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# An efficient design methodology for subsea manifold piping systems based on parametric studies

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A B S T R A C T

Subsea manifolds are widely used in the development of oil and gas fields to simplify the subsea system, minimise the number of subsea pipelines/risers and optimise the flow path in a piping system. The piping system is designed to satisfy the requirements for internal pressure, thermal loads, hydrostatic collapse and external operational loads under extreme environmental conditions. At present, however, there are no efficient and well-defined design procedures available that accurately predict the effects of extreme environmental conditions on pressure drop, total deformation, weight and erosion characteristics given varying design parameters considered throughout the piping system. Therefore, it is necessary to develop an new design procedure for subsea manifold piping systems with complicated shapes capable of sustaining erosion inside the piping system. The aim of this study is to develop a design procedure for subsea manifold piping systems based on a variety of parameters of influence under extreme environmental conditions, including high pressure and high temperature. A detailed numerical analysis of nonlinear finite element method and finite volume method is conducted to develop the proposed design procedure based on the results of parametric studies and generates some recommendations for the design of optimal subsea manifold piping configuration systems. The design procedure presented here will assist the design and analysis of subsea manifold piping systems.


## 1. Introduction

The global demand for energy continues to increase, and onshore and shallow water energy sources are becoming significantly depleted. As the world's economies and populations grow, oil and gas prices are expected to continue to rise. This prediction of oil prices improves the economic feasibility of offshore deep-water oil field development, although the environmental features are extreme. Lu et al. (2011) noted that the environmental features of deep water reservoir (915–3000 m) are extreme conditions such as high pressure (HP: 69–207 MPa) and high temperature (HT: 149–177 °C), and claimed that the development of enduring HP and HT technologies is essential to the efficient operation of subsea systems in deep water. Therefore, high pressure and high temperature related subsea engineering technologies are becoming increasingly attractive as the oil and gas industries continue to explore and exploit deeper waters.

Recognising the importance of offshore deep-water oil fields, oil producing countries and industries have pushed the development of subsea technologies, especially subsea manifolds that simplify subsea systems, minimise the number of pipelines/risers and optimise the flow path in subsea systems. This explains why the role of subsea manifolds has become increasingly important in deep-water field development to save costs.

In oil and gas industries, components of subsea manifold piping system including, straight piping, header, and branch piping should be designed based on DNV OS-F101 (DNV OS-F101, 2010) or ASME B31.4 (ASME B31.4, 2009). According to them, a thickness of the entire piping should be designed to satisfy the requirements for internal pressure, thermal loads, hydrostatic collapse, and external operational loads. Further, when designing piping components, there are a lot of analysis issues to be considered including internal pressure, hydro-testing, thermal loads, operating with jumper loads, flowline jumper connection loads, well jumper connection loads, environmental loads, external corrosion, internal corrosion/erosion and piping supports to accommodate all anticipated loading, deflections, and vibrations. Current design methodologies are sequential design procedure which moves to next design step when satisfying each requirement. The strength of sequential design procedure is that it is able to achieve systematic and reliable design, while it has the weakness that it is unable to consider the interactions among design parameters. Furthermore, when the initial design changes, it is highlighted that all requirements must be reviewed from scratch. In this aspect, it is noticed that development of a design procedure considering the interaction of design parameters is very important from the point

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**Nomenclature**

| | |
|---|---|
| $C_p$ | Specific heat of fluid |
| $D_I$, $D_O$ | Inner and outer diameter of piping |
| $D_S$ | Mean diameter of sand particles |
| $E$ | Young's modulus |
| $H$ | Horizontal length of Model 04 piping |
| $L$, $L_1 \sim L_9$ | Total length and local lengths of piping |
| $M_S$ | Mass flow rate of sand particles |
| $P_1$, $P_2$ | Fixed points at both ends of the piping models |
| $p,T,u,k$ | Pressure, temperature, velocity and thermal conductivity of fluid |
| $V$ | Vertical length of Model 04 piping |
| $R$ | Bend radius of elbow pipe |
| $W$ | Total weight of piping |
| $P_{Ex}$ | External pressure of piping |
| $\alpha$ | Maximum erosion rate density |
| $\alpha_T$ | Thermal expansion of X80 material |
| $\beta$ | Mean erosion rate density |
| $\delta$ | Total deformation of piping |
| $\eta$ | Surface roughness of sand particles |
| $\Delta p$ | Pressure drop |
| $\nu$ | Poisson ratio of X80 material |
| $\rho$ | Density of crude oil and X80 material |
| $\sigma_Y$ | Yield stress of X80 material |

of view of reducing design costs under deep-water environmental features.

