FDE449 Physical Properties of Foods

Content

1) Viscosity characteristics of some foods
2) Viscosity measurement methods

Viscosity characteristics of some foods

- Milk products
- Oils and fats
- Sugar solutions
- Hydrocolloids

Milk and milk products

- It consists of an aqueous phase containing lactose, minerals, soluble proteins (whey proteins), water-soluble vitamins and trace elements.
- Dispersed in the aqueous phase as very small dropets or globules is a fat phase.
- The characteristic milky appearance is due to a colloidal dispersion of milk protein (casein) and calcium in the solution.
- There are considerable differences between the composition of milk from different species.
- Furthermore, milk from a particular species can show a considerable fluctuation in composition from animal to animal and from season to season.
- Ordinary cows' milk contains about 3.8% fat and 3.3% protein (2.6% casein).
- As such, the dynamic viscosity of fullcream milk is of the order of 2×10^{-3} N s/ m^2 (2 cP) at 20^oC and under moderate conditions of shear it acts as a Newtonian fluid.

- Milk can be processed by a variety of techniques to prolong its shelf-life and to convert it to milk-based products.

- Most processing techniques may alter the condition of one or both of the dispersed and aqueous phases, and therefore the dynamic viscosity.

- Table gives an indication of the range and viscosities of some milk-derived products.

Viscosities of some milk and dairy products

Product	Temperature (^oC)	Viscosity
Skim-milk (5% lactose)	20	1.70 $x10^{-3}$ N s/m^2
Skim-milk (5% lactose)	72	0.60 $x10^{-3}$ N s/m^2
Whole milk (5% lactose)	20	2.10 $x10^{-3}$ N s/m^2
Whole milk (5% lactose)	72	0.75 $x10^{-3}$ N s/m^2
Cream (20% fat)	20	6.1 $x10^{-6}$ m^2/s
Cream (35% fat)	20	14 $x10^{-6}$ m^2/s
Cream (45% fat)	20	35 $x10^{-6}$ m^2/s
Butter	30	60 $x10^{-6}$ m^2/s

- Heat treatment of milk normally gives a slight increase in the viscosity, probably because of the denaturation of whey proteins.
- Homogenization will increase the viscosity of full-cream milk by up to 15%.
- Milk that is to be sterilized or UHT treated will require homogenization to prevent fat separation during storage.
- Some pasteurized milk is also homogenized.
- Homogenization appears to give the milk a creamier mouth feel.
- Cream products also require homogenization. Single cream (18% fat) undergoes considerable homogenization (up to 200 bar) to improve the consistency and to give the cream.
- Whipping cream (35% fat) requires very little, or no, homogenization and appears to have a runny consistency before it is whipped.
- Homogenization would impair the whipping behaviour of the cream.

- Double cream (48% fat) requires a low homogenization pressure (around 30 bar); if the homogenization pressure is too high, the cream may well solidify in the pack.
- The rheology of cream products is extremely complicated and the final viscosity of the cream will depend upon such factors as the separation temperature, fat content, heat treatment, rate of cooling and storage conditions.
- Skim-milk, full-cream milk and cheese whey are evaporated to as high a solids content as possible, prior to spray drying. The final concentration may be limited by either the viscosity of the feed or the solubility limits of lactose.
- Such fluids can also be concentrated by membrane techniques such as reverse osmosis and ultrafiltration.
- Again the extent of the concentration is governed by the viscosity characteristics of the concentrate.
- Any process that results in the souring of milk normally increases the viscosity of the product.

Oils and fats

- Oils and fats are essentially esters of glycerol and fatty acids, derived from plant and animal sources.
- Different oils will have different fatty acid compositions and hence different viscosities.
- Oils are normally liquid at ambient temperature; fats are normally solid.
- Oils are generally more viscous than aqueous solutions.
- They are usually Newtonian in behaviour, although they might show pseudoplastic behaviour at high shear rates.
- In general terms, the viscosity will increase as the amount of long-chain fatty acids increase and as the degree of saturation increases.
- Thus, hydrogenation will increase the viscosity.

