Water Management for Hydraulic Fracturing – Part 4

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This is the fourth of several articles on the subject of water management for unconventional hydraulic fracturing. In the third article, the subject of suspended solids removal using coagulation/flocculation and electrocoagulation was discussed. A detailed explanation was given as to why those technologies are justified based on the characteristics of flow back fluids and the objective of removing suspended solids. In this article, the use of Mechanical Vapor Compression as a desalination technology is discussed.

The main motivation behind these articles is to explain which technologies are being used for which applications, and to explore whether or not they are appropriate and cost effective. In talking to operators, there is often a sentiment that there are too many technologies to choose from and little basis upon which to make the selection. Indeed, water management for hydraulic fracturing has become a magnet for every water treatment scheme imaginable. It helps therefore to look at a few successful technologies, in some detail, and to try to understand why they are appropriate.

In general, desalination of recycle flow back water is becoming less important. New formulations of salt tolerant polymers and fluids are being developed and applied. Some of these HF fluids are more expensive on a per pound basis but become cost-competitive when overall reduction in water source, treatment and disposal costs are taken into account. Nevertheless, there is still a need in some regions to desalinate. This is particularly true when specific compounds must be removed such as boron, or various scaling components.

In industrial and municipal water treatment, there are two general technologies for desalination, i.e. thermal processes and membranes. Thermal desalination processes are much older than membrane processes. Despite the rapid advance of membrane processes in the last two decades, at least 1/3 of the installed worldwide desalination capacity is provided by thermal desalination. Other technologies could be included in the list of desalination including ion exchange, electrodialysis and softening. However, these technologies are not applicable in the high range of salinities for HF flow back fluids where desalination is needed.

Due to the high fouling tendency of HF flow back fluids, and due to the high salinity in some regions, membrane based desalination technology is not viable. Spiral wound Nano Filtration (NF) and Reverse Osmosis (RO) membranes are the workhorses for onshore and offshore desalination of seawater. Neither can be used when the concentration of organic fouling material exceeds a few tens of mg/L. As discussed in Part 2 of this series, the Slick Water formulations contain several hundred mg/L of spent polymer. The linear and cross-linked gels (mostly guar based polymer) contain a few to several thousand mg/L of organic fouling material.

In industrial and municipal water treatment, the main thermal desalination technologies are Multi-Stage Flash (MSF), Multiple-Effect Distillation (MED) and Mechanical Vapor Compression (MVC). The market shares of these three processes are 87, 12, and 0.2%, respectively [1]. An additional and important variation of these technologies is Multiple Effect Distillation/Thermal Vapor Compression MED/TVC), which is a hybrid combination of MED and vapor compression. It is important because it has high energy efficiency, compared to the others. Briefly, MSF involves the use of multiple evaporation chambers each having lower pressure and therefore lower temperature. The chamber, or stages are designed for maximum heat recovery. MED

Thermal desalination processes consume much greater energy than the RO process. Depending on the particular technology, the energy required can be as high as 10–15 kWhr/(m^3 of water) (1.6 to 2.4 kWhr/bbl). This is high compared to 5 kWh/m^3 (0.8 kWhr/bbl) for RO in a seawater application, which is itself considered to have a significant energy requirement in the form of pumping. However, the reliability, low fouling tendency, and extensive field experience with these thermal desalination technologies keeps them in demand, particularly for large facilities where waste heat is available.

MSF and MED systems are often applied in cogeneration plants where power and water are produced simultaneously. This is convenient because both systems require low pressure heating steam which can be easily extracted from the power plant at fairly low cost. The MVC system is operated solely on electric power, which is both a benefit and a drawback. It is a benefit since MVC can be applied where no waste heat is available. It is a drawback since the electricity cost can be high. The high electrical cost makes it less preferable in the industrial and municipal water industries. But as discussed for electrocoagulation, MVC is a niche technology with features that make it appropriate for desalination of hydraulic fracturing flow back fluids.

Since MVC does not require waste heat, it is the preferred desalination technology for use in some hydraulic fracturing operations. Before discussing where it is most applicable, the principle of operation is discussed first.

