Hagedorn and Brown

Correlation overview

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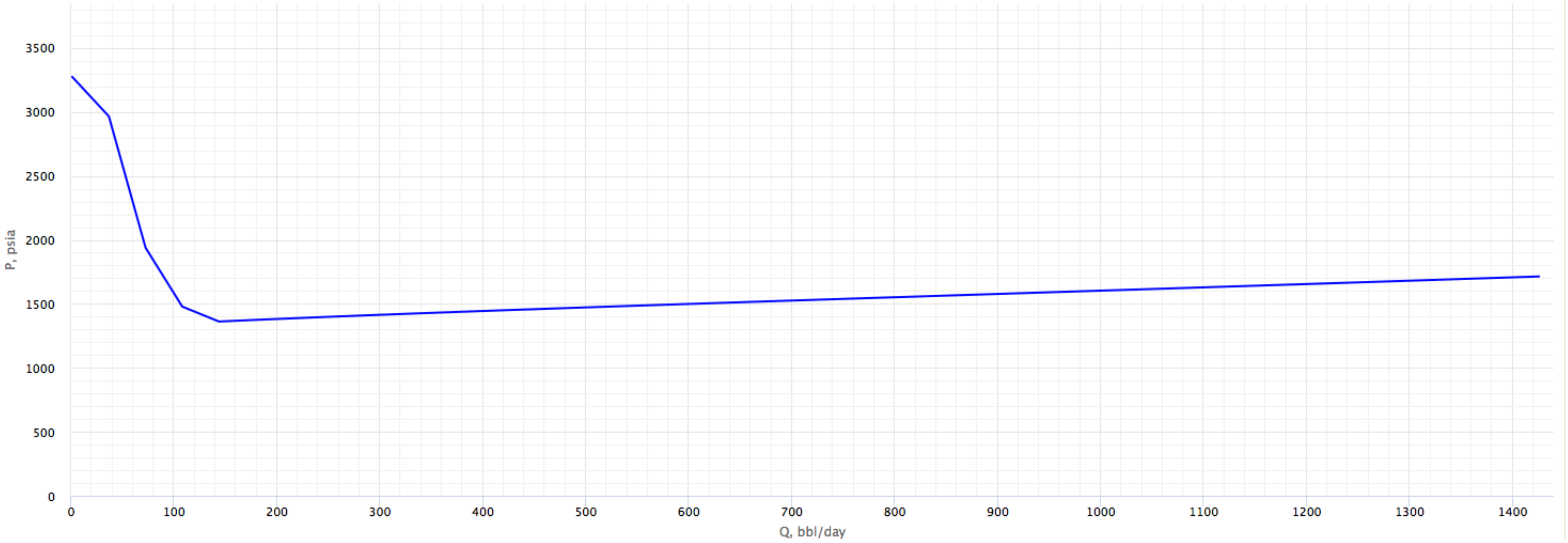
What is the Hagedorn and Brown correlation?

- Multi-phase flow correlation
- Typically used to calculate the VLP curves for the OIL wells
- *Hagedorn, A. R.; Brown, K. E. (1965). "Experimental study of pressure gradients occurring during continuous two-phase flow in small-diameter vertical conduits". Journal of Petroleum Technology. 17(04): 475–484.*

What is the VLP curve?

Vertical Lift Performance Curve :



