Prepared Discussion of:

**Equipment Design Considerations for Lime and Ion Exchange Treatment of Produced Water in Heavy Oil Extraction**

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The Holloway and Page paper “Equipment Design Considerations for Lime and Ion Exchange Treatment of Produced Water in Heavy Oil Extraction” is an excellent summary of design concerns and cautions regarding warm and hot lime softeners, after filters, and WAC Softeners. The authors have many years of extensive design and field experience in produced water treatment that they have brought to bear on their topic. They provide design numbers, proven through their experience, along with operational improvements they have garnered in their time on site. Their purpose in this paper is to share that experience in design and operation in an effort to assist the designers of produced water treatment systems and the producers themselves, and if implemented, should lead to higher production and ultimately to higher ROI for the end users. The authors focused on items that have been questionably handled or over-looked in recent systems provided in the Alberta Oil Sands.

The learnings they have made will be useful to designers and end users and justify due consideration whether discussing Greenfield plants or debottlenecking existing installations.

**Introduction**

The authors suggest that production problems are due to capitol cost control and to sales competition however, several other significant reasons exist to account for performance issues that they are addressing here. We would suggest that their causes could be further complemented with the following considerations.

Pressure from stakeholders is another cause of problems encountered. Operators are under pressure to maintain production in some cases even when they experience a major upset and recognize the need for immediate and drastic measures. Shutting down a 30,000 BBL/D plant can result in $2,100,000/Day loss in revenue (at $70/BBL oil) as the authors have pointed out. As well, this does not include the actual costs for the repairs themselves which can also be significant. There is consequently high pressure to keep the plants running if at all possible, sometimes to the detriment of other equipment in the plant such as the boilers particularly.
Another cause of problems is inexperience in the workforce. With the high level of design and construction activity currently ongoing in the Oil Sands, there are many people entering the industry in every field with minimal related experience: engineering, trades people, quality control, and even in management. Driven by tight timelines established as a result of competitive conditions in the marketplace, as well as initial capital budgets that sometimes make provision of adequate equipment difficult, inexperience has cost the industry dearly in some instances as the authors have pointed out. The high price of oil at this time is one such major marketplace driver that is encouraging various new corporations to enter the marketplace very quickly to capitalize on the opportunity.

The industry is going through a steep learning curve at this time as a result of the fact that the SAGD (Steam assisted gravity drainage) process is a relatively young process and a retiring workforce is necessitating rapid training and advancement of replacement personnel. Further, the high demand for manpower due to the large number of projects is also resulting in competition for experienced manpower which makes it difficult to maintain continuity on any given job site.

**Process Background**

Covering four processes in one paper is an ambitious undertaking and the authors have done a very good job and have been very concise. However some background would be beneficial for people inexperienced in this area. While an individual paper could be required to begin to explain each of these areas, we will provide a very brief description only to provide a preliminary understanding for the reader.

**Produced water** is water that is produced with the oil as it is removed from the formation. This water must be separated from the oil and treated before it can be sent to the boilers to be recycled and converted to steam to inject back into the formation again. Through this process, the water is re-used and conserved, although with some on-going losses, so that the demand for makeup can be minimized.

**Hot lime softening** (HLS) is the precipitation/clarification process where lime (and/or also Magnesium Oxide, Soda Ash, and polymer as the main treatment chemicals. The specific chemicals which vary with water analysis are added to the produced water to reduce primarily hardness and silica. This process is typically operated at temperatures of 100 – 105 Degrees C and usually deaeration is done at the same time. This process operates under a low pressure or near atmospheric pressure.

**Warm lime softening** (WLS) is a similar clarification process to hot lime softening, using the same chemicals, an enclosed tank, and most often operates between 70 and less than 100 Degrees C.

**Cold lime softening** (CLS) is also similar to warm lime softening except is operated typically at less than 30 Degrees C, and usually is not an enclosed tank.
After filters (also called lime softener filters; AF’s or LSF’s) are filters which follow the lime softening step to remove any lime carryover from the clarifier and the post-precipitation material (to protect the WAC resin from becoming coated with lime or other solids).

