Applied Ocean Research 46 (2014) 94–103

Contents lists available at ScienceDirect

Applied Ocean Research

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

Modeling for the optimization of layout scenarios of cluster manifolds with pipeline end manifolds

Yingying Wang[a,c], Menglan Duan[a,*], Junkai Feng[c], Dongfeng Mao[a], Minghua Xu[b], Segen F. Estefen[c]

[a] Offshore Oil/Gas Research Center, China University of Petroleum, Beijing 102249, PR China
[b] School of Mathematics & Physics, Changzhou University, Changzhou 213164, PR China
[c] COPPE, Federal University of Rio de Janeiro, Rio de Janeiro 21941-972, Brazil

ARTICLE INFO

Article history:
Received 10 May 2013
Received in revised form 10 January 2014
Accepted 25 February 2014
Available online 25 March 2014

Keywords:
Subsea production system
Layout of cluster manifolds
Pipeline end manifolds
Mathematical model
Optimization algorithm

ABSTRACT

The pipeline end manifold (PLEM) is an important subsea facility, which can greatly reduce the cost and risk of the development scenarios of deepwater oil and gas fields by declining the number of export pipelines and risers. However, the employment of PLEMs is a multidiscipline task involving substantial financial and technical factors. Due to various uncertainties of influencing factors, the evaluation process may take several months or years by the engineers with rich project experience. Thus, how to develop quantified reference tools using mathematical models to assist engineers in efficiently making their crucial decisions is essential. In this paper, the optimization of the layout scenarios of cluster manifolds with PLEMs is discussed, where a proposed mathematical model and its dedicated algorithm are illustrated. The optimal solution at the lowest cost can be obtained through in-house routine in MATLAB, including the optimal layout scenario, the number and locations of PLEMs, and the connection relations. Besides, the numerical simulations are performed to demonstrate the validity of the proposed mathematical model and its algorithm. The results show that this optimization layout problem in engineering can be described accurately by the presented mathematical model and the convergence rate of the given algorithm is efficient.

1. Background and motivation

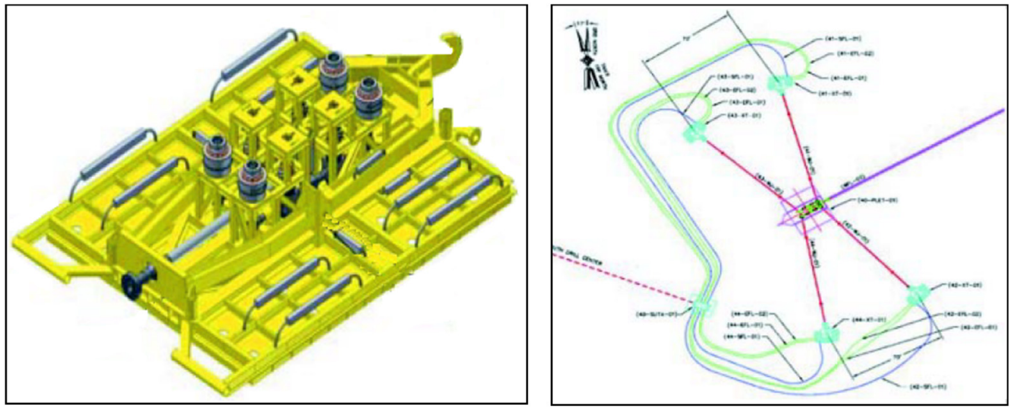
The cluster manifold as the hub transportation system has been widely applied in the development of deepwater oil and gas fields, especially in ultra deepwater. It has several advantages, such as being installed before the arrival of floating platforms, winning the first barrels of oil in a short period, and the flexibility of tie-back of subsea facilities or floating platforms, and so on. The cluster manifold has become one of the main layout types of deepwater subsea production system [1,2].

In this layout type, the number of well slots on a cluster manifold is the maximum number of subsea wells that can be connected to this cluster manifold. If there is a small number of the cluster manifold for a large size of deepwater reservoir, many wells need to be connected to the cluster manifold that might be much bigger and heavier. The installation of larger manifold is a huge challenge for advanced installation techniques and well equipped vessels, which may induce the higher risk and cost. Hence, the number of cluster manifolds may be greater when cluster manifolds with 4, 6 or 8 well slots are used as the most common type. As a consequence, more export pipelines connected to the headers of cluster manifolds and more connection facilities may be required to transport the production fluids. The workload of their installation and maintenance may be also much heavier, which will increase considerably the risk and cost of flowlines. Thus, how to optimize the layout scenarios of cluster manifold by declining the number and length of flowlines has become a crucial issue in ocean engineering. It is the PLEM that can be used to optimize the layout scenarios when the number of the cluster manifold is two or greater.

