Typhoon Valve System

ONS 2018
Innovation Award Winner!

mokveld

typhonix
cleaner production
Why develop a low shear control system *(produced water)*

New fields
- Formation water ~5% of oil production

Mature fields -
- Formation water + Injection water ~ 500-5000m³/hr
- Formation water + Injection water + Produced water re-injection
  ~ 5-10 bbl water per bbl oil
Why develop a low shear control system (produced water)

Water produced during oil and gas extraction operations constitutes the industry’s most important waste stream on the basis of volume. The oil and gas industry produces approximately 14 billion bbl. of water annually. Produced water is most often considered a waste. Water handling practices must also be environmentally protective or the operator could face regulatory action.

Source: ALL Consulting LLC – Argonne National Laboratory & US D.O.E. 2004

What do we do with all this water?

- Water overboard in case offshore
- Evaporation ponds, agriculture, re-inject into wells in case onshore
Regulation (cleaner production)

Produced water requires treatment;
- To remove volatile organic compounds (toxicity)
- To remove solids, bacteria for PWRI to protect reservoir & equipment
- To manage scale, corrosion in piping systems (acidity)
- To meet environmental regulations (<30ppm OiW – OSPAR convention - BREF)

Improving the oil / water separation process
- reduces processing and operational costs
- increases production longevity of the well / platform
Gravity Based Separation (Stokes Law)

\[ v_t = \frac{g \cdot d_{\text{droplet}}^2 \cdot (\rho_c - \rho_d)}{18 \cdot \mu_c} [\text{m/s}] \]

\[ \frac{H}{v_t} = \frac{L_{\text{eff}}}{\nu_h} [\text{m/s}] \]

- \( d_{\text{droplet}} \) influences terminal velocity, \( v_t \), of dispersed droplet according to Stokes’ Law
- \( d_{\text{droplet}} \) influences separation efficiency (performance) of existing vessels
- \( d_{\text{droplet}} \) influences retention time (by definition of \( v_t \))
  Higher \( v_t \), shorter required retention time
  Less retention time \( \rightarrow \) more capacity
## Oil / Water Separation Technologies

<table>
<thead>
<tr>
<th>Separator Type</th>
<th>Technology</th>
<th>Droplet Size Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>API separator</td>
<td>Gravity</td>
<td>~ min. 150 µm</td>
</tr>
<tr>
<td>Corrugated Plate / Tilted Plate Interceptor</td>
<td>Gravity with coalesce</td>
<td>~ min. 40 – 50 µm</td>
</tr>
<tr>
<td>Horizontal IGF</td>
<td>Gas flotation (no flocculants)</td>
<td>~ min. 20 – 25 µm</td>
</tr>
<tr>
<td>Hydro-cyclones</td>
<td>Centrifugal Force</td>
<td>~ min. 10 – 15 µm</td>
</tr>
<tr>
<td>Horizontal IGF</td>
<td>Gas flotation (with flocculants)</td>
<td>~ min. 5 µm</td>
</tr>
<tr>
<td>Filtration</td>
<td>Adsorption / Barrier</td>
<td>&lt; 0.01 – 5 µm</td>
</tr>
</tbody>
</table>

Source: ALL Consulting LLC – Argonne National Laboratory & US D.O.E. 2004
Emulsions are more difficult to separate. Factors affecting stability of emulsions:

- Heavy polar material in the crude oil
- Fine solids including organics (asphaltenes, waxes) and inorganics (clays, scales, corrosion products)
- Temperature
- *Droplet size and droplet size distribution*
- pH of the brine
- Brine composition
- Surfactants

Emulsification (Increased production)
Droplet breakup caused by energy dissipation (viscous and inviscid/inertial shear forces)

Davies (1985)
\[ d_{\text{max}} = C^* \left( \frac{4 \sigma_{\text{interface}} + \eta_d u_{\text{in}}}{\rho_c} \right)^{3/5} \varepsilon^{-2/5} \]