relates how much pressure is required to lift the fluid to the surface

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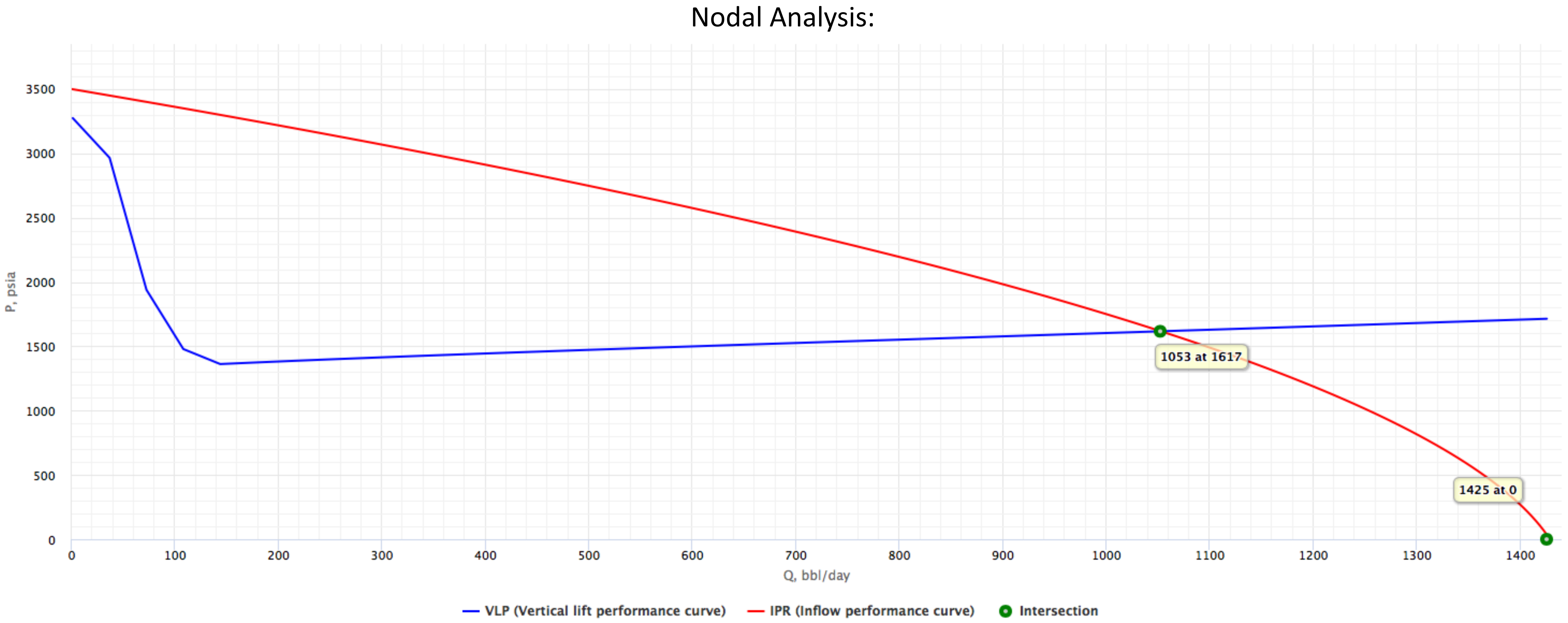
How do we use the VLP curve?



