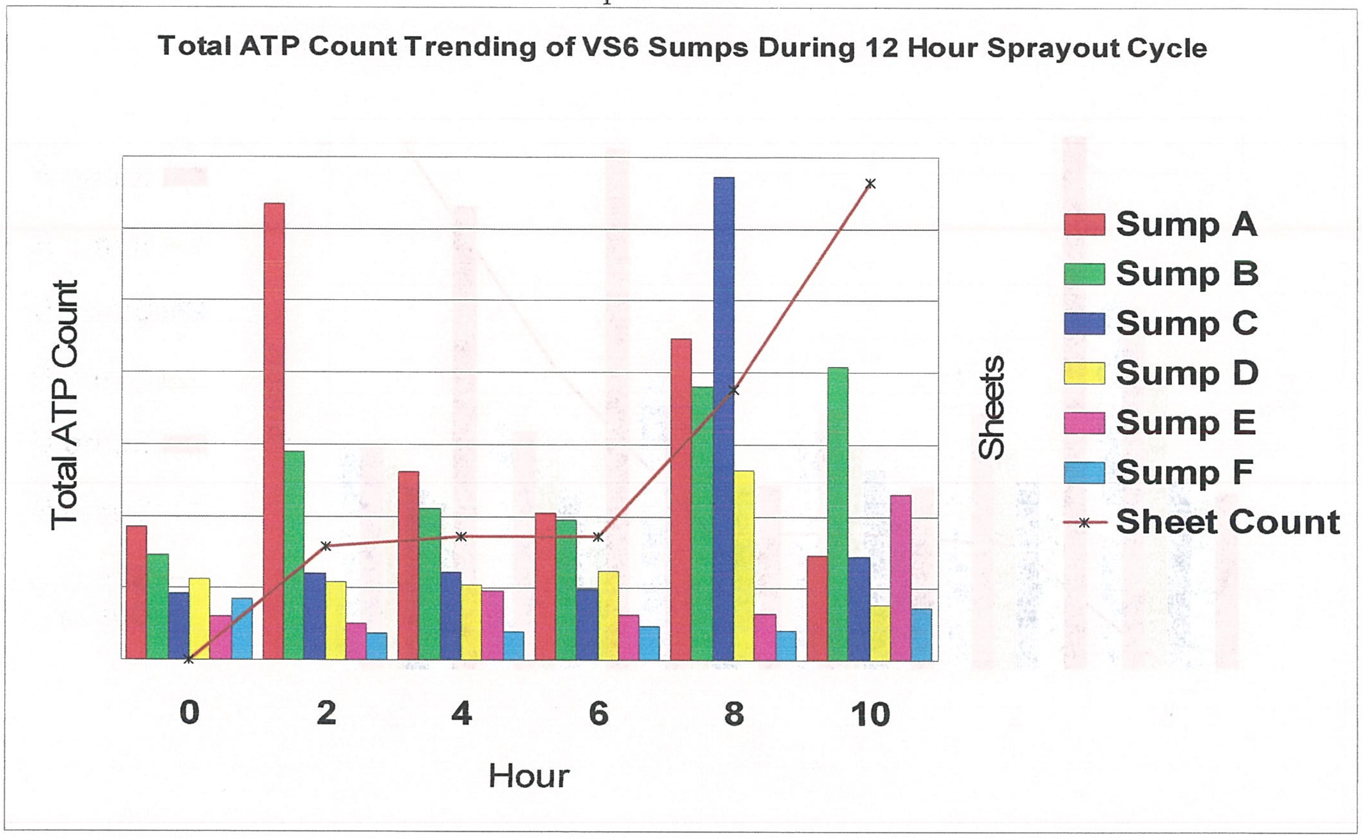


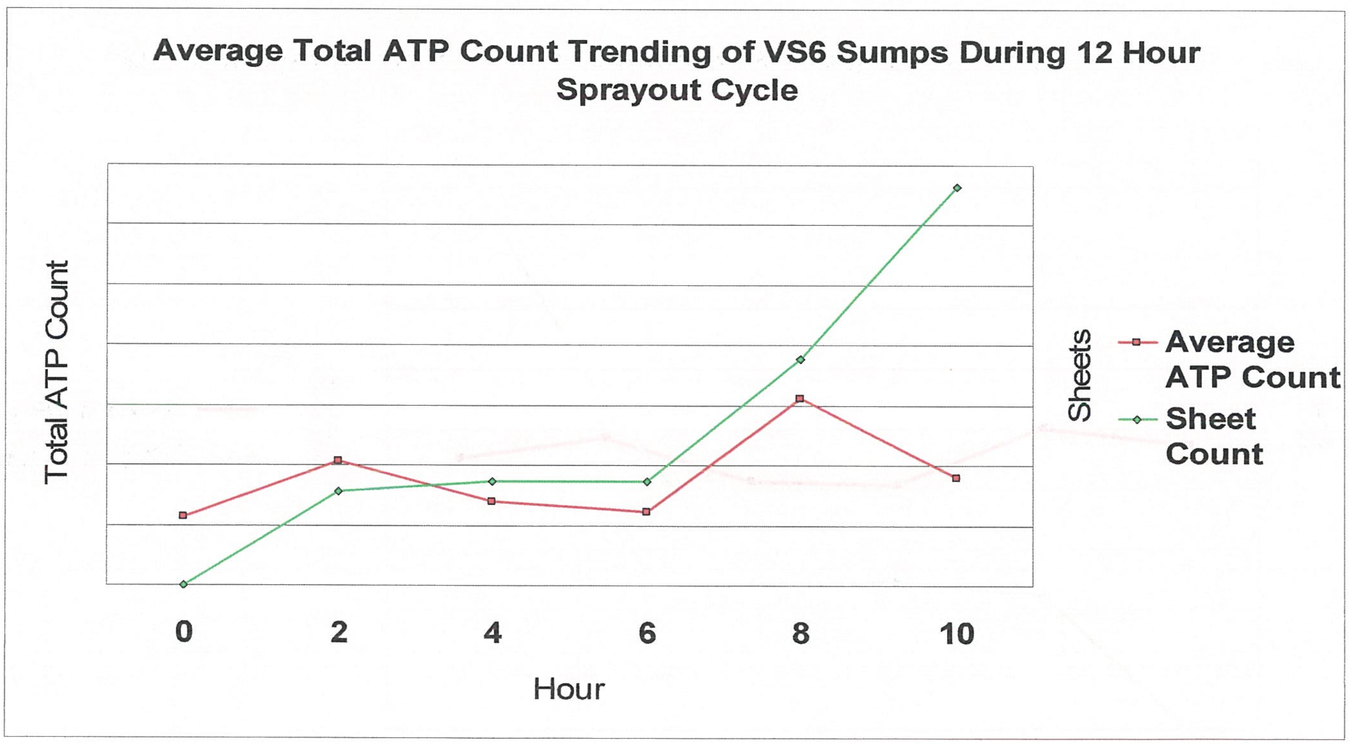
Graphs 25 and 26



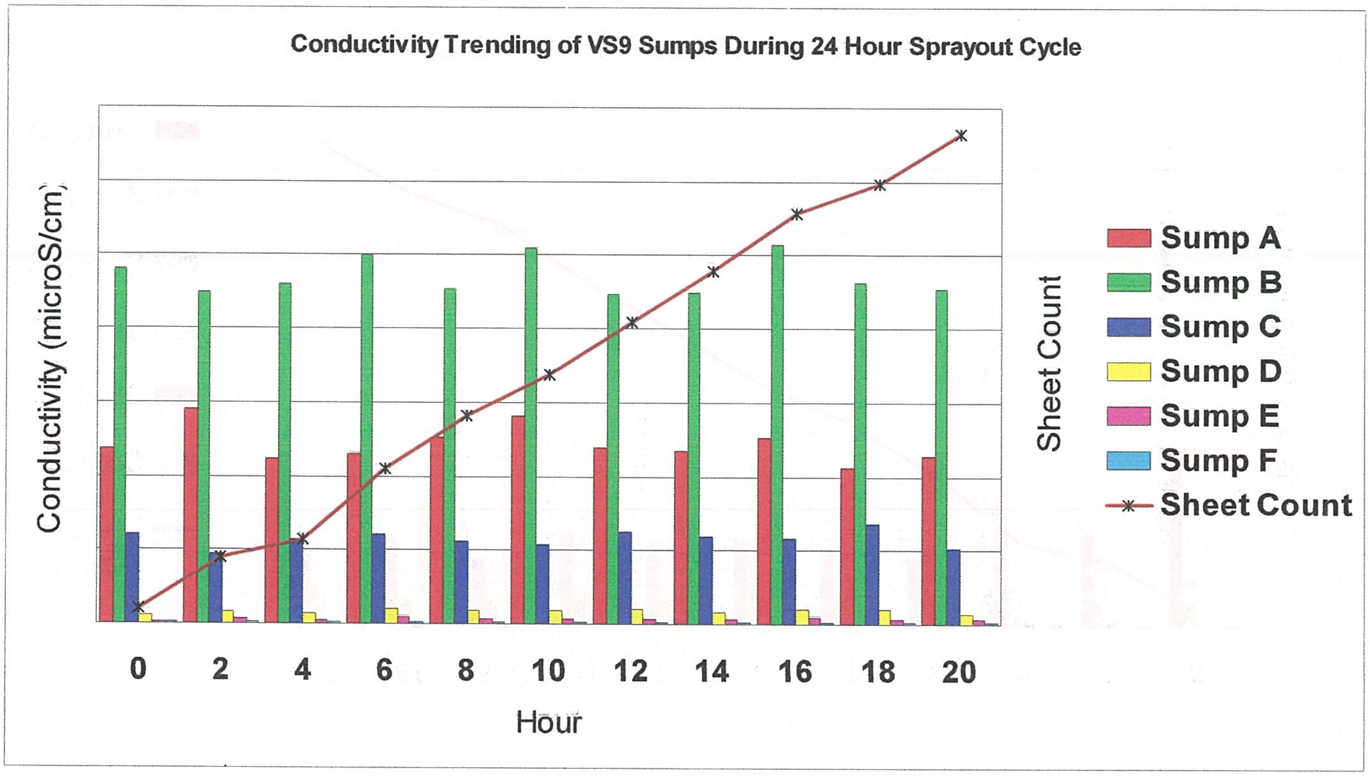


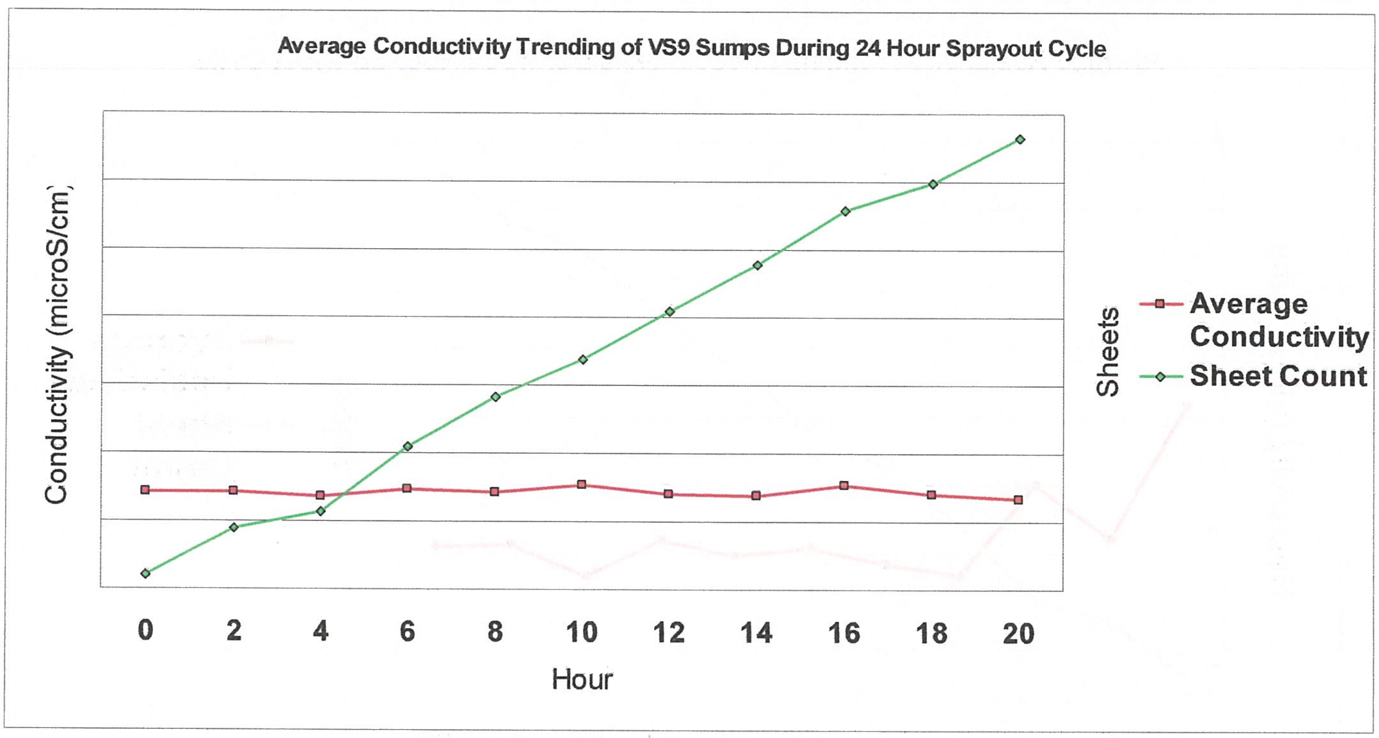
Graphs 27 and 28



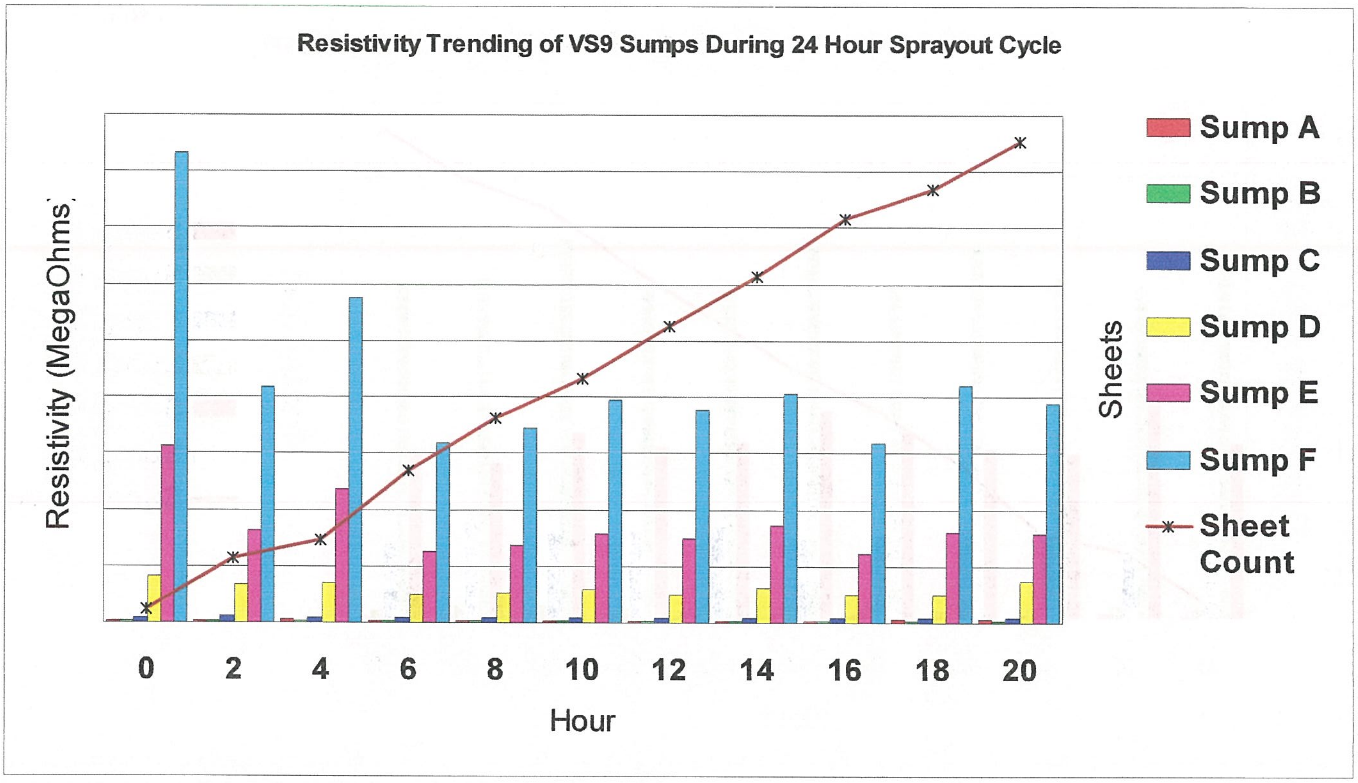


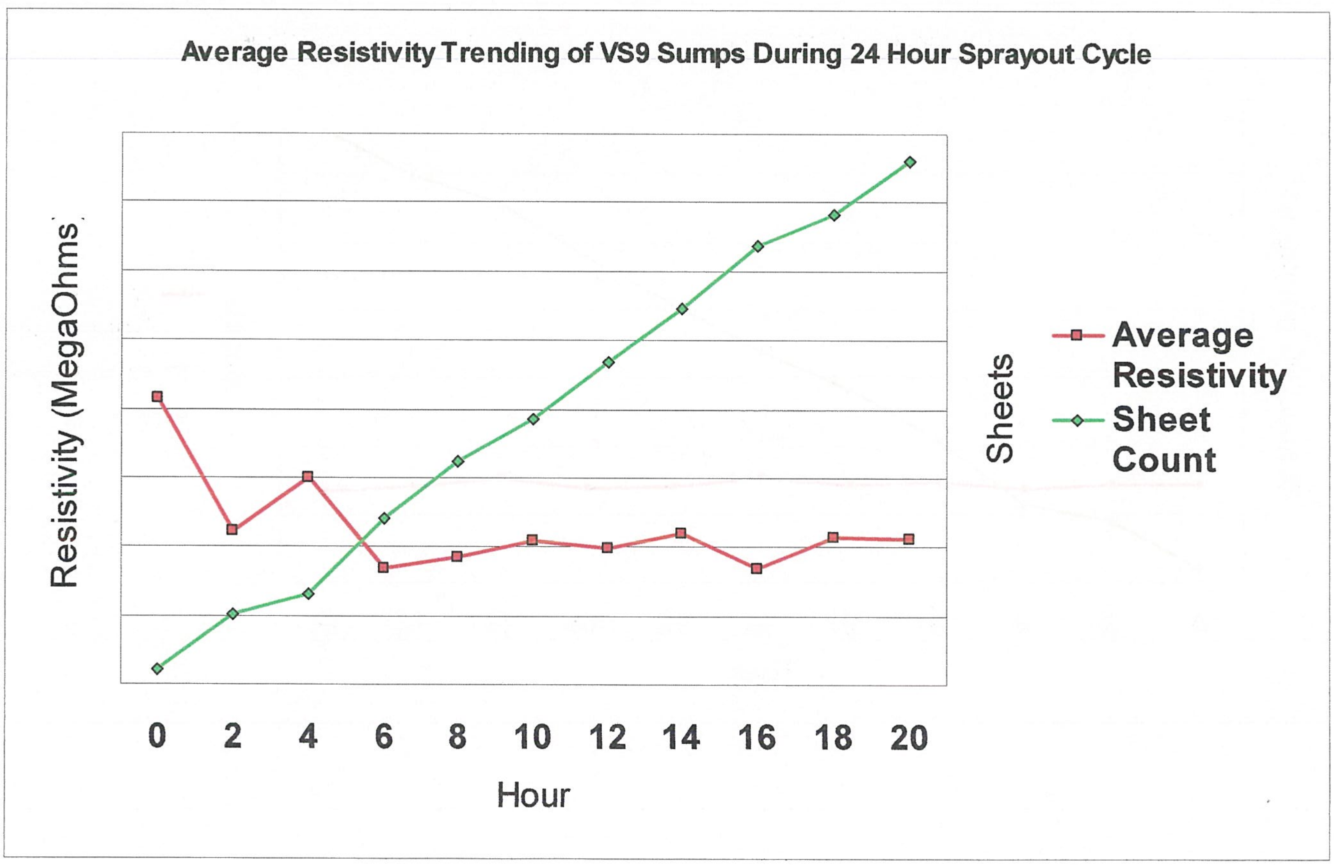
