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Investigation of a Choke Valve Erosion in the Gas Lifted Systems

Kaindi Mandilindi and Simon I Marandu
Department of Mechanical and Industrial Engineering, University of Dar es Salaam, P.O. Box 35131, Dar es Salaam, Tanzania
Corresponding author: smarandu@udsm.ac.tz, marandus15@gmail.com
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Abstract

Erosion is one of the common causes of failure in subsea operations. However, erosion of subsea systems has many patterns, trends and uncertainties. This has led to production losses due to the failure of prediction of the useful life of the components in the gas lifted system. This work experimentally studied the effect of flow rate and pressure variations on the erosion of the choke valve in the gas lifted system by using flow streams containing either liquid or liquid injected with gas. Cameras installed on both sides of the erosion box captured images of the probe after every one second, followed by image analysis using the RGB model in MATLAB. Erosion consistently occurred after 120 minutes, followed by a significant reduction of the probe area with time. Severe erosion was observed on the liquid streams with no injected gas. Differential pressure in the erosion box varied with higher flow rates. High volumetric flow rates are found to increase erosion of the choke valve. Adding sand in the rig is crucial on establishing the trends of the erosion of the choke valve because of eminent production of sand in the matured gas wells.

Keywords: Erosion, Choke Valve, Gas Lift, Christmas Tree, RGB.

Introduction

In subsea oil and gas production, erosion due to gas and or sand flow is inevitable. Fluid flow rates, differential pressures and solid phase particles such as sand contribute to the erosion of these subsea components in oil and gas production wells (Raghavendra et al. 2014 and Guo et al. 2022). With time, most subsea components are exposed to erosive damage as the production field matures due to decrease in the reservoir pressure, sometimes below 6.9 MPa. This condition is severe during the late stages of production due to significant increase in sand production. This study establishes the effect of flow rate and pressure variations on the erosion of the choke valve in a gas lifted system to optimize production operations in the matured gas wells. Thus, the effects of flow rates and pressure of the fluid flow on the life span of the components of the gas lifted systems are investigated for condition monitoring of the production wells. Limited (2003), described components that are most vulnerable to erosion in subsea production are reducers, weld intrusions, tees and elbows, straight pipes, choke valves, sudden constrictions and partially closed valves. These components experience high flow velocities caused by high volumetric flow rates, sudden changes in flow direction due to flow restrictions.

Specifically, the study focuses on the erosion of the choke valve, which is more vulnerable to erosion among the subsea components of the gas lifted systems. Choke valve is a special type of control valve used in heavy industries such as oil and gas production for controlling operating conditions such as temperature, pressure and flow rates (Grace and Frawley 2011). A Choke valve, illustrated in Figure 1, with a list of its components provided in the respective key, is generally located in the production block, also known as the Christmas Tree or XT.

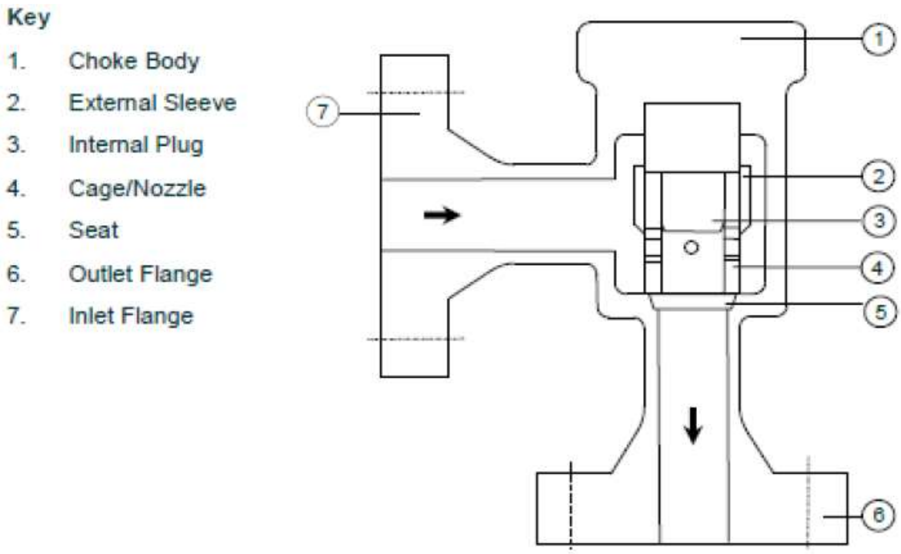


Figure 1: A subsea choke valve (Sauther 2010).

