

Mechanical Vapor Recompression for the Treatment of Shale-Gas Flowback Water

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Summary

Used extensively by the food, chemical, and pharmaceutical industries, the mechanical-vapor-recompression (MVR) process is viewed as a reliable method for recovering demineralized water from concentrated brines. Devon Energy has supported the operation of an advanced MVR system at a north-central Texas (Barnett shale region) treatment facility. At this facility, pretreatment included caustic addition and clarification for total-suspended-solids and iron control. Pretreated shale-gas flowback water was then sent to three MVR units, each rated at 2,000–2,500 B/D (318–398 m³/d). Data were collected during a 60-day period in the summer of 2010. Distilled-water recovery volume averaged 72.5% of the influent water to the MVR units. The influent total dissolved solids (TDS) fed to the MVR units averaged just under 50 000 mg/L. More than 99% of the TDS were captured in the concentrate stream. The fate of multivalent cations; total petroleum hydrocarbons (TPH); and benzene, toluene, ethylbenzene, and xylenes (BTEX) throughout the treatment system was determined. Most of the iron and TPH removal (90 and 84%, respectively) occurred during pretreatment. The total removal of iron, magnesium, calcium, barium, and boron from the distillate exceeded 99%. BTEX removal from the distillate exceeded 95%. Electric power at the facility was provided by two natural-gas generators, and compressors associated with the MVR units were driven by natural-gas-fueled internal-combustion engines. Energy requirements at the entire treatment facility were tracked daily by total natural-gas use. Best-fit correlations between treated water and distillate production vs. total plant use of natural gas indicated that there was a base power load throughout the facility of approximately 120 to 140 Mscf/D (3400 to 3960 m³/d) of gas. Approximately 48 scf natural gas/bbl influent water treated (270 m³/m³ influent) or 60.5 scf/bbl distillate produced (340 m³/m³ distillate) was required; this represents an energy cost of less than USD 0.25/bbl treated (USD 0.04/m³ treated) and approximately USD 0.30/bbl of distillate product generated (USD 0.048/m³ distillate), assuming a natural-gas cost of USD 5/million Btu (USD 4.72/GJ). Performance in terms of water recovery and product-water quality was stable throughout the 60-day test.

Introduction

As shale gas emerges as one of the world's most abundant, affordable, and clean-burning sources of energy, sustained growth in the development and production of these resources will require intensive levels of sourcing and management of water. In most shale plays, hydraulic fracturing is a necessary step for initiating economical energy production. During the hydraulic-fracturing process, between 1 and 4 million gal (between 3780 and 15 120 m³) of water are mixed

with sand (which serves as proppant) and chemical additives (e.g., friction-reducer polymers, corrosion inhibitors, scale inhibitors, biocides), and the mixture is injected "downhole" as a necessary step in the well-completion process. Approximately 10 to 50% of this water is recovered during the months that follow a well completion. The recovered fluid can contain elevated concentrations of dissolved salt (picked up from mineral solubilization), suspended solids, TPH, and soluble organics, and low concentrations of chemical additives (Hayes 2009; Galusky and Hayes 2011). Therefore, recovered flowback water and produced-water streams present a water-management challenge and a significant cost component in the operation of the well. The challenges of managing and treating produced water for reuse and disposal have been addressed by others (SPE 2011; Coughlin and Arthur 2011; Gaudlip et al. 2008) because shale-gas brines generally have high salt concentrations, concentrated levels of calcium and barium that form scale on surfaces, and highly varied TPH compounds and BTEX.

The dimensions of water management for each shale-gas developer can be seen more clearly when considering that current trends favor the construction and completion of 10 to 30 wells from one or two well pads in each well field (an effort requiring 1 to 3 years). The installation of dozens or hundreds of well fields within a development area that is roughly the size of a county (400 to 1,100 sq miles or 1025 to 2800 km²) could require more than a decade. Under full-scale development, hundreds of millions of gallons of fresh water must be found and transported to well sites each year by means of tens of thousands of truckloads. In addition, the management of flowback water and produced water collected from an ever-growing population of completed wells requires options for the transportation and management of thousands of truckloads of brine that usually range in salt content from 30 000 mg/L of TDS (as seen in early flowback water) to more than 150 000 mg/L of TDS (as seen in many produced-water streams). MVR is a highly efficient distillation process. A mechanically driven blower or compressor is used to increase the pressure of the vapor that is produced from the boiler to improve heat-transfer efficiencies. An increase in the water vapor pressure increases the condensation temperature of the steam, rendering it useable for heating the original mixture (in the boiler) in a heat-transfer device or heat exchanger. The major advantage of MVR over conventional distillation is the ability to recycle the latent heat of flashed vapors to the bottom fluids, saving 10 to 15% of the total energy of distillation. In the past decade, the MVR process has increasingly been evaluated for its ability to convert saline brines into demineralized water streams that are easily handled, stored, and reused with a very low potential impact to the environment because of salts and organics.