Oils and fats

- Viscosity is not one of the physical tests that is used to characterize an oil,
- but the viscosity will be important when processing oils and fats.
- The viscosity values are recorded for some common vegetable oils in Table.

Kinematic viscosities of oils

Oil	Temperature (°F)	Kinematic viscosity (cSt)
Almond	100	43.2
Olive	100	46.7
Rape seed	100	50.6
Cotton seed	100	35.9
Soya bean	100	28.5
Linseed	100	29.6
Sunflower	100	33.3
Castor	100	293.4
Coconut	100	29.8
Palm kernel	100	30.9

Sugar solutions

- There are a whole range of sugar solutions available to the food processor.
- The viscosity characteristics of single sugars depend upon the temperature and the concentration.
- As the temperature decreases and the solids content increases, the viscosity will increase.
  - Most single sugar solutions are Newtonian in behaviour.
  - For corn syrups, high-fructose corn syrups and invert sugar solutions, an extra factor affecting the viscosity is the degree of conversion or inversion.
  - A wide variety of concentrated fruit juice and purées is pseudoplastic at high concentrations.

Hydrocolloids

- Hydrocolloids are polymeric materials that are soluble or dispersible in water.
- They are usually added to food formulations to increase their viscosity or to obtain a gelled consistency.
- In very dilute solutions, most of the listed materials are Newtonian in behaviour.
- As the concentration increases, the viscosity rapidly increases and there is often a transition from Newtonian to non-Newtonian behaviour.
- Many of them form gels at relatively low concentrations.
- They are derived from a wide variety of plant or animal sources, or by the process of fermentation.

Viscosity data for some hydrocolloids

Hydrocolloid	Viscosity of solutions (cP or mPa s)		Temperature (°C)	Transition concentration from Newtonian to non-Newtonian behaviour (%)	Quantity of hydrocolloid to obtain a viscosity of 100 cP (mg per 100 ml of water)
	1% solution	5% solution			
Gum arabic	1.2	2.7	30	40	Very high
Gum ghatti	2.0	288	25	—	—
Gum karaya	800	2×10^4	25	0.5	—
Gum tragacanth	500–3000	—	—	0.5	—
Locust bean-gum	150	—	25	—	455
Guar gum	5000	—	—	0.5	500
Carrageenan	120 (gelation)	—	40	—	Gelation
Xanthan	1000	—	25	—	—
Cellulose gums	5–600	60–>30000	20	—	780–4600

This table shows, where available, the viscosity of 1% and 5% dispersions, the experimental temperature and the transition concentration from Newtonian to non-Newtonian behaviour.

Hydrocolloids

- The viscosity of many hydrocolloids may be significantly affected by the pH of the medium and the presence of substances such as salts, sugars and proteins.
- The Brabender (amylograph) viscometer is often used for such materials.
- Proteins form a special class of polymeric material.
- The flow behaviour of dilute and concentrated proteins in solution depends upon pH, ionic strength and temperature (as is the case for many of the hydrocolloids).