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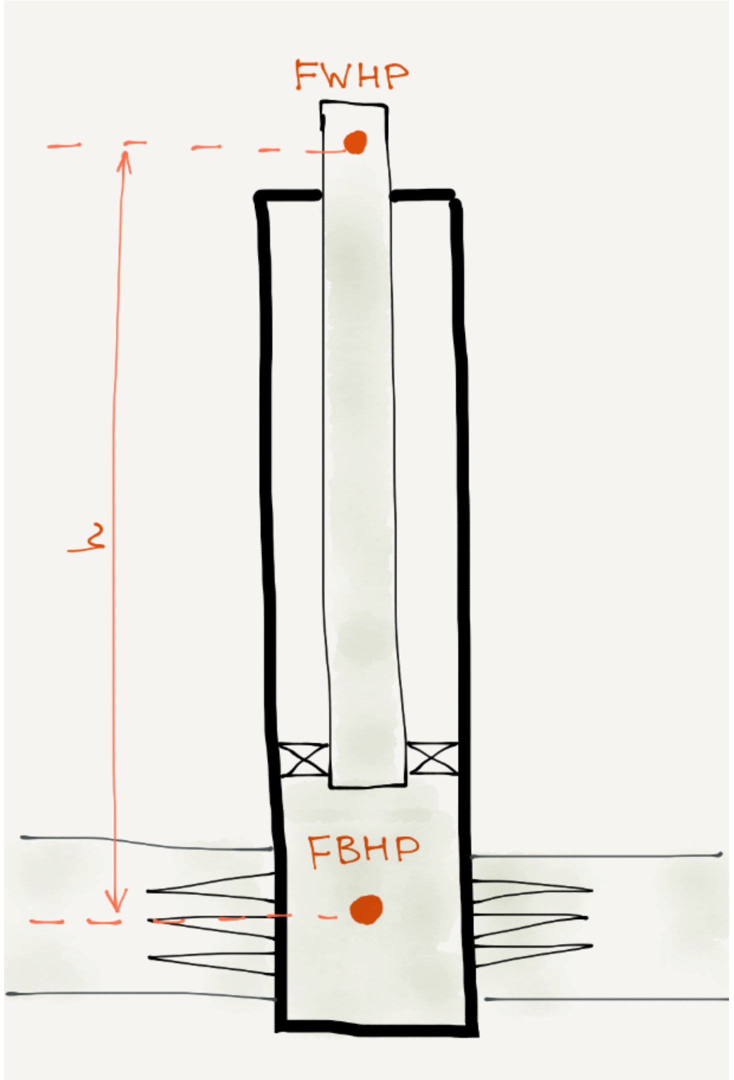
How to calculate the VLP curve?



$$\frac{dp}{dh} = \left(\frac{dp}{dh}\right)_{GRAVITY} + \left(\frac{dp}{dh}\right)_{FRICTION} + \left(\frac{dp}{dh}\right)_{KINETIC}$$