Graphs 29 and 30

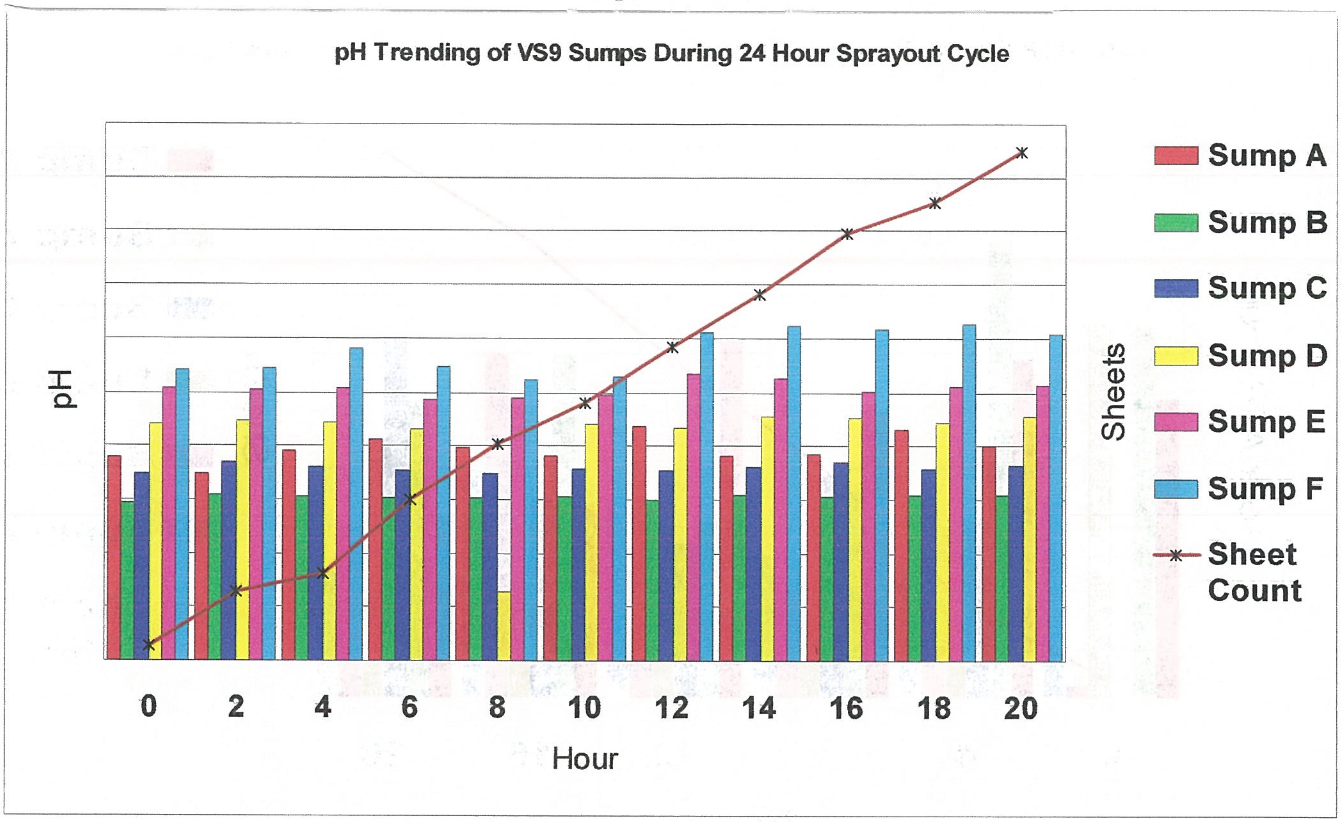


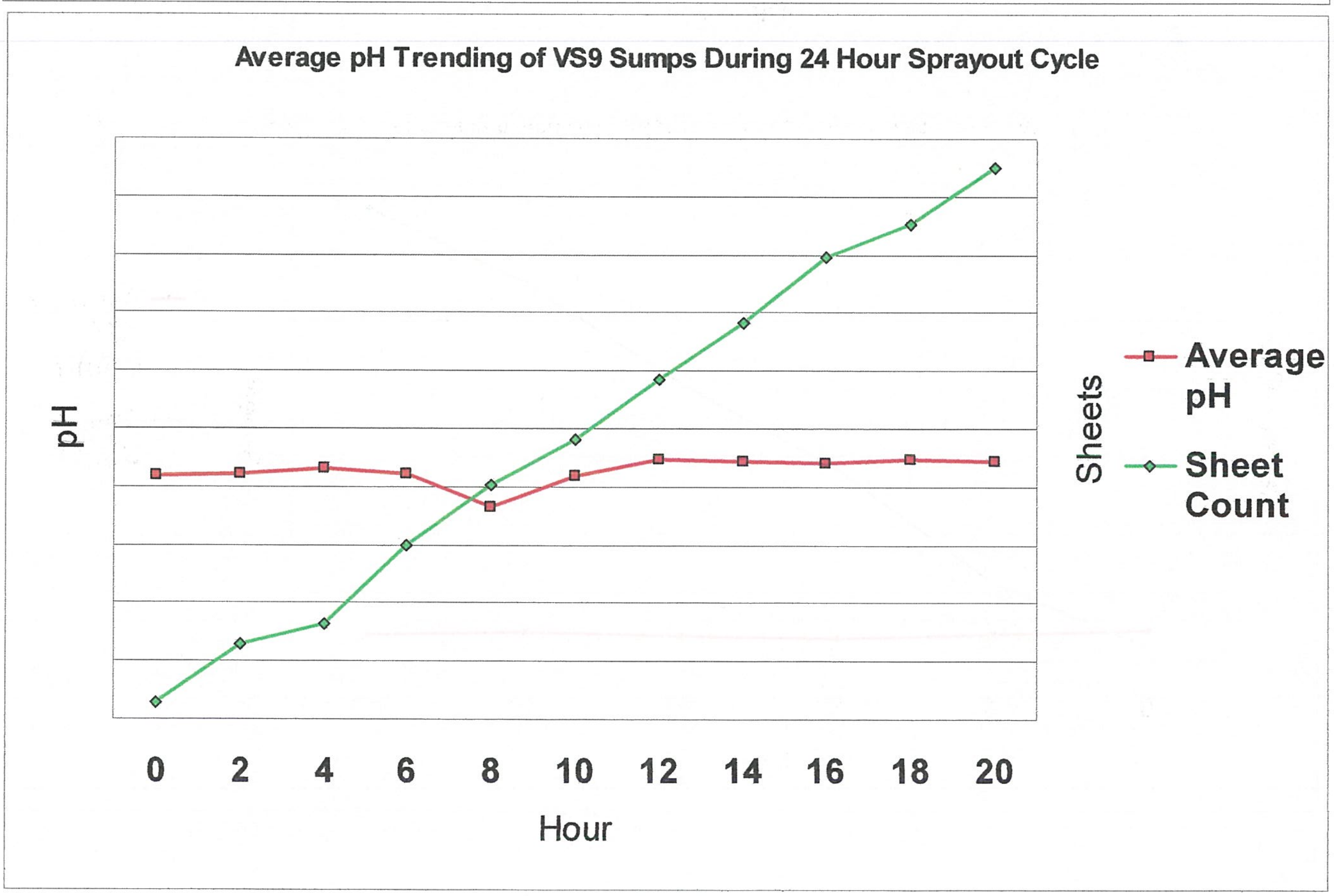


Graphs 31 and 32

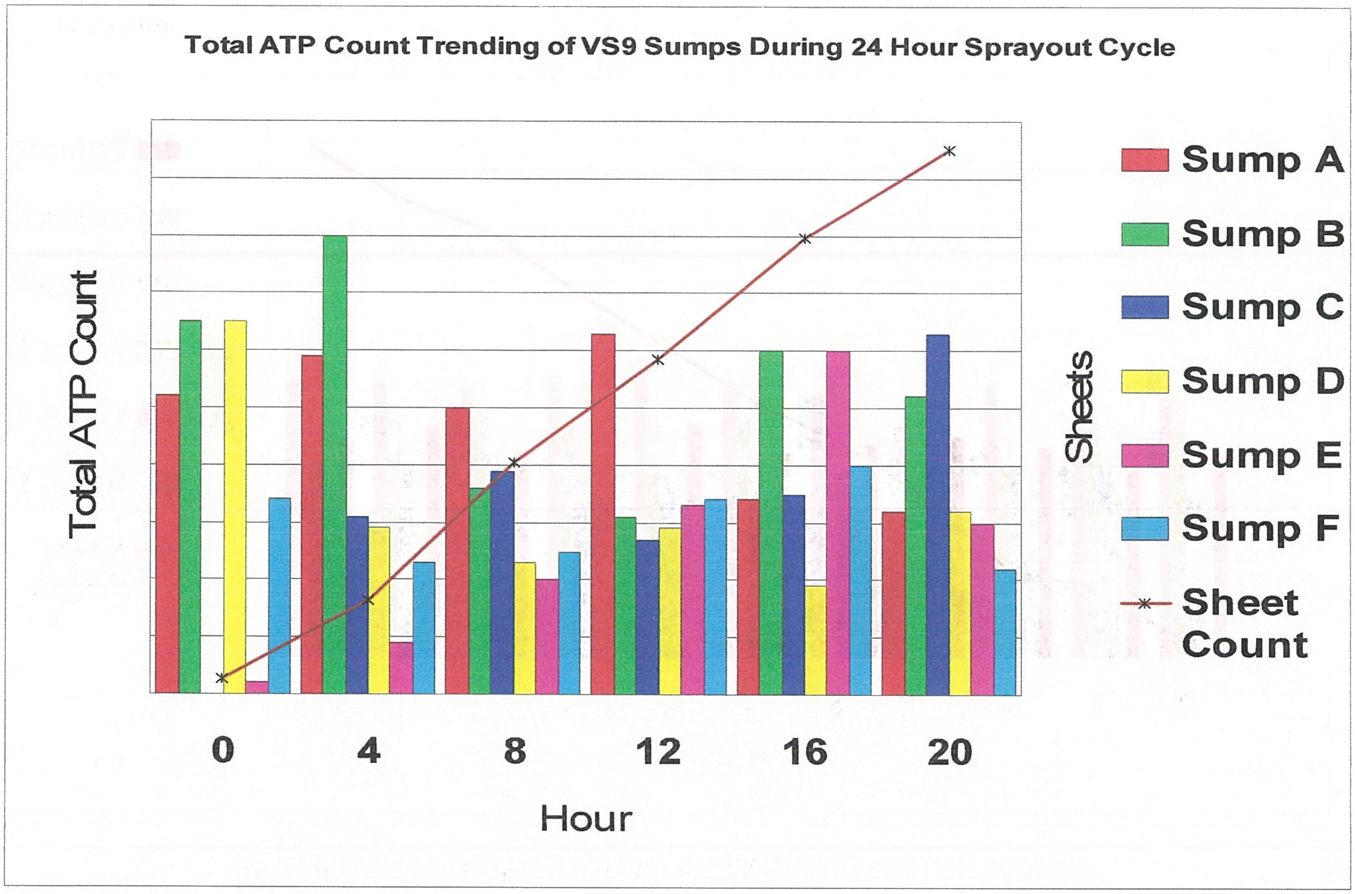


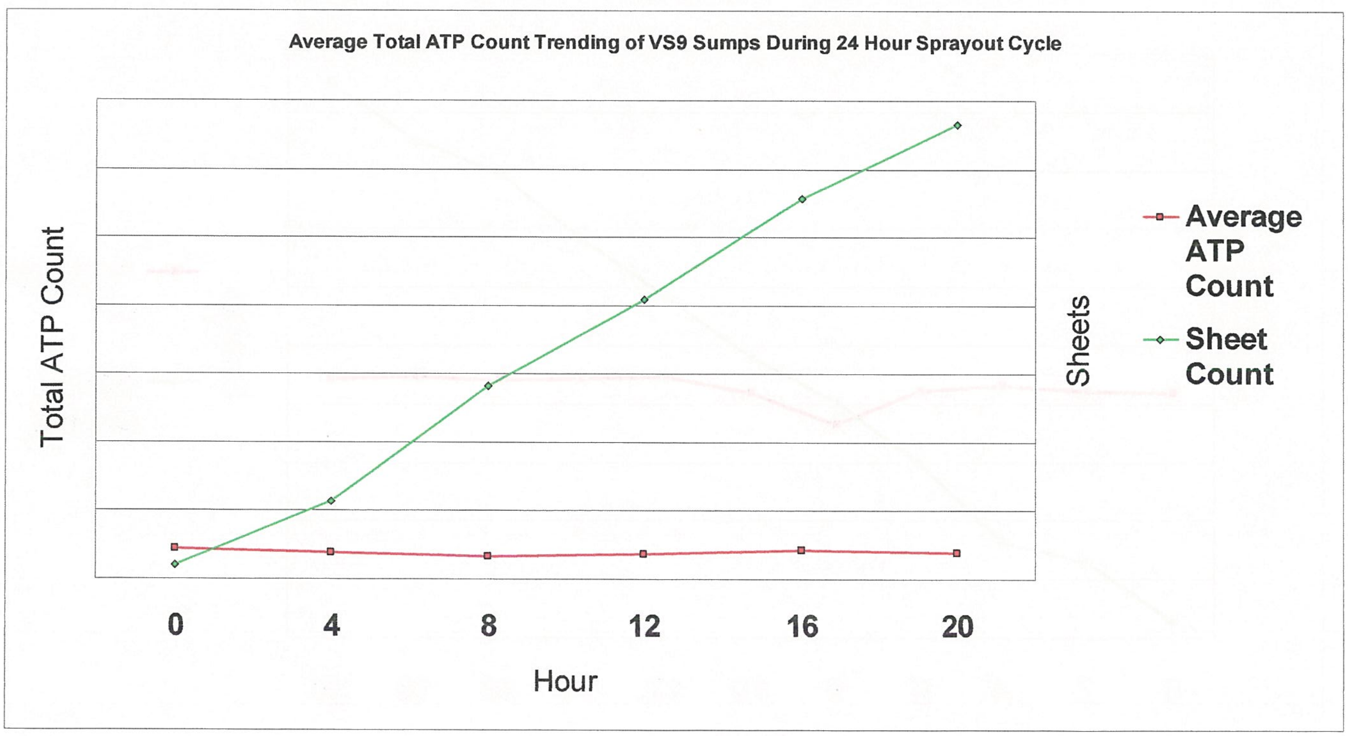



pH Trending of VS9 Sumps During 24 Hour Sprayout Cycle
