Frying

PRO

Ch. 17 of Fellows

- 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 100ºC.
- 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.

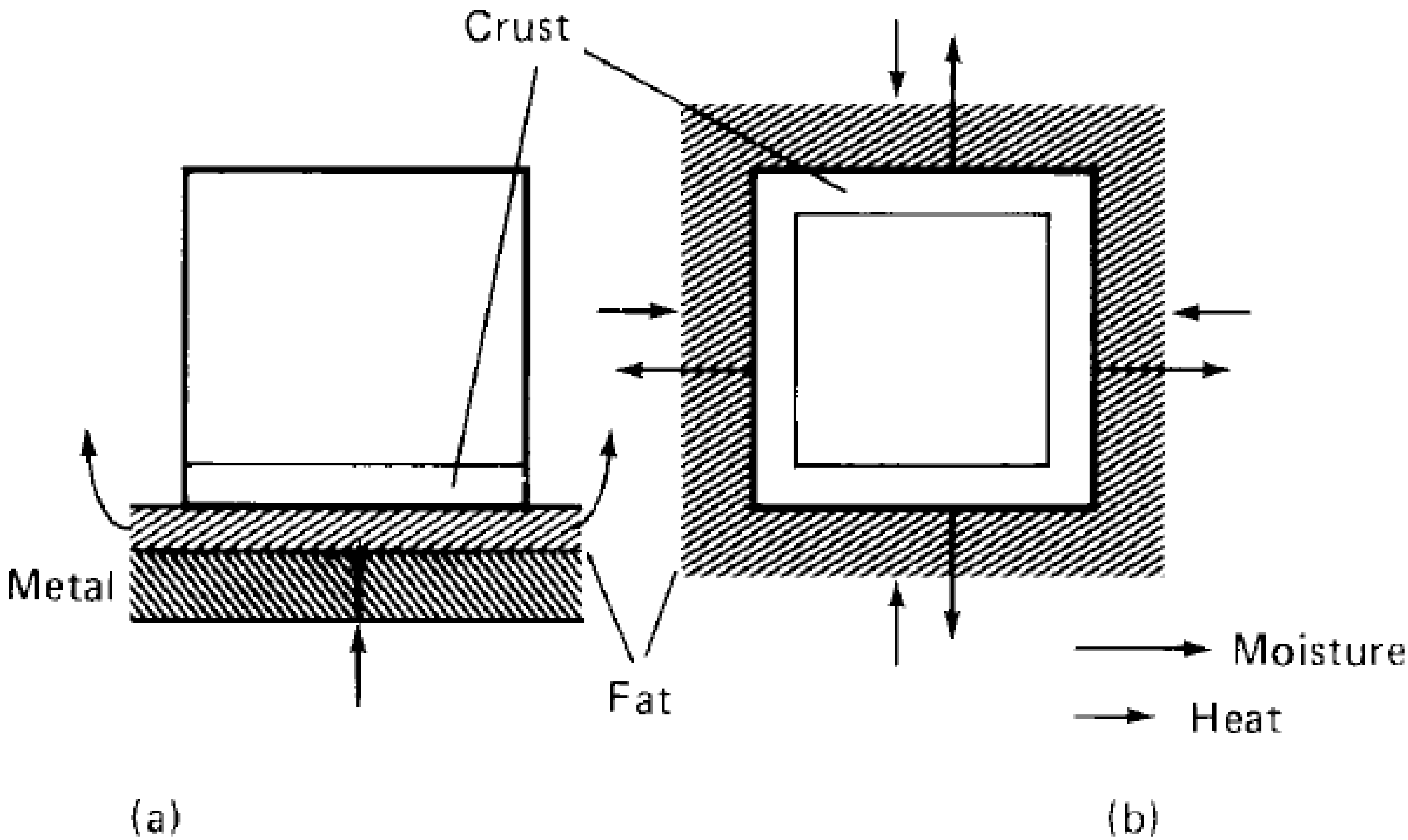
Shallow (or contact) frying

- 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 → irregularities in food surface.
- This + the action of steam bubbles which lift the food off the hot surface → 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 250–300$Wm^{-2}K^{-1}$ before evaporation of moisture from surface begins, then increase to 800–1000$Wm^{-2}K^{-1}$

  → 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.
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- Moisture loss is proportional to the square root of frying time

- Oil absorption occurs as moisture is removed from the food.

