Terminologies in Power Calculation

(i) Flow Number

$q \,\alpha\, n D_a^3$ $$N_Q = \frac{q}{nD_a^3}$$

Where q is the volumetric flow rate, measured at the tip of the blades, n is the rotational speed (rpm), Da is the impeller diameter.

N_Q is constant for each type of impeller. For flat-blade turbine (FBT), in a baffled vessel, N_Q may be taken as 1.3; For marine propellers (Square pitch), $N_Q = 0.5$; For four blade 45$_o$ turbine, $N_Q = 0.87$;

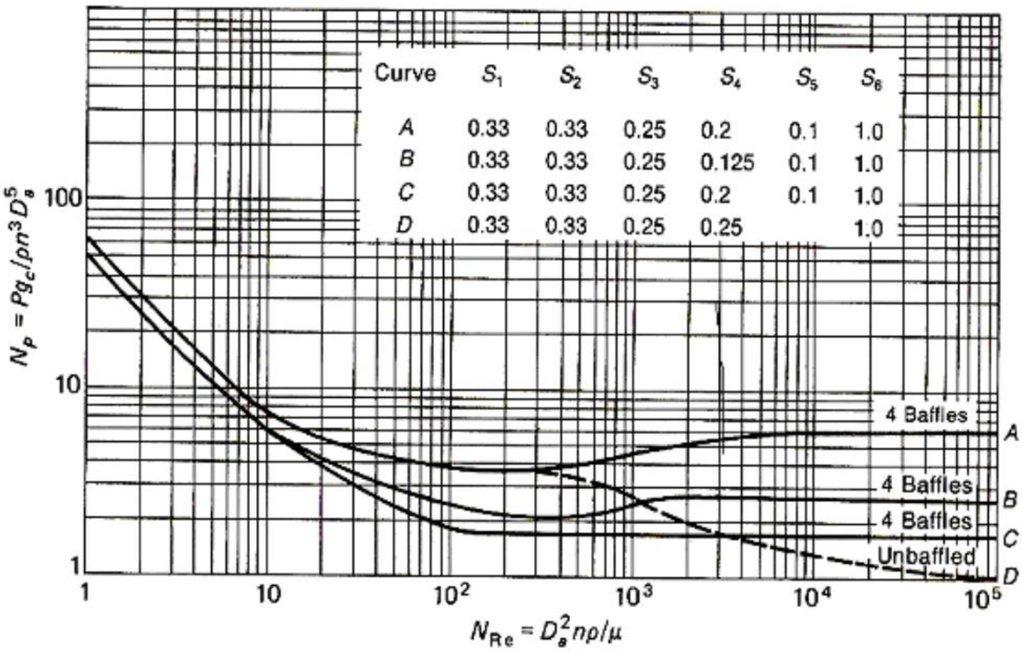
(ii) The Reynolds number, N_{Re}

$$N_{RE} = \frac{D_a^2 n\rho}{\mu}$$

(iii) The Froude number, N_{Fr}

$$N_{Fr} = \frac{n^2 D_a}{g}$$

Froude No. is a measure of the ratio of the inertial stress to the gravitational force per unit area acting on the fluid. It appears in the dynamic situations where there is significant wave motion on a liquid surface.



Power number N_P versus N_{Re} for six-blade turbines. With the dashed portion of curve D, the value of N_P read from the figure must be multiplied by N_{Fr}^m.

Flow number (N_Q)

Let u_2 be the blade velocity Vu_2' and Vr_2' tangent and radial velocity V_2' is the total liquid velocity of blade

$$\text{Assume } Vu_2' = Ku_2 \quad \_\_\_\_\_ 1$$

We know that

$$U_2 = \pi D_a n \quad \_\_\_\_\_ 2$$

Where n = Impeller speed

Substitute 2 in 1

$$Vu_2' = K \pi D_a n \quad \_\_\_\_\_\_\_ 3$$

$$q = Vr_2' \times A_p \quad \_\_\_\_\_\_\_ 4$$

where Ap = Area of cylinder

$$A_p = \pi D_a W$$

From diagram

$$Vr_2' = (u_2 - Vu_2')\tan\beta_2' \quad \_\_\_\_\_\_\_ 5$$

$$= (\pi D_a n - K \pi D_a n) \tan\beta_2'$$

$$Vr_2' = \pi D_a n(1-K) \tan\beta_2' \quad \_\_\_\_\_\_ 6$$

Substitute 6 in 5

$$q = \pi D_a n(1-K) \tan\beta_2' \times \pi D_a W$$

$$q = \pi^2 D_a^2 n(1-K) \tan\beta_2' W \quad \_\_\_\_\_\_\_ 7$$

for, similar geometry impellers Da= W

$$q = \pi^2 D_a^3 n(1-K) \tan\beta_2'$$

Given some values of K and β_2'

