APPLICATIONS OF DIMENSIONLESS NUMBER IN DAIRY AND FOOD PROCESSING OPERATIONS

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ABSTRACT: *Dimensionless numbers are of key importance in parametric analysis of engineering problems. They are also extremely useful in understanding the similarity among problems belonging to the different unit operations. Very large number of dimensionless number used in heat and mass transfer, fluid mechanics, food and dairy processing. Well-known dimensionless numbers, like Reynolds, Prandtl, Nusselt, Grashof, Biot, Furier, Power, Lews and Laplace number in dairy and food processing operations. The main goal of this paper is to present a physical interpretation of the different dimensionless numbers, significance and application in dairy and food processing operations.*

KEYWORDS: Physical interpretation, Heat and mass transfer, Prandtl Number, Dimensionless Number

1.0 INTRODUCTION: Dimensionless numbers reduce the number of variables that describe a system, thereby reducing the amount of experimental data required to make correlations of physical phenomena to scalable systems. This means that a lot of experimental runs are avoided if data is correlated using appropriate dimensionless parameters. Besides this fundamental application of the dimensionless numbers, they also serve as an important mechanism for understanding the physics and engineering phenomenon. There are two widely used ways for obtaining the dimensionless numbers. The first one is the use of the well-known π-theorem (Langhaar, 1951), where it is, first, chosen the important variables of the physical process, including physical properties, geometry and flow variables, followed by the solution of a linear system for determining the exponents of the different variables which form the dimensionless numbers. The second approach for determining dimensionless numbers is through the use of the partial differential equations governing the physical phenomena. The key issue in this approach is the definition of the dimensionless dependent and independent variables. A good choice is required to end up in dimensionless numbers that properly correlate the physical data. Dimensionless numbers are of very high importance in Dairy and food processing including mode of heat and mass Transfer, pumping of dairy and food products, agitation and mixing of dairy and food products and design of different equipments of dairy and food plant and its scale-up and scale-down.

Using scale analysis, made strong contribution in clarifying several important aspects related to these numbers. In this work it is presented a physical interpretation, significance and application of the Reynolds, Prandtl, Peclet, Grashof, Nusselt, Froude, Power numbers etc.There are important reasons for writing complex equations in dimensionless form. These are:

- It is easier to recognize when to apply familiar mathematical techniques.
- Correlate with some performance parameter and greatly aid engineering analysis.
- It reduces the number of times we might have to solve the equation numerically.
- It gives us insight into what might be small parameters that could be ignored or treated approximately.
- Can be used in the analysis of prototype models to product behavior in similar full scale systems.

Following dimensionless number its physical interpretation, significance and application in dairy and food processing operation are discuss below.

2. DIMENSIONLESS NUMBERS:

2.1. REYNOLDS NUMBER (Re)

The Reynolds Number is a non-dimensional parameter defined by the ratio of dynamic pressure (ρu^2) and shearing stress ($\mu.u/L$) and named after Osborne Reynolds who published a series of papers describing flow in pipes (Reynolds, 1883).

$$Re = (\rho u^2) / (\mu u / L) = \rho u L / \mu = u L / \nu \text{ ---------------------------------(1)}$$

Where,
Re = Reynolds Number (non-dimensional)
ρ = density (kg/m^3)
u = velocity (m/s)
μ = dynamic viscosity (Ns/m^2)
L = characteristic length (m)
ν = kinematic viscosity (m^2/s)

Significance:

- ❖ Re is the ratio of Inertial forces to the Viscous forces.
- ❖ Primarily used to analyze different flow regimes i.e Laminar, Turbulent, or Transient Flow.
- ❖ When Viscous forces are dominant (i.e low value of Re) it is a laminar flow and characterized by smooth, constant fluid motion.
- ❖ When Inertial forces are dominant (i.e high value of Re) it is a Turbulent flow and characterized by to produce chaotic eddies, vortices and other flow instabilities.
- ❖ For forced convection, the heat transfer correlation can be expressed as Nu=f (Re, Pr).