Equipment

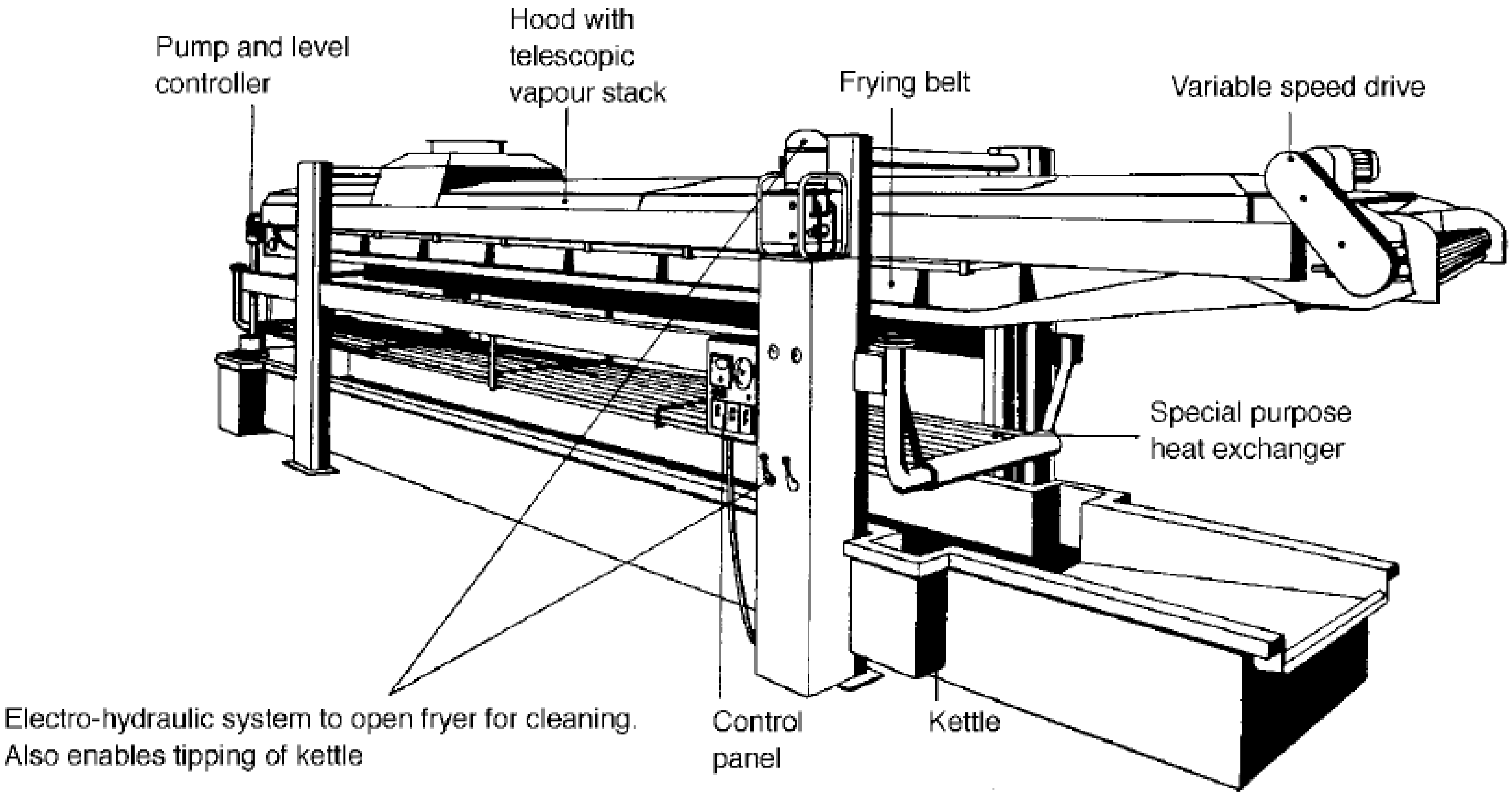
Shallow-frying equipment

- a heated metal surface covered in a thin layer of oil.