Generally, the PLEM is a subsea structure set at the end of pipelines and it is used to connect rigid pipelines with other subsea structures, such as manifolds or trees. In essence, the PLEM is a kind of the cluster manifold, which also has some important functions for gathering oil and gas or assigning water, gas and chemical agents [3–5]. Sometimes, the cluster manifold may be replaced by the PLEM when there are few subsea wells or no complicated requirements for the production. A PLEM with four well slots was applied to a water injection system in deepwater oil and gas field as shown in Fig. 1 [6]. It was noted that one water injection flowlines from the floating platform, rather than four, was connected to the PLEM to distribute the water into each well. By this way, the cost and risk of flowlines can be decreased because fewer water

* Corresponding author. Tel.: +86 13601218186.
E-mail address: mlduan@cup.edu.cn (M.L. Duan).

0141-1187/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apor.2014.02.006



(a) PLEM structure (b) layout scenario

Fig. 1. Typical PLEM with four well slots for water injection (Jasmin and Mohamed [6]). (a) PLEM structure (b) layout scenario.

injection flowlines were used. Although additional costs of the PLEM are incurred, the capital and operating expenditures (CAPEX and OPEX) in deepwater fields should be descended because of the significant reduction of the costs from flowlines.

Hence, the necessity of incorporating PLEMs to decrease the CAPEX and OPEX is usually addressed in the front end engineering design (FEED). Too many aspects related to drilling, pigging, flow assurance, and so on, need to be considered, which make the process of evaluation more complicated. Meanwhile, high uncertainties associated with variable factors may make the project experience from engineers highly demanded. Although the determination of the optimal layout scenario of cluster manifolds may be ultimately drove by the human interpretation and intuition, the reference software tools should be developed to play a theoretical technique support role in assisting the engineers in decision-making process.

Recently, the optimization methods using mathematical models have been widely used to solve many problems in various areas, where theoretical judgment still plays an important role. In fact, many researchers have been dedicating to reduce the CAPEX or OPEX of the development of oil and gas fields in onshore or subsea [7–10]. Neuroth et al. applied fuzzy logic for the control of a pump station in a pipeline system, which made the reduction of OPEX in oil and gas transport systems [11]. Guarize et al. presented a very efficient hybrid artificial neural network to perform a nonlinear mapping in the random dynamic analysis of floating mooring lines and deepwater risers, which can reduce response time-histories for the less OPEX [12]. Souza et al. proposed a framework for the analysis of continuous deepwater gas lift systems by an optimization algorithm, which made some important information of the conceptual design phase estimated for the optimal gas lift scenario [13]. Park et al. proposed a nonlinear fuzzy programming approach combined with a hybrid genetic algorithm for the optimal design of gas-production systems, where the gas production rate of each well and the optimal pipeline networks were optimized to minimize the investment [14].

Previous work studied mostly the optimization of wells, gas production system or subsea facilities to while minimizing CAPEX or OPEX. However, mature mathematical models related to the optimization of the layout of cluster manifolds are still rare. Wang et al. addressed initially the optimal partition for subsea wells in the layout of cluster manifolds [15]. In previous work, the number and ideal locations of cluster manifolds were obtained at the lowest cost by the proposed mathematical model and its efficient algorithms, which can provide possible partition scenarios to the engineers for the references.

The partition of subsea wells is a basic work and further investigations need to be implemented for the optimal layout scenario. In this paper, the authors continue to conduct the optimization problem of the layout of cluster manifolds based on previous partition work, where PLEMs are included. A new mathematical model and its dedicated algorithm programmed in MATLAB are developed. The numerical simulations are performed to demonstrate that the proposed model is capable of optimizing the layout of cluster manifolds with PLEMs in accuracy and efficiency.

2. Description of the optimization problem in engineering

In engineering, there may be two connection types between cluster manifolds if there are one or more subsea production loops. In the same production loops, cluster manifolds are connected one by one using subsea connection facilities, which are called the series connection. In the different loops, cluster manifolds may be connected by PLEMs when the number of production loops is two or greater, which is called the PLEM connection. Hence, the optimal layout scenario of cluster manifolds may be with the PLEMs or not.

Generally, the optimal layout scenario without PLEMs needs to be found firstly, including the optimal number of production loops and the series connection relations between cluster manifolds in each same loop. Then, it is necessary to reduce further the initial lowest layout cost by adding PLEMs. Here, there are several main characteristics of the layout of cluster manifolds as follows:

B1: The cluster manifolds in the same production loops are connected in series and there may be one or more production loops connected to the Floating Production Storage and Offloading (FPSO).
B2: Any two pipelines are not permitted to be crossed except their endpoints.
B3: All of the cluster manifolds are connected to the FPSO, directly or indirectly.
B4: No closed loops are allowed in the layout scenarios.

For simply understanding the problem in this paper, we just assume that there are one FPSO and five cluster manifolds, where their locations are shown in Fig. 2(a). Possible optimal scenarios without PLEMs are shown in Fig. 2(b)–(f). Let the scenario of Fig. 2(f) be the optimal one at the lowest cost A. Now, we need to find the scenario with lower layout cost than A by adding PLEMs to Fig. 2(f). If a PLEM that meets the conditions exists, one end of the PLEM must be connected to the cluster manifolds connected directly to the FPSO in the optimal layout scenario without PLEMs. The other end of the PLEM must be connected to the FPSO directly. In this