Modelling and Optimization of Compact subsea separators

Fahad Matovu

Supervisor: Johannes Jäschke
Co-Supervisor: Sigurd Skogestad

NTNU

June 3, 2015

Outline

- Introduction
- Motivation
- Modelling of Separation units
- Optimization of system
- Results
- Conclusion
- References

Introduction

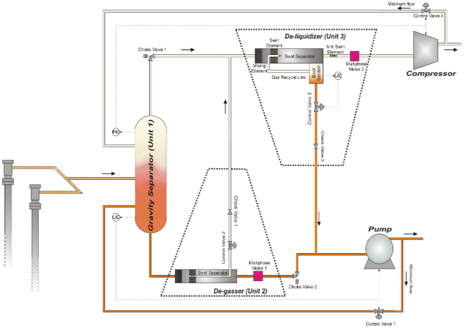


Figure: Compact separation system

[Ellingsen, 2007]

Introduction

- Compact systems-minimise space and weight while optimizing separation efficiencies.
- “Inline” technology-designed to have almost the same dimensions as the transport pipe.
- Use centrifugal forces thousands of times greater than gravitational forces used in conventional separators [Hamoud et.al, 2009].

Motivation;

- Application in existing installations makes increased production possible [FMCtechnologies, 2011].
- Reduced size and weight limits on space and load requirements thus reducing on associated costs.
- Applicable top-side and sub-sea due to small size.

Modelling of separation units

Aim: Predict phase separation and outlet flow rates and fractions based on known inlet conditions and separator geometry.

- Gravity separator
    - Inlet pipe entrainment
    - Droplet size distribution (Upper-limit log normal distribution)[Simmons M.J., Hanratty T.J., 2001]
    - Determine “critical” droplet size for separation
- Deliquidizer
    - Uniform droplet distribution
    - Radial settling velocity
    - Time of flight model
    - Separation efficiency
- Degasser-concepts similar to deliquidizer.

Optimization of the system

Aim: Maximize gas and liquid fractions to the compressor and pump respectively.

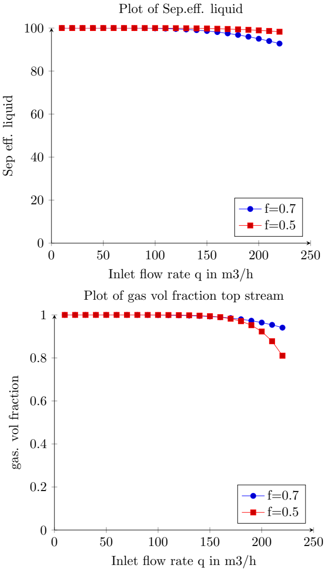
- 2 Degrees of freedom (split fractions on degasser and deliquidizer)
- Disturbance variables-Inlet flow rate and phase fraction.
- Output variables-Exit stream phase fractions and flow rates.

Optimization of the system

- Objective function $J = -0.5(f_7 + \beta_9)$
- Linear inequality constraints -split fractions between 0 and 1.
- Non-linear constraints -phase fractions ≤ 1 and flow rates ≥ 0.
- Optimization cases- Base case and 4 cases for sensitivity analysis.

Optimization done in Matlab using fmincon.

Results-Gravity separator

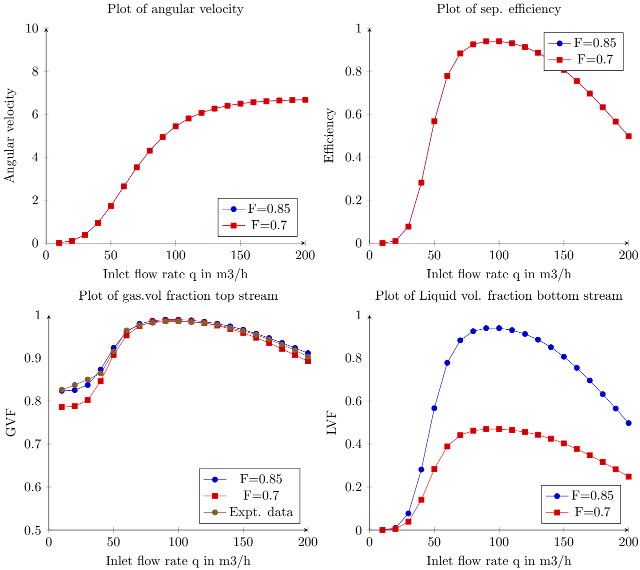


Results-Gravity separator

Explanation

- Low q, low gas velocity ug, high terminal velocity ut, high liq sep.eff
- $\uparrow$ q, $\uparrow$ ug $>$ ut, liq in gas and $\downarrow$ Gas vol fraction GVF.
- For gas, smaller rise velocity ur(high liq viscosity), high bottom liq velocity ul, gas in liq bottom stream, $\downarrow$ LVF bottom stream.
- Sep. eff drop more pronounced in gas. Gas low ur(high liq viscosity), liq high ut(low gas viscosity).
- Same q, $\downarrow$ inlet gas fraction f(0.7 to 0.5), $\uparrow$ gas entrainment, $\downarrow$ gas. sep eff. Bottom more gas thus $\downarrow$ in LVF and top less gas $\downarrow$ in GVF.