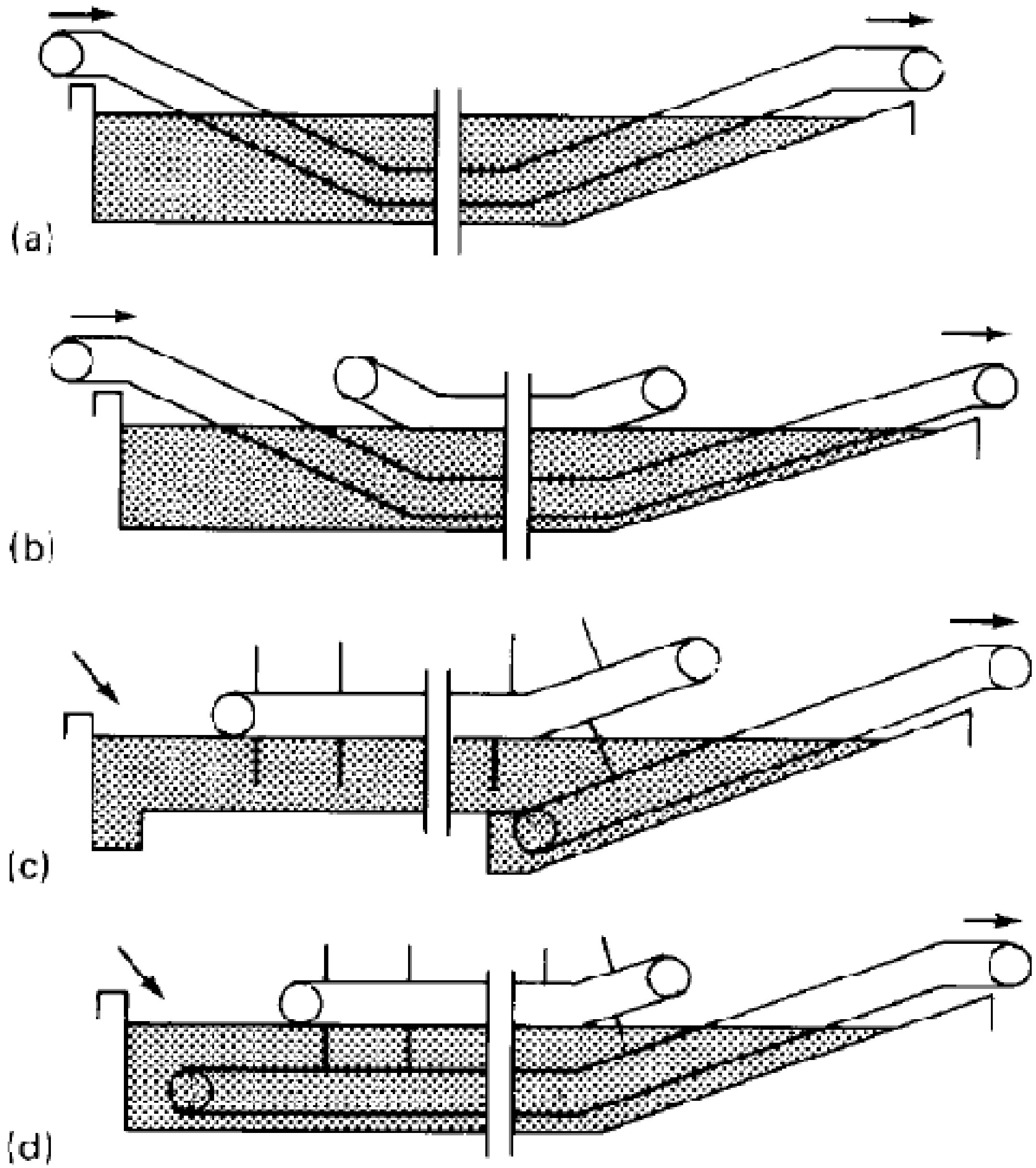
Continuous deep-fat friers

- 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.

