JET PUMP PERFORMANCE IN LIQUID AND GAS PUMPING

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Jet pump

- Transfers momentum from power fluid $Q_P$ to suction liquid $Q_L$ (water and oil) and to suction gas $Q_G$ (natural gas)
Jet pumps in oil wells

- Robust tool for harsh environment
  - No moving parts
-Insensitive of pumped fluid (water, oil, natural gas, sand, …)
- Model includes
  - Pipes
  - Jet pump

Jet pump (water, oil, gas)
Feed water pump
Gas separation
0.5 - 3 km
Commercial software
jet pump and pipes (water, oil, natural gas)
Multiphase pipe flow

- Orkiszewski’s method for vertical pipe
  - Oil field specific
- Varying fluid properties including phase changes (natural gas)
History

- First documented jet pump 1858
  - Steam locomotive feed pump
- One-dimensional subsonic
  - Gosline and O’Brien (1934)
  - Cunningham (1969-1994)
- One-dimensional subsonic
- CFD

Steam locomotive jet pump image:
One-dimensional theory

• Compressible two-phase flow
• Conservation of mass, momentum and energy
• Equation of state, ideal gas
• Phase changes assumed negligible
• Losses modelled with minor loss coefficients

\[ \Delta p_f = \frac{1}{2} k \rho V^2 \]
Equations

\[ p_i - p_n = Z_n (1 + k_n) \]

\[ M (p_s - p_o) + p_s \phi_s \ln \left( \frac{p_s}{p_o} \right) - Z_n \frac{(SM + \gamma \phi_s)}{c^2} (1 + k_e) (M + \phi_o)^2 = 0 \]

\[ p_t^2 - Z_n [2b - b^2(2 + k_t)(1 + SM + \gamma \phi_s)(1 + M) + 2(SM + \gamma \phi_s)(M + \phi_o) \frac{b^2}{a - b} + \frac{p_o}{Z_n}] p_t \]

\[ + Z_n [b^2(2 + k_t)(1 + SM + \gamma \phi_s)p_s \phi_s] = 0 \]

\[ p_d - p_t + \frac{p_s \phi_s}{1 + M} \ln \left( \frac{p_d}{p_t} \right) = \]

\[ Z_n b^2 \left[ \frac{1 + SM + \gamma \phi_s}{1 + M} \right] [(1 + M \phi_t)^2 - a^2 (1 + M + \phi_d)^2 - k_d (1 + M + \phi_t)(1 + M)] \]
Jet exit pressure $p_n$

- Strongly non-one-dimensional flow in the circled area
- Jet exit pressure must be chosen
- $p_n = (1 - \theta)p_s + \theta p_o$
Results

Single-phase (water)

Two-phase (water-air)

Comparison of experimental data [5, 11, 14] with the one-dimensional theory and CFD results. In Fig. a water is pumped with water and in Fig. b air is pumped with water. ($sp = x/d_t$, see Fig. 1)
Conclusion

• One-dimensional theory gives excellent results if enough experimental data is available
  – Better loss correlations are needed
  – Better fluid property correlations are needed
• CFD is preferred if experimental knowledge is not available
Future research

Experimental work

General purpose multiphase flow program

More results
CFD

- Axisymmetric two-dimensional mesh
- Only one-phase case solved
- Easy to automatize and embed into existing one-dimensional code
- Extension to multiphase flow straightforward
- Accurate for one-phase incompressible flow
- Accuracy unknown for multiphase flow
Equations

\[ p_i + \frac{\rho_p v_i^2}{2} = p_n + \frac{\rho_p v_n^2}{2} + \frac{k_n \rho_p v_n^2}{2} \]

\[ \frac{dp}{\rho} + V dV + \frac{dp_f}{\rho} = 0 \]

\[ (p_o - p_t)A_t - \tau A_{wall} = \dot{m}_T V_{Tt} - \dot{m}_p V_{Pn} - \dot{m}_{LG} V_{To} \]

\[ \dot{m}_T - p_t + p_s \frac{Q_{Gs}}{Q_p + Q_L} \ln \left( \frac{p_d}{p_t} \right) = \]

\[ \frac{\dot{m}_T}{Q_p + Q_L} \left[ \frac{1}{2} A_t^2 \left( Q_p + Q_L + \frac{p_s}{p_t} Q_{Gs} \right)^2 - \frac{1}{2} A_d^2 \left( Q_p + Q_L + \frac{p_s}{p_d} Q_{Gs} \right)^2 \right] - \frac{k_d \dot{m}_T}{2A_t} \left[ Q_L + \frac{p_s}{p_t} Q_{Gs} \right] \]
Why jet pumps?

- Oil wells are deep and hard to access
  - Up to 3000 m deep
  - Remote locations
- Easy to adapt to drops in reservoir pressure