Simulation of Erosion Wear in Choke Valves using CFD

[1]Raghavendra H N
M.Tech. student (Thermal Power Engg.),
Dept. of Mechanical Engg. SIT, Tumkur, India

[2]M. Shivashankar M.Tech
Associate Professor,
Dept. of Mechanical Engg, SIT, Tumkur, India

[3]Prem Anand Ramalingam
Engineering. Manager,
Pentair Valves & Controls, Bangalore, India.

***Abstract* - Oil & Gas Choke valves or Control valves are extensively used in the petrochemical and process industries for the regulation of fluid flow. They experience a wide range of operating environments. Some of these operating conditions are extremely aggressive being not only corrosive but also erosive due to entrainment of sand in to the production flow. These are referred to as severe service conditions in oil & gas industries.**
Sand production is a known problem in the oil & gas industry. This produced sand carries through chokes (Control Valves) present in wellheads. Chokes are typically suffering for this in form of erosive damage. The erosive damage is decided by many different factors where the flow rate velocity of the fluid, sand rate, thermodynamic properties of the service conditions, fluid flow pattern, flow directions & materials are important ones.

Dedicated effort is required to counter the control valve erosion to be able to maintain oil & gas production at an optimal level with attention to avoid unscheduled maintenance, safety and availability of other equipments also.

Use of Computational Fluid Dynamics (CFD) has been essential in this work by simulating fluid flow through the control valves for optimizing the design, choosing the optimal erosion resistant material, coming up with improved erosion-related models and better mechanised operational procedures of the control valves.

From the present simulation analysis of erosion wear the importance of pressure drop, flow velocity and flow pattern is analysed. Erosion rate is analysed for a 51mm bore (2, 1/16" – 5000 psi) choke valve as up to 0.24 mm per year for a 50% valve opening.

Keywords – Erosion rate, mm per year, Erosion rate density.

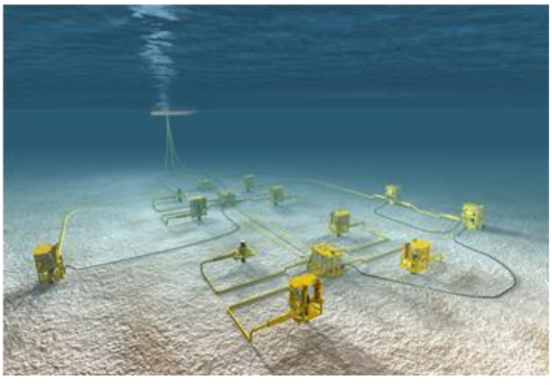

Fig.1 Subsea Oil & Gas production system

I. INTRODUCTION

The production part of oil & gas extraction platform involves topside & subsea manifolds arrangement. These manifolds is an assembly of equipment's including tubing head adapters, valves, tees, crosses, top connectors and chokes attached to the uppermost connection of the tubing head used to control well production in oil & gas industries **[2].**

They are rated for working pressures of 14 Mpa (2000 psi) to 103 Mpa (15,000 psi). Choke is the only device used to limit the production of flowing fluids. Chokes hold a back pressure on a flowing well to make better use of compressible fluid such as natural gas lift and control the bottomhole pressure for recovery reasons. In vertical pipe flow, gas expands rapidly with decreasing hydrostatic head and the fluid moves in slugs through the tubing.

Solids in the produced fluids (Natural gas) are the major source of failures of chokes. Abrasion from sand, scale, ice, corrosion particles and other solids can cut through choke restriction and cause the well to load up with fluids and solids.

Production of oil and gas from most reservoirs are associated with impurities like water, CO_2, H_2S and sand particles. These impurities result in degradation of the production system due to erosion, corrosion and erosion-corrosion and may eventually result in the need for repair and replacement or, in worst case, leakage to the environment.

Sand particles entrained in the well stream may result in erosive wear throughout the production system; e.g. in the production and template piping, in pipe bends, chokes valves, manifold, separator inlet, etc. The erosion rate is strongly dependent on the amount and size distribution of the sand particles, production conditions (e.g. rate, pressure and temperature), field characteristics (e.g. oil or gas field), as well as on the geometry and the material of component.

