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The Potential of Nuclear Reactor Technology to Treat Produced/Brackish Water for Oil & Gas Applications

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Authors' contributions

This work was carried out in collaboration between both authors. Author HH designed the study, conducted the research and the discussion on the part relating to oil and gas section, wrote the protocol, and the first draft of the manuscript. Author JW managed the discussion on the nuclear energy and related sections. Both authors read and approved the final manuscript.

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ABSTRACT

A merger of two mature technologies (the nuclear and petroleum industries) has the potential to process water produced from oil and gas operations to drinking quality standards at a reasonable price of $0.30 to $0.40 per 42-gallon barrel. This "RO" process treats the produced water with the process heat from a small nuclear reactor with ~125 MW of power. This process also improves the efficiency of hydraulic fracturing and directional drilling, plus significantly reduces the volume of disposed water into formations while at the same time it increases public safety by reducing the probability of earthquakes [1].

For at least most of the past 10 years, the oil and gas industry in the United States has struggled to manage the ever-increasing costs of disposing and handling produced-water and other wastewater from oil and gas production in the Permian Basin and the US. This includes trying to develop and maintain the required high-quality fresh water supplies for both horizontal drilling, and new production techniques such as hydraulic fracturing. In fact, the current cost of water management for oil and gas production in the region has risen to the point where it has arguably become the industry's most important cost issue. A successful approach to water management will maximize

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profit by promoting higher operational efficiency, leading to reduced costs.
The nuclear energy industry is well known for being a capable generator of electricity in the US. In the past 10 years, the Department of Energy's (DOE) Idaho National Laboratory (INL) has verified an innovative nuclear reactor design that has been constructed and tested in the US to treat any water source to "drinking water" quality, plus a "waste" stream." According to DOE/INL Reports, this can be accomplished in the cost range of ~$0.38 per 42-gallon "barrel" (or less than a half a cent per gallon) [2].
This would improve the efficiency of the Oil & Gas production industry through the utilization of "clean" water sources, plus also potentially re-establish the freshwater resources (e.g., the Ogallala Aquifer) that have been both depleted and polluted by both the petroleum industry and agriculture over the past 75 years or so.
The "process heat" required to treat this produced water to "drinking water" quality would be supplied by a 25 MW(thermal) "High-Temperature, Gas-cooled (nuclear) Reactor" (HTGR) that would be operated at temperatures up to 1700^{o} F and cooled by the inert gas Helium (He). Further, this facility will never have to be "turned off" for refueling for ~70 years (the estimated life of the facility) since, in this reactor design, that process is automatic, and driven simply by gravity as described below.
The nuclear fuel is contained in thousands of small fuel-bearing microspheres that are ~1 mm in diameter and also made of graphite. The fuel-bearing microspheres are then mixed with more graphite and placed in thousands of graphite "pebbles" that are approximately the size of a tennis ball. These tennis ball sized pebbles are then placed in the reactor core in a manner analogous to a moving "gum-ball" machine. They enter the core at the top and start their travel to the core bottom. When these tennis-ball sized pebbles reach the bottom, via gravity, the fuel is completely used and they automatically fall out of the reactor core bottom for disposal. When this occurs, space is made at the top of the reactor core for a new fuel pebble to start its journey to the bottom of the core.
The cost of a "first" commercial plant with this design, constructed and privately financed in west Texas by the US private nuclear reactor engineering, design, and construction company named X-Energy, is estimated to be ~$1-2 billion. However, this cost is expected to be significantly reduced if X-Energy is 1) successful in financing this facility with municipal bonds and other non-governmental sources, plus 2) also working with the Trump administration in streamlining the "construction approval and licensing process" performed by the USNRC (United States Nuclear Regulatory Commission).
It is X-energy's belief that the current cost estimates by the federal government are inflated, and that by using engineering, design and construction processes currently required and used by other governments around the world, the total cost will be significantly reduced by up to 50%. In addition, this X-Energy facility will be the very first nuclear facility that will be constructed in the US using entirely private equity funds and financing which should also lower costs!
And in fact, the Trump administration is currently reviewing other projects such as this, and X-Energy believes that the secret to lowering the facility costs of nuclear reactors in the US is to drastically streamline the regulatory process for the facility design, engineering and construction of all reactors.
The attractive economic projections for this facility indicate both, a significant cost reduction of treating "produced water" from Oil & Gas Operations, and also provide a good path to both clean up and recharge existing fresh-water aquifers that have been polluted by agriculture and/or the petroleum industry. This marriage of technologies in the Petroleum and Nuclear industries can truly "make a difference" in improving the quality of drinking water in West Texas and also lead to a significant increase in profit for the oil and gas industry.
It is also important to emphasize that the proposed nuclear reactor design that will be used for these applications have been proven to be "intrinsically safe" throughout the world. In this case, "intrinsically safe" is defined as "if this reactor starts to have any potentially catastrophic problem (generally caused by fuel "failure"), it will automatically *and without human intervention shut itself down*" This ability is due to the unique design of the fuel system.
The concepts presented in this paper are transformational since this facility will utilize the technologies and experience of two gigantic and effective energy-producing entities in addressing and developing true "energy security" for the US and the world.

