P.2.1. Sol 80

Power (P) $[ML^2T^{-3}]$

Density (ρ) $[ML^{-3}]$

r.p.m (N) $[T^{-1}]$

Diameter (D) $[L]$

gr. acc. (g) $[LT^{-2}]$

Head (H) $[L]$

$P = f(\rho, N, D, g, H)$

$P = k(\rho^a, N^b, D^c, g^d, H^e)$

$[ML^2T^{-3}] = [ML^{-3}]^a [T^{-1}]^b [L]^c [LT^{-2}]^d [L]^e$

for $M \Rightarrow 1 = a \Rightarrow a = 1$

for $T \Rightarrow -3 = -b - 2d \Rightarrow b = 3 - 2d$

for $L \Rightarrow 2 = -3a + c + d + e$

$c + d + e = 5 \Rightarrow c = 5 - d - e$

$P = k(\rho^1, N^{3-2d}, D^{5-d-e}, g^d, H^e)$

$P = (\rho N^3 D^5) k \left[\left(\frac{g}{N^2 D}\right)^d, \left(\frac{H}{D}\right)^e\right]$

$P = (\rho N^3 D^5) f\left[\frac{g}{N^2 D}, \frac{H}{D}\right]$

multiple $\frac{N^2 D^2}{g H}$ since it is dimensionless group

$P = (\rho N^3 D^5) \cdot f\left[\frac{D}{H}, \frac{N^2 D}{g}\right]$

$\therefore P = (\rho N^3 D^5) f\left[\frac{N^2 D^2}{gH}\right]$

P.4.16. sol:-

$$\phi Re^2 = \frac{-\Delta P d^3 \rho}{4 L \mu^2}$$

$$= \frac{(8000)(0.025)^3(1000)}{(4)(5)(1\times10^{-3})^2} = 6.25\times10^6$$

from 3-8 $\Rightarrow Re = 5\times10^4$

$$u = \frac{(5\times10^4)(1\times10^{-3})}{(1000)(0.025)} = 2 m/s$$

$$Q = \frac{2\pi}{4}(0.025)^2 = 0.982\times10^{-4} m^3/s$$

$$\text{total } Q = \frac{11(1000)}{(1000)(3600)} = 0.3056 m^3/s$$

$$\text{no. of tubes req.} = \frac{0.3056}{0.982\times10^{-4}} = 31.1 \text{ tubes}$$

velocity of fluid if 10% are blocked

$$= \frac{2}{0.9} = 2.22 m/s$$

$$Re = \frac{5\times10^4}{0.9} = 5.5\times10^4$$

from 3-7 $\phi = 0.00245$

$$\Delta P = (4)(0.00245)\left(\frac{5}{0.025}\right)(1000)(2.22)^2$$

$$= 9650 Pa$$

P. 2.2.Sol:-

Resistance(R)	$[ML^{-1}T^{-2}]$
velocity (u)	$[LT^{-1}]$
length (L)	$[L]$
viscosity (μ)	$[ML^{-1}T^{-1}]$
Density (ρ)	$[ML^{-3}]$
gr. acc. (g)	$[LT^{-2}]$

$R = f(u, L, \mu, \rho, g)$

$R = K(u^a, L^b, \mu^c, \rho^d, g^e)$

$[MLT^{-2}] = [LT^{-1}]^a [L]^b [ML^{-1}T^{-1}]^c [ML^{-3}]^d [LT^{-2}]^e$

for M $\Rightarrow 1 = c + d \Rightarrow c = 1 - d$

for T $\Rightarrow -2 = -a - c - 2e \Rightarrow a = 2 - c - 2e$

$a = 1 + d - 2e$

for L $\Rightarrow 1 = a + b - c - 3d + e$

$b = c + d + 1 \Rightarrow b = 1 + d + e$

$R = K(u^{1+d-2e}, L^{1+d+e}, \mu^{1-d}, \rho^d, g^e)$

$R = (uL\mu)K\left[\left(\frac{u\rho}{\mu}\right)^d, \left(\frac{gL}{u^2}\right)^e\right]$