Choke valves are applied to control the flow and/or reduce pressure in oil and gas production units. At high differential pressure across the choke, or low fluid density, extremely high velocities (e.g. 300 – 500 m/s) may occur within the choke. At these high velocities the erosion rates may become very high. Experience has shown that the service life for choke valves may be very short, in extreme cases even as low as days or hours. At normal operational conditions, services lives from some months up to 2–3 years have been experienced, fig 4.

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In the present work the CFD programmed CFX fluid flow version 14.5 is applied. The prediction method for sand erosion applies the results from flow solution and a particle track calculation to calculate the erosion rate on the internal surfaces of the geometry. Specific models have been developed to calculate erosion rates based on the results from CFD simulations.

The CFD analysis is performed in four steps;

- Grid generation,
- Flow solution,
- Particle track calculation and
- Erosion rate calculation.

Chokes with lower opening tend to erode faster in general. This is due to the following arguments:

- Low choke openings normally causes high pressure drop across the choke.
- High pressure drop combined with low fluid density causes high particle velocity through the cage ports.
- Deeper erosion grooves can potentially appear because the particles are focused on a small surface area.

Fig. 2 Manifold System comprising equipment's

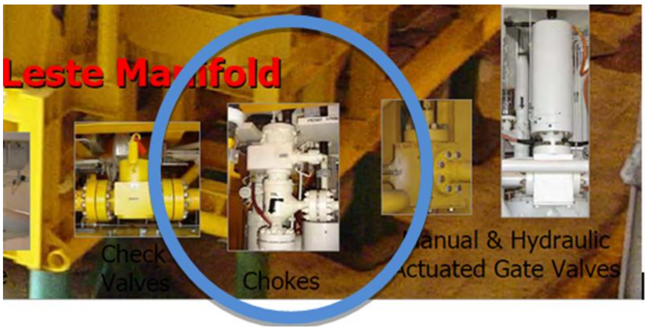

Fig. 3 Enlarged view for location of Chokes

Fig. 4 Sand erosion damage to flow control part

II. CFD METHODOLOGY

The term erosive wear means the same as the term erosion, but is in some relations better to use. Erosion rate is the "amount" of lost original material due to erosive wear given in [mm/yr.]. This general model is further explained below [5]:

$$E_L = \frac{K * u^n * m_p * F(\alpha)}{A * R_w}$$

E_L: Erosion rate [mm/yr]
M_p: Mass flow rate of particle (sand) that hit the area [kg/s]
K: Material constant
n: Velocity exponent dependent on wall material
u^n: Impact velocity [m/s]
F (α): A number between 0 and 1 given by a functional relationship dependent of the wall material and the impact angle α [see figure below].
A: The size of the area exposed to erosion [m^2]
R_w: Wall material density [Kg/m^3]

Simplified mathematical model for erosion rate calculation is;

*E_L = {K *(Erosion rate density [kg m^-2 s^-1] / Density of the wall material [kg m^-3])}*

Material	K	n	R_w
Steel Grade	2.0×10^{-9}	2.6	7800 Kg/m^3
Tungsten Carbide (WC)	1.1×10^{-10}	2.3	15250 kg/m^3

For 'K', 'n' & Rw values above table is used as reference.

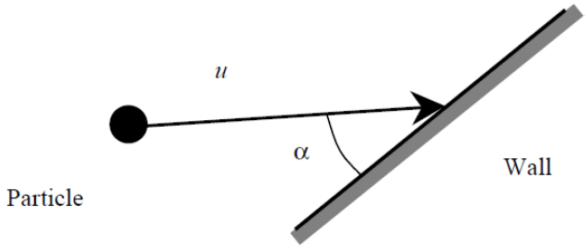

Fig. 5 Definition of flow parameter

Computational Fluid Dynamics (CFD) is a tool for predicting the behaviour of fluid passing through certain set of physical parameters through identified geometry.

We solve basic transport equations in computational fluid dynamics problem. They are Continuity equation, Momentum equation (Navier Stokes equation) and Energy equation. The CFD procedures are as below:

- Identify Physical nature of the problem
- Identify the Geometry of the interested fluid Domain
- Formulate the Mathematical Statements and equations
- Discretize Equations & Geometry
- Develop or Choose the Algorithm
- Develop or Select Software
- Choose Computing Hardware / High Performing Computing (HPC servers)
- Compute the Solution
- Analyze & Interpret Results
- Storage and Manipulate Large Data Sets
- Post Processing and Visualization

In this paper we have limited the CFD analysis of erosion wear to results and discussions only.
After identified the interested flow geometry is taken in to meshing environment where in whole fluid geometry is discretised in to each control volumes for thorough fluid analysis.
Then the fluid set-up is done using available physical parameters obtained in step 5 of mathematical modelling. Simulation runs are carried out for number of iterations till all the fluid mechanics transport equations gets converged.

