

FLUID MECHANICS

SAMPLE

Chapter Two

Properties of Fluids

Unit Introduction

A property is just a technological feature that may describe in any way. The qualities of *pressure* (P), *temperature* (T), *volume* (V), as well as *mass* (m), are examples of well-known properties. This list could be expanded and include fewer common ones, including *viscosity*, *heat capacity*, *elasticity modulus* temperature expansion coefficient, electrical resistivity, speed, and altitude (Millat et al., 1996).

Properties are categorized either as extensive or intense, depending on their size. Temperature, pressure, and density are examples of intense properties since they are not affected by the amount of mass present in a system. The value of a property is said to be extensive if it depends on the system's size or extent. Extensive character andies include total mass, usable capacity V , and improving working. These are only a few examples. Imagining a partition that divides the structure into two equal portions provides a quick and straightforward method for determining if a feature is extensive or intense. This method is illustrated in Figure. 2–1. Every component of the new system will receive a value for its intense qualities that is identical to that of the prior system; however, the value for its widespread properties would be cut in half (Panagiotopoulos, 1987).

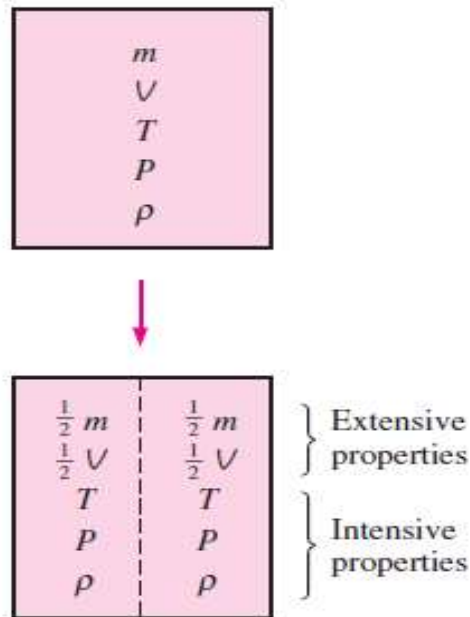


Figure 2.1. Differentiating factors between general and intense characteristics (Source: Ricardo Zavala-Yoe, Creative Commons License).

Lowercase characters indicate comprehensive characteristics, except *mass* m , denoted with a capital letter. Upper-case letters are applied to indicate different terms except for *mass* m . (with *pressure* P and *temperature* T being the obvious exceptions). Specific characteristics are extensive qualities expressed as a function of the unit mass. Volume, which may be calculated using the formula ($v = V/m$), and a particular amount of energy ($e = E/m$), are two instances of specific characteristics (Pitzer, 1955).

They can use system attributes to describe the condition it is now in. However, we have previously learned that even to correct a condition, we don't need to describe every property. When the values of a significant number of variables are stated, the values for the remaining properties are assumed to be those specified for those properties. It is necessary to provide a fixed amount of characteristics to establish a state. The condition postulate provides the following formula for determining the number of attributes present to stabilize the system's current state. Two entirely different and exhaustive qualities can fully characterize the status of a basic compressing system (Assael & Tsolakis, 1996).

Learning Objective

At the end of this chapter, students will be able to:

1. Have a working knowledge of the fundamental properties of fluids and understand the continuum approximation
2. Have a working knowledge of viscosity and the consequences of the frictional effects it causes in fluid flow
3. Calculate the capillary rises and drops due to the surface tension effect

Key Terms

1. Ideal gases
2. Continuum
3. Vapor pressure
4. Viscosity
5. Specific heat

2.1. Continuum

Atoms inside the gaseous state of substance are widely spread apart. However, it is convenient to ignore a substance's atomic structure and consider it a continuous, homogenous mass without any holes or a continuum. We may consider characteristics as point functional and presume they change continuously in space without leap discontinuities thanks to the continuous idealized version. This idealization is accurate when the system we're dealing with is sizable compared to the distance between molecules. This is true of almost all issues except for a few highly specialized issues. Many of our statements, like "the water density inside a glass remains the same in any position," include an implicit continuous idealization. Imagine a watertight container containing oxygen under atmospheric circumstances to get a feel of the distances involved at the molecular scale. The oxygen molecule has a diameter of around 3×10^{-10} m and a mass of 5.3×10^{-26} kg. At 1 atmosphere pressure at 20°C, its mean accessible oxygen pathway is 6.3×10^{-8} m. In other words, an oxygen molecule typically travels 6.3×10^{-8} m (or almost 200 times its diameter) without colliding with some other molecule (Austin & Smith, 1990).