Methods for determining viscosity

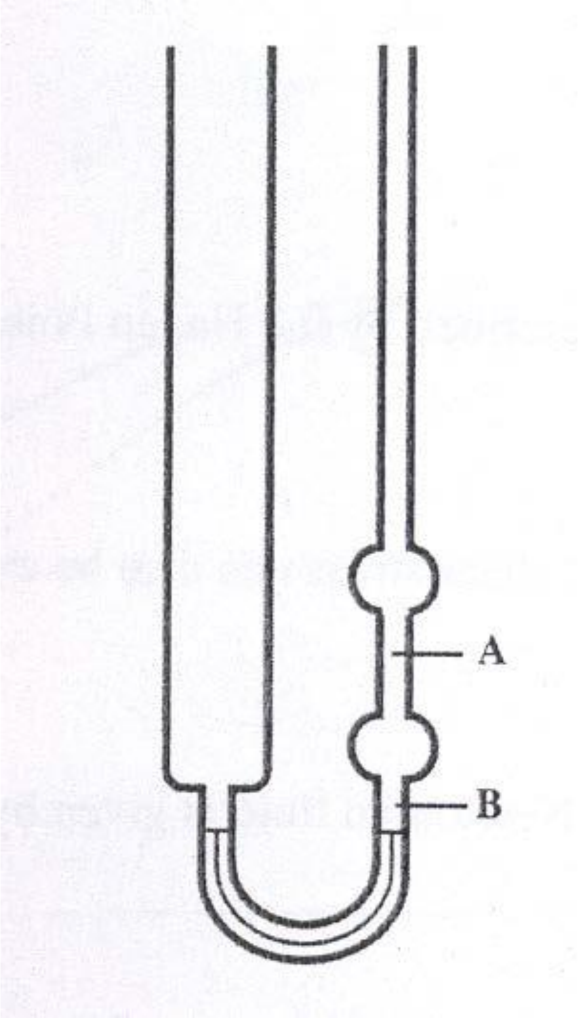
- Successful measurement and evaluation of the rheological properties of a system depends on the selection of the appropriate method and an accurate viscometer.

- The design of viscometers is based on temperature and process parameters.

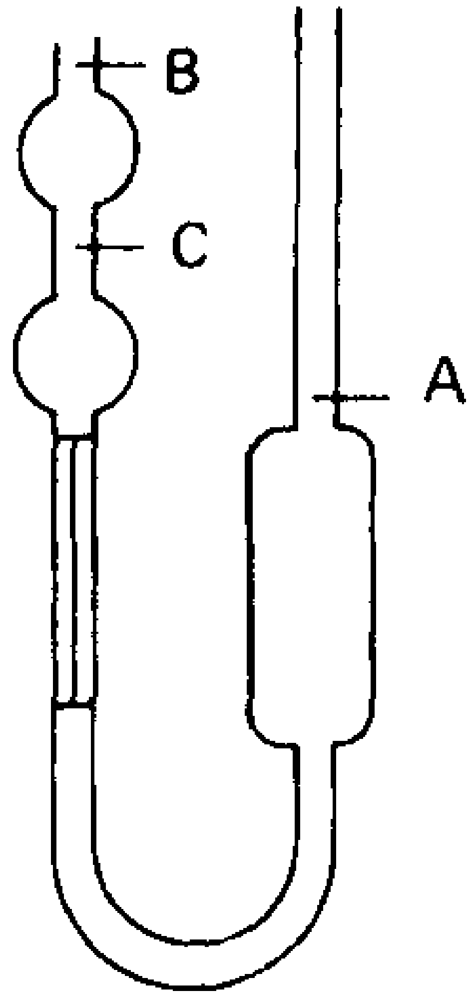
The most commonly used viscosity measurement devices

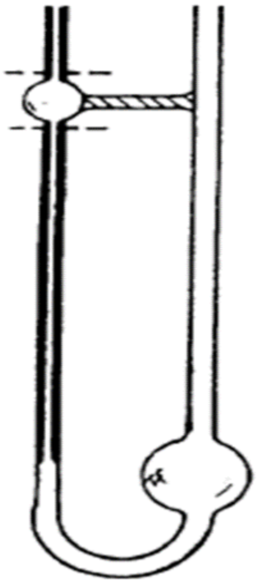
- Capillary flow viscometers,
- Orifice type viscometers,
- Falling ball viscometers, and
- Rotational viscometers.

Capillary flow viscometers

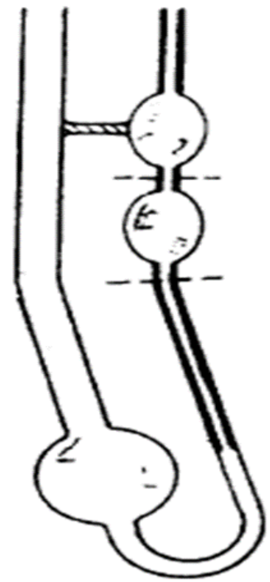


Reverse- flow viscometer.