The valves are used to control flow rates of gases and liquids that flow through the pipes and protect equipment in the low stream from damage due to unusual pressure fluctuations. Choke valves work a great deal in holding back pressure on a flowing well to make use of the compressible fluid such as natural gas lift as well as control the bottom hole pressure for recovery reasons (Raghavendra et al. 2014). On the other hand, Verheyleweghen and Jäschke (2018) reported that well reservoir's pressure declines with maturity to a point of stopping production. To extend the life of the well, external air pressure is pumped to the well to reduce the pressure drop and increase the volume flow and velocity, thus prolonging the life of the well. The process is commonly referred as Gas lift (Jung and Lim 2016). Gas lift operating principle is based on the reduction of tubing gravitational pressure gradient (Guet and Ooms 2006). However, the process has its consequences such as reduced density of the fluid and accelerated erosion of the vulnerable internal parts of system such as choke valves and bends due to trapped sand in the fluid flow.

Furthermore, erosion involves changing of a surface by mechanical action, friction, thermal expansion, contraction or impact. Therefore, continuous exposure of choke valves to the abrasive flow conditions leads to erosion on the sealing surfaces and the body of the choke valve. Once the valve circular openings undergo erosion, the geometry of the valve changes causing increase in valve flow coefficient (Nystad et al. 2010).Several researches (e.g., Malavasi et al. 2018, Jahren et al. 2021 , Zang et al. 2022) have studied failure of choke valves due to erosion. Their studies based on modelling and prediction of choke valve erosion by different techniques such as data driven modelling and computational fluid dynamic in slurry conditions to predict the remaining useful life of the choke valves and maintenance strategies to apply of the production systems. Nystad et al. (2010) used the DNV-GL choke valve to estimate erosion and remaining useful life of an oil production system using the Gamma process method. The method could capture uncertainty of erosion of the choke valve erosion over a lifetime. Although, the trend of erosion was established including the lifetime of the choke valve, still the method had several uncertainties. Hansen et. al (2016) studied the flow parameters in a multi-phase stream to see how changes in the liquid and gas velocities would affect failure rate and estimated lifetime of elbows and chokes. Assumptions were density and viscosity remained constant across the valve. But in order for any flow to occur there must be a pressure difference. Investigating the effect of flow rates and differential pressures on the erosion of the choke valves to establish the dynamics for modeling the erosion of the choke valve as a function of flow rates and differential pressure is crucial in optimizing the useful life of the choke valves.

Materials and Methods

The study used an experimental rig which mimicked a matured well in a gas production system and required artificial gas lift. The experimental fluids used in the rig were water as liquid and air as gas due to their availability and lower cost. Water was used to mimic the natural gas flowing in the system with provision for injecting pressurized air thus posing a safe and low-cost experiments. The rig consisted of various components that represented a real gas lift system, such as pipes, water reservoir tanks and filter, centrifugal pump, control valves and erosion boxes, risers and a separation tank as shown in Figure 2. The rig was designed with three channels (wells), each consisting of a control valve and an eroding probe in the erosion box connected to the riser. A continuous fluid flow goes on during the experiment while recycling of the fluid back to the system. The experiment utilized only two wells in which control valves for controlling air injection were placed just after the water valve. The operational set up of the rig was: (1) Valves acting as pump re-fluxes were opened. (2) The air valves were checked to ensure that were turned off. (3) The computer was turned on and zeroing of the set points was done, except for pump flow rate; which was set at 30 ml/s. (4) The air valves were turned on to allow the flow of air to the system. (5) The pressure regulators were turned on. (6) The fluid flow and LabVIEW program were started followed by setting the pump on. (7) MATLAB program was subsequently started to begin capturing the images. To avoid high foam formation occurring in the tank, because of the Polyvinyl Alcohol (PVA) erosion probe, 5 ml of anti-foam solution was added to the tank.