MVR technology has become a standard method of high-efficiency distillation since its commercial introduction in the 1960s. The process has been used at thousands of facilities for the desalination of seawater (Veil 2008), the crystallization of sugars in the food industry, dewatering of products in the chemical and pharmaceutical

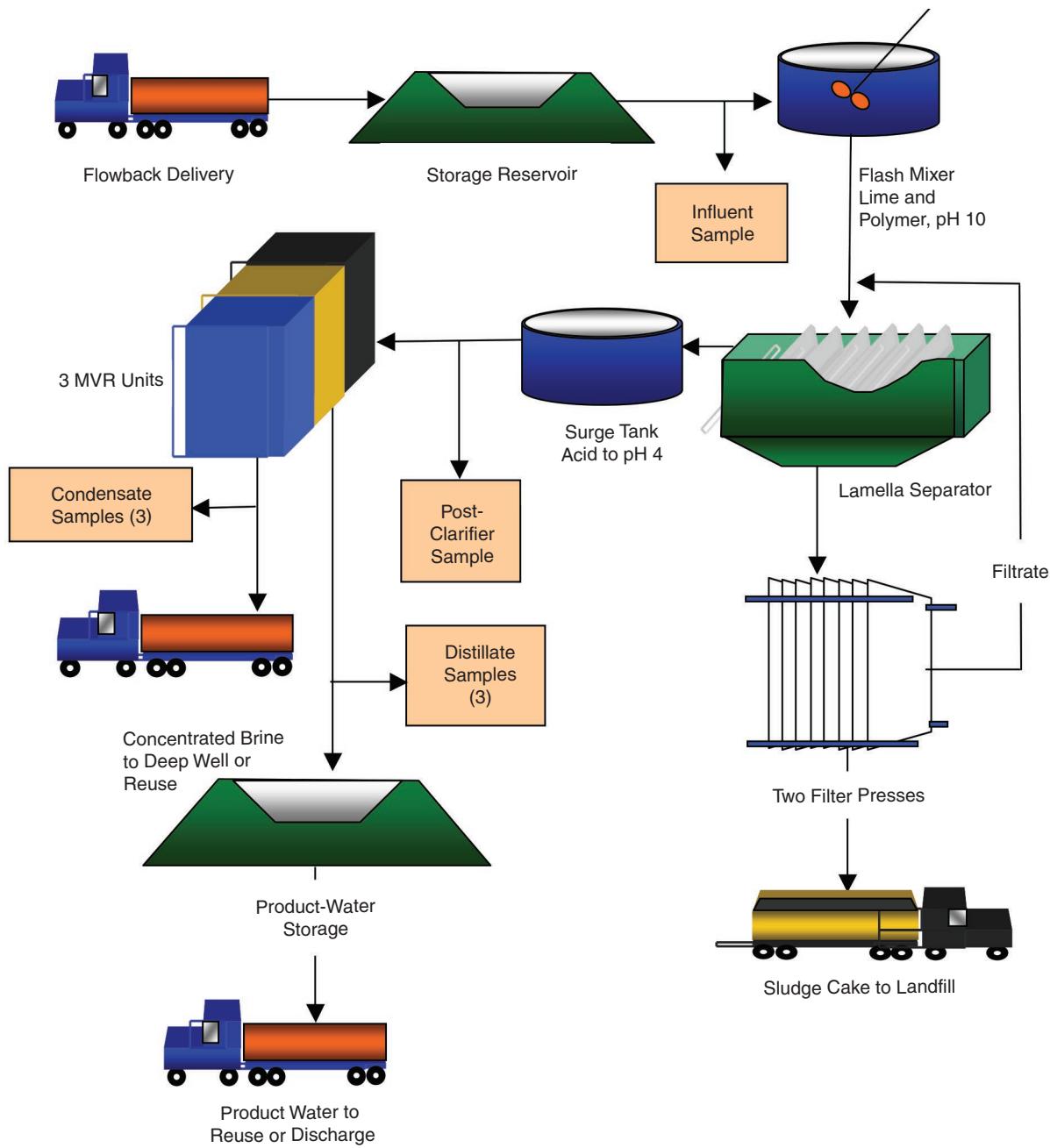


Fig. 1—MVR-process flow sheet, Maggie Spain facility.

industries (Becker and Zakak 1985), and lately, in the recovery of industrial wastewaters (Razzaghi and Spiering 2002).

Veil (2008) presented a cursory evaluation of the MVR units at the Devon Energy water-reclamation facility in Decatur, Texas, USA. This site (also called the Maggie Spain facility, which is the subject of the present report) treats flowback water and process water from Devon's shale-gas wells located at multiple well fields in Denton County, Texas, for the purpose of recovering demineralized water for reuse in subsequent shale-gas-well completions.

Methods of Sampling and Analysis

The Maggie Spain Water-Recycling Facility (**Fig. 1**) comprises an influent impoundment and a water-preconditioning train, followed by multiple MVR modules. At the heart of this facility is the MVR system, comprising three MVR skid units. The MVR skid units are operated in parallel to generate a demineralized

product-water stream and a concentrate stream. The diluate, representing greater than 70% of the water flow, is discharged to a product-water impoundment. The concentrate, representing less than 30% of the water flow and greater than 99% of the TDS, is collected in effluent storage tanks for future disposal. Fig. 1 shows the locations in the flow sheet where water samples were taken for analysis (sampling twice weekly). Analyses included conductance, total organic carbon, BTEX, TPH, total heavy metals, TDS, suspended solids, pH, alkalinity, sulfate, total ammonia, and phosphorus.