Hinze (1955)
\[ d_{\text{max}} = \left( \frac{\text{We}_{\text{crit}}}{\rho_c} \right)^{3/5} \left( \frac{\sigma_{\text{interface}}}{\rho_c} \right)^{3/5} \varepsilon^{-2/5} \]

Kolmogorov scale (1949)
\[ \lambda_0 = \left( \eta^{3/4} \rho_c^{3/4} \varepsilon^{-1/4} \right) \]

\( \varepsilon \) = Mean energy dissipation rate per unit mass
\( \varepsilon = \dot{\varepsilon}/m \) where \( \dot{\varepsilon} \) is the turbulent energy dissipation rate, the rate at which the turbulence energy is absorbed by breaking the eddies down into smaller and smaller eddies until it is ultimately converted into heat by viscous forces (shear forces exerted on the fluid)
Kundu 1990: \( \dot{\varepsilon} = \Delta P \cdot Q \)
Droplet size reduced by shear forces

- Energy dissipation rate → break droplets
- Main energy dissipation developed in valves (energy dissipation)
- Choke and control valves degrade oil-water separation and we place them in front of separation vessels!
Shear Reduction

- Maximum stable droplet size in turbulence zone as defined by Hinze (1955);

\[ d_{\text{max}} = W_e^{3/5} \cdot \left( \frac{\sigma}{\rho_c} \right)^{3/5} \cdot \varepsilon^{-2/5} [m] \]

\( W_e_{\text{crit}} \): Weber Number is the ratio between the inertial force and the surface tension force

Hinze (1955) determined by experiments that \( W_e_{\text{crit}} \sim 0.725 \)

\( \sigma \): interfacial tension [N/m]

\( \rho_c \): density [kg/m³]

- Mean energy dissipation rate per unit mass, \( \varepsilon \);

\[ \varepsilon = \frac{\bar{E}}{m} \]

\( \bar{E} \): Turbulent energy dissipation rate, the rate at which the turbulence energy is absorbed by breaking the eddies down into smaller and smaller eddies until it is ultimately converted into heat by viscous forces (shear forces exerted on the fluid)

\[ \bar{E} = \Delta P \cdot Q \]

\( \Delta P \): pressure [Pa], \( Q \): flowrate [m³/s] [Kundu 1990]

\[ m = V_{\text{dis}} \cdot \rho_c \]

\( V \): [m³], \( \rho_c \): [kg/m³]

\[ \varepsilon = \frac{\Delta P \cdot Q}{\rho_c \cdot V_{\text{dis}}} \] [W/kg]
Typhoon Valve System

Conventional Valve

Energy Dissipation
small $V_{dis}$

Typhoon System

Energy Dissipation
is much larger $V_{dis}$

Standard valve(s)
medium volume

Other valve(s)
smallest volume

Axial Typhoon®
Largest active volume
Energy dissipation (production choke valve)
Typhoon Valve System (Laboratory Testing)
Typhoon Valve System (Laboratory Testing)

Prototype produced water testing

Typhoon Valve System was tested with produced water made up of 13 different North Sea crudes grades ranging from grades API 19 - 45

Conclusions:

• Systematic reduction of droplet break-up with all crudes
• Oil droplets are typically twice as large with Typhoon Valve System installed compared to conventional valve(s)
Typical droplet size distribution

Dv(x) on valve outlet typically 2 - 3 times larger with Typhoon System
OiW – 1000 ppm,
Q – 20 m³/h,
ΔP - 5 bar
Typhoon Valve System (Laboratory Testing)

OiW – 1000 ppm,
Q - 20 m³/h,
ΔP - 5 bar
Typical droplet size distribution

Results of the experiments with a North Sea crude oil. The experiments are performed with a water/oil mixture with an oil concentration of approximately 2000 ppm.

