PROTECTING FLOW ASSURANCE AND MAXIMIZING INJECTIVITY IN THE MIDSTREAM WATER SPACE

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ABSTRACT

In the last 10-15 years, the US has seen a remarkable surge in the production of oil and natural gas as the industry learned how to properly complete and produce previously non-productive formations. With this increased hydrocarbon production, we have also seen an increase in the amount of water that is produced and must be managed. The large volumes of water that must be gathered, managed, and eventually disposed, along with a growing trend for operators to prioritize their capital spend on drilling and completing revenue-producing wells, has created an opening for midstream water companies dedicated to produced water. While some of this produced water is treated to some degree and then used in ongoing completions to offset an equal volume of fresh water, most of it is destined for disposal via Class II UIC wells. Often this produced water has some degree of mineral scale over-saturation or may be mixed with other waters that may or may not be compatible from a mineral standpoint. The water may contain various quantities of dispersed hydrocarbons, suspended organic material or inorganic solids such as iron sulfide or iron oxide - all of which can potentially impair the ability of the injection well to take water. Last, but not least, bacteria such as acid producing bacteria or sulfate reducing bacteria may be present in the produced water and may cause corrosion issues when allowed to contact bare steel and can generate biomass that again can impair injectivity. This paper will discuss the potential issues with the movement and injection of produced water outlined above. It will also outline and detail the best methods to monitor and analyze for these potential issues, the best approach to correcting or preventing of issues that may impair flow or injectivity and, finally, how to best monitor long-term to document success and properly optimize the preventative treatment program.

INTRODUCTION

This paper will discuss the various methods in which flow assurance in produced water handling and disposal injectivity may be adversely affected and how best to address these issues. The goal is to present a roadmap for maximizing flow assurance and long-term injectivity in a disposal well. Areas of concern to the midstream operator or disposal well owner are oil recovery, corrosion, mineral scale, bacteria and improved injectivity. Additionally, a suggested monitoring program is recommended to ensure that the system and well(s) operate at peak performance.

OIL RECOVERY

Much of the produced water being sent to disposal wells often contains some quantity of dispersed oil. It is critical that this oil be removed prior to injection of the water into a disposal well for two reasons: 1) recovered oil has a value and can be marketed to help with the economics of operating the disposal system and 2) oil and oil-wet solids can adhere to the formation rock in the disposal zone and impair injectivity. Over time, this can significantly lower achievable injection volumes thus impairing the economic viability of the disposal well. In most disposal operations, the first tank incoming water enters is a gunbarrel. These tanks are specifically designed to aid in the gravimetric separation of produced crude and water. This is assuming that a chemical(s) present in the water is not inducing a reverse emulsion, also known as an oil-in-water emulsion. This is particularly true for post completion, or flowback fluids, as these fluids can contain surfactants, viscosifying polymers or organic gel remnants that can contribute to a reverse emulsion. Gun barrels are not particularly adept at resolving reverse emulsions and often a specialty chemical is necessary to aid in this separation and ultimate recovery of the oil from the water.

How does the midstream operator or disposal well owner know if his gun barrel and surface tankage is adequately recovering any incoming oil? This is done through regular monitoring for total oil and grease up and downstream of the gunbarrel and at the disposal pump suction or discharge (or at the disposal well). Currently, the most common method of determining oil and grease is via EPA method 1664A which employs n-hexane to extract the oil from an aliquot of the water being evaluated. Ideally, the water entering the disposal well should contain less than 50 mg/l of dispersed crude oil and a significant reduction in oil content should be seen between the water incoming the gunbarrel and the water exiting the gunbarrel.

CORROSION

Produced water is nearly always corrosive to one degree or another owing primarily to the facts that it contains salts (which provide an electrolytic path for electron transfer), dissolved acid gases such as carbon dioxide (CO_2) and hydrogen sulfide (H_2S) and has an acidic pH (<7). Additionally, produced water can occasionally contain dissolved oxygen (O_2) which works as a cathodic depolarizer greatly enhancing the potential corrosion rate. Produced water can also contain bacteria that contribute to the corrosion process, but these will be addressed in greater detail in a later section of this paper.

