Introduction to Jet Pumps

A basic jet pump is a very simple device without any moving parts that utilizes a source of higher pressure

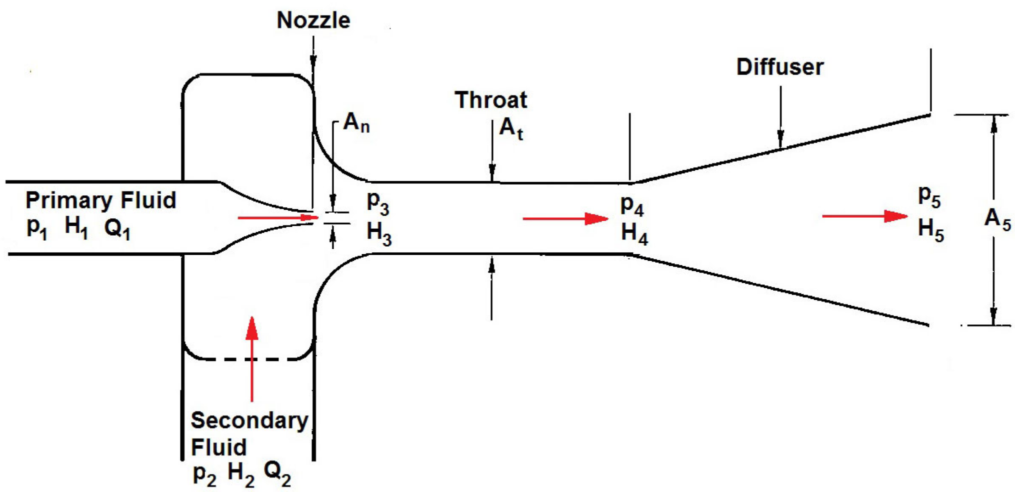

Figure 1: Basic jet pump geometry and notation.

fluid to pump a stream of another fluid that may be the same or different or a multiphase mixture. The basic components are depicted in Figure 1. The high velocity stream of primary fluid produced by the nozzle entrains and thereby pumps the stream of secondary fluid by utilizing the Venturi effect. Since there are no moving parts, the jet pump is very reliable and needs little maintenance. Moreover, it can be fitted into confined spaces where access is very difficult if not impossible. They are also useful for pumping heavy multiphase fluid mixtures such as occur in oil wells. As a result jet pumps have been used in a variety of technical contexts including inside nuclear reactor vessels and submerged in oil wells. Figure 2 exemplifies the deployment in an oil well.

The basic fluid mechanics of the jet pump were first expounded by Gosline and O'Brien (1934) (see also Mueller (1964)) and are presented in detail by Sanger (1968a, 1968b) and others. Conventionally, the one-dimensional notation and parameters of the flows are as follows. The cross-sectional areas of the nozzle flow and the mixing section are denoted by A_n and A_t respectively. The volume flow rates and total heads of the primary and secondary fluids (assumed incompressible) are denoted by Q_1 and Q_2 and H_1 and H_2 respectively. The discharge total head is denoted by H_5. Then the key non-dimensional parameters are defined as follows:

- Nozzle to throat area ratio = $A = A_n \ / \ A_t$
- Flow ratio = $M = Q_2 \ / \ Q_1$
- Head coefficient = $\psi \ (M) = (H_5 - H_2)/(H_1 - H_5)$
- Efficiency = $\eta = \psi M$
- Coefficient of pressure = $C_{px} = (p_i - p_2)/(\rho Q_1^2/2gA_n^2)$

where the fluid density is denoted by ρ and the fluid pressures at various locations, i ($i = 1, 2, 3, 4, 5$ respectively at the primary inlet, the secondary inlet, the throat inlet, the throat discharge and the diffuser

