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The document then discusses dimensionless numbers related to transport phenomena, droplet formation, and provides a list of standard dimensionless numbers used in fluid mechanics.0 ratings0% found this document useful (0 votes)173 views7 pagesThis document discusses dimensionless numbers in fluid mechanics. Dimensionless numbers describe ratios of important fluid characteristics such as density, viscosity, speed of sound, and floAI-enhanced title and description100%(1)100% found this document useful (1 vote)457 views5 pagesThe document defines and describes 12 major dimensionless numbers used in fluid mechanics and heat transfer analyses. It provides the symbol, formula, and significance of each number, includAI-enhanced title and descriptionSaveSave Dimensionless Numbers And Their Significance For Later100%100% found this document useful, undefined100%(1)100% found this document useful (1 vote)457 views5 pagesThe document defines and describes 12 major dimensionless numbers used in fluid mechanics and heat transfer analyses. It provides the symbol, formula, and significance of each number, including the Reynolds, Prandtl, Schmidt, Lewis, Peclet, Stanton, Nusselt (or Sherwood), Grashof, Biot, Rayleigh, and Fourier numbers. The numbers are ratios that characterize different flow regimes, transport phenomena, or compare relative magnitudes of forces and transport mechanisms.100%(1)100% found this document useful (1 vote)457 views5 pagesThe document defines and describes 12 major dimensionless numbers used in fluid mechanics and heat transfer analyses. It provides the symbol, formula, and significance of each number, includAI-enhanced title and description1. Important Dimensionless NumbersKeerthi Vasan MChemical Engineering Graduate (2020)kvasan166@gmail.comTamil Nadu, INDIA1. Schmidt number (Sc) : Sc gives the relative ease of momentum and mass transport ina flow system and it is the mass transfer analogue of Prandtl number (Pr). It relates thethickness of the momentum and diffusion boundary layers.Sc =Momentum diffusivity ()Mass diffusivity (D)= D=DD - Diffusivity of the system (m2/s), - Density (kg/m3), - Dynamic viscosity of the fluid(Pa s).2. Prandtl number (Pr) : Pr gives the relative ease of momentum and energy transportin a flow system. It is more frequently used in heat transfer calculations. It relates thethickness of the momentum and thermal boundary layers. If Pr 1, heat diffuses quickly orthermal boundary layer is much thicker when compared to velocity/momentum boundarylayer. Generally for gases Pr ' 0.1 and for liquid metals Pr ' 0.01 to 0.04.Pr =Momentum diffusivity ()Thermal diffusivity ()= kCP =CP k - Density (kg/m3), - Dynamic viscosity of the fluid (Pa s), k - Thermal conductivity(W/m K), CP - Specific heat capacity (J/kg K).3. Lewis number (Le) : Le is used to characterize a flow system where simultaneous heatand mass transfer occurs. For a air-water vapour system, Le = 1. Which results in the Lewisrelation (used to prove that Wet Bult Temperature (TWBT) is equal to Adiabatic SaturationTemperature (Tas)).Le =ScPr=Thermal diffusivity ()Mass diffusivity (D)=kCP D=k D CPLewis relation derivation for air-water vapour system : Chilton - Colburn Analogy givesfF2|{z}jM=kC Sc2/3v| {z }jD=h Pr2/3G CP| {z }jH(1)Le = 1 implies, Pr = Sc. Therefore equation (1) gives, kCv= hG CP. Now by doing thefollowing substitution = c MB, ky = kc c, Cp = Cs and kY = MB ky, we get Lewis relationashkY Cs= 1 . - Density (g/m3), k - Thermal conductivity (W/m K), CP - Specific heat capacity (J/kgK), fF - Fanning friction factor, kC - Mass transfer co-efficient for concentration drivingforce, v - fluid velocity (m/s), h - Convective heat transfer co-efficient (W/m2K), G - Massvelocity in kg/ m2s (= v), Cs - Humid heat of the air-water vapour system, MB - Molecularweight of dry air (= 29 g/mol), c - Concentration of vapour in the mixture (mol/m3), ky -Mass transfer co-efficient for mole fraction driving force, kY - Mass transfer co-efficient forabsolute humidity driving force.1 2. 