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DYNAMIC MODELLING AND MULTIPHASE FLOW OPTIMISATION – GARANTEUR OF SAFE AND SECURE HYDROCARBON PRODUCTION

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Abstract

These days petroleum and condensate formations, especially offshore ones, are actively being developed. The main feature of such formations is multiphase flow in tubing and riser. During production flow liquid slugs, adverse pressure pulses, and often hitting impacts are detected as a result of high gas content, interphase tension forces and complicated pipeline geometry, leading to pressure surges. The energy and very functioning efficiency of both gaslift and fountain operated wells is thus drastically reduced with the disturbance of the optimal production regime. In this paper it has been determined that a novel approach to multiphase flow management allows for decrease in emergency failures and operational expenses. Thus, right modelling and optimization of phase slippages can become a good guaranteur of safe and secure well operations.

Keywords: optimization, multiphase, TPR, flux, dynamic pressure

I. Introduction

Multiphase systems (liquid-gas, liquid-solid particles, etc.) periodically exert significant dynamic pressures on production facilities, such as tubings, gathering pipelines, flare jackets, compressor inlets, separators, pipelines transporting unrefined gas from site to the refinery, etc. There are facts of discard of sucking collectors of vacuum gas lift compressor stations, flare pumping units, support piles kinks at "earth-air" split under the pipelines, catastrophic riser failures, etc. As a rule of thumb, dynamic loads arise at pipeline turns when density of the transported multiphase medium is subject to swift and significant changes.

Pipeline location affects the inner liquid flow characteristics including pressure changes, speeds, and phase concentrations. This is an interesting and multifaceted modern pipeline construction and operation challenge, especially relevant for multiphase well liquids gathering and transportation pipelines [1]. Complicated geometry of manifolds, well piping and underwater equipment of offshore petroleum production systems is in it of itself a configuration matrix, each element of which is capable of drastically changing not only direction but also type and characteristics of the multiphase flow.

II. Methods

It is known that multiphase flow regime boundaries are under visible influence of each individual phase's speed, density, viscosity, flow direction, physical and chemical properties, as well as pipeline geometry, and many other parameters.

According to [2] bubble regime borders in vertical pipe lie between gas speed of 1 to 10 m/s and liquid speed up to 2 m/s. Diameter increase of more than 10 sm leads to widening of the with probable bubble regime zone: gas speed boundaries are 0,1 to 10 m/s and remain roughly the same for liquid speed. When one zone boundaries move, the respective changes happen in boundaries of slug flow, churn flow, annular flow, and mist flow – i.e. all types of multiphase flow.

Problems of formation of a "severe" slug flow or pulsing flow that manifest in subsurface pipelines (gaslift pipelines) of various geometries are discussed in detail in [3, 4].

When considering multiphase flow dynamics, it is vital to clearly understand that flow structure may change with changes in flow rates. Dispersed structure forms at higher mixture flow rates, when its speed exceeds critical, during which structural changes manifest.

In this case the components mixture is a homogenous structure characterized by constant density across all of the flow's volume. If the flux is maximal, speed of the mixture is below critical, thus gradient-speed field tension [5, 6] of the flow is not sufficient for the homogenous mixture to form. The flow consists of alternating gas and liquid slugs. Flow components are divided by a phase boundary.

Flow regime also characterizes its layered structure. Unbalanced dynamic loads appear at turns of the pipelines during slug flow. To determine the maximal value of these dynamic forces affecting multiphase pipeline, it is vital to determine critical mixture speed value at which structure changes evolve. To determine this speed the following equation is used:

$$v = 1.26\sqrt{g\left(\rho_l - \rho_g\right)D/\rho_g} \qquad 1)$$

Where, ρ_l, ρ_g – respectively liquid and gas density kg/m^3
D – pipeline diameter, m;
g – gravitational acceleration, m/s^2

The force acting on the pipeline with change of mixture density is defined as multiplication of residual of dynamic pressures by cross-sectional area of the pipeline.

$$F = \left(\rho_l - \rho_g\right)v^2\pi D^2/4 \qquad (2)$$

Considering features of multiphase flow in vertical pipelines and as a result of analysis of different models it is possible to diagnose optimal operational zone of a multiphase gaslift which corresponds to enhanced energy efficiency of hydrocarbon production. Having that in mind as a result of gaslift well testing in coordinates liquid flow rate (Q_l), gas flow rate (Q_r) and at constant pressure drop performance relationship curves are built (Fig. 1).

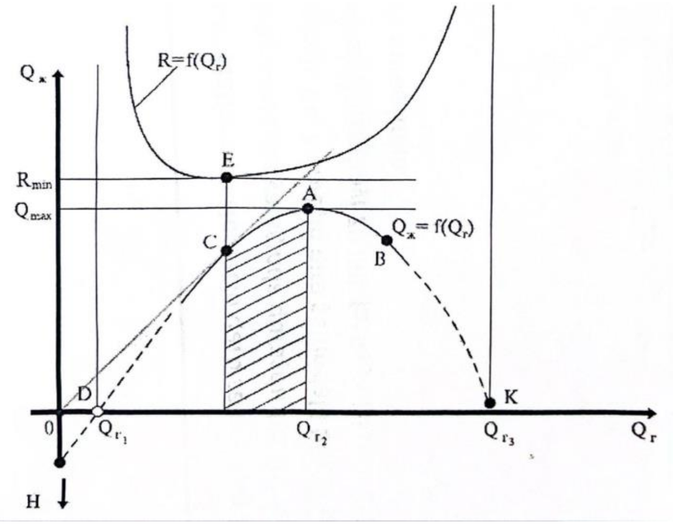

Figure 1: *Gaslift working regime performance relationships*

The following points of interest can be observed on the curve:
- Point D – flow initiation;
- Point A – maximal flow;

- Point K – flow termination.