Coatings

Ideally, due to the relative high fluid volume applications, corrosion is best controlled in midstream water systems and saltwater disposal wells with internal coatings in tankage and internally coated tubing in the injection well itself. All surface tankage should be cleaned, prepped according to industry accepted standards, and thoroughly coated with a coating rated for the expected year-round temperature range of the tank. If the tanks are coated when manufactured and then shipped to site for installation, the internal surfaces of the tank(s) should be “jeeped” to check for holidays that may have formed during transportation. All holidays should be addressed and recoated prior to placing the tank(s) in service.

Cathodic Protection

As an added layer of protection to a coated tank, cathodic protection can be employed to address corrosion potential from any holidays that may form over time in the tank coating. In the corrosion process, metal is lost into solution at the anode with electrons being transferred to the cathode. This process can occur on a single piece of metal or pipe wall. In cathodic protection, the surface to be protected is made entirely cathodic with metal loss occurring at a sacrificial anode. These sacrificial anodes (usually magnesium or zinc-based) are mounted just off the bottom of the tank or suspended from the top down into the produced water. The anodes must have a clear connection to the tank itself and will transfer any potential corrosion from the internal tank surface to the anode until the anode is ultimately consumed. Periodically, the potential current measured from the tank to the anode(s) should be measured to ensure that the anode is still functioning as intended. For anodes mounted just of the bottom of the tank, it is recommended that these be manually inspected at a minimum of once per year.

Chemical Inhibition

If the water being moved through a midstream operating system or being disposed in Class II UIC wells is sufficiently corrosive to warrant concern and the in-service tankage, piping and injection tubing is not internally coated, a chemical program designed to inhibit the corrosion process will be necessary. This will typically involve a water-soluble inhibitor designed for continuous application. Water-soluble inhibitors tend to form single molecule thick films that regularly attach and detach only to reattach further along the pipe wall. In this fashion, they present a barrier to corrosive agents contacting the steel surface of the tank internals, piping ID or injection tubing ID. Additionally, conventional water-soluble corrosion inhibitors, many of which are quaternary ammonium compounds (QAC), offer a surfactancy quality that helps with handling solids in midstream systems and disposal operations. Examples of these types of chemistries are dodecyl dimethyl benzyl ammonium chloride (DDBAC) and alkyl dimethyl benzyl ammonium chloride (ADBAC).

Combination Products

In systems where both corrosion is a concern and mineral scale deposition is a potential, there may be a desire to use a combination corrosion and scale inhibitor. By doing so, this can reduce the number of tanks and containments needed at the site and can allow for a single headed pump for injection of the chemistry. This temptation should be avoided as it invariably leads to over (or under) injection of one of the chemical properties. Adjusting the chemical dosing of the combination product to ensure that adequate corrosion inhibition is being applied may mean that the scale inhibitor dosing is either under or over the optimum concentration. Conversely, if the combination product is dosed in such a concentration to assure that the optimum dosing of the scale inhibitor portion is present them it is likely that the corrosion inhibitor faction is either under- or over-dosed.

While more upfront expense is required to allow for injection of both a corrosion inhibitor and a scale inhibitor, this type of setup allows for each product to be fed at the optimum recommended rate thus ensuring that the under-lying concern is addressed without the waste of overfed chemical. This optimization more than makes up for the necessary initial expense.

MINERAL SCALE

Mineral scale poses a risk to the midstream water operator thru three primary avenues: 1) solids formation in incoming tankage leading to pad buildup or tank bottoms that will eventually need to be cleaned and potentially disposed of, 2) partial or total blockage of surface piping, pump internals or disposal well tubing and 3) potential build up in the targeted formation near wellbore area leading to decreased injectivity and increased injection pressure. The most common mineral scales found to be over-saturated in oilfield brines are calcite (calcium carbonate, $CaCO_3$) and the iron compounds, iron sulfide (FeS) and siderite (iron carbonate, $FeCO_3$). To a lesser extent and varying by geographic areas, mineral scales such as barite (barium sulfate, $BaSO_4$), celestite (strontium sulfate, $SrSO_4$) and gypsum (calcium sulfate dihydrate, $CaSO_4$-$2H_2O$) may also be present in over-saturated states.