4. Peclet number (Pe) : Pe is used in convective heat transfer calculations. It is the ratio ofthermal energy convected to the fluid to the thermal energy conducted within the fluid. Inpractical applications, Pe is very high. Sometimes, Pe is also known as Bodenstein number(Bo).Pe =Heat transport by convectionHeat transport by conduction= Re Pr = v L =L vSimilarly mass transfer analogue of Pe is defined asPe =Mass transport by convectionMass transport by conduction= Re Sc = v L D =L vDDispersion number is defined as 1Pe. Dispersion number is a important dimensionless numberwhich measures the extend of axial dispersion in a chemical reactor.ReactorNature ofreactorDispersion/Diffusion coefficient (D)Pe or Dispersion numberIdealCSTRInfinite axialmixingVery high D Pe = 0 (or) Dispersion number = IdealPFRZero axialmixingVery low D or zero D Pe = (or) Dispersion number = 0 - Density (g/m3), v - Fluid velocity (m/s), L - Characteristic length of the system (m), - Dynamic viscosity of the fluid (Pa s), - Momentum diffusivity (m2/s), - Thermaldiffusivity (m2/s), D - Diffusivity of the system (m2/s) / Dispersion co-efficient.5. Nusselt number (Nu) : It is defined as a ratio of convective heat flux to conductive heatflux in a fluid boundary layer. Nu represents the enhancement of heat transfer through afluid layer as a result of convection relative to conduction across the same fluid layer.Nu =Convective heat fluxConductive heat flux (Fouriers law)=h 4Tk 4TL =h LkNu =1, Heat transfer across the fluid layer is by pure conduction1 10, Laminar flow100 1000, More active convection or Turbulent flowh - Convective heat transfer co-efficient (W/m2K), T - Temperature (K), k - Thermalconductivity (W/m K), L - Characteristic length of the system (m).6. Sherwood number (Sh) : It is the mass transfer analogue of Nusselt number (Nu). It isdefined asSh =Convective mass fluxConductive mass flux (Ficks law)=kc 4CD 4CL =kc LDkc - Mass transfer co-efficient for concentration driving force, D - Diffusivity of the system(m2/s), L - Characteristic length of the system (m).7. Biot number (Bi) : It is similar to Nusselt number (Nu) but it is for a solid body. Whereas,Nu is for a fluid layer. It arises in the transient heat conduction calculations, particulary inlumped heat capacitance model.Bi =Convective heat fluxConductive heat flux (Fouriers law)=Internal conductive resistanceSurface convective resistance=Lk 1h =h Lk2 3. If Bi 0.1, then internal conductive resistance is zero which makes the system a perfectlumped heat capacitance system. There wont be any resistance for heat flow on thebody. So, temperature is uniform through out the body. If Bi 1, then the system can be considered as a approximate lumped heat capacitancesystem. If Bi 1, then internal conductive resistance is significant. So, temperature distributionis non-uniform across the body and the calculations become complex.Important fact : Ratio of Nusselt number to Biot number gives,NuBi=h Lk fluidh Lk solid=ksolidkfluid=RfluidRsolid=Conductive resistance of fluidConductive resistance of solidh - Convective heat transfer co-efficient (W/m2K), T - Temperature (K), k - Thermalconductivity (W/m K), L - Characteristic length of the system (m).8. Fourier number (Fo) : It arises in the unsteady state heat conduction calculations. Mainlyin the lumped heat capacitance systems (from the term (hAt/CV)).hAtCV=htCL= hLk ktCL2 = Bi tL2 = Bi FoALh - Convective heat transfer co-efficient (W/m2K), A - Cross sectional