Application of the Reynolds number:-

✓ Reynolds Number for a flat surface:

On a flat plate experiments of any food product confirm that, after a certain length of flow, a laminar boundary layer will become unstable and turbulent. This instability occurs across different scales and with different food fluids, usually when Rex $\approx 5\times10^5$ where x is the distance from the leading edge of the flat plate, and the flow velocity is the free stream velocity of the fluid outside the boundary layer.

✓ Reynolds Number for a Pipe, tube and duct:

For a pipe tube and duct the characteristic length is the hydraulic diameter. The Reynolds Number for a duct or pipe can be expressed as

$$Re = \rho u d_h / \mu = u d_h / \nu \text{ ---(2)}$$

Where,
d_h = hydraulic diameter (m)

The flow is laminar when Re < 2300, transient when 2300 < Re < 4000 and turbulent when Re > 4000 in circular tube or pipe. Based of flow laminar and turbulent, design of various dairy and food pumping equipments.

✓ **Reynolds number in pipe frictions:**

Pressure drops flow of dairy and food fluid through pipes can be predicted using the Moody diagram which plots the Darcy–Weisbach friction factor(f) against Reynolds number (Re) and relative roughness(ε / D). The nature of pipe flow is strongly dependent on whether the flow is laminar or turbulent.

✓ **Agitation of tank and Stirred Vessel:**

In a cylindrical vessel stirred by a central rotating paddle, turbine or propellor, the characteristic dimension is the diameter of the agitator (D). The system is fully turbulent for values of Re above 10 000.

✓ **Critical Reynolds numbers**

At transition flow condition, Reynolds numbers are also called critical Reynolds numbers, and were studied by Osborne Reynolds around 1895. The critical Reynolds number is different for every geometry.

✓ **Scaling up and scaling down problem**:

Reynolds number is also used in scaling of fluid dynamics problems, and is used to determine dynamic similitude between two different cases of fluid flow, such as between a model aircraft, and its full size version. Such scaling is not linear and the application of Reynolds numbers to both situations allows scaling factors to be developed.

2.2. PRANTDL NUMBER (Pr):-

Define that gives the ratio between momentum diffusivity to thermal diffusivity.

$$\mathbf{Pr}= \frac{v}{\alpha} = \frac{Cp\,.\mu}{K} \quad \text{---(3)}$$

Where,
Pr= Prantdl Number
v= Momentum Diffusivity / Velocity
α= Heat Diffusivity
c_p=Specific Heat Capacity at a constant pressure
k= Thermal Conductivity of the fluid
μ = dynamic viscosity (Ns/m^2)

Significance:

- ❖ Depends only on fluid & its properties.
- ❖ It is the ratio of momentum diffusivity to heat diffusivity of the fluid.
- ❖ It is also the ratio of velocity boundary layer to thermal boundary layer.
- ❖ Pr = small, implies that rate of thermal diffusion (heat) is more than the rate of momentum diffusion (velocity). Also the thickness of thermal boundary layer is much larger than the velocity boundary layer.

The application of the Prandtl number:-

✓ **Boundaries layers calculations:**

The Prandtl number may be seen to be a ratio reflecting the ratio of the rate that viscous forces penetrate the material to the rate that thermal energy penetrates the material. As a consequence the Prandtl number is proportional to the rate of growth of the two boundary layers:

$$\delta/\delta_t = Pr^{1/3} \quad \text{--(4)}$$

If Pr= 1, then the thickness of the hydrodynamic and thermal boundary layers will be exactly the same. On the other hand, if Pr<<1, the molecular diffusivity of heat will be much larger than that of momentum. Therefore, the heat will dissipate much faster, as in the case of a liquid metal flowing in a pipe. For gases, Pr is about 0.7, and for water it is around 10.