$$\frac{q}{nD_a^3} = N_Q$$

N_Q = flow number, Ability of impeller to discharge the liquid inside the vessel

<u>Power number (N_p)</u>

Power required for the tank can be calculated as volume produced by impeller and kinetic energy per unit volume/m3

$$N_p = qE_k$$

$$q = N_Q n D_a^3$$

$$E_k = \frac{\rho V_2^2}{2g_c}$$

V_2' – small than u_2

$$\frac{V_2'}{u_2} = \alpha$$

$$E_k = \frac{\rho \alpha V_2^2}{2g_c} = \frac{\rho \alpha^2 \pi^2 n^2 D_a^2}{2g_c}$$

Substitute all equation in Np

$$P = \frac{D_a^2 N_Q n \rho \alpha^2 \pi^2 n^2 D_a^2}{2g_c}$$

$$= \frac{n^3 D_a^5 \rho}{g_c}\left(\frac{\alpha^2 \pi^2 N_Q}{2}\right)$$

$$\frac{P g_c}{n^3 D_a^5 \rho} = N_p = \frac{\alpha^2 \pi^2 N_Q}{2}$$

<u>Power number is function of Reynolds number and flow number</u>

$$P = f(D_a, n, P, g, \mu \rho)$$

$$D_a - m = L$$

$$\rho - kg/m^3 = ML^{-3}$$

$$\mu - kg/m\text{-}s = ML^{-1}T^{-1}$$

n – rpm = T^{-1}

P- W.J/s= kgm^2/s^3= $ML^{-2}T^{-3}$

g – m/s^2= LT^{-2}

we know that,

$\varphi(D_a n P g \mu \rho)=0$

Number of variables =6

Number of fundamental quantities = 3

Total number of π -terms = 6-3

$\pi_1 = (D_a^a \rho^b n^c)P$ __________ 1

$\pi_2 = (D_a^a \rho^b n^c)\mu$ ___________ 2

$\pi_3 = (D_a^a \rho^b n^c)g$ ___________ 3

From 1

$M^0 L^0 T^0 = L^a (ML^{-3})^b (T^{-1})^C (ML^2 T^{-3})$

Equation 'M' terms

0= b+ 0 => b= -1

'L' terms

0 = a-3b+2

'T' terms

0= -C-3

C = -3

Substitute the value in 'L'

a = -5

$\pi_1 = D^{-5} \rho^{-1} n^{-3} P$

$\pi_1 = \frac{P}{D^5 n^3 \rho}$

Similarly $\pi_2 = (D_a^a \rho^b n^c)\mu$

$M^0 L^0 T^0 = L^a (ML^{-3})^b (T^{-1})^C (ML^{-1} T^{-1})$

'M' terms 0=b+1 ; b= -1

'L' terms 0=a-3b-1 ; a= -2

'T' terms 0 = -c-1 ;c=-1

Substituting the values in above equation

$\pi_2 = (D_a^{-2} \rho^{-1} n^{-1})\mu$

$\pi_2 = \frac{\mu}{\rho n D_a^2}$

$\pi_3 = (D_a^a \rho^b n^c) g$

$M^0 L^0 T^0 = L^a (ML^{-3})^b (T^{-1})^C (L T^{-2})$

'M' terms b=0

'L' terms 0= a-3b+1 ; a=-1

'T' terms 0=-c-2 ;c=-2

$\pi_3 = (D_a^{-1} \rho^0 n^{-2}) g$

$\pi_3 = \frac{g}{D_a n^2}$

$\varphi(\pi_1, \pi_2, \pi_3) = 0$

$\varphi(\frac{P}{D^5 n^3 \rho}, \frac{\mu}{\rho n D_a^2}, \frac{g}{D_a n^2}) = 0$

