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RESEARCH ARTICLE

REMEDIATION PROGRAM (KERP): HANDLING OF TARCRETE CONTAMINATION IN SOUTH EAST KUWAIT & NORT KUWAIT OIL FIELDS

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ABSTRACT

The State of Kuwait is situated in the northern edge of Eastern Arabia at the tip of the Persian Gulf. During the Gulf war in 1990-1991, oil wells and related infrastructure in Kuwait were impacted for discharge of huge volume of crude oil into the environment that affected nearly 114 Km2 of the desert land. The oil contamination of the soil occurred due to the devastation of the oil wells and the actions taken to battle oil gushing well and associated oil spills for airborne deposition of crude oil and combustion products. Further, this led to creation of different oil contaminated features like wet and dry oil lakes, contaminated piles, wellhead pits, coastal oil deposits, oil-filled trenches as resulted in the contaminated land (i.e., 26 million m3 of contaminated soil). Additionally a thin layer of tarcrete formed from as aerial dispersion of burning crude oil from gushing oil well to form extensive thin hard crust upon cooling of crude oil. This had resulted in the contamination of landscape of an additional of approximately 198 Km^2 has impacted the desert land. This has extensively damage changed the landscape, ecology and habitat of the flora and fauna in Kuwait. As part of Kuwait Environmental Remediation program (KERP), Kuwait Oil Company (KOC) is completely responsible for the planning and execution of the remediation and restoration projects in KOC oil fields with oversee of Kuwait Nations Focal Point (KNFP). Under the KERP, KOC further established the Total Remediation Strategy (TRS) to remediate the foresaid contaminated features. The TRS comprises of elements such as Risk Based Approach (RBA), Site Soil Characterization (SSC), Unexploded Ordnance Program (UXO), Remediation Treatment Technologies, and Sludge Disposal via Beneficial Recycling or Re-use and Engineered landfills. In order to minimize the remediation of the contaminated features, KOC has conducted the Risk Based Approach (RBA) studies where oil product is present as a continuous cemented mat, (i.e., as a tarcrete). The tarcrete is one type of contaminated feature is the fallout deposits of oil mist and soot solidified as a crust on the desert surface, with an average thickness of 1 to 1.5 cm; this may not present itself as a potential risk to the local environment. The qualitative and quantitative assessments was carried out with considering the physical nature of the sources of historical tarcrete contamination present in the oilfields, for human health, ecology and groundwater were undertaken as part of the RBA studies. The outcomes of RBA study, tarcrete material is considered suitable to be left in-situ and undisturbed, allowing for natural degradation. Additionally, if requires to remove tarcrete from specific areas for oil field development or construction, KOC has developed a procedure for the handling of tarcrete material in KOC oil fields. The main intent of this procedure to provide the guidance to Company's Area Owners, concerned teams or contractors working within company projects to expose and advise of handling of tarcrete contaminated martials with tarcrete material management into prepared project-specific waste management plans (where required) in compliance with Company and Kuwait Environment Public Authority (KEPA) requirements. The tarcrete handling activities covered by this guideline includes tarcrete breaking, scraping, removal, stockpiling/temporary storage, transportation, disposal/landfilling, or no action due to low to negligent risk. It is also intended to ensure compliance to health and safety of the employees, protection of the environment and the interests of the stakeholders.

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INTRODUCTION

After the Gulf War, over than 798 oil wells in Kuwait were ignited, causing the largest environmental and ecological disaster in its history. Approximately 20-25 million barrels of ignited crude oil were extinguished using 12 billion gallons of seawater collected in artificial pounds to control the fire. The damaged oil wells spilled crude oil across the land surface and created "Oil lakes" in low-lying land. These oil lakes affected approximately 114 km2 of land in the northern and southern oil fields of Kuwait (1). The aerial dispersion of crude oil forms a laterally extensive thin hard crust named as "Tarcrete" and oily contaminated soil spread over in the landscape of approximately 198 Km^2 of the KOC oil fields. The crude oil released had negative short-term and long-term impacts on chemical and physical characteristics of the soil, vegetation, and wildlife and threatening precious groundwater resources. Today, over than 30 years, these contaminated features (~26 million cubic meters of heavily oil-contaminated soils) and more or less than 198 km2 of the tarcrete mat are still exist in the oil field areas. In order to efficiently remediate the contaminated soil, the Total Remediation Strategy (TRS) was developed as a viable and an environmental friendly approach to replace the initial remediation strategy, which requires constructing a massive number of landfills to contain the impacted oil contaminated soil. The TRS will ensure remediation through more sustainable environmental approaches such as Risk Based Approach (RBA) and Remediation of the majority of these materials and therefore reducing the number of landfills for containment (2).