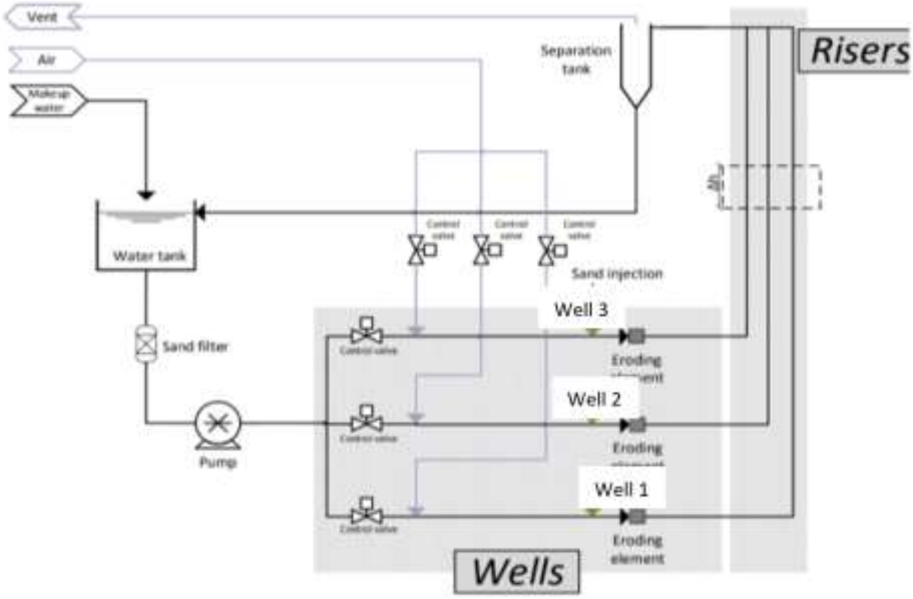
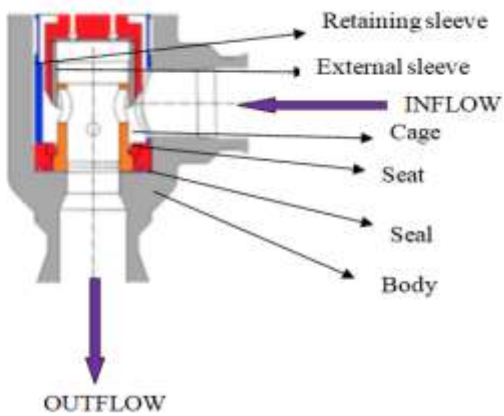


Figure 2: A schematic of the experiment rig.

At this experimental stage, sand was not injected in the rig to avoid accelerated erosion of the choke valve. The shape of the probe shown in Figure 3(a) was designed in similarity to the choke valve geometry shown in Figure 3(b). Despite the static and dynamic difference of the natural gas and water, the setup sufficiently demonstrates the hydrodynamics of the system, which are similar to the real system, only differing in scale and time. The experiments were done under controlled condition with continuous water flow through the erosion box causing degradation of the probe

Cameras set at the sides of the erosion box, facing the probe captured images of the probe at every second showing the evolution of the probe material. The rig was synchronized with LabVIEW and MATLAB programs for online data acquisition and processing. Collected data were further analyzed using MATLAB with additional tools, CASADI and Image Processing Toolbox. The main method of analysis was Image analysis, where the captured images were used to calculate the area in terms of number of pixels. The decrease in area indicated the erosion of the component.

(a) PVA-made model Choke Valve



(b) A positive flow choke valve (masterflo.com)

Figure 3: A model and physical Choke valve used in oil and gas system.

