Advanced Composite Materials for Coiled Tubing Deep Geothermal Applications and Offshore Production Riser Systems

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Introduction

During the past decades, the oil and gas industry has proceeded to utilize offshore fields in ultra-deep water depths, and the geothermal exploration is going to deeper reservoirs in harder rock. Thus, application of existing technologies such as steel based drill and production pipes in those environments impose technical and economic challenges indicating the need for alternative, innovative products and solution to harness deep geothermal energy.

In order to overcome some technical challenges during ultra-deep water and deep geothermal drilling applications, new materials by means of coiled tubing, self-supporting composite riser (SSCR) and production systems are introduced in this paper as one innovative technical and economic option. The SSCR is designed to support its own weight during installation, production and intervention applications specifically carried out during coiled tubing operations.

At the International Geothermal Centre (GZB) in Bochum, many innovative methods have been explored to find an economic and technical feasible ultra-deep geothermal drilling solution. Amongst them, composite coiled Tubing drilling technology has shown promising advantages in efficiency with continuous and excellent horizontal drilling capabilities, fast trip times, small footprint and logistics, easy usage in stable, hard rock environments, micro hole drilling capabilities, etc. In order to further push and develop this coiled tubing drilling technology for deep drilling exploration and production application, full scale composite coiled tubing testing platform and demonstrator drill rig has been designed and built.

Advanced composite materials may currently be the best option for offshore riser systems and coiled tubing applications as it has a greatly improved fatigue life and a significant reduction in total weight, which translates into lower required top tension and consequently lessens mooring tension and platform size.

Composite materials in general are defined as any material which is fabricated from two or more distinct materials with enhanced properties. Advanced Composite materials offer the potential to overcome the limitation of isotropic metals by increasing the service life of the tubular and extending the operational parameters (Barbero E. , 2012).

This paper presents the theoretical design and analysis of advanced composite material design for a self-supporting composite riser and deep drilling coiled tubing demonstrator. The design and environmental groundwork is based on advanced composite material theories (Barbero E. j., 2012) (Daniel, 2010) and standard ultra-deep water requirements (API, 1988) (DNV, 2001).

Advanced composite material configuration

The analysis of the drilling/production tubular system is done in two stages: global and local analysis (Podskarbi & Kakar). In local analysis the composite material is configured by defining the reinforcement material, thickness and orientation of each ply.

The anisotropic behavior of the composite materials brings the necessity to use theoretical models based on a multi-scale modeling techniques. The theories used in this study include Composite Micromechanics, Composite Ply mechanics and Composite Macromechanics which were used in the mentioned order to model and scale the material properties from micro to macro scale. Then as the next step, the stresses and strains in each ply are calculated and are used to verify the design safety based on appropriate failure criterion.

Various composite material configurations were studied and analyzed in depth using the composite laminate theory to find the optimum layout to meet the requirements of the project. Based on the obtained results and available commercial composite pipes the following composite configuration was chosen for the riser system: (Figure 1 shows the simulated model of the configured advanced composite pipe)

- Ten E-glass fiber-reinforced layers

- Symmetrical layer orientation stackup of: ±35/80°
- Polyethylene(PE) as core and coating material
- Pipe inner radius: 50mm

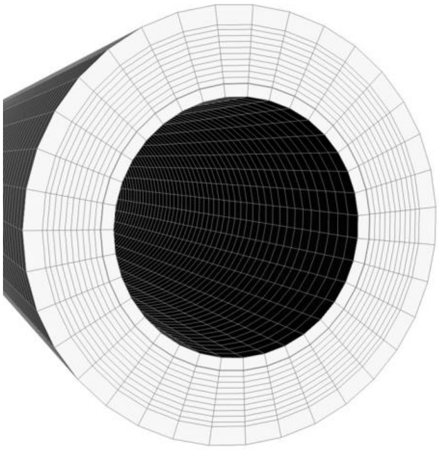

Figure 1 *overview design of the configured composite pipe. The composite pipe consists of overall 12 layers including 10 E-glass fiber reinforcement, Core and coating layers.*

Buoyancy module

A buoyancy system simply reduces the submerged weight of a riser structure by increasing its external volume. However, the composite riser system, due to its very low specific weight, is designed to be self-supporting with no need to be held by the production vessel.