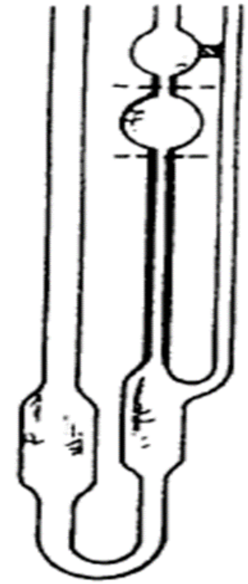

B
C
A



OSTWALD



CANNON-FENSKE



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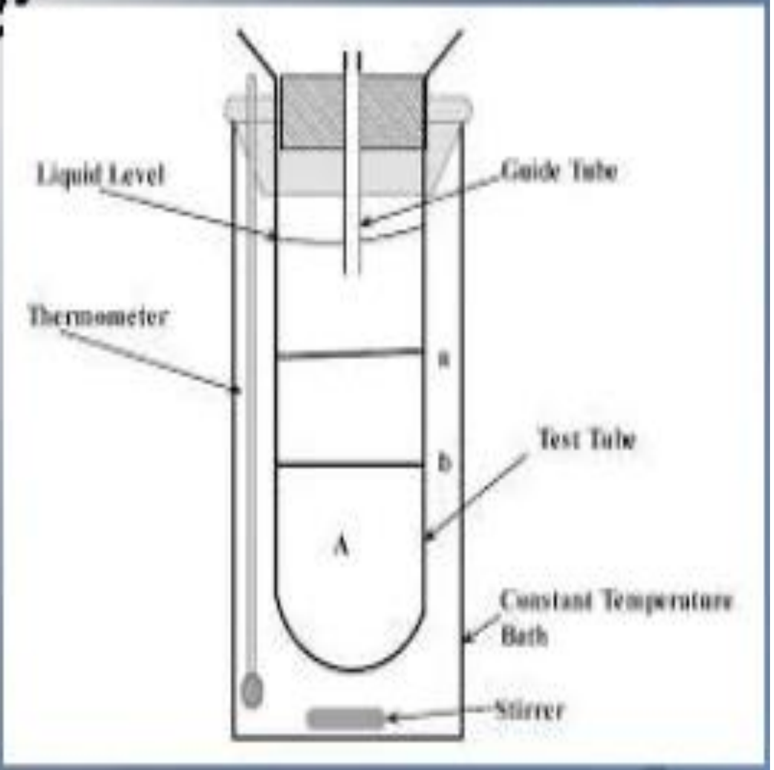
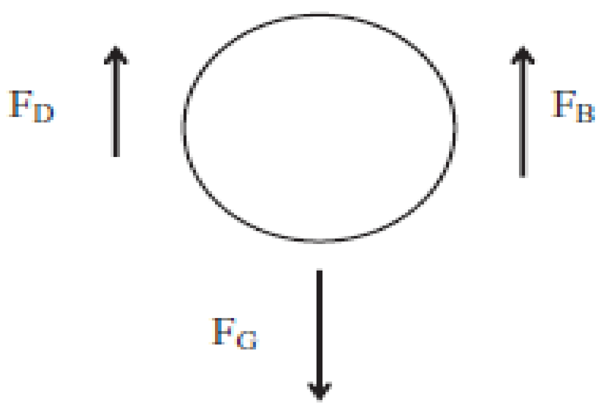
1.Orifice viscometer