Image Analysis of the Eroded Choke Valve

The image analysis of the eroded choke valve after being subject to flowing water in a controlled conditions involved procedures and techniques used for recognizing, differentiating, and quantifying images as described by Park and Lu (2015). The images were analyzed using the RGB model where each color appears in its primary spectral components of red, green and blue. This model is based on the Cartesian coordinate system as reported by Kumar and Verma (2010). The assumption made was that, every pixel has a flag connected to the red, green and blue colour. If the level of one of the colours is higher than a threshold, the correspondent flag is set to one or zero otherwise. For each pixel, the product of these three flags was analyzed and represented in grayscale. If the product is 1, the assumption is that, it is white otherwise black. White represents non eroded part of the probe while black represents the background.

MATLAB program separated the non-eroded part of the probe from the background by comparing the initial and final image frame and detecting the change in pixels. The image was cropped in order to completely isolate the probe from the background as shown in Figure . The images in Figure 5 show stages for cropping the eroded part, separating it from the background. The images in Figure 6 show the eroded probe in RGB channels and in Grayscale. The data was then quantified in terms of pixels using MATLAB codes and the area in number of pixels was calculated based on the cropped/reshaped image. Figures 7 shows the evolution of the probe from the initial stage progressively to final stages during the experiment.

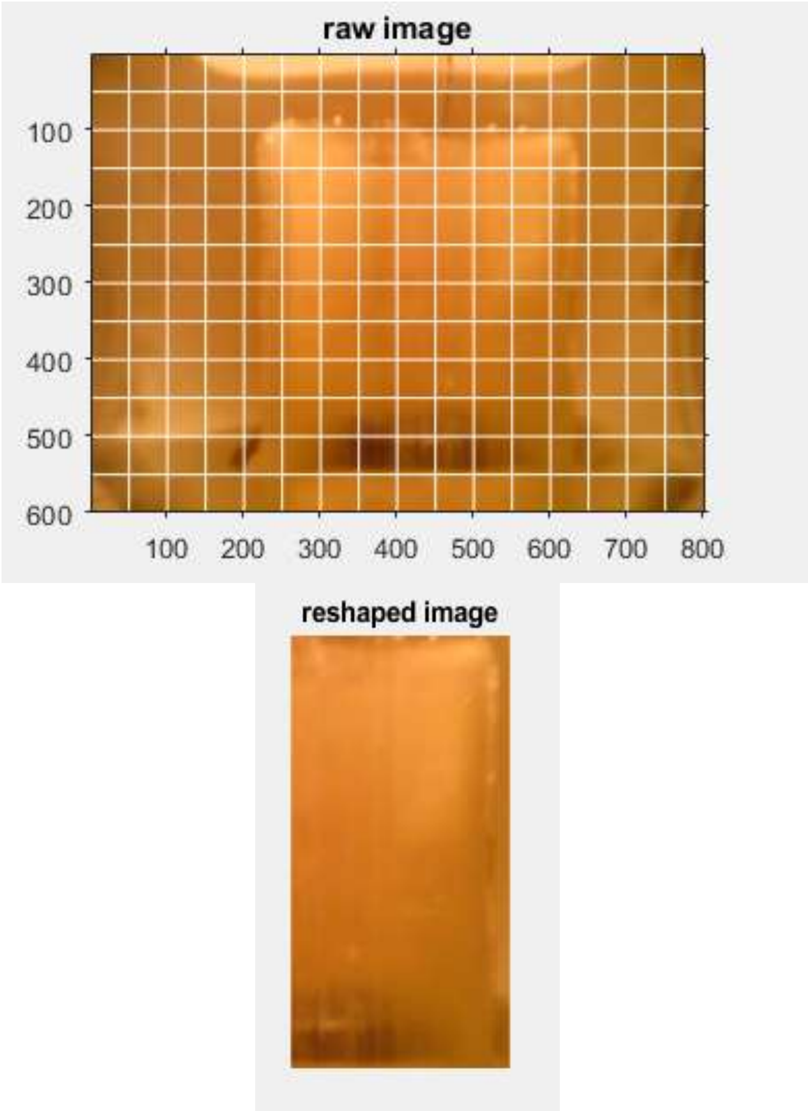


Figure 4: Illustration of the raw image and the cropped image during the analysis.

