A multi-disciplinary evaluation has established subsurface injection as a viable and sustainable methodology for managing the nearly 1.5 million bbls of drilling wastes generated at Kazakhstan's giant Karachaganak gas-condensate field.

Highly engineered subsurface injection of solid and liquid drill wastes has been applied successfully throughout the Former Soviet Union. Consequently, operator Karachaganak Petroleum Operating B.V. (KPO) considered the technology as a drilling waste management option for its 174 square miles (280 km²) Karachaganak field in northwestern Kazakhstan. To evaluate its feasibility, KPO initiated an all-inclusive study that included a subsurface investigation to identify a suitable geologic repository domain with corresponding hydraulic fracture simulations to confirm waste containment within the targeted injection intervals.

Once the potential injection formations were identified, industry ‘best practices’ and an evaluation of subsurface fracture pressures were considered to determine the injection parameters, surface equipment capacity and applicable pressure ratings. The study included the climate-intensive design of equipment and facilities capable of safely handling the expected solid and liquid drilling waste volumes. Additionally, since this project would mark the debut of solid and liquid waste injection technology in Kazakhstan, the feasibility study analysed local regulations to ensure compliance.

Successful implementation of the waste injection approach would eliminate sophisticated and costly treatment of cuttings and liquid waste, as well as the construction of additional landfill sites. In addition, the technology would considerably minimise transportation costs and the associated health, safety and environmental (HSE) risks.

**Evolution of waste injection**

When engineered, executed and monitored appropriately, the downhole injection of slurrified drill cuttings and liquid waste has been established as a cost-effective technology for efficient drilling waste management, promoting compliance with zero discharge requirements. The waste injection process involves the continuous injection of slurry and liquid wastes through the
initiation of disposal hydraulic fractures in scientifically selected downhole formations.

In recent years, drilling waste injection has advanced from a straightforward pumping operation to one that employs sophisticated wellbore modelling software, dedicated geoscientific teams and new-generation configurations that essentially decouple drilling and injection operations, thereby allowing the two activities to continue simultaneously.

The technique was first used in 1988, and has since emerged as a preferred solution to the logistical and environmental challenges of drilling waste management, particularly in offshore and onshore zero discharge environments. Today, waste injection is used extensively in the US, China, the North Sea, South America, West Africa and the Former Soviet Union. The first waste injection project in the Former Soviet Union was unveiled off Sakhalin Island in 2004, and a year later extended to the Azerbaijan ACG field, with Western Siberia following suit in 2008. At the time of writing, more than 8.2 million bbls of drilling waste has been safely injected in the Former Soviet Union with extremely low non-productive time (NPT) averaging 0.01%.

**Karachaganak waste management**

Located close to the town of Aksai in the West Kazakhstan oblast, the KPO Karachaganak field holds reserves calculated at more than 1.2 billion t of oil and condensate and over 47.6 trillion ft³ (1.35 trillion m³) of gas. Operator Uralskneftegazgeologia discovered the field in 1979 with first production in 1984. In 1997, the KPO consortium, comprising the BG Group (32.5%), ENI (32.5%), ChevronTexaco (20%) and LUKOIL (15%), signed a 40 year Final Production Sharing Agreement (FPSA) with the Republic of Kazakhstan that gives it operatorship of the field.
Owing to its location, the Karachaganak field experiences a significant variance in ambient temperature, with extremely cold winters and hot summers. Between December and March, winter temperatures can drop to -43 °C, while between April and November, summer temperatures can reach 44 °C. The wide swing in temperatures must be taken into account when designing surface equipment.

Currently, drilling waste management at the Karachaganak field consists of skips to collect all solid and liquid drilling waste onsite. The collected waste is transported to an Eco Centre for treatment and storage. Located in the northern part of the field’s subsurface waste polygon area, the Eco Centre consists of storage and processing facilities for field-generated waste.

Before assessing the viability of downhole depository regimes, investigators first had to estimate how much waste would be injected. Waste volume calculations were performed using a typical production well profile and an assumed drilling rate of 10 wells/year using three active rigs over the next five years.

Assuming 10 wells/yr drilling rate, approximately 47 800 bbls (7600 m³) of wet cuttings and 100 600 bbls (16 000 m³) of liquid waste would be produced annually in the Karachaganak field. Additionally, approximately 700 000 bbls (110 000 m³) of field-produced water would be used yearly for mixing a slurry with 20% volumetric solids concentration. Finally, the total slurry volume to be injected over the next five years was estimated to be 0.72 million bbls (114 000 m³).

The waste injection feasibility study
The first step was to define the primary objectives of the waste injection project envisioned for the Karachaganak field. Of course, the principal aim was to process and inject drill cuttings, as well as the injection of oily wastewater generated from drilling activities and part of produced water used for mixing the slurry.

In engineering a successful waste injection project, the predominant criterion is ensuring containment of injected waste within the targeted formations. Therefore, correct placement of the injection wells and the suitability of the receiving geological structure are paramount to preventing any long term liability from breaches to the surface or groundwater.

Earlier in the evaluation, attention focused on an existing subsurface waste polygon in the western part of the field. Produced water re-injection wells were already located in the area, which sits within a trough between two major salt walls. For waste injection purposes, the site had distinctive advantages, including the presence of sand bodies with permeability adequate for sufficient fluid leak-off and pressure dissipation into the formation, as well as the existence of interbedded and overlying claystone layers that act as stress and permeability barriers to inhibit vertical fracture growth. Moreover, the area is large enough to accommodate placement of waste injection wells sufficiently distant from water injectors, while still affording the opportunity to use nearby wells for pressure and fluid sampling and monitoring during the waste injection operation.