A key element of the TRS Strategy is Risk Based Assessment (RBA). Its aim is to avoid any unnecessary remediation activity where it can be demonstrated, through the development site-specific conceptual site models and appropriate risk assessment, and fate and transport modelling that human health and the environment are sufficiently protected in the absence of remedial activities. This RBA study was focused the physical state of the contaminants (i.e. tarcrete crust) together with contaminant concentrations and the potential for exposure of harmful substances. It also takes into consideration the locality with respect to identified ecological and human receptors. RBA provides justification for areas to be left undisturbed and provides the justification and rational for reasonable remediation efforts, if such required. Undertaken RBA for tarcrete areas in Kuwait included ecological, groundwater, and human health considerations. Based on the conducted RBA, tarcrete material is not required for remediation and decision to leave it in place and undisturbed, affirmatively for natural degradation. Company has established a procedure for handling of tarcrete material to deal with tarcrete material in Company's oil fields during field development and construction areas. The tarcrete handling activities covered by this procedure includes for tarcrete breaking, scraping, removal, stockpiling/temporary storage, transportation, disposal/landfilling, or no action due to negligent risk.

1.**General Description for Tarcrete Affected Areas :**

Tarcrete was formed by the aerial dispersion of crude oil from damaged oil wells. It forms a laterally extensive thin hard crust, the result of oil being sprayed into the air, landing and leading to its large spatial distribution across the oilfield. The crust is of varying thicknesses (averaging 1.1 ± 0.49 cm)and composition. It is typically found either as a layer of broken granular material or as a continuous sheet across an area. Tarcrete is identified by this crust and the presence of underlying deemed 'clean' sand/soil material. Contaminated (above 1% TPH level) soil materials are generally absent under the tarcrete crust.

The historical studies Consortium of International Consultants (CIC) investigation, 2002 (3) & 2003 (4); KOC/AMEC E&T and Site Soil Characterization (SSC), 2014-2017 (5) ;AMEC Foster Wheeler Limited Scope Site Soil Characterization, August 2015 (6); Worley Site Soil Characterization FEED report, 2019 identified approximately 198 km2 of area in Kuwait damaged/covered by tarcrete. This included approximately 19.8 km2 in the North Kuwait oilfields and 175 km2 in the South Kuwait oilfields. In addition, approximately 3.2 km2 of tarcrete-affected land was identified outside the fence of the Burgan oilfield.

Fig.01. Tarcrete contamination in SEK & NK fields

2. Risk Based Approach (RBA): The RBA approach adopted is in accordance with the internationally recognized Risk-based Corrective Action (RBCA) methodology. This approach has been agreed with Kuwait Environment Public Authority (KEPA) and the widely accepted RBCA framework published by American Society for Testing and Materials (ASTM) was considered appropriate for use in the State of Kuwait, where oil product is present as a continuous cemented mat, (i.e., tarcrete crust), this may not present itself as a potential risk to the local environment in Industrial settings. Moreover, qualitative and quantitative assessments were carried out with considering the physical and chemical nature of the sources of historical tarcrete contamination present in the oilfields for human health, ecology and groundwater were undertaken as part of the RBA studies. The RBA takes into consideration the physical and chemical state of the contaminants (i.e. tarcrete) together with leach ability contaminant concentrations and the potential for exposure of harmful substances. It also takes into consideration the locality with respect to identified ecological and human receptors. RBA provides justification for areas to be left undisturbed and provides the justification and rational for reasonable remediation efforts, if such required. Undertaken RBA for tarcrete areas in Kuwait included ecological and groundwater, and human health considerations.