All of the energy required by the facility is supplied by natural gas from the shale-gas wells of Devon Energy. The electricity required for pretreatment and general site needs is supplied by two natural-gas-driven generators. Each MVR skid is powered by an internal combustion engine fueled by natural gas, and each engine is capable of delivering up to 700 hp (522 kW) of power. Total-en-

TABLE 1—INFLUENT AND POST-CLARIFIER WATER ANALYSIS

All Units (mg/L) Except pH and Conductance (mS/cm)	Influent Water			Post Clarifier		
	Average	Median	Standard Deviation	Average	Median	Standard Deviation
Specific conductance	55,835	55,650	24,890	57,989	61,050	24,243
TDS	49 550	44 900	10 959	49 133	46 900	9921
Total suspended solids	1272	357	3443	140	132	45
pH	NA	6.9	6.7–7.7	NA	3.7	3.1–4.6
Alkalinity	405	385	126	12	4	14
Total organic carbon	42	12	118	10	9	5
TPH*	388*	19	1363	5	4	2
BTEX	3.3	2.9	1.4	2.3	2.1	0.8
Ammonia	84	84	26	81	84	24
Sulfate	309	316	153	221	205	123
Phosphorus	3	3	2	2	2	1
Barium	15	7	19	13	6	17
Boron	17	18	4	16	16	3
Calcium	2916	2570	975	2876	2705	922
Iron	28	27	10	3	2	3
Lithium	12	11	3	12	11	3
Magnesium	316	291	131	319	296	114
Potassium	484	296	524	504	349	494
Sodium	10 741	10 700	3622	12 400	12 100	2821
Strontium	505	467	182	528	483	161

* TPH data were overwhelmed by a single event of 5893 mg/L. The TPH average is 38 ± 43 when this event is disregarded.

ergy-demand measurements were obtained from daily readings of the natural-gas use at the facility.

Results

Performance documentation included the analyses of energy demand and mass flows through the treatment system. The treatment train consists mainly of the water-preconditioning and MVR stages. The sample points are identified in Fig. 1. Chemical-composition data were analyzed to determine the fate of certain constituents of interest throughout the treatment train.

Preconditioning. The preconditioning section of the Maggie Spain facility provides suspended-solids removal, TPH control, iron removal, and calcium-stable water. Water is delivered by truck at a rate of 4,000 to 6,000 B/D (636 to 950 m³/d) to a 1.4-acre (5664-m³) storage reservoir. Water samples were collected on 18 scheduled sampling days during the 60-day performance-evaluation period covered by this effort. Chemical analysis of the water leaving the reservoir (representing influent water to the clarifier) is presented in Table 1. The average TDS is approximately 50 000 mg/L. The raw water contains a number of scale-forming cations, including calcium, iron, strontium, magnesium, and barium. Small amounts of TPH and BTEX are also present.

Water from the storage reservoir is sent to a clarifying flash-mix chamber, followed by a lamella clarifier. Caustic sodium hydroxide (NaOH) is added at the flash mixer to increase the pH of the water to approximately 10. Depending on the raw-water quality, approximately 500 to 1,000 gal (1.9 to 3.8 m³) of caustic solution (50% NaOH) is added per day to reach the target pH. The shift in pH causes much of the iron to precipitate. Polymer is added occasionally to aide in the coagulation of the solids. Precipitated iron, TPH, and other suspended solids are removed across a lamella-plate clarifier. The coagulation and sedimentation steps that are performed remove approximately 90% of the suspended solids, more than 90% of the total iron, and more than 80% of the TPH. The

chemical analysis of the post-clarifier water is also presented in Table 1.

The solids from the clarifier are dewatered with a pair of plate-and-frame filter presses. The solids contribution from the clarifiers to the filter is approximately 2,500 dry lbm/D (1135 kg/d). The cake solids produced from the presses are approximately 20 to 25% dry matter, yielding a wetted-solids stream of 10,000 to 12,500 lbm wet solids/D (4540 to 5680 kg wet solids/d). A 20-yard tote is removed from the site once per week, and the solids are sent to a landfill. The sludge from the clarifier has been tested against standard protocols from the US Environmental Protection Agency (EPA 2007) for the toxicity characteristic leaching procedure (TCLP). To ensure compliance with respect to constituents of concern (e.g., TPH and benzene by use of TCLP protocols), the sludge has been disposed of in a secured landfill.

Clarified water is sent to a surge tank where the pH is adjusted to 4 to stabilize the scale-forming cations, such as calcium. Typically, this pH adjustment requires the daily addition of approximately 250 to 500 gal (0.948 to 1.895 m³) of muriatic acid (36% HCl) to reach the low-pH target level. This pH-adjusted water is the feed stream to the MVR units.

MVR. The Maggie Spain facility has three MVR modules. All of the energy needs for these units are supplied by natural gas. Within each unit, a natural-gas-fired boiler is used to bring the module up to temperature during startup and a 700-hp (520-kW) natural-gas-fueled internal-combustion engine drives the compressor. Electricity used for ancillary lighting, controls, and data acquisition is supplied by on site generators that are fueled by natural gas. The footprint of the MVR facility is modest; a three-MVR processing facility occupies an area of approximately 250×250 ft (approximately 1.4 acres or 5660 m³). Each MVR module (Fig. 2) has a processing capacity of up to 2,800 B/D (445 m³/d) of influent brine.

Each MVR system consists of chemical conditioning plus three skids—pretreatment, engine, and evaporator heat exchanger.



Fig. 2—View of a single MVR.

Chemical conditioning consists of antifoam agents and corrosion control. The pretreatment skid provides 5 μ m of bag filtration and preheating economizers. The engine skid (**Fig. 3**) houses a mechanical compressor. The evaporator skid (**Fig. 4**) provides the liquid/vapor heat exchangers, evaporator tank, and distillate-collection tank.

Operation of the MVR process (**Fig. 5**) is started by heating a portion of water from the distillate-collection tank with an auxiliary startup boiler. When the process reaches its target temperature, the boiler is extinguished. The compressor is fed a balanced mixture of vapor (fresh distillate) from the vapor-separating concentrate tank and water (existing distillate) from the distillate-collection tank. The compressor increases the fluid pressure, creating a saturated vapor. The saturated vapor enters a liquid/vapor heat exchanger on the exchanger skid. The hot side of the exchanger is the saturated distillate vapor. The cool side of the exchanger is concentrated liquor fed from the vapor-separating concentrate tank. The process is designed to vaporize approximately 10% of the concentrated liquor.

