Journal of Environmental Radioactivity 152 (2016) 35–45

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Radiochemical characterization of produced water from two production offshore oilfields in Ghana

D.O. Kpeglo [a, b, c, *], J. Mantero [a, d], E.O. Darko [b, c], G. Emi-Reynolds [b, c], A. Faanu [b, c], G. Manjón [a], I. Vioque [a], E.H.K. Akaho [c], R. Garcia-Tenorio [a, e]

[a] Department of Applied Physics II, E.T.S.A., University of Seville, Seville, Spain
[b] Radiation Protection Institute, Ghana Atomic Energy Commission, P. O. Box LG80, Legon, Accra, Ghana
[c] Graduate School of Nuclear and Allied Sciences, University of Ghana, P. O. Box AE1, Kwabenya, Accra, Ghana
[d] Department of Radiation Physics, Institute of Clinical Sciences, Salhgrenska Academy at University of Gothenburg, Sweden
[e] Centro Nacional de Aceleradores (CNA), Seville, Spain

ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form
22 October 2015
Accepted 24 October 2015
Available online 28 November 2015

Keywords:
NORM
Oil industry
Produced water
Anions
Cations
Trace elements

ABSTRACT

Produced water from two Ghanaian offshore production oilfields has been characterized using alpha spectrometry after radiochemical separation, non-destructive gamma spectrometry and ICP-MS and other complimentary analytical tools. The measured concentrations of main NORM components were in the range of 6.2–22.3 Bq.L^{-1}, 6.4–35.5 Bq.L^{-1}, and 0.7–7.0 Bq.L^{-1} for ^{226}Ra, ^{228}Ra and ^{224}Ra respectively. A good correlation between several physico-chemical parameters and radium isotopes was observed in each production oilfield. The radium concentrations obtained in this study for produced water from the two oilfields of Ghana are of radiological importance and hence there may be the need to put in place measures for future contamination concerns due to their bioavailability in the media and bio-accumulation characteristics. The results will assist in critical decision making for future set up of appropriate national guidelines for the management of NORM waste from the emerging oil and gas industry in Ghana.

1. Introduction

Produced water is the highest volume waste generated in association with oil and gas production operations. Produced water, which is extracted during oil and gas production, includes formation water, injected water, small volumes of condensed water, and any chemical added downhole or during the oil/water separation process (USEPA, 1993). Despite treatment prior to discharge to satisfy regulatory limitations on oil content, produced water contains a certain amount of Naturally Occurring Radioactive Materials (NORM) such as ^{226}Ra and ^{228}Ra. NORMs are difficult to remove from produced water, which make the assessment of their effects on human health important to the oil and gas producing industries (Chowdhury et al., 2004).

Produced water volumes vary considerably between installations and over the lifetime of a field, with a typical range of 2400–40,000 m^3/d for oil producing facilities and 1.5–30 m^3/d for gas production (E & P Forum, 1994). Produced water may contain ^{226}Ra, ^{228}Ra, ^{224}Ra and ^{210}Pb as dominant radionuclides, in concentrations of up to a few hundred becquerels per litre but is virtually free of ^{228}Th and other natural radionuclides. Mean concentrations of 4.1 Bq/L of ^{226}Ra and 2.1 Bq/L of ^{228}Ra were recorded from a recent survey of Norwegian offshore oil production installations (Strand et al., 1997) but the concentrations at individual facilities may well reach levels 50 times higher.

^{226}Ra is the NORM material of major interest because it is an intermediate member of the Uranium-238 series, is water soluble, and therefore is classified as water borne pollutant. Radium is brought to the surface dissolved in the water that accompanies the hydrocarbons (produced water). Uranium and thorium, on the other hand, are not very soluble and remain in the reservoir, as they will not be leached into passing fluids. Potassium, which is released slowly upon dissolution from the rock matrix, is also present in the water.

The Ra content depends on the amount of Ra present in subsurface formation, formation water chemistry, extraction and treatment processes and the age of the waste after production. In

* Corresponding author. Department of Applied Physics II, E.T.S.A., University of Seville, Seville, Spain.
E-mail addresses: dokoh@us.es, d.okpeglo@gaecgh.org, kpeglokkd@yahoo.com (D.O. Kpeglo).

http://dx.doi.org/10.1016/j.jenvrad.2015.10.026
0265-931X/

general, the solubility of radium in water increases with the increase of saline content and at both high and low pH values.

A wide range of inorganic compounds, in widely differing concentrations, occur in produced water. Cation concentrations can be very high when brine is co-produced. They comprise not only the elements of low potential toxicity: Na, K, Ca, Ba, Sr and Mg, but also the more toxic elements Pb, Zn, Cd and Hg. The health implications of the last two are the focus of particular attention by regulatory bodies and international conventions (IAEA, 2003).

Ingestion of food grown in contaminated soils or seafood harvested in areas contaminated by produced water outfalls may result also in radiation exposure increments. A risk assessment for radium discharged in produced waters indicated a potential risk of exposure exists for an individual who ingests large amounts of seafood harvested near a produced water discharge point over a lifetime (Smith, 1992).

Accurate data on radio isotopic signatures as well as other chemical constituents of oilfield produced water is of paramount importance in order to carry out any potential human health risk assessment due to discharge of the produced water. These data will be useful not only to evaluate the present radiological state of the marine environment, but also for subsequent evaluations of the possible future environmental contamination due to activities of the extractive industry particularly in emerging ones like the oil and gas industry in Ghana.