The literature review Al-Baroud et al. (7) focused on Risk Based Study (RBA) mainly conducted in Groundwater Risk Assessment for Tarcrete across the Raudhatain and Sabriyah Oil Fields, North Kuwait by Kuwait Oil Company (KOC) in 2020. As part of this assessment, conceptual site model (CSM) and complete risk-based modelling was carried out which includes derivation of site-specific assessment criteria (SSAC)

and quantification of risk to identified groundwater resource receptors posed by tarcrete impacted areas. The outcome of this assessment was determined that the residual tarcrete deposits across the site area shall not create risks to the groundwater quality and the remedial action to remove the surficial tarcrete deposits is not considered and warranted

2.1 Ecological and Groundwater Risk Assessment Considerations: The Ecological Risk Assessment for tarcrete was conducted for portion of 13.4 km2 of the South Burgan Oilfield (AMEC Foster Wheeler, 2017) (8) in order to estimate the probability of an adverse effect on a floral and/or faunal population whose risk for harm was evaluated. Potential risks have been identified to some mammals, birds, soil invertebrates, and terrestrial plants from hydrocarbons present in tarcrete. These risks have tended to be identified based on maximum concentrations only and thus, potential adverse effects may occur only to the individual animals in these immediate environments; toxicological effects are not apparent on a large scale across the oilfields.

There is the potential for tarcrete to act as a physical barrier, preventing precipitation from percolating into the soil and/or seedlings to penetrate through it. However, as the tarcrete is typically a thin layer, based on observations on site, plants appear able to establish themselves by exploiting cracks and gaps through the surface of the tarcrete mat. There are large areas present in the oilfields that demonstrate an abundance of vegetation during fall/spring in wide areas of tarcrete. Available site-specific and regional tarcrete data has been reviewed and used to define an initial Conceptual Site Model (CSM) and conduct qualitative and quantitative risk assessments for the sensitive areas of groundwater resources (49.3 km2) in the Sabriyah and Raudhatain oilfields in North Kuwait (Advisian, 2021) (11), and shallow groundwater in South Burgan Oilfield (AMEC Foster Wheeler, 2017) (9). Analytical models were developed to quantify and evaluate the potential risks to groundwater resources (including Sabriyah and Raudhatain) from the tarcrete impacted surface soils. The outcome CSM provided a representation of the conditions and the processes that control the transport, migration and potential/actual impacts of tarcrete-related contamination of groundwater receptors at the site. The sources of contamination, pathways and receptors were clearly defined as part of the CSM. Resulting completed quantitative RBA has determined that the tarcrete deposits across the North Kuwait oilfields are very unlikely to cause pollution of the groundwater resources and remedial action to remove the surficial tarcrete deposits is not considered warranted. Similar modelling results for South Kuwait Burgan Oilfield show that concentrations of hydrocarbon contaminants in surface tarcrete material do not pose a risk to the shallow groundwater because of the confirmed absence of dissolved hydrocarbons in the existing groundwater above the water quality targets.

2.2 Human Health Risk Assessment Considerations: Existing tarcrete information from historical investigations on site, supplemented by literature information has been collated to develop an initial human health CSM for the tarcrete sites Fig .02 (AMEC Foster Wheeler, 2016) (8). The CSM identified land uses and human receptors that may be affected by tarcrete contamination; characterized tarcrete in terms of the contaminants present; their concentration and their form; and determined potential pathways, transport mechanisms for human exposure, and potential pollutant linkages. In addition, a qualitative assessment for human health, considering the physical nature of the tarcrete present at sites was undertaken as part of the RBA Part 1 in South Burgan Oilfield (AMEC Foster Wheeler, 2017)(10).

Transport Mechanisms: T1 - Direct contact, T2 - Wind erosion, T3 - Tracked back dusts, T4 - Volatilization, atmospheric dispersion and migration into buildings/ vehicles, T5- Volatilization and atmospheric dispersion

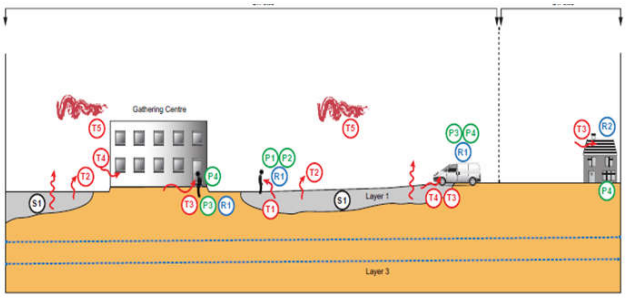

Fig.02. Initial Conceptual Site Model for Tarcrete in SEK and NK oilfields

Exposure Pathways: P1 - Dermal contact and incidental ingestion, P2 - Ingestion and inhalation of dusts and inhalation of vapors (outdoors), P3 - Ingestion and inhalation of dusts and inhalation of vapors (in buildings / vehicles), P4 - Dermal contact, ingestion and inhalation of tracked back dusts (in buildings / vehicles).