✓ **Measurement of thermal conductivity of gases:**

For most gases over a wide range of temperature and pressure, Pr is approximately constant. Therefore, it can be used to determine the thermal conductivity of gases at high temperatures, where it is difficult to measure experimentally due to the formation of convection currents. The Prandtl numbers of gases are about 1, which indicates that both momentum and heat dissipate through the fluid at about the same rate.

2.3. NUSSELT NUMBER (Nu) :-

Define as ratio of convective heat transfer of the fluid to conductive heat transfer. Name given by Wilhelm Nusselt.

$$\mathbf{Nu = h.L/k_{fluid}} \quad \text{--(5)}$$

Where,
Nu= Nusselt Number,
k_{fluid}= Thermal Conductivity of the fluid
L=Characteristic Length
h=Heat Transfer Coefficient

Significance:

- ❖ Ratio of convective to conductive heat transfer coefficient across the boundary layer.
- ❖ Low Nu => conduction is more => Laminar flow and High Nu => convection is more => Turbulent flow.
- ❖ The conductive component is measured under the same conditions as the heat convection but with a (hypothetically) stagnant (or motionless) fluid.
- ❖ It can also be viewed as conduction resistance to convection resistance of the material.
- ❖ Free convection: Nu = f(Ra, Pr)
- ❖ Forced Convection: Nu = f(Re, Pr)

The application of the Nusselt number:-

- ✓ **Magnitude of conduction and convection heat transfer:**

Nusselt number may be viewed as an enhancement in the rate of heat transfer caused by convection over the conduction mode. Therefore, if Nu=1, then there is no improvement in the rate of heat transfer due to convection. However, if Nu =5, the rate of convective heat transfer due to fluid motion is five times the rate of heat transfer if the fluid in contact with the solid surface is stagnant. The fact that by blowing air over a hot surface we can cool it faster is due to increased Nusselt number and consequently to an increased rate of heat transfer.

- ✓ **To determine Convective heat transfer coefficient (h) of different types of surfaces:**

Consider again the correlation that we have developed for laminar flow over a flat plate at constant wall temperature

$$\mathbf{Nu_x = 0.323 \cdot Re_x^{1/2} \cdot Pr^{1/3}} \quad \text{--(6)}$$

To put this back into dimensional form, we replace the Nusselt number by its equivalent, hx/k and take the x/k to the other side:

$$\mathbf{h = 0.323 \cdot (k/x) \cdot Re_x^{1/2} \cdot Pr^{1/3}} \quad \text{--(7)}$$

We see that as the boundary layer thickens, the convection coefficient decreases. Some designers will introduce a series of "trip wires", i.e. devices to disrupt the boundary layer, so that the buildup of the insulating layer must begin anew. This will result in regular "thinning" of the boundary layer so that the convection coefficient will remain high.
Average correlation for laminar flow over a flat plate with constant wall temperature.

$$\mathbf{Nu_L = 0.646.Re_L^{0.5}.Pr^{1/3}} \quad \text{--(8)}$$

✓ **Reynolds Analogy and friction drag coefficient (C_f):**

The Reynolds analogy is extremely useful in obtaining a first approximation for heat transfer in situations in which the shear stress is ``known." An example of the use of the Reynolds analogy is in analysis of a heat exchanger.

Reynold's noted the strong correlation and found that fluid friction and convection coefficient could be related. This is known as the Reynolds Analogy. Knowing the frictional drag, we know the Nusselt Number. If the drag coefficient is increased, say through increased wall roughness, then the convective coefficient will also increase (Mahulikar and Herwig, 2008).

$$C_f = Nu_x / Re_x Pr^{1/3} \quad \text{-----(9)}$$

✓ **Von-Karman analysis for turbulent flow:**

The local fluid friction factor, C_f, associated with turbulent flow over a flat plate is given as:

$$C_f = 0.0592/Re_x^{0.2} \quad \text{-----(10)}$$

$$Nu_x = 0.0296 \cdot Re_x^{0.8} \cdot Pr^{1/3} \quad \text{----- (11)}$$

Note: The critical Reynolds number for flow over a flat plate is 5 x 10^5; the critical Reynolds number for flow through a round tube is 2000.