Additionally, at 1 atm pressure at 20°C, there are approximately 2.5×10^{16} oxygen molecules in a small space of 1 mm³ (Fig. 2–2). The continuum concept can be used if the system's great when it comes, just like its diameter—is significantly greater than that of the particles' mean accessible route. The average free path might grow at high vacuums or heights (for example, it is about 0.1 m for atmospheric air at an elevation of 100 km). The restricted gas flow theory must be applied in these situations, and the

effects of specific molecules must be considered. This article restricts our discussion to elements that lend themselves to continuum modeling (Liu, 2002).

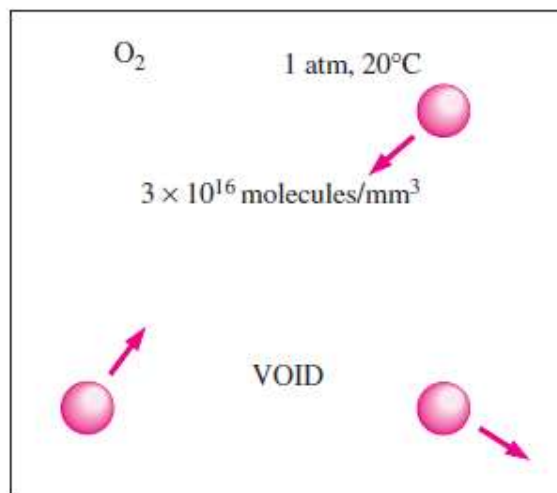


Figure 2.2. A material can be considered a continuum even if there are significant distances between its molecules due to the extraordinarily high molecular density, even in a relatively tiny volume (Source: Wikipedia.org, Creative Commons License).

2.2. The density of Ideal Gases

However, occasionally it is helpful to have certain straightforward relationships between the characteristics that are sufficiently accurate and complete. Properties tables give exact data on the properties. Any state's equation would be any relation between a product's pressure, temperature, density, or volume. This ideal-gas equation, written as is the most straightforward and well-known state equation for compounds inside the gas phase (Rao & Purohit, 1976).

$$Pv=RT \quad \text{or} \quad P=\rho RT$$

Whenever P remains the absolute pressure, v is the specific size, T is the thermodynamical (absolute) temperature, r is the density, and R is the continuous gas. The continuous gas R is different for each gas and is strongminded from $R = R_u / M$; somewhere, R_u is the worldwide gas continuous whose value is $R_u = 8.314 \text{ kJ/mol} \cdot \text{K} = 1.986 \text{ Btu/lb. mol} \cdot \text{R}$. M is the gas's molar mass (also called molecular weight) (Hutchinson & Waser, 2007).

Did you know?

There are three physical properties of fluids that are particularly important: density, viscosity, and surface tension.

2.3. Vapor Pressure and Cavitation

It is commonly known that pressures and temperatures have a relationship and that they are dependent attributes for pure components throughout each. The saturated temperature T_{sat} is when a pure material transforms into a different phase at a specific pressure. The saturation pressure, or P_{sat} , is when a pure material transforms into a different phase at a specific temperature. For instance, the saturated water temperature is 100°C at a typical pressure atmosphere (1 atm or 101.325 kPa). On the other hand, water has a saturation pressure of 1 atm at 100 °C (Chivate & Pandit, 1995).

The pressure a pure substance's vapor exerts when it is in equilibrium conditions, including its fluid at a specific temperature, is known as its vapor or P_v . The saturated pressure P_{sat} of a liquid ($P_v = P_{sat}$) is the same as P_v , a characteristic of the pure material. It's important to distinguish between vapor pressure and partial pressure. The pressure of the vapor or gas, combined with other gases, is referred to as the pressure head. As an illustration, atmospheric air is made up of dried air and water vapor; therefore, air pressure results from adding both partial pressures. Because air primarily comprises nitrogen and oxygen, its partial pressure for water vapor only makes up a minor portion (often below 3 %) of atmospheric pressure. When no fluid is available, such a vapor's partial pressure must be lower or equivalent to vapor pressure. The system is also referred to as being saturated if both vapor and liquids are available and in equilibrium since the vapor pressure should equal the evaporation rate. The differential between partial and vapor pressure regulates evaporation across open water bodies like lakes. For instance, water has an evaporation rate of 2.34 kPa at 20 °C (Yan & Thorpe, 1990).