Hagedorn and Brown Math & Physics

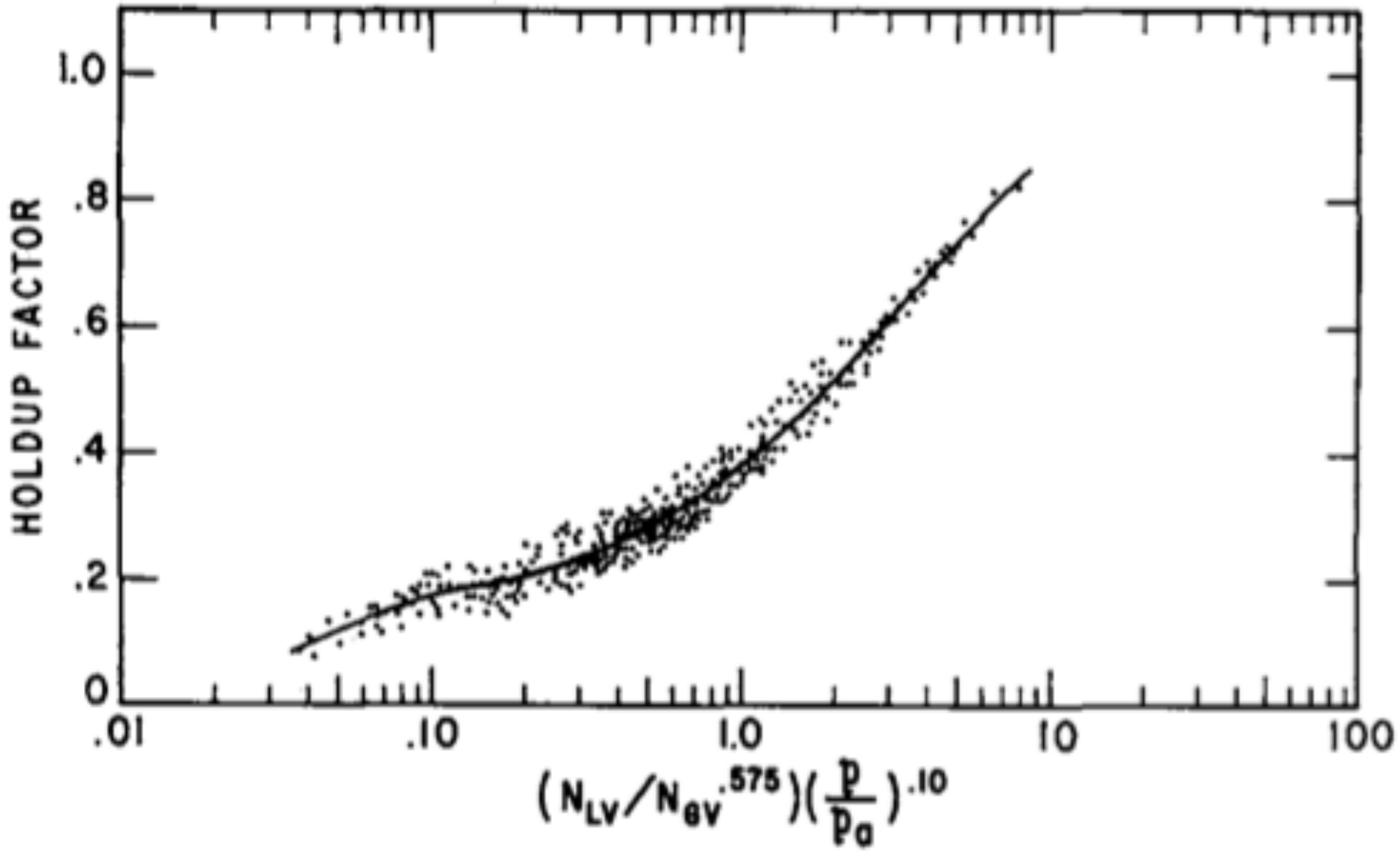
$$144\frac{\Delta p}{\Delta h} = \overline{\rho_m} + \frac{f\ q_L^2\ M^2}{2.9652 \times 10^{11}\ D^5 \overline{\rho_m}} + \overline{\rho_m}\frac{\Delta\left(\frac{v_m^2}{2g_c}\right)}{\Delta h}$$ [1]