The result of the above integration is:

$$Nu_x = 0.037 \cdot (Re_x^{0.8} - 871) \cdot Pr^{1/3} \quad \text{-----(12)}$$

Note: Fluid properties should be evaluated at the average temperature in the boundary layer, i.e. at an average between the wall and free stream temperature.

$$T_{prop} = 0.5(T_{wall} + T_\infty) \quad \text{-----(13)}$$

2.4. GRASHOF NUMBER (Gr):

It is the ratio of the buoyancy to viscous force acting on a fluid. It's believed to be named after Franz Grashof. Though this grouping of terms had already been in use, it wasn't named until around 1921, 28 years after Franz Grashof's death. It's not very clear why the grouping was named after him.

$$Gr = \frac{g\beta\,(Ts - T\infty)L3}{v2} \quad \text{-----(14)}$$

Where,

g = acceleration due to gravity

β = volumetric thermal expansion coefficient

Ts = source temperature

T∞ = quiescent temperature

L = characteristic length

ν = kinematic viscosity

Significance:

- Ratio of Buoyancy force to viscous force in natural convection.
- Grashof number is used in natural convection, *Nu = f(Gr,Pr)*

The application of the Grashof number:-

✓ **Magnitude of Free Convection Heat Transfer Correlations:**

Quite often experimentalists find that the exponent on the Grashof and Prandtl numbers are equal so that the general correlations may be written in the form:

$$Nu = C[Gr \cdot Pr]^m \quad \text{-----(15)}$$

2.5. RAYLEIGH NUMBER (Ra)

It is product of Grashof number and Prandtl dimensionless number.

$$Ra = Gr.\,Pr \quad \text{-----(16)}$$

The application of the Rayleigh number:-

- ✓ Used in heat transfer and free convection calculation
- ✓ Laminar to Turbulent Transition

At a Rayleigh number of about 10^9 the flow over a flat plate will become transitional and finally become turbulent. The increased turbulence inside the boundary layer will enhance heat transfer leading to relative high convection coefficients because of better mixing.

2.6. BIOT NUMBER (Bi):-

It is named after the eighteenth century French physicist Jean-Baptiste Biot (1774–1862), and gives a simple index of the ratio of the heat transfer resistances inside of and at the surface of a body.

$\mathbf{Bi = h.L/k_{solid}}$ ---(17)

Where,

Bi= Biot Number,

k_{solid}= Thermal Conductivity of the fluid

L=Characteristic Length = V/A_s

h=Heat Transfer Coefficient

Significance:

- ❖ Used in unsteady state (transient) heat transfer conditions.
- ❖ Ratio of heat transfer resistance inside the body to heat transfer resistance at the surface of the body. OR ratio of internal thermal resistance to external thermal resistance.
- ❖ Shows the variation of temperature inside the body w.r.t to time.
- ❖ Bi < 0.1 => heat transfer resistance inside the body is very low => inside the body conduction takes place faster compared to convection at the surface. => no temperature gradient inside the body (uniformity in temperature) vice versa implies that Temperature is not uniform throughout hte material volume.

The application of the Biot number:-

- ✓ Lumped parameter analysis:

Whenever the Biot number is small, the internal temperature gradients are also small and a transient problem can be treated by the “lumped thermal capacity” approach. As a thumb rule, if the Biot number turns out to be less than 0.1, lumped capacity assumption is applied.

- ✓ Solving transient heat transfer problems.
- ✓ The study of heat transfer in micro-encapsulated phase-change slurries is an application where the Biot number is useful (Delgado et. al, 2012).
- ✓ Fin application:

The Biot number has a variety of applications, including transient heat transfer and use in extended surface heat transfer calculations.

- ✓ Measurement of thermal time constant and sensitivity of thermocouple.