Weak Acid Cation Exchangers (WAC’s) are Ion exchange units that follow the after filters and in PWT primarily remove Calcium and Magnesium hardness (Ca++, Mg++) by exchanging with Na+. Primarily this is to lower hardness in the water heated in the boilers. Note that whether the resin is in H+ or Na+ form depends on a number of factors but the high TDS of the produced water requires it to be most often in the Na+ form. The hardness to alkalinity ratio is another such consideration.

Strong Acid Cation Exchangers (SAC’s) are Ion exchange units that remove virtually all Calcium and Magnesium cations (hardness), also with the purpose of reducing hardness. In PWT the resin is again most often used in Na+ form.

Oil Removal Filters (ORF’s) are sand or walnut shell filters that are utilized in the de-oiling train to reduce that amount of oil entering the PWT train.

As mentioned above, many complete papers have been written regarding each one of these processes. This information will however provide at least a starting point to the layperson reading the paper.

Oil removal

As explained by the authors, lime softeners are really not the ideal place for oil removal. The authors have made a number of valid points and yet it would add value to the paper to discuss the design purpose and history of lime softeners development to further illustrate the reason for this. Lime softeners were originally designed primarily for reduction of Calcium, Magnesium, silica, alkalinity, TDS, organics, and suspended matter. Dissolved Oxygen is also typically reduced in HLS units by virtue of the high temperature or by the steam stripping. Oil removal was not one of the original design focuses when lime softening units were first developed. It is our understanding that HLS was developed in pre WWll first for the Pulp and Paper Industry and shortly after for the U.S. Refineries. In both cases however, it was used for raw water treatment (make up water) and there was typically no oil involved. As well, these were most likely low pressure boilers.

Due to upsets or incomplete oil removal in the de-oiling train, which allow oil into the lime softener, at some point, it was discovered that the HLS units would remove some of the oil as well as perform their designed process treatment. As a result, the manufacturers of lime softeners have been obliged to attempt to assist with oil removal in the lime softener even though they were not designed for this. This however was a logical progression of the debottlenecking procedure which fortunately for everyone has proven somewhat effective. Experience has subsequently shown in fact that some oil
removal is possible in most lime softeners however the extent has not been properly qualified. Perhaps we should consider that the better approach would be to leave oil reduction to a properly functioning de-oiling train, and not to count on the robustness of lime softeners to perform a function for which they were not originally designed or intended.

On the other hand, oil reduction in HLS units is being done as the authors point out and it will be seen that it can also be done to a more limited extent in CLS or WLS units. This can be explained more fully by “clarifying” some of the differences between cold, warm and hot lime softeners.

Cold lime softeners are typically open topped vessels and are thermally infeasible in the PWT (Produced water treatment) process as too much heat would be lost making them energy inefficient. They are consequently never used in PWT. They do function similarly to the WLS units however are nominally less efficient chemically as well as they operate at lower temperatures at which the chemicals take longer to react. A rough rule of thumb is that chemical reaction rates in lime softening double with each 10 °C increase in temperature. (ie. Reaction times halve with every 10 °C temperature increase). This relationship accounts for why the reaction vessel size required typically becomes smaller as you move from cold to warm to hot lime softening.

The key issue here in oil removal however is that all of these units are clarifiers that remove the treated effluent with launders at the tops of the rise zone within the vessels. As oil can attach to sludge particles and float, it can exit with the treated water. One possible solution to this is to install a skimming weir and collection box to skim some of this oil off before the effluent leaves cold or warm lime softeners. This will however alleviate but not solve the problem that oil in SAGD operations is often present (as the authors point out) in reverse or micro-emulsions. As well, adjustment of the weir would be very difficult in WLS units and practically impossible in HLS units. As well, it introduces another waste stream which would have to be dealt with as well.

