ABSTRACT: Over the past several years, there has been a shift from the use of traditional warm lime softening and weak acid cation SAGD produced water treatment to the use of evaporative treatment, including the use of drum boilers for steam generation. Since this shift has occurred, there have been several advancements in the evaporative produced water treatment technology that have improved the economics and reliability of combined evaporator and drum boiler systems. These advancements include (1) optimization of the high pH evaporator process, resulting in reduced chemical / caustic consumption, (2) implementation of contaminant reduction systems to improve evaporator distillate quality for use in high pressure drum boilers, (3) reduced electrical consumption through the use of unique evaporator configurations, (4) advancements in evaporator cleaning procedures that allow for in-situ cleaning without interrupting operation, (5) improvements in Total Installed Costs (TIC) and project schedule resulting from optimized modularization designs, and project execution techniques.

This presentation provides a case study of the produced water evaporator and drum boiler system recently installed at the Connacher Algar site. Commissioning of this system is due to take place prior to the presentation of this paper. This case study will detail and provide data regarding the process advancements and optimizations that have been implemented at the Algar site. In addition, information and data documenting the low TIC that was achieved at this site will be presented, including the methods used to achieve these low installation costs, which have become the industry benchmark.
INTRODUCTION

Over the past several years, there has been a shift from the use of traditional softening and ion exchange to the use of high pH evaporation for the treatment of produced water from in situ thermal production techniques such as steam assisted gravity drainage (SAGD). This shift has been driven by several factors including lower overall lifecycle costs for the entire SAGD facility, higher water recycle and lower water disposal volumes, higher reliability and on-stream availability of both the water treatment equipment and steam generation equipment, lower capital and Total Installed Costs (TIC) associated with using highly modularized evaporation system designs, and dramatically improved boiler feed quality that allows the use of standard drum boilers, as well as other factors.

In most cases, the SAGD facility operating costs, as well the capital and installed costs, have been shown to be lower for the evaporative approach as compared to the traditional approach. However, in certain circumstances at specific SAGD facilities, a combination of high caustic consumption and difficulties with evaporator blowdown disposal have resulted in these advantages being only marginal for the evaporative approach. Significant development work has been undertaken to optimize the evaporative produced water treatment process, specifically targeting operating costs, capital equipment and total installed costs, improved distillate quality, and improved project schedule. This paper presents the results of this continued development work as it has been applied at the 10,000 barrel per day Connacher Algar SAGD facility. This project represents the first facility which will utilize all the current process and modularization improvements developed over the past several years. Start-up of this facility is scheduled to occur prior to the presentation of this paper.

HIGH pH EVAPORATION REVIEW

While the main objective of this paper is to detail the process advancements and design / installation improvements in high pH evaporation which have been implemented at the Algar facility, it is useful to first discuss on overview of the technology. Vertical tube, falling film evaporation is utilized in SAGD produced water treatment in lieu of other types of industrial evaporators because it provides
optimal heat transfer characteristics and minimizes fouling potential. A high heat transfer coefficient is needed to efficiently evaporate the water and save energy. The vertical tube, falling film arrangement, in conjunction with proper brine distribution techniques, allows evaporation to occur with reduced fouling effects by keeping the heat transfer surfaces wetted at all times and by operating with a very low temperature gradient across the heat transfer tubes. A flow schematic detailing a vertical tube, falling film, mechanical vapor compression (MVC) evaporator system used to treat produced water is shown in Figure 1.

![Figure 1 – Vertical Tube Falling Film Mechanical Vapor Compression Evaporator Flow Schematic](image)

The de-oiled produced water and any makeup water streams enter the evaporator feed tank where sodium hydroxide (NaOH, caustic) and antifoam are added to the resulting mixture. In a high pH evaporator system caustic is added to the combined feed to raise the pH and ensure that silica solubility is maintained throughout the evaporative process. The mixed feed is pumped to a heat exchanger where hot distillate exchanges sensible heat with the incoming wastewater, raising its temperature to the boiling point. The feed water then flows to a deaerator, which removes non-condensable gases such as oxygen. Hot deaerated feed enters the evaporator sump, where it combines with the recirculating brine. The brine is pumped to the top of a bundle of two-inch diameter heat transfer tubes where it flows through proprietary liquid distributors to ensure a smooth, even flow of brine down each tube. As the brine flows down the tubes, a small portion evaporates and the rest falls into the sump to be recirculated.