Because of this, a water-filled bucket at 20°C left inside a room to low humidity at 1 atm would then proceed to evaporate until either all of the moisture evaporates (there isn't enough liquid inside the room to create phase equilibration) or the evaporative cooling stops whenever the partial pressure of water vapor inside the room begins to rise to 2.34 kPa, where at point process equilibrium is created (Qiu et al., 2016).

The saturation pressure, as well as the vapor pressure, remain equal in pure vapor activities between such a pure product's phases of liquid and vapor. Be aware that the value will remain the same whether the pressure is determined inside the vapor or liquid phase (assuming it is measured at a position near the liquid-vapor boundary to avoid the hydrostatic effects). With increasing temperature, vapor pressure

rises. As a result, a material that boils at lower pressures at greater temperatures. For instance, water is boiling at 134°C in a pressure cooker with a 3 atm total pressure, while at 2000 m elevation, in which the air pressure is 0.8 atm, it boils at 93°C in a regular pan. Appendices 1 and 2 provide various chemicals' saturated (or vapor) pressures. Table 2-1 briefly references the mini table regarding water (Molland et al., 2004).

Table 2.1. Water's saturation (or vapor) pressure at different temperatures

Temperature $T, ^\circ\text{C}$	Saturation Pressure $P_{\text{sat}}, \text{kPa}$
-10	0.260
-5	0.403
0	0.611
5	0.872
10	1.23
15	1.71
20	2.34
25	3.17
30	4.25
40	7.38
50	12.35
100	101.3 (1 atm)
150	475.8
200	1554
250	3973
300	8581

We are interested in vapor pressure because liquid pressure in aqueous systems can fall under vapor pressure in certain places, leading to unintentional vaporization. For instance, in areas (including the tips areas of impellers or even the suction ends of pumps), when the pressure goes below 1.23 kPa, water at ten °C would flash, becoming vapor and creating bubbles. As they are pushed away from low-pressure zones, the vapor bubbles, also known as Cavitation, because they create "cavities" inside the liquid and collapse, creating incredibly damaging and exceptionally high waves (Aspinwall et al ., 2011).

Cavitation is a phenomenon that frequently results in performance problems and sometimes even impeller blade attrition. It is a crucial factor to consider when designing hydraulic turbines and pumps (Fig. 2.3). Cavitation should be reduced (or reduced) in flow regimes because it impairs performance and produces obtrusive vibrations and noise that damages equipment. Long-term pressure spikes brought on by many bubbles bursting close to a solid surface can lead to erosion, surface pitting, fatigue

damage, and, eventually, the machinery's or elements' breakdown. Cavitation's distinctive tumbling sound may be used to detect its existence in a flow system (Schultz & Matthews, 1997).