area of the body(m2), t - Time (s), - Density of the body (g/m3), C - Specific heat capacity of the body(J/ mol K), V - Volume of the body (m3), L - Characteristic length of the system (m), k -Thermal conductivity (W/m K), Bi - Biot number, - Thermal diffusivity (m2/s).9. Stanton number (St) : St is generally used in the forced convective heat transfer calcu-lations and in heat, mass and momentum transfer analogies like Reynolds analogy, Chilton- Colburn analogy, etc. It is defined as a ratio of heat transferred to a fluid to the heat ca-pacity of the fluid. The stanton number arises in the consideration of geometeric similarityof the momentum boundary layer, where it can be used to express a relationship betweenthe shear force at the wall (due to viscous drag) and the total heat transfer at the wall (dueto thermal diffusivity).St =Heat transfered to a fluidThermal capacity of the fluid=NuRe Pr=h v CP=hG CPSimilarly mass transfer analogue of St is defined asSt =ShRe Sc=kc LD v L D =kcvNu - Nusselt number, Re - Reynolds number, Pr - Prandtl number, Sh - Sherwood number,Sc - Schmidt number, h - Convective heat transfer co-efficient (W/m2K), - Density (g/m3),v - Fluid velocity (m/s), CP - Specific heat capacity (J/kg K), G - Mass velocity in kg/ m2s (= v), kc - Mass transfer co-efficient for concentration driving force, L - Characteristiclength of the system (m), D - Diffusivity of the system (m2/s), - Dynamic viscosity of thefluid (Pa s).10. Damkohler number (Da) : It is used to relate the chemical reaction rate to the transportphenomena rate occuring in a system. For a general nthorder chemical reaction A B,Da is defined asDa =Rate of consumption of A by reactionRate of transport of A by convection=rA VFA0=kCnA0V0CA0= kCn1A0 3 4. Therefore for a 1storder chemical reaction, Da = k .rA - Rate of consumption of A in the reaction (mol/m3s), V - Volume of the reactionmixture (m3), FA0 - Molar flow rate of A (mol/s), k - First order rate constant (s1),CA0 - Initial concentration of A (mol/m3), 0 - Initial volumeteric flow rate (m3/s), -Space/residence time (s) (= V0).11. Dean number (De) : It is used in the study of flow and heat transfer in coiled tube/pipesand channels.De = RerD2RCDean numberReynolds numberHydraulic diameterPath curvature radius12. Reynolds number (Re) : Boundary layer seperation occurs when Re 1 and the flowdecelerates due to separation.Re =Interial forceViscous force=maA=muA= A u2 uL A= u L=u LQ = Auut uL dudym - Mass (g), a - Acceleration (m/s2), - Shear stress (Pa), A - Area (m2), u - Velocity(m/s), t - Time (s), - Dynamic viscosity (Pa s), L - Characteristic length of the system(m), - Density (g/m3), Q - Volumetric flow rate (m3/s), - Kinematic viscosity (m2/s).13. Froude number (Fr) :Fr =sInterial forceGravity force=s A u2m g=s A u2 A L g=uLg V ' L3' ALm - Mass (g), A - Area (m2), u - Velocity (m/s), L - Characteristic length of the system(m), - Density (g/m3), g - Acceleration due to gravity (m/s2).14. Euler number (Eu) : Ruark number Ru =qInterial forcePressure force=q A u24P A= uq4P Euler number = 1Ru= 1uq4P. For frictionless flow, Eu = 1. Euler number (Eu) is called Cavitation number (Ca) when 4P = P Pv.Pv- vapour pressure (Pa), A - Area (m2), u - Velocity (m/s), - Density (g/m3).15. Weber number (We) :We =rInertial forceSurface tension force=sAu2L = urLL2 - Density (g/m3), A - Area (m2), u - Velocity (m/s), - Surface tension (N/m), L -Characteristic length of the system (m).4 5. 