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ESP Performance Enhancement Using Multiphase Ejector to Reduce and Recover Casing Pressure as Sales Gas

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Abstract. The major issue of mature offshore facilities along ESP well operations, atmospheric casing venting has been performed as a quick guideline to prevent gas lock occurrence. Considered as field rule of thumb, this practice is able to optimize well production substantially by maintaining the desirable fluid level above submersible pump intake. In order to overcome both operational and environmental excellence, this paper deliver the extensive design, selection, sizing, and application of multiphase ejector to address: casing pressure reduction, ESP performance enhancement without loss flow phenomenon due to gas lock, and emission reduction by recovering casing gas as sales gas.

Energy-efficient solution of multiphase ejector for ESP is developed using fluid dynamic modelling. Transient mode of "k-epsilon" approach is being applied during the computational process to accommodate fully turbulent flow phenomenon whereas occurred along mixing chamber between high pressure motive fluids attracting low pressure casing gas. The eddy viscosity formulation is used to account the transport effect of the turbulent shear stress inside multiphase ejector. Once computational fluid dynamic complete, field fabrication and workshop test is being conducted prior to field commissioning to obtain the best ejector performance. Benefit from tree cap of ESP wells, high pressure motive fluid is being used to generate vacuum effect inside ejector, attract low pressure casing gas, and displace the flow to medium pressure destination of pipeline network.

In general, gas lock phenomenon occurred in several ESP well along baturaja carbonate reservoir with depth± 2500-2700ft TVDS and sand thickness ± 40ftTVD. Based on data shown in this paper, multiphase ejector is designed to attract the accumulated casing gas using heavy (18API) and viscous (35cp) motive fluid. The customized "Y-type" ejector succeded in lowering casing pressure of ESP-G6 well up to 15 psig followed by a wider ESP operability in terms of frequency, higher pump discharge, and a stable motor temperature. This solution reliable to deliver an instant rate of 61 MCFD of casing gas without any further atmospheric casing venting application preventing further occurrence of gas lock phenomenon and better ESP operability shown by the intermittent flowing patterns.Success story of the "Y-type" ejector is the unique ventury entrance of motive fluid to disperse heavy fluid delivering suitable choke condition and vaccuum effect inside the mixing chamber of ejector. Therefore A stable ejector operations is important to be maintained as a assurance of the continuous vaccuum effect.

Keyword(s): ejector, multiphase, esp, annulus, and performance.

1 Introduction

To be greater than having a giant reservoir with an estimated OOIP of 850 – 1030 MMBO, "Z" area is being operated using ESP (Electric Submersible Pump) for its artificial lift strategy producing a daily production around 2000 BOPD in 2021. To be precise, the producing oil is considered unique compared to the majority of Java Sea fluid produced with a properties of heavy oil (API below 20) and viscosity up to 2000 cp. Based on the field stratigraphy, main challenge of handling "Z" area is extracting the oil around baturaja carbonate reservoir with depth of ± 2500-2700 ft TVDS and sand thickness ± 40 ft TVD under several high current gas column maps around its main oil zone. Therefore, the unexpected high GVF (Gas Volume Fraction) production has becoming issues generating gas lock occurrence which leads to ESP performance deterioration gradually. The gas cap expansion is derived from several causes such as annulus gas accumulation, gas slugging, or even low influx phenomenon. Moreover, free gas induction preventing a further fluid intake along multistage submersible pump and interfere fluid pumping operations shown by erratic operating ampere of ESP's variable speed drive.

2 Problem Statement

A customized gas handler equipment has been applied on the working field as an expected barrier to avoid further gas interference throughout ESP package delivering best fluid pumping operations and achieve daily production target. However, it is limited to hold back the continuous flow of high associate gas rate along production tubing and interfere liquid dominancy during the pumping. As described by Agus and Pramudita, an increasing casing pressure will push the liquid level down, forcing a small volume of annulus fluid entered into ESP chamber that would lead to ESP underload. Through this paper, decreasing casing pressure is being taken as an approach in maintaining the optimum level of fluid flux for certain ESP completion. By default, atmospheric casing venting has becoming a field strategy to maintain well performance notwithstanding limited to be conducted due to negative impact to the environment and process safety.
Based on those constrains, an environmental friendly and safe mechanism must be developed delivering an operational excellence strategy for ESP wells which experiencing any gas lock phenomenon. In order to address this issue, an ejector is taken into account as a solution to attract a continuous amount of accumulated casing pressure gas using high pressure three phase heavy oil flow and discharge those mixture to the pipeline network as addition in gas production. This innovation is designed without any moving parts and reliable to convert high pressure motive flow onto desirable vacuum effect value to attract casing gas, diffuse the mixture, and generating velocity energy to displace the product into medium pressure value.