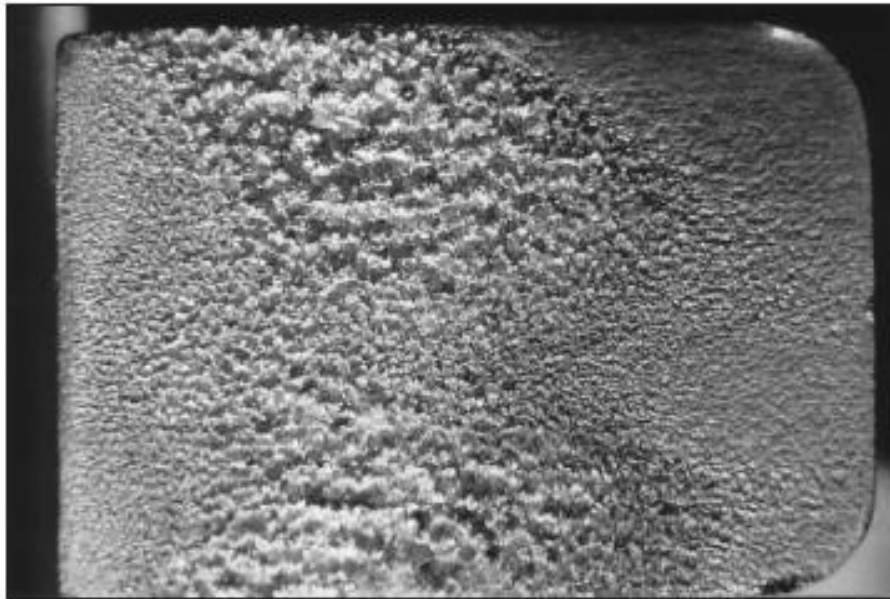


Figure 2.3. A 16 mm by 23 mm piece of aluminum suffered cavitation damage during a 2.5-hour test run at 60 m/s. The sample was found downstream of a cavity generator created deliberately to provide significant harm potential (Source: Wikipedia.org, Creative Commons License).

2.4. Energy and Specific Heats

The overall energy E (or e on such a unit mass basis) of such a system could occur in various forms, including thermal, physical, kinetic, potentially electric, electromagnetic, chemical, and nuclear energy. The term "*microscopic energies*" refers to the types of energy connected to a state's molecular structure and the intensity of its molecular activities. The interior power of a system, indicated by U , is the total, including all microscopic types of energy (or u on a unit mass basis) (Angell & Borick, 2002).

Movement and external factors affect a state's macroscopic energy, including gravitational, magnetic, electrical, and surface tension. Kinetic energy refers to the energy a system contains due to its mobility within a specific frame of reference. The kinetic energy per unit weight is defined as $ke = V^2/2$ when every system component moves at the same speed. V stands for the system's speed concerning a stable frame of reference. Potential energy, which refers to the power which a means being able because of its elevation inside a gravity field, has been displayed on a per-unit mass basis as $pe = gz$, in which g is just the angular velocity, as well as z , seems to be the elevation of the program's gravity center position concerning a specific arbitrarily chosen reference frame. The perceptible and latent types of energy

stored are usually referred to as heat in everyday life, and the heat contents of bodies are also discussed. To avoid any misunderstanding with heat exchange, those types of energy are typically known as thermal in engineering (Struble & Brown, 1986).

2.5. Viscosity

A frictional force forms at the contact area with direction counter to motion whenever two stable bodies in touch move concerning one another. For instance, to raise a table on the floor, we must exert a force on it in the horizontal plane sufficient to counteract the frictional forces. The *friction coefficient* between the tables and the floor determines how much force is required to raise the table (Fenghour & Vesovic, 1998).

The circumstances are comparable whenever fluid travel concerning a solid or when two liquids flow about one another. We can move relatively quickly in the air, unlike in the sea. The slowed downward movement of a glass ball deposited in an oil-filled tube shows how difficult it might be to move in oil. Viscosity seems to be the attribute that best captures a fluid with low viscosity ability to resist motion, often known as its "*fluidity*." The *drag force* is still the force a moving fluid applies on an object inside the flow direction; its magnitude is somewhat determined by viscosity (Fig. 2.4) (Huber et al., 2009).

