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Thermal Insulation Material for Subsea Pipelines: Benefits of Instrumented Full-Scale Testing To Predict the Long-Term Thermomechanical Behaviour

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Abstract

External coating systems of flowlines and risers ensure both structural and thermal insulation functions which should be efficient throughout the design life in-service, typically 25 years. In that context, the long term behaviour of thermal insulation materials is difficult to predict due to the coupled effects of three factors: hydrostatic pressure up to 300 bar, thermal gradient over 120°C between internal effluents and external sea water and the water absorption of constitutive materials. In addition, laboratory data collected on small size specimens of insulation materials are normally used to predict the thermo-mechanical behaviour of full scale systems, but laboratory testing simply do not properly simulate the service conditions, in particular the complex loading existing through the coating thickness. This paper covers the background to the development of both test facilities and models to study the thermo-mechanical behaviour of production coated steel pipe in ultra deep water conditions. This original work was launched to provide both experimental and computed data to better understand and predict the thermo-mechanical behaviour of insulation materials whilst considered as a full scale system. On the one hand, experimental data obtained on instrumented insulated pipes immersed in large scale facilities simulating ultra deep water are presented in both steady and transient states. On the other hand, a finite element model dedicated to the abovementioned insulated pipes was developed to predict their thermo-mechanical behaviour. Correlation between full scale experimental data and related model predictions are discussed to validate the predictive model taking into account the coupling between hydrostatic pressure and temperature gradient. Additional modelling developments to include the water absorption are planned to reach a suitable prediction of the whole service life.

Introduction

Optimistic estimations of oil reserves in deep water and current oil & gas prices sustain the increasing interest towards offshore deepwater field production. The ultra deep water (3000m water depth) is one of the next issues. Indeed, 4% of the world offshore surface with WD>1500m includes sedimentary areas with hydrocarbon potential (minimum sediment thickness of 2000m) [1]. Those ultra-deepwater fields, between 100 to 500 [1], are expected to be located in the Gulf of Mexico, in the Atlantic off Brazil, Nigeria and Angola, and also near Aegypta in the Nil delta. It is worth noting that the hydrocarbon reserves identified and to be identified in both onshore and conventional offshore sedimentary basins represent 19% of the world surface. In comparison to onshore and conventional offshore hydrocarbons, the partial exploitation of ultra-deep reserves, about 1% of the world surface, would correspond to 30 billion to 100 billion of barrels equivalent petrol [1]. As a consequence, the ultra-deep offshore production representing 10% of the offshore production in 2005 is expected to grow to 25% in 2025 [2].

In that context, flow assurance continues to be a critical part of system design and operations, with lower seabed temperatures - typically in the 1 to 4°C range at 1500m-3000m depth - and rising insulation costs in deepwater [3]. Among others, the heat management in normal (steady state) and dynamic (transient) operations relies on the selection of proper insulation materials and designs for subsea flowlines and risers to meet the increasing demand for deeper waters. Pipe-in-pipe configurations are under study to optimize their performance but their heavy weight may be a limitation. Advanced insulation materials and coatings are also being developed and designed for subsea use to offer both appropriate thermal and mechanical properties in ultra-deep water applications [4, 5]. Moving towards ultra-deep water applications also emphasises the need to have test methods and facilities that establish whether a given coating system is fit-for-purpose - either new insulation materials/systems or existing materials/systems to be subjected to conditions for which there are no available data. Full-scale thermal testing protocoles and facilities have been developed since the late 1980's to study the behaviour of thermal insulation coating systems on lengths of pipe under simulated service conditions [6, 7]. Such full-scale tests are becoming part of the