The overall water balance for typical operation was generated by examining the distribution of water between the distillate and concentrate of the individual MVR units (**Table 2**). **Fig. 6** shows a plot of distillate and concentrate volume vs. the volume fed to each unit. The slope of each line represents the fraction of the influent recovered. The MVR units, as operated in this process period, generated 72.5% distillate and 27.5% concentrate. All of the distillate was collected and stored in a clean impoundment, and this water was then trucked to shale well-pad locations for reuse in hydraulic fracturing. The concentrate was collected and stored in tanks for transport to a deep-well disposal facility, which was located less than a mile from the facility and that was permitted as a Class II injection well (a category of well for the disposal of fluids associated with oil and gas operations).

The overall salt balance for typical operation was generated by examining the distribution of TDS between the distillate and concentrates of the individual MVR units. This evaluation is presented in **Fig. 7**. The slope of each line represents the fraction recovered in that process stream. The plot shows that the concentrate reliably contains greater than 99.7% of the total salts, while less than 0.3% remains in the distillate.

Total daily natural-gas consumption (scf/D) was measured for the entire Maggie Spain facility. Energy consumption for individual MVR units at this facility was unavailable. Total natural-gas demand was plotted as a function of overall influent loading and product-water yield to determine the overall energy requirement for the facility (including MVR operation plus electricity generation). **Fig. 8** presents a graph of total scf of gas use as a function of treated water



Fig. 3—Compressor engine skid.



Fig. 4—Evaporator skid.

or distillate generated. The plots appear linear with respect to either total volume of water treated or the volume of distillate produced. The slopes of the lines in this plot indicate that the process requires approximately 48 scf/bbl influent (270 m³/m³ influent) or 60.5 scf/bbl distillate (340 m³/m³ distillate) produced above the base loading.

Some of the scatter in the data is inevitably a result of other process loads on the generators, such as drive motors and hydraulic pumps on the clarifier and filter-press skids, site lighting, and miscellaneous office and maintenance activities. The raw-gas numbers also reflect inefficiencies in electricity generation and transmission. Assuming that the field efficiency of the gas generators is approximately 35% to produce the required electricity, then the value of 60.5 scf/bbl distillate is equivalent to 6.4 kWh/bbl distillate (40.2 kWh/m³). This is convincingly within the range of results reported for electrically driven MVR units (Leatherman 1983; Gallerani et al. 2002). If the apparent base load (e.g., electricity generation, non-MVR heating) is added to the incremental-processing energy requirements, the overall treatment requires 72 scf/bbl treated (404 m³/m³) or 100 scf/bbl distillate produced (562 m³/m³).

Fate of Environmental Constituents

The following plots summarize the fate of important environmental constituents at various points in the Maggie Spain pretreatment and