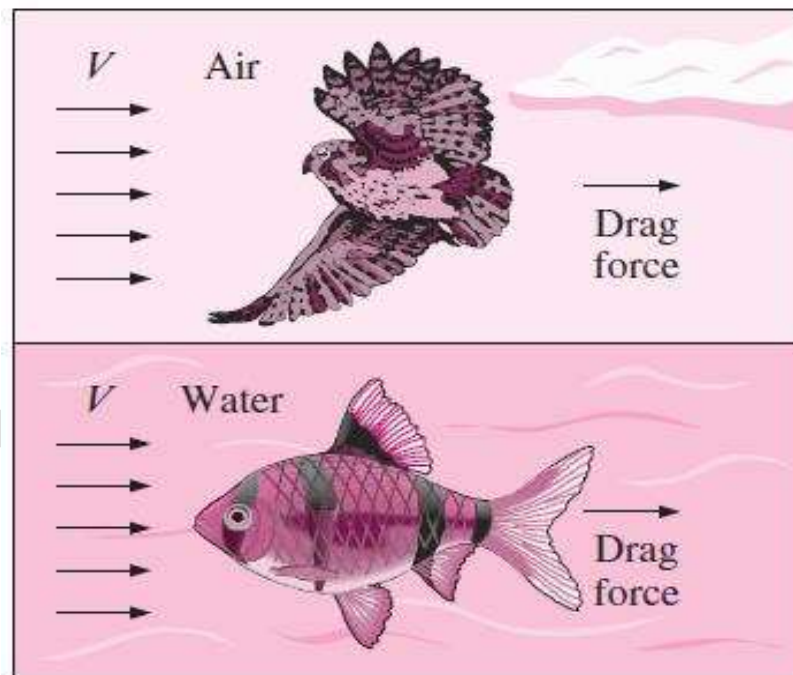


Figure 2.4. Due in part to friction brought on by viscosity, a fluid moving relative to a body causes a drag force to be applied to the body (Source: tecscience.com, Creative Commons License).

I am considering a fluid layer among two massive parallel plates (or two parallel plates submerged in a vast body of fluid) spaced by a distance l . to establish a relationship for viscosity. Then, while holding the bottom plate stationary, a consistent perpendicular force F is exerted on the top plate (Crandall, 1997).

The top plate moves continually under the effect of such a force at a steady speed V just after early transient conditions. The fluid layer under the interface with both the top plate travels together at a similar speed while adhering to a plate surface. This same shear force on just this flowing fluid is

$$\tau = \frac{F}{A}$$

Where A represents the region in which the plate and the fluid come into touch. Keep in mind that such a fluid layer is continually deformed by shear force (Andrade, 1930).

Remember:

By definition, anything that can flow is fluid. The water we drink and the air we breathe are all examples of fluids. Essentially, all liquids and gases are fluids.

2.6. Surface Tension and Capillary Effect

A drop of plasma constructs a hump on such a horizontal glass, a drop of mercury shapes a nearly perfect spherical shell and could be started rolling over a single layer like such a steel ball; water droplets from rain, as well as dew, hold from trees as well as leaves of tree branches, a mist of globular particles are formed by liquid fuel injection system into such an engine, spherical droplets are formed by condensation pouring from such a leaky faucet, a detergent bubble is released into the atmosphere (Pasandideh-Fard et al ., 1996).

Water particles act like tiny spherical bubbles filled with fluid in such and other observations, while the liquid's surface behaves like a stretched flexible membrane beneath stress. According to the attraction interactions between the liquid's particles, a pulling pressure that produces this tension occurs parallel to its surface. Surface tension, often known as σ , is the strength of such a force per unit length and is typically given in units of N/m (or lbf/ft in English terminology). The corresponding unit of $N = m/m^2$ or J/m^2 represents this phenomenon, also known as surface energy. Inside this instance, σ stands for the quantity of stretch required to expand the liquid's contact area by a given amount (Chevalier et al ., 2018).

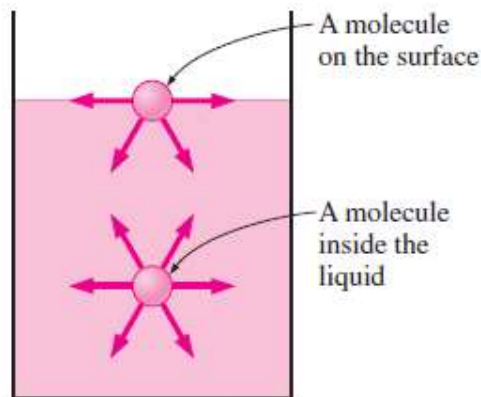


Figure 2.5. *Attractive forces are present on the liquid's surface and inside its molecules (Source: Visionlearning.com, Creative Commons License).*

We offer a microscopic perspective of surface tension in Fig. 2.5 by concentrating on two fluid particles, one located on the liquid's surface and another deep into the liquid body. Due to symmetry, the forces of attraction exerted on the inside molecule by molecules around it balance one another. However, the attractive forces operating on the particles on the surface are still not symmetrical, and the forces of attraction generated by the gas particles above are often relatively tiny. As a result, a net attraction force acts on each molecule at the liquid's surface, which tends to draw those molecules in that direction. The compacted molecules generate the repelling forces underneath the surface balance of that force (Perlin & Schultz, 2000).