The authors have pointed out that part of the cause of the oil emulsion problem is related to poor interface control in the oil/water separation vessels. In fact, it is true that to break up the solids formed at the interfaces in the separation vessels, they in fact form the very emulsions that later make their way through the HLS or other lime softeners. To return to the actual cause (as opposed to a symptom) and study ways to coalesce the emulsion may be another worthwhile endeavour. Perhaps the addition of a coalescing filter ahead of the lime softener or better yet, revising the chemical regime would help to begin solving this complicated problem. In any case, we certainly strongly agree with the authors that as a minimum, ORF’s (Oil removal filters) should not be removed from the process. These suggestions however impact budgets and budget considerations could only be addressed properly in a further paper.

The HLS unit does have the best capability to remove oil of the three units because its’ sludge is more often the most dense and there is greater solids contact (as the authors aptly point out). The sludge concentration has however been seen to go as high as 20-
25% by weight in both HLS and WLS depending on operation. More dense and deeper sludge together can effectively capture more of the oil and that oil is removed with the blow down to the lime storage ponds. The sludge concentration, depth, and consequent oil removal, is a function of the operation of the unit and varies substantially from site to site. Note though that deep sludge (storage) is a problem that has caused some rake failures in WLS units so as the sludge should not be as deep, the WLS tends to be less effective in oil removal.

Ultimately though, while the removal of oil (best in the HLS blowdown) protects the WAC’s and boilers and these are fundamental concerns, it still creates an oil separation and disposal problem in the lime storage ponds. We strongly agree with the authors that the industry would benefit from research that would publish data on sludge concentrations in each type of installation. As well, research would be welcomed in the area of the further separation of the oil in the lime storage ponds. These are relatively new problems and the practical experience in this area is still being generated. The need for additional treatment is rapidly accelerating as the space and water available for each of these sites diminishes.

Of the authors thorough comments regarding the damage done by not removing oil before the lime softening stage, it is important to add that rubber linings in internally regenerated WAC units may be degraded by either slug upsets of oil or by exposure to continuous low concentrations of oil. Again this substantiates the need for complete removal of oil ahead of the lime softeners but particularly ahead of the WAC’s. The authors could also add value to their paper by pointing out that externally regenerated WAC’s would lessen the oil contamination concern significantly. This is the case as external regenerated WAC’s do not need rubber lining in the service vessels. The cost to replace a rubber lining (from an internally regenerated unit) has been seen to range from $250,000 to $500,000 when all aspects of the removal, replacement and repair have been taken into account. Even this however does not take into account the lost revenue which is dramatic as the authors have pointed out and as we have reiterated already even if production is off line for just a brief period.

**Hot Lime Softening**

The main issue addressed by the authors in this area is that of the straight side of the HLS units. As has been well explained by the authors, the rise rate in larger flow vessels only drops briefly to the design figure of 2.0 gpm/sf. It would benefit the readers to point out that this is effectively a budget constraint and if performance dictated that a greater amount of straight side was needed, it could be added. However, performance to date has not indicated that this is required. Designs to date have been based on the need for attaining the design rate momentarily only. That in conjunction with meeting the retention time specifications is the key sizing consideration and the approach produces designs that are performing to the established requirements. In fact, it is more likely that reaction zone retention is the area that might be studied and increased. Lastly, it should
be noted that there are in fact different styles of HLS units for specific applications, but that is again a subject for a future paper.

Increasing the straight side to some extent may however be an avenue that could be explored to provide additional expansion capacity for the future, should the owners desire to spend present dollars to allow for this. It is not clear at this time if that would permit less carryover or in fact allow a higher rise rate if either. More research would be required to determine the benefits of this design change.

Our investigation into backwash storage compartments leads us to agree with the authors that gravity feed of dirty backwash water into the reaction zone has been found not to be as reliable as pumped backwash. However, we have seen that this difficulty can be mitigated by the use of steam lance maintenance but of course this can be avoided with the use of pumped supply to the reaction zone as the authors indicate.

**Warm Lime Softening**

The authors point out that allowance for future expansion is a wise use of present dollars given the difficulty finding space to add another unit later on a crowded plant site. This is absolutely true; however, they could also recommend caution should be employed that too much size not be added to an initial WLS prematurely. Increasing the diameter of the unit too much can result in a low rise rate at initial flows that is inadequate to suspend the bed / solids within the rise/ settling zone of the unit. If the solids settle out, poor treatment will result leading to substandard effluent levels until the higher flow rates are attained. Allowing for higher sludge recirculation rates may help in this respect but the specific flows for each installation should be carefully studied. Too many safety factors are not always a good thing. We have however yet to see an installation that has not been pushing to increase capacity beyond design numbers soon after it starts production.