The vapor travels down the tubes with the brine, and is drawn up through specially designed mist
eliminators on its way to the vapor compressor. Compressed vapor with a small amount of superheat flows to the outside of the heat transfer tubes, where its latent heat is given up to the cooler brine slurry falling inside. As the vapor gives up heat, it condenses as distilled water. The distillate is pumped back through the heat exchanger to heat the incoming wastewater. This distilled water is directed to the boiler where steam is produced for downhole injection to fluidize the heavy oil. Blowdown from the boiler systems can be recycled to the evaporator feed tank, eliminating the need to dispose of this waste stream.

A small amount of the brine slurry is continuously released from the evaporator to control density. The evaporator blowdown is disposed of in a salt cavern, disposed of via deep well injection, or treated further by a crystallizer and solids dryer or solidification system. Utilization of crystallization and drying or solidification processes eliminates liquid wastes making the entire system a zero liquid discharge (ZLD) system. The drying process produces a dry, free flowing solid product suitable for disposal in a specially lined landfill. The solidification process produces a stable solid that passes the Paint Filter Test and may be disposed of in a standard landfill.

ADVANCEMENTS IN HIGH pH EVAPORATION

Full-scale commercial production facilities have utilized the distillate from produced water evaporators for boiler feed water for over seven years. The extensive operating data and lessons learned from these plants, in conjunction with results from several pilot and bench scale tests and detailed design studies, have resulted in several economic advancements in high pH evaporation technology. The Connacher Algar project is the first facility to utilize all these advancements, which resulted in significant savings in both operating costs and total installed costs as well as substantial improvements in distillate quality. This section details these advancements and quantifies the positive impacts on the Algar facility.

Reduction In Caustic Consumption – One of the most significant advancements has been the optimization of the amount of caustic added to high pH evaporation systems treating produced water. Prior to the technology being proven commercially over a wide range of produced water chemistries, it was important to design and operate the high pH evaporator systems at a conservative
pH, thereby guaranteeing that silica will remain soluble at the high temperatures and concentrations inherent in an evaporative process. It was common to design for a room-temperature sump pH of 12.0 to 13.0, depending on the particular application. The cost of this conservative design philosophy drove significant developmental work by the operating facilities and technology provider.

As operational data from several full-scale commercial facilities was analyzed in detail, it was apparent that the targeted sump pH in the system designs was not only conservative, but overly so. Two years of development work both onsite commercially and offsite on pilot and bench scale tests confirmed that silica solubility could be maintained comfortably at typical evaporator concentrations with a target room-temperature sump pH of 10.5 to 11.7, depending on actual chemistry conditions. This change in the critical design parameter of a high pH evaporative system results in a reduction in caustic consumption of 40 to 60%, depending on the specific application.

In the case of Connacher Algar, the caustic consumption will be able to be further reduced or completely eliminated since the evaporator blowdown from the two evaporators at the 10,000 barrel per day Connacher Great Divide facility, which are already treated with caustic, will be fed directly into the Algar evaporators. The Algar evaporators are essentially reusing the caustic already added to the Great Divide evaporators, thereby significantly reducing the operating costs of the Algar facility.

A photograph of one of the high pH falling film MVC evaporator units at the Connacher Algar project is shown in Figure 2.
Series Evaporator Configurations – Over the past few years, several ongoing development programs were focused on reducing capital and operating costs of high pH evaporator systems. One such program studied how a series evaporator system configuration could be applied to high pH produced water evaporation and found that series configurations have several advantages over a parallel configuration. The advantages of this configuration, which is utilized at Algar, are detailed below.

Increased System Redundancy and Availability – Due to operational complications associated with reheating a cooled reservoir, SAGD facilities require sufficient process redundancy to ensure that a major unit process can be brought offline for cleaning or maintenance without reducing steam being sent to the reservoir below the level required to maintain temperature. Because of this and the existing belief that series evaporator configurations reduced system redundancy, all early produced water evaporator systems were designed with multiple units operating in parallel. However, as the development team investigated the merits of applying series or cascade evaporator configurations to SAGD produced water evaporation, it was found that such configurations could be designed with system redundancy equal to or even greater than a parallel configuration. Figure 3 shows the Connacher Great Divide evaporator system with two evaporators operating in parallel.
In a series evaporator configuration, such as is utilized at Algar, the produced water feed, and any other make-up water and miscellaneous waste streams, all enter the upstream evaporator (rather than being split between two evaporators as is the case in a parallel configuration). The majority of the evaporation, typically 75% or more, occurs under very dilute conditions in the upstream evaporator. The blowdown from the upstream evaporator is then directed to the downstream evaporator, where the remainder of the produced water concentration and evaporation takes place.