The liquid reduces its surface area as a response to the compressing action. This explains why droplets tend to take on such a spherical form with a little surface area per unit volume.

You might have also laughed when you noticed that certain insects could walk or land on water and that tiny steel needles could float. Likewise, surface tension balances the masses of various items and enables these occurrences (Deike & Melville, 2015).

2.7. Capillary Effect

The *capillary effect*, which is the rising and fall of such fluid in a thin tube put into the fluid, is another fascinating impact of surface tension. Capillaries are limited-flow tubes or similarly tiny tubes. This phenomenon causes kerosene to rise via a cotton wick placed within kerosene lamp reservoirs. Water can also ascend to the summit of big trees due partly to the capillary action. Meniscus refers to a liquid's concave surface layer inside a capillary tube (Tzanakis et al., 2015).

When water contacts a glossy coating at the margins, it typically bends up slightly. Mercury, however, does the exact opposite and curves downward at the corners. The typical way to describe this

phenomenon is to remark that while mercury doesn't wet the glassware, water does so by adhering to it. The contracting (or *soaking*) angle θ , which is the angle formed just at the point of interaction by the tangential to a liquid surface and the solid surface, serves as a measure of the capillaries effect occurs strength. Along that same tangent line, the surface tensile stress pushes against the solid surface. Whenever a liquid touches the surface $\theta < 90^\circ$, it is thought to be wet, but when it is not $\theta > 90^\circ$, it is said to be dry. Water and many other organic solvents have a virtually zero contact angle on glass in the surrounding atmosphere or $\theta \approx 0^\circ$. The water inside a glass tube experiences surface tension, which exerts an upward force around the tube's perimeter, trying to draw the water up. Water rises inside the tube as just a response till the mass of a liquid well above the liquid level of storage balances the surface strain energy. The contact angle between mercury glass and kerosene glass in the air is 130° and 26° , respectively. Remember that varied settings often result in varying contact angles (such as another gas or liquid in place of air) (Liang et al., 2019).

Activity 2.1

Give a detailed presentation on capillary effect.

Summary

This chapter discusses several characteristics that are often utilized in *fluid mechanics*. The remainder is referred to as intense characteristics, whereas the mass-dependent qualities of a body are known as extended characteristics. Specific volume denotes volume per unit weight, whereas density is defined as the mass of a volume. The proportion of a product's *density* to that of freshwater at 4°C is known as its *specific gravity*.

$$SG = \frac{\rho}{\rho_{H2O}}$$

Wherein ρ is the *density*, P seems to be the absolute *pressures*, T is the thermodynamics temperatures, and R represents *gas constants*. Saturating pressure refers to the pressure that occurs when a pure material transforms into a different phase at a specific temperature. The saturated pressure is also known as the vapor pressure P_v during processes that occur when a pure material transitions between its vaporous and liquid phases. When vapor bubbles develop in lowland areas of a liquid (a process known

as *Cavitation*), they burst as they are pushed away from the low-pressure areas, creating incredibly damaging and incredibly high waves.

Review Questions

1. What is the main difference between fluids and solids?
2. How do fluids differ from liquids?
3. What is the most familiar type of fluid?
4. What distinguishes a fluid from a solid?
5. What is the primary characteristic of a fluid?

Multiple Choice Questions

1. What is the name of the fluid property that describes a fluid's resistance to shearing or flow?
 - a) Viscosity
 - b) Density
 - c) Surface tension
 - d) Compressibility
2. Which of the following is NOT a fluid property?
 - a) Viscosity
 - b) Density
 - c) Surface tension
 - d) Mass
3. What is the name of the fluid property that describes a fluid's resistance to flow?
 - a) Viscosity
 - b) Density
 - c) Surface tension
 - d) Compressibility
4. What is the name of the fluid property that describes the amount of space a fluid occupies?
 - a) Viscosity
 - b) Density
 - c) Surface tension
 - d) Volume

Answers to Multiple Choice Questions

1. (a) 2. (d) 3. (a) 4. (d)

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