OiW – 1000 ppm,
Q = 20 m³/h,
ΔP = 5 bar
Droplet Breakup (Bimodal distribution)

Mohamed A. Siba, Wan Mohd Faizal Wan Mahmood, Mohd Z. Nuawi, Rasidi Rasani and Mohamed H. Nassir
International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS Vol.15 No:02
Typhoon Valve System (Multiphase Flow Testing)

Test at Multi Phase Flow Loop, 2009
Typhoon Valve System (Multiphase Flow Testing)

Test Results Multi Phase Flow Loop, 2009

Mokveld Typhoon System slide
Full scale erosion testing
Erosion testing at DNV/GL Flow Center

Typhoon® Valve at GL Flow Centre

Internals in erosion resistant materials tested by injecting 500kg of sand at gas velocities of >50m/s

- Zero weight loss in cage and venturi
Offshore Pilot Installation (conditions), 2012

Conditions:
• 50 - 55% WC
• 10 - 13 GLR u/s choke (actual)
• 72 - 78 bar dP at normal production
• 92 - 96 bar dP at reduced production

OiW = Oil in water concentration
WiO = Water in oil concentration
Dv(x) = Oil droplet size measurements
Challenging test conditions
Systematic improvement of water quality; 45%
Successful offshore installation of Typhoon® System on Statoil’s Troll C

Mokveld’s low shear Typhoon System has once again demonstrated the robustness of the technology. The system is installed on the Statoil operated Troll C platform controlling well fluids from the Fram Vest field. Operating at the most challenging conditions for which the unit is designed, the Typhoon System showed an impressive 60% improvement in the produced water quality (OiW) in comparison to the conventional choke valve that is installed in parallel with the unit.

Combined with the previously obtained improvements of 60-90% water quality during the prototype test and the 45% improvement in water quality during the pilot test on Statoil’s operated Oseberg C platform, the Typhoon System’s patented technology to reduce shear forces on dispersed liquids is unquestioned and unparalleled.

The low shear flow control Typhoon System, developed in cooperation with Typhonix AS, is the simplest and most cost efficient manner to improve separation of mixed liquids. No additional equipment, expensive modifications, high heat input, or chemicals are required. Just install the Mokveld Typhoon System in place of conventional choke or control valve technology and separation is improved.

With additional units being deployed in the near future in the Dutch sector of the North Sea and in the Gulf of Mexico, the low shear flow control Typhoon System results in cleaner production, enhanced separation processes and reduced chemical usage in the production of our energy needs today. One of the reasons why the sponsors Statoil, ENI, Total, Shell, Engie, ConocoPhillips and Petrobras embraced the development of this new technology.
Conclusion(s)

- Increased droplet size after pressure reduction in comparison to existing valve technology
- Complete droplet size distribution improves by a factor 2-3
- Both axial flow control valve as well as angle production choke valve give improvements on droplet sizes
- OiW concentration after separation decreases by 50% on average
- WiO concentration after separation decrease as well
- Longer economic field lifetime
- Less cost for chemicals, less heating of the emulsion
- Smaller vessels with same output quality, or same size vessel with higher flowrate
- Cleaner production and easy compliance to environmental regulations
Benefits - Separator Efficiency
(smaller separator liquid volume or higher liquid production)

\[ v_t = \frac{g \cdot d_{\text{droplet}}^2 \cdot (|\rho_c - \rho_d|)}{18 \cdot \mu_c} \]  
Stoke’s Law

\[ D_{\text{sep}} \cdot L_{\text{eff}} = C \cdot \frac{Q_c \cdot \mu_c}{(|\rho_c - \rho_d|) \cdot d_{\text{droplet}}^2} \]  
Droplet Settling Equation

Conclusion;
A conservative increase in droplet size of 15% will result in a possible increase of liquid production by 32% or a decrease of the effective liquid separation volume 24%
Benefits - Hydrocyclone Efficiency

20% increase in droplet size results in double efficiency of the hydrocyclone

Cyclotech – Separasjonsteknologi 2007, Stavanger
Benefits - Reduced chemical usage

6 CONCLUSION

This thesis is based on the results from the typhoon pilot test at Oseberg C. The work conducted has shown that the typhoon valve gives a significant positive effect on the produced water system. For estimations all choke valves are assumed to be typhoon valves. The most important findings during this work are:

Dispersed oil released with the produced water has been revived to be reduced by 55%. The reduction increases the amount of system upsets the facility can handle before the maximal OiW limit is reached.