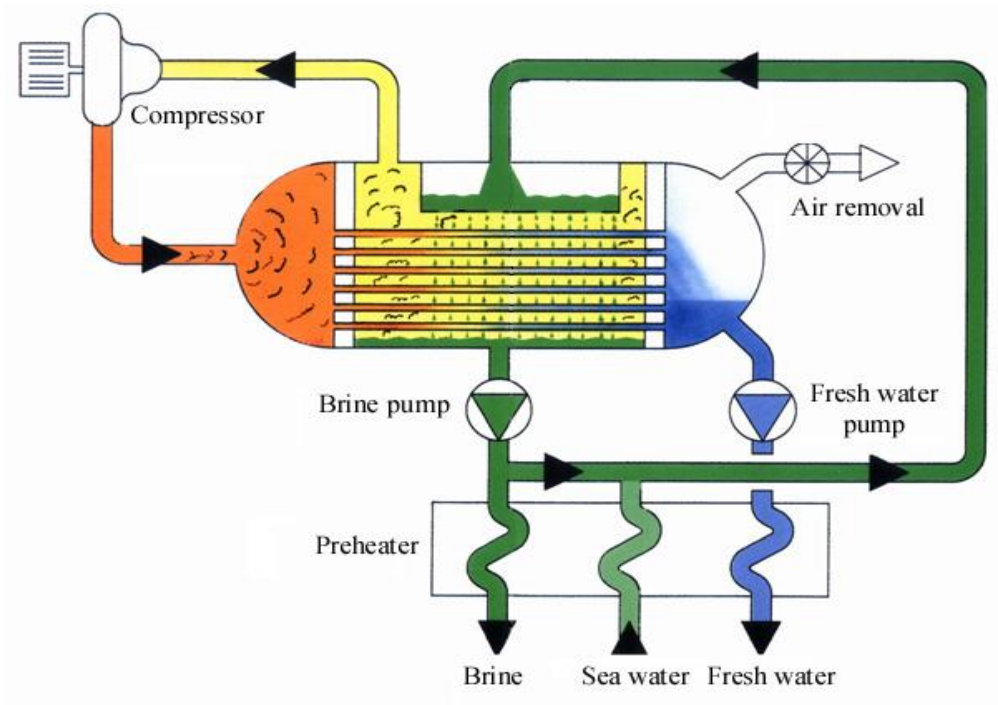

Figure 1. Mechanical Vapor Compression – Process Flow Diagram

- Incoming (feed) brine is heated in a waste heat recovery heat exchanger (Preheater). The hot effluent brine, and fresh water is used to heat the cool incoming brine.
- The brine enters the MVC unit at the top of the tube bundle where it is sprayed onto the outside of the tubes. The brine flows over the tubes as a thin film.
- Vapor is generated from the brine which is sucked into the vapor compressor. The compressor has a dual function. It lowers the gas pressure which promotes evaporation, and it compresses the vapour, which heats it (like a heat pump), and pushes the vapour it into the tube side of the tube bundle.
- The hot vapor exchanges heat with the cooler brine. Thus causing the vapor to condense. The condensed fresh water is discharged.
- A stream of brine is discharged from the bottom of the brine sump and is pumped to the top of the tube bundle, together with incoming brine.
- A fraction of the circulating brine is discharged. This fraction is referred to as the drawdown and is typically expressed as a fraction of the incoming feed brine flow rate. If the drawdown is 10 percent, then it has a salinity ten times that of the incoming brine. In this case, the recovery is then 90 percent.

In any of the desalination processes, the flow rate of concentrated brine is a critical process parameter. The smaller the follow volume, the greater the concentration of waste brine. Typically, scaling tendency is the limiting factor. From a technical standpoint, it is possible to further concentrate the brine into a high solids sludge, which could be dried into a granular solid. It is even possible to produce various salt products. In general though, these further process steps add significantly to cost and are generally not practiced. Instead, the concentrated waste brine is disposed of. The economics of desalination must therefore also include the cost of this waste disposal.

An important point that often gets missed in discussions of MVC is that it does not involve distillation. Distillation involves nucleate boiling, in which vapor is generated on the surface of a heat exchange tube. Since vapor is such a poor conductor of heat, local tube surface temperature can be several degrees above the boiling point of the liquid. Further, if the tube is immersed in the boiling liquid, then there is a hydraulic head that must be overcome in order to form the vapor, which further increases the temperature of boiling. The presence of vapor on the tube surface, and the elevated temperatures creates a significant scaling potential for all but the most pure liquids. Thus, distillation is not appropriate for fluids with high scaling and fouling tendency.

MVC is more precisely referred to as evaporation processes. Nucleate boiling is minimized in order to minimize scaling potential and therefore to allow desalination of highly contaminated feed streams. Vapor is generated by heating across a large surface area, and application of partial vacuum such that operating temperature is well below the boiling point of the liquid. MVC has been applied in Steam Flood (e.g. Oxy Mukhaizna project, Oman), and in Steam Assisted Gravity Drainage (SAGD), which is applied extensively in Alberta, Canada.

In oilfield application, typical scale forming components include the carbonates (calcium, magnesium and iron carbonate), and silica. The carbonates are problematic since their solubility decreases with higher temperature. Also, as CO_2 is vaporized out of the brine, the pH of the brine goes up which causes the carbonates to precipitate. Additional techniques used to prevent scale deposits include high surface area (and low thermal driving force), mist mats to prevent liquid carryover into the vapor, the use of scale inhibitors, softening, ion exchange, pH adjustment, the use of a seeded slurry or the use of ball pigs. Equipment suppliers such as Sasakura have specialized scale prevention strategies optimized for oilfield brines. Scaling and fouling is also a concern in the auxiliary equipment such as the heat exchanges. Companies such as Alfa Laval have developed high surface area vertical heat exchanges that reduce fouling.