3 Methodology

By having a unique high pressure motive flow of heavy oil stream and limited fabrication sequence on the working field, the exit plane of "Y" type ejector's motive nozzle is designed within the suction or mixing chamber. As described by Keenan's theory, this ejector is classified as a CPM type (Constant Pressure Mixing) under constant static pressure condition during the diffusion. This concept is taking into account for further computational fluid dynamic simulation of k-epsilon model. The main goal is to integrate the two phase flow condition inside mixing chamber delivering the desirable convergence criteria under a value of 10^{-5} at the end of its computational dynamic. The numerical values is expected to represent internal flow field during transient mixture stream and capture the effect of certain structure parameter up to diverging area of discharge ejector. The computational

A precise geometry pre-processing step under 2D model is performed with fine mesh up to 48K mixed cells and 27K nodes to accommodate sufficient finite elements calculation and accurate post-solution. Watanawanavet detailed the steady-state equation in term of integral form for an arbitrary control volume (*V*) expressed in equation (1). The discretization of the governing equation will be done based on the scalar field parameter quantity of (ϕ) as per defined control volume of ejector.

$$\oint \rho\phi\vec{v}\,.\,d\vec{A} = \oint \Gamma_\phi \nabla\phi\,.\,d\vec{A} + \int_v S_\phi dV \qquad (1)$$

Cell sizes is important to be maintained sufficient during this step for a continuous mathematical adaptation, integrating two different energy conservations inside ejector. At first, high pressure motive flow is being introduced as initial energy source to the system generating a massive pressure drop at the tip of its nozzle, whereas pressure conserves into velocity produces a shock region attracting low pressure fluid source. Carry on to the next step, high velocity stream begins to play its role forcing the mixture exit mixing chamber and being induced gradually to generate velocity to pressure conservation under a divergence structure at the exit of ejector against further back pressure condition from the system.

The standard “k-epsilon” viscous model and “enhanced wall treatment with pressure gradient effects” become the basis of further dynamic computation. Equation (1) of turbulent kinetic energy k and equation (2) of dissipation ε are being used for further numerous iteration with a wide range of turbulence flow. Both equations represents [rate of change of k or ε in time] + [transport of k or ε by advection] is = with [transport of k or ε by diffusion] + [rate of production of k or ε] – [rate of destruction of k or ε].

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij}E_{ij} - \rho\varepsilon \qquad (2)$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho \varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t E_{ij}E_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \qquad (3)$$

Here, heavy oil condition being described as a fluid under a density of 940.8 kg/m3 and viscosity of 0.275 poise. Second order upwind discretization is being used to calculate numerically through further iterations for momentum, turbulence kinetic energy, and turbulence dissipation rate of “standard k-epsilon model” under scheme of equation (4). To be precise, the gradient of each equation of upstream cells of ($\nabla\phi$) is being evaluated comprehensively along displacement each finite vector from centroid of the upstream cell onto 948 discretize faces of ($\nabla\overrightarrow{S}$) which is defined previously inside ejector.

$$\phi_f = \phi + \nabla\phi . \nabla\vec{S} \qquad (4)$$

The iteration process of computational fluid dynamic is being initialized holistically from entrance to exit area of ejector. Shown in figure 1, iterations reaches residual convergence criteria of flow continuity, x velocity, y velocity, k, and epsilon with a value 10^{-5} after 4200 iterations. The pressure-velocity coupling algorithms of SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) is being used to incorporate velocity-pressure corrections enforcing mass conservation to generate pressure field. Therefore, two energy conservation adaptation could be well visualized at the end of computational fluid dynamic.