To determine if a water intended for transportation and disposal in a midstream water operation poses a risk to the operator, an accurate water analysis should be utilized with modern mineral scale modeling software to determine potential over-saturations (Saturation Index) and the maximum amount of solids that could potentially be deposited from the water (often referred to as Potential Deposition or Momentary Excess). To generate the most accurate modeling, several segments of the water analysis must be conducted onsite when the water is initially sampled. These critical segments are pH, alkalinity, dissolved CO_2 and dissolved H_2S. These four items begin changing once a produced water is removed from a pressurized environment as dissolved gases migrate out of the water. If the analyses are not conducted until the water arrives at the laboratory a day or two later, the values determined will not reflect what is actually in the system.

A positive Saturation Index (SI) is an indication of calculated over-saturation for that mineral species and is based on a $\log_{10}$ scale so that a SI of 2 is ten times stronger that a SI of 1. Where positive SI's are calculated, a Potential Deposition (or Momentary Excess) is generated which represents the amount of that mineral that would need to instantaneously precipitate to return the water to equilibrium for the mineral. Some software presents Potential Deposition's in a mg/l value, but you will commonly see Potential Deposition's also referred to in term of pounds per thousand barrels (pptb) of water which is more relatable to SWD operations. For conversion, one (1) mg/l equals 0.35 pptb. Figure 1 demonstrates calculated Saturation Indices and Potential Depositions for a Midland Basin disposal operation.

In addition to potential mineral scale over-saturation for various mineral scales, the midstream water operator must also be alert to the potential of mixing two or more waters in their system that may be incompatible with one another. For example, mixing a produced water that contains a significant amount of barium (Ba^{++}) and little or no sulfates ($SO_4^=$) with one that contains little or no barium and a significant amount of sulfates can result in instantaneous precipitation of a mineral scale that is virtually acid insoluble. Most of the mineral scale modeling softwares have the capability to theoretically mix two or more waters to determine the potential for incompatibilities.

Where mineral scale formation is a likelihood, a compatible scale inhibitor known to provide excellent protection against the offending mineral should be applied continuously into the system as far upstream as possible and most definitely before two or more incompatible waters will be mixing. If the water is found to have an over-saturation for an iron compound such as iron sulfide, an iron chelant or acid surfactant should be applied at the inlet to the SWD facility to prevent iron solids build up in gunbarrel(s), disposal pumps and disposal wellbores.

Due to varying levels of many produced water components, particularly divalent cations (Ba^{++}, Ca^{++}, Mg^{++}, Sr^{++}), some scale inhibitors, iron chelants and acid surfactants may not be compatible with the water. This incompatibility may partially or completely impair the selected chemical's ability to perform as intended. Figure 2 demonstrates results seen from one compatibility test. In this test, the product labeled as bottle #14 is indicating a compatibility issue with this water.

BACTERIA

Bacteria are naturally occurring in many producing formations and have been studied and addressed for many decades. Additionally, introduction of non-formation water such as surface water or groundwater used in drilling, completion or workover activities can introduce bacteria species that may not have been originally present in the formation water. Bacteria can cause many issues in midstream water storage, transportation and injection systems including corrosion, generation of hydrogen sulfide (H_2S) and impairment of injectivity. Bacteria can be grouped by many different qualities such as respiration, how they exist in the brine and common traits such as the ability to reduce the sulfate ion ($SO_4^=$) or to produce acid.

Respiration

Like most organisms, bacteria need oxygen for metabolism, and they are generally grouped according to how they obtain oxygen. Aerobic, or "oxygen loving", bacteria prefer waters with significant quantities of dissolved oxygen such as groundwater or surface waters. Aerobic bacteria utilize this dissolved oxygen for respiration. Anaerobic bacteria do not need dissolved oxygen to survive and prefer waters that are free of dissolved oxygen. These bacteria can strip oxygen from other molecules to use in their metabolism. A perfect example of this is sulfate-reducing bacteria. Sulfate reducers take a sulfate anion ($SO_4^=$) and strip all the oxygen leaving the sulfide ion ($S^=$) which readily attaches to two hydrogen ions (H^+) to form hydrogen sulfide (H_2S).