This Algar series configuration, which processes about 85% of the produced water in the upstream evaporator, results in a more reliable, higher availability system as compared to a comparable parallel configuration. Since the majority of the evaporation occurs in the upstream evaporator under dilute conditions (only about six times more concentrated than the feed water), the fouling potential in the upstream evaporator is greatly reduced. This will result in extended runtimes between cleanings and overall higher availability. Other benefits, such as reduced electrical consumption and improved distillate quality, are discussed later in this section.

The downstream evaporator is designed to normally operate under more concentrated conditions than the upstream evaporator. As such, the downstream evaporator is designed with a lower extraction rate (i.e., lower heat flux) and more heat transfer area per cubic meter of evaporation as compared with the upstream evaporator. This lower heat flux reduces the fouling potential associated with the higher brine concentrations that exist in the downstream evaporator. It should be
noted that the conditions that exist in the downstream evaporator are identical to those that would exist in both evaporators in a parallel configuration. That is, with a parallel design, both evaporators operate at the high brine concentrations and have similar fouling tendencies to the downstream evaporator of the series configuration. Confining the highly concentrated brine to only the downstream evaporator provides a significant improvement in reliability, availability, and fouling tendencies. In addition, depending on the chloride concentration of the produced water, it also serves to isolate the need for upgraded materials of construction to the downstream evaporator only.

**Reduced Electrical Consumption** – Placing evaporators in series also significantly reduces system energy consumption. A lower energy consumption is achieved because the first stage evaporator, where the majority of the evaporation takes place, operates at a low brine concentration in the sump and, therefore, the evaporation occurs at a lower boiling point. Evaporation at this low boiling point results in lower head requirements for the vapor compressor and, consequently, reduces electrical consumption. Evaporation at a higher boiling point is isolated to the downstream evaporator where a relatively small amount of evaporation takes place. Note that in a parallel configuration, all of the evaporation takes place at the higher boiling point and, therefore, uses significantly more energy.

The reduction in electrical consumption by using a series configuration is typically 20-40%, depending on application and system design. For the case of Connacher Algar, the energy consumption is about 25% lower than the comparable parallel configuration.

A photo of the evaporators supplied for the Connacher Algar project, which operate in a series configuration, is shown in Figure 4.
Figure 4 – The SAGD produced water evaporators, operating in a series configuration, from the Connacher Algar project.

Lower Capital Costs – As previously mentioned, in a parallel configuration each evaporator operates at the same concentration. Thus, in a parallel design, each evaporator is constructed of the same materials, as determined by the corrosiveness of the recirculating brine and vapor. However, in a series configuration, the larger upstream evaporator operates at a much lower concentration than the downstream evaporator. This design aspect allows the upstream evaporator to be constructed of a lower grade material such as 316L SS. Depending on the composition of the produced water, and the required number of cycles of concentration to achieve the desired water recovery, the downstream evaporator may need to be constructed of higher grade, more expensive materials of construction such as 6% moly stainless steel. This results in a significant cost reduction as compared to a parallel configuration where all evaporators must be constructed of the higher grade materials. It should also be noted that, in many cases, the capital costs can be further reduced by “splitting” the downstream evaporator sump, thereby further isolating the expensive, higher grade materials to only the most concentrated portion of the downstream evaporator. In the case of Algar, 316L SS is used for the entire upstream evaporator and for about half of the downstream evaporator (which is a split sump design). Higher grade materials are only required for the concentrated half of the downstream evaporator.
**Improved Distillate Quality** – The distillate quality from a produced water evaporator is determined by several factors including vapor velocities, type of mist eliminator, distance between the tube ends and the sump liquid level, etc. However, when comparing series and parallel configurations, it is important to focus on the impact of the concentration in the evaporator because this is where the two configurations differ. In a parallel configuration the evaporators operate at the same concentration so a droplet that carries over into the distillate of one evaporator will have an equal impact on distillate quality as a droplet from another evaporator operating in parallel. In a series configuration and assuming equivalent mist elimination efficiency, a droplet of carryover in the upstream evaporator will have much less of an impact on distillate quality than a droplet of carryover from the downstream evaporator. Again, this is due to the difference in concentrations between the evaporators. In a system design where the upstream evaporator produces a large majority of the distillate, this difference can have a significant impact on blended distillate quality.

