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Simulataneous water and energy optimization in shale exploration

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ABSTRACT

Because of several environmental challenges associated with the development of shale resources around the world especially in the area of water management as well as flaring of co-produced gas. It is important to find a better strategy that can alleviate these environmental issues by developing a more integrated approach to address the challenges of the water-energy nexus in shale exploration.

This thesis presents a mathematical framework for simultaneous optimization of water and energy usage in hydraulic fracturing using superstructure-based optimization technique. First, a continuous time formulation for scheduling is developed for the hydraulic fracturing activities. Recycle/reuse of fracturing water (flowback water) is achieved through purification of flowback wastewater using thermally driven membrane distillation (MD). A detailed design model for this technology is incorporated within the water network superstructure in order to account for the design specifications and the energy requirement of the system. The feasibility of utilizing the co-produced gas that is traditionally flared as a potential source of energy for MD is also examined. The applicability of the proposed model is determined using a case study which is a representative of Marcellus shale play.

Next, the mathematical formulation is extended to account for shale gas production, processing, distribution, usage in power generation, and transmission of produced power in which the effect that the type of gas to be produced in a particular shale play/region will have on the infrastructure development is investigated. The study considers natural gas as fuel for commercial, industrial and residential customers, as well as fuel for electric power generation, with the goal of maximizing the overall profit. The resultant model is applied to a case study, which is a representative of Marcellus shale play. The application of the model results in 23.2 % reduction in freshwater consumption, 18.6 % savings in the total cost of freshwater and 42.7 % reduction in the energy requirement of the regenerator. The thermal energy consumption is in the order of 160×10^3 kJ/m^3 of water. Two types of gas are considered: wet gas and dry gas. The results indicate that the cost incurred in the network involving wet gas is 41.76 % higher than the network involving dry gas due to the processing requirement of wet gas.

In addition, the multi-contaminant property of flowback water is investigated through implementation of an on-site pre-treatment technology to remove contaminants like total suspended solid (TSS), Total organic compound (TOC), oil, grease and scaling materials whereby, specification for water reuse can be achieved. This is achieved by considering

detailed ultrafiltration model in order to evaluate the sustainability of the system in terms of energy consumption and associated costs. The study also looks into the feasibility of using the gas that would otherwise be flared to generate electrical energy for the membrane system via an onsite gas generator. The application of the proposed model in a case study results in 21.4 % reduction in the amount of water required for fracturing and 10.3 % reduction in the amount of energy needed by the regenerator. The system consumes 0.109 kWh/m^3 of energy at an operating pressure of 3.69 bar. This indicates a very low-energy consumption compared to a typical energy requirement for wastewater reclamation which usually ranges between 0.8 and 1.0 kWh/m^3 for membrane filtration. The study indicates the possibility of reducing the operating cost of the regeneration network by 61 % if the electrical energy needed is generated onsite using the gas that would otherwise be flared.

The effect of using multiple/ hybrid treatment technologies in maximizing hydraulic fracturing wastewater reuse while accounting for the sustainability of the process in terms of energy and associated cost is also investigated. The study considers ultrafiltration and membrane distillation processes as possible pre-treatment and desalination technologies for flowback water management. Two different scenarios are considered to cover possible flowback water composition in hydraulic fracturing in terms of salinity. Application of the proposed model to a case study leads to 24.13 % reduction in the amount of water required for fracturing. In terms of energy requirements, the approach led to 31.6 % reduction in the required thermal energy in membrane distillation and 8.62 % in the energy requirement for UF. For flowback water with moderate TDS concentration, 93.6 % of the wastewater reuse comes from pre-treated water by ultrafiltration and 6.4 % from membrane distillation. However, as the flowback water salinity becomes higher, the percentage of pre-treated water that could be reused reduced to 81.1 % and the percentage supply through membrane distillation increased to 18.9 %. In all cases, the results indicate that the decision to allow the pre-treated water to pass through desalination technology strictly depends on the volume of water required by a particular wellpad and the salinity of the wastewater.

In general, although the obtained results may not generally applicable to all shale plays, the proposed framework and supporting models aid in understanding the potential impact of using scheduling and optimization techniques in addressing flowback wastewater management.