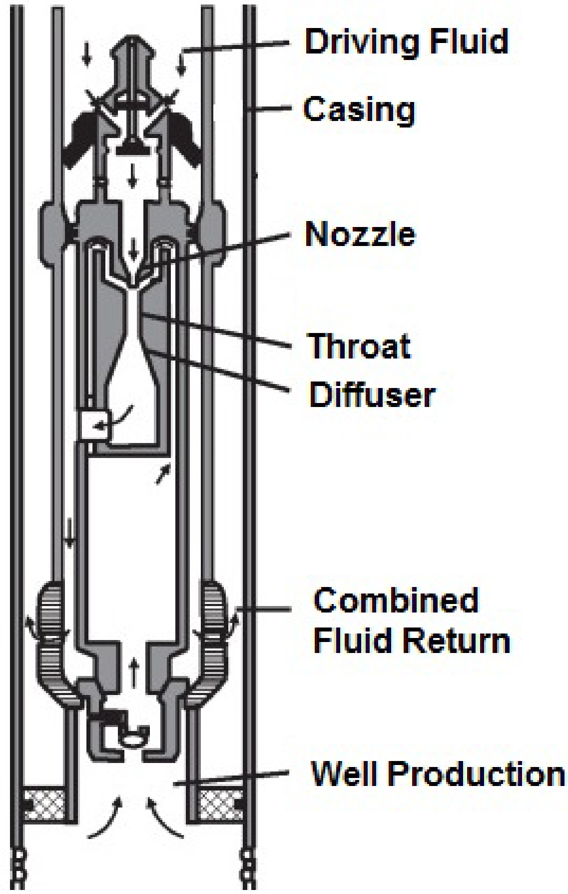

Figure 2: A deep oil well installation incorporating a jet pump. Adapted from Lea, Nickens and Wells (2008).

discharge). In addition, Sanger incorporated hydraulic loss coefficients for the flows as follows:

$$K_p = \left[(p_1 - p_n)/\rho Q_1^2/2gA_n^2\right] - 1 \tag{Mbh1}$$

$$K_s = \left[(p_2 - p_3)/\rho (Q_1 + Q_2)^2/2gA_t^2\right] - 1 \tag{Mbh2}$$

$$K_t = \left[(p_2 - p_4)/\rho (Q_1 + Q_2)^2/2gA_t^2\right] \tag{Mbh3}$$

$$K_d = \left[(p_4 - p_5)/\rho (Q_1 + Q_2)^2/2gA_t^2\right] \tag{Mbh4}$$

Then, by applying conventional one-dimensional flow analyses, Sanger obtained the following theoretical expression for the head coefficient, ψ:

$$\psi = \frac{\left[2R + \frac{2R^2M^2}{(1-R)} - (1 + K_t + K_d)R^2(1+M)^2 - \frac{(1+K_s)R^2M^2}{(1-R)^2}\right]}{\left[1 + K_p - 2R - \frac{2R^2M^2}{(1-R)} + R^2(1+M)^2(1 + K_t + K_d)\right]} \tag{Mbh5}$$

Sanger (1968a, 1968b) made a thorough experimental investgation of these loss coefficients and demonstrated that the theoretical performance represented by equation (Mbh5) was in good agreement with his performance measurements, a sample of which is presented in Figure 3.