$$\overline{\rho_m} = \rho_L H_L + \rho_g(1 - H_L)$$

[1] Hagedorn, A. R.; Brown, K. E. (1965). "Experimental study of pressure gradients occurring during continuous two-phase flow in small-diameter vertical conduits". Journal of Petroleum Technology. 17(04): 475–484.

Hagedorn and Brown - H_L

(1)

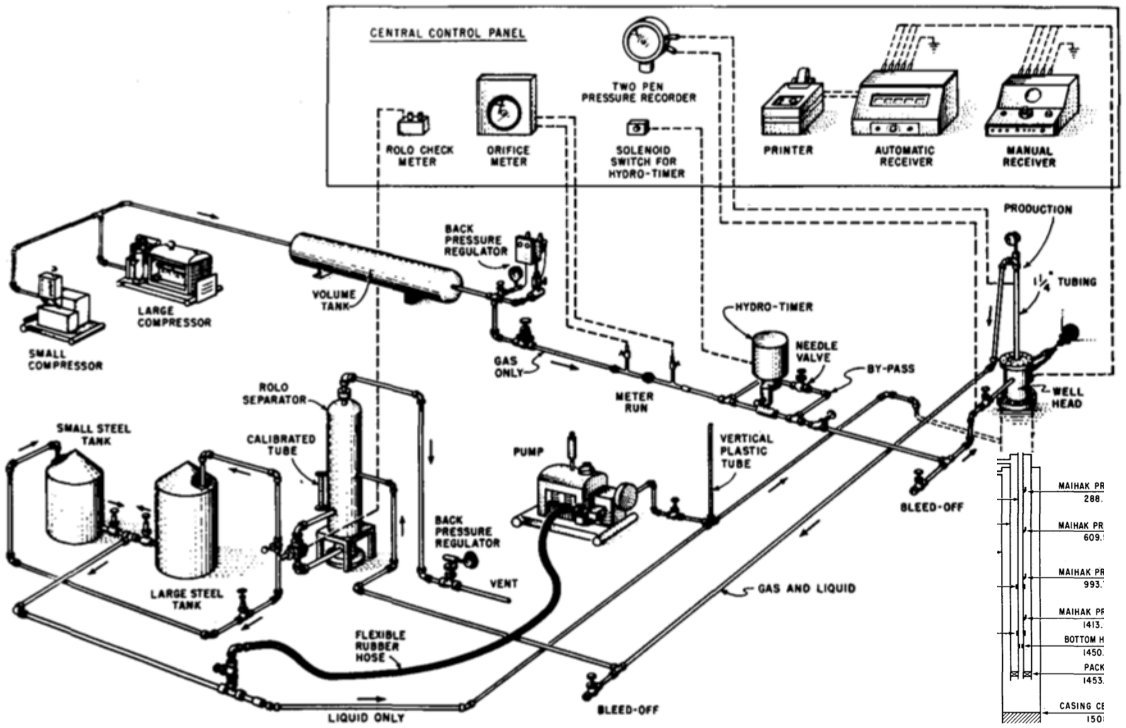


[1] Hagedorn, A. R.; Brown, K. E. (1965). "Experimental study of pressure gradients occurring during continuous two-phase flow in small-diameter vertical conduits". Journal of Petroleum Technology. 17(04): 475–484.

Hagedorn and Brown quick facts

- Test well in Dallas, TX
- Nominal pipe D: 1, 1¼, 1½ in
- Pipe length 1500 ft
- q_L was varied
- For each q_L GOR was varied as well
- Pressure gradient was measured
- 475 tests & 2905 pressure points
- Published in 1965

(1)



(1) Hagedorn, A. R.; Brown, K. E. (1965). "Experimental study of pressure gradients occurring during continuous two-phase flow in small-diameter vertical conduits". Journal of Petroleum Technology. 17(04): 475–484.