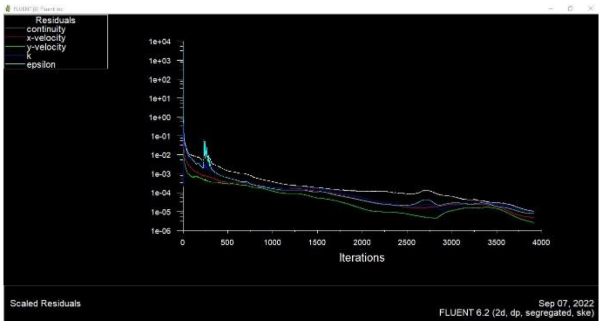

Figure 1. Residual results

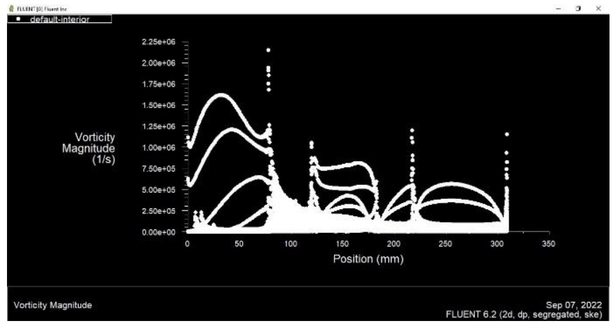

Figure 2. Vorticity magnitude profile

Post simulation detailed in figure 2, vorticity diffusion occurs dynamically along ejector early entrance ejector position up to discharge section. This vorticity dominancy inside ejector is a good sign of desirable flow pattern generating a sufficient vacuum effects attracting casing pressure gas continuously and push back fluid mixture from diffusion chamber into medium pressure of discharge section.

4 Result & Discussion

In general, gas lock phenomenon occurred in several ESP well along baturaja carbonate reservoir with depth ± 2500-2700 ft TVDS and sand thickness ± 40 ft TVD. Based on simulation with finite element method analysis and shown in figure 3 and figure 4, "Y-Type" Ejector can be used to recover annulus gas with high pressure fluid as a motive and they mixed along the ejector discharge to the production header. Effendi A.S, et all, described that a proper casing venting system could be implemented along mature field facilities to enable ESP produce at low flowing bottom hole pressure. Based on simulation, at the tip of motive exit, shock occurs under a vorticity magnitude fluctuations at pressure condition of +/-12-35 psi. This condition helps in preserving the flow continuity during casing gas pressure attraction throughout the ejector.

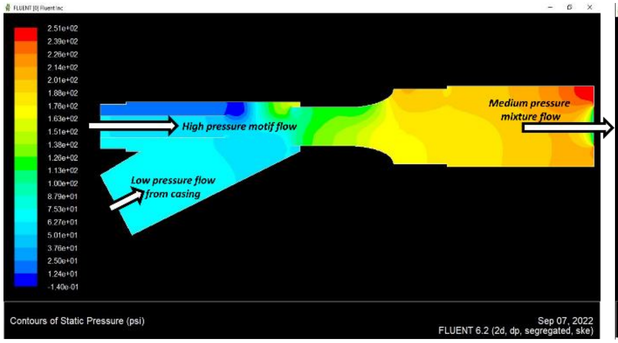

Figure 2. Y Type Ejector *static pressure* result

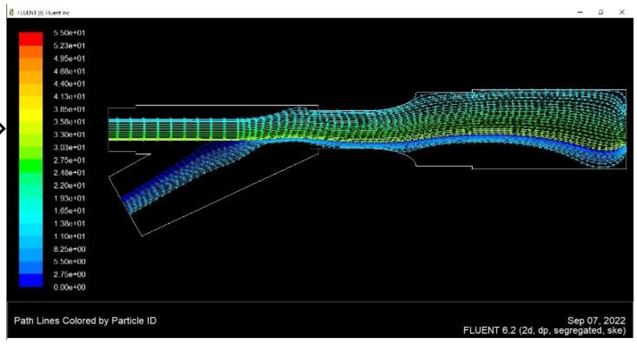

Figure 4. Y Type Ejector *path lines* result

Based on actual condition, “Y-Type” Ejector successfully attract annulus gas using heavy (18API) and viscous (35cp) motive fluid with maximum 15 psig pressure reduction in annulus casing pressure and 61 MCFD instant flowrate as an additional gas beyond the produced gas from the well.