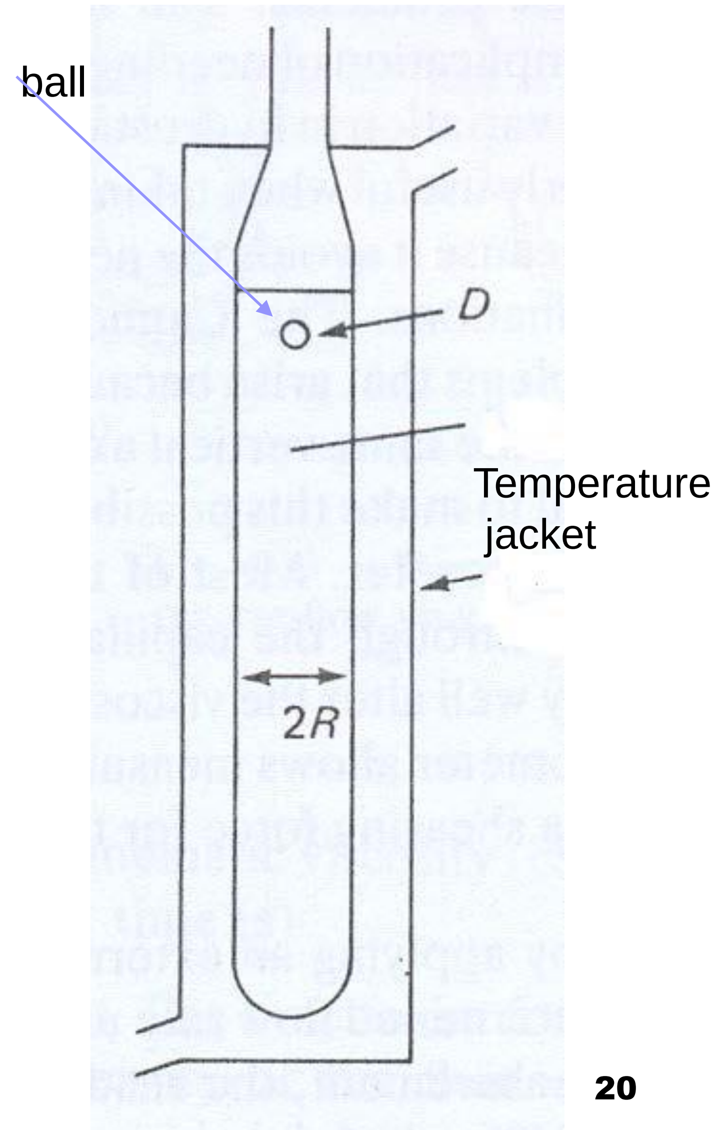
- An orifice viscometer usually consists of a cup with a hole, through which the fluid flows.
- Viscosity is determined by timing how long it takes the cup to empty, and is measured in cup seconds.
- Orifice viscometers are easy to use manually, thanks to the fact that they're simply dipped into the fluid being worked with — making them popular in painting industries. They include Zahn Cups, Ford Cups, and more.



Falling-sphere (ball) viscometers

- These types of viscometers involve a vertical tube where a ball is allowed to fall under the influence of gravity.
- It operates on the principle of measuring the time for a ball to fall through a liquid under the influence of gravity.
- When the ball falls through the fluid, it is subjected to gravitational force, drag force, and buoyancy force (Fig.).





Falling-sphere (ball) viscometers

Net force (F_{Net}) = Gravitational force (F_G)- Buoyancy force (F_B)- Drag force (F_D)

- When equilibrium is attained, the upward forces and downward forces are balanced and the object moves at a constant velocity (the terminal velocity).
- If the flow is streamline for a spherical particle of diameter D, these forces can be represented as:
- This equation is known Stokes' law

