Enhanced Oil Recovery (EOR) as a Stepping Stone to Caebon Capture and Sequestration (CCS)

By Dana M Abdulbaqi, Carol Dahl and Mohammed AlShaikh

OVERVIEW

Fossil fuels promise continuous domination of the global energy mix with mounting carbon emissions and climate threat for decades to come. While the growth of enhanced oil recovery that utilizes CO_2 (CO_2-EOR), especially in the US, has been curbed primarily because of limits on accessibility to affordable supplies of CO_2. Environmental concerns about carbon emissions coupled with the oil industry's need to secure additional CO_2 for EOR has sparked interest in the potential CO_2-EOR may have in jumpstarting carbon capture and sequestration (CCS).

Dana M Abdulbaqi and **Mohammed AlShaikh** are Petroleum Engineers at Saudi Aramco, Dhahran, Saudi Arabia. **Carol Dahl** is Resarch Professor at Colorado School of Mines, Boulder, Colorado, USA, and Luleå Technical University, Luleå, Sweden. E-mails: dana.abdulbaqi@gmail.com, cadahl@mines.edu, moalalshaikh@gmail.com

Published work highlighting the viability of CCS when coupled with EOR have generally placed more focus strengthening one aspect: engineering or economic policy. Furthermore, associated modeling efforts presented stop at the end of the productive life of the field. Most engineering studies focus on the technical aspects of the design of the CO_2-EOR project to produce the maximum amount of oil while simultaneously storing the most CO_2 with the economics as an afterthought. While most economic studies found have focused on a singular aspect of the issue such as impacts of exogenously varying injection rates. We found only one study (Leach et al. (2011)) that simultaneously modeled engineering and economic policy aspects of the co-optimization of CO_2-EOR and CCS in a dynamic optimization framework. We build on the limited previous work by combining robust engineering and economic policy aspects to investigate the practicality of wide scale implementation of CCS when partnered with CO_2-EOR.

METHODS

Published work highlighting the viability of CCS when coupled with EOR have generally placed more focus strengthening one aspect: engineering or economic policy. Furthermore, associated modeling efforts presented stop at the end of the productive life of the field. Most engineering studies focus on the technical aspects of the design of the CO_2-EOR project to produce the maximum amount of oil while simultaneously storing the most CO_2 with the economics as an afterthought. While most economic studies found have focused on a singular aspect of the issue such as impacts of exogenously varying injection rates. We found only one study (Leach et al. (2011)) that simultaneously modeled engineering and economic policy aspects of the co-optimization of CO_2-EOR and CCS in a dynamic optimization framework. We build on the limited previous work by combining robust engineering and economic policy aspects to investigate the practicality of wide scale implementation of CCS when partnered with CO_2-EOR.

The oil producer in our first stage maximizes profits by optimizing the choice of using CO_2 from natural or captured sources to achieve their optimal CO_2 injection rate which impacts both oil production and CO_2 sequestration. The carbon tax penalizes the producer for every unit of CO2 emitted when their oil is consumed as well as every unit of CO_2 they extract from natural sources during operations. The producer is also credited for every unit of CO_2 they sequester in the EOR process. This stage allows us to simulate oil production, CO_2 usage and sequestration by source to the end of the economically productive life of the field subject to a known oil stock constraint, natural CO_2 stock constraint and reservoir capacity constraint. Tracking the consumption of CO_2 from both natural and captured sources under increasing levels of carbon tax shows a transition from usage of natural CO_2, currently the most common and cheapest source of CO_2, to captured CO_2. The second stage involves extending the model beyond oil production activities. The oil producer maximizes profits from selling pore space for sequestration of captured CO_2 via their optimal CO_2 injection rate subject to a reservoir capacity constraint. Our reservoir capacity constraint in this stage is a function of cumulative oil production resulting from our first stage. This stage allows us to simulate CO_2 sequestration beyond oil production activities during which all production wells are capped and CO_2 is injected into the reservoir with no physical outlet.