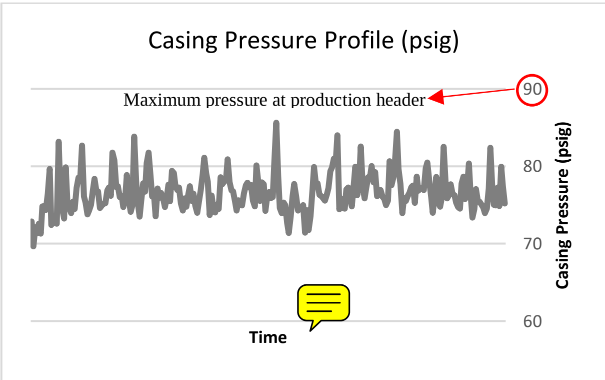

Figure 5. Casing Profile Pressure with ejector

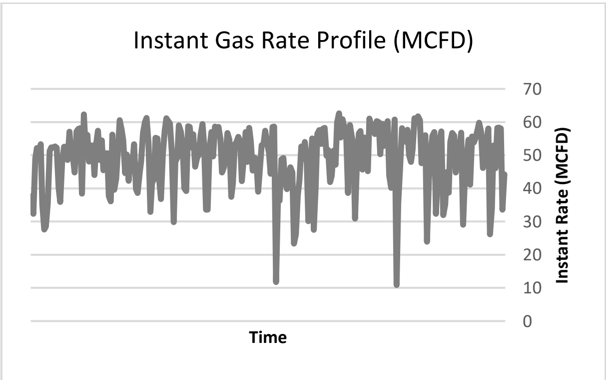

Figure 6. Instant gas rate produced by ejector

ESP parameters after ejector installation shown on figure 7, hypothetical explanation based on actual results are divided into 4 sections:

1. Ejector installed with live well condition and gas lock protection feature in active condition, there is no significant effect to ESP parameters (Pump Intake Pressure (PIP), Pump Discharge Pressure (PDP), and motor ampere). The culprit of this condition is due to packed gas along the production tubing that made no fluids flowing from ESP into the flowline.
2. Shut in well to release the packed gas along production tubing until suction and discharge pressure equal.
3. Start up well without gas lock protection feature activation, then there is a changes in ESP Parameters. Motor Ampere now correlated with Pump Discharge Pressure. This condition means the fluids is flowing with intermittent condition.
4. Gas lock protection feature is activated, Motor Ampere still correlated with Pump Discharge Pressure.

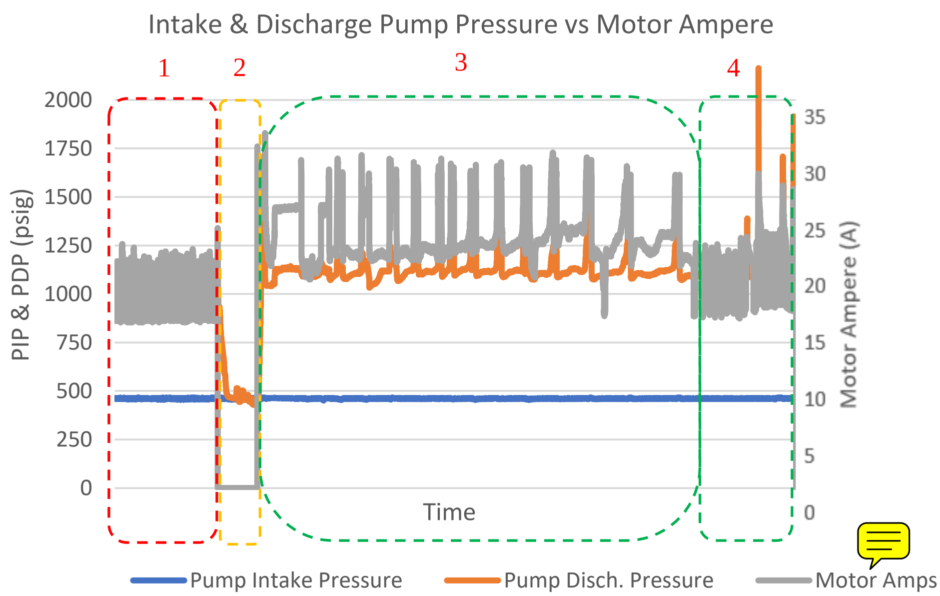

Figure 7. ESP parameter after ejector installation

Based on these results above, post ejector installation gives an enhancement in ESP performance. Which can lead to the ESP wider operability in terms of frequency, higher pump discharge, and stable motor temperature.

5 Conclusion & Recommendation

Ejector can be a reliable solution for gassy ESP wells to reduce casing pressure to give an enhancement for ESP Performance and recover the annulus gas as a sales / fuel gas. Success story of the "Y-type" ejector is the unique venturi entrance of motive fluid to disperse heavy fluid delivering suitable choke condition and vacuum effect inside the mixing chamber of ejector. Therefore, a stable ejector operation is important to be maintained as an assurance of the continuous vacuum effect.

In order to optimize the utilization of this ejector, series / parallel configuration may be used. Then further studies for using series ejector configuration or parallel configuration to achieve optimum process condition.

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