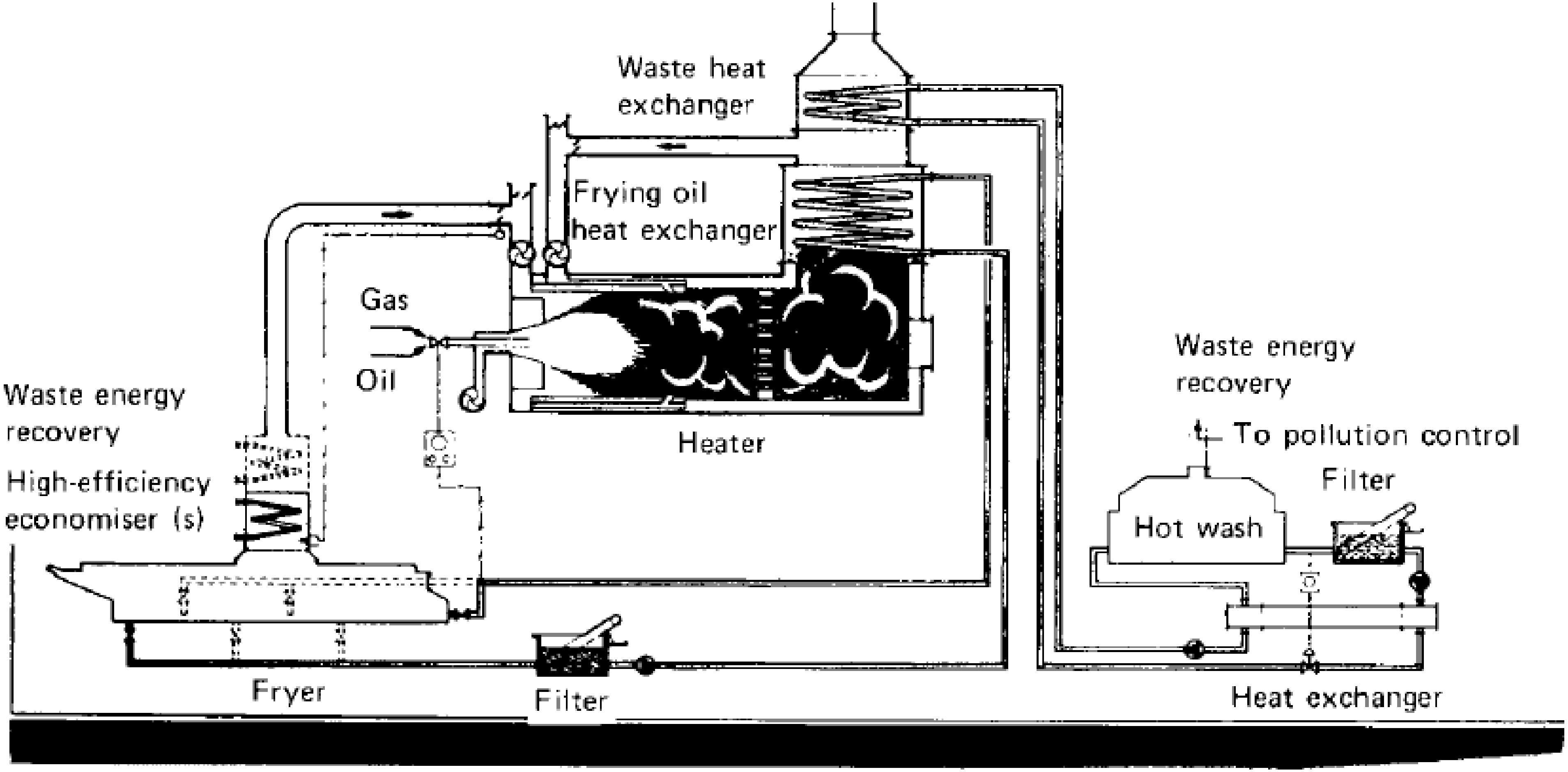
- Oil is continuously re-circulated through external heaters & filters to remove particles of food
- Fresh oil is added automatically to maintain the desired level in the tank.
- Food particles that would burn & affect flavour & colour of the product be removed.
- Oil viscosity is important for optimum 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


Start
Manual Auto
Repeat Cycle
VACUUM FRYING
Rinnai

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^{o}C
- Garayo & Moreira (2002) → potato chips fried under vacuum (3,115 kPa, 144^{o}C) had more volume shrinkage, were slightly softer, & lighter in color than the potato chips fried under atmospheric conditions (165^{o}C)

  → Vacuum frying is a process that could be a feasible alternative to produce potato chips with lower oil content & desirable color & texture