RESULTS AND CONCLUSIONS

The producer switches from one stage to the next when the total benefits that can be obtained from sequestering CO_2 is more than the total benefits that can be obtained during CO_2-EOR. This decision is affected by the interaction of geological, technical and market conditions. The major findings relate to the optimal time of switch from one stage to the other, total volumes of captured CO_2 sequestered and how each is influenced by the tax and oil price levels set in the first stage. The intent is to be able to inform policy makers how to design policy in the presence of a market for CO_2.

Adjusting the Leach et al policy to penalize the producer for every unit of natural CO_2 used is effective in encouraging the producer to transition from sole use of natural CO_2 to sole use of captured CO_2 in the first stage. Under the assumption that CO_2 from both sources are perfect substitutes, the tax threshold above which the producer switches from sole use of natural CO_2 to sole use of captured CO_2 is equal to the difference in price between captured and natural CO_2. Natural CO_2 usage declines with increases in tax levels up to the tax threshold because the credit they receive for sequestering CO_2 gets negated by the tax they have to pay for every unit of natural CO_2 they use. Above the threshold captured CO_2 usage increases with higher tax levels. The revenues accrued to the producer from CO_2 sequestration provide the needed incentive to increase CO_2 usage which will positively impact both sequestration and production

We consequently see a significant jump in net sequestration above the tax threshold. The jump in sequestration of captured CO_2 at tax levels above the threshold is attributed to the transition to sole use of captured CO_2 at those tax levels. Model results suggest that the amount of captured CO_2 sequestered in the EOR process (stage one) is on the order of hundreds of thousands of barrels which equates to tens of thousands of tonnes. Mirroring the Leach et al. results, we observe that at higher oil prices resulting in higher revenues make it optimal to increase CO_2 injection levels over the life of the project leading to increases in cumulative sequestration. With higher tax rates, initial CO_2 injection rates are increased but we also observe a more rapid decline in the injection rates over time which results in an accelerated switch to water flood. Nonetheless, the impact on cumulative sequestration is positive because the amount of CO_2 sequestered early on when injection rates were higher more than compensates for the lower sequestration later due to reduced injection and earlier switch to water flood.

The amount of CO_2 we can sequester in our second stage is a function of cumulative oil production resulting from the first stage. We assume in the second stage that the producer sells available pore space to facilities in need of storage space for their captured CO_2. As expected, total volumes of sequestered CO_2 across both stages eventually increases with higher tax rates. But, at lower oil prices we see the trend in volumes of captured CO_2 sequestered over both stages decrease until the tax threshold and then increase post the tax threshold. The burden of the tax at lower oil prices induces limited or no use of CO_2 in the production process leading to less cumulative oil production. This leads to less sequestration across both stages because of the limited use of CO_2 and less cumulative oil production in stage one; releasing less space for sequestration in stage two.

Oil price and tax levels will also influence the timing of the switch from our first stage to the second. We find that at fixed price levels, but increasing tax rates the time of switch from one stage to the next is accelerated. Increased tax accelerates oil production in the first stage which results in a quicker decline in oil production thus inducing the accelerated switch to the second stage where the operator can accrue greater profits from just sequestration. On the other hand at fixed tax levels, but increasing prices the time of the switch from stage one to two is delayed. Higher oil prices encourage longer production periods coupled with the volumes of oil produced and CO_2 sequestered outweigh potential benefits from our second stage for longer periods of time.

The model developed appropriately values CO_2 emissions and reservoir pore space. The results of the model in conjunction with estimates of CO_2 demand for EOR purposes provide an appropriate foundation for future work. We aim to continue bridging the gap between engineering and economic policy aspects whilst providing an easy to use tool that allows for evaluation the practicality of wide scale implementation of CCS when partnered with CO_2-EOR.

References

Leach, A., Mason, C. F., van't Veld K., 2011. Co-optimization of Enhanced Oil Recovery and Carbon Sequestration. Resource and Energy Economics 33, 892 – 912.

van't Veld, K, Wang, X., Alvarado, V., 2014. Economic Co-optimization of Enhanced Oil Recovery and CO_2 Sequestration. Paper SPE-170880-MS presented at the 2014 SPE AT&CE, The Netherlands.