$\frac{P}{D^5 n^3 \rho} = \varphi(\frac{\rho n D_a^2}{\mu}, \frac{D_a n^2}{g})$

Power No = $\varphi(N_{Re}, N_{Fr})$

Newtonian fluid and non- Newtonian fluids

A **Newtonian fluid** is a fluid in which the viscous stresses arising from its flow, at every point, are linearly correlated to the local strain rate—the rate of change of its deformation over time. That is equivalent to saying those forces are proportional to the rates of change of the fluid's velocity vector as one moves away from the point in question in various directions. More precisely, a fluid is Newtonian only if the tensors that describe the viscous stress and the strain rate are related by a constant viscosity tensor that does not depend on the stress state and velocity of the flow. If the fluid is also isotropic (that is, its mechanical properties are the same along any direction), the viscosity tensor reduces to two real coefficients, describing the fluid's resistance to continuous shear deformation and continuous compression or expansion, respectively. Newtonian fluids are the simplest mathematical models of fluids that account for viscosity. While no real fluid fits the definition perfectly, many common liquids and gases, such as water and air, can be assumed to be Newtonian for practical calculations under ordinary conditions. However, non-Newtonian fluids are relatively common, and include oobleck (which becomes stiffer when vigorously sheared), or non-drip paint (which becomes thinner when sheared). Other examples include many polymer solutions (which exhibit the Weissenberg effect), molten polymers, many solid suspensions, blood, and most highly viscous fluids. Understanding whether a fluid is Newtonian or not is important in certain industrial processing industries including food processing and pharmaceutical manufacturing. In these industries, the nature of the fluid being processed, and whether or not its viscosity changes when exposed to force, can affect product attributes such as texture, taste, and appearance.

Newtonian fluids are named after Isaac Newton, who first used the differential equation to postulate the relation between the shear strain rate and shear stress for such fluids.

Examples

Water, air, alcohol, glycerol, and thin motor oil are all examples of Newtonian fluids over the range of shear stresses and shear rates encountered in everyday life. Single-phase fluids made up of small molecules are generally (although not exclusively) Newtonian.

A **non-Newtonian fluid** is a fluid that does not follow Newton's law of viscosity, i.e., constant viscosity independent of stress. In non-Newtonian fluids, viscosity can change when under force to either more liquid or more solid. Ketchup, for example, becomes runnier when shaken and is thus a non-Newtonian fluid. Many salt solutions and molten polymers are non-Newtonian fluids, as are many commonly found substances such as custard, honey, toothpaste, starch suspensions, corn starch, paint, blood, melted butter, and shampoo. Most commonly, the viscosity (the gradual deformation by shear or tensile stresses) of non-Newtonian fluids is dependent on shear rate or shear rate history. Some non-Newtonian fluids with shear-independent viscosity, however, still exhibit normal stress-differences or other non-Newtonian behavior. In a Newtonian fluid, the relation between the shear stress and the shear rate is linear, passing through the origin, the constant of proportionality being the coefficient of viscosity. In a non-Newtonian fluid, the relation between the shear stress and the shear rate is different. The fluid can even exhibit time-dependent viscosity. Therefore, a constant coefficient of viscosity cannot be defined. Although the concept of viscosity is commonly used in fluid mechanics to characterize the shear properties of a fluid, it can be inadequate to describe non-Newtonian fluids. They are best studied through several other rheological properties that relate stress and strain rate tensors under many different flow conditions—such as oscillatory shear or extensional flow—which are measured using different devices or rheometers. The properties are better studied using tensor-valued constitutive equations, which are common in the field of continuum mechanics.

Examples

Many common substances exhibit non-Newtonian flows. These include:

- Soap solutions, cosmetics, and toothpaste
- Food such as butter, cheese, jam, mayonnaise, soup, taffy, and yogurt
- Natural substances such as magma, lava, gums, honey, and extracts such as vanilla extract
- Biological fluids such as blood, saliva, semen, mucus, and synovial fluid
- Slurries such as cement slurry and paper pulp, emulsions such as mayonnaise, and some kinds of dispersions

Reference

Panton, Ronald L. (2013). Incompressible Flow (Fourth ed.). Hoboken: John Wiley & Sons. p. 114. ISBN 978-1-118-01343-4.

Batchelor, G. K. (2000) [1967]. An Introduction to Fluid Dynamics. Cambridge Mathematical Library series, Cambridge University Press. ISBN 978-0-521-66396-0.

Kundu, P.; Cohen, I. Fluid Mechanics.

"Newtonian and Non-Newtonian Fluids: The Importance in Processing". Central States Industrial. Retrieved 2021-04-27.

Volobuev, A. N. (2012). Basis of Nonsymmetrical Hydromechanics. New York: Nova Science Publishers, Inc. ISBN 978-1-61942-696-2.

Tropea, Cameron; Yarin, Alexander L.; Foss, John F. (2007). Springer handbook of experimental fluid mechanics. Springer. pp. 661, 676. ISBN 978-3-540-25141-5.

Schramm, Laurier L. (2005). Emulsions, Foams, and Suspensions: Fundamentals and Applications. Wiley VCH. p. 173. ISBN 978-3-527-30743-2.

Rao, M. A. (2007). Rheology of Fluid and Semisolid Foods: Principles and Applications (2nd ed.). Springer. p. 8. ISBN 978-0-387-70929-1.

Rupp, Rebecca (1998). "Magic Mud and Other Great Experiments". The Complete Home Learning Source Book. pp. 235–236. ISBN 9780609801093.

Barra, Giuseppina (2004). The Rheology of Caramel (PhD). University of Nottingham.

Cartwright, Jon (2 September 2011). "Microscopy reveals why ketchup squirts". Chemistry World. Royal Society of Chemistry.