2.7. FOURIER NUMBERS (Fo):-

In this context, *a dimensionless time*, known as the Fourier number, can be obtained by multiplying the dimensional time by the thermal diffusivity and dividing by the square of the characteristic length.

$\mathbf{F_{oh}= \alpha t/ L^2}$ ---(18)

$\mathbf{F_{om}=Dt/L^2}$ ---(19)

Where,

F_{oh}= fourier number for heat transfer

F_{om}= fourier number for mass transfer

α= Heat Diffusivity

L= length through which conduction occurs
D= diffusivity
t= characteristic time

Significances:-

- ❖ The Fourier number indicates the relation between the rate of heat conduction through the body and the rate of heat stored in the body.
- ❖ The larger value of the fourier number indicates, the higher rate of heat transfer through the body.
- ❖ The larger value of the fourier number indicates,the lower rate of heat transfer through the body.

The application of the Fourier number:-

- ✓ Calculation of unsteady-state heat transfer.
- ✓ The fourier number is also used in analysis transient mass transfer system.

2.8. SHERWOOD NUMBER (Sh):-

It is measure of the ratio of convective and diffusive mass transfer in a fluid.

$$S_h = h_D . L/D \quad \text{------(20)}$$

Where,
h_D= mass transfer coefficient
L= Characteristic length

Significance:

- ❖ Ratio of rate of heat conduction to the rate of heat storage.
- ❖ Used along with Biot number to solve transient state heat transfer problems.
- ❖ For mass transfer by diffusion, Fourier number for Mass Transfer is used.
- ❖ It can also be understood as current time to the time taken to reach steady state.

2.9. SCHMIDT NUMBER (Sc):-

Define as ratio of the momentum and mass diffusivity.

$$Sc = \mu / \rho . D \quad \text{------(21)}$$

Significance:

- ❖ Analogous to Prandtl number of Heat Transfer.
- ❖ Used in fluid flows in which there is simultaneous momentum & mass diffusion.
- ❖ It is also the ratio of fluid boundary layer to mass transfer boundary layer thickness.
- ❖ To find mass transfer coefficient using Sherwood number, we need Schmidt number.

2.10. LEWIS NUMBER(Le):-

It is define as ratio of thermal diffusivity (α) to mass transfer (D_{AB}).

$$Le = \alpha / D_{AB} \quad \text{------(22)}$$

Significance:

- ✓ It is ratio of Scchmidt number to Prandtl number.
- ✓ Comparing the correlation for the heat and mass transfer.
- ✓ For gases, the Prandtl and the Schmidt number are almost equal. In this case a simple approximation for the relationship between the mass and heat transfer coefficient can be derived, which is the so-called Lewis relation

$$\frac{h_{mass}}{h/c_p} = 1 \text{ --(23)}$$

2.11. FROUDE NUMBER (Fr):-

It is defined as the square root of the ratio of inertial forces to gravitational forces in fluid.

$$\mathbf{Fr} = \sqrt{\frac{\mathbf{F_i}}{\mathbf{F_g}}} = \frac{\mathbf{v}}{\sqrt{\mathbf{g\,l}}} \text{ --(24)}$$

Where,
v= velocity of small surface wave and
l= depth of flow.

Significance:

- ❖ Froude number enters into formulation of hydraulic jumps (rise in water surface elevation) that occurs under certain conditions
- ❖ Generally used for study of motion of ships in sea and also wave motion up and down stream. Fr<1, Surface wave will move upstream. Fr>1, Surface wave will be carried downstream and Fr=1, Critical velocity.
- ❖ It is used to analyse fluid flow problems where there is a free surface. For example, In agitated vessels, for governs the formation of free surface vortices.
- ❖ Froude number is useful to describe the flow in open channels, flow over notches and weirs, the motion of a ship in turbulent sea conditions (ship resistance), flow over spillways, etc.