Results-Deliquidizer


Plot of angular velocity

Plot of sep. efficiency

Plot of gas.vol fraction top stream

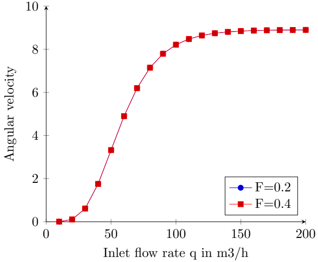
Plot of Liquid vol. fraction bottom stream

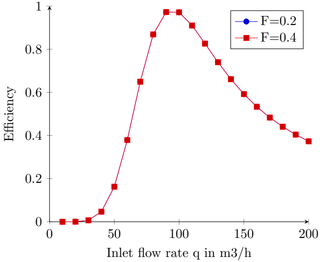
Results-Deliquidizer

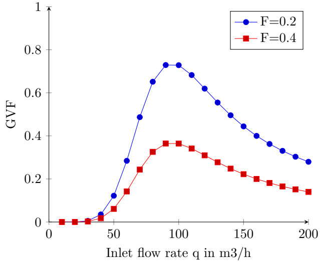
Explanation

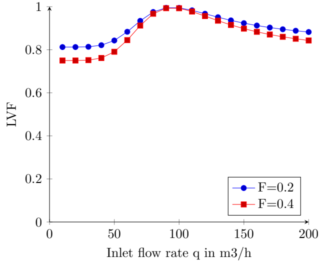
- Low q, low angular velocity w ,low radial velocity ur, low liq sep.eff.
- $\uparrow$ q, $\uparrow$ ur, $\uparrow$ in separation forces, $\uparrow$ in liq sep.eff and $\uparrow$ Gas vol fraction GVF. More liq sep, more liq in bottom and $\uparrow$ in LVF.
- Levelling off in angular velocity w, influence of mixup of separated phases(turbulence effects), same radial time bse no change in w, $\uparrow$ q, $\downarrow$ in droplet axial time, $\downarrow$ liq sep.eff, $\downarrow$ in GVF and LVF.
- Same q, split fraction top stream (0.85 to 0.7). Liq in top fixed(same sep eff), $\downarrow$ gas in top, $\downarrow$ GVF, more gas bottom stream, $\downarrow$ LVF.

Results-Degasser


Plot of angular velocity


Plot of sep. efficiency


Plot of gas.vol fraction top stream


Plot of Liquid vol. fraction bottom stream

Results-Degasser

Explanation

- Low q, low angular velocity w ,low radial velocity ur, low gas sep.eff.
- ↑ q, ↑ ur, ↑ in separation forces, ↑ in gas sep.eff and ↑ Gas vol fraction GVF. More gas sep, less gas in bottom and ↑ in LVF.
- Levelling off in angular velocity w, influence of mixup of separated phases(turbulence effects), same radial time bse no change in w, ↑ q, ↓ in bubble axial time, ↓ gas sep.eff, less gas to top, ↓ in GVF and LVF.
- Same q, split fraction top stream (0.2 to 0.4). gas in top fixed(same sep eff), ↑ liq in top, ↓ GVF, less liq bottom stream, ↓ LVF.

Optimization results

Table: Optimization results for the 5 different cases

Case2($+5\%\ q_1$), Case3($-5\%\ q_1$), Case4($+10\%\ f_1$) and Case5($-10\%\ f_1$)

Variable	Init. guess	Base-case	Case2	Case3	Case4	Case5
F1	0.2	0.3384	0.3898	0.2658	0.1327	0.3788
F2	0.6	0.9951	0.9939	0.9962	0.9937	0.9964
J	-	0.9748	0.9917	0.9483	0.8953	0.9877

Optimal performance indicates no liquid in top stream from degasser and no gas in bottom stream from deliquidizer.
An average of not more that 5% of undesirable phase in exit streams to the compressor and pump.

Sensitivity analysis

Relative sensivity $S_P^C = \frac{\partial C^{opt}/C^{opt}}{\partial P/P}$ [Edgar et.al, 1989].

Table: Sensitivity analysis

Cases	$S_{q_1}^{J}$	$S_{q_1}^{F1}$	$S_{q_1}^{F2}$	$S_{\alpha_1}^{J}$	$S_{\alpha_1}^{F1}$	$S_{\alpha_1}^{F2}$
Case2	0.35	3.04	-0.02	-	-	-
Case3	0.54	4.29	-0.02	-	-	-
Case4	-	-	-	-0.82	-6.08	-0.01
Case5	-	-	-	-0.13	-1.19	-0.01

Largest relative influence on optimal F1 by changes in q_1 and α_1

Conclusion

- Steady state models have been developed for predicting phase separation of gas and liquid phases and trends in results are in agreement with theoretical expectations.
- Optimization has been carried out. Results have shown an average of not more that 5% of dispersed phase in continuous phase in exit streams to the compressor and pump.

Shortcomings

- Lack of experimental data.

References

Christian Ellingsen (2007)
Compact sub sea separation: Implementation and comparison of two different control structures
Master Thesis, NTNU

A Hamoud(2009)
New application of an inline separation technology in a real wet gas field.
Saudi Aramco Journal of Technology.

FMCtechnologies (2011)
Compact total separation systems.

M.J.,Simmons,T.J.,Hanratty(2001)
Droplet size measurements in horizontal annular gas-liquid flow.
International Journal of Multiphase flow 27 (5), 861–883.

T.F., Edgar(1989)
Optimization of chemical processes.
McGraw-Hill.