pH
Sheets
Sump A
Sump B
Sump C
Sump D
Sump E
Sump F
Sheet Count
0 2 4 6 8 10 12 14 16 18 20
Hour

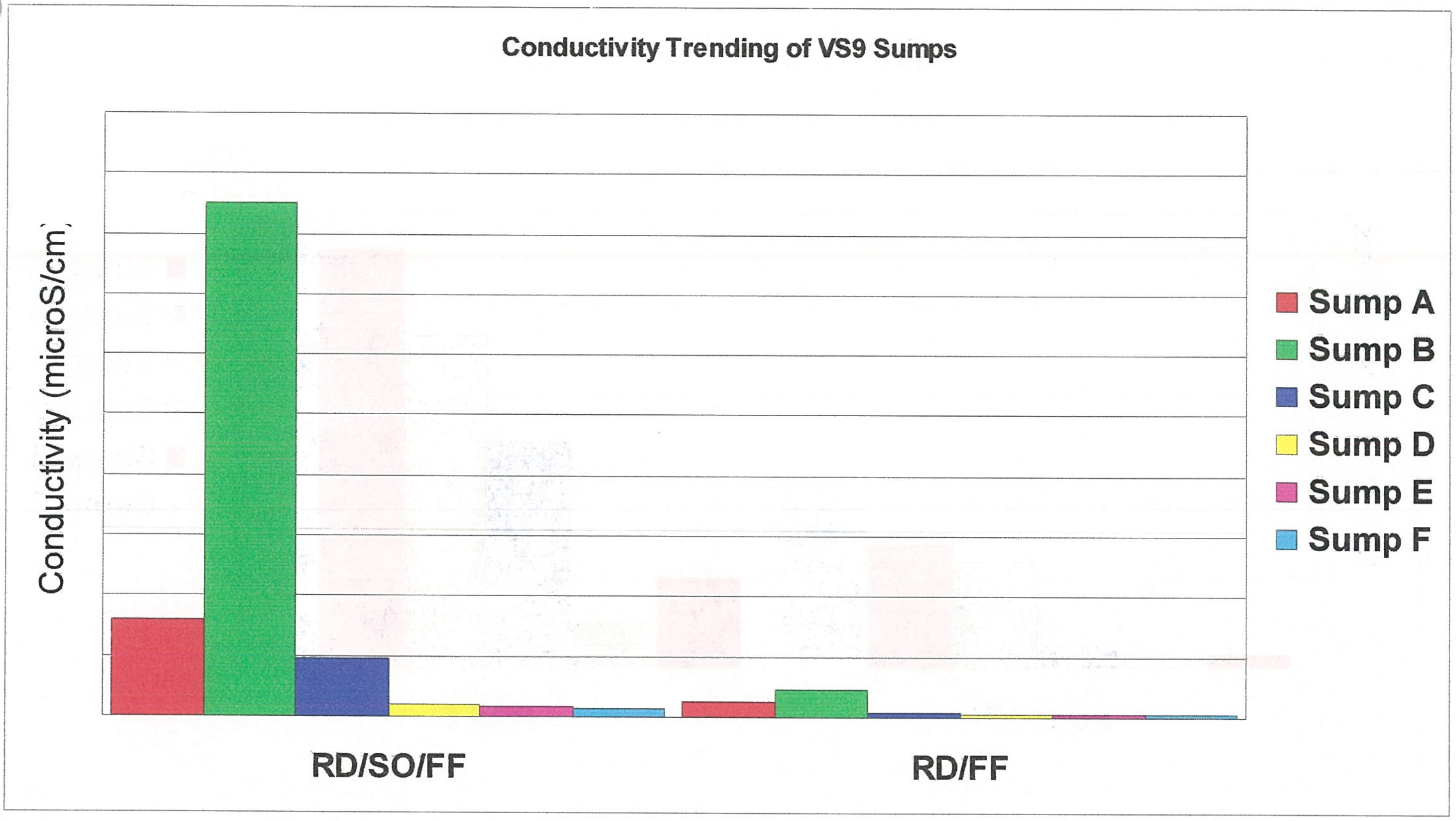

Average pH Trending of VS9 Sumps During 24 Hour Sprayout Cycle
pH
Sheets
Average pH
Sheet Count
0 2 4 6 8 10 12 14 16 18 20
Hour

