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Use of membrane technology for oil field and refinery produced water treatment—A review

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ABSTRACT

With the advent of modern drilling technology namely sand-tar, hydraulic fracturing and enhanced oil recovery, the amount of waste water to be treated before reuse and/or discharge to the environment has increased manifold in recent time. The treatment of produced water and refinery waste water from the oil industry has been traditionally done by physical as well as chemical processes. The use of membrane technology for the produced and refinery waste water treatment has been recent phenomenon and active research has been focused to enhance the efficiency and life time of the membrane during the operation of the waste water treatment. In this review we briefly focus on the produced and refinery waste water treatment by primary and secondary treatment in historical perspective followed by focusing on various membrane technologies starting from microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Finally we also focus on the membrane distillation (MD) in combination with forward osmosis (FO) as potential future technology.

Contents

1. Introduction

It is no exaggeration to state that the modern life style depends on the reliable energy supply. Among the various energy sources, the fossil fuel is the most convenient source of energy for more than century and even today it is the primary energy source for humankind. Among the fossil fuels, except coal, all other fuels namely oil, gas, coal bed methane (CBM), and

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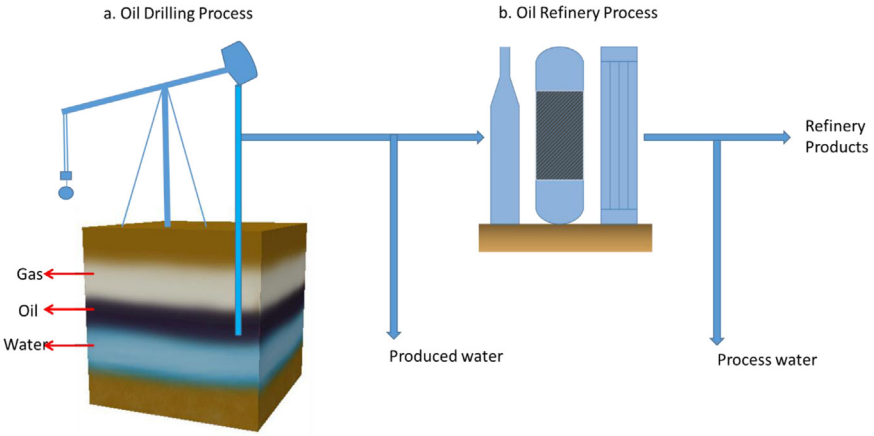

Fig. 1 – (a). General schematic representation of oil & gas well with the formation (produced) water in the reservoir and (b). The refinery process which produces process waste water (The figure is for representation only and not mentioned in the true scale bar).

recent advent of hydraulic fracturing of shale oil and gas are produced by deep drilling of the earth to recover the hydrocarbon energy sources. In the drilling process, water has always been produced as by-product which is generally known as produced water (PW) or co-produce water (co-PW) or flowback water. The term co-produce water or flowback water refers the fresh water comes out with formation water from the well. The fresh surface water was generally used for the pressurization and thereby pumping out the crude oil and/or gas from the well. The volume of PW is particularly vast quantity for the oil industry whereas the gas drilling produces comparatively less quantity of water. The amount of PW varies from well to well as well as the age of reservoir. The volume of PW typically increases with the age of reservoir and in certain cases it can reach up to 98% of the total fluid volume (Igunnu and Chen, 2012; Alzahrani and Mohammad, 2014). However, it is generally recognized as 1:3 ratio for oil & water for most of the oil well. The typical source of produced water is depicted in Fig. 1a (Igunnu and Chen, 2012). The produced water is part of natural formation water existing beneath or within the oil/gas reservoir. Thus the constituents of PW are based on natural geological formation and it is often acidic in nature with various soluble mineral ions depending on the geology of the particular the reservoir.

Invariably all the recovered crude oil and gas by drilling the reservoir are further subjected to "refinery processing" before the final use. Thus the refinery processes for oil and sweetening of the gas also produce large amount of waste water which is generally called as "process water" (Fig. 1b). Particularly the oil refinery industry uses large volumes of fresh water for the processing. The major contributing processes in the oil refinery are desalter effluent, sour water, tank bottom draw and spent caustic (Petroleum, 2010). The major difference between produced water and process water is that the produced water contains the majority of the dissolved mineral ions whereas the refinery process water generally contains comparatively less dissolved inorganic (mineral) ions. However, the refinery process creates many breakdown chemical compounds during the chemical transformation which are generally less or nonexistence in the produced water. The major notable constituent increment in the process water due to the refinery processing is phenols, ammonia, H_2S and BTEX (benzene, toluene, ethylbenzene and xylenes). The chemical structure of these compounds are shown in Fig. 2. Thus, the produced and process water differs considerably in terms of concentration of the pollutant present. In general the produced water contains high salt content whereas the refinery process water contains high organic matters (see Tables 1 and 2) (Igunnu and Chen, 2012; Fakhru'l-Razi et al., 2009; Olsson et al., 2013). The pre-treatment for both produced and process water using MF and/or UF membrane can be considered comparable because of the removal of macro constituents by these membrane technologies. Since the quality and quantity of the produced water (and oil and gas also) varies from well to well therefore accordingly the refinery processing, we discuss the treatment of produced and processing water as single progression in this review. In many literature, the model refinery process water is prepared using crude oil and therefore it is considerably similar in nature compared to the produced water (Al-Malack and Siddiqui, 2013; Chakrabarty et al., 2008). Additionally there are studies that deals with both produced and process water using similar membrane treatment protocol for the water purification (Ayse, 2009). Therefore hereafter in this review PW refers both produced and process (refinery) water (Table 3).

In general, the treatment of PW can be simplified in the following three classes based on the macro and molecular level separation. (1) Removal of organics which include dispersed, dissolved and emulsified oil, grease and gases. (2) The removal of dissolved inorganic matters which is commonly referenced as TDS. If naturally occurring radioactive materials (NORM) is present in PW, then special care should be

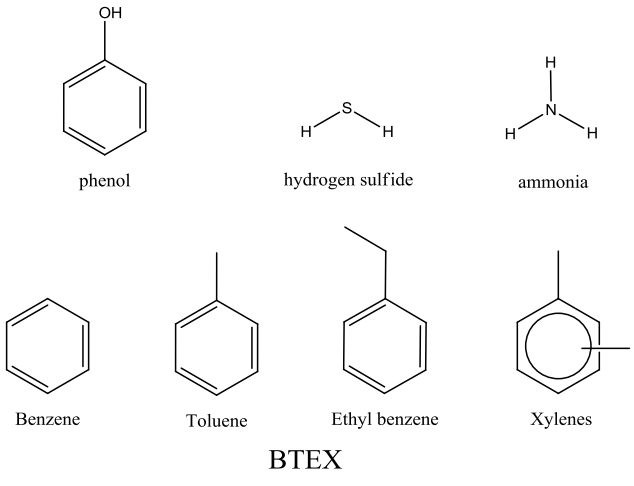

Fig. 2 – The chemical structure of few selective compounds present in the refinery waste water.