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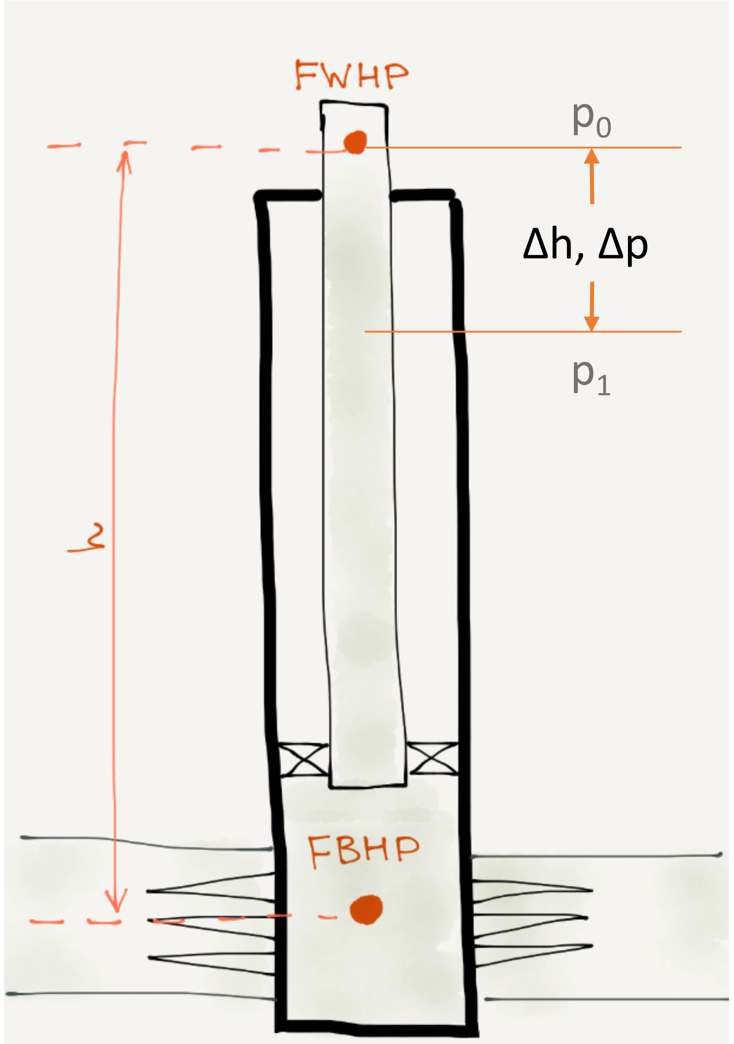
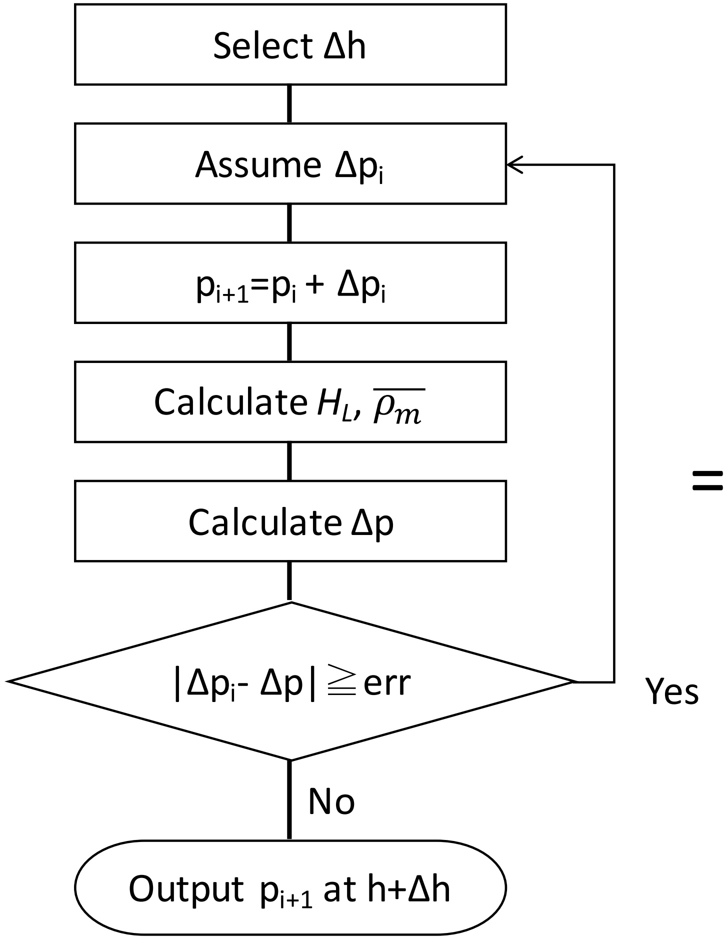
How it works?



$$\frac{dp}{dh} = \left(\frac{dp}{dh}\right)_{GRAVITY} + \left(\frac{dp}{dh}\right)_{FRICTION} + \left(\frac{dp}{dh}\right)_{KINETIC}$$

For each q_L

[0 to AOF]



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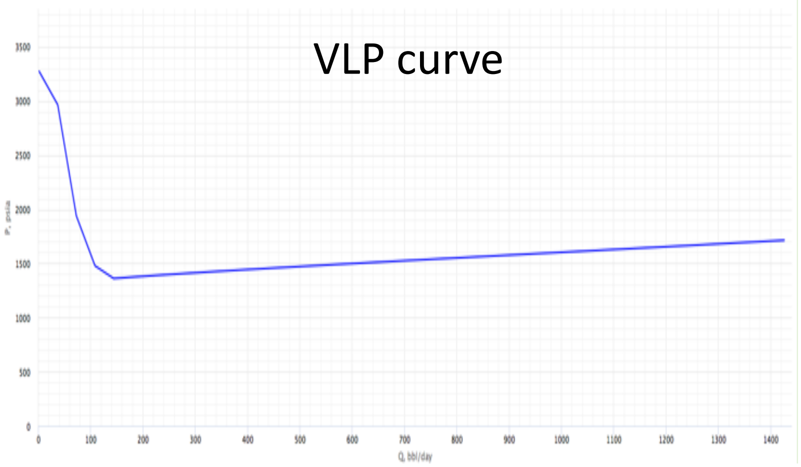