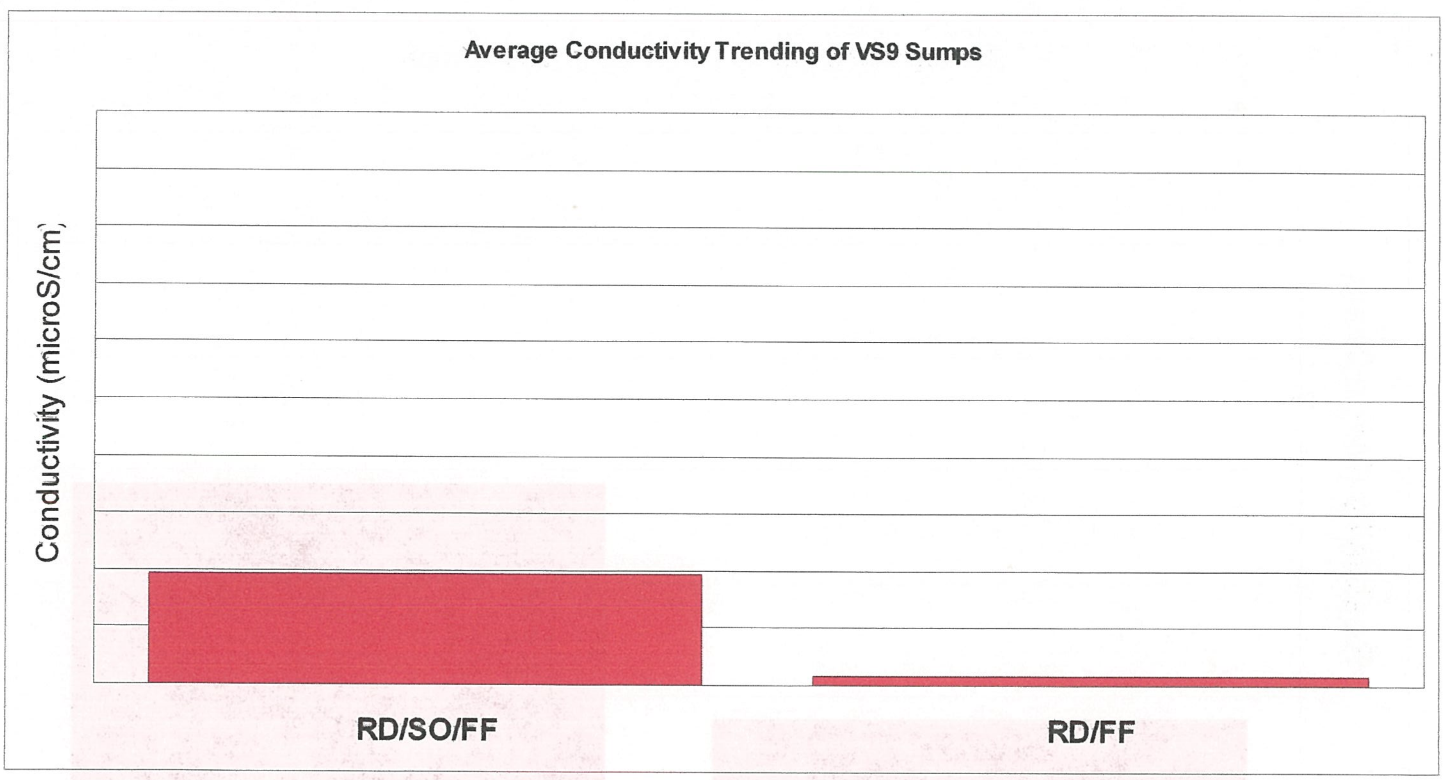
Graphs 35 and 36



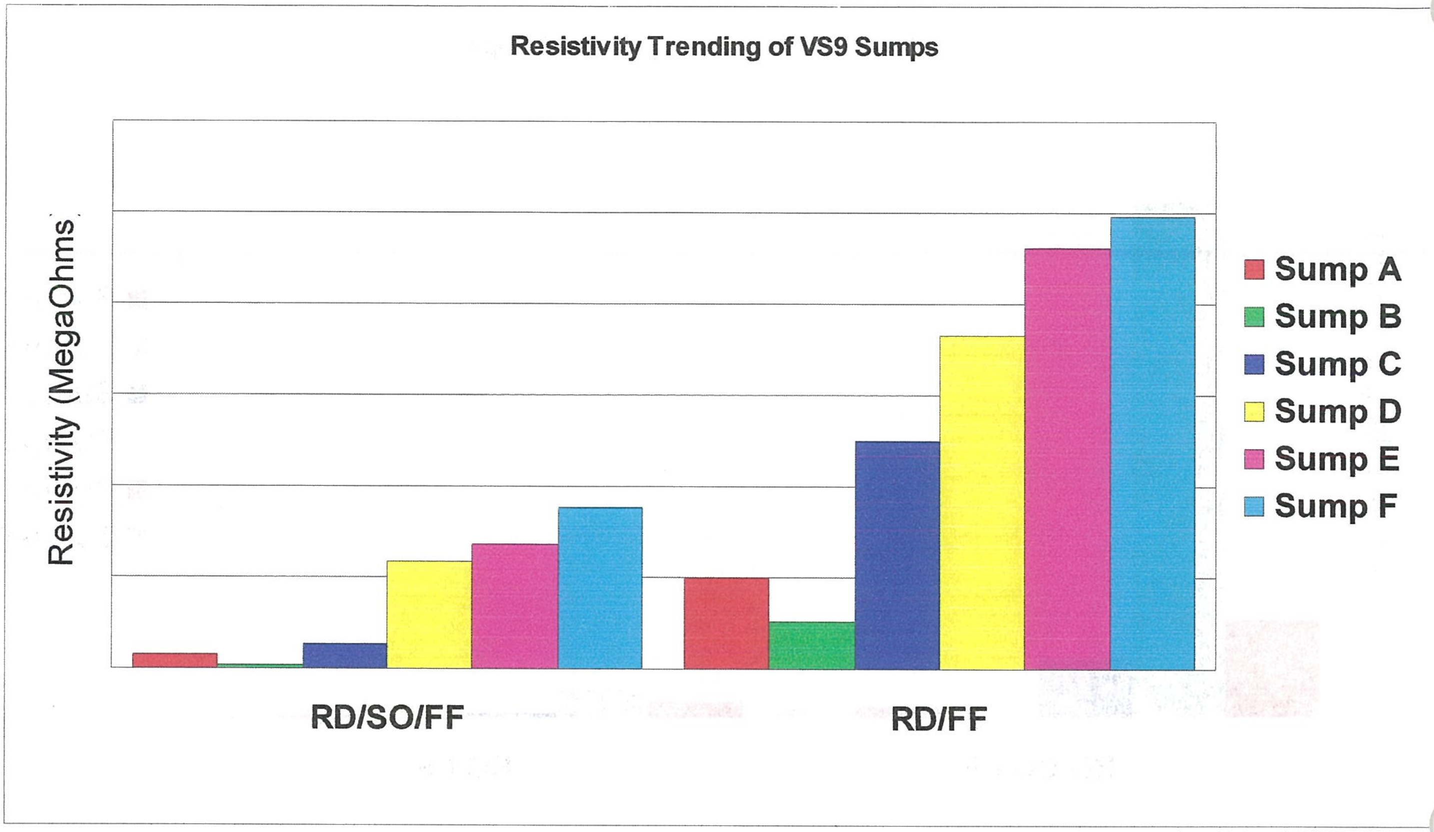


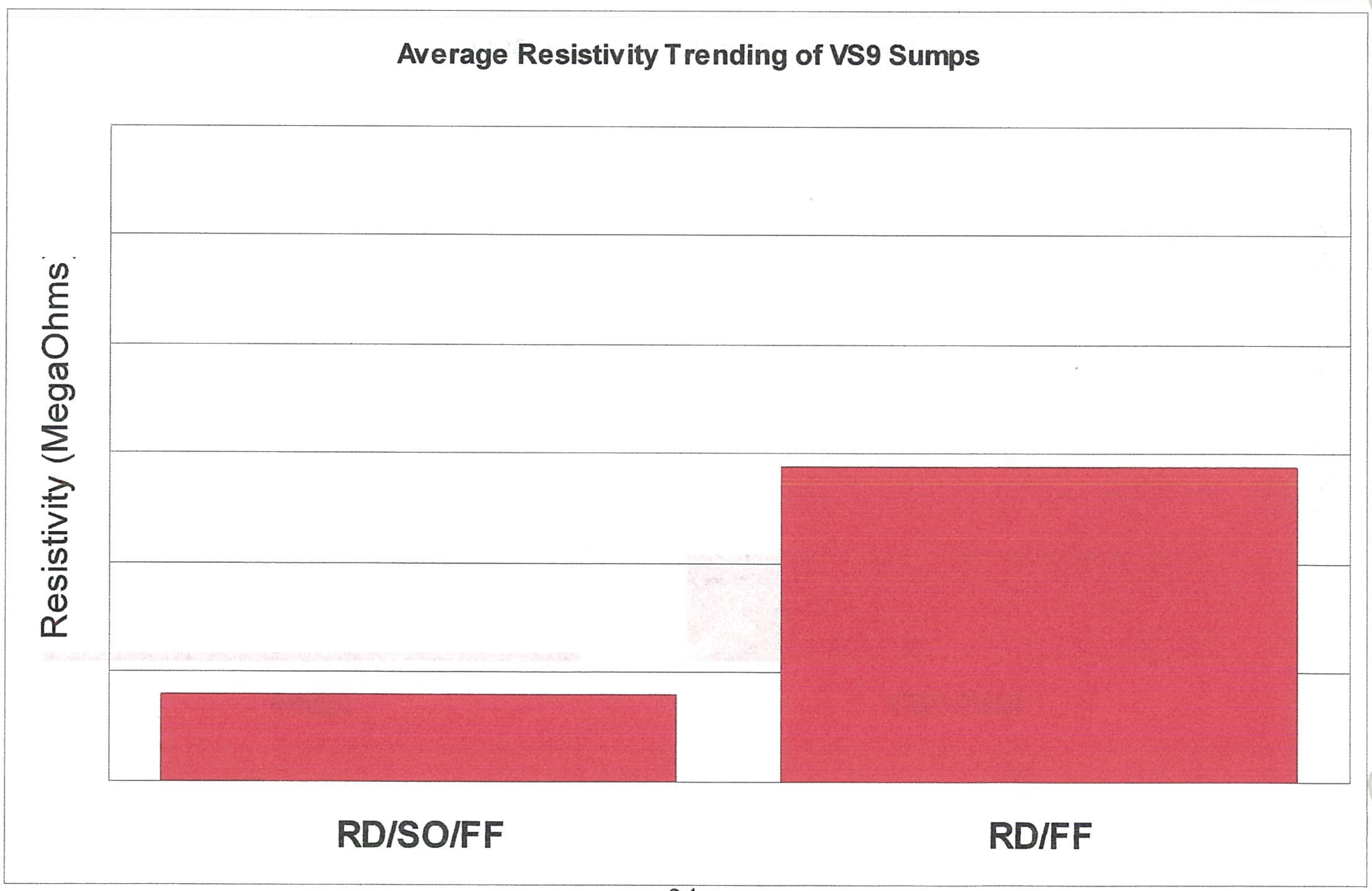
Graphs 37 and 38



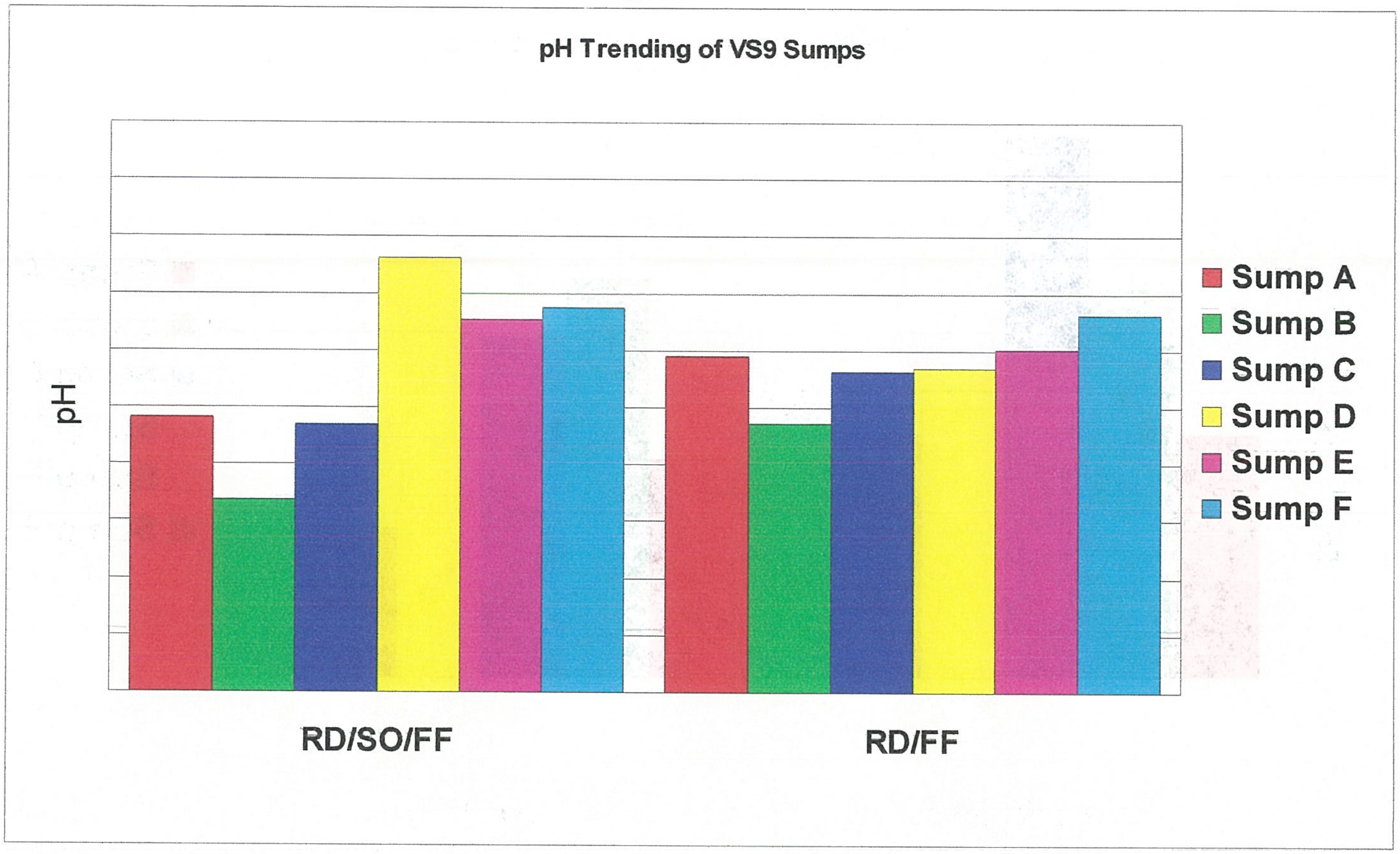


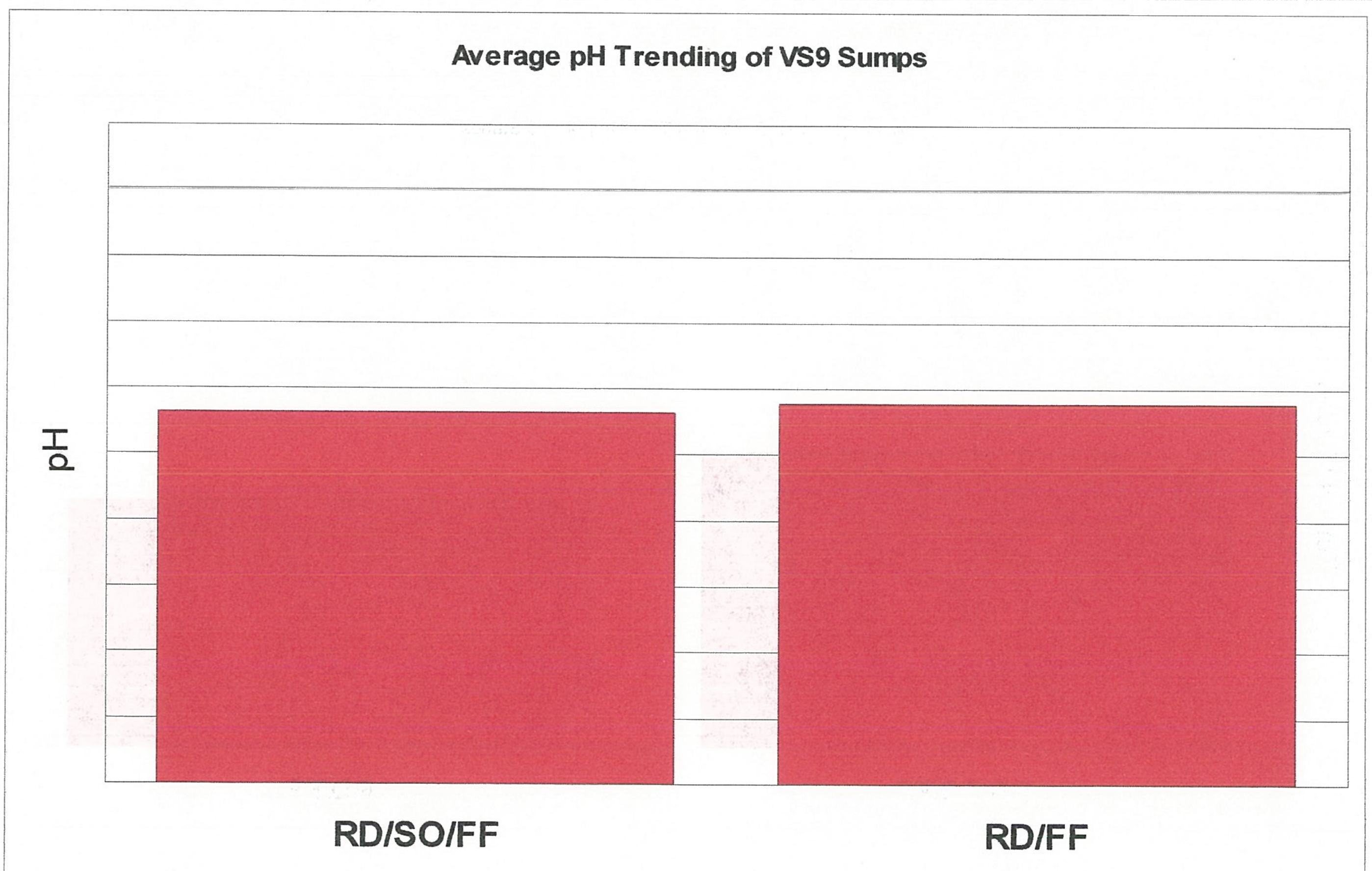
Graphs 39 and 40



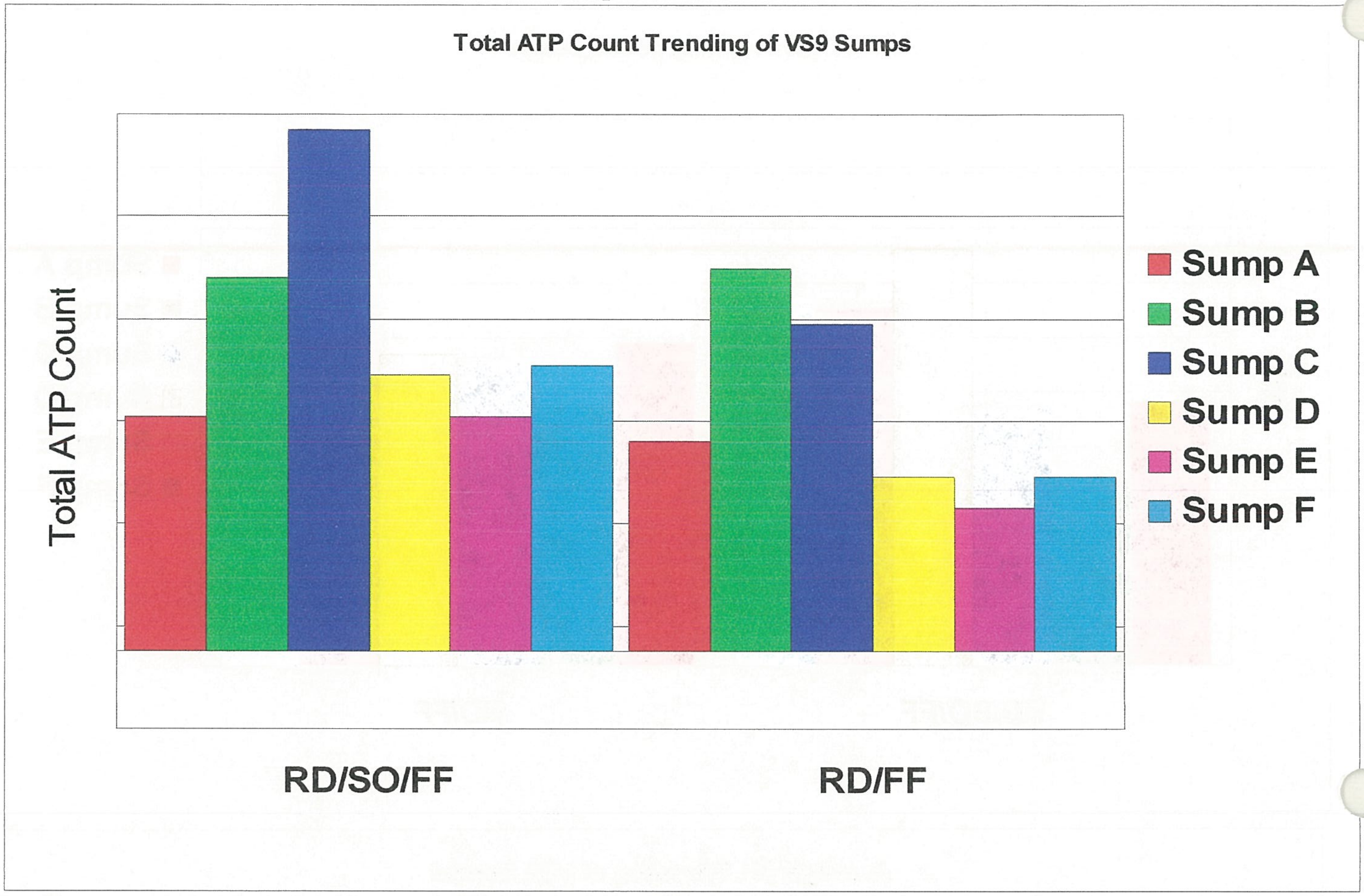


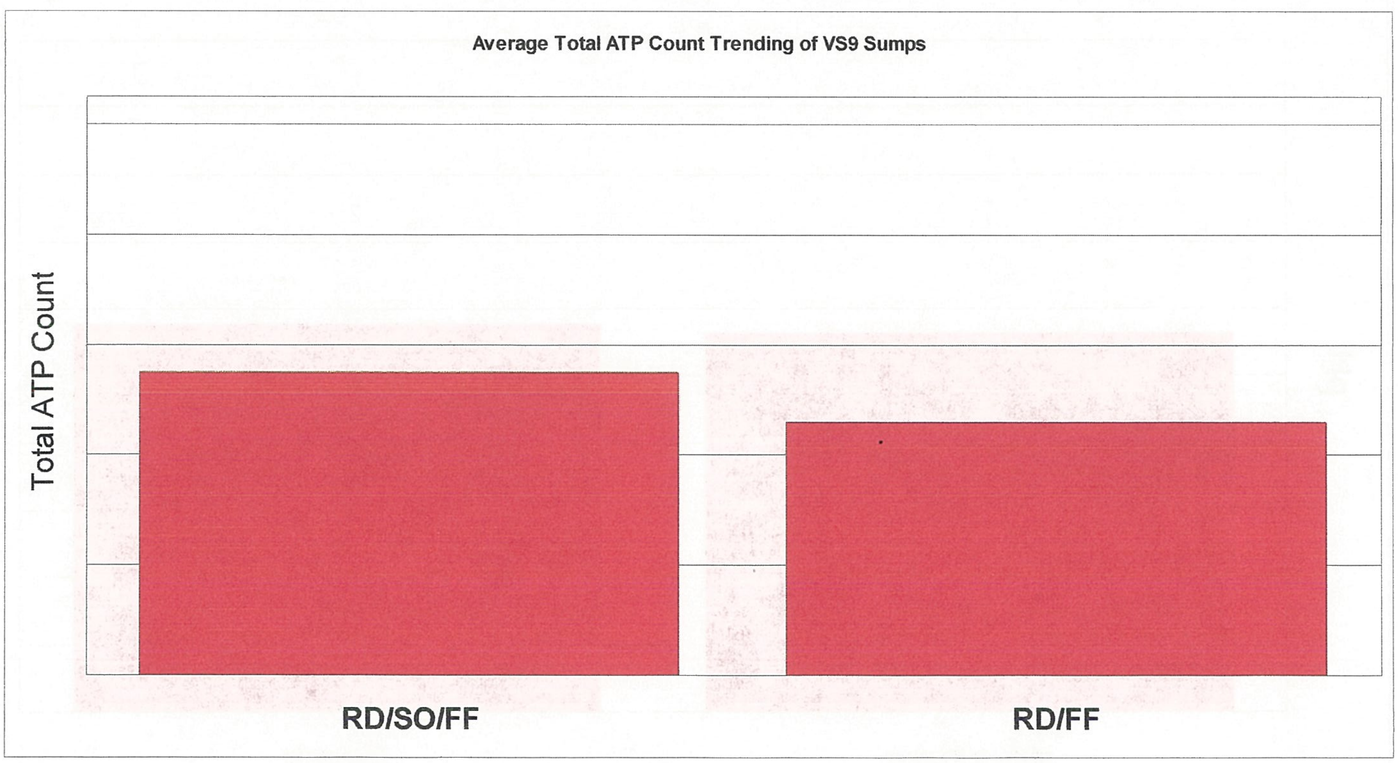
Graphs 41 and 42



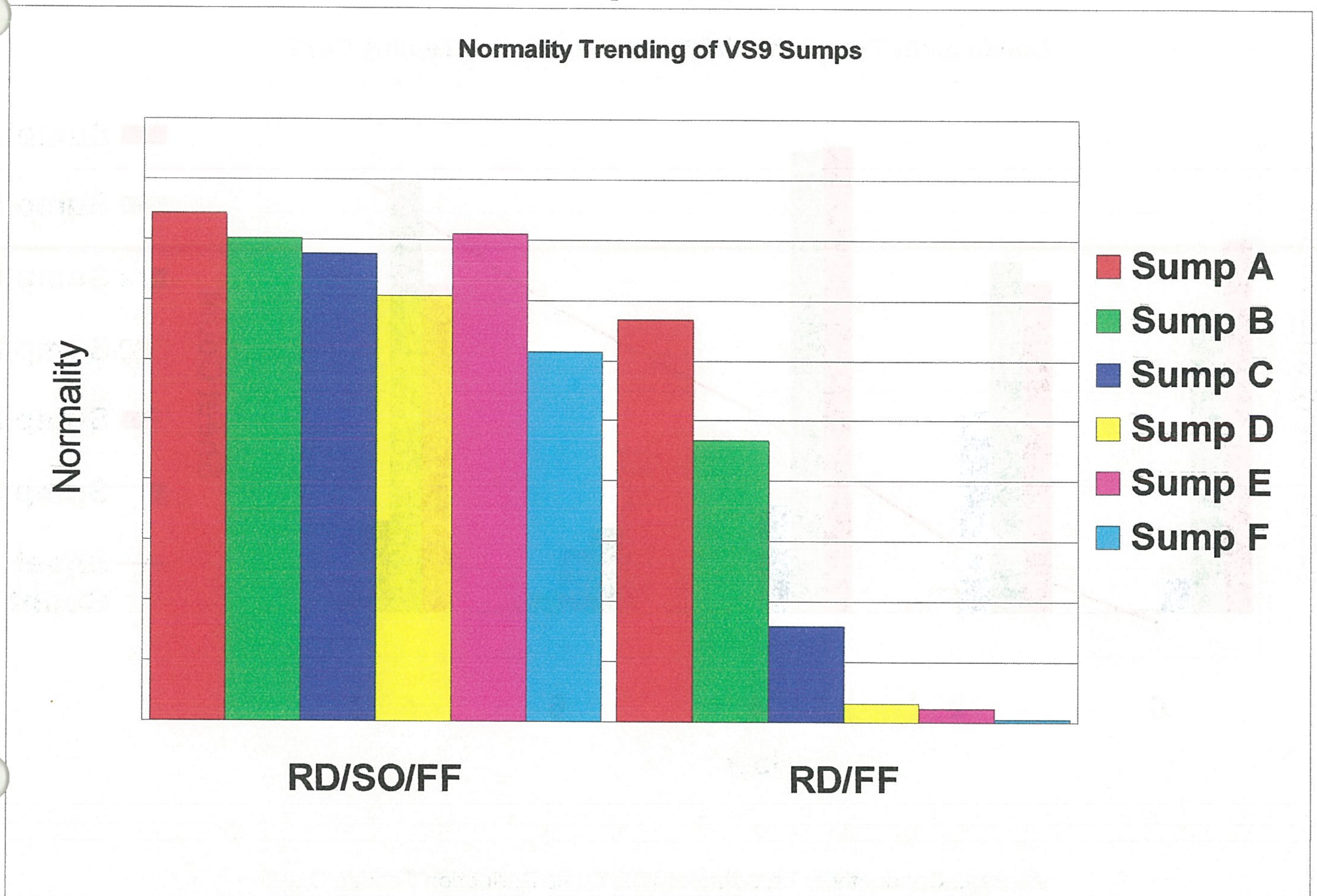


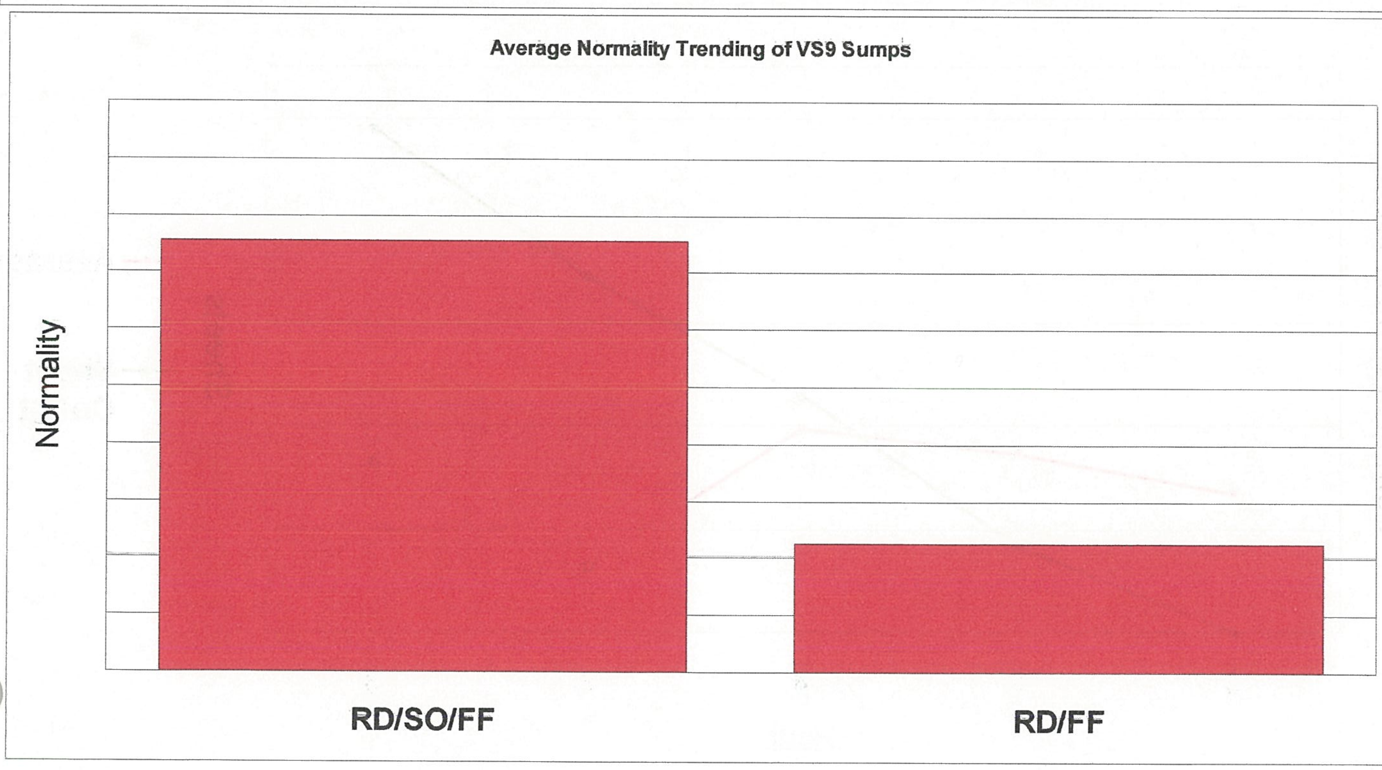
Graphs 43 and 44



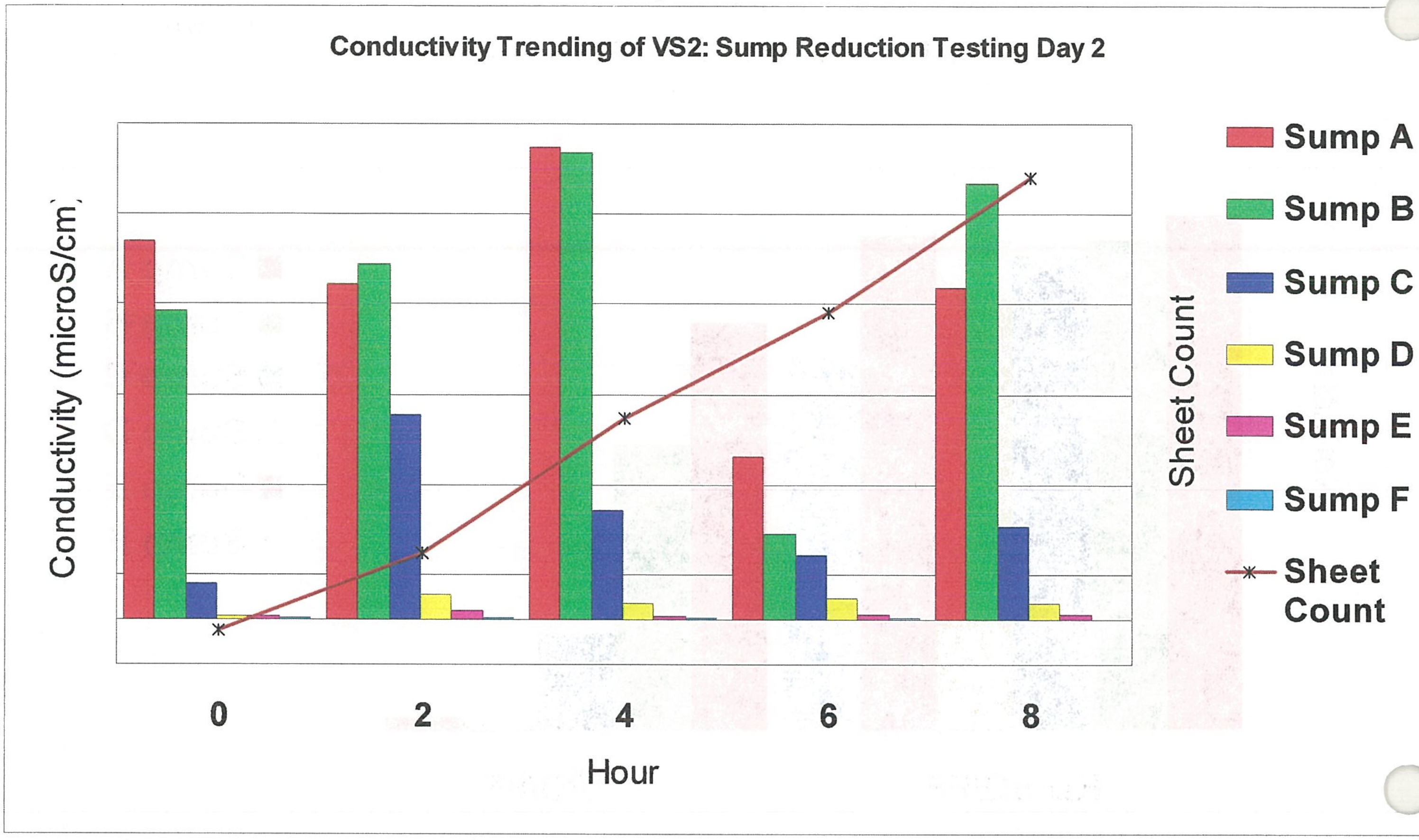


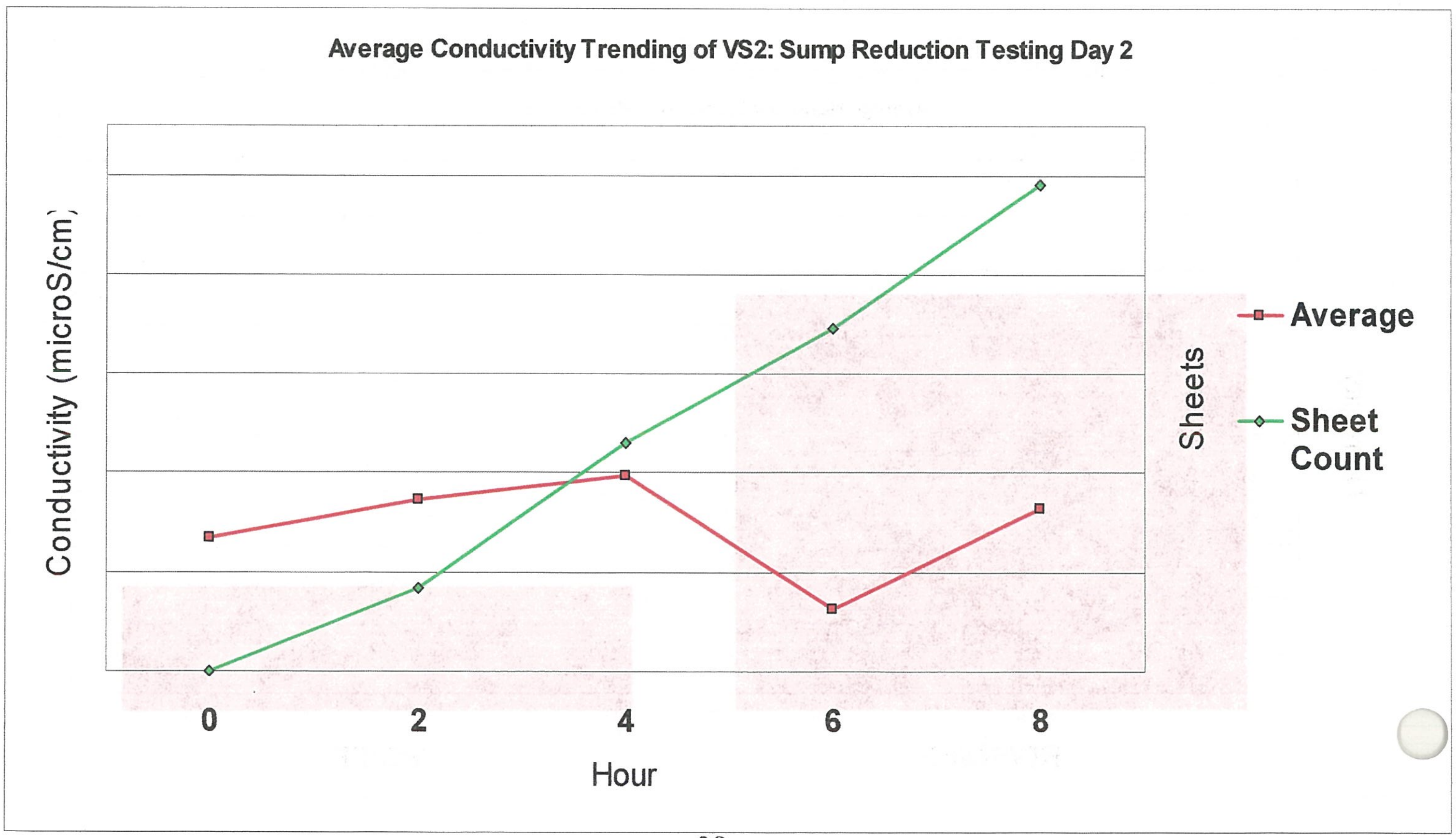
Graphs 45 and 46



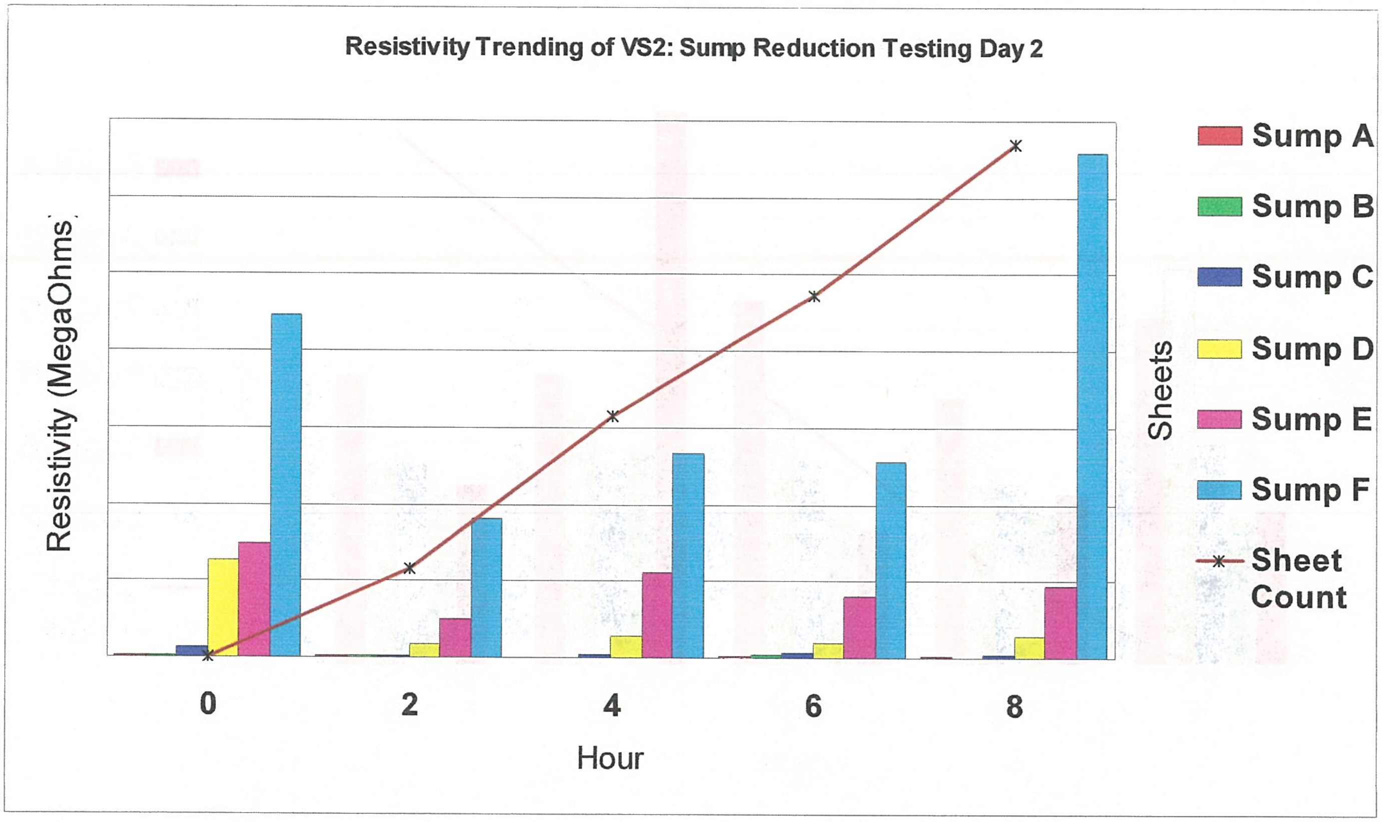


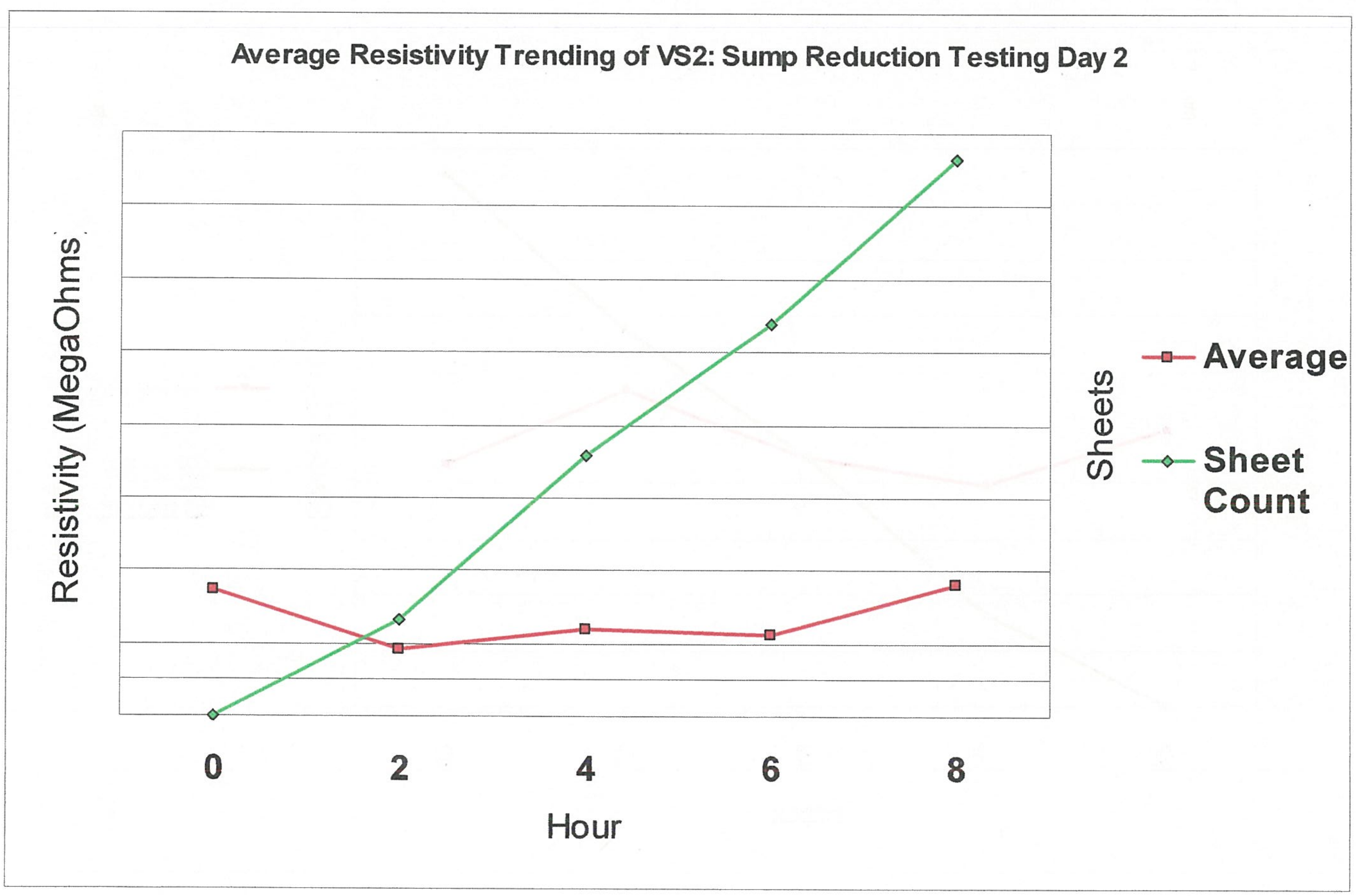
Graphs 47 and 48



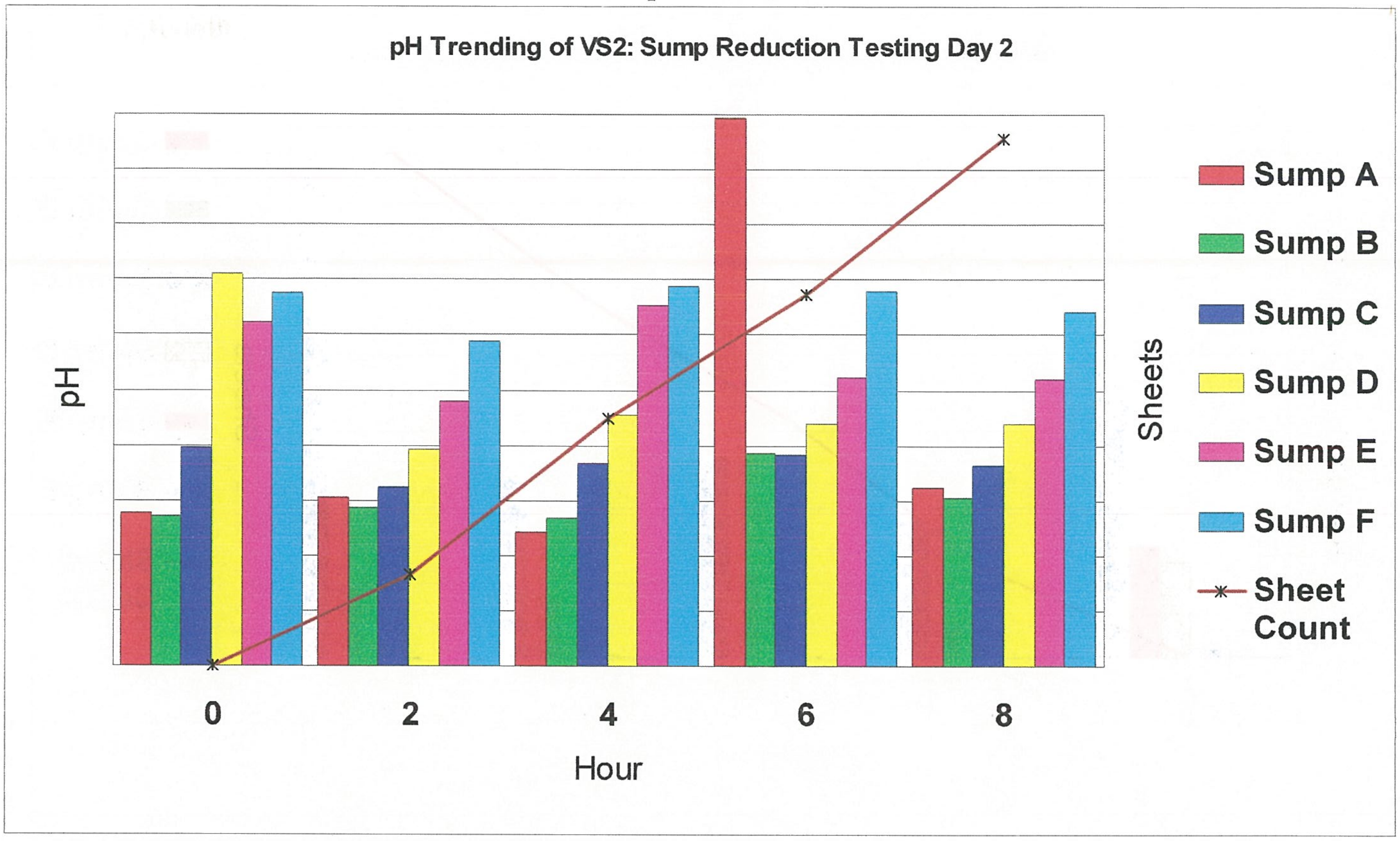


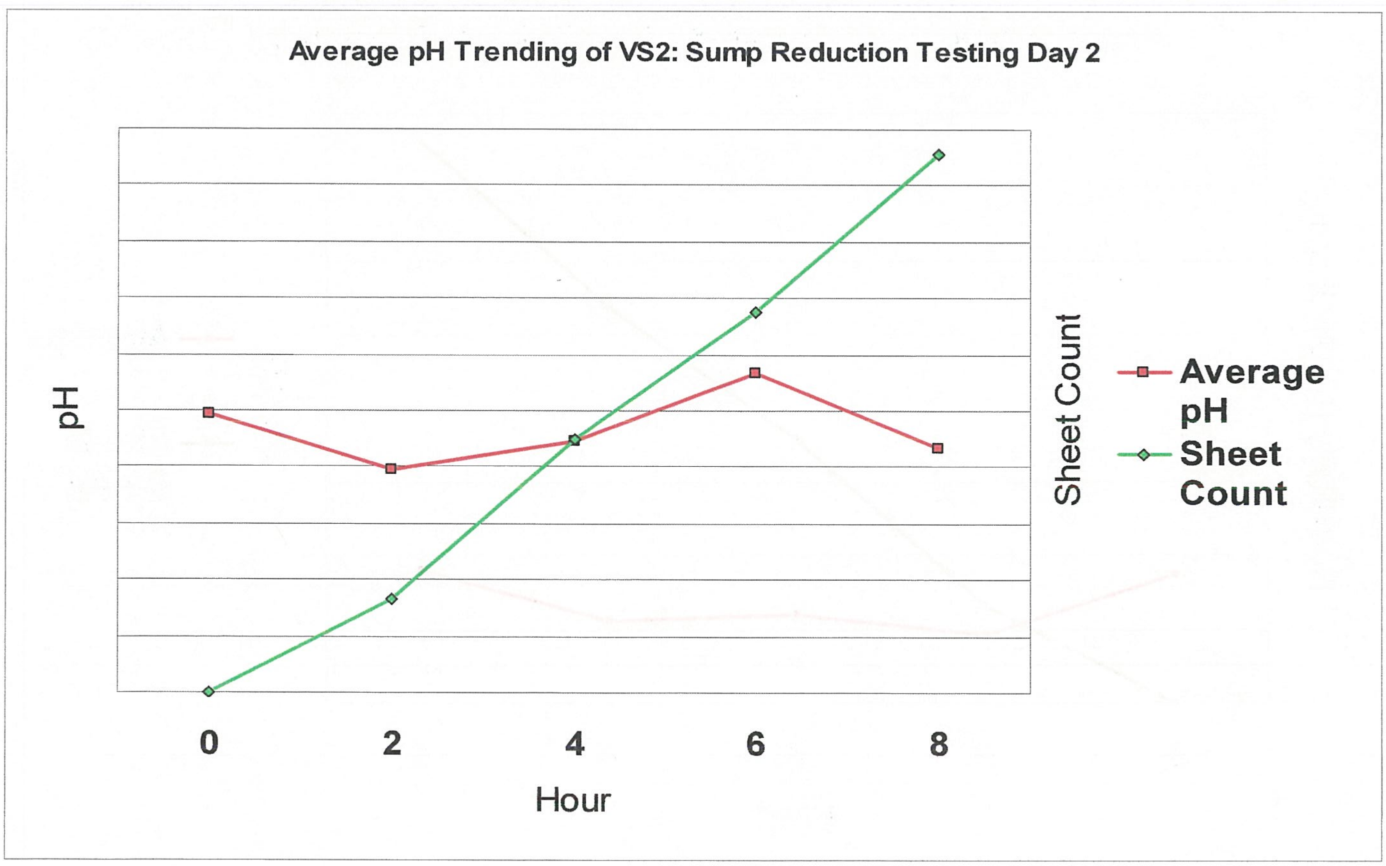