Receptors: R1 - On-site users, R2- Off-site families of workers

The results of this assessment indicate that tarcrete material is likely to present a low risk to site workers based on the following:

- There is limited potential for particles to be ingested as soil or dust if present as a hard continuous Layer on the surface;
- The coarser particles, which tend to be associated with tarcrete, are less likely to adhere to the Skin, in comparison to the contaminated sands present within dry oil lakes and wet oil lakes Layers.
- Given the nature and use of the sites, it is considered unlikely that animals on site will form a substantial part of workers and local residents' dietary needs, therefore exposure via the food chain was excluded as a potential pathway for exposure..

Based on the conducted RBA, tarcrete material is considered suitable to be left in-situ and undisturbed, allowing for natural degradation.

3. Requirements for Tarcrete handling:

The following portions are more elaboration about tarcrete removal, handling and disposal.

3.1 UXO Clearance and Related Activities for Tarcrete Affected Areas: Due to the historical legacy of Explosives Remnants of War (ERW) associated with the past conflicts in

Kuwait, it is possible that Unexploded Ordnance (UXO) items will exist within the sub-surface of the tarcrete areas designated for works. Given the potential UXO risk, it is paramount that all the areas have valid EOD clearance Certificates prior to commencement of works for tarcrete handling activities. Explosive Ordnance Disposal (EOD) clearance certificate to be obtained as per the Company requirements. The Company EOD clearance certificate provides evidence that an area has undergone surface and subsurface UXO survey to a certain clearance depth below surface level defined at the time of the survey. Any intrusive excavation, drilling, or similar works within tarcrete-covered areas would require UXO monitoring and UXO support efforts. For example, the potential exists for UXO not to be detected during prior UXO clearance activities and for hidden UXO to be found underneath the tarcrete. Such UXO efforts requirements shall be evaluated for relevance to the project activities particularly for safety measures and the safety of the field workers and shall be included into contractor's Project Execution Plan (PEP).

3.2 Tarcrete Breaking, Scraping and Removal: Deterioration of tarcrete layer is natural over time. The hydrocarbon and soil materials that tarcrete is composed of begin to crack and break down from rain, sunlight, overlaying traffic, domestic livestock trampling, development activities, sand deposition on the surface, and other factors. With an indicated typical average depth of tarcrete of 1.1 ± 0.49 cm it is not possible to separate most of the tarcrete before beginning / or during construction, excavation, or soil management activities. For the same reason of graduate tarcrete deterioration over time, it is not required to perform breaking (fragmentation) of tarcrete areas within the oilfields in advance (with the exception of the areas where revegetation activities are planned). Furthermore, tarcrete may act as a protective layer preventing soil erosion and allowing local plants to establish the roots underneath. Therefore, intentional breaking of tarcrete is not considered feasible and not recommended for there as with no planned development. In other areas, identified for revegetation and development activities, tarcrete fragmentation should be done by mechanical means considering measures to prevent tarcrete migration off-site and dust suppression measures. In such areas, as well in some areas where tarcrete layer is thick (more than2 cm depth), and in the areas designated for soil remediation, or construction/operations activities, the contractor must develop the measures to segregate, remove/scrape and stockpile the contaminated tarcrete material from clean soil surface before the development of the area. Contractors shall use tools and mechanical equipment to break up any solidified tarcrete material as required, then apply all due affords to separate contaminated tarcrete material from underneath on-contaminated soil, and stockpile at the approved locations.