The primary aim of the study shown in this paper has been to determine and characterize the radioactivity levels and physico-chemical parameters in produced water discharged from two Ghanaian offshore production oilfield platforms in order to establish baseline data. The emphasis of this study is on the determination of the activity concentrations and distribution of several naturally occurring radionuclides of the U/Th decay series, ^{40}K and physico-chemical characteristics of produced water using mainly alpha-particle and high-resolution gamma-ray spectrometric techniques.

2. Materials and methods

2.1. Study area

2.1.1. Saltpond oilfield and geology

Saltpond is the capital of the Mfantseman Municipal district in the central region of Ghana. The geographical coordinates of Saltpond are 5° 12′ 0 N, 1° 4′ 0 W. It has moderate temperatures, which range between 24 °C and 28 °C. The oilfield (Fig. 1) is located about 12 km off the coast of Saltpond in the northern-central area of the Takoradi Arch and approximately 100 km west of Accra, in a water depth of 25.9 m (85 feet) and extends over an area of 5 square kilometres.

The Saltpond Basin is a Palaeozoic wrench modified pull-apart basin centrally located between the Tano-Cape Three Points and Accra-Keta basins. It covers an area of approximately 12,294 km^2. Sediments in the basin were deposited in non-marine to coastal marine environments. The basin has been stratigraphically divided into formations namely Elmina Sandstone, Takoradi Sandstone, Takoradi Shales, Efia Nkwanta Beds, Sekondi Sandstone. The structure of the basin is characterized by multiple faulting, which has resulted in a complex set of horsts and grabens.

The only known and proven petroleum system in the Saltpond Basin is the Lower Paleozoic Petroleum System. This system has Devonian source rocks and Devonian to Carboniferous reservoirs. The reservoirs are sandstones of the Takoradi Sandstone Formation. Trapping is both structural (fault-bounded blocks) and stratigraphic (sandstones interfingering into shales) with sealing provided by the Takoradi Shale Formation (MoF, 2014).

2.1.2. Jubilee oilfield and geology

In the western region of Ghana is located a small peninsula called Cape Three Points. It forms the southernmost tip of Ghana and nearest a location in the sea which is at 0 latitude, 0 longitudes, and 0 altitudes. It experiences temperature range of 23.8–26.4 °C with mean temperature of about 24.9 °C. It has two main oil blocks, namely West Cape Three Points and Deep Water Tano. The Jubilee Field (Fig. 2), an oil and gas reserve located offshore Ghana is approximately 60 km from the nearest coast and lies in deep water (1100–1700 m), straddling the two oil concession blocks.

The Tano-Cape Three Points Basin is a Cretaceous wrench modified pull-apart basin. The basin was formed as a result of trans-tensional movement during the separation of southern West Africa and northern South America. Active rifting resulted in the formation of a deep basin. With time the continental crust further thinned and sea floor spread. New oceanic crust formed at the trailing edges of the two continental plates as they began separating and the two plates finally separated. Prevailing conditions at the time were ideal for the deposition of shales, thus thick organic rich shale was deposited. Several river systems contributed significant clastic into the deep basin and led to deposition of large turbidite fan/channel complexes. Some sandstones were in tilted fault blocks as reservoirs. Trapping is both stratigraphic and structural. The hydrocarbon potential of Ghana's portion of the basin has been known since the 1890's based on onshore oil seeps but the first major discovery was made in 2007 at the Jubilee Field with oil production commencing in December, 2010 (MoF, 2014).

2.2. Sampling and measurement of physical and chemical parameters

Samples of produced water were collected from the two offshore production oilfields located in the west coast of Ghana between October, 2013 and April, 2014. At the time of commencing this study, there were seven oil and gas companies holding concessions or blocks in the Jubilee field (deep-water offshore) of Ghana in addition to the Saltpond offshore producing company limited (SOPCL) operator of the Saltpond field (shallow water offshore). Out of these companies, it is only Tullow Ghana Limited and SOPCL that are into oil and gas production at present and the rest of them are into exploration and exploitation activities. Thirteen (13) composite samples (Mixture of produced water pumped from different wells within the field, produced into and sampled from the floating production, storage and offloading vessel (FPSO)) were collected from 3-phase separators and water treatment pumps from the two oilfields (description of samples from each field and sampling date are summarized in Table 1). Two litres (2 L) of each composite sample was taken to laboratory for analysis. After homogenization, the physical parameters such as temperature, pH, conductivity, TDS and salinity were measured in the laboratory using HACH multi-metre with probes, model SanSion 5 (the physical parameters were measured in the field and checked in the Laboratory). Anions and cations were determined using a UV–VIS Spectrophotometer (Model UV-1201 by HIMADZU of Japan) and atomic absorption spectrometry (Model Varian AAS240FS). Morphological and elemental composition of an aliquot of solid dried fraction from produced water sample was analyzed using a JEOL 6460LV scanning electron microscope (SEM). Quantitative elemental analyses were carried out using an Agilent 7500C ICP-QMS provided with an Octopole Reaction System (ORS). Element concentrations, quality checks and calculation of dead time or count rates corrections were carried out using a mix of single elemental standard solutions. The samples were screened for gross alpha and gross beta activity using a low background Gas-less Automatic Alpha/Beta counting system (Canberra iMaticTM)