Arranging produced water evaporators in a series configuration results in a 30 to 60% reduction in contamination due to non-volatile constituents, when compared to an evaporator system with equal heat transfer area arranged in a parallel configuration. In the case of Connacher Algar, use of the series configuration results in more than a 50% improvement in distillate quality. The distillate quality of a produced water evaporator system can be further improved through the use of a proprietary Contaminant Reduction System, which is detailed later in this paper. Algar uses such a Contaminant Reduction System, which provides improvements to the distillate quality over and above that discussed above.

**Other Series Configuration Considerations** – In addition to the aforementioned benefits of a series configuration compared to a parallel configuration, consider the cases of low liquid discharge (LLD) or Zero Liquid Discharge (ZLD), where a crystallizer is required downstream of the evaporator system. In this situation, the evaporator system must perform as much of the evaporation as possible, because evaporation is more energy intensive in a crystallizer and because a crystallizer is always constructed of the highest-grade, most expensive materials so its size should be minimized. In the situation of LLD or ZLD, the downstream evaporator must be constructed of higher-grade materials and will often require substantially more energy per unit of evaporation than the upstream evaporators. Therefore, a series configuration minimizes both the capital cost and electrical
consumption of the system. The Algar series evaporator system was designed for LLD. The crystallizer has been constructed and will be installed at a later date, most likely in conjunction with a future plant expansion.

Also note that an installed and operating parallel evaporator system can reap the availability, energy efficiency, and distillate quality benefits of a series configuration by adding a downstream evaporator and operating the already installed evaporators at a lower concentration factor. This has been done at one such SAGD facility in Alberta in conjunction with a plant expansion.

**Contaminant Reduction System** – One of the primary drivers for the transition from traditional treatment processes to evaporative treatment of SAGD produced water is that the improved boiler feed water quality allows for the use of standard drum boilers. Historically, the drum boilers installed downstream of produced water evaporators have operated at modest pressures (less than 1000 psig). As more SAGD projects considered high-pressure drum boilers (1,000+ psig), the quality of distillate from the evaporators required improvement. Specific constituents of concern for drum boilers include iron, copper, silica, and low volatility (or so-called “non-volatile” organics).

There are two basic types of mist elimination systems that can be used with falling film evaporators; mist eliminators that are internal to the evaporator body (with or without a high efficiency Contaminant Reduction System) and those contained in an external vessel. Use of external mist eliminator bodies result in a higher solids loading on the mist elimination system due to higher vapor velocities leaving the evaporator vessel, adds equipment and installation costs, requires space in a plant layout, and produces a waste that must be disposed of. Internal mist elimination systems, in general, provide improved distillate quality and do not have the disadvantages of the external systems discussed above.

In order to achieve the improved distillate quality required for use in high pressure boilers, advancements have been made to the standard internal mist elimination system. The improved internal mist elimination system, known as the “Contaminant Reduction System”, only adds a small equipment cost and provides the required superior results.
A Contaminant Reduction System includes the following steps of contaminant elimination:

1. The annular area between the tube bundle and the sump is sized such that the vapor velocity is maintained between the minimum and maximum critical velocities for the demisters.
2. The first level of demisters is comprised of chevrons, which knocks out greater than 95% of the droplets. The changes in the direction of the chevron surfaces cause the larger mist particles to impinge upon the chevrons, coalesce as larger particles and drop to the sump.
3. The next demister level has multiple, distinct layers of mesh pad of varying design, which remove virtually all of the rest of the mist. The mesh wire size and arrangement causes different size mist particles to impinge and collect on each of the different meshes. The wire arrangement enables the mist liquid to flow downward on each wire, come together at wire intersection so as to grow in size and finally be directed into troughs, which protect the liquid from the rising vapor. This liquid in the troughs then flows to the sump wall and pours down into the sump.

This demisting process is the mechanism that removes colloidal silica, which is in the mist particles. A continuous spray of distillate with dilute caustic is directed upward onto the mesh pads, in order to dissolve trace levels of silica vapor in the vapor stream. Empirical data on vapor liquid equilibria for all silica species indicates that the caustic wash will reduce the silica vapor by a factor of more than 100, probably 1,000. The NaOH within the spray dissolves silica as electrically charged hydroxide complexes, which have no vapor pressure. The spray also collects on the wire mesh, flows into the above-mentioned troughs and then down into the sump. Henry’s Law data, solubility data and vapor pressure data for very high boiling organics, which are in the feed, indicate that the compounds are probably organic alcohols and other similar organic compounds. In that case, the high pH distillate wash on the demisters would readily “dissolve” these vapors. The Henry’s Law constants for these organics show a preferential distribution to liquid over vapor of a 1,000 to one or even higher.