Among various desalination technologies, Mechanical Vapor Recompression (MVR, or alternately Mechanical Vapor Compression) stands out as appropriate for hydraulic fracturing application in a semi-permanent or modular configuration. This is explained below. But first, a review of the various stages of HF water treatment is required.

To understand where and why MVC is appropriate for HF flow back treatment, the unique aspects of the economics of HF flow back water treatment must be considered. In Part 1 of this series, the concept of stages of field development was discussed. It is worthwhile to repeat some of that discussion because it emphasizes the reason why evaporation technologies are being deployed for modular applications, and not being deployed from mobile units.

From a water treatment standpoint, there are three stages of shale field development. These stages are defined below in terms of the type of water treating equipment deployed.

Granted, this is a rather unique way of looking at the world, and not the typical viewpoint of the oil and gas industry. Nevertheless, it is important to make a distinction between these stages of field development because they are critical to the selection of water treatment technology.

1) Stage 1: Remote and isolated well development –
   mobile water treating systems

2) Stage 2: Well clusters with some in-field drilling and completions –
   modular water treating systems

3) Stage 3: Extensive in-field development with infrastructure to transport water to and from a centralized treatment facility –
   centralized water treatment plants

Mobile Stage of Development:
In the early stage of development of an unconventional field, a number of individual wells are drilled and completed. In the US, mineral rights are owned by the land leaseholders. The initial wells in a region will typically be drilled in remote and isolated areas. If water recycle is carried out, the water treating equipment must be mobile. Such equipment is compact and placed on a flatbed truck.

The economics of this kind of water treatment are significantly different from industrial water treatment economics. Capital cost is typically a small fraction of the total cost. Most of the cost of water treatment is due to staff time related to transportation to site, setup of the equipment, operation of the equipment, and demobilization and return transportation. If the equipment is complex, then additional time is required to mobilize and setup the equipment. Also, additional operators will be required. These factors add to the cost. If the capacity is low, then additional time is required to process the water volumes. As a general observation, the water treatment rate must be at least or exceed 5 to 7 barrels of water per minute. Lower capacity will just simply take too long and the cost of personnel on site will be too high. These factors are the main cost drivers. Thus, appropriate equipment in this stage of development is compact, simple, and relatively high capacity. Very few technologies meet these criteria. MVC certainly does not. Thus, to my knowledge, there are few if any mobile MVC units operating successfully in HF flow back applications.

Modular Stage of Development:
As field development progresses, the leases are secured and the drilling campaign becomes more structured. Clusters of wells are drilled and completed. It is then possible for several adjacent wells to be developed in sequence or simultaneously, facilitating the use of a modular water treating system.

In this case, a daisy chain or hub-and-spoke type of water piping arrangement can be constructed to feed the water treatment unit and to convey treated water to the wells that require it. Lay-flat hose, storage tanks, pond liners are all important components of the water management tool kit. In this case, a semi-permanent / modular water treatment facility is justified. The equipment would be transported on a few flat bed trucks. A few weeks would be required to prepare the site and erect the equipment. When a few or several wells are involved, the construction cost of a modular treating system is justified.

Aquatech provides a so-called Advanced Modularized Evaporation System which is designed as a package for rapid installation. It is transported in modular units, and erected with a minimum of field staff. The Nomad system from Fountain Quail is an MVR evaporator packaged in self-contained skid-mounted units. It is capable of processing 20,000 Bbl water per day and requires only three operators. It operates 24/7, when there is sufficient water. The capacity of the Nomad system must be integrated into the storage capacity of spent HF flow back water, the storage capacity of fresh water, the volume of water required for each HF, and the load recovery. Nomad is being applied in several shale developments including the Barnett and Marcellus.

Centralized Stage of Development:
Later in field life, there may be many wells in relatively close proximity. Over time, the construction of a water conveyance network, together with a centralized water treatment facility, becomes justified. This is the current trend in the Marcellus Shale. It has also been successfully implemented in the Pinedale Anticline in southwestern Wyoming (Boschee 2012). The capital cost of the water transport system, and of the water treatment facility are the main cost drivers. In this case, the capital costs contribute significantly to the overall cost. Due to plant automation, and the ability to achieve relatively stable steady state operation (not always achieved!), the number of operators is minimized, compared to the previous stages of field development.

In the centralized application of desalination, MVC is not the only thermal desalination that could be applied. If low grade steam is available, then MSF or MED could be used for reduction of energy use.

References

1) International Desalination Association, Worldwide Desalting Plants Inventory, 2006.
2) Boschee, P. 2012. **Handling Produced Water from Hydraulic Fracturing.** *Oil and Gas Fac. 1* (1): 22 – 26.