Graphs 49 and 50



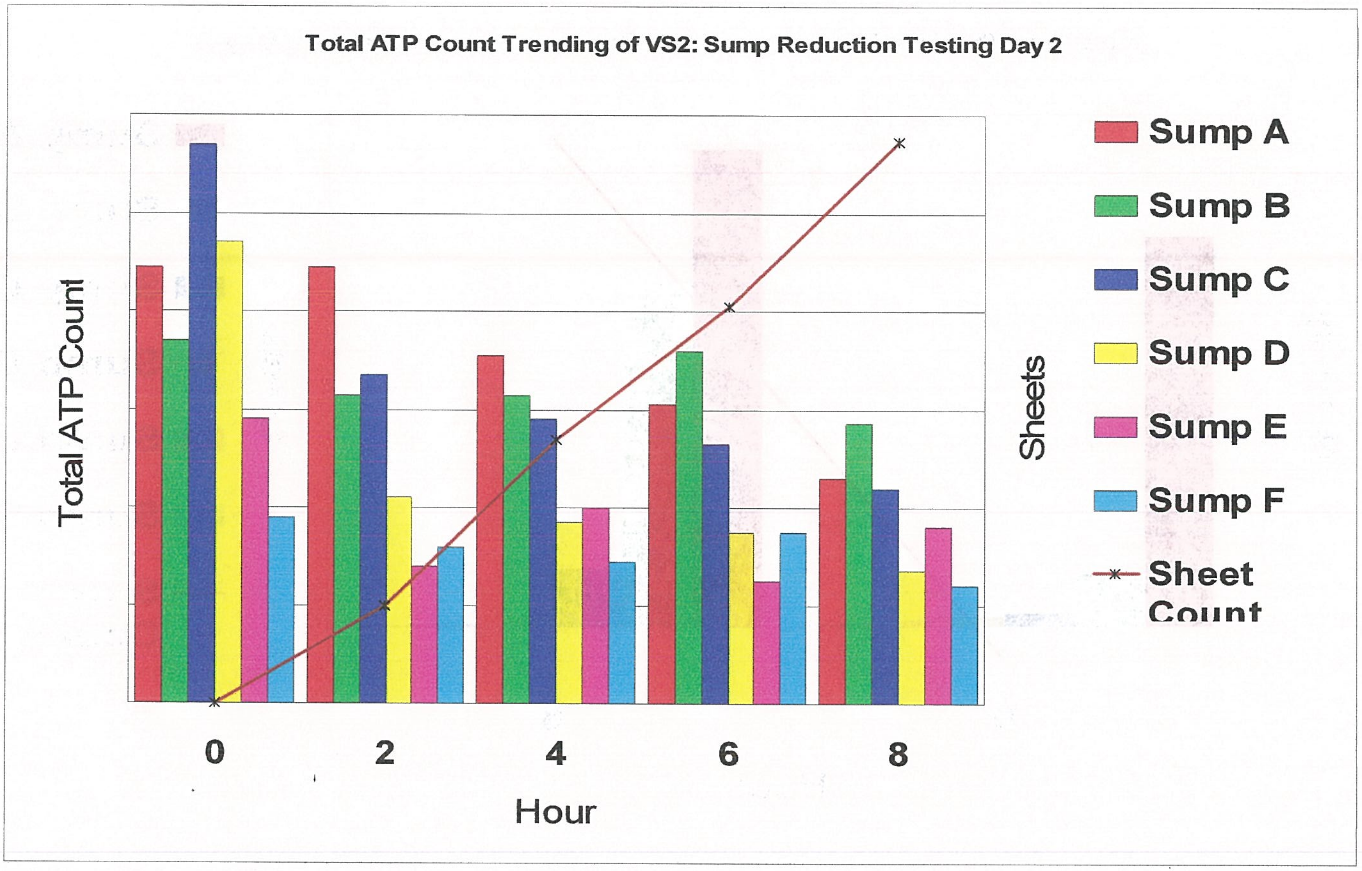


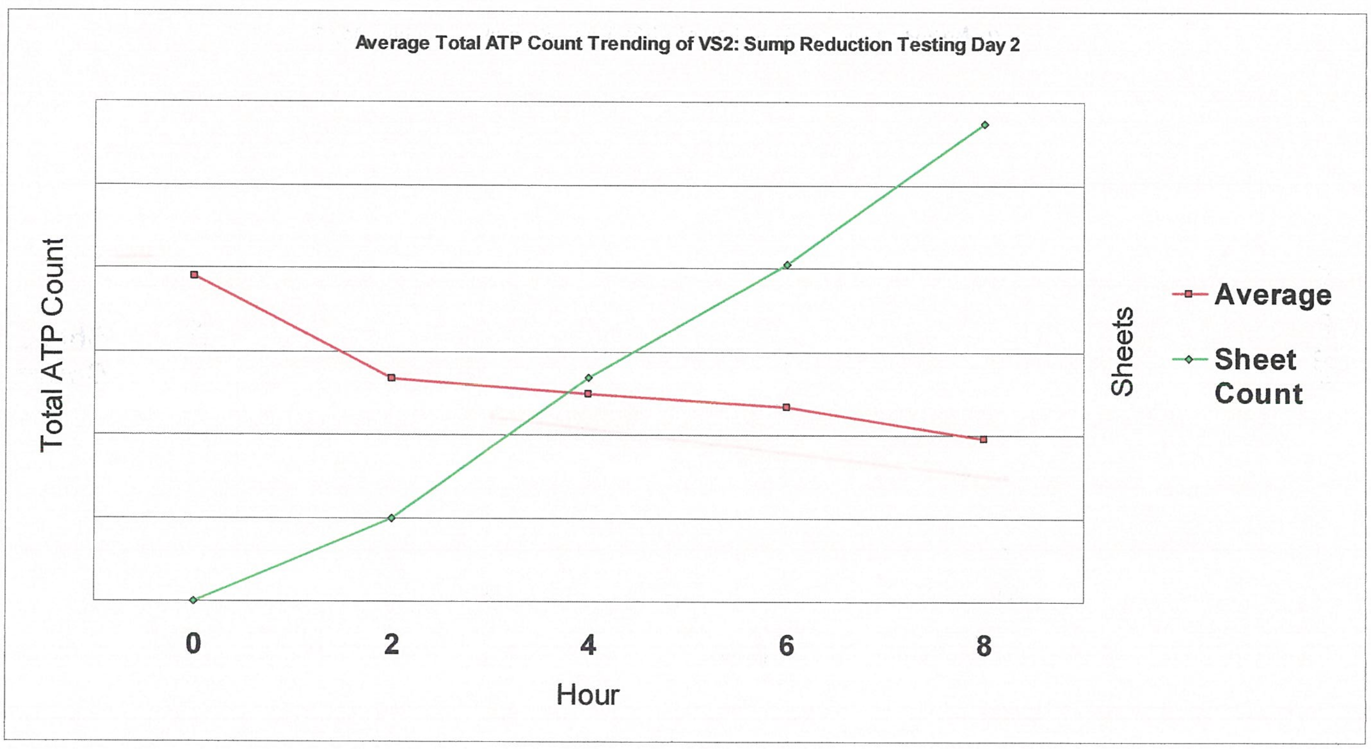
Graphs 51 and 52



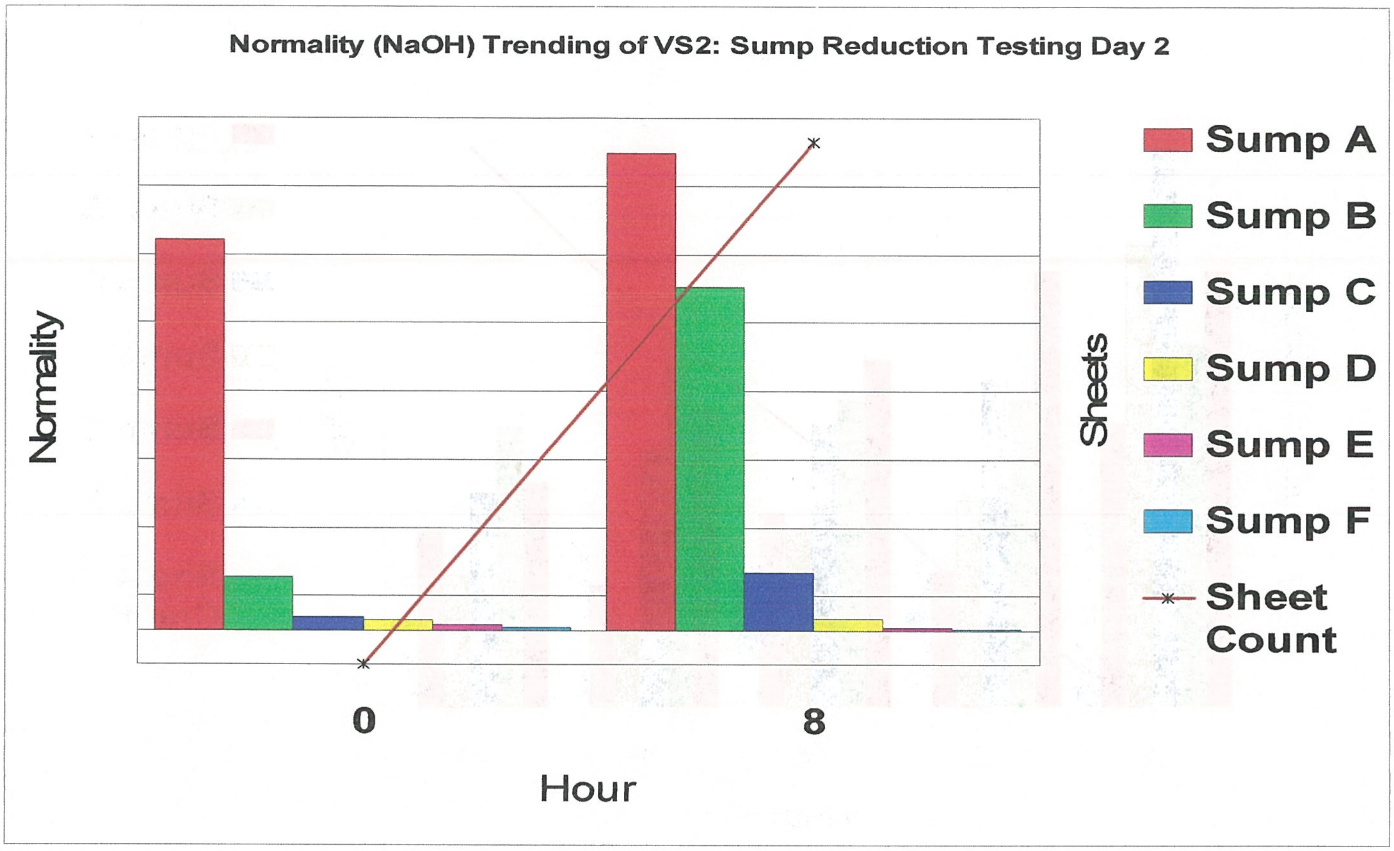


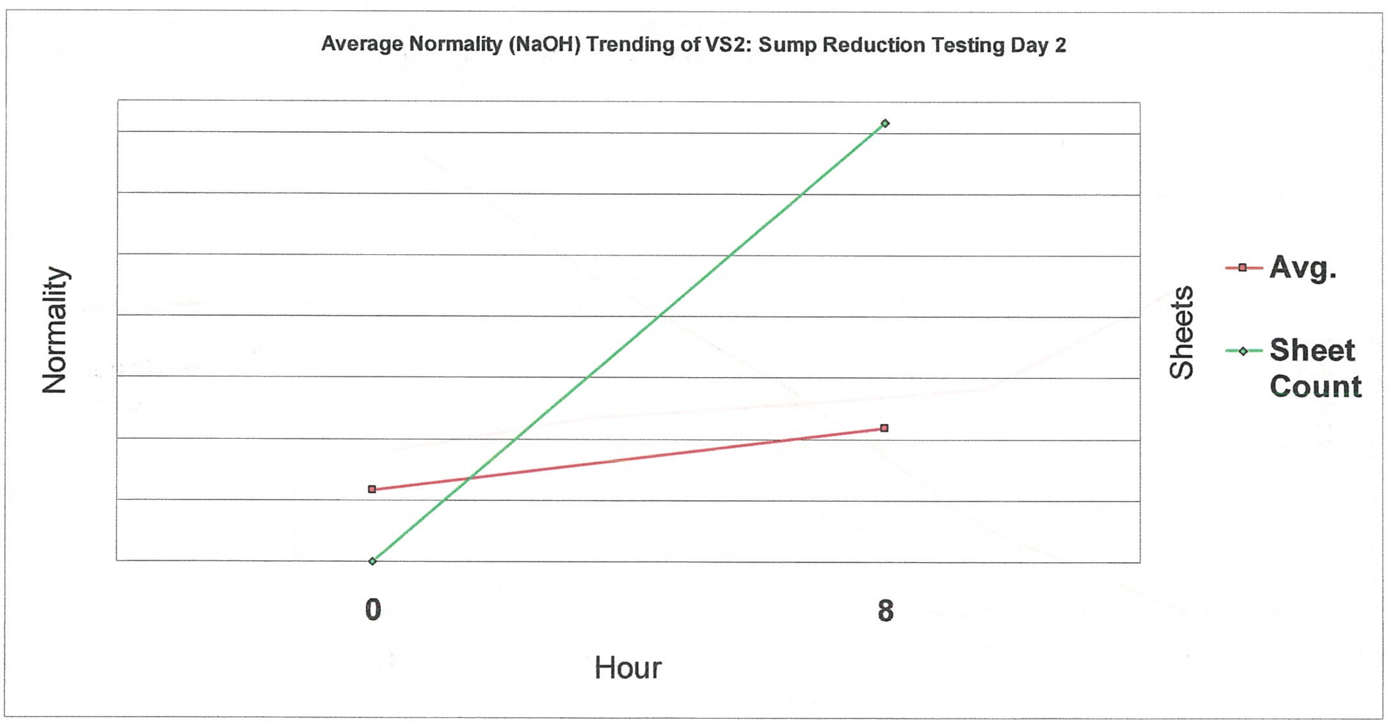
Graphs 53 and 54





Graphs 55 and 56





Calculations

Abstract
17 Cookouts/year x 900 Gallons/cookout x 2 machines + 26 Cookouts/year x 900 Gallons/cookout x 1 machine = 54,000 Gallons DI/year

13 Cookouts/year x 900 Gallons/cookout x 3 machines = 35,000 Gallons/year → 19,000 Gallons saved/Year

5 Sprayouts/Day x 300 Gallons/Sprayout x 365 Days/Year = 550,000 Gallons/year

3 Sprayouts/Day x 300 Gallons/Sprayout x 365 Days/Year = 330,000 Gallons/year → 220,000 Gallons/year saved