Keywords: Produced water treatment; oil and gas; nuclear energy; hydraulic fracturing.

1. INTRODUCTION

The southern-most part of the Ogallala Aquifer has been the fresh water "life-line" for both agriculture and livestock in the Permian Basin and Midwestern US since the late 1890's. However, in the last half of the 20th Century, the growth of the Oil and Gas industry in the Permian Basin has multiplied the need for fresh water to the point that the quality of the Ogallala, and other local shallow fresh water resources, are quickly diminishing via their intermingling with "produced water" from the oil and gas production [3].

The oil and gas industry is facing a dilemma in the Permian Basin and elsewhere regarding the availability of sufficient freshwater resources required to produce hydrocarbons. Applications of horizontal drilling and hydraulic fracturing, also called "fracking," both require considerable amounts of fresh water. Based on some estimates, hydraulic fracking requires about 5 million gallons of fresh water per well and horizontal drilling about 3-4 million gallons respectively [4]. Considering the fact that there are about 160,000 active oil wells, plus another 22,500 active gas wells in the Permian Basin [5], some of which will certainly need fracking, plus there are additional wells that will continue to be drilled in the Permian Basin over the next 5 to 10 Years, our freshwater use will be significant! The current water stress in the region makes the issue even more sensitive, not only economically, but also in terms of the priorities vis-a-vis clean water for human consumption and agriculture. Therefore, water management has arguably become one of the top priorities for further development of the oil and gas industry in Texas and the Permian Basin.

2. CURRENT APPROACH TO PRODUCED WATER

Steps have been taken by the oil and gas industry to mitigate the impact of fresh water shortages. For example, several companies conduct wastewater treatment to "varying degrees." The treated water is reused/recycled for further applications. However, this minimal treatment does not by any means, promote the required environmental protection to the fullest, and does not provide ample water for additional fracking and drilling activities. More importantly, water cost for energy production is steadily increasing making it continually more expensive to produce hydrocarbons. Therefore, an innovative approach to the water problem and its management is mandatory.

It is worth noting that on average, ~10 barrels of water is produced per barrel of oil [6] in the current production process in the Permian Basin. The industry currently disposes of the produced water by deep injection into porous formations, which is an added expense to the hydrocarbon recovery effort. Therefore, the production process potentially experiences water costs for both

1) oil and gas production, and 2) wastewater disposal.

The real nature of the problem is the lack of ample, suitable, fresh water required for energy production at reasonably low prices. To remedy this problem, the oil and gas industry can use these small nuclear reactors to create "drinking quality" water for fracking, from "produced water" at reasonable prices.

Along these lines, there have also been efforts to treat wastewater/flow back water for recycling/reuse in oil and gas production operations [7]. However, the current industry practice of recycling and reusing "flow-back water" has been disappointing. The nature of this practice is a water conservation measure, but the process is environmentally less than effective, and fails to significantly reduce the need for fresh water demands required for production.

Meanwhile, brackish water has also been utilized for energy production as well. Though this type of effort is a step in the right direction, the required water quality and cost can be significantly improved.