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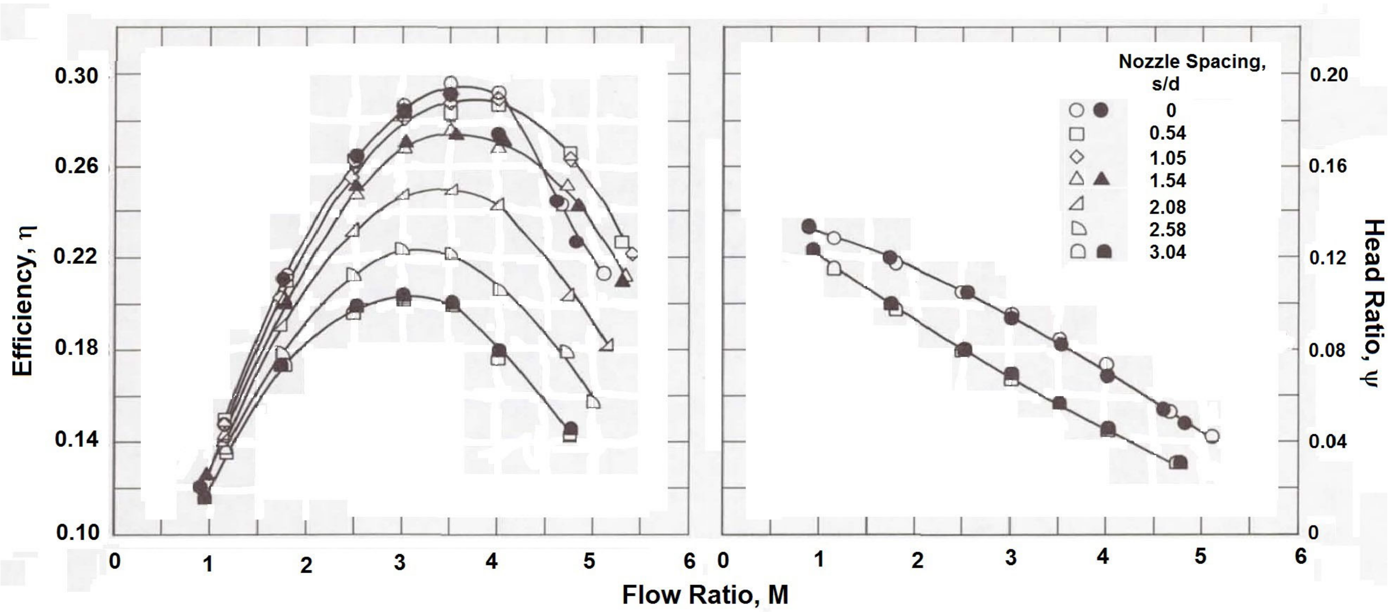

Figure 3: Typical jet pump performance curves from Sanger (1968a, 1968b): the head ratio, ψ, and efficiency, η, as a function of the flow ratio, M, for various relative locations of the nozzle (s/d) and two different flow rates (open and closed symbols).

Often jet pumps are combined with downstream centrifugal pumps in order to maximize efficiency and performance: a typical arrangement is shown in Figure 4 in which some portion of the discharge from the centrifugal pump is fed back to provide the primary flow for the jet pump.

This combination will operate most effectively in a particular range of jet pump flow ratios, M, as can be demonstrated as follows. Assuming that cavitation is absent, the centrifugal pump will yield a head coefficient, ψ_P, that is roughly linear with the flow coefficient, ϕ_P, in the vicinity of the design point (see section (Mbbe)). For convenience we will approximate this performance line by

$$\psi_P = C_1 - C_2\phi_P \tag{Mbh6}$$

where the constants C_1 and C_2 are assumed known. Correspondingly the performance of the jet pump can by approximated by a linear relation as demonstrated by Figure 3:

$$\psi = C_3 - C_4 M \tag{Mbh7}$$

where, again, as illustrated by Figure 3, the constants C_3 and C_4 are assumed known. Then, neglecting some of the minor hydraulic losses in the connecting pipes, it is readily shown that the overall head coefficient, ψ_C, for the combination is given by

$$\psi_C = \psi_P[1 + C_3 - C_4 M] - C_2\phi_P/M \tag{Mbh8}$$

where the same non-dimensionalizing factor is used in defining ψ_P and ψ_C. It follows from equation (Mbh8) that there is an optimal flow ratio for the jet pump given by

$$(M)_{optimal} = \left[\frac{C_2}{C_4}\frac{\phi_P}{\psi_P}\right]^{1/2} \tag{Mbh9}$$