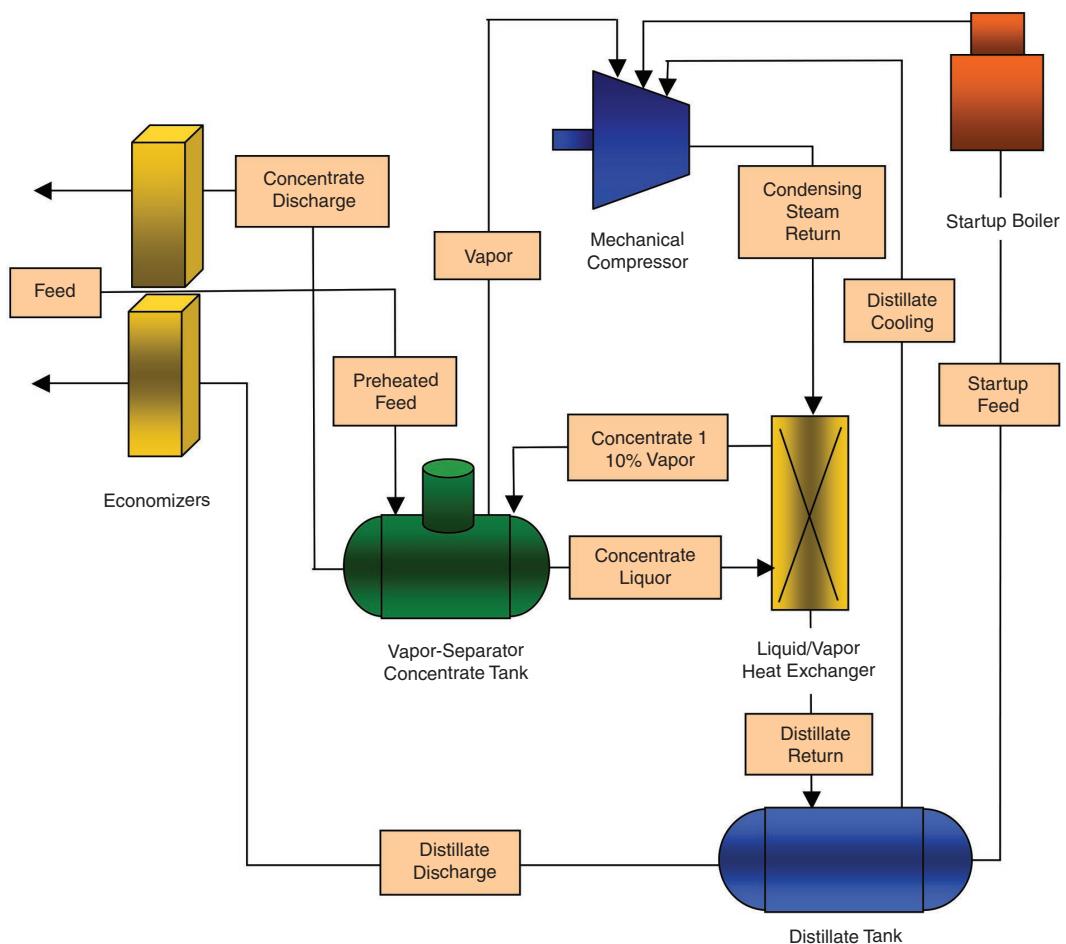


Fig. 5—Simplified flow diagram for the MVR process.

TABLE 2—CHEMICAL ANALYSIS OF THE DISTILLATE AND CONCENTRATE STREAMS—COMBINED DATA FROM THREE MVR UNITS

All Units (mg/L) Except pH and Conductance (mS/cm)	MVR Distillate*			MVR Concentrate		
	Average	Median	Standard Deviation	Average	Median	Standard Deviation
Specific conductance	267	161	280	162,818	158,500	83,327
TDS	171	103	179	168 465	162 000	29 239
Total suspended solids	9	4	12	617	519	319
pH	NA	10.7	10.5–10.9	NA	6.7	6.3–6.8
Alkalinity	263	248	85	162	143	73
Total organic carbon	22	16	17	12	12	4
TPH	4.6	4.0	2.3	4.3	4.0	1.1
BTEX	0.2	0.1	0.2	0.0	0.0	0.0
Ammonia	68	64	26	113	114	50
Sulfate	6	5	2	887	793	631
Phosphorus	0.1	0.1	0.2	7	6	8
Barium	0.1	0.1	0.0	27	5	48
Boron	0.4	0.4	0.1	63	62	13
Calcium	3.2	0.8	6.8	9699	8960	2485
Iron	0.1	0.1	0.0	4	2	4
Lithium	0.1	0.1	0.0	42	38	11
Magnesium	0.4	0.1	0.8	1132	1055	355
Potassium	0.5	0.1	1.4	2028	1675	1576
Sodium	14.3	3.6	31.6	41 302	39 000	8046
Strontium	0.5	0.1	1.0	1739	1735	430

* Distillate TDS calculated from specific conductance.

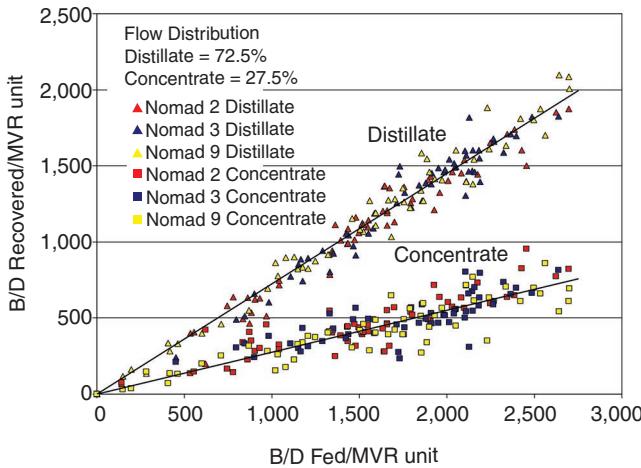


Fig. 6—Water distribution between distillate and concentrate during the 60-day sample period.

MVR processing stages. Data for these figures were generated from Tables 1 and 2.

The bar chart of **Fig. 9** depicts the overall fate of TDS. The storage reservoir and clarification have no effect on TDS concentrations. The MVR units concentrate the TDS, removing most salts from the distillate stream.

The bar chart of **Fig. 10** summarizes the fate of calcium, magnesium, and strontium, which are potential scale-forming components. This figure shows that the fate of these compounds is similar to that of the TDS. The storage reservoir and clarification have no effect on calcium, magnesium, and strontium concentrations. The MVR units concentrate these cations and remove them from the distillate stream.

The bar chart of **Fig. 11** describes the fate of barium, boron, and iron in the water. Barium and boron follow the familiar trend for TDS and are similar to calcium, magnesium, and strontium. The pre-treatment has little effect, and the ions are captured in the MVR concentrate stream. Iron, however, is precipitated by the initial caustic addition in the rapid-mix tank and much (90%) is removed by the clarifier. Any remaining iron is removed preferentially in the MVR unit and deposited in the MVR concentrate.

Suspended-solids-removal data are presented in **Fig. 12**. Approximately 90% of the suspended solids are removed by the clarifier, while the remaining suspended solids are transferred to the concentrate stream. It is also possible that certain cations, such as barium and strontium, reach saturation equilibrium within the MVR concentrate stream and generate excess suspended material.

TPH are largely removed with the suspended solids in the clarifier step (**Fig. 13**). More than 84% of the TPH are removed by clar-

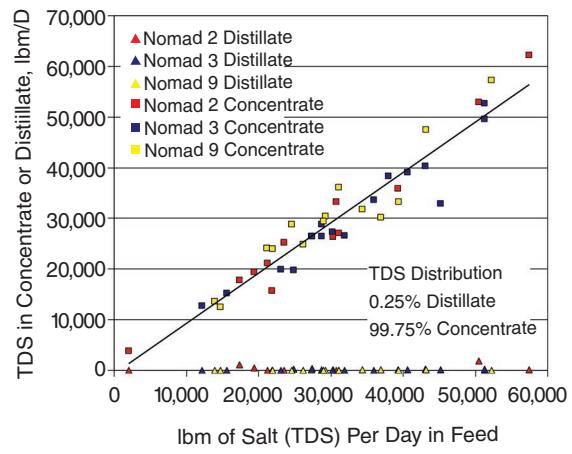


Fig. 7—Distribution of dissolved salts between the distillate and the concentrate streams during the 60-day sample period.