The authors also point out the importance of carefully evaluating the actual rise zone of a WLS unit. They could enhance this recommendation by suggesting that specifying engineers request dimensions and retention times for the draft tube and flocculation hood with the RFQ (Request for quotation). This is one of the major considerations pertaining to the evaluation of a proposal and cannot be overlooked. Of course, the sizing of all of the internals should be considered, as the authors point out, so that there is no weak link in the chain if expansion is to be properly planned for. One very important consideration is the use of radial collectors as opposed to peripheral launders. Figure 5 shows a WLS with peripheral launders which would not be recommended for PWT as its use will usually result in flow short circuiting, and higher localized velocities which inhibit settling.

While the authors appropriately point out one aspect of quality control (plumbness of the turbine) there are many other quality control points that could be added to this. It would strengthen the paper to list more of these such as roundness of the draft tube, clearance of turbine, weld quality, and more. Every aspect of the installation should be checked to
ensure the specifications have been met. As well, allowance would be well made in the RFQ to obtain startup assistance from the manufacturer. Typically this will result in the fastest resolution of any problems that may be encountered. Each unit is different and even experienced operators may not have operated every design of unit on the market. Each manufacturer is intimately familiar with the intricacies of their units and so best able to spot and trouble shoot them.

The authors recommend that the rake and drive should be heavy duty and sized for maximum future capacity. To that they could add that torque ratings and gearbox ratings, gear hardness ratings, as well as bearing life etc. should be specified or at least compared once bids are in to ensure comparable units are being considered. The gear drives are the heart of the unit and their failure would cause extended downtime and lost production as replacement drives are not usually stock.

Regarding the author’s discussion on retention time, it would make this observation more useful to point out that if larger diameter units have more total retention time, this should be striven for as possible as greater retention allows greater chemical action and treatment. The final selection should however be optimized with other considerations such as operating philosophy. It can create a more reliable production plan to have two 50% units as opposed to one 100% unit. Similarly, two 75% units could provide expansion capacity as well as more production if the units are down for any reason such as annual maintenance.

The authors have also provided excellent guidelines addressing the rate of change of flow and temperature in WLS units. This is extremely important and would be further beneficial to note that changes don’t make it all the way through the unit instantaneously and can take up to 24 hours to thoroughly stabilize. Increasing flow by 10 % per hour will prevent upsetting the bed but the more time given to allow the chemical reactions to stabilize, the better. As well, samples should be taken every two hours to monitor performance properly and ensure that all chemical feeds are working properly. However, it is not a perfect world, and seldom is it possible to allow 24 hours between incremental increases in flow rate. Consequently, some amount of performance loss may be seen in these circumstances.

Another good suggestion was made by the authors to utilize a blending tank ahead of the WLS unit to attempt to normalize the temperature going into the WLS. They could also point out that this blending has other benefits in addition to temperature equalization. The more uniform the influent can be made in every respect (eg. Temperature, water quality, and flow rate), the more effective will be the treatment chemicals, and the more likely you will be to avoid thermal currents which could otherwise upset your treatment within the vessel. Some sites we know are even pre-heating some of the streams to assist in attaining a uniform temperature before entering the WLS.

Of the last of the points made by the authors pertaining to WLS units, very important is their comment about the difficulty in viewing the rapid mix zone and effluent. A helpful improvement to this may be found in the advent of low cost camera systems connected to
computer systems that may represent an opportunity to improve the monitoring capability in the near future. The inability to visually monitor the closed WLS process has been a weakness for WLS technology in the past however current technology trends suggest that this could soon be an economical feature that could be added. This would further enhance operation and control of these units.