Finally, how to find H_L?

$$M = SG_o\ 350.52\ \frac{1}{1+WOR} + SG_w\ 350.52\ \frac{WOR}{1+WOR} + SG_g\ 0.0764\ GLR$$ [1]

$$\rho_L = \frac{62.4\ SG_o + \frac{Rs\ 0.0764\ SG_g}{5.614}}{B_o}\frac{1}{1+WOR} + 62.4\ SG_w\ \frac{WOR}{1+WOR}$$ [5]

$$\rho_g = \frac{28.967\ SG_g\ p}{z\ 10.732\ T_R}$$ [5]

$$\mu_L = \mu_o\frac{1}{1+WOR} + \mu_w\frac{WOR}{1+WOR}$$ [5]

$$\sigma_L = \sigma_o\frac{1}{1+WOR} + \sigma_w\frac{WOR}{1+WOR}$$ [5]

$$N_L = 0.15726\ \mu_L\sqrt[4]{\frac{1}{\rho_L\sigma_L^3}}$$ [1]

$$CN_L = 0.061\ N_L^3 - 0.0929\ N_L^2 + 0.0505\ N_L + 0.0019$$ [2]

$$v_{SL} = \frac{5.615q_L}{86400A_p}\left(B_o\frac{1}{1+WOR} + B_w\frac{WOR}{1+WOR}\right)$$ [5]

$$v_{SG} = \frac{q_L\left(GLR - R_s\left(\frac{1}{1+WOR}\right)\right)}{86400A_p}\ \frac{14.7}{p}\ \frac{T_K}{520}\ \frac{z}{1}$$ [5]

Well, it's a lot of equations :)

$$N_{LV} = 1.938\ v_{SL}\ \sqrt[4]{\frac{\rho_L}{\sigma_L}}$$ [1]

$$N_{GV} = 1.938\ v_{SG}\ \sqrt[4]{\frac{\rho_L}{\sigma_L}}$$ [1]

$$N_D = 120.872\ D\sqrt{\frac{\rho_L}{\sigma_L}}$$ [1]

$$H = \frac{N_{LV}}{N_{GV}^{0.575}}\ \left(\frac{p}{14.7}\right)^{0.1}\frac{CN_L}{N_D}$$ [2]

$$\frac{H_L}{\psi} = \sqrt{\frac{0.0047 + 1123.32H + 729489.64H^2}{1 + 1097.1566H + 722153.97H^2}}$$ [6]

$$B = \frac{N_{GV}N_{LV}^{0.38}}{N_D^{2.14}}$$ [2]

$$\psi = \begin{cases} 27170B^3 - 317.52B^2 + 0.5472B + 0.9999, & \text{if } B <= 0.025 \\ -533.33B^2 + 58.524B + 0.1171, & \text{if } B > 0.025 \\ 2.5714B + 1.5962, & \text{if } B > 0.055 \end{cases}$$ [6]

$$H_L = \frac{H_L}{\psi} \times \psi$$ [1]

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Summary

- Hagedorn and Brown correlation
- History and practical application
- Math & Physics
- Flow diagram to get the VLP curve
- Workflow to find H_L

What next?

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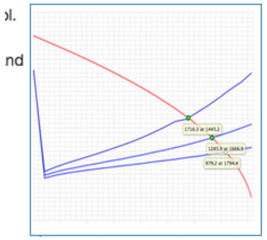

Thanks!

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