16. Mach number (Ma) :Ma =rInertial forceElastic force=rAu2kA= urk=uC - Density (g/m3), A - Area (m2), u - Velocity (m/s), k - Elastic stress, C - Velocity of thesound in the fluid (m/s) (=qk).17. Grashof number (Gr) : Gr is used in the free/natural convection calculations to classifythe flow (flow classification is done based on the value of the term GrPr). Gr has the samefunctionality as the Reynolds number (Re). Grashof number (Gr) is defined asGr =Buoyancy forceViscous force=FbFv(2)Since in natural convections, we need to consider changes in density of the fluid whichresults in fluid motion. To account those density changes, we consider Thermal coefficientof expansion (). =1V dVdT P= d(1)dT= 1ddT= d(ln)dT(3)Z od(ln) = Z TT0 dT (4) = 0(1 (T T0)) = 0(1 4T) (5)Molar volume (m3/mol)Molar density (mol/m3)For a ideal gas, PV = nRT = PRT = 1T. Buoyancy force term of the equation (2)is given byFb = mf g = (o)Vf g (6)ALSubstituting from equation (5) in equation (6), we getFb = (04T)(AL)g (7)Viscous force Fv = uL A. From dimensional analaysis, we get viscous force = interial force.Therefore, uL A = Au2 u =uL(8)Substituting u from equation (8) into Fv expression, we getFv = uL A Fv =2AL2(9)From equations (7), (9) and (2), we getGr =(04T)(AL)g 2AL2 =2L3g4T2(10) Property values (CP , , , , etc.) are measured at film temperature Tf = Ts+T02.5 6. Important relationship for natural and forced convection obtained by dimensional anal-ysis includes, Natural convection: Nu = f(Gr, Pr) Forced convection: Nu = f(Re, Pr) or St = f(Re, Pr) In a combined forced and natural convection process,GrRe2 = 1, Natural convection dominates1, Both convection are comparable 1, Forced convection dominatesT - Temperature (K), T0 - Free stream temperature (K), 0 - Bulk fluid density (g/m3), -Fluid density inside heated air (g/m3), P - Pressure (Pa), V - Volume (m3), n - Number ofmoles (moles), R - Universal gas constant (J/mol K), T - Temperature (K), mf - Mass offluid (g), g - Acceleration due to gravity (m/s2), Vf - Volume of fluid (m3), A - Area (m2),L - Characteristic length of the system (m), - Dynamic viscosity of the fluid (Pa s), u -Fluid velocity (m/s), CP - Specific heat capacity (J/kg K), Tf - Film temperature (K), Ts- Surface/wall temperature (K), Nu - Nusselt number, Pr - Prandtl number, St - Stantonnumber, Re - Reynolds number.18. Rayleigh number (Ra) :Ra = GrPr =Buoyancy forceViscous forceMomentum diffusivityHeat diffusivity| {z }1Heat diffusion rate = =CPk=2L3g4TCPk Property values (CP , , , , etc.) are measured at film temperature Tf = Ts+T02. Ra (= GrPr) is used in the free convection calculations to classify the flow. - Density (g/m3), - Thermal coefficient of expansion (K1), T - Temperature (K), g -Acceleration due to gravity (m/s2), L - Characteristic length of the system (m), - Dynamicviscosity of the fluid (Pa s), CP - Specific heat capacity (J/kg K), Tf - Film temperature(K), Ts - Surface/wall temperature (K), T0 - Free stream temperature (K), k - Thermalconductivity (W/m K), Gr - Grashof number, Pr - Prandtl number.19. Graetz number (Gz) : It is used to characterize fluid flow in a pipe under laminar flowconditions and also it correlates thermally developing flow.Gz =Thermal capacityConvective heat flux= DHL RePr = DHL PeSimilarly mass transfer analogue of Gz is defined asGz = DHL ReScDH - Hydraulic diameter (m), L - Characteristic length of the system (m), Re - Reynoldsnumber, Pr - Prandtl number, Sc - Schmidt number, Pe - Peclet number.20. Knudsen number (Kn) : It is defined as the ratio of the molecular mean free path lengthto a representative physical length scale. This length scale could be, for example, the radiusof a body in a fluid.Kn =Molecular mean free pathCharacteristic length of the system=L6 7. If Kn 10, Knudsen diffusion happens. Knudsen diffusivity (Dk) = DV3= 48.5DqTMKnudsen diffusion flux can be found by replacing DAB by Dk in the ficks law ofdiffusion.Dk 6= f(P)= f(Pore diameter, molecular velocity)= f(Pore diameter, Temperature, Molecular weight) Kn 1100, Molecular (or) Ficks diffusion happens. If 10 Kn 1100, Transition region