$$v = \frac{D^2(\rho_2 - \rho_1)g}{18\mu}$$

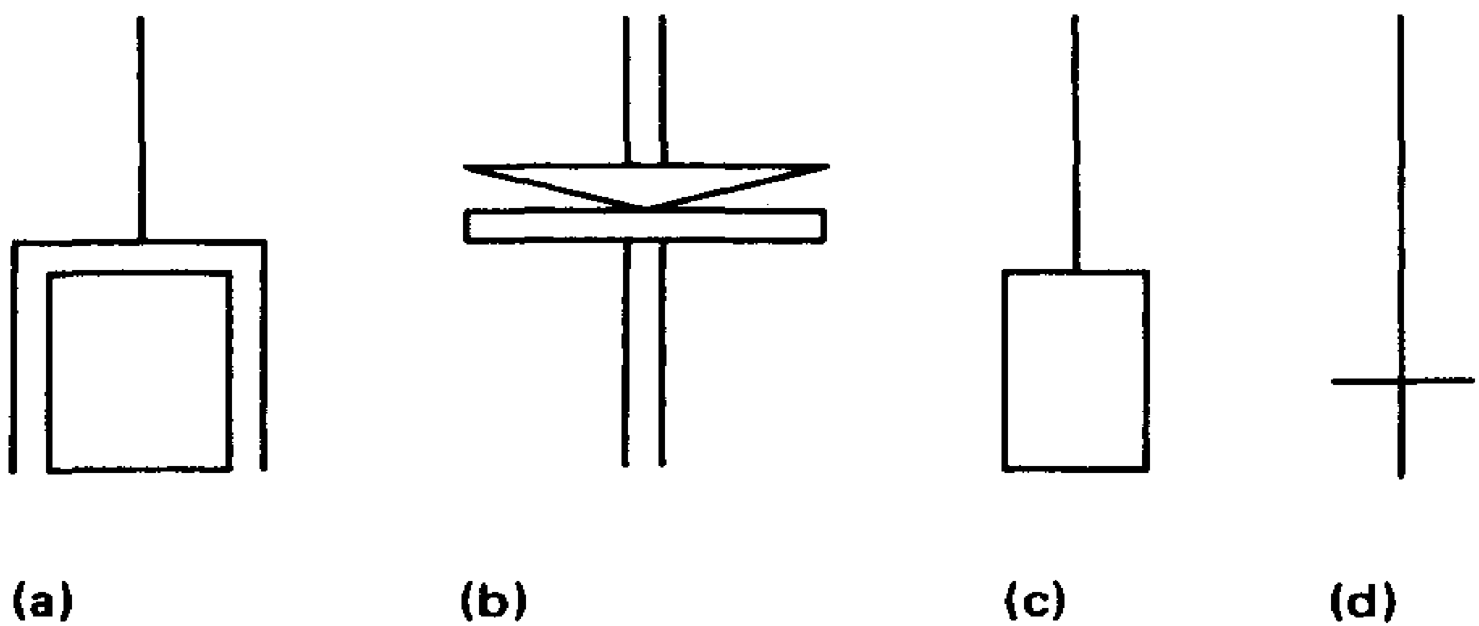
where v (m/ s) is the terminal velocity, D (m) is the particle diameter, p_2 (kg/ m^3) is the particle density, p_1, (kg/m^3) is the fluid density and μ (N s/m^2) is the dynamic viscosity.

Rotational viscometers

The major types of rotational viscometers:

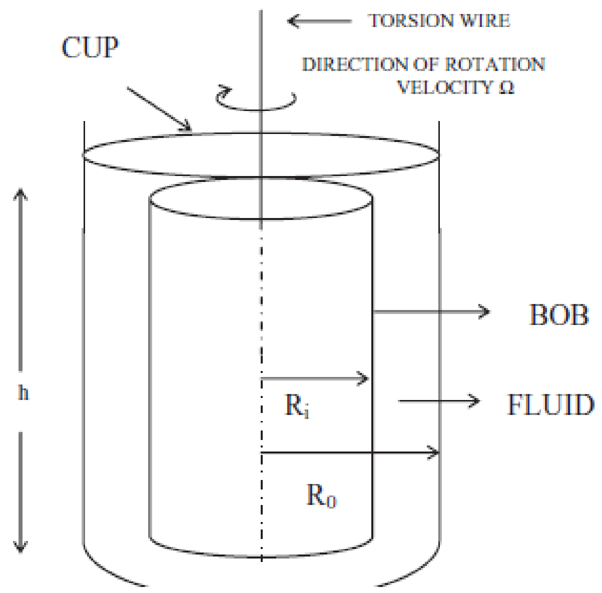
- The concentric-cylinder type
- The cone-and-plate type
- The single-spindle type