It has been shown that this arrangement of mist elimination within the evaporator vessel is significantly more effective than a separate, external mist eliminator body because the vapor velocity is kept low right from where it leaves the cascading brine all the way through the demisters. It reaches a higher velocity only when it has left the demisters and enters the ducting to the compressor. Maintaining the vapor velocity low at all points upstream of the demisters, especially in
the area where the vapor exits the brine curtain (the vapor-liquid disengagement zone), is key to minimizing the load on the mist eliminators and to maintaining distillate quality.

The table below displays the distillate quality of a produced water evaporator system utilizing two evaporator units in series and operating with an internal Contaminant Reduction System. This is the arrangement used at Connacher Algar.

### Table 1 – Quality of distillate from produced water evaporator systems utilizing an internal Contaminant Reduction System.

<table>
<thead>
<tr>
<th>Distillate Quality Parameter</th>
<th>Contaminant Reduction System (^{(1),(2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved O(_2)</td>
<td>&lt; 0.007 ppm</td>
</tr>
<tr>
<td>Total Iron</td>
<td>≤ 0.01 ppm</td>
</tr>
<tr>
<td>Total Copper</td>
<td>≤ 0.01 ppm</td>
</tr>
<tr>
<td>Total Hardness</td>
<td>&lt; 0.05 ppm as CaCO(_3)</td>
</tr>
<tr>
<td>pH</td>
<td>8.8 – 9.6</td>
</tr>
<tr>
<td>Non-Volatile TOC</td>
<td>≤ 1.0 ppm</td>
</tr>
<tr>
<td>Oily Matter</td>
<td>≤ 0.2 ppm</td>
</tr>
<tr>
<td>Silica (SiO(_2))</td>
<td>≤ 0.20 ppm</td>
</tr>
</tbody>
</table>

Note (1): Assumes evaporator system is arranged in a series configuration.

Note (2): Values based on GE Water & Process Technologies full-scale operational data and test results.

**Chemical Cleaning Improvement** – As discussed previously, system availability is of the utmost importance for a produced water evaporator system in a SAGD facility. This is why it is important to note that in situ chemical cleaning is now a standard protocol for some high pH produced water evaporator systems operating at SAGD facilities. Simply adding a special cleaning chemical to the evaporator feed tank and letting the evaporator continue to operate normally results in sustained heat.
transfer coefficient recovery (i.e., cleaning) without negatively impacting system operation or distillate quality. The cleaning chemical and waste products are discharged from the system via blow down and sent to disposal or the crystallizer, in the case of LLD or ZLD. The Connacher Algar facility will be able to use this new cleaning method.

ADVANCEMENTS IN PROJECT EXECUTION, MODULARIZATION, TOTAL INSTALLED COST REDUCTION, AND PROJECT SCHEDULE IMPROVEMENT

It is currently estimated that there are in excess of 170 billion barrels of recoverable bitumen reserves in the Athabasca oilsands fairway. Due to the nature of the depositions, it is further estimated that 80% of these reserves will be, by necessity, extracted utilizing some in situ technique. In addition, resource owners are discovering smaller deposits whose reserves do not justify the levels of capital investment seen in the mega projects that have been typical in the oilsands sector in the past.

In order for the resource owners to exploit smaller reserve parcels, it has been necessary for project groups to develop more efficient processes and to revise project execution strategies to reflect the requirements of reduced capital and shorter lead times. Of particular importance to this strategy is that the smaller resource companies not put themselves in a position where is it necessary for them to compete with the mega projects for such resources as engineering talent, fabrication shops and field contractors.

The financing requirements for smaller operators are more onerous for the development of oilsands projects than they are for conventional oil and gas developments principally due to substantially higher per barrel capital requirements and the significantly longer lag between the expenditure of capital and the initiation of cash flow.

The western Canadian oil and gas industry has consistently responded to technical challenges with innovative solutions. The evolution of in situ bitumen exploitation is no different, as smaller producers have brought their conventional expertise and execution strategies into the oilsands arena.
Project execution

In response to the previously mentioned issues, a paradigm shift in project management techniques has been of critical importance to the recent successes in execution of smaller in situ oilsands development. It is conceded that fabrication and construction techniques are similar when comparing various projects, but what has differentiated the Connacher Oil and Gas Limited projects in terms of schedule and budget success is the overall approach to the project execution and risk management.

The project execution includes the following aspects which are reviewed in detail below:

- Process design;
- Contracting strategy/risk management;
- Shop fabrication/procurement;
- Logistics/transport;
- Field construction.