3. A NEW SOLUTION TO PROVIDE "DRINKING QUALITY" WATER

To remedy this problem, we are proposing to integrate oil and gas production efforts with the nuclear industry. The nuclear industry has a successful record of water treatment/ desalinization using process heat from small nuclear reactors (<100 MW th) all over the world. A convergence of efforts by both energy industries to treat the wastewater/produced water from the oil and gas production make it feasible to reuse/recycle the treated water for further energy production. In other words, the treated produced water not only becomes the source for fresh water for the needed oil and gas operations, it also reduces the stress on the fresh water availability for human consumption, and/or agriculture and other applications. In fact, this approach also helps the oil and gas industry become more self-sufficient on the subject of "drinking quality water" availability for hydrocarbon production at a reasonable cost.

As mentioned above, the integration of the efforts of the two industries will make the challenging water problem manageable. However, the financial aspects of this effort need to be addressed as well. It is estimated that an investment of about 1.5 to 2.0 billion dollars is needed to build the first small nuclear reactor to supply the process heat for this water treatment plant. At the discretion of the water treatment facility operator, the process heat can either be used to treat the produced water or, "to generate electricity." But in either case, the reactor will never have to shut down for refueling over the 70-year lifetime of the facility since the fueling system is driven simply by gravity.

This type of effort that uses a nuclear reactor to create the fresh water from produced water, will not only better protect the environment, but will also improve the efficiency of fracking and drilling operations in the petroleum industry. Fresh water/treated water of up to drinking quality, is preferred over the minimally treated wastewater currently used in the Permian Basin. This is potentially an attractive undertaking for the oil and gas industry, the nuclear industry, the local environment, and the community at large.

As a solution to the dire need for much-needed water in the Permian Basin, this paper is proposing the construction of at least one nuclear reactor with an adjacent "produced water treatment plant." The estimated cost of the "first" nuclear plant in Ector County, Texas, will be about 1.5 to 2 billion dollars and it will have a footprint of approximately one city block. The produced water from the oil and gas fields in the vicinity of the Ector county site will be either piped to, and/or truck-transported to, the plant. The details of the water transfer are of high importance since that of itself is of significant cost to the operators. It would be of high importance to pipe the produced water for treating to the plant which reduces cost significantly. The estimated cost to pipe the water is ~ $0.02 per barrel per mile, while trucking water to the plant will be in the order of $0.09 per barrel per mile [8]. The capital cost of the pipeline will vary as the distance between the producing fields and the water treatment facility. However, construction of a pipeline will require up-front investment capital which will be considerable, relative to the hauling option. Currently, disposing of produced water costs about $1 to $4 per barrel in the Permian Basin [9].

4. RESULTS AND ANALYSIS

The business/technological merger of the two giant energy entities (O&G and Nuclear) paves the way for a transformational experience on both the national and global scale. It is the first time that the capabilities of the nuclear industry are implemented for energy production through the oil and gas industry. By that, we mean that the "produced water," which is a byproduct in the production of hydrocarbons, is treated by utilizing the process heat of a nuclear reactor for the benefit of oil and gas production.

The initial benefits of this project will revolve around the economics of this undertaking. Table 1 below [2] shows the estimated price range for the water treated in this process as determined by a study by the Department of Energy's Idaho National Laboratory.

Table 1. Price range for treated produced water

Price	$/42 gal BBL	$/gal
Lowest	$0.16	$0.004
Highest	$0.60	$0.014

Based on these estimates, produced water can be treated to drinking water quality at an average cost of about $0.38 per barrels. In addition, there are now also techniques developed by MYCELX [10] that reduces the hydrocarbon content RO-treated "produced water" down to levels less than 1 ppm. This treated water may be used for the oil and gas applications, and also may be blended with brackish water if it is desired. This gives rise to a flexible schedule of water qualities as alternatives for various applications. In the latter case, the cost of the treated water used is lowered by these hybrid alternatives.