Boundary conditions used for the erosion analysis are inlet fluid pressure, inlet fluid temperature, inlet sand mass flow rate and size. Outlet fluid pressure and temperature.

Step 1: Obtain all the physical properties of fluid such as fluid mass flow rate, specific volume of fluid, density of fluid, fluid viscosity using process data hand book.

Step 2: Calculate Reynolds's number and decide type of flow, whether laminar or turbulent.

If turbulent, choose the turbulence model, turbulence intensity and length using CFD set-up menu.

$$R_e = \frac{ØvD}{u}$$

Step 3: The three important factors that affect the sand particulate erosion wear in choke valves are,

1. Effect of pressure drop
2. Effect of flow velocity
3. Effect of fluid flow pattern, sand size.

Let's learn how the above factors vary with respect to erosion wear.

Step 4: Pressure drop contours through location of choke valve

Choke holds back pressure by restricting the flow opening at the wellhead. Back pressure restricts the uncontrolled expansion and rise of gas and thus helps keep the gas dispersed in way up tubing.

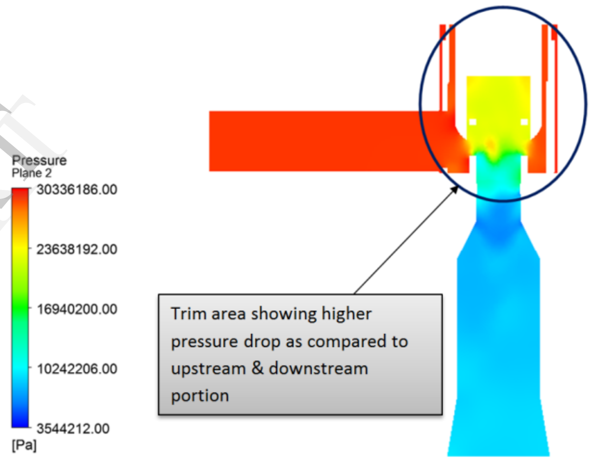

Fig. 7 Pressure drop Contour

One of the most important characteristics of erosion wear is the variation of pressure drop across chunks of choke valve. It is evident that during trim stages a higher reduction in pressure as compared to that of other parts of choke.

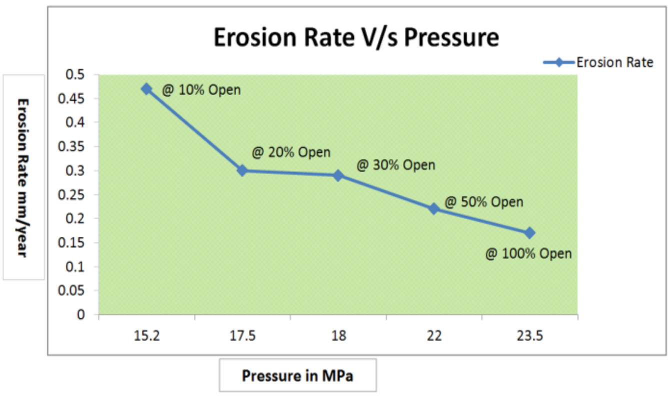

Fig. 8 Effect of Pressure drop on Erosion Wear

The pressure drop V/s erosion rate is summarized for trim area for all the percentage valve openings.
Effect of pressure drop on erosion rate is depicted in figure 8. From the figure, the trends shows that as the pressure increases, i.e. as pressure drop decreases at various valve openings ranging from 10% to 100 % opening, erosion rate decreases.
At 10% valve opening, pressure is 15.2 Mpa and erosion rate is 0.47 mm/year. Similarly at 20 % valve opening, erosion rate measured is 0.30 mm/year.
Similarly at 100% valve opening, pressure is 23.5 Mpa i.e. pressure drop is decreasing and the erosion rate measured is 0.17 mm/year. Hence it concludes as the pressure drop decreases erosion rate also decreases **[4].**