$R = (uL\mu)f\left[\frac{u\rho}{\mu}, \frac{gL}{u^2}\right]$

$(L^3 T^{-1}) = (L)^a (L)^b (ML^{-3})^c (MT^{-1}L^{-})^d (LT^{-2})^e$

For m $\Rightarrow 0 = c + d \Longrightarrow \boxed{c = -d}$

For L $\Rightarrow 3 = a + b - 3c - d + e$

For T $\Rightarrow -1 = -d - 2e \Longrightarrow \boxed{d = 1 - 2e} \Rightarrow$

$2e = -d + 1 \Rightarrow e \boxed{= \frac{-d}{2} + \frac{1}{2}}$

$3 = a + b + 3d - 1 + 2e$

$a = 3 - b - 3d + 1 - 2e$

$a = 4 - b - 3d - 2e$

$h, D^{\frac{7}{2}} \cdot D^{-a} \cdot D^{-\frac{1}{2}}, \rho^{-d}, \mu^{d}, g^{\frac{1}{2}} \cdot g^{-\frac{1}{2}})$

Q. 2.3. Sol^{n}:-

Discharge (Q) $[L^3T^{-1}]$

Head (h) $[L]$

Diameter (d) $[L]$

Density (ρ) $[ML^{-3}]$

Viscosity (μ) $[ML^{-1}T^{-1}]$

gr. acc. (g) $[LT^{-2}]$

$Q = f(h, d, \rho, \mu, g)$

$Q = K(h^a, d^b, \rho^c, \mu^d, g^e)$

$[L^3T^{-1}] = [L]^a[L]^b[ML^{-3}]^c[ML^{-1}T^{-1}]^d[LT^{-2}]^e$

for $M \Rightarrow 0 = c + d \Rightarrow c = -d$

for $T \Rightarrow -1 = -d - 2e \Rightarrow e = +\frac{1}{2} - \frac{d}{2}$

for $L \Rightarrow 3 = a + b - 3c - d + e$

$b = \frac{7}{2} - a - \frac{3d}{2}$

$Q = K(h^a, D^{\frac{7}{2}-a-\frac{3d}{2}}, D^{-d}, \mu^d, g^{+\frac{1}{2}-\frac{d}{2}})$

$Q = (D)^{\frac{7}{2}}(g^{\frac{1}{2}})K\left[\left(\frac{\mu}{D^{\frac{3}{2}}\rho g^{\frac{1}{2}}}\right)^d, \left(\frac{h}{D}\right)^a\right]$

$Q = (D)^{\frac{7}{2}}\sqrt{g}\, f\left[\left(\frac{\mu}{D^{\frac{3}{2}}\rho g^{\frac{1}{2}}}\right), \left(\frac{h}{D}\right)\right]$

P.2.4. Sol:-

Force (F) $[MLT^{-2}]$
length (L) $[L]$
Velocity (V) $[LT^{-1}]$
Viscosity (μ) $[ML^{-1}T^{-1}]$
Density (ρ) $[ML^{-3}]$

$(\varepsilon) = -V\frac{dP}{dV} = (L^3)(ML^{-1}T^{-2})(L^{-3}) = [ML^{-1}T^{-2}]$

$n = 6,\ m = 3,\ \pi = n - m = 3$

no. of repeating vars. $= 3 = m$

repeating vars. (V, ρ, L)

$F = K(L, V, \mu, \rho, \varepsilon)$

$f(F, L, V, \mu, \rho, \varepsilon) = 0$

$\pi_1 = V^{a_1}\rho^{b_1}L^{c_1}F$

$\pi_2 = V^{a_2}\rho^{b_2}L^{c_2}\mu$

$\pi_3 = V^{a_3}\rho^{b_3}L^{c_3}\varepsilon$

for $\pi_1 \Rightarrow [M^0L^0T^0] = [LT^{-1}]^{a_1}[ML^{-3}]^{b_1}[L]^{c_1}[MLT^{-2}]$

for $M \Rightarrow 0 = b_1 + 1 \Rightarrow b_1 = -1$

for $T \Rightarrow 0 = -a_1 - 2 \Rightarrow a_1 = -2$

for $L \Rightarrow 0 = -a_1 + c_1 - 3b_1 + 1 \Rightarrow c_1 = -2$

$\therefore \pi_1 = V^{-2}\rho^{-1}L^{-2}F \Rightarrow \pi_1 = \frac{F}{V^2\rho L^2}$

for $\pi_2 \Rightarrow [M^0L^0T^0] = [LT^{-1}]^{a_2}[ML^{-3}]^{b_2}[L]^{c_2}[ML^{-1}T^{-1}]$

