PROCESS SAFETY AND ENVIRONMENTAL PROTECTION 103 (2016) 183–191

Contents lists available at ScienceDirect

Process Safety and Environmental Protection

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

Well specific oil discharge risk assessment by a dynamic blowout simulation tool

Ruochen Liu[a], A. Rashid Hasan[b], Amar Ahluwalia[c], M. Sam Mannan[a,*]

[a] Mary Kay O'Connor Process Safety Center, Department of Chemical Engineering, Texas A&M University, TX, USA
[b] Department of Petroleum Engineering, Texas A&M University, TX, USA
[c] DNV GL, Katy, TX, USA

ARTICLE INFO

Article history:
Received 15 February 2016
Received in revised form 19 June 2016
Accepted 28 June 2016
Available online 5 July 2016

Keywords:
Blowout
Oil spill
Oil discharge amount
Risk assessment
Prevention and mitigation
Risk management

ABSTRACT

Despite the implementation of multiple sophisticated safety barriers, well blowout, the most undesired disaster for the petroleum industry, still happens as Macondo or Montara incidents show. The crush of crude price has pushed the operators toward cost-cutting plans. Such plans, in short terms, may significantly reduce the exploration and operation costs and relieve financial pressures. On the other hand, such measures may also compromise the balance among safety, reliability and cost in the long term and potentially lead to catastrophic accidents. The current regulation in the Gulf of Mexico region requires the operators to report a single value for the worst-case discharge (WCD) during a possible blowout. However, it does not provide any additional value to manage risk of uncontrolled wellbore flow event and the impact to the marine environment. In this paper, a practical and comprehensive oil spill risk assessment method is introduced. It couples the reservoir/wellbore models and distribution of uncertainties to depict the risk picture of uncontrolled wellbore flow events. Statistical design of experiments is conducted to determine important uncertainties to the blowout risk. As shown by sensitivity analysis, this method can guide the operators to allocate limited resources to the important barriers and make proper risk reduction plans, so that the blowout risks are effectively controlled.

1. Introduction

A blowout is defined as the uncontrolled release of formation fluid, including crude oil and/or natural gas, from the formation to the outside surroundings after the wellbore control measures have failed. Although the drilling and production well planning may be good, the measurement and detection systems used are sophisticated and accurate, and personnel receive comprehensive training, blowout events can still occur and lead to severe consequences, as evidenced by Macondo. These consequences, including personnel fatalities and injuries, production and asset loss, and damage to environment, could lead to significant threats to the oil and gas exploration and production operations. At present, many oil and gas companies have moved to the harshest exploration environments, including ultra-deepwater and HPHT reservoirs, which add complications to the operations. The plummeting of crude price has pushed the operators to cost-cutting plans. Such plans may significantly reduce short term cost of exploration and production, and hence offer relief of financial pressure. However, they may also compromise the balance between safety, reliability and cost in the long term and potentially lead to catastrophic incidents. Most of the well-known incidents of the past can be categorized as "low likelihood and high consequence" events. These events have led to the current regulation in the Gulf of Mexico region requiring operators to report a single value of the worst-case discharge (WCD) based on the highest daily flow rate. However, the single value of WCD does not provide any additional values to manage the risk of the uncontrolled wellbore flow event and the impact to the marine environment. More importantly, it would be completely inadequate to represent the risk and mislead the risk picture to the general public.

---

* *Corresponding author*. Tel.: +1 9798623985; fax: +1 9798456446.
E-mail address: mannan@tamu.edu (M.S. Mannan).

http://dx.doi.org/10.1016/j.psep.2016.06.037

Nomenclature

a_n	series roots of Eq. (2)
B	oil formation volume factor, bbl/STB
c_t	total compressibility, psi^{-1}
h	net pay, ft
J_1	Bessel functions of the first kind
k	permeability, md
p_i	initial reservoir pressure, psia
p_{wf}	flowing bottomhole pressure, psia
$\bar{p}$	average reservoir pressure, psia
q	fluid flow rate at standard conditions, STB/D
r_e	reservoir drainage radius, ft
r_{eD}	dimensionless reservoir drainage radius with respect to wellbore radius, dimensionless
r_w	wellbore radius, ft
s	mechanical skin, dimensionless
t	blowout duration, h
t_{Dw}	dimensionless time
Y_1	Bessel functions of the second kind
μ	viscosity, cp
ϕ	porosity, fraction
π	mathematical constant, 3.14159