Process Design – Although there are several in situ techniques currently in various phases of development, steam assisted gravity drainage (SAGD) is the only technique presently in use on a commercial basis. Accordingly, Connacher Oil and Gas Limited has elected to utilize this proven process to exploit their bitumen resources at the Great Divide. Additionally, after an exhaustive review, Connacher Oil and Gas Limited elected to utilize evaporative technology coupled with packaged boilers for the water process and steam generation, in contrast to the more typical SAGD facility installations. The relative merits of this design choice have been the subject of previous papers and further review in this regard is outside the scope of this paper.

The overall success of the project is ultimately determined by the function of the facilities once operational, including process efficiency, operating costs and reliability. In order to reduce risks in this area, the project management team put emphasis on the following aspects of the design:

- Detailed process review to ensure that the design basis clearly meets the needs of the
production group in terms of steam oil ratio (SOR), operating pressures, plant throughput and process measurement;

- Early involvement of operations expertise to address plant operability, redundancy, reliability and HAZOP/HSE issues;
- Ability of the design and project management team to quickly evaluate process options incorporating input from all stakeholders and to implement decisions rapidly;
- Ability of the team to recognize unit operations that have been successfully utilized on previous projects and not waste time on re-evaluations unless justified.

One of the stated goals of the project team was to take the modularization of the facilities to the next level. The advantages of the approach are significant and include:

- Reduced labour rates for trades working in fabrication shops as opposed to in the field;
- QA/QC and NDT is easier and less expensive to administer in a shop environment;
- Productivity of the trades in the shop is typically higher due to the absence of the harsh climactic conditions frequently encountered in the field;
- Trades working in fabrication shops do not incur transportation or subsistence costs;
- A shop schedule will not require flexibility to accommodate down days resulting from bad weather.

It is a significant challenge for the detailed designers to achieve this level of modularization. In order to accomplish it, the designers have implemented a number of innovations to improve execution in the field:

1. Pipe racks are designed as transportable modules with flanged connections. Although this results in more welding, it speeds up the construction process by minimizing pressure welding in the field, which is often more difficult due to accessibility (scaffolding) and climate. It also eliminates the need to undertake hydro-testing and other NDT in the field.
ii. Major equipment packages are awarded immediately following finalization of process design based either on a bid or sole source justification basis. This expedites the schedule and allows the design team to initiate detailed design around the pre-engineered packages as early as possible. Selection of sub-suppliers of major equipment packages, such as the evaporator system, who have significant experience in modularization is critical.

iii. Pipe racks are heat traced and insulated in the shops. Again, the advantages of shop versus field labour costs and efficiencies are realized. This approach is made feasible by the development of area-rated heat trace plugs that allow heat tracing to be joined much the same way piping flanges are bolted up. On past projects, heat tracing and insulation have been the critical path and frequently there were conflicts with other trades, resulting from congestion in certain areas. Shop installation has significantly improved this aspect of the construction process.

iv. Electrical cable trays are installed on the pipe modules in the shop. As mentioned, this realizes the shop versus field costs advantages and it improves the schedule by allowing the electrical contractors to immediately begin pulling cable as soon as the equipment is set. This is further enhanced by pre-installing certified fall protection on high racks which reduces scaffolding requirements and gets the contractor immediate access once equipment is in place.

v. All instrumentation and wiring is installed on pre-packaged skids in the shop and wired to a
skid edge junction box. This significantly reduces cable pulling and termination work in the field, and allows loop checks to be done in a shop environment which provides similar benefits related to QA/QC and NDT associated piping, as previously mentioned.

vi. Careful consideration is given in establishing MCC locations in the plant layout to minimize cable requirements and reduce congestion during field terminations. Also, the switchgear is pre-installed in the various MCC buildings and tested prior to the buildings’ shipping from the shop.

vii. Loose ship spools are designed with flanged connections and are hydro-tested prior to shipping. This requires extreme attention to detail based on 1/8” design tolerance and an overall 98% fit was achieved at Algar on shop-built spools.

Contracting Strategy And Risk Management – A major contributor to increased lead time on most projects is the requirement that each aspect of the project be subject to a rigorous bid process. This requires a much higher level of completion in engineering prior to bid, increases complexity of project management due to legal involvement and often puts the project managers in an adversarial relationship with contractors and vendors. It is widely believed that his approach reduces project risk. However, there have been several recent high-profile failures, major cost overruns and schedule delays on projects that adhere to this strategy.