for $M \Rightarrow 0 = b_2 + 1 \Rightarrow b_2 = -1$

for $T \Rightarrow 0 = -a_2 - 1 \Rightarrow a_2 = -1$

for $L \Rightarrow 0 = a_2 - 3b_2 + c_2 - 1 \Rightarrow c_2 = -1$

$\therefore \pi_2 = V^{-1}\rho^{-1}L^{-1}\mu \Rightarrow \pi_2 = \frac{\mu}{V\rho L}$

for $\pi_3 \Rightarrow [M^0L^0T^0] = [LT^{-1}]^{a_3}[ML^{-3}]^{b_3}[L]^{c_3}[ML^{-1}T^{-2}]$

for $M \Rightarrow 0 = b_3 + 1 \Rightarrow b_3 = -1$

for $T \Rightarrow 0 = -a_3 - 2 \Rightarrow a_3 = -2$

for $L \Rightarrow 0 = a_3 - 3b_3 + c_3 - 1 \Rightarrow c_3 = 0$

$\pi_3 = V^{-2}\rho^{-1}L^0\varepsilon \Rightarrow \pi_3 = \frac{\varepsilon}{V^2\rho}$

since $f(\Pi_1, \Pi_2, \Pi_3) = 0$

$\therefore f\left(\frac{F}{\omega^2 \rho L^2}, \frac{\mu}{\omega \rho L}, \frac{\varepsilon}{\omega^3 \rho}\right)$

$F = \rho L^2 \omega^2 f\left[\left(\frac{\mu}{\omega \rho}\right), \left(\frac{\varepsilon}{\omega^3 \rho}\right)\right]$.

التحليل بالأبعاد الوحدات

P.2.5.Sol

Efficiency (η) $[M^0L^0T^0]$

Density (ρ) $[ML^{-3}]$

Viscosity (μ) $[ML^{-1}T^{-1}]$

Velocity (ω) $[T^{-1}]$

Diameter (D) $[L]$

Discharge (Q) $[L^3T^{-1}]$

$\eta = K(\rho, \mu, \omega, D, Q)$

$f(\eta, \rho, \mu, \omega, D, Q) = 0$

$n = 6, m = 3, \pi = n - m = 3$

no. of repeating var. $= 3 = m$

repeating vars. (ω, D, ρ) ، والباقي

$\pi_1 = \omega^{a_1} D^{b_1} \rho^{c_1} \eta$

$\pi_2 = \omega^{a_2} D^{b_2} \rho^{c_2} \mu$

$\pi_3 = \omega^{a_3} D^{b_3} \rho^{c_3} Q$

For $\pi_1 \Rightarrow [M^0L^0T^0] = [T^{-1}]^{a_1}[L]^{b_1}[ML^{-3}]^{c_1}[M^0L^0T^0]$

for $M \Rightarrow 0 = c_1 \Rightarrow c_1 = 0$

for $T \Rightarrow 0 = -a_1 \Rightarrow a_1 = 0$

for $L \Rightarrow 0 = b_1 - 3c_1 \Rightarrow c_1 = 0$

$\therefore \pi_1 = \omega^0 D^0 \rho^0 \eta \Rightarrow \pi_1 = \eta$

for $\pi_2 \Rightarrow [M^0L^0T^0] = [T^{-1}]^{a_2}[L]^{b_2}[ML^{-3}]^{c_2}[ML^{-1}T^{-1}]$

for $M \Rightarrow 0 = c_2 + 1 \Rightarrow c_2 = -1$

for $T \Rightarrow 0 = -a_2 - 1 \Rightarrow a_2 = -1$

for $L \Rightarrow 0 = b_2 - 3c_2 - 1 \Rightarrow b_2 = -2$

$\therefore \pi_2 = \omega^{-1} D^{-2} \rho^{-1} \mu \Rightarrow \pi_2 = \frac{\mu}{D^2 \omega \rho}$

for $\pi_3 \Rightarrow [M^0L^0T^0] = [T^{-1}]^{a_3}[L]^{b_3}[ML^{-3}]^{c_3}[L^3T^{-1}]$

for $M \Rightarrow 0 = c_3 \Rightarrow c_3 = 0$, for $T \Rightarrow 0 = -a_3 - 1 \Rightarrow a_3 = -1$

for $L \Rightarrow 0 = b_3 - 3c_3 + 3 \Rightarrow b_3 = -3$

$\therefore \pi_3 = \omega^{-1} D^{-3} \rho^0 Q \Rightarrow \pi_3 = \frac{Q}{\omega D^3}$