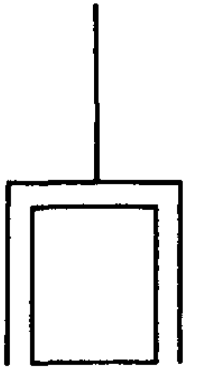
The principle is the same for all types.



Types of measuring system used with rotational viscometers:
(a) concentric cylinder; (b) cone and plate; (c) single spindle;
(b) (d) T-piece spindles (for high-viscosity fluids and gels).

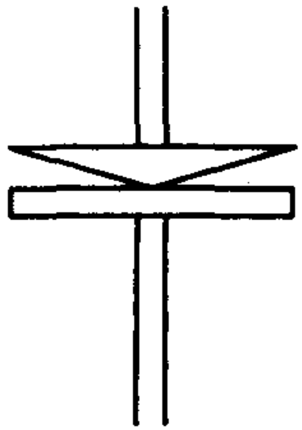
Concentric-cylinder type



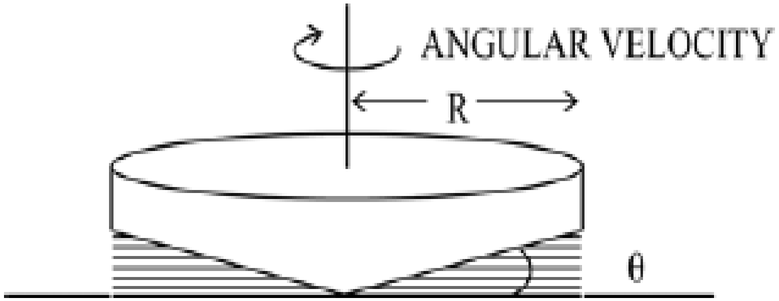


(a)

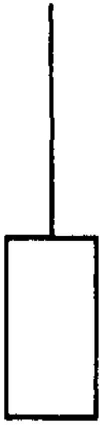
Cone-and-plate viscometers



(b)



Single-spindle viscometers (Brookfield viscometer)



(c)

Brookfield viscometer

Single-spindle viscometers

- Normally, it operates at eight different speeds, and it is a matter of trial and error to select a suitable spindle and a rotational speed for a particular fluid.
- The steady-state deflection is noted and a conversion chart is provided to estimate the apparent viscosity under the test conditions.
- It is possible to determine the apparent viscosity at different speeds (shear rates) but, because it is not possible to predict the exact shear rate, the results are normally presented in the form of apparent viscosity against rotational speed.
- When viscosity data are obtained using a Brookfield viscometer, the model number, the spindle size, the rotational speed and the temperature should always be quoted; otherwise, it would be difficult for such data to be reproduced.

Viscometer selection

- Simple viscometers can be constructed very cheaply, e.g. using a length of capillary tube, a few small metal spheres and a clear tube (even from laboratory filter funnels).
- At slightly more expense, but still relatively cheap, are the U-tube capillary flow viscometers. Each viscometer has a narrow measuring range, but within that range they are very accurate.
- Therefore, several U-tube viscometers would be required to cover the viscosities of typical food materials.

Viscometer selection

- Rotational viscometers are much more expensive.

  The Brookfield viscometer is extremely useful and popular.

- As the viscometer became more sophisticated, it became possible to program them, and to take a fluid through a shear stress-shear rate cycle, to increase or decrease the shear rate at fixed rates or to hold at a constant shear rate for a fixed time.

- The results can be plotted on an x-y recorder (shear stress against shear rate) or an x-t recorder (apparent viscosity or shear stress against time) at a constant shear rate.