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BAS-4 cavern abandonment risk analysis Frisia Salt Harlingen

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Abstract

Frisia Zout BV (Frisia), via ESCO part of the K+S Group in Germany, operates solution mined salt caverns near Harlingen in the Northwest of the Netherlands at depths between 2500 and 3000 m. Cavern BAS-4 approaches the end of its operational lifetime because land subsidence is close to the prescribed limit of 30 cm. Frisia has decided to increase cavern brine pressure to minimize the subsidence rate. As a result, the open cavern volume can potentially grow up to 1.4 million m^3. According to State Supervision of Mines, such large cavern can cause extra risks after abandonment because of land subsidence, probably exceeding the allowed limit, and groundwater pollution.

Based on previous Frisia experience with shut-in caverns BAS-2 and BAS-3 /3O, the risk of cavern instability and hydraulic fracturing has been evaluated for enlarged cavern BAS-4 volume. A typical geological feature above the salt formation, from which the halitic brine is produced, is the presence of a carnallitite salt layer covered by a thick anhydrite layer. When, after cavern shut-in, migrating halitic brine reaches the overlying carnallitite, either by permeation or through hydraulic fracturing, the brine converts into carnallitic brine, resulting in expanded brine volume and increased pressure.

BAS-2 cavern pressure evolution from shut-in until abandonment indicated that equilibrium between increasing and reducing pressure processes is reached for brine pressure roughly at 98% of the local lithostatic gradient. Thermal expansion of cavern brine after shut-in will most likely not lead to hydraulic fracturing because of the long time required for brine heating up. Nevertheless, if hydraulic fracturing or mechanical failure of the roof would occur, halitic brine flows into the overlying carnallitite formation and converts to carnallitic. In view of recent cavern BAS-3 /3O observations, lateral hydraulic fracturing of the carnallitite layer is expected, instead of progressive vertical fracturing, because of low tensile strength of carnallitite and reduced local lithostatic stress compared to the overlying anhydrite layer. During brine production, cavern pressure is at circa 60% of lithostatic stress, inducing salt creep and stress relaxation of the salt near the cavern. Because anhydrite is relatively stiff, stress within the anhydrite layer does not relax, as confirmed by FEM simulations. Instead of stress relaxation, the stress within the anhydrite layer increases through arching effects. Combined with high anhydrite tensile strength, the anhydrite layer constitutes a barrier to upward fracturing. Consequently, only *gradual brine permeation* is considered for risk evaluation of land subsidence and groundwater pollution.

The worst case situation is full conversion of 1.4 million m^3 halitic brine into 2.9 million m^3 carnallitic brine, completely migrating into permeable overburden rock and potentially leading to 29 cm extra subsidence (only in center of bowl) on top of the 30 cm limit. However, cavern convergence after abandonment occurs on timescales up to millennia and no measurable rates of subsidence are expected. Salt creep and rebound will flatten and widen the subsidence bowl, making the extra subsidence purely *theoretical.*

The local hydrogeological basis of groundwater is positioned at depths between 350 and 400 m. There are massive clay layers underneath the basis to circa 1000 m depth. Shallow groundwater pollution by carnallitic brine or unrecoverable blanket diesel can be *practically* excluded. All cavern fluids will be contained (trapped) in the subsurface in the porous Buntsandstein, with the Zurich claystone (top at 1920 m depth) as the first overlying confinement horizon.

Very recently, State Supervision of Mines reviewed the above described environmental risk analysis. Main results of the (academical) review are summarized in this paper and commented from a mining-technical point of view, with ‘worst-case’ approach as basic safety and risk philosophy.