To properly assess and manage the blowout risk, the consequence of blowout events at different conditions should be first understood. Unfortunately, only a few papers have addressed the physical phenomenon of the blowout events. Clark and Perkins (1981) are perhaps the first researchers who presented a pioneering work to calculate the critical flow velocity, pressure, and temperature at the exit of an oil well blow-out. Hasan et al. (2000) also investigated the wellbore dynamics during an oil well blowout. In 1996, a method for blowout rate prediction for sour gas wells was studied by Kikani et al. (1996). Oudeman (1998, 2006, 2010) accomplished a series of work focusing on simulating blowouts based on observations, such as wellhead pressure and temperature, plume shape and size, noise field around the wellhead, the pressure response of nearby wells, and production data of the wells with high flow rates, to develop proper well control strategies. Blowout events are dependent on not only the wellbore configurations, but also the reservoir conditions. In addition, the interaction between the wellbore and the reservoir must be taken into consideration. However, none of the prior works mentioned earlier covered all these important components. Liu et al. (2015) coupled the wellbore dynamics with a reservoir model to estimate blowout rate and the total discharge amount in an onshore gas well blowout for the first time. A similar approach is used in this paper for the determination of offshore well blowout consequences. Extensive modifications are made to take the uniqueness of offshore oil well into account, particularly multiphase flow and heat transfer.

At present, some regulatory bodies, such as Petroleum Safety Authority Norway, have required operators to prepare an environmental risk analysis and an oil spill contingency analysis for any exploratory drilling permit to be granted. Several reports are available in the public domain to assess the environment impact of the offshore exploration wells in North Sea due to potential oil spill incidents (DNV, 2010; ACONA, 2012). The initial blowout rate, which was obtained from commercial wellbore fluid flow simulators, was used to depict the total blowout risk by coupling with the probability distribution of uncertainties for potential blowout events. However, Liu et al. (2015) showed that the reservoir pressure depletion was a dominating factor for the exponential decrease in blowout rate, and illustrated the overestimation of blowout event consequence/risk if a constant value of blowout rate is assumed during the event. In addition, only uncertainties, such as flow path, which are available in the historical database, are considered in these studies. One important uncertainty – blowout duration – has not been taken into account because of the difficulty to determine the dynamic blowout rate. Moreover, during the well planning phase, the reservoir characteristics may not be fully known. It is important to be aware of that the reservoir parameters could be different even for wells in the same field. As a result, introducing the well-specific uncertainties associated with the reservoir will enable us to estimate the blowout risk more precisely.

The purpose of the investigation is to quantitatively assess the blowout risk for the wells not only in the planning phase but also in the operational phase. A well-established blowout consequence model couples the nature of transient-fluid flow in the reservoir and the fluid and heat flows in the wellbore. Combining the consequence model and the uncertainties from both historical database and well-specific parameters provide great opportunities to understand and manage the blowout risk. In addition, a case study is presented to demonstrate how this method could be practically applied in typical industrial settings. The risk reduction plan is also discussed in the later sections by statistical and sensitivity analysis.

2. Methodology

2.1. *Offshore oil well blowout consequence model*

When a subsurface offshore oil well blowout occurs, the formation fluid reaches the mudline through one of the three flow paths without any control. These flow paths include drill string, annuli space between drill string and casing (annulus), or casing (open hole). Meanwhile, the hydrocarbon production leads to the depletion of the reservoir. During a blowout event, the blowout rate and total production loss are determined by the reservoir characteristics, especially reservoir pressure, and fluid dynamics in the wellbore. To understand this synergetic effect, the blowout model is split into three parts: the reservoir, the wellbore, and their interactions. In the following paragraphs, we discuss these three parts in details.

The reservoir is assumed to be homogeneous and reservoir pressure remains above the bubble point of the fluid, so that reservoir flow is that of single-phase oil. Material balance is used to calculate the average reservoir pressure as following:

$$\bar{p} = p_i - \frac{0.234qBt}{\phi c_t h(\pi r_e^2)} \tag{1}$$

In the beginning of a blowout event, hydrocarbon fluid flows into the wellbore from high pressure reservoir. It is very common to observe a single liquid phase near the bottom of the well at high pressure. As oil ascends upward in the wellbore, its pressure decreases primarily due to static head loss and secondarily due to friction loss. At the point where the local pressure is less than the bubble point pressure, gas starts to separate from the liquid phase, forming a bubbly flow. With further decrease in pressure, more gas would separate from the liquid phase and a wide range of flow patterns, including bubbly, slug, disperse bubbly, churn, and even annular flow, might be observed. Existing flow pattern depends on the property of the liquid and gas phases, fluid pressure, and temperature. In this paper, we adopted the multiphase flow model developed by Hasan et al. (2010). This model reveals the hydrodynamic conditions for the various flow-pattern transitions, and estimates the pressure drop in each flow regime. It is important to estimate flow-pattern accurately to calculate in situ gas volume fractions during a blowout event, so that the oil and gas blowout rates can be calculated separately to reflect the individual phase discharges. Fig. 1 shows an example of the gas volume fraction and gas velocity in the wellbore