As a numerical example, we use the data for a centrifugal pump shown in section (Mbbe) for which $\phi_P \approx 0.09$, $\psi_P \approx 0.35$ and $C_2 \approx 2.05 - 4.75$ depending on the volute geometry. Coupling this with the jet pump of Figure 3 for which $C_4 \approx 0.025$ yields

$$(M)_{optimal} \approx 4.5 - 7 \tag{Mbh10}$$

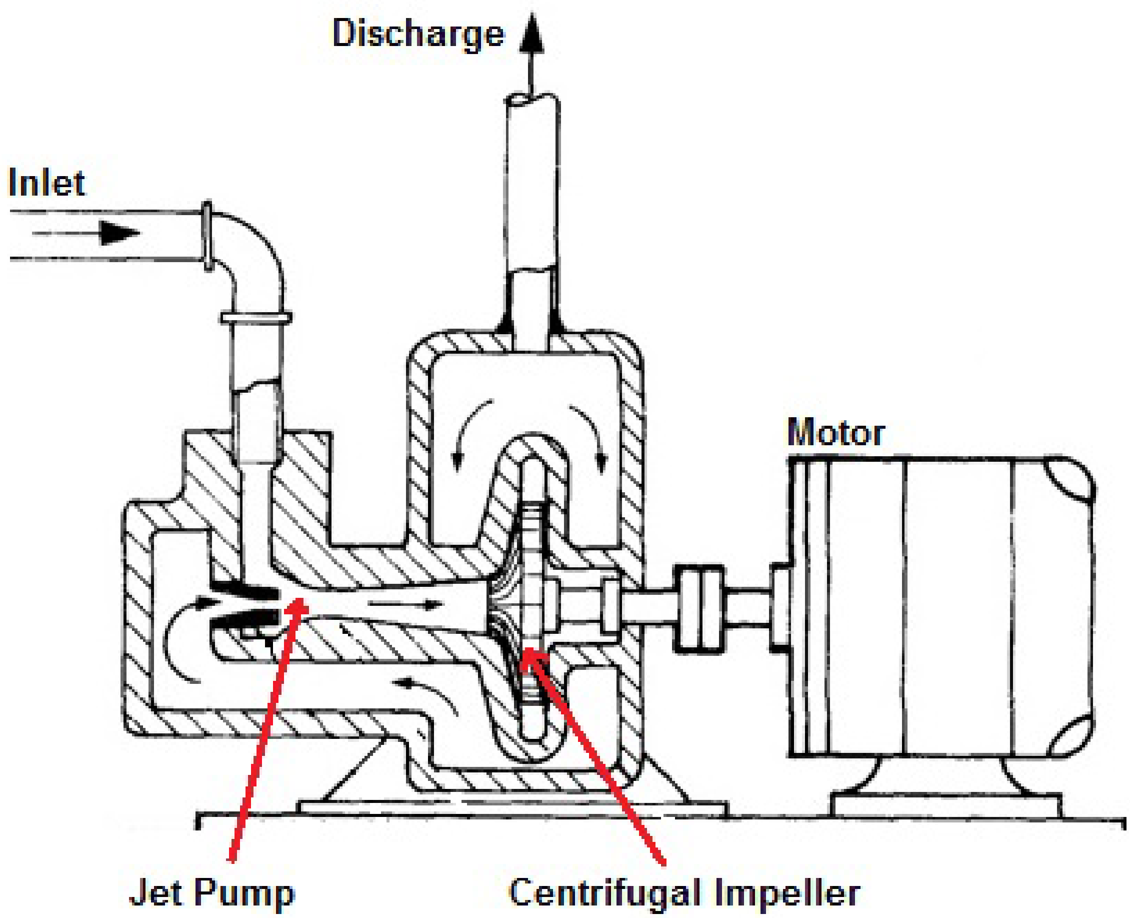

Figure 4: A typical combination of a jet pump with a centrifugal pump.

which implies that the combination performs best for the high values of the flow ratio, M.

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Cavitation can have a substantial effect on the performance of a jet pump (see, for example, Hansen and Na (1968), Sanger (1968b), Cunningham *et al.* (1970), Cunningham (1995)). As the pressure level is decreased or the jet velocity is increased, cavitation first occurs in the shear layer surrounding the jet. As the cavitation increases, the flow in the throat becomes choked and the performance of the jet pump declines. Consequently, cavitation limits the velocity of the jet and the flow ratio, M, at which the jet pump can operate. Cunningham (1995) reviews the criteria for that limiting flow ratio.