Aerobic bacteria are also commonly referred to as "slime forming" and tend to cause more issues with loss of injectivity in disposal wells than they do corrosion issues. Anaerobic bacteria cause both corrosion concerns and injectivity issues through the generation of biomass.

Bacterial State

Bacteria exist in a water in one of two states – either planktonic (free floating) where they are dispersed throughout the water or sessile in which they are attached to a surface and exist in a colony of biomass. While bacteria in the planktonic state can contribute to injectivity issues, they do not cause a concern with regards to corrosion. Once they become sessile, they are a potential corrosion threat as many produce acid as a part of their metabolism and H_2S which is an acid gas.

INJECTIVITY

In addition to the avenues of concern and the recommended steps to ensure flow assurance discussed in the previous sections, the midstream operator may have the ability to maximize long-term injection volume through the application of a surfactant to lower interfacial tension between the disposal water and the targeted formation. When a midstream operator has a well that is injecting at its permitted maximum pressure, the application of a surfactant can allow for additional disposal volume at the same pressure. Where a disposal well is not at maximum pressure, a proper surfactant can lower injection pressure saving on power costs, help with keeping disposal pumps cleaned and provide longer wellbore life.

To select the best surfactant for this application, the water intended for disposal is pushed, with and without surfactants, through 0.45-micron Millipore™ filters at a constant 20 psig. Filtered water is measured and elapsed time recorded for volume increments (100 ml, 200 ml, etc.). from this information, filtration speed in a ml/sec format can be calculated and plotted versus filtered volume. From this plot, various products can be compared to the blank (no surfactant) to determine if filtration rate increased and then increased or declined as compared to the blank as filtered volume increased. This last item is determined by comparing the slope of the linear trend of the plotted blank values versus the slope of the linear trendlines for the various surfactant plots. An example of this evaluation is seen in Figure 3.

In Figure 3, the blank water (no surfactant) is represented by the heavy dashed black line. In this example, all of the surfactants were screened at 20 ppm and many did not perform as well as the blank. Several provided quicker water filtration initially but ultimately fell off quite dramatically in filtration speed. Two of the products, D and F, were found to have shown strong increases in filtration rate and improved total volume filtered. Of these two, Product D, was the selected product as it also reduced the slope (from -1.0981 for the blank to -0.08566) thus demonstrating slower plugging of the Millipore™ filter. While Product F had an improved initial filtration rate, it was not selected as its steepened negative slope indicated a faster plugging rate than the blank.

After a suitable surfactant has been selected through a screening process as described above, the selected surfactant should be screened at varying concentrations to see if performance improves or decreases at other doses and to test for potential compatibility issues with increased dosages. In Figure 4, Product D from the test above has been retested at 5, 10, 15, 20, 30 and 50 ppm in the same water. Once again, the untreated water (blank) is represented by the dashed black line. In this example, 5 ppm of Product D did not perform as well as the blank, but all the other concentrations improved performance over the blank. Increasing the dosing to 30 and 50 ppm increased initial filtration speed but, in both cases, the trendline slope for both dosages was more negative than that for the 20 ppm test; thus the initial recommendation would be to apply this surfactant at 20 ppm. Once on the system, daily volumes injected and injection pressures can be plotted versus actual surfactant dose rate to determine optimum concentration.

MONITORING

The key to maximizing flow assurance and injectivity in a midstream disposal operation is to identify the critical system concerns, design a chemical program that properly and efficiently addresses these concerns and then to regularly monitor the system to determine if the concerns are being addressed as intended or if alterations to the designed program are necessary. Minimum monitoring recommendations are given below for each of the areas addressed previously in this paper.