The background of the engineering contractor (AMEC BDR) and project management team (Drifter Projects) has predominantly been on smaller to mid-sized capital projects of relatively short duration. It was their collective experience that the best project results are achieved when the goals of the project team, vendors and contractors are aligned.

In order to accomplish this, the following was proposed to Connacher management;

- Detailed design, procurement and project services from the engineering contractor would be provided on a fixed lump sum based on a percentage of the original ± 10% AFE Estimate;
- In the case where several viable sources were able to supply process components, a full sealed bid process was utilized to select the vendor;
- In the case where a single source with a proven track record was the obvious or only
available supplier, contracts could be awarded based on a fixed price with a documented sole source justification;

- In certain situations, suppliers were given a time and materials contract based on a cost estimate. These contracts were subject to weekly cost updates to monitor performance;
- Field contracts were offered to proven contractors on an hourly rate basis. Rates were compared to area standards to ensure consistency and field supervisors approved tickets daily to monitor costs.

The success of this approach is predicated on the ability of the project managers to choose good contractors and suppliers, to supervise the details of each contract and to ensure an open link of communication between all the disciplines. In addition, this approach was favored by the majority of the vendors as it allowed a reasonable guarantee of profit without assumption of undue risk.

Having previously demonstrated the successful implementation of this approach on similar projects, the engineering contractor and project management team were encouraged by an enlightened and forward thinking management team at Connacher Oil and Gas Limited to replicate this success at both Great Divide Pod 1 and Algar projects. It was determined that the previous utilization of this project management style would more than adequately mitigate project risk. The schedule and cost performance on both projects has affirmed this.

**Shop Fabrication and Procurement** – The onus is on the engineering contractor during this phase of the project. A detailed schedule and cash burn forecast are developed as soon as all major equipment contracts are awarded. This also establishes the field schedule and the requirements for the engineering contractor to issue IFC drawings.

The successful management of the shop fabrication and procurement are the cornerstones on which the execution of the project is based. Attention to detail is the key, and several systems of checks and balances have been established to maintain adherence to cost constraints and schedule.

As mentioned previously, it is important for projects of this size not to compete for shop space with larger projects that may be under construction at the same time. In accordance with this and in
keeping with the overall project philosophy, the engineering contractor and project management team utilized the services of several small shops with whom they have a history of successful collaboration.

Typically these shops are not required to bid this work but are given a time and materials type contract and are subject to extreme scrutiny by shop inspectors. Both the shops and the inspectors understand that future considerations are strictly dependent on cost, schedule, and accuracy and historically they have provided the results. Simply put, inspectors and shops that don’t “measure up” are removed and not invited back on future projects. A benefit of this approach is that it has established a friendly rivalry such that shops that demonstrate better efficiency are awarded a bigger share of the project.

*Logistics and Transport* – The entire project execution plan is integrated and a breakdown in one area adversely affects the results in others. The Great Divide project area is remote and road access is via the notorious Hwy 63. This highway is subject to slow travel times on a frequent basis resulting from transportation of large loads. It is famous for poor road conditions due to weather and is frequently shut-down because of accidents.

In a situation where there are fixed bid contractors on site waiting for equipment deliveries, the project owners are required to cover stand-by. The approach at Algar allows the site supervisors to deploy contractors according to availability of equipment and materials, and crew sizes can be modified to optimize cash burn. In the same vein, the transport contract is devised so that the contractor is paid on a per kilometer delivered basis and not penalized for issues not within his control. There is significant communication between logistics coordinators, shop inspectors, trucking dispatchers and site supervisors to ensure smooth flow of equipment and materials. Where possible, skids are not handled multiple times; they are loaded at the shop, transported to site, and set on their permanent foundations on location.

*Field Construction* – Under this project execution scenario, field construction presents the greatest risk and uncertainty for cost control. The success of this final step is dependant on a multitude of factors including weather and the efficiency of the project management team and engineering
contractor to deliver. The contracting strategy provides site supervisors the flexibility to manage manpower deployment to optimize cash burn, which means that the ultimate success of the project is strongly influenced by the decisions made in the field.

A prime mechanical contractor is chosen and at least one secondary mechanical, two electrical and miscellaneous others. The majority of the contractors are working on an hourly rate basis and are subject to deployment and accountable for productivity from their respective site supervisors. There is minimal overlap; the prime contractor provides services to the others on site. As an example, the electricians frequently require welding. Under this scenario the mechanical contractor provides it. Under a bid, the electrical contractor would have to provide it and have an extra welder on site, driving up costs. The examples of this are numerous: from duplication of crane service, scaffolding and laydown space just to name a few. Without competition from contractors under a strict bid scenario there is better cooperation between contractors and a more cohesive approach to project execution.