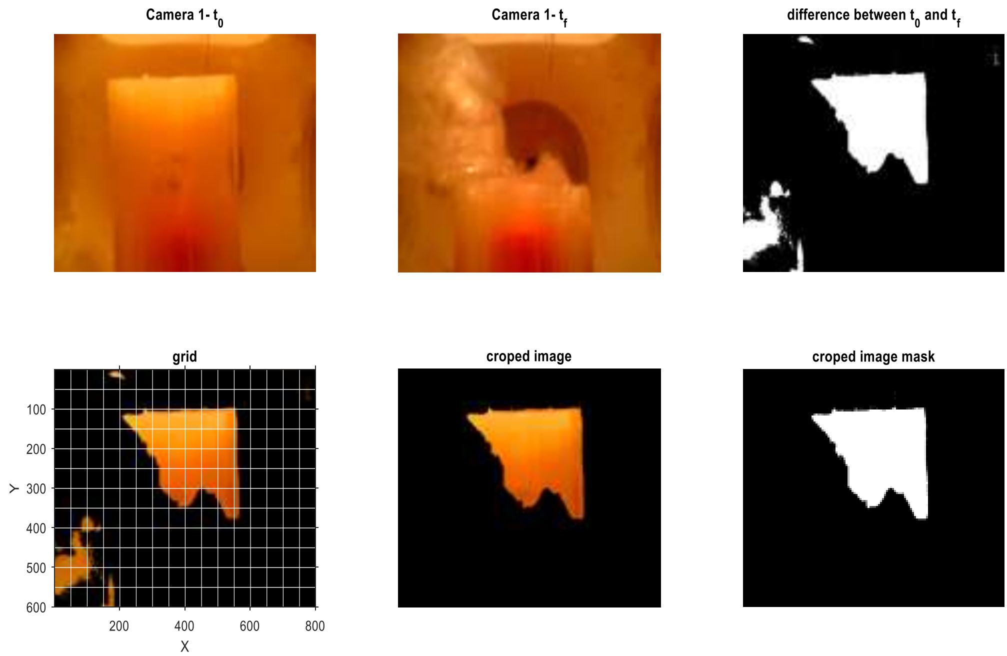


Figure 5: Images of the probe during Image per-processing stages.