Tarcrete removal shall be completed using graders or other suitable machinery (mechanically), or if not feasible – using manual excavation methods. Tarcrete excavation activities shall be carried out in accordance with company's "Excavation Safety Procedure" and other relevant procedures, as well as per Company approved work method of statements (WMS) for tarcrete excavation/stockpiling/disposal. During tarcrete removal,contractors shall apply all affords to prevent spreading of contaminated material and avoid cross contamination with clean material and shall layout the site such, that runoff from this area does not leave during a rainfall event. Temporary berming or other grading controls may be required as part of the excavation methods. During tarcrete removal planning activities, as well as tarcrete loading, segregation and transportation, contractors must consider implementation of dust emission control measures to prevent on-site personnel exposure to contaminated dust materials. The common dust suppression technique is addition of water to tarcrete material that need dust control. Water is applied topically to increase the density and cohesion of soil/tarcrete particles, thus preventing release to the atmosphere.

3.3 Tarcrete Stockpiling, Transportation and Disposal: Stockpiling of tarcrete material shall be only at the locations approved by Company's Area Owners. Measures shall be taken to prevent vertical and lateral spread of stored tarcrete material, demonstrating no detrimental impact to adjacent potential receptors. The stockpile area floor shall be prepared to withstand operation of material handling equipment. For temporary storage and placement of contaminated tarcrete material on clean soils, contractors shall place tarcrete on a minimum of 5 mm plastic liner/sheeting or shall prepare a clean working surface of compacted gatch of a minimum of 100 mm thickness (unless otherwise directed by Company).Provisions for control of storm water and soil erosion shall be provided. This may require temporary berms or other grading controls including a full temporary cover (plastic or tarpaulin) of tarcrete piles. Contractors shall provide temporary barriers and temporary caution tapes for stockpiled materials in accordance with Company standards. If allocated by the contract provisions with company, stockpiled tarcrete material may be assigned for transportation and disposal at Kuwait Environmental Public Authority (KEPA) and/or approved landfill facility.

Upon Company review and approval of tarcrete disposal option, contractors shall submit an action plan for transportation and disposal activities. Further, Contractors shall employ best management practices to prevent any spillages of tarcrete material to the surrounding clean soil along the established routes and working areas. Tarcrete requires to transport must be adequately covered to ensure it does not spill out of the dump trucks or create dust during transportation. Any spilled tarcrete materials shall be immediately cleaned-up by the responsible contractor and disposed of as directed by Company's Area Owners.

4. Monitoring and Reporting: To ensure the safe and compliant management of the contaminated tarcrete material, it is required and recommended to organize proper monitoring during tarcrete handling activities. It is also contractor's responsibility to monitor and avoid cross-contamination of underlying clean soil by impacted tarcrete during mass excavation. Contractors should exercise caution and lookout for potential hydrocarbon impacted soil underneath tarcrete layer during excavation. If suspect impacted soil is encountered, then contractor shall immediately inform Company's controlling team. Contractors, in the course of work, shall be aware of their scope and area of responsibility. The Contractor shall assume full responsibility and liability for compliance with all Company and KEPA regulations pertaining to work practices, protection of workers and personnel at the site relative to the presence of contaminated tarcrete material during development. Air quality and dust monitoring shall be undertaken throughout all works to ensure

compliance with the levels identified in the Environmental Social Impact Assessment (ESIA) as part of the established environmental compliance-monitoring program. Workers involved in excavation or handling of tarcrete shall be trained in the purpose, proper selection, fitting, use, and limitations of personal protective equipment's (PPE), including gloves, protective clothing and respiratory protection. Contractors performing excavation, handling or loading of tarcrete material shall prepare a site-specific Health and Safety Plan that addresses the potential presence of contaminants.

5. Conclusion

Tarcrete contamination handling procedure outlines accountabilities and actions for managing sites with residual tarcrete contamination formed as a result of the Gulf War of 1991 within Company operational areas. The procedure describes the process to ensure that the tarcrete areas are addressed in a safe and environmentally sound manner, taking into consideration the interests of the company and the type of future development. The procedure deals with the evaluation of potential risk posed by tarcrete by assessing current and future land use, representative characterization of tarcrete conditions within each development area, and identification of measures necessary to reduce the risk to a level appropriate for the intended future land use. It is also intended to ensure health and safety of the employees and workers, protection of the environment and the interests of the stakeholders and compliance with company and regulatory requirements.

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