When OiW concentrations in the produced water is reduced the need of flocculants are also reduced. A 55 % reduction was estimated, reducing the yearly use of flocculants by 36.7-110 ton. Indirect positive effects can be that an upgrade of the chemical system can be delayed or avoided. Reduction of dispersed oil and the amount of flocculent also reduces the EIF.
Benefits - Heating savings (fuel gas)

- One factor affecting stability of emulsions is temperature. Considering that the droplet size/distribution advantages of Typhoon technology would allow you to reduce the temperature of the fluids while maintaining the same quality of produced water, your savings on heating fuel can be calculated.

<table>
<thead>
<tr>
<th>Typhoon Fuel Gas Savings</th>
<th>Reduced Heating Requirements of the Emulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INPUT</strong></td>
<td><strong>Case 1</strong></td>
</tr>
<tr>
<td>Oil flow rate [m³/hr]</td>
<td>39.7 ~6000 bpd</td>
</tr>
<tr>
<td>Produced Water flow rate [m³/hr]</td>
<td>59.6 Watercut ~60%</td>
</tr>
<tr>
<td>Natural Gas flow rate [nm³/hr]</td>
<td>145.0 GOR ~20%</td>
</tr>
<tr>
<td>Operating temperature @ heater [degC]</td>
<td>50.0</td>
</tr>
<tr>
<td>Heating gas price [€/kWh]</td>
<td>0.041 (default € 0.0413) - <a href="http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do">Link</a></td>
</tr>
<tr>
<td>Specific Gravity oil [-]</td>
<td>0.845 ~API grade 38 = Brent</td>
</tr>
<tr>
<td>Specific Gravity produced water [-]</td>
<td>1.010</td>
</tr>
<tr>
<td>Molecular weight natural gas [-]</td>
<td>20.00</td>
</tr>
<tr>
<td>Temperature change [degC]</td>
<td>2.5</td>
</tr>
<tr>
<td>( c_p ) crude oil ([kJ/kg degK])</td>
<td>2.03 (default to ( c_p = (0.4352+0.001^{t degC})/4.1868 ) - TEMA standards)</td>
</tr>
<tr>
<td>( c_p ) produced water ([kJ/kg degK])</td>
<td>3.93 (default to ( c_p = 3.93 ))</td>
</tr>
<tr>
<td>( c_p ) natural gas ([kJ/kg degK])</td>
<td>2.34 (default to ( c_p = 2.34 ))</td>
</tr>
<tr>
<td>Heater efficiency [%]</td>
<td>75% (default to 75%)</td>
</tr>
</tbody>
</table>

**INTERMEDIATE CALCULATIONS**

| Oil flow rate [kg/day]    | 805116                                         |
| Produced water flow rate [kg/day] | 1444704                                 |
| Natural gas flow rate [kg/day] | 3105                                         |
| Oil heating energy requirement [kJ/day/K] | 1635541                                   |
| Produced water heating energy requirement [kJ/day/K] | 5677687                                  |
| Natural gas heating energy requirement [kJ/day/K] | 726                                |
| Heating energy requirement [kJ/day/K] | 7320494                                      |
| Total heater energy requirement [kJ/day/K] | 9760659                               |

**Results**

- Saving [€/day/degC]  € 112
- Typhoon Total Fuel Gas Savings [€/year]  € 102,179
The adsorbent can be easily overloaded with large concentrations of organics. The media also eventually becomes consumed with contaminants and must be disposed or regenerated using chemicals. Regeneration creates a liquid waste product that must be disposed. Media may require frequent replacement or regeneration depending on type and feedwater quality.

Benefits - Prolonged lifetime
(adsorption, filtration, membranes)
Typhoon® System Applications

Choke Valves

Level Control Valves
Typhoon Valve System

Other Publications relating to low shear

OTC-20029-MS
OTC-28660-MS
SPE OGF - SAVVY SEPARATOR SERIE, PART 5
WWW.LOWSHEARSCHOOL.COM

Thank you for your attention

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