$f(\pi_1, \pi_2, \pi_3) \Rightarrow f\left(\eta, \frac{\mu}{D^2 \omega \rho}, \frac{Q}{\omega D^3}\right)$

$$\eta = f\left[\left(\frac{\mu}{\rho \omega D^2}\right), \left(\frac{Q}{\omega D^3}\right)\right].$$

P.2.6. Sol:-

pressure drop (ΔP) $[ML^{-1}T^{-2}]$	$\frac{\Delta P}{L}$
velocity (u) $[LT^{-1}]$	
length (l) $[L]$	
Diameter (D) $[L]$	ρa
Viscosity (μ) $[ML^{-1}T^{-1}]$	
roughness (e) $[L]$	$\Rightarrow h\ \rho\ g$

$\Delta P = K(u, L, D, \rho, \mu, e)$

$f(\Delta P, u, L, D, \rho, \mu, e) = 0$

$\frac{m}{1}\ \frac{kg}{m^3}\ \frac{m}{s^2}$

$n = 7,\ m = 3 \Rightarrow \pi = n - m = 4$

no. of repeating vars. $= 3 = m$

repeating vars. (u, ρ, L)

$\frac{kg}{ML^{-1}T^{-2}}$

$\pi_1 = u^{a_1} \rho^{b_1} L^{c_1} \Delta P$

$\pi_2 = u^{a_2} \rho^{b_2} L^{c_2} D$

$\pi_3 = u^{a_3} \rho^{b_3} L^{c_3} \mu$

$\pi_4 = u^{a_4} \rho^{b_4} L^{c_4} e$

for $\pi_1 \Rightarrow [M^0L^0T^0] = [LT^{-1}]^{a_1}[ML^{-3}]^{b_1}[L]^{c_1}[ML^{-1}T^{-2}]$

for $M \Rightarrow 0 = b_1 + 1 \Rightarrow b = -1$, for $T \Rightarrow 0 = -a_1 - 2 \Rightarrow a_1 = -2$

for $L \Rightarrow 0 = a_1 - 3b_1 + c_1 - 1 \Rightarrow c_1 = 0$

$\therefore \pi_1 = u^{-2} \rho^{-1} L^0 \Delta P \Rightarrow \pi_1 = \frac{\Delta P}{u^2 \rho}$

for $\pi_2 \Rightarrow [M^0L^0T^0] = [LT^{-1}]^{a_2}[ML^{-3}]^{b_2}[1]^{c_2}[L]$

for $M \Rightarrow 0 = b_2$, for $T \Rightarrow 0 = -a_2 \Rightarrow a_2 = 0$

for $L \Rightarrow 0 = a_2 - 3b_2 + c_2 + 1 \Rightarrow c_2 = -1$

$\therefore \pi_2 = u^0 \rho^0 L^{-1} D \Rightarrow \pi_2 = \frac{D}{L}$

for $\pi_3 \Rightarrow [M^0L^0T^0] = [LT^{-1}]^{a_3}[ML^{-3}]^{b_3}[L]^{c_3}[ML^{-1}T^{-1}]$

for $M \Rightarrow 0 = b_3 + 1 \Rightarrow b_3 = -1$

for $T \Rightarrow 0 = -a_3 - 1 \Rightarrow a_3 = -1$

for $L \Rightarrow 0 = a_3 - 3b_3 + c_3 - 1 \Rightarrow c_3 = -1$

$\therefore \pi_3 = u^{-1} \rho^{-1} L^{-1} \mu \Rightarrow \pi_3 = \frac{\mu}{uPL}$

for $\pi_4 \Rightarrow [M^0L^0T^0] = [LT^{-1}]^{a_4}[ML^{-3}]^{b_4}[L]^{c_4}[L]$

for $M \Rightarrow 0 = b_4$, for $T \Rightarrow 0 = -a_4 \Rightarrow a_4 = 0$

for $L \Rightarrow 0 = a_4 - 3b_4 + c_4 + 1 \Rightarrow c_4 = -1$

$\pi_4 = u^0 \rho^0 L^{-1} e \Rightarrow \pi_4 = \frac{e}{L}$

$f(\pi_1, \pi_2, \pi_3, \pi_4) = 0$

$f\left(\frac{\Delta P}{u^2 \rho}, \frac{D}{L}, \frac{\mu}{u \rho L}, \frac{e}{L}\right) = 0$

