Laboratory investigation of mineral scale deposition kinetics by adopting a plug-flow tube reactor

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Abstract

Mineral scale (scale) is the sparingly soluble inorganic deposit from aqueous solution. Scale deposition can pose a serious problem to the safe and economical operations of various industrial facilities, costing hundreds of billions of dollars of damage globally per year. Scale deposition can lead to equipment blockage with a narrowed tubing inner diameter and a reduced flow rate. In this presentation, laboratory investigation of mineral scale deposition kinetics was evaluated by use of a plug-flow type tube reactor. Compared with the conventional approach, the tube reactor has the advantage to maintain a constant solution pH, surface area and a controlled saturation index and hydraulic condition during the deposition study. Two scenarios of scale solid deposition were considered in this study, including deposition of scale on clean surfaces and also deposition of scale on a surface pre-coated with scale solid. The results show that the overall scale deposition process can be divided into multiple stages with different deposition kinetics and different solid morphologies. It is obvious that experimental conditions, such as solution chemistry, flow rate, temperature and saturation index, can have a considerable impact on scale deposition kinetics. These results provide an in-depth understanding of the process involving scale deposition onto the surface of a pipe material or a conduit. This tube reactor apparatus expands our capability of investigating mineral scale deposition kinetics and the influences of various experimental factors on scale deposition kinetics.

Flow assurance is a subject within the petroleum industry to ensure hydrocarbon flow from subsurface reservoir to the point of sale in a safe and economical manner (Gudmundsson, 2017). Other than multiphase flow simulation, flow assurance engineers deal with managing the formation and subsequent precipitation of unwanted solids from either hydrocarbon phase or water phase. Depending on the nature of these oilfield precipitated solids, some of the common oilfield flow assurance challenges include mineral scale precipitation, asphaltene precipitation, hydrate blockage, to name a few. Properly handling these flow assurance challenges become especially critical for offshore deepwater operations where the operating conditions of high reservoir pressure, low seawater temperature and high salinity can considerably exacerbate the flow assurance issues (Gao et al., 2006; Wang et al., 2018). Laboratory studies and field observations suggest that flow assurance related operational issues can result in a substantially elevated operational risk as well as a significant financial loss (Gao et al., 2006; Mackay et al., 2005; Zhang et al., 2017). Mineral scale (hereafter referred to as “scale”) is the hard crystalline inorganic precipitate formed from the aqueous phase. Scale formation is a ubiquitous phenomenon in nature and in daily life. However, massive scale formation and subsequent precipitation can lead to throughput reduction and eventually pipe/conduit blockage in various industrial processes (Bukuaghangin et al., 2016; Ghaderi et al., 2009; Jordan et al., 2012; Kan and Tomson, 2012; Lecerf et al., 2005; Rostami et al., 2019; Vazquez et al., 2016; Zhang et al., 2018b). Scale associated operational issues are particularly challenging in oilfield operations and especially in deepwater productions (Fink, 2011). Scale particles can form in the pore space of wellbore formation, leading to a severe formation damage (Moghadasi et al., 2019a, b). The most commonly observed oilfield scales include carbonate scales, particularly calcium carbonate ($CaCO_3$). The formation of $CaCO_3$ is mainly driven by pressure reduction from reservoir to different upstream locations of the production system (Frenier and Ziauddin, 2008; Kan and Tomson, 2012; Kan et al., 2019). The reduction in pressure will result in evolution of CO_2 gas from aqueous solution, giving rise to a higher solution pH and subsequent dissociation of bicarbonate into carbonate. The combination of Ca ion, which is abundant in oilfield produced water, with the formed carbonate species can lead to $CaCO_3$ precipitation. For a typical oilfield, the water cut will normally increase considerably towards the end of the field life (Fink, 2011). This suggests that the amount of scale formation can markedly rise together with produced water. Other than $CaCO_3$ scale, other types of carbonate scales are also frequently observed in oilfield operations, such as barium carbonate ($BaCO_3$). Barium species is commonly present in oilfield produced water with an aqueous concentration ranging from less than 0.1 mg L^{-1} to over 2000 mg L^{-1} (Neff and Sauer, 1995).

It has been discussed in a number of recent studies that thermodynamics and kinetics are two key aspects of the scale deposition process (Bukuaghangin et al., 2016; Sanni et al., 2017; Zhang et al., 2018a, 2019). Thermodynamic studies aim at understanding the extent of scale saturation and the amount of scale solid precipitated. The most critical notion in the thermodynamic study is the Saturation Index (SI) which indicates the level of aqueous solution superstation with respect to the solid of concern (Frenier and Ziauddin, 2008; Kan and Tomson, 2012; Kan et al., 2019). SI is calculated as the base 10 logarithm of the ratio of ion activity product with solubility product (Pitzer, 1991). If a SI value is higher than zero, this suggests that the solution is supersaturated with the solid and scale deposition is expected. If

SI is lower than zero, scale threat will not be anticipated. As the chemical driving force, SI can be impacted by various factors, such as, pressure, temperature and water chemistry. Extensive studies have been carried out for the purpose of calculating SI at different operating conditions. Particularly, efforts have been made in the calculation of activity coefficient as a function of system conditions and brine chemistry (Kan and Tomson, 2012; Kan et al., 2019; Pitzer, 1991; Zuber et al., 2013). A number of commercial software packages are available for this purpose.

Biography:

Ping Zhang has been an Assistant Professor in Faculty of Science and Technology, University of Macau since 2017. He has received his BS degree in Environmental Science from Nankai University, Tianjin, China in 2006. He has obtained his MS and PhD degrees both in Civil and Environmental Engineering from Rice University in Houston, Texas, in 2008 and 2011, respectively. He has also obtained his Professional Engineer (PE) license in the dual disciplines of Chemical/Environmental Engineering in the State of Texas in 2016. He is also a Chartered Chemist (CChem) of Royal Society of Chemistry of the UK since 2017. His research interests are solid precipitation and deposition, oilfield mineral scale control and environmental aquatic chemistry

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