Oil recovery

Water should be sampled upstream and downstream of the surface tankage at least once per month and tested per the USEPA Method 1664A for total oil and grease content. Desired target for injected water is to have less than 50 parts per million of total oil and grease. Monitoring frequency can be increased if system volumes are large or if total oil and grease is above desired concentrations.

Corrosion

In systems where bare steel or impaired internal coatings have required the installation of cathodic protection, the anodes should be tested monthly to insure they are intact or are performing as intended. In systems where the application of a corrosion inhibitor or combination corrosion and scale inhibitor has been deemed necessary, a corrosion weight-loss coupon should be installed to be constantly in the water stream downstream of the inhibitor injection. This coupon should be pulled and replaced monthly and submitted to a laboratory for corrosion rate calculations. In an all-water system such as a disposal operation, acceptable general corrosion rates are 5 mpy or less with no observed pitting attack.

Bacteria

Monthly, the disposal water should be tested upstream and downstream of the surface tankage for bacteria. Upstream lets the operator know what is coming into their system and downstream may indicate bacteria growth in the surface tankage. At present, it has become very common to utilize a bacteria test procedure based on measuring the level of adenosine triphosphate, or ATP, in a water sample. ATP is a rapid test providing quick results but does not distinguish between the various species or families of bacteria. To determine concentrations of various bacteria types, serial dilution vials with broths specifically designed for bacteria such as sulfate reducing and acid producing should be inoculated per API RP-38, “Recommended Practice for Biological Sampling of Subsurface Injection Water”.

Mineral scale

If a scale inhibitor is being applied to a midstream water operation, one or more scale coupons should be installed downstream of the injection point of the inhibitor. These coupons are manufactured with holes drilled in the metal coupon to encourage scale and solids formation. Once a month, the coupon(s) should be pulled, inspected, and photographed and then re-inserted into the system (if clean). If scale is present on the coupon, steps should be taken to understand why the injected scale inhibitor is not preventing this. Additionally, the system water downstream of the charge pump or disposal pump should be filtered through 0.45-micron Millipore™ filters once or twice per month to test for total dissolved solids and a breakdown of these solids into hydrocarbon, acid soluble carbonates, acid soluble iron compounds and acid insoluble fractions. In this testing, desirable water quality is when the total suspended solids minus the hydrocarbon fraction is less than 50 mg/l.

Injectivity

If a surfactant is being applied to the disposal water, daily water injection volumes and pressures should be plotted monthly versus surfactant dose rate. If disposal volumes are decreasing and disposal pressure is increasing, if disposal volume is steady but pressure is increasing or if pressure is steady, but disposal volumes are decreasing, first – evaluate the disposal operation to determine if another factor such as a new water source or much higher total suspended solids may be a cause. If the system has been steady in operations, re-evaluate the original selection of the surfactant.

CONCLUSION

Midstream water operators invest a considerable amount of capital in disposal operations and the constituents found in most oilfield waters can potentially negatively impair these operations. In this paper, methods to identify these risks have been presented along with applications to minimize the same. Lastly, minimal recommendations have been given to monitor these recommended applications to ensure the midstream assets are being protected as intended. In most midstream disposal operations, flow assurance can be protected and injectivity maximized with a minimal investment of $.01 to $.03 per barrel of water treated.