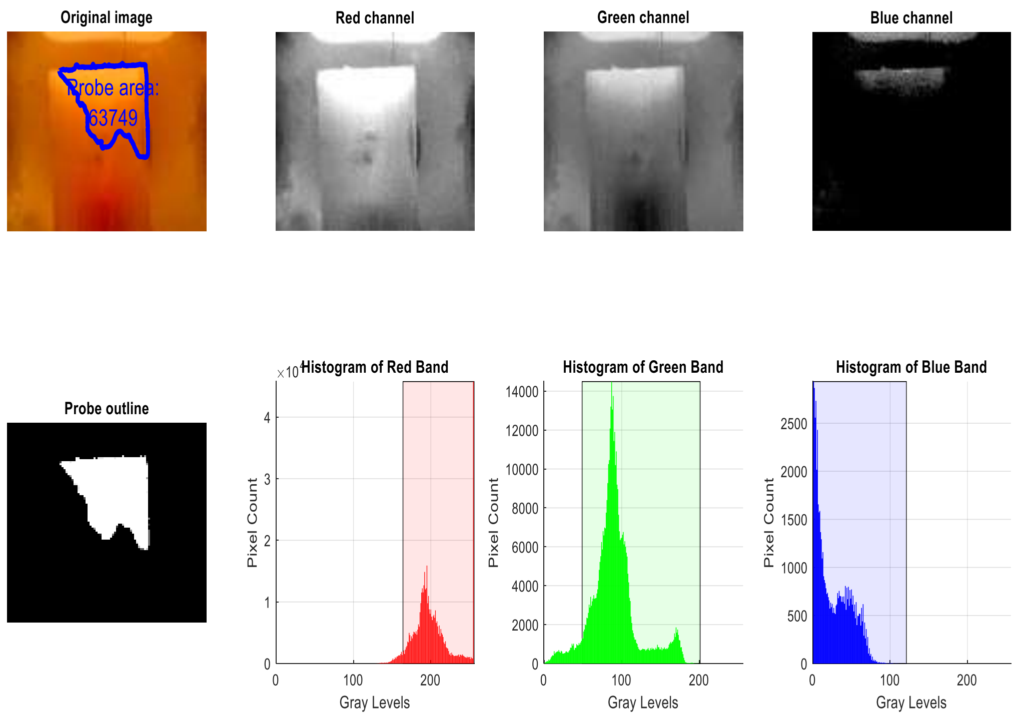


Figure 6: Images of the probe represented in RGB channels and Grayscale (as Probe outline).

Figure 7: Images showing evolution of the choke valve probe due to erosion.

Results and Discussion

Results of the experiments were obtained by-controlling and varying flow rates of water and air through the choke valves at the following conditions:-Q_l= 10 L/min, Q_g= 0 sL/min, coded as experiment Q_l10-Q_g0; Q_l= 8 L/min, Q_g= 0 sL/min coded as experiment Q_l8-Q_g0; Q_l= 8 L/min, Q_g= 2 sL/min coded as experiment Q_l8-Q_g2; Q_l= 6 L/min, Q_g= 0 sL/min coded as experiment Q_l6-Q_g0; Q_l= 6 L/min, Q_g=2sL/min coded as experiment Q_l6-Q_g2; The results of these experiments are plotted in Figure 8-11 with legend as shown in each Figure. Each condition was considered for the two wells, (i.e. Well 1 and Well 2). Each well results are independent of one another, that is to say results from Well 1 are independent of the results from Well 2. This is because the Wells had flowing fluid in different streams. Slope for each graph was calculated and represents the decrease in area with time and is expressed in percentage per minute. Table 1 represents the summary of the erosion rates with respect to time at the different flow rates.

Table 1: Erosion rates (in % per minute) with respect to time at different flow rates for the Well 1 and 2

Flow Rates		Erosion rate (% per minute)		Differential pressure	
Liquid flow rate (L/min)	Gas flow rate (sL/min)	Well 1	Well 2	Well 1 (mbar)	Well 2 (mbar)
10	0	4.28	1.60	13.00	9.00
8	2	3.17	5.00	12.50	13.00
8	0	1.03	0.73	12.00	6.50
6	2	1.00	1.22	11.00	7.00
6	0	0.70	0.92	3.50	4.00

Figure 8 shows observations made from Well 1 for 120 minutes in which the reading of the probe area for the choke valve remained stable without a noted erosion, followed by a rapid decrease of the area of the choke valve in the well for the flow rates Q_l8-Q_g0, Q_l6-Q_g0, Q_l6-Q_g2, Q_l8-Q_g2, respectively. The sudden reduction in the area of the choke valve signifies its rapid erosion.