Mathematical equation to calculate pressure drop through system is as below:

$$\Delta p = 0.6253 \frac{\forall K W^2}{d^4}$$

From the above equation values of '∀' &'W' of the fluid can find using process flow data. 'K' is the total flow resistance. Flow in pipes is always accompanied by friction of fluid particles rubbing against one another and consequently by loss of energy available for work.

$$K_1 = f\frac{L}{D} \qquad K_2 = 14f_T$$

$$K_3 = \frac{K^1{}_3 + \beta[0.5(1-\beta^2)^2 + (1-\beta^2)^2]}{\beta^4}$$

$$K = K_1 + K_2 + K_3$$

Step 5: Velocity distribution contour through location of choke valve

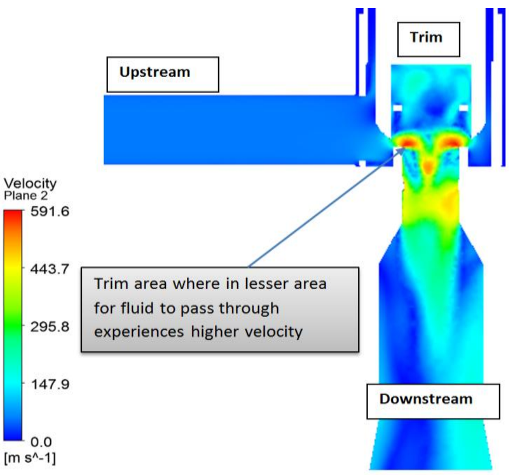

Fig. 9 Flow velocity distribution

Erosion is mainly due to jet impingement of sand particles inside the bean part of the choke valve. Higher fluid velocity up to 500 m/s measured at trim area shown in figure 9 forms fluid jet kind of formation in the slugs of the choke bean.
So even in worst case at smaller choke openings like 20%, fluid velocity reaches Mach number more than 1(Supersonic).

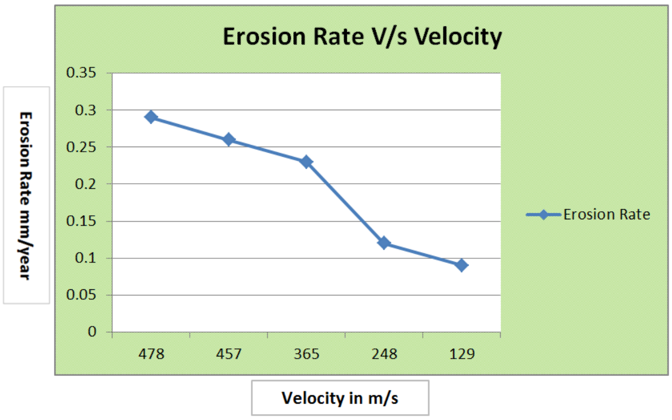

Fig. 10 Effect of flow velocity on Erosion Wear

Flow velocity V/s erosion rate behaves linearly as shown from the figure 10. According to API 14E (Recommended practice for Design and Installation of Offshore Production Platform Piping Systems), the process equipment's like headers chokes, manifolds should be primarily be sized on the basis of flow velocity.

From the figure it is clear that, at 478 m/s flow velocity, erosion rate is 0.29 mm/year. Similarly at 129 m/s flow velocity, erosion rate measured is 0.09 mm/year. Hence it is clear that as flow velocity increases erosion rate also increases.

Mathematical equation to calculate fluid velocity through system is as below:

$$V_1 = 21.22 * \frac{Q}{d^2}$$

Where 'Q' is the volume flow rate of fluid passing in lit/min. this can calculated using below equation;

$$q^1{}_h = 0.01361 * Sq\,rt\left(\frac{P^2 1 - P^2 2}{f L_m T S_g}\right) * d^5$$

Step 6: Erosion rate in mm/year is calculated using CFD is as shown in below;

Erosion pattern study:
Erosion mapping was performed for all the chokes opening combinations using CFX fluid flow. The operating field severe service conditions are created using the data's available.
The particle tracks were determined and sand particle impacts were applied at the choke internals in order to calculate the

erosion rates on the walls. Erosion rates were determined in terms of millimeter wall thickness reduction in the tungsten carbide sleeve downstream the choke.