After Filters

The authors point out here that the proper sizing of after filters continues to be a problem. They can be undersized or oversized for each installation depending on the type of technology being offered. The addition of recommended rates for service and backwash for both ORF’s and after filters (AF’s) would have been another substantial addition to the paper but this would be just too much to cover in this paper.

As pointed out by the authors, Nitrogen assisted backwash of anthracite filters is very effective at cleaning the beds. The authors could have added that the effectiveness of this backwashing agent rivals the mechanical energy input into walnut shell type filters and when the lower capital cost of anthracite filters is considered, the operating cost of the Nitrogen can be justified.

The authors also make a strong point that the use of ORF’s to remove both oil and lime precipitates after the lime softener is not recommended. We concur that attempting to perform both tasks in one step is problematic. This approach is presented as a cost saving option however in the long run it is more likely to lead to problems that will necessitate the investment of additional funds to solve the problems created.

In addition to the backwash rates given, the authors could also have added value to this part of the paper by pointing out to evaluators that careful comparison of the flow rates and pipe sizes offered will give evaluators a good indication of the quality of the system offered.

The author’s Figure 6 which outlines “Filter Backwash Rate vs. Temperature” is a must have approach for every person designing and operating filters. Operators must know the temperature of the water they are using for backwashing and if it changes seasonally be prepared to make the adjustments in flow rate accordingly. Failure to do so can result in media being lost during backwash if backwash rates are left too high when water temperatures drop. The table attached could be revised however to reflect the higher temperatures and resultant flow rates we see in PWT applications. As well, it would be important to know what type of media the curve was established for: sand, anthracite, or walnut shell, and also the size of the media. All of these factors have a bearing on correct selection of the back wash rate for a specific application, as does the temperature. All of these factors must be carefully considered for your application to correctly establish your graph and subsequent back wash rate.
WAC Softeners

SAC (Strong acid cation ion exchangers) softeners were not mentioned in this paper but are closely related piece of equipment used in some PWT treatment trains. Their application is more limited however they still merit some mention. Most likely the authors felt that SAC’s are simpler and well enough understood that they did not need to share any learnings in this area. However, a discussion of the application of SAC / WAC softeners use in PWT would help to add to the completeness of this paper by adding very relevant background to the entire process. We have as a result added a quick guide however, there are many issues to consider in making these selections and this is meant only to show that SAC softeners have a place that could also have been considered in this paper. We are well aware that the authors are also very familiar with this chart or variations of it.

Process Selection for Ion Exchange Softening of Oilfield Produced Water

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<th>Influent Water Quality</th>
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As also outlined by the authors, external regeneration helps to protect rubber WAC liners from temperature excursions (exposure to higher than their design temperatures) in addition to oil exposure already discussed. It is important to emphasize that excessively high temperatures can cause breakdown of the liners just as oil can. While liners have improved in both oil resistance and temperature limitations in the last 15 years, taking the liners out of harms way is very valuable, if possible. This is a strong argument in favour of the utilization of external regeneration and should be carefully considered. Not having to replace WAC liners can save the owners millions of dollars of lost revenue in even a small plant in just one instance of a system failure. Note that it would be very unusual for just one vessel liner to fail. The economics of the selection of external regeneration (over internal regeneration systems) however become most attractive for larger plants requiring four or more WAC units when only the capital equipment is considered. However, if the opportunity cost (lost revenue) associated with oil damage to internally regenerated WAC’s was considered in every evaluation (as this represents a very real if only defrayed cost to the owner) the selection would shift decidedly to externally regeneration systems.
Concerns regarding the transfer of the resin in externally regenerated WAC’s are also very well addressed by the authors. Provided are several valuable design guidelines that warrant attention.

Regarding the transfer velocities (5-8 ft/sec), while these are the recommended velocities, we suggest that marginally higher velocities might be beneficial and that to date resin attrition has not been a result of the resin velocities but due to oil and other fouling.