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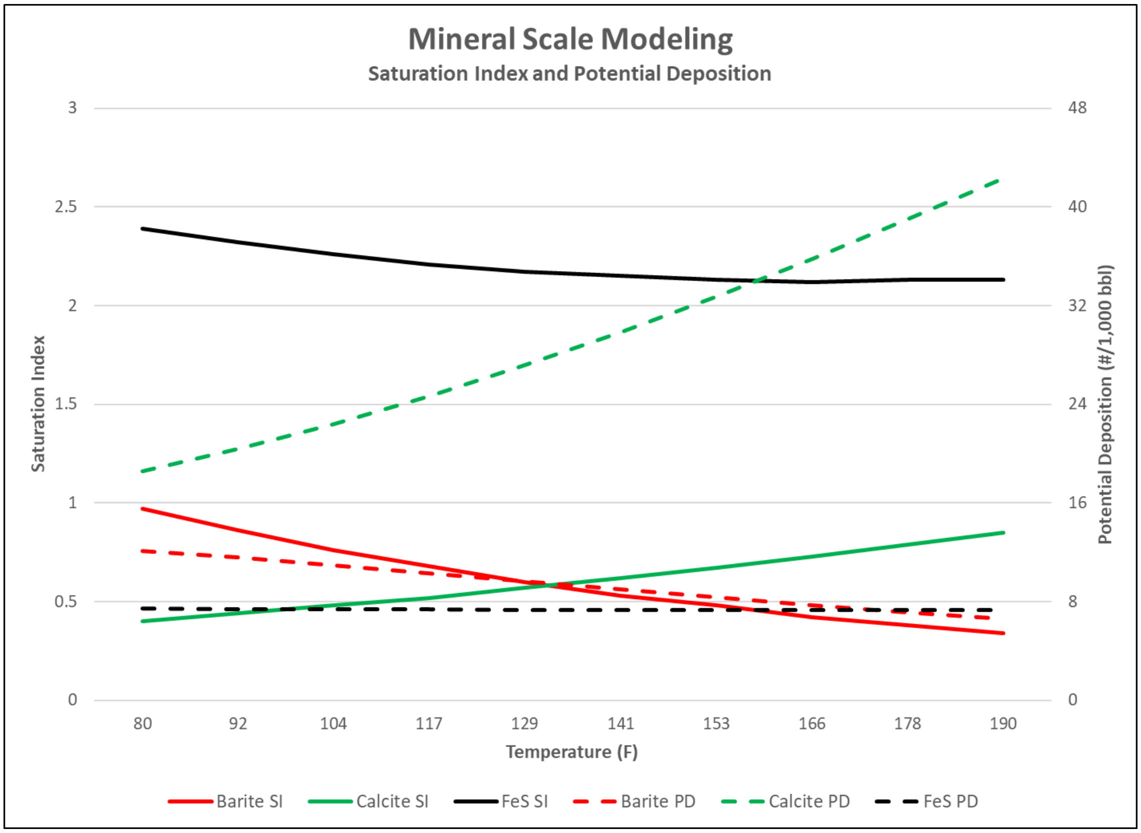