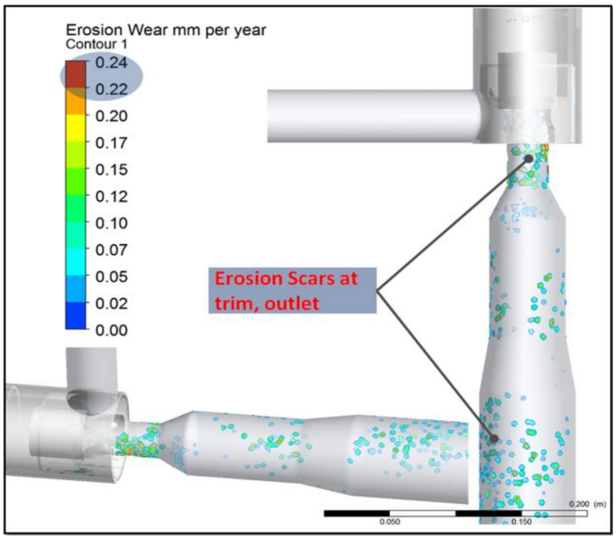

Fig. 6 Erosion Scar through choke valve

The erosion pattern reveals that the trim and outlet section of the choke experiences the sand particulate erosion scars is shown in all the figures. Erosion pattern also reveals that how particulate erosion occurs in chokes. The swirling fluid flow i.e. cris cross or non-parallel flow of natural gas fluid along with sand particles rotate and recirculate. Resulting in formation of small grooves along the trim to extent of outlet of choke called scars.

Step 7: Study of effect of Flow pattern & Sand size

Fluid mixed with sand particles when flowing through inner portions of the choke parts does not uniformly follow the shapes of the choke. The flow may discontinue at times through critical portions causes the sand particles stay at some portions and forms grooves. These small grooves formation also assisted by the non-parallel flow through choke outlet as shown in figure 11. The small grooves or scars at the choke shown in figure.

Sand particle studied in the present case study is 280 microns and the mass flow rate taken as 0.02g/s at room temperature conditions.

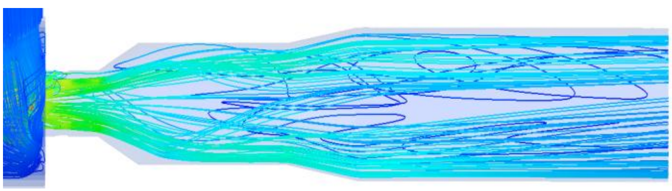

Fig. 11 Effect of flow pattern on Erosion Wear

Flow is not fully parallel. There is cri-cross or non-parallel flow observed in erosion of outlet of choke valve as shown in figure 11. Fluid + sand particle impingement at centre of trim portion of valve. These types of flow patterns observed higher erosion rates.

III. CONCLUSION

Erosion in choke valves operating either in top side or subsea field subjected to sandy severe service conditions are considered as problems in oil & gas industries.

1. Critical location of the choke valve is trim components subjected to higher pressure drop also experiences higher flow velocity causes erosion in choke valves.
2. Particulate erosion in mainly due to jet impingement of sand particles inside the trim components of choke. Higher velocity causes the jet impingement.
3. Sand erosion rate is higher with increased pressure drop in low percentage valve openings.
4. Fluid flow pattern and sand particle sizes, hardness also influences in erosion rate for choke valves.

IV. ACKNOWLEDGEMENT

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Table 1

Parameter	Units	Symbol
Pressure Drop	MPa	Δp
Specific Volume	M^3/Kg	$\forall$
Total resistant coefficient		K
Mass flow rate of Fluid	Kg/s	W
Inner dia of pipe	mm	d
Flow resistant due to pipe		K_1
Friction Factor		f
Pipe Length		L / L_m
Flow resistance due to elbows		K_2
Friction factor-elbows		F_T
Flow resistant due to valve		K_3
Diameter ratio		β
Density of fluid	Kg/m^3	Ø
Reynolds's Number		R_e
Velocity of fluid	m/s	v
Viscosity of fluid	cp	μ
Pressure at Inlet	MPa	P_1
Pressure at Outlet	MPa	P_2
Temperature	K	T
Specific Gravity		S_g