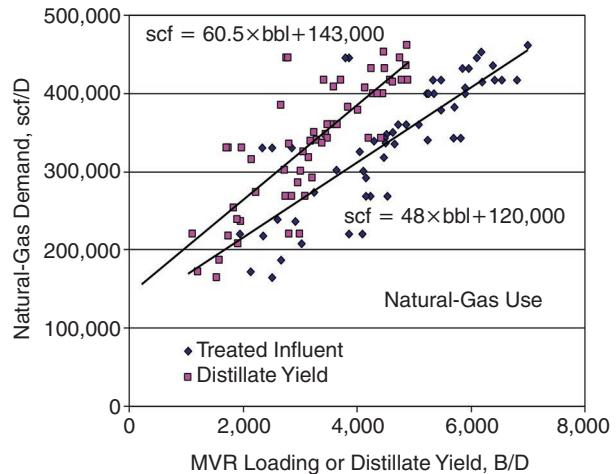


Fig. 8—Daily natural-gas demand vs. influent loading and distillate product yield (composite of three MVR units).

fication, and, presumably, are removed with the sludge cake from the filter press. Note that TPH data were overwhelmed by a single event of 5893 mg/L. The TPH average is 38 ± 43 when this outlier event is disregarded. **Fig. 13** presents the amended value of 38 mg/L influent, which is reduced to trace TPH levels (4 to 5 mg/L) in the post-clarifier, distillate, and concentrate streams. Oils and greases were not included in the analysis of the water streams; however, the

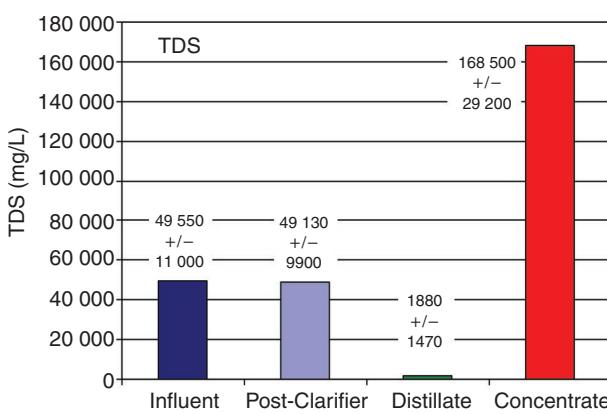


Fig. 9—Fate of TDS in the Maggie Spain facility.

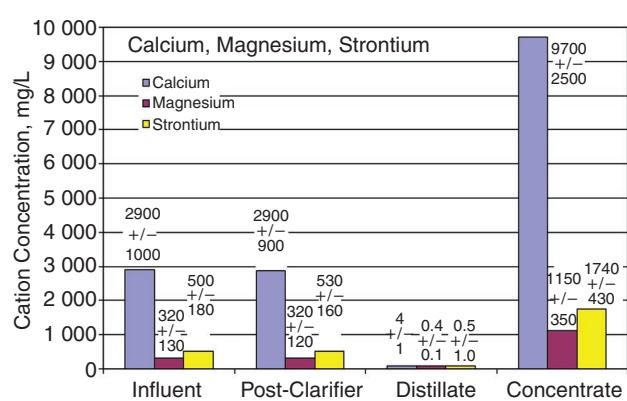


Fig. 10—Fate of calcium, magnesium, and strontium in the Maggie Spain facility.

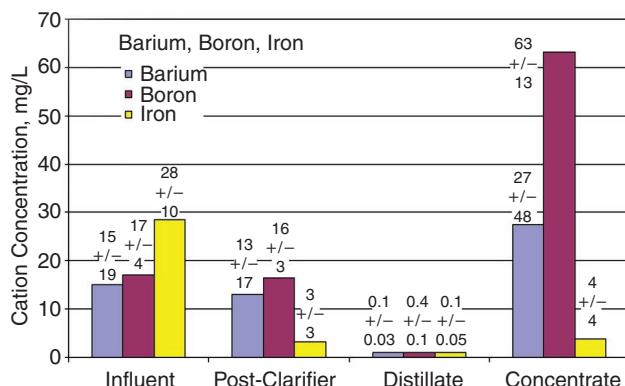


Fig. 11—Fate of barium, boron, and iron in the Maggie Spain facility.

fate of free oils and grease would likely be similar to the fate of TPH (>84% removal).

Total BTEX represents a volatile fraction of the organic matter in the water stream. Some (30%) of the BTEX is removed between the influent and the end of the clarification process (Fig. 14). Presumably, much of this removal occurs at the rapid-mix tank from surface volatility. Much of the remaining BTEX is removed (an additional 90 to 95%) in the MRV process. It is likely that this organic component is volatilized and expelled at degassing or pressure-relief valves throughout the separator tank. Notably, the remaining BTEX is preferentially found in the distillate, indicating that these volatile compounds remain with the vapor side of the MRV process.