$\Delta P = u^2 \rho f\left[\left(\frac{D}{L}\right)\left(\frac{\mu}{u \rho L}\right)\left(\frac{e}{L}\right)\right]$

2.6

head (h_f) $[L]$, Fanning friction factor f $[M^0 L^0 T^0]$

Length (L) $[L]$

Diameter (d) $[L]$

Velocity (u) $[LT^{-1}]$

gr. acc. (g) $[LT^{-2}]$

$h_f = K(f, L, d, u, g)$

$f(h_f, f, L, d, u, g) = 0$

$n = 6, m = 2, \pi = 6 - 2 = 4$

no. of repeating vars. $= 2 = m$

Selected repeating vars. (u, L)

$\pi_1 = u^{a_1} L^{b_1} h_f$

$\pi_2 = u^{a_2} L^{b_2} f$

$\pi_3 = u^{a_3} L^{b_3} d$

$\pi_4 = u^{a_4} L^{b_4} g$

for $\pi_1 \Rightarrow [M^0 L^0 T^0] = [LT^{-1}]^{a_1} [L]^{b_1} [L]$

for $T \Rightarrow 0 = -a_1 \Rightarrow a_1 = 0$, for $L \Rightarrow 0 = a_1 + b_1 + 1 \Rightarrow b_1 = -1$

$\therefore \pi_1 = u^0 L^{-1} h_f \Rightarrow \pi_1 = \frac{h_f}{L}$

for $\pi_2 [M^0 L^0 T^0] = [LT^{-1}]^{a_2} [L]^{b_2} [M^0 L^0 T^0]$

for $T \Rightarrow 0 = -a_2 \Rightarrow a_2 = 0$, for $L \Rightarrow 0 = a_2 + b_2 \Rightarrow b_2 = 0$

$\therefore \pi_2 = u^0 L^0 f \Rightarrow \pi_2 = f$

for $\pi_3 \Rightarrow [M^0 L^0 T^0] = [LT^{-1}]^{a_3} [L]^{b_3} [L]$

for $T \Rightarrow 0 = -a_3 \Rightarrow a_3 = 0$, for $L \Rightarrow 0 = a_3 + b_3 + 1 \Rightarrow b_3 = -1$

$\therefore \pi_3 = u^0 L^{-1} d \Rightarrow \pi_3 = \frac{d}{L}$

for $\pi_4 \Rightarrow [M^0 L^0 T^0] = [LT^{-1}]^{a_4} [L]^{b_4} [LT^{-2}]$

for $T \Rightarrow 0 = -a_4 - 2 \Rightarrow a_4 = -2$, for $L \Rightarrow 0 = a_4 + b_4 + 1 \Rightarrow b_4 = 1$

$\therefore \pi_4 = u^{-2} L^1 g \Rightarrow \pi_4 = \frac{gL}{u^2}$

$f(\pi_1, \pi_2, \pi_3, \pi_4) = 0$

$f\left(\frac{h_f}{L}, f, \frac{d}{L}, \frac{gL}{u^2}\right) = 0 \Rightarrow \frac{h_f}{L} = 1 f\left(f, \frac{d}{L}, \frac{gL}{u^2}\right)$

$f(\pi_1, \pi_2, \pi_3, \pi_4) = 0$

$f\left(\frac{\Delta P}{u^2\rho}, \frac{D}{L}, \frac{\mu}{u\rho L}, \frac{e}{L}\right) = 0$

$\Delta P = u^2\rho\, f\left[\left(\frac{D}{L}\right)\left(\frac{\mu}{u\rho L}\right)\left(\frac{e}{L}\right)\right]$

Head (h_f) [L] , Fanning friction factor [f]

Length (L) [L]

Diameter (d) [L]

Velocity (u) $[LT^{-1}]$

gr. acc. (g) $[LT^{-2}]$

$h_f = K(f, L, d, u, g)$

$f(h_f, f, l, d, u, g) = 0$

$n = 6, m = 2, \pi = 6 - 2 = 4$

no. of repeating vars. $= 2 = m$

Selected repeating vars. (u, L)

$\pi_1 = u^{a_1} L^{b_1} h_f$

$\pi_2 = u^{a_2} L^{b_2} f$

$\pi_3 = u^{a_3} L^{b_3} d$

$\pi_4 = u^{a_4} L^{b_4} g$

for $\pi_1 \Rightarrow [M^0 L^0 T^0] = [LT^{-1}]^{a_1}[L]^{b_1}[L]$

for $T \Rightarrow 0 = -a_1 \Rightarrow a_1 = 0$, for $L \Rightarrow 0 = a_1 + b_1 + 1 \Rightarrow b_1 = -1$