As well, the authors point out that oil and lime precipitate carryover can contribute to clumping of the resin and make its transfer to the regeneration vessel difficult. However, it could be noted that the action of regular fluidization and transfer of the resin for regeneration will help to prevent this clumping from occurring. Nitrogen scour in the service vessels will also help as it does in the regeneration vessels. It will experience more turbulence which will help to break up any lumps that might be starting to form. As well it will help to mix the resin up more so the tendency to clump is reduced and so the resin can be more easily cleaned. If any resin is found to have clumped and stuck in the bottom, it can easily be removed in a maintenance check and topped up. Clumping will happen for the same reasons in both systems however it is easier to remove if it is left behind in the service vessel than if it is on the bottom of the internally regenerated unit underneath the rest of the media. If resin is clumped and coated, it will not be able to function well in either case. In any case, clumping is a symptom of upstream problems in the de-oiling, lime softening unit or after filters that needs to be addressed. Lastly, it appears that newer resins developed recently may have a lesser tendency toward clumping. This will help reduce the problem for both systems if it is in fact found to be the case. This is another area that could provide valuable information if it was to be studied and verified.

The comments of the authors pertaining to reliability of regeneration are very well taken. The use of more than one external regeneration vessel is a logistical improvement as Hazop reviews will typically reveal.

Well explained by the authors is the impact of fouled resin on the bottom line of the owner. They suggest that oil fouling is the main culprit consequently it is safe to conclude that better, more reliable oil removal systems can save a lot of money for every end user and conversely if not provided will cause the same amount of lost revenue in due course.

**Conclusion**

The authors make a very good point that good decisions at the beginning of a project can avoid many problems. We would suggest that they could add further benefit to this point by suggesting that capital cost for much needed equipment could be delayed by providing space within the plant for additional equipment that could be added after the plant is up and generating cash flow. These additions could be designed at the outset but not installed in the first phase. The plant would run, generate revenue and could then fund
the additional equipment. The plant would run adequately in the short term and the improvements would allow it to produce more at lower cost in the long term. This would reduce the initial cash flow required and make the additions relatively easy.

Items to consider when designing the plant such that they could be added once in production would be additional ORF’s and coalescing filters for better oil removal.

Recommendations by the authors to utilize performance bonds have been seen to be effective on many jobs. We would suggest however that while effective to some extent, more thorough specs and performance criteria may be a better approach. Provision of performance bonds usually drives the cost of the job up, and they are still only as good as the technical documents supporting them. We submit that everyone wants to see the job done right and good performance as a result. To this end, once a supplier is selected, working with them to ensure all bases are covered properly to the end of the job is still a positive and worthwhile approach to meeting the objectives of the project.

It is important to remember that the optimum design directive and operating objective should always be to have each step in the process do the job for which it was designed. The system will only function effectively if all of the components do their jobs properly. It is unlikely that if any one step in the PWT train is out of service that you would be able to continue to meet your process objectives. This should be recognized up front and decisions made in advance as to what action operators should take in various major failure conditions. Costs and benefits must be examined and risks analyzed carefully to determine the best course of action in a given situation.

The authors have provided an excellent paper highlighting many important design considerations. The paper is written for people experienced in PWT and requires some understanding of the basics of each of the areas that is discussed for it to be the most meaningful. Even the additional support we have provided herein will only be a start at providing the background necessary to understand all of the issues discussed. Readers that have an existing background in PWT will find this a very helpful paper to refer to when involved in the design or trouble shooting of PWT plants. Careful consideration of the points made should result in a higher production facility and ultimately greater return for the owners involved.

The author’s paper would be strengthened, on the whole, if the information in the paper could be supported by pertinent field data. However, we recognize the difficulty of doing this in a paper that has covered as much ground as the authors have herein. Their experience however does agree with our own to the greatest extent.

The scope chosen for this paper was very ambitious and could easily have been divided into several papers. Most professionals working in the SAGD PWT field would benefit from further papers from these highly experienced experts if they were prepared to present more on related topics.
KEYWORDS:

After Filters (AF’s; same as LSF’s)
Cold lime softening (CLS)
Hot lime softening (HLS)
Lime softening filters (LSF’s; same as AF’s)
Oil removal filters (ORF’s)
Produced Water Treatment (PWT)
Request for quotation (RFQ)
Return on investment (ROI)
Steam assisted gravity drainage (SAGD)
Warm lime softening (WLS)