Discussion

MVR has been considered an attractive alternative when the recovery of demineralized water from brines for the purposes of reuse and/or reduction of brine volumes is used to control transportation and disposal costs. In future years, the shale-gas industry will continue to strive to implement water-management solutions that meet environmental-compliance goals at reasonable operational costs. In many development areas—especially where access to Class II well disposal is becoming constrained—water reuse is recognized as having the potential advantages of reducing water demand and controlling transportation costs while reducing the volumes of brines requiring final disposal. Where water reuse is planned, there are at least two water-conditioning approaches that are seriously considered: primary treatment of the collected brines for the removal of TPH, suspended solids, and scale-forming cations followed by blending of the conditioned brine with fresh water (e.g., surface water or groundwater) to create an influent stream for the next fracturing job; or primary treatment of the collected brine (as described previously) followed by demineralization of the brine before blending with fresh water. The advantage of the second option in reuse is that the resulting water blend will contain salinity levels well below 3000 mg/L TDS, and the associated impoundment needed to store this blend will likely be lower in cost and easier to permit because of the reduced salt concentrations. This option, however, involves the additional cost of demineralization, which is why it is of importance to understand the capability and costs associated with a leading commercial MVR process.

The MVR system of the Maggie Spain facility discussed in this paper is an excellent example of an MVR process that has been adapted effectively to the water-management challenges of the shale-gas industry. All unit processes are mobile and can be operated on natural gas, an obvious advantage in a natural-gas field.

Multiple capabilities of the process are evident from perusal of the analytical data. Most of the constituents of interest, including trace organics and multivalent metals, are effectively removed in either the pretreatment or the distillation process. The distillate is sufficiently pure to be reused in place of fresh process water, or could be discharged to a receiving stream with little or no additional con-

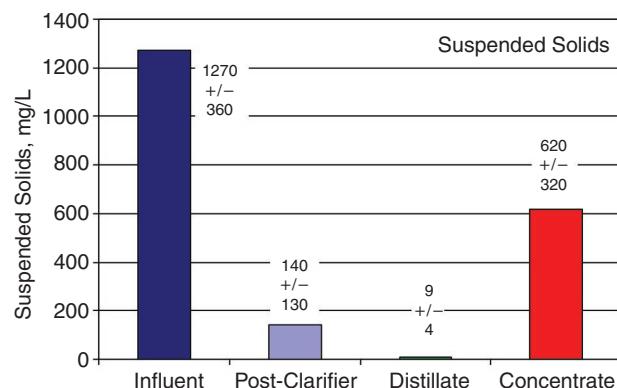


Fig. 12—Fate of suspended solids in the Maggie Spain facility.

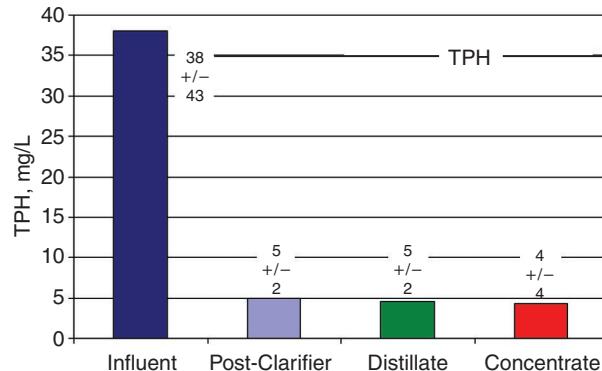


Fig. 13—Fate of TPH in the Maggie Spain facility.

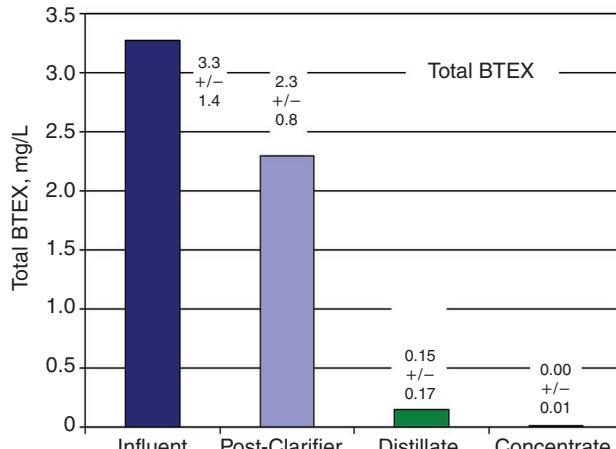


Fig. 14—Fate of total BTEX in the Maggie Spain facility.

ditioning. The concentrate volume represents less than 28% of the original volume, resulting in lowered ultimate disposal costs.

The overall treatment (entire facility) required 72 scf natural gas/bbl treated (404 m³/m³ treated) or 100 scf/bbl distillate produced (562 m³/m³ distillate). MVR costs are more difficult to detail from the data collected; however, best-fit correlations indicate that there is a base natural-gas load to the facility that requires 120 to 140 Mscf/D (3400 to 3960 m³/d). In terms of MVR-specific demands, the energy required per incremental barrel of treating influent water and per barrel of distillate generated was estimated to be 48 and 60.5 scf, respectively, (270 and 340 m³/m³, respectively). Assuming 35% efficiency of electrical-power generation from natural gas, the energy requirement is approximately 6.4 kWh/bbl (40.2 kWh/m³) distillate. The energy demand of the Maggie Spain

facility in the processing of shale-gas waters appears to be as favorably low as the most efficient MVR processes cited in the literature for the treatment of far-less-aggressive waters in terms of organics and scale-forming constituents.