diffusion happens. - Molecular mean free path (m) = qm2kBT , L - Characteristic length of the system(m), - Dynamic viscosity of the fluid (Pa s), - Density (g/m3), m - Molecular mass (g),kB - Boltzmann constant (J/K), T - Thermodynamic temperature (K), D - Pore diameter(m), DAB - Diffusion coefficient (m2/s), P - Pressure (Pa),Important Correlations Using Dimensionless Numbers1. Dittus-Boelter equation :Dittus-Boelter equation for turbulent flow inside a circular cross sectional area pipe isNu = 0.023 Re0.8Prn(11)hdk= 0.023 vd0.8 CP kn(12)Where, n =(0.4, Fluid heated0.3, Fluid cooledSimilarly mass transfer analogue of Dittus-Boelter equation is Sh = 0.023 Re0.8Scn. Validitychecks to use the Dittus-Boelter equation are Ld 60, 0.6 Pr 100, and 2500 Re 1.25 106.Constant average velocity (v) :From equation (12) we get,hd d0.8 h d0.2Constant mass flow rate (m) :In equation (12), replace v by QA v 1d2 .We get,hd (vd)0.8 hd dd20.8 h d1.8Nu - Nusselt number, Re - Reynolds number, Pr - Prandtl number, Sh - Sherwood number,Sc - Schmidt number, h - Convective heat transfer co-efficient (W/m2K), d - Diameter(m), k - Thermal conductivity (W/m K), - Density (g/m3), v - Average velocity (m/s), -Dynamic viscosity of the fluid (Pa s), CP - Specific heat capacity (J/kg K), L - Characteristiclength of the system (m), Q - Volumetric flowrate (m3/s), A - Area (m2).2. Sieder-Tate equation :Sieder-Tate equation for turbulent flow inside a circular cross sectional area pipe isNu = 0.027 Re0.8Pr(1/3) bw0.14(13)hdk= 0.027 vd0.8 CP k(1/3) bw0.14 h d0.2(14)7 8. Validity checks to use the Sieder-Tate equation are Ld 60, 0.7 Pr 16700, and Re 10000. Sieder-Tate equation for laminar flow inside a circular cross sectional area pipe isNu = (RePr) dL(1/3) bw0.14(15)Nu - Nusselt number, Re - Reynolds number, Pr - Prandtl number, h - Convective heattransfer co-efficient (W/m2K), d - Diameter (m), k - Thermal conductivity (W/m K), -Density (g/m3), v - Average velocity (m/s), - Dynamic viscosity of the fluid (Pa s), CP -Specific heat capacity (J/kg K), L - Characteristic length of the system (m), b - Dynamicviscosity of the fluid at bulk temperature (Pa s), w - Dynamic viscosity of the fluid at walltemperature (Pa s).3. Liquids metals (Hg, Na, Lead Bismuth alloy, etc) : High liquid metals can be used where high heat removal is to be achieved (e.g :-Coolants in a nuclear reactors). Since for liquid metals , Pr ' 0.01 to 0.04. Nu = f(Pe). - Thermal diffusivity (m2/s), Hg - Mercury, Na - Sodium, - Momentum diffusivity (m2/s),Pr - Prandtl number, Nu - Nusselt number, Pe - Peclet number.4. Mass transfer in liquids flowing past single sphereSh =kCdDAB= 2 + 0.95 Re(1/2)Sc(1/3)When sphere is placed in a still fluid, Re= 0. So, Sh = 2 .Sh - Sherwood number, kC - Mass transfer co-efficient for concentration driving force, d -Diameter (m), DAB - Diffusivity of the system (m2/s), Re - Reynolds number, Sc - Schmidtnumber.5. For a convective mass transport over (external flow) a flat plate under laminar conditionSh = 0.664 Re(1/2)Sc(1/3)and local Shx =Sh2Sh - Sherwood number, Re - Reynolds number, Sc - Schmidt number.8 The paper explores dimensionless groups in fluid mechanics, providing a comprehensive overview of various dimensionless numbers crucial for understanding fluid behavior under different conditions. It discusses significant groups such as Archimedes, Bingham, Bond, and Cauchy numbers, detailing their formulas, notations, and applications in practical scenarios involving fluid dynamics and flows. The analysis emphasizes the importance of these groups in predicting fluid behavior in various engineering and scientific applications.

Dimensionless numbers in fluid mechanics and their significance. Dimensionless numbers in fluid mechanics. Fluid dimensionless numbers.