• a unit operation mainly to alter the eating quality of a food, to preserve → thermal process & reduction in Aw at the surface or throughout the food.

• Shelf life of fried foods is mostly determined by the moisture content after frying

• The quality is maintained by adequate barrier properties of packaging materials & correct storage conditions.
Theory

- When food is placed in hot oil, the surface temperature rises rapidly and water is vaporised as steam.
- The surface begins to dry out in a similar way as baking & roasting (see Ch. 16).
- Plane of evaporation moves inside food; a crust is formed.
- Surface temperature of the food rises to that of the hot oil, & internal temperature rises more slowly towards 100°C.
- Rate of heat transfer is controlled by the temperature difference between oil & food and by surface heat transfer coefficient.
- Rate of heat penetration into the food is controlled by the thermal conductivity of the food
• The surface crust has a porous structure, consisting of different-sized capillaries.

• During frying, water & water vapour are removed from the larger capillaries & replaced by hot oil.

• Moisture moves from the surface of the food through a boundary film of oil; the thickness controls rate of heat and mass transfer.

• The thickness of the boundary layer is determined by the viscosity and velocity of the oil.

• The water vapour pressure gradient between the moist interior of the food & the dry oil is the driving force behind moisture loss
• Time for food to be completely fried depends on:
  – the type of food
  – the temperature of the oil
  – the method of frying (shallow or deep-fat frying)
  – the thickness of the food
  – the required change in eating quality.

• Foods that retain a moist interior are fried until the thermal centre has received sufficient heat to destroy contaminating micro-organisms & to change the organoleptic properties to the desired extent.
• Temperature used for frying is determined mostly by economic considerations & the requirements of the product.

• At high temperatures (180–200ºC),
  → processing times are reduced & production rates are increased.
  → cause accelerated deterioration of the oil
  → formation of free fatty acids → alter the viscosity, flavour & colour of the oil and promote foaming.

• Acrelein is a breakdown product of oil, produced at high temperatures, which forms a blue haze above the oil and is a source of atmospheric pollution.
• Crust & moist interior foods are produced by high-temperature frying.

• Rapid crust formation is beneficial in that it seals moisture into the food but restricts rate of heat transfer to the interior.

• The bulk of food retains a moist texture & flavour of the ingredients.

• Foods which are dried by frying are processed at a lower temperature to cause the plane of evaporation to move deeper inside the food before the crust forms.

• Methods of commercial frying: shallow frying & deep-fat frying.
Shallow (or contact) frying

• to foods which have a large surface-area-to-volume ratio (eg. bacon slices, eggs, burgers & other types of pattie).

• mostly by conduction from hot surface of pan through a thin layer of oil.

• Thickness of oil layer varies \(\rightarrow\) irregularities in food surface.

• This + the action of steam bubbles which lift the food off the hot surface \(\rightarrow\) causes temperature variations as frying proceeds and produces the characteristic irregular browning of shallow fried foods.

• Shallow frying has a high surface heat transfer coefficient (200–450 Wm\(^{-2}\)K\(^{-1}\)), although not uniformly across the entire surface.
Deep-fat frying

• Heat transfer is a combination of convection within the hot oil & conduction to the interior of the food.

• All surfaces of the food receive a similar heat treatment to produce a uniform colour and appearance.

• for foods of all shapes, but irregularly shaped food or pieces with a greater surface:mass ratio tend to absorb and entrain a greater volume of oil when it is removed from the frier

• Heat transfer coefficients 250–300Wm$^{-2}$K$^{-1}$ before evaporation of moisture from surface begins, then increase to 800–1000Wm$^{-2}$K$^{-1}$

→ violent turbulence caused by steam escaping from the food.
Heat and mass transfer in (a) shallow frying and (b) deep fat frying.
• if rate of evaporation is too high, a thin film of water vapour remains around food & reduces heat transfer coefficient.

• Moisture loss is proportional to the square root of frying time

• Oil absorption occurs as moisture is removed from the food.
Equipment

Shallow-frying equipment
• a heated metal surface covered in a thin layer of oil.

Continuous deep-fat friers
• a stainless steel mesh conveyor submerged in a thermostatically controlled oil tank.
• Heated by electricity, gas, fuel oil or steam.
• Food is metered into oil by slow-moving paddles & sinks to a submerged conveyor or, if the food floats, is held below the surface by a second conveyor
• Inclined conveyor removes food & allows excess oil to drain back into the tank.
• Oil is continuously re-circulated through external heaters & filters to remove particles of food.

• Fresh oil is added automatically to maintain the desired level in the tank.

• Food particles that would burn & affect flavour & colour of the product be removed.

• Oil viscosity is important for optimum heat transfer & minimum entrainment in the food.

• Correct viscosity is achieved when the oil is heated until free fatty acid content reaches 0.4%.

• Methyl silicone may be added to prevent foaming.

• Heat & oil recovery systems → to reduce energy and oil costs.
Continuous deep-fat frier.
(Courtesy of Coat and Fry Ltd.)
Different conveyor arrangements: (a) delicate non-buoyant products (for example fish sticks); (b) breadcrumb-coated products; (c) dry buoyant bulk products (for example half-product snacks); (d) dual purpose (for example nuts and snacks).