17 Cookouts/year x 900 Gallons/cookout x 2 machines + 26 Cookouts/year x 900 Gallons/cookout x 1 machine + 5 Sprayouts/Day x 300 Gallons/Sprayout x 365 Days/Year x 70% = 415,000 Gallons Saved/year

17 Cookouts/year x 900 Gallons/cookout x 2 machines + 26 Cookouts/year x 900 Gallons/cookout x 1 machine + 5 Sprayouts/Day x 300 Gallons/Sprayout x 365 Days/Year – (13 Cookouts/year x 630 Gallons/cookout x 3 machines + 3 Sprayouts/Day x 630 Gallons/Sprayout x 365 Days/Year) = 490,000 Gallons/year

Dragout
.0028 Gallons Dragout/minute x 60 minutes/hour x 24 hours/day x 365 days/year x 3 machines x 70% effective runtime = 3,100 gallons dragout/year

10 Liters/minute = .353 ft^3/minute

.353 ft^3/minute x 60 minutes/hour x 24 hours/day x 365 days/year x 3 machines x $.21/10000ft^3 = $120/year

Ozone
.353 ft^3/minute x 60 minutes/hour x 24 hours/day x 365 days/year x 3 machines x $.21/10000ft^3 = $120/year

Peroxide Cookout
6 gallons peroxide/sump x 6 sumps x 60 cookouts/year = 2,200 Gallons Peroxide/year

900 gallons water/cookout x 60 cookouts/year = 54,000 gallons water/year

6 gallons peroxide/sump x 6 sumps x 21 cookouts/year = 800 gallons peroxide saved/year

900 gallons water/cookout x 21 cookouts/year = 19,000 gallons water saved/year

2 hours labor/cookout x $55/hour x 21 cookouts/year = $2,400 saved/year

Sprayout
5 sprayouts/day x 300 gallons/sprayout x 365 days/year = 550,000 gallons water/year

10 gallons heated water/minute x 10 minutes sprayed/sprayout x 365 days/year = 37,000 gallons heated water/year

2 sprayouts/day x 300 gallons/sprayout x 365 days/year = 220,000 gallons water/year saved

.4 x 37,000 gallons heated water/year = 15,000 gallons saved/year

2 sprayouts/day x 1 hour/sprayout x $15/hour = $11,250 saved/year

10 gallons heated water/minute x 10 minutes sprayed/sprayout x 365 days/year x 5 sprayouts/day = 180,000 gallons heated water saved/year

.25 hours/sprayout x 5 sprayouts/day x 365 days/year x $15/hour = $7,000

Sump Reduction
17 Cookouts/year x 900 Gallons/cookout x 2 machines + 26 Cookouts/year x 900 Gallons/cookout x 1 machine + 5 Sprayouts/Day x 300 Gallons/Sprayout x 365 Days/Year – (13 Cookouts/year x 630 Gallons/cookout x 3 machines + 3 Sprayouts/Day x 630 Gallons/Sprayout x 365 Days/Year) = 490,000 Gallons/year

** All estimations made are assumed to be independent unless otherwise noted.

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