Contracting strategy, while a significant contributor to project efficiency, is not in itself the principle factor. Construction innovation has been the primary reason for the repeatable success of the project management strategy. Two of the most significant construction innovations implemented at Algar are summarized below:

i. Civil Construction: The conventional civil foundation design typically goes according to the following sequence:

- Pound piles, cut to height, and install caps;
- Excavate, form, and pour grade beams;
- Install rebar for slabs;
- Pour slabs (hoarding or tent seasonal dependant);
- Set equipment on pile caps;
- Erect building structural;
- Erect building skin;
- Wire building.
The disadvantages in this system are mainly the grade beams and slabs frequently need to be hoarded due to weather, and no other activity is allowed until the slab is poured and cured.

The foundation design at Algar proceeded as follows:

- Pound piles, cut to height, and install caps;
- Excavate and install steel grade beams;
- Set equipment on pile caps;
- Erect building structural;
- Erect building skin;
- Wire building;
- Install rebar for slabs;
- Pour slabs.

This system significantly expedited the availability of the building for access by the trades, and since heat can be applied to the building, it improves working conditions during winter construction and eliminates the need for any hoarding during cement pours. This innovation reduced foundation installation by 40% compared to the conventional approach.

**ii. Modularization:** The extent to which modularization improved field construction is the most significant factor in reducing field costs and improving schedule performance. An example is the Stage 1 evaporator. It was decided to shop fabricate the vessel and at 128” tall and exceeding 220,000 lbs the unit presented some challenges related to transport and lifting but it was set in place in one day. Field erection would have required the crane on site 200 plus days, scaffolding, insulators, and electricians and would have increased costs significantly. Overall, the reduction in field costs attributed to modularization contributed a 25% reduction in field mechanical costs and a 15% reduction in electrical labor costs to the project’s bottom line. Figure 6 shows one tower going up while another tower is transported to site. Figure 7 demonstrates how building block modules enable fast assembly of a complex building.
Figure 6 – Pre-fabricated towers both set in one day at Connacher Algar.

Figure 7 – Building block modules enable fast assembly of complex building
CONCLUSIONS

1. The optimized high pH produced water evaporator system design requires between 40 and 60% less caustic than the initial high pH system design utilized at most operating facilities. In the case of Connacher Algar, the caustic consumption will be able to be further reduced or completely eliminated since the evaporator blowdown from the two evaporators at the 10,000 barrel per day Connacher Great Divide facility, which are already treated with caustic, will be fed directly into the Algar evaporators.

2. The series evaporator configuration used at the Algar facility provides a number of benefits over a parallel evaporator configuration:
   a. Improved system reliability due to the fouling potential being limited to the smaller, downstream evaporator,
   b. Increased energy efficiency due to a lower boiling point rise and vapor compressor power requirements in the upstream evaporator,
   c. Reduced capital costs due to expensive materials of construction being isolated to the downstream evaporator, and
   d. Superior distillate quality due to the majority of distillate being produced by the larger upstream evaporator, which operates at a lower TDS than the downstream evaporator so the impact of droplets that carry over into the distillate is less.

3. An internal Contaminant Reduction System greatly improves distillate quality by:
   a. Limiting vapor velocities until the vapor has passed through the demisters,
   b. Utilizing high efficiency chevrons as the first level of demisting,
   c. Including multiple, distinct layers of mesh pad that causes different size mist particles to impinge and collect on each of the different meshes, and
   d. Spraying a dilute caustic wash over the mist elimination equipment and vapor space thereby reducing the amount of volatilized silica and organics that end up in the distillate.

4. High pH produced water evaporators can now be designed for in situ chemical cleaning,
thereby reducing downtime and maximizing system availability. This technology is available for the Algar facility.

5. The most significant contributors to the repeated on-time and on-budget success of the SAGD projects for Connacher Oil and Gas at Great Divide are:

a. An enlightened and forward thinking management team at Connacher who are able to understand the advantages to an unconventional project execution strategy and decisive enough to implement it.

b. An experienced engineering contractor that is particularly accurate in terms of design and drafting in order to realize the full benefits of modularization.

c. Use of experienced sub-suppliers for critical equipment packages, such as the evaporators, that have significant experience in modularization.

d. An experienced project management team, especially in the area of site supervision, that provides the attention to detail required to mitigate risk and bring the project in on time and on budget.

REFERENCES