III. Results

In order to increase efficiency and safety of the gaslift or fountain wells performance relationship curves in coordinates $Q_l = f(Q_g)$ are tied to TPR of the gaslift well that is constructed in coordinates pressure drop (ΔP) vs gas flow Q_g at various liquid flow rates (Fig. 2). In this figure zero liquid flow rate ($Q_l = 0$) corresponds to sparging.

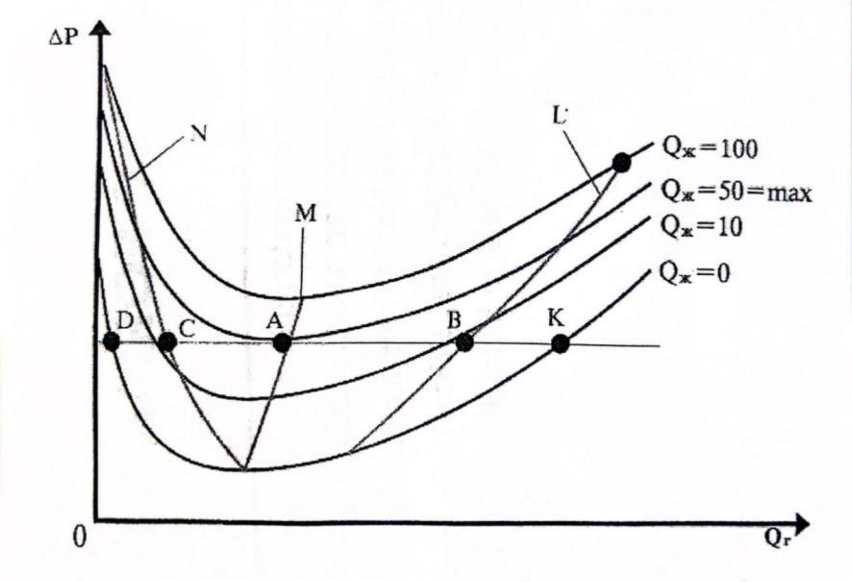

Figure 2: *Multiphase well TPR at constant liquid flow rates*

Should we draw a constant pressure drop line on the TPR curve, three characteristic points D, A and K ae obtained, as on performance relationship curve. Points D and K cross the line of zero liquid flow rate, point A is tangential to the maximal flow rate curve in minimal pressure drop regime. Line N corresponds to minimal specific gas flow rate R_{min}, line M – to minimal pressure drop, P_{min} and line L to minimal specific pressure drop. Zone between lines N and M corresponds to optimal work regime from minimal pressure drop to minimal specific energy expenditure.

Inflow and tubing performance relationship are also important elements of well performance prognosis. Inflow and tubing performance relationship curves intersection point prognoses the future well performance (Fig. 3).

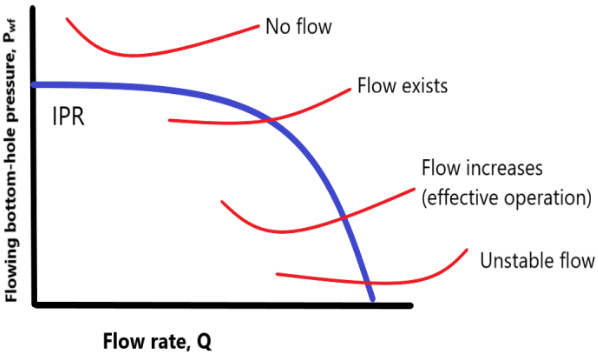

Figure 3: *Modes of TPR crossing IPR*

Fig. 3 represents different TPRs and their correlation modes with IPR. It is apparent that the TPR must intersect the IPR to the right of the extremum of the multiphase TPR otherwise well should be considered unstable.

IV. Discussion

Determination of direction and numerical value of dynamic loads in multiphase pipelines is paramount with regard to safety of transportation. A mathematical model has been proposed to determine these loads considering critical speed and structural changes in multiphase flows.

It has been demonstrated, that to increase safety and efficiency of the gaslift operations performance relationship curves in coordinates $Q_l = f(Q_g)$ must be tied to gaslift TPR curve at various liquid flow rates.

Multiphase flow features must be carefully considered when designing the most economically sound and technologically safe flow diagram.

References

[1] Falcone, G. Multiphase flow metering principles/ G. Falcone, G. F. Hewitt, C. Alimonti. – Amsterdam: Elsevier Science, 2009. – 328p. – Direct text.

[2] A critical review of flow maps for gas-liquid flows in vertical pipes and annuli/ B. Wu, M. Firouzi, T. Mitchel [et al.]. DOI: 10.1016/j.cej.2017.05.135. – Direct text // Chemical Engineering Journal. – 2017. – T.326. – Pp. 350-377.

[3] Han, P. Numerical simulation of terrain-induced severe slugging coupled by hydrodynamic slugs in a pipeline-riser system/ P. Han, L. Guo. – DOI: 10.1016/j.ijheatfkuidfkiw.2015.10.005. – Direct text // International Journal of Heat and Fluid Flow. – 2015. – T.56. – Pp. 355-366.

[4] Li, W. Effects of a long pipeline on severe slugging in an S-shaped riser/ W. Li, L. Guo, X. Xie. – DOI: 10.1016/j.ces.2017.05.017. – Direct text // Chemical Engineering Science. – 2017. -T.171. – Pp. 379-390.

[5] Sitenkov V.T. Gradient velocity field theory M.: OJSC «VNIIOENG», 2004, 308 p.

[6] Sitenkov V.T., Lebedeva E.V. Reduction of dynamic loads on field pipelines / Oil industry, 1998, №6, pp.67-68.