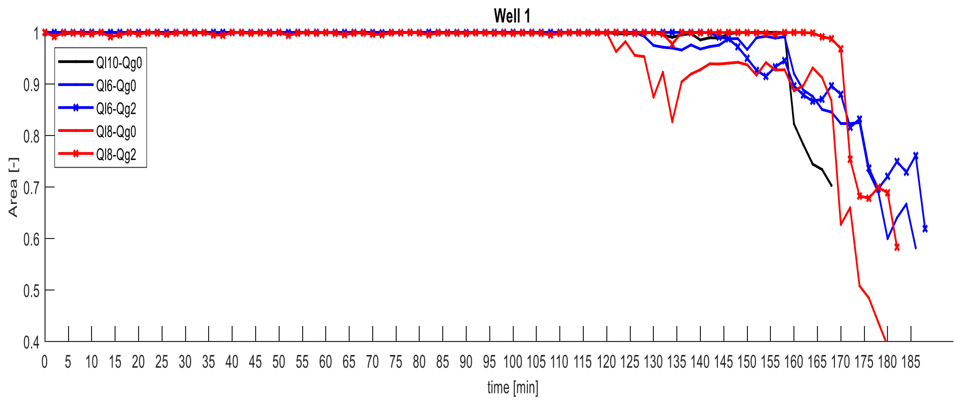


Figure 8: Erosion of the Choke valve with respect to time for Well 1

However, a deviation is noted with the flow rate Q_l10-Q_g0, contrary to the expectation that it would start to decrease in area due to high flow rate. The phenomenon is not clear, but could be attributed to the permeability and shear strength of the materials for the probe. Streams with flow rates containing no air injection, that is when Q_g=0 sL/min, are observed to have fast erosion rates compared to those streams with flow rates in which air has been added to the well streams. This is attributed to the higher flow velocity of water stream with no added air, compared to the lower velocity of flow rates of water stream when air has been injected to the water streams due to the frictional interaction between the water and air molecules, a condition reported by Verheyleweghen and Jäschke (2018).

Figure shows trends of erosion in Well 2 in which flow rates Q_l8-Q_g0, has notably declined after 120 minutes, signifying start of erosion of the choke valve, followed by flow rates Q_l10-Q_g0 and Q_l6-Q_g0 at 135 minutes, followed by, Q_l6-Q_g2 then Q_l8-Q_g2. The noted trends in the Well 2, is in good agreement to literature as when more gas is added, the velocity of the water stream is reduced, due to higher frictional interaction of water and air molecules in the stream and hence reduce erosion rate of the choke valve.

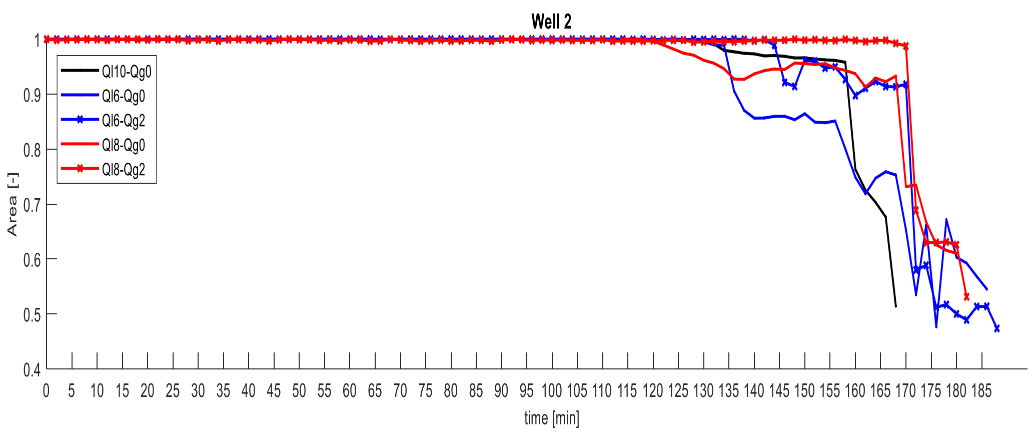


Figure 9: Erosion of the Choke valve with respect to time for Well 2

The plots for differential pressure in Figure 10 from Well 1 show that higher flow rate of water, have higher differential pressure in the erosion box, thus indicating the two flow rate parameters are directly proportional. For streams with the same flow rates, the higher the gas flow rates**,** the higher the differential pressure. This causes deterioration of the probe of the choke valve as reported by Gou et al. (2022)

