Modeling, Simulation, and Testing of Swelling Elastomer Seals

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Abstract

Swelling elastomers are a new type of advanced polymers, and have started to play an important role in improving existing oil and gas wells, and in aiding oil recovery from difficult or abandoned fields. Major applications of swell packers include zonal isolation, water shutoff, alternate to cementing, and other enhanced oil recovery operations. Failure of these swell packers can lead to significant losses in terms of time, effort, and money. Performance evaluation of swelling-elastomer packers and other sealing elements prior to being put to use is therefore critically important.

The main aim of this work is to evaluate the performance of swelling (and inert) elastomer seals used in petroleum applications. Closed-form (analytical) solutions are derived for sealing pressure distribution along the elastomer seal as a function of seal material properties, seal dimensions, seal compression, and differential fluid pressure acting on the seal ends. Seal performance is also modeled and simulated numerically. Analytical and numerical results are found to be in good agreement, validating that the analytical solution gives good prediction of sealing behavior of the elastomer. Detailed investigation is then carried out to find out the effect of variation in seal design parameters (seal geometry, seal compression, differential pressure, elastomer material, and swelling period) on seal performance. For both analytical and numerical models, properties of the seal material at various stages of swelling are needed. A series of experiments were designed and conducted to study the effect of swelling on mechanical properties ($\boldsymbol{E}$, $\boldsymbol{G}$, $\boldsymbol{K}$, and $\boldsymbol{v}$) of the sealing material.

It was found that sealing pressure distribution along the seal is not constant but varies nonlinearly depending on seal parameters and loading conditions. Maximum sealing pressure occurs at the center of the seal length. Longer seals are not necessarily better; after a certain seal length, the sealing pressure reaches a steady value for a given set of field conditions. Similarly, thicker seals do generate a little more sealing pressure, but after a certain value of seal thickness the effect is not significant. Obviously, higher seal compression gives higher sealing pressure; seal compression can be increased either by tubular expansion or by selecting an elastomer that swells more, or a combination of the two.

Results of this study can be used by (a) field engineers for proper selection of swell packers for different field conditions, and (b) by development companies for improvement of seal design. Better seal performance translates directly into economic benefits for the oil and gas industry.