2.12. MACH NUMBER (Ma):-

It is defined as square root of the ratio of inertial force to elastic force in fluid.

$$\boldsymbol{Ma} = \sqrt{\frac{\boldsymbol{F_i}}{\boldsymbol{F_e}}} = \frac{\boldsymbol{v}}{\sqrt{\boldsymbol{E}/\boldsymbol{\rho}}} \text{ ---(25)}$$

Or

The Mach number is the ratio of the fluid velocity to the sound in that medium.

Significance:

- ❖ Generally used to differentiate between compressible and incompressible flow.
- ❖ Water hammer problems in pipeline and pumps.
- ❖ Ma<1, Subsonic flow. Ma>1, For gasses if Ma<3/10 and Ma>1, supersonic flow
- ❖ In dairy and food industry mach number is commonly used in calculations involving high velocity gas flow.

2.13. PECLET NUMBER (Pe):

It is defined to be the ratio of the rate of advection of a physical quantity by the flow to the rate of diffusion of the same quantity driven by an appropriate gradient.

Significance:

- ❖ Product of Re & Pr for Pe(HT)
- ❖ product of Re & Sc for Pe(MT)
- ❖ Ratio of Heat transported by convection to Heat transported by conduction.
- ❖ Measure for the relative importance of the random fluctuations and of the systematic average behavior in mesoscopic systems

2.14. STANTON NO (St)

Define as the ratio of heat transferred into a fluid to the thermal capacity of fluid (Hall, 2018). The Stanton number is named after Thomas Stanton (engineer) (1865–1931).

$$St = \frac{h}{\rho . u . Cp} = \frac{Nu}{Re . Pr} \quad \text{------------(26)}$$

Significance:

- ✓ For HT, It is the ratio of heat transferred to the fluid to the heat capacity of the fluid.
- ✓ For HT, It's the ratio of Nusselt Number to Peclet Number i.e St(HT) = Nu/(Re.Pr).
- ✓ Used to find heat transfer in forced convection flows.
- ✓ For MT, It's the ratio of Sherwood Number to Peclet Number i.e St(MT) = Sh/(Re.Sc).

2.15.GRAETZ NUMBER (Gz)

$$Gz = \frac{DH}{L} Re . Pr \quad \text{------------(27)}$$

Where,

D_H =hydraulic diameter in arbitrary cross-section ducts

L= length

Re =Reynolds number and

Pr= Prandtl number.

Significance:

- ❖ Characterizes laminar flow in a conduit OR transfer of heat by streamline fluid flow in a pipe.
- ❖ In case of mass transfer, Pr is replaced by Sc.
- ❖ Determining the thermally developing flow entrance length in ducts.

2.16. EULER'S NUMBER (EU):

It is defined as the square root of the ratio of inertial force to the pressure force in fluid.

$$Eu = \sqrt{\frac{F_i}{F_p}} = \frac{v}{\sqrt{p/\rho}} \quad \text{------------(28)}$$

Applications:

- ✓ Generally used in situations where fully developed turbulent flow in pipes, cavitation situations are encountered.
- ✓ Significant in cases where pressure gradient exists such as flow through pipes, water hammer pressure in penstocks, discharge through orifices and mouthpieces, etc.

2.17. **WEBER'S NUMBER (WB):**

It is defined as square root of the ratio of inertial force to surface tension force in fluid.

$$Wb = \sqrt{\frac{F_i}{F_s}} = \frac{v}{\sqrt{\sigma/\rho\, l}} \quad \text{------------(29)}$$

Applications:

- ✓ Generally used in situations where capillary rise in narrow tubes, capillary movement of water in soil, flow over weirs for small heads etc. are encountered.
- ✓ Atomization of liquids,
- ✓ Determines the onset of this phenomenon called the entrainment limit (Weber number greater than or equal to 1).