Looking into the details of subsea piping configuration recommended by the rules ISO 13628-15 (ISO 13628-15, 2011), the minimum length of straight pipe should be 7 times the inner diameter ($D_I$) of piping and the location of bends should allow straight runs of at least 3D before and after. According to ASME B16.28 (1994), the bend radius should be the same as nominal pipe size (NPS). It is however found that the design criteria for piping components are available but the design procedure of piping configuration is not proposed yet. This is meant by that the piping configuration, arrangements of manifold piping components and use of flanged or welded components are basically dependent on the designer. Thus, in industries, the piping configuration is dependent on manufacturers' criteria, because only functional requirements are typically established by the operators. In the current design environment, total weight of subsea manifolds is only dependent on designer's choice although it is one of the primary issues for installation. In the installation of subsea equipment, light design proposal is more beneficial. In this aspect, it is better to consider an optimisation of piping configuration in an early design stage in order to reduce total weight of subsea manifolds.

It has been also recognised that pressure drop in pipes is an important consideration when designing a variety of industrial fluid flow equipment. A single-phase pressure drop in pipe flow is not only the basis for determining the single-phase friction pressure drop, but also the foundation of pressure drop calculations for multiphase flow. The design technologies associated with pressure drop in two-phase flow have proven to be an important issue for the oil and gas industries. The study of pressure drop in pipe flow (Nikuradse, 1933; Colebrook, 1938; Moody, 1944; Dang and Hihara, 2004; Huai et al., 2005; Incropera and DeWitt, 2001; Son and Park, 2006; Yoon et al., 2003) has been documented widely in the literature and the basic hydrodynamic characteristics are fairly well understood for simple pipelines. However, previous studies are focused on developing equations of friction factors for simple and large structures based on the physical phenomena, which are insufficient for designing subsea manifold piping systems relatively small and complicated shapes. Therefore, a design procedure for subsea manifold piping systems considering the interaction of parameters on pressure drop is needed.

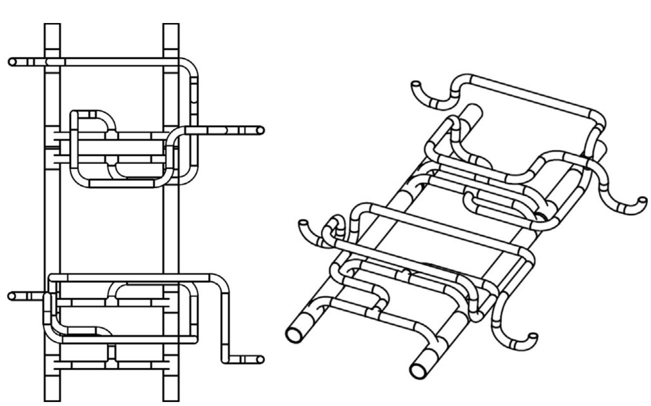

**Fig. 1.** Example of subsea manifold flowlines (4-slot).

In the oil and gas industries, design technologies related to the flow of fluids usually contain hard particulate matter that can cause equipment degradation through surface material erosion. This aspect will be more pronounced in the deep-water environment, because subsea structures are typically subjected to extreme actions arising from service requirements. The maintenance of eroded subsea structures is very costly, and thus the procedure of damage-tolerant designs and condition assessments of subsea structures are desirable for academic purposes even though current design methodologies overestimate erosion effects to avoid the erosional issues. For this purpose, we must better understand how operational and environmental conditions affect pressure drop, maximum and mean erosion rate densities. Several studies have addressed this topic in the literature (Venkatesh, 1986; Huser and Kvernvold, 1998; Salama and Venkatesh, 1983; Svedeman and Arnold, 1993; Salama, 1998; Bourgoyne, 1989; McLaury et al., 1997; Barton, 2003), but it is still necessary to develop the design procedure for subsea manifold piping systems with complicated shapes capable of sustaining erosion inside the piping system.

The aim of this study is to propose the design procedure based on the numerical results of nonlinear structural response and flow characteristics with varying design parameters for subsea manifold piping. Although there are a lot of aspects to be taken into account when designing subsea manifold piping systems, the present study is concerned with parametric studies of pressure drop, total deformation and erosional characteristics. The proposed design procedure is constructed in two phases, *Step 1* and *Step 2*. In each step, a sensitivity analysis is carried out based on the results of parametric studies. In order to validate the proposed design procedure, an applied example is performed for the four-slot cluster manifold shown in Fig. 1. The design conditions of the present study is shown in Table 1 and thus the optimisation will be carried out.

The strength of numerical methods includes enhanced design, better insight into critical design parameters, virtual prototyping, a faster and less expensive design cycle and increased productivity compared to experiments. On the other hand, it is well known that the speed of a numerical simulation is slow for large structure