Since, in this case, the source of the water is basically the produced water from oil and gas production, for as long as there is oil and gas production in the Permian Basin (i.e. Ector County), there will be an ample amount of produced water for treatment purposes. In other words, the source of water is sustainable. The only issue which will need to be addressed is the water gathering system for delivery to the treatment facility which will, by itself, require either piping, hauling, or a combination of the two. In short, our plan/project is capable of reducing true water treatment cost for the oil and gas production operations with significantly improved water quality. This translates to more efficient and cost-effective operations. Finally, lower costs translate to higher profits! The nuclear industry will recover its investment by charging the Oil & Gas Operators for the treatment of the produced water and generation of electricity required by the Oil & Gas operators. The Oil & Gas industry will profit by treating the produced water to the point it significantly reduces their production costs.

Benefits of this project extend to Ector County in three ways,

i) Increased Revenues
ii) Increased Employment
iii) Economic Diversification

The increased revenues will be in the forms of increased taxes, and a larger workforce that will come about due to the facility construction, operations and the economic activities that will follow. However, one of the main aspects of this project is the broadening and diversification of Ector County's tax base and economic capacity. There is a strong link between the oil and gas and nuclear industries in this project, but there is an implicit dependency to the oil and gas industry which uses the services of the nuclear industry to aid in the production of hydrocarbons. In addition, these plants may also one day be used to provide the regional fresh water for human consumption from either brackish or produced water. This implicit diversification will be a benefit to the region as it is being introduced to the economics of the Ector County.

A primary benefit of this project is it safeguards the development of additional freshwater resources. The current practice of handling the produced water is to haul and dispose of it, via deep injection, to "non-fresh water" aquifers. The hauling is an expense by itself, as is also the injection. As a result of this current practice, the waste products are injected into the aquifer formations, which leads to loading these formations with more and more waste water. This practice has its implications in terms of also potentially causing seismic activities in the region. *Our approach primarily reduces injected fluid volume and is primarily a generator of fresh water, which is a cleaner effluent than the wastewater presently injected.*

In addition, the oil and gas industry will have the opportunity to replace fresh water in depleted aquifers, by using the treated produced water. In other words, the required water for the oil and gas industry will be, and can be, supplied by the treated water, while the public can also benefit by having new freshwater resources for their needs.

Another important consequence of this project is the reduction of injected fluids to the aquifers. This reduction, in-turn mitigates the stress build-up in the formations, and thus reduces the chance of seismic activities in the Permian Basin. Currently the Permian Basin experiences some minimal seismic activities that are not of high concern [11]. However, the seismic activities we see in the state of Oklahoma, is a warning sign that that needs to be carefully noted.

The National impact of this project is 1) in developing continental oil and gas production which reduces the need for oil and gas imports, 2) economic prosperity, and 3) exportation of oil to overseas and US markets. As a result, national security is enhanced! On a smaller scale, this enhanced environmentally safe oil and gas production in the Permian Basin improves the regional economic well-being of both the Permian Basin and the state of Texas, which ultimately provides better living standards, and ultimately public safety.

The energy security aspects of this project are also one of top priority. It is of utmost importance that this topic is analyzed and proper credence be attached to this issue. This energy production is dependent on the availability of water, and water is essential for the sustainability of human life. This project ascertains both aspects of this equation: the human consumption needs and energy production priority.

5. CONCLUSIONS

Following conclusions can be made from this preliminary report:

1. There is a need to effectively address the water stress issue in the Permian Basin! The 1.5-billion-dollar treatment plant for the produced and brackish water treatment is a potential remedy of this problem.
2. The application of process heat leads to an average unit treated water production cost of $0.38/bbl.
3. The treatment plant may implicitly address and mitigate induced seismic activities in the region (earthquakes) caused by deep injection of untreated produced water into the formations.
4. This synergistic approach by both the oil and gas industry and the nuclear industry is unique for this region and globally.

5. The treated water can be used for both human consumption and industrial applications like the oil and gas industries.
6. Produced water treatment is not only a sound means of protecting the environment, its use also increases the bottom line (profit!) of the oil and gas production industry.

6. RECOMMENDATIONS

1. A cost estimation of pre-treatment of the process needs to be completed.
2. Detailed work is needed to complete the specifics of the treatment process.
3. The means of produced water transfer to the Treatment Facility needs to be investigated and cost of this operation must be determined.
4. Water treatment process and the capacity of the facility needs to be discussed in more details.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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