In order to ensure that the dynamic riser is held in the correct wave configuration after it is submerged, a buoyancy module was designed to be applied to the system. It consists of three modular parts including two separable main parts and a seal located at top to stabilize and hold the riser as is shown in Figure 2, to ease and reduce the installation process and time.

The dimensions and material properties of the buoyancy module are chosen in a way to provide enough top tension force for the riser system. The buoyancy can is fabricated from a blend of synthetic foam (John.B, 2010) and is calculated to be placed 50m below the sea level.

The induced force magnitudes are calculated with consideration of ocean wave current, drag force, acting inertia forces and induced pressures. An FEM analysis was performed on the designed buoyancy module and based on the obtained results, the module provides the assumed 153 KN required top tension without occurrence of any failure.

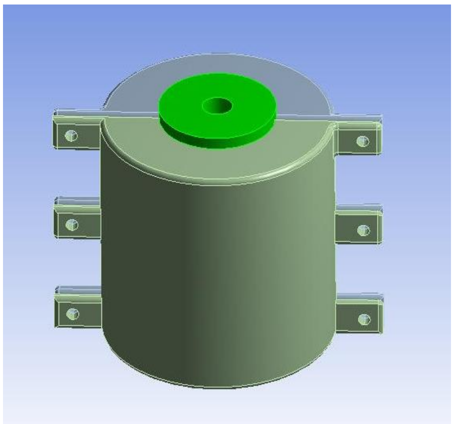

Figure 2 *The buoyancy module. The inner radius, outer radius and height of the module are 1.2, 1.5 and 6 m respectively.*

Production System analysis

The global analysis of the production system was performed as the next step to identify the deflection of riser, maximum deformation occurring in each layer and the maximum and minimum von Mises stresses occurring in the composite production pipe. A schematic of the analyzed riser system is shown in Figure 3. The analysis is performed with consideration of the fact that subsea wellhead is located at 1.500 m below sea level and the production fluid is either air, water or methane to cover all possible production fluids for Geothermal and gas reservoirs.

The main considered points include:

- Three base load scenarios were considered as follows:
  1. pipe is filled with air
  2. pipe is filled with water
  3. pipe is filled with methane
- The total length of the pipe is 1.500 m and it is held in vertical position with the help of the buoyancy module, which is placed 50m below the sea level. The bottom of the pipe is considered to be connected to a connector at the sea bottom.
- The wave forces acting on the pipe are calculated using wave theory (Faltinsen, 1990) (Brouwers, 1982) and uniformly vary between 0 to 6.2 N/m from bottom to top.
- The internal and external pressures acting on the pipe are in range of 100-120 bar and 200- 220 bars respectively.
- The buoyancy force required to hold the pipe is 150KN, which is also considered in the analysis.

