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What's in oilfield wastewater matters for injection-induced earthquakes

August 6 2020

In this April 2019 photo, Assistant Professor Ryan Pollyea (standing) teaches undergraduate students about permeability in the lab section of Groundwater Hydrology (GEOS 4804). Credit: Virginia Tech

A team of geoscience researchers in the Virginia Tech College of

Science has developed a new theory to explain how and why injection-induced earthquakes continue to occur even when injection rates decline.

Experts have known since the 1960s that when oilfield wastewater is pumped into the ground with deep injection wells, earthquakes can occur. Over the past decade, injection-induced earthquakes have become regular occurrences throughout oil and gas basins worldwide, particularly in the central United States, and potentially in China and Canada, as well.

Oil and gas production are often accompanied by highly brackish groundwater, also known as oilfield brine. These fluids can be five to six times saltier than seawater, so they are toxic to terrestrial ecosystems and have little beneficial use. As a result, oilfield brine is considered to be a waste product that is disposed of by pumping it back into deep geologic formations.

When fluids are pumped into deep injection wells, they alter the naturally occurring fluid pressure in deep geologic formations. These fluid pressure changes can destabilize faults, leading to earthquakes, such as the damaging magnitude-5.8 event in Pawnee, Oklahoma, in September 2016.

Among the more vexing scientific questions about injection-induced earthquakes is why they seem to be getting deeper in such places as Oklahoma and Kansas, where injection rates have been declining due to a combination of earthquake mitigation measures and declining oil and gas production.

In a study published Aug. 5 in *Energy & Environmental Science*, Ryan M. Pollyea, assistant professor in the Department of Geosciences, and a team of student researchers proposed a new theory that the wastewater itself plays an important role in the processes that cause injection-induced earthquakes.

"We know that earthquakes are getting deeper in Oklahoma," said Pollyea, who directs the Computational Geofluids Lab at Virginia Tech, "so we're trying to figure out what conditions make this possible. Our research suggests that it's caused by combination of the geology, natural fluids in the basement rocks, and the wastewater itself."

Although researchers have known for decades that deep fluid injections can trigger earthquakes, Pollyea said previous research misses some consequential details about how they occur. Specifically, he pointed out that oilfield brine has much different properties, like density and viscosity, than pure water, and these differences affect the processes that cause fluid pressure to trigger earthquakes.

"The basic idea is that oilfield brine has a lot of dissolved solid material, which makes the wastewater heavier than naturally occurring fluids in deep geologic formations," said Richard S. Jayne, a co-author of the study and former Ph.D. student at Virginia Tech who is now a research hydrogeologist at Sandia National Laboratory, "so the dense wastewater sinks, increases fluid pressure, and causes deeper earthquakes than would be predicted if the fluids have the same material properties."

Using supercomputers at Virginia Tech's Advanced Research Computing division, Pollyea and his team tested their idea by producing more than 100 models of oilfield wastewater disposal using various combinations of geologic properties, wastewater temperature, and wastewater density. With this computational approach, the team isolated both the conditions and physical processes that alter fluid pressure in the geologic formations.

"We found that there are really two different processes that drive fluid pressure deep into the basement, where earthquakes occur," saidys

Pollyea. "The first is called pressure diffusion, which occurs when wastewater is forced into geologic formations that are already full of water. This process has been known for a long time, but the second process occurs when high-density wastewater sinks and pushes lower density fluids out of the way."

According to this new theory, the density difference between wastewater and deep basement fluids is much more important for induced earthquake occurrence than was previously known. "This is one of the areas that has been neglected in induced-seismicity research," said Megan Brown, an assistant professor of geology who specializes in fluid triggered seismicity at Northern Illinois University and was not involved in this study. "Density-driven pressure transients are an intuitive consequence of a density differential between injected fluids and formation fluids."

Although earthquake occurrence has been decreasing in the central U.S. since the peak years of 2014 and 2015, this new theory not only explains why earthquakes are getting deeper in Oklahoma, but it also explains why several magnitude-5+ earthquakes struck Oklahoma in 2016, when injection rates were decreasing state wide.

"One fascinating aspect of our study is that sinking wastewater plumes do not require pumping to migrate deeper underground," said Pollyea, "in fact, they'll continue sinking under their own weight for decades after injections cease, and our study shows that the wastewater doesn't have to be much heavier for this to occur."

In terms of earthquake mitigation and regulatory practices, this study has far-reaching implications: The research team pointed out that high-density brines occur throughout many oil and gas basins in the U.S. But they also argued that using this study in practice requires much more information about the fluids. "This study emphasizes the need for sitespecific data and increased sampling," said Brown, because "density differences as a driving factor of near-field pressure transients may also lead to pre-injection mitigation actions."

Pollyea said that his research team is continuing to work on their new theory for the hydrogeologic processes that cause induced earthquakes. "We're really interested to know how our ideas about fluid chemistry affect regionally expansive injection operations in places like Oklahoma and Texas," said Pollyea. "And one of our recent M.S. graduates, Graydon Konzen (a study co-author), has done some exciting new work in this area."

More information: Ryan M. Pollyea et al. A new perspective on the hydraulics of oilfield wastewater disposal: how PTX conditions affect fluid pressure transients that cause earthquakes, *Energy & Environmental Science* (2020). DOI: 10.1039/D0EE01864C

Provided by Virginia Tech