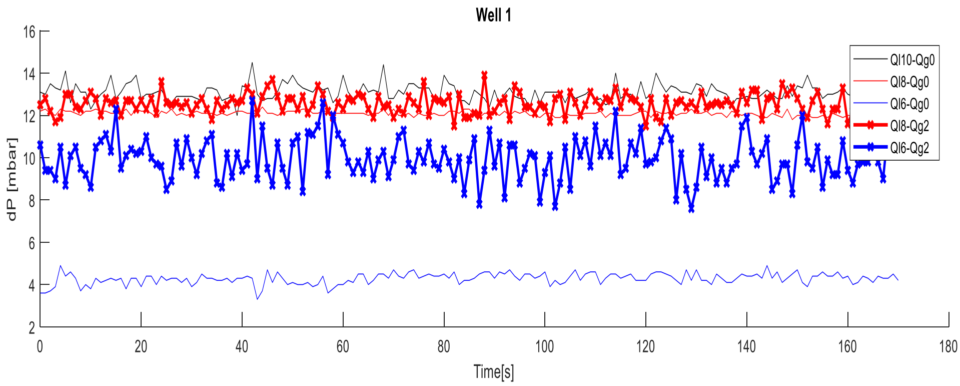


Figure 10: Differential Pressure variation in flow streams with respect to time in Well 1

Similarly, Figure shows differential pressure variation with time in Well 2. It is observed that the streams with injected air have higher differential pressure variations compared to the streams without injected air. This is due to the fact that introducing micro size bubbles of air into flowing water, reduce the flow velocity due to the drag effect between water and air molecules, thus causing the differential pressure variations build up with time in the flow stream. At high differential pressure across the choke valve, extremely high velocities may occur within the choke causing high erosion rates. The pressure drop is directly proportional to erosion. The higher the pressure drop the higher the flow velocity leading to erosion in choke valves (Raghavendra et al. 2014).

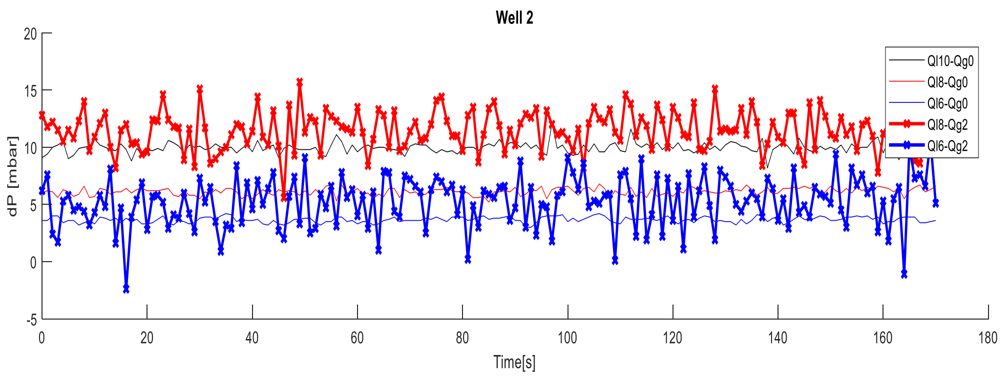


Figure 11: Differential Pressure variation in flow streams with respect to time in Well 2

Conclusions

The findings have shown that increase in gas and liquid flow rates in the choke valves significantly influence an increase in erosion. The area of the probe decreased with an increase in flow rates of the fluids. Erosion propagates slowly at some point followed by a rapid decrease in area which indicates steady erosion as the surface of probe of the choke valve changes from smooth to rough. Likewise, the differential pressure in the erosion box shows constant variations with increase in differential pressure when air is injected in the flow streams. The fluid flow rate and pressure have shown to be important factors affecting erosion of the choke valve.

The data generated from the rig while varying fluid flow rates can be used as inputs for developing auto regressive models to predict the remaining useful life of choke valve as a function of flow rates and differential pressure. On the other hand, it has been established that water and air can be used to mimic the liquid and gas system in the gas lifted systems in order to study the effect of flow rates and differential pressures in the evolvement of the erosion of the choke valves in gas lifting systems. It is recommended to add sand in the rig to establish its influence on the erosion of the choke valve because sand production is eminent in the matured gas production wells. This could provide much better data to model erosion for condition monitoring of the subsea components as erosion rate is positively correlated with the amount of sand.

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Declaration

We have no conflicts of interest to disclose.

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