$\therefore \pi_1 = u^0 L^{-1} h_f \Rightarrow \pi_1 = \frac{h_f}{L}$

for $\pi_2 [M^0 L^0 T^0] = [LT^{-1}]^{a_2}[L]^{b_2}[M^0 L^0 T^0]$

for $T \Rightarrow 0 = -a_2 \Rightarrow a_2 = 0$, for $L \Rightarrow 0 = a_2 + b_2 \Rightarrow b_2 = 0$

$\therefore \pi_2 = u^0 L^0 f \Rightarrow \pi_2 = f$

for $\pi_3 \Rightarrow [M^0 L^0 T^0] = [LT^{-1}]^{a_3}[L]^{b_3}[L]$

for $T \Rightarrow 0 = -a_3 \Rightarrow a_3 = 0$, for $L \Rightarrow 0 = a_3 + b_3 + 1 \Rightarrow b_3 = -1$

$\therefore \pi_3 = u^0 L^{-1} d \Rightarrow \pi_3 = \frac{d}{L}$

for $\pi_4 \Rightarrow [M^0 L^0 T^0] = [LT^{-1}]^{a_4}[L]^{b_4}[LT^{-2}]$

for $T \Rightarrow 0 = -a_4 - 2 \Rightarrow a_4 = -2$, for $L \Rightarrow 0 = a_4 + b_4 + 1 \Rightarrow b_4 = 1$

$\therefore \pi_4 = u^{-2} L^1 g \Rightarrow \pi_4 = \frac{gL}{u^2}$

$f(\pi_1, \pi_2, \pi_3, \pi_4) = 0$

$f\left(\frac{h_f}{L}, f, \frac{d}{L}, \frac{gL}{u^2}\right) = 0 \Rightarrow \frac{h_f}{L} = f\left(f, \frac{d}{L}, \frac{gL}{u^2}\right)$

P.2.7. Sol:-

Power(P) $[ML^2T^{-3}]$

Diameter(D) $[L]$

Velocity(ω) $[T^{-1}]$

Discharge(Q) $[L^3T^{-1}]$

Density(ρ) $[ML^{-3}]$

$P = k(D, \omega, Q, \rho)$

$f(P, D, \omega, Q, \rho)$

$n = 5, m = 3, \pi = n - m = 2$

no. of repeating vars. $= 3 = m$

selected repeating vars. $= (D, \omega, \rho)$

$\pi_1 = D^{a_1} \omega^{b_1} \rho^{c_1} P$

$\pi_2 = D^{a_2} \omega^{b_2} \rho^{c_2} Q$

for $\pi_1 \Rightarrow [M^0L^0T^0] = [L]^{a_1}[T^{-1}]^{b_1}[ML^{-3}]^{c_1}[ML^2T^{-3}]$

for $M \Rightarrow 0 = c_1 + 1 \Rightarrow c_1 = -1$

for $T \Rightarrow 0 = -b_1 - 3 \Rightarrow b_1 = -3$

for $L \Rightarrow 0 = a_1 - 3c_1 + 2 \Rightarrow a_1 = -5$

$\therefore \pi_1 = D^{-5} \omega^{-3} \rho^{-1} P \Rightarrow \pi_1 = \frac{P}{\omega^3 \rho D^5}$

for $\pi_2 \Rightarrow [M^0L^0T^0] = [L]^{a_2}[T^{-1}]^{b_2}[ML^{-3}]^{c_2}[L^3T^{-1}]$

for $M \Rightarrow 0 = c_2$ & for $T \Rightarrow 0 = -b_2 - 1 \Rightarrow b_2 = -1$

for $L \Rightarrow 0 = a_2 - 3c_2 + 3 \Rightarrow a_2 = -3$

$\therefore \pi_2 = D^{-3} \omega^{-1} \rho^0 Q \Rightarrow \pi_2 = \frac{Q}{\omega D^3}$

$f(\pi_1, \pi_2) = 0$

$f\left(\frac{P}{\omega^3 \rho D^5}, \frac{Q}{\omega D^3}\right) = 0$

$P = (\omega^3 \rho D^5) f\left(\frac{Q}{\omega D^3}\right)$