Economics

As with the implementation of many water-treatment processes, the “/bbl” pricing for shale-gas water treated in the MVR water-reclamation facility depends on setting and a number of other factors (e.g., overall water quality, average salinity of feed waters, actual deliveries of water vs. design capacity, year-by-year projection of flowback and produced-water deliveries) that affect the efficiency and nature of the operation. In the energy industry, most shale-gas developers prefer to contract out the water-treatment needs for brine conditioning that are needed for water reuse and/or disposal. Energy companies typically do not choose to own or operate water-treatment equipment, but prefer instead to contract out water conditioning on a USD/bbl basis. Commercial information obtained from the equipment operator indicates that the cost of brine pretreatment for removal of suspended solids, iron, and TPH will come in at less than USD 1/bbl (USD 6.30/m³), and the cost for the application of MVR technology for the recovery of demineralized water from moderately concentrated produced water (approximately 50 000 mg/L TDS) ranges from USD 3 to 5/bbl (USD 18.9 to 31.4/m³) for facilities in the range of 3,000 to 6,000 B/D (475 to 950 m³/d) of brine-processing capacity. This cost is reduced toward the USD 2/bbl cost level when economies of scale for capital are realized at the larger processing facilities. Energy is a minor component of this cost. Because approximately 48 scf natural gas/bbl influent water treated (270 m³/m³ influent) or 60.5 scf/bbl distillate produced (340 m³/m³ distillate) was required, an energy cost of less than USD 0.25/bbl treated (USD 1.60/m³ treated) and approximately USD 0.30/bbl of distillate product generated (USD 1.90/m³ distillate) (assuming a natural-gas cost of USD 5/million Btu or 4.72/GJ) would be incurred in most applications.

Operational experience spanning more than 9 years in shale-gas plays has led to practical enhancements in equipment selection, integration, and design and has led to improved decision making regarding ease-of-maintenance and cost control. The vendor of the Maggie Spain equipment has emphasized the importance of using highly mobile and modular equipment that is rugged, durable, and easy to disassemble, clean, and reassemble to quickly address maintenance needs with minimal downtime. This has been applied to the front-end brine-pretreatment package and to the MVR skids. During the 60-day test period of this evaluation, no significant interruption of brine processing in the treatment facility was observed.

The overall rationale for the use of the MVR-treatment technology is the recovery of demineralized water for ease of handling and reuse for hydraulic fracturing of nearby shale-gas wells and for the reduction of brine volumes requiring transportation and disposal. In the Barnett, the cost of disposal of brines in Class II wells is relatively low, ranging from USD 0.40 to 0.60/bbl (USD 2.50 to 3.80/m³); transportation costs range from USD 0.02 to 0.04/bbl/mile (USD 0.08 to 0.16/m³/km). Total costs, including transportation and disposal, range from USD 1.45 to 1.90/bbl (USD 9.10 to 12.00/m³), depending on the distance to Class II well facilities. However, in the Barnett and other shale plays in Texas, water conservation is a high priority and is considered to be critical to the industry’s sustainability. Typically, flowback water that is collected from a single well after completion and reused to complete the next shale well can potentially reduce freshwater demands by hundreds of truckloads, thereby reducing community impacts (e.g., traffic, road wear, emissions), while showing progress toward industry goals of water conservation. The incremental cost of using the MVR technology allows more than 75% of the water content of flowback brines to be recovered as demineralized water and reused without the needed expense of no-leak transportation and double-lined impoundments to prevent release of salts.

Summary and Conclusions

A commercially available MVR system was operated at the Maggie Spain shale-gas water-treatment facility for 17 months. This report covers an intensive sampling and evaluation over a 60-day period in the summer of 2010. During this period, the treatment system recovered demineralized water from shale-gas brines on a daily basis without major interruption.

Pretreatment at this plant, which included caustic addition and clarification, was highly effective in achieving efficient removals of total suspended solids and iron. Pretreated water was then distilled with three MVR units, each rated at a distillate-generation capacity of 2,000 to 2500 B/D (318 to 398 m³/d). Distilled-water recovery averaged 72.5% of the influent to the MVRs. The influent TDS fed to the MVRs averaged just under 50 000 mg/L. More than 99% of the TDS were captured in the concentrate stream. The distillate averaged 171 mg/L TDS. The fate of multivalent cations, TPH, and BTEX was followed. Most of the iron and TPH removal (90 and 84%, respectively) occurred in the clarification step. The removal of iron, magnesium, calcium, barium, and boron from the distillate exceeded 99%. BTEX removal from the distillate exceeded 95%. All of the distillate product water was reused for hydraulic-fracturing operations that were performed in proximal shale-gas-development areas.

Power at the facility was provided by two natural-gas electric generators and natural-gas-fueled engines driving the compressors on each of the three MVR skids. Gas use was measured on a daily basis during the test period. The facility required 72 scf natural gas/bbl treated (404 m³/m³ treated) or 100 scf/bbl distillate produced (560 m³/m³ distillate). Best-fit correlations between treated water and distillate production vs. natural-gas use indicated that there was a base power load throughout the facility of approximately 120 to 140 Mscf/D of gas (3400 to 4000 m³/d). Incremental power requirements greater than the baseline were approximately 48 scf/bbl influent water treated (270 m³/m³ influent) or 60.5 scf/bbl distillate produced (340 m³/m³ distillate).

These data indicate that MVR technology is adaptable to shale-gas water treatment. Commercial information obtained from the developer of the Maggie Spain site indicates that the cost of brine pretreatment for removal of suspended solids, iron, and TPH will come in at less than USD 1/bbl (USD 6.30/m³), and that the cost for the application of MVR technology for the recovery of demineralized water from moderately concentrated produced water (approximately 50 000 mg/L TDS) ranges from USD 3 to 5/bbl (USD 18.90 to 31.40/m³).

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