(Courtesy of Coat and Fry Ltd.)
Heat and oil recovery system.
(Courtesy of Flomech Ltd.)
Effect on foods

- Effect of frying on foods involves
  - effect on the oil influencing quality of food
  - direct effect of heat on fried product.

Effect of heat on oil

- Prolonged heating of oils at the high temperatures + moisture & oxygen released from foods causes oxidation of the oil to form a range of volatile carbonyls, hydroxy acids, keto acids & epoxy acids.
  - Unpleasant flavours & darkening of the oil.
• Breakdown products: volatile decomposition products (VDP) & non-volatile decomposition products (NVDP).

• VDPs have a lower molecular weight than oil & are lost in vapour from the frier.

• Analysis of vapour → up to 220 different components form the smoke & odour of frying.

• These components are also present in the oil & contribute to the flavour of fried product.

• NVDPs are formed by oxidation & polymerisation of oil & form sediments on the sides and at the base of the frier.
• Polymerisation in the absence of oxygen produces cyclic compounds & high-molecular-weight polymers increase oil viscosity.
  → lowers the surface heat transfer coefficient during frying & increases the amount of oil entrained by food.

• Many of these compounds are polar & slow the evaporation of water & generate foam.

• They add flavour to the fried food, contribute towards the characteristic golden brown colour & optimum fat retention.

• Oil that has been used for a short period gives improved frying compared to fresh oil because these polar compounds promote better contact between the oil & both water on the product surface & vapour leaving the product.

• Quality deteriorates when oil is used for a longer period.
• Oxidation of fat-soluble vitamins in the oil results in a loss of nutritional value.

• Retinol, carotenoids & tocopherols are each destroyed & contribute to the changes in flavour & colour of oil.

• The preferential oxidation of tocopherols has a protective (antioxidant) effect on the oil.

→ most frying oils are of vegetable origin contain a large proportion of unsaturated fats which are readily oxidised.

• The essential fatty acid, linoleic acid, is readily lost & changes the balance of saturated and unsaturated fatty acids in the oil.
Effect of heat on fried foods

- Main factors control changes to colour & flavour:
  - type of oil
  - age & thermal history of the oil
  - interfacial tension between oil & product
  - temperature & time of frying
  - size, moisture content & surface characteristics of food
  - post-frying treatments.
• Each of these factors, together with any pre-treatments, such as blanching or partial drying, influences the amount of oil entrained within the food.

• In many fried foods, oil can account for up to 45% of the product.

→ creating pressure on processors to alter processing conditions to reduce the amount of oil absorbed or entrained in their products.
• Texture of fried foods is produced by changes to proteins, fats & polymeric carbohydrates.

• Changes to protein quality occur as a result of Maillard reactions with amino acids in the crust.

• Losses of carbohydrates & minerals are likely to be small.

• Fat content of food increases owing to oil absorption & entrainment, but the nutritional significance of this is difficult to determine as it varies according to factors, incl. type & thermal history of oil & the amount entrained in food.
• Effect of frying on nutritional value depends on type of process.

• High oil temperatures produce rapid crust formation & seal the food surface.
  → reduces the extent of changes to the bulk of the food
  → retains a high proportion of the nutrients.

Few losses during storage, e.g.
• 17% loss of available lysine in fried fish; this increased to 25% when thermally damaged oil was used

• Shallow-fried liver lost 15% thiamin & no folate.

• Vitamin C losses in fried potatoes are lower than in boiling
  The vitamin accumulates as DHAA owing to the lower moisture content whereas, in boiling, DHAA is hydrolysed to 2,3-diketogluconic acid & therefore becomes unavailable.
• Frying intended to dry food & to extend the shelf life cause substantially higher losses of nutrients, particularly fat-soluble vitamins, e.g.

• Vit E, which is absorbed from oil by crisps during frying, is oxidised during subsequent storage; 77% loss after 8 weeks at ambient temperature. Oxidation proceeds at a similar rate at low temperatures.

• French-fried potatoes lost 74% of vit. E in a similar period under frozen storage.

• Heat- or oxygen-sensitive water soluble vitamins are destroyed by frying under these conditions.
Vacuum Frying

• carried out under pressures well below atmospheric levels, preferably below 50 Torr (6.65 kPa)

• Due to the pressure lowering, the boiling point both of the oil & the moisture in foods are lowered
Advantages of vacuum frying

- Can reduce oil content in the fried product
- Can preserve natural color & flavors of the product due to the low temperature & oxygen content during the process
- Has less adverse effects on oil quality
Some studies

- Shyu & Hwang (2001) → vacuum fried apple chips, 3.115 kPa, 100-110°C
- Garayo & Moreira (2002) → potato chips fried under vacuum (3,115 kPa, 144°C) had more volume shrinkage, were slightly softer, & lighter in color than the potato chips fried under atmospheric conditions (165°C)
  → Vacuum frying is a process that could be a feasible alternative to produce potato chips with lower oil content & desirable color & texture