- ✓ Thin layers of fluid passing over surface.
- ✓ Study of heat pipes

2.18. DEAN NUMBER (De):

The Dean number (De) is a dimensionless group in fluid mechanics, which occurs in the study of flow in curved pipes and channels. It is named after the British scientist W. R. Dean.

$$\mathbf{De} = \frac{Re}{\sqrt{(\frac{R}{h})}} \text{ ------------------------------------(30)}$$

Applications:

- ✓ Dean number deals with the stability of two-dimensional flows in a curved channel with mean radius R and width 2h.
- ✓ Theoretical solution of the fluid motion through curved pipes for laminar flow by using a perturbation procedure from a Poiseuille flow in a straight pipe to a flow in a pipe with very small curvature (Dean, 1927).

2.19. DEBORAH NUMBER (D_{eb})

Defined as the ratio of the time it takes for a material to adjust to applied stresses or deformations, and the characteristic time scale of an experiment (or a computer simulation) probing the response of the material:

$\mathbf{D_{eb} = tc / tp}$ --(31)

Where,

tc = relaxation time

tp =characteristic time scale, typically taken to be the time scale of the process (Poole, 2012).

Applications:

- ✓ Commonly used in rheology to characterize how "fluid" a material is.
- ✓ Deborah number should be used to describe flows with a non-constant stretch history, and physically represents the rate at which elastic energy is stored or released.

2.20. ECKERT NUMBER (Ec):

$\mathbf{Ec = U^2 / Cp.\Delta T}$ ---(32)

Where,

U=local flow velocity of the continuum,

Cp=local specific heat of the continuum,

ΔT=difference between wall temperature and local temperature.

Applications:

- ✓ Important role in high speed flows for which viscous dissipation is significant.
- ✓ To characterize heat transfer dissipation.

2.21. ARRHENIUS NUMBER (Ar)

The Arrhenius equation is a formula for the temperature dependence of reaction rates. The Arrhenius number is the exponent for that equation. Define as ratio of activation energy (Ea) to thermal energy.

Ar= Ea/ (R.T) --(33)

Applications:

- ✓ Establishes a relation between the temperature of the reaction and the rate of the reaction.

2.22. KNUDSEN NUMBER (Kn):

Defined as the ratio of the molecular mean free path length to a representative physical length scale. This length scale could be, for example, the radius of a body in a fluid. The number is named after Danish physicist Martin Knudsen (1871–1949).

Kn = λ/L ---(34)

Applications:

- ✓ The Knudsen number also plays an important role in thermal conduction in gases.
- ✓ It has also been successfully demonstrated for use in hydrogen production from water (Kogan, 1998).

2.23. POWER NUMBER (Po):

The **power number** N_p (also known as **Newton number**) is a commonly used dimensionless number relating the resistance force to the inertia force.The power-number has different specifications according to the field of application. E.g., for stirrers the power number is defined as

Po= P/ (N^3.ρ.D^5) ---(35)

Where,

P= power

ρ=fluid density

N=rotational speed in revolutions per second

D=diameter of stirrer

Applications:

- ✓ Power consumption in mixer and agitator.
- ✓

2.24. **STEFAN NUMBER (Ste):**

The Stefan number is defined as the ratio of sensible heat to latent heat.

Ste = $\frac{Cp.dT}{Lm}$ ---(36)

Applications:

- ✓ Useful in the study of heat transfer during phase change.

3. CONCLUSIONS: Dimensionless numbers or non-dimensional numbers are those which are useful to determine the flow characteristics of a fluid. This makes also them a powerful tool for scaling operations from model to pilot and beyond. Dimensionless number also extremely useful in understanding the similarity among problems belonging to the different unit operations. Very large number of dimensionless number used in heat and mass transfer, fluid mechanics, food and dairy processing. Well-known dimensionless numbers, like Reynolds, Prandtl, Nusselt, Grashof, Biot, Furier, Power, Lews and Laplace number in dairy and food processing operations. Dimensionless numbers helps to compare the systems that are vastly different by combining the parameters of interest.Using dimensionless analysis, we can design an equipments in such a way that, it's minimize the capital cost and heat loss. Dimensionless numbers are of very high importance in Dairy and food processing operations.

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