From the resulting litho-stratigraphy and geological survey, as well as an analysis of logs and formation characteristics, two primary target injection formations were identified: Upper Permian Tatarian sand body between 8041 and 8182 ft (2451 - 2494 m) true vertical depth (TVD) and Triassic Reservoir III from 6552 - 8022 ft (1997 - 2445 m) TVD. Evaluators were confident the high net sand content of these formations would result in a lower minimum in-situ stress in the injection formations. Relatively high permeability provides faster fluid leak-off during injection, while restricting fracture size and vertical propagation.

The researchers were satisfied that several overlying clay-prone layers (intra-Triassic ‘Seals’ A, B and C) would provide sufficient stress barriers to confine vertical fracture growth. The stress regime for the injection area was defined as normal, with overburden stress higher than the maximum horizontal stress. Estimated pore pressures for the Jurassic and Triassic formations were 1.06 sg and 1.17 sg, respectively. Fracture pressure tests conducted in post-reservoir sequence within the Triassic suggest fracture gradients ranging from 2.0 sg to 2.4 sg or from 0.87 psi/ft to 1.04 psi/ft.

Hydraulic fracture simulations
Two different hydraulic fracture simulations were performed, using the mechanical properties of the intended disposal formations and
assuming a continuous injection of large waste volumes. This exercise was carried out to define the extent of the created hydraulic fractures and assess injected waste containment.

The first simulation assumed that the large stress contrast would prevent the fracture from spreading through “Shale” C; the second simulation took the ‘no-stress barriers’ approach and was performed under the assumption that a uniform fracture gradient existed over the entire fracture propagation interval. The ensuing simulations revealed that in case of uncontained vertical fracture growth, the disposal hydraulic fracture would extend up to 4921 ft (1500 m) TVD and the maximum possible lateral extent would be 1476 ft (450 m) from the injection point. These simulations were carried out with a batch volume of 1.8 million bbls (287 000 m³) and a higher than usual injection rate varying between 5.2 and 15.7 bbls/min. (50 - 150 m³/hr) with different stress profiles.

As part of the simulations, actual waste injection operations were performed via the injection of small-volume and intermittent batches with alternating shut-ins. Furthermore, extensive slurry injection experiments on field cuttings confirmed that the extent of the hydraulic fractures during batch injections is considerably less than those from continuous injection of the same volume.

Fracture simulations with 5000 bbl. (794.9 m³) injections were conducted earlier for different stress profile scenarios, resulting in a maximum lateral extension of 610 ft (186 m) with fracture height of 656 ft (200 m).

The fracture containment simulation using the 1.8 million bbl. (287 000 m³) injection verified safe containment of the disposal fractures. Since approximately 0.72 million bbls (114 000 m³) of slurry is actually expected for injection, the larger simulation volume provided a comfortable cushion. Pressure response analysis from actual injections would show more definitively whether a single well could accommodate all the waste generated from the planned drilling campaign.

Proper slurry conditioning, setting and strict adherence to proper operational procedures, while continuously monitoring the injection, play pivotal roles in achieving full utilisation of an injection well’s domain capacity. Doing so will help avoid fracture plugging, solids settling, waste breach to freshwater aquifers and other associated risks.

As for the actual injection parameters, global experience and best practices from numerous projects indicate an injection rate of 4 to 5 bbl./min. is sufficient for propagating the hydraulic fractures and safely placing the injected waste within the created fractures. This rate range also helps avoid excessive erosion of both the equipment and the injection well itself. Anticipated injection pressures in this project were calculated based on leakoff test (LOT) results and using industry-accepted equations to determine the surface injection pressure and hydraulic horsepower (HHP) requirements.

**Surface facility design**

The feasibility study included the design of a centralised waste injection facility in close proximity to the Eco Centre waste management complex, which was engineered to safely handle the expected drilling waste volumes without interrupting drilling rates. The equipment and processes within the facility included a slurrification unit capable of processing between 20 and 25 t/hr of cuttings, high-pressure injection equipment, a vacuum unit and applicable holding tanks. The slurrification and injection pump package were fully automated and operated by Human Machine Interface (HMI) process control. This system relied on a minimum number of personnel to assure slurrification within uniform properties at the specified injection rates.

The conceptualised and fully winterised complex was equipped with an HVAC system to control internal temperatures within a range of 68 to 77 °F (20 - 25 °C) and 50% humidity year round. Taking into account ambient winter temperatures of ~43 °C, a cuttings reception tank was located inside the facility with a heating system to thaw frozen drill solids. Figure 6 shows the layout of the proposed surface facility.

The design of the projected facility takes into consideration all the operational parameters, the required pump capacity and the injection well pressure ratings identified in the subsurface analysis. The facility included a reliable method of measuring and recording the injection rate, pressure and volume in relation to time and a secure laboratory for testing water and cuttings slurry properties.

**Study conclusions**

The feasibility study verified that the proposed waste injection slurrification and slurry handling system would handle the average cuttings generation rate for three rigs drilling continuously and provide an effective solution for the waste management requirements of the Karachaganak field. Moreover, it concluded all of the subsurface and surface risks identified could be mitigated with adherence to proper engineering design and operational procedures, as well as careful and continuous monitoring throughout the operation. The process, as designed, likewise would comply with all pertinent Kazakhstan regulations for a zero discharge environment. 

**Note**

*M-I SWACO is a Schlumberger company.