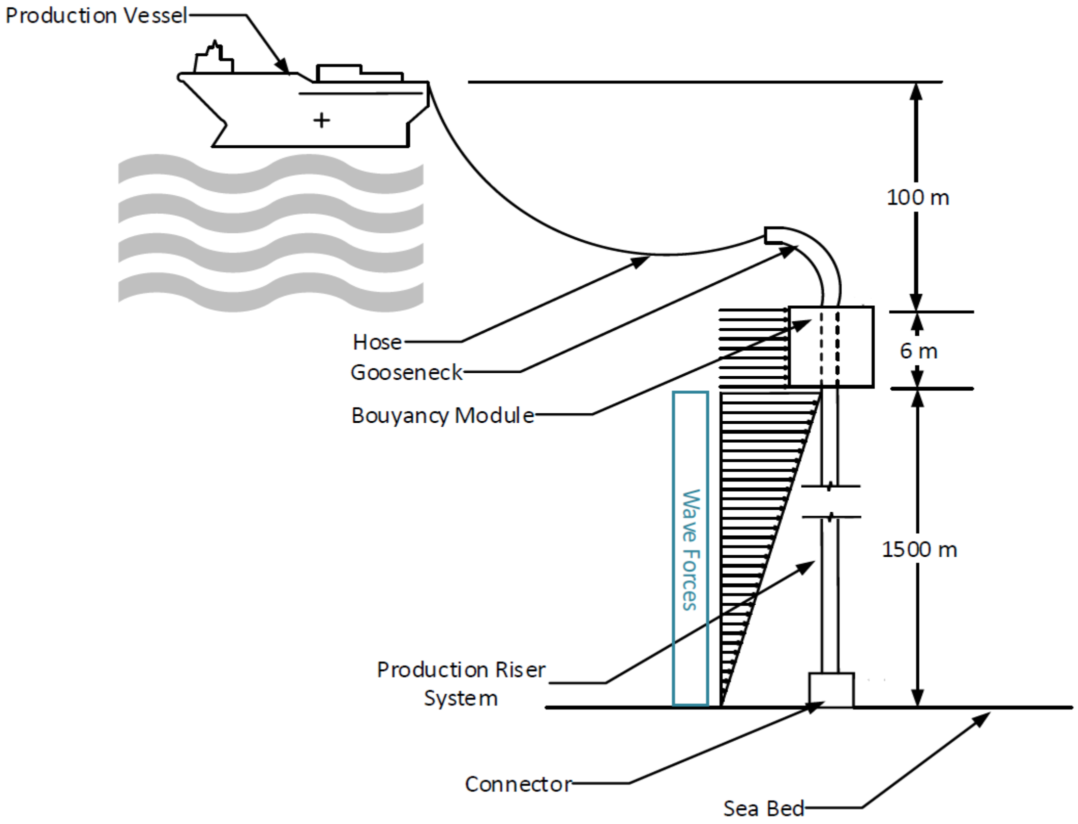

Figure 3 *schematic overview of the riser production system.it should be noted that the analyzed model does not include gooseneck, hose and production vessel.*

The simulations were performed on the pipe, using the FEM analysis software ANSYS, considering all the three mentioned base case scenarios. The following steps are taken to perform the simulation:

- The material properties of composite pipe is defined
- The structural geometry of the pipe is defined: Internal diameter, external diameter and thickness of pipe.
- Each layer material properties, orientation and thickness values are defined.

- The contact elements are defined.
- Geometry meshing is defined.
- Forces and boundary conditions are applied.
- Pipe is fixed at the bottom and top tension force is acting on top.
- The von Mises stress, values are obtained.
- Deflection and deformation values are calculated and analyzed based on results.

Main results from the analysis show that deflection values are in acceptable range (approx. 6m) and there will not be any occurrence of failure in the composite riser system by comparing the von Mises stress values with pipe mechanical properties. Composite material data and evaluation had been and can be done with the Coiled Tubing demonstrator rig at GZB in Bochum.

Conclusion

In order to meet today's challenges of deep offshore and geothermal drilling applications; innovative composite materials have been evaluated for their use in in such environments.

As examples a self-supporting composite riser system concept has been designed and analyzed for deep water application, and a coiled tubing demonstrator unit has been setup in Bochum for the testing of such materials.

It has been demonstrated that the proposed SSCR design is technically feasible and advantageous at 1.500 m water depth or beyond with possibility to be used in onshore deep geothermal drilling and production applications. The main advantages of using composite tubulars include their excellent strength to weight, stiffness to weight ratios, and thus, reduced tension requirement and improved fatigue resistance found in composite materials. The major economic benefit comes from the rather simple installation method, which allows for utilization of rather small vessel of opportunity.

As an overall conclusion, composite materials may become a favorable option for applications in ultra-deep water, geothermal and coiled tubing, especially in more sever environmental conditions, but their use will depend mostly on availability of pipes at low cost. Temperature requirements may be another factor to be considered.

Acknowledgment

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