Figure 1

Figure 2

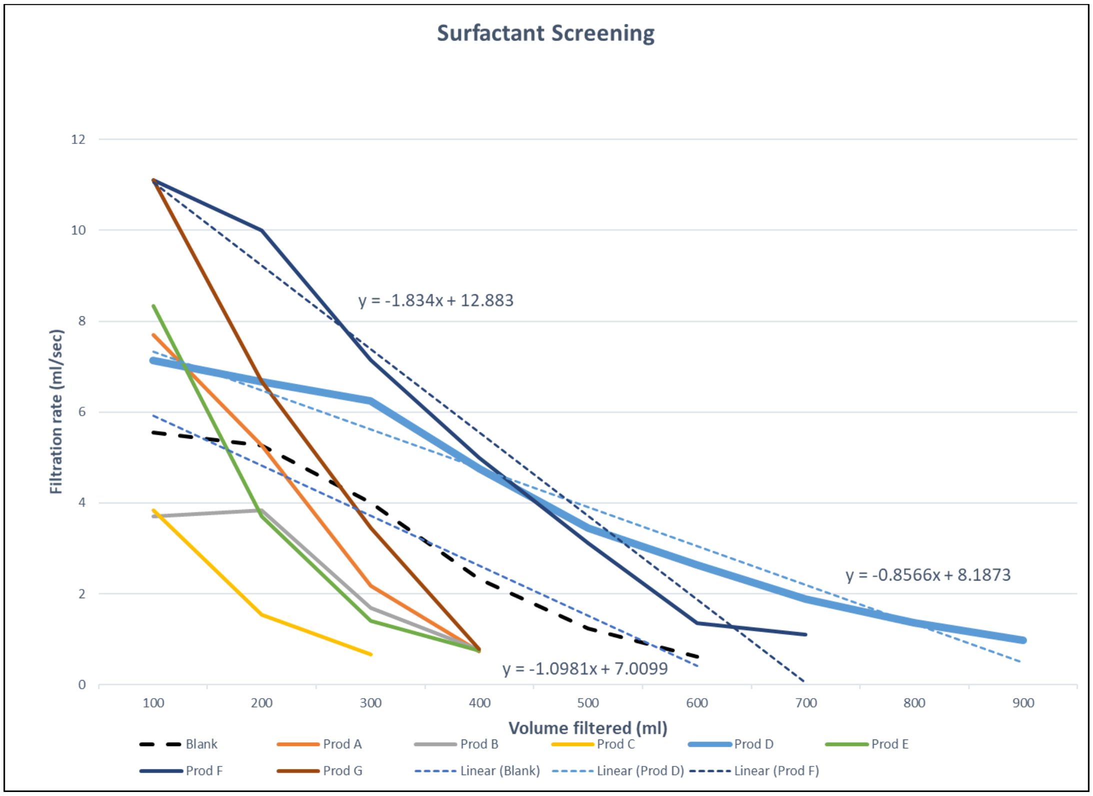

Figure 3

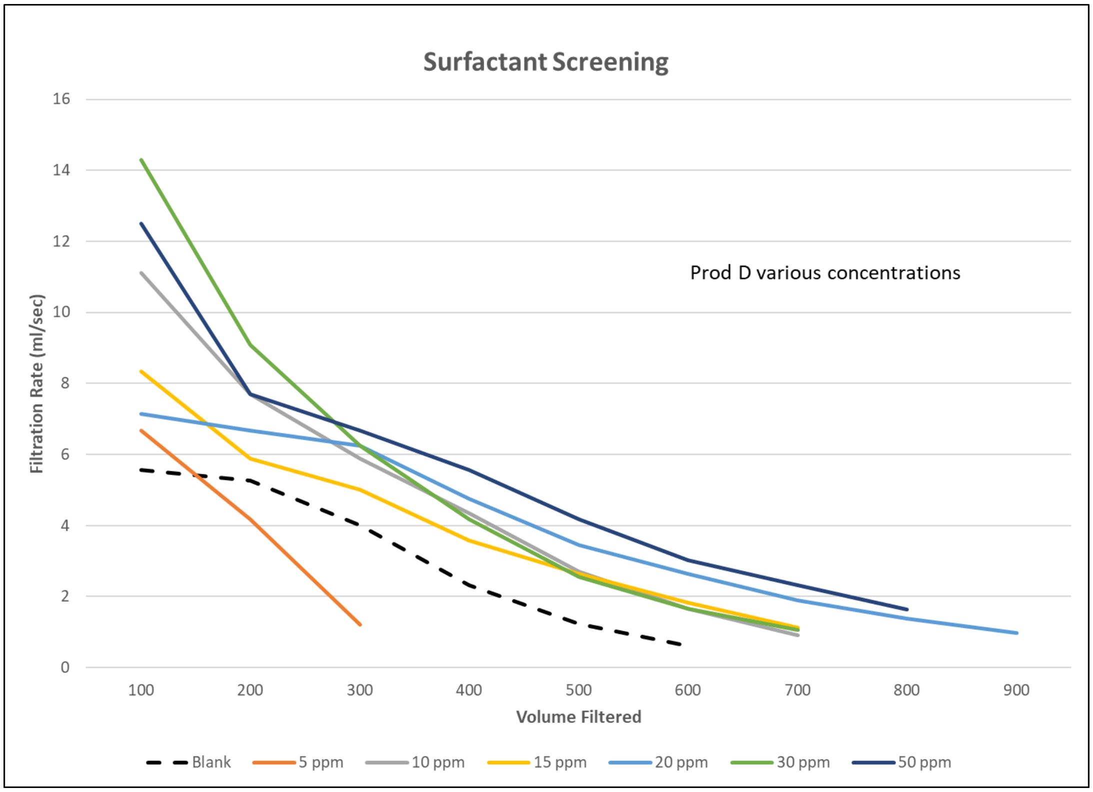

Figure 4