focus on industry

What happens in an oil refinery?

ʒefore use, petroleum (crude oil) is separated into fractions by distillation in an oil refinery

Exam links

This 'Focus on industry' is relevant to the following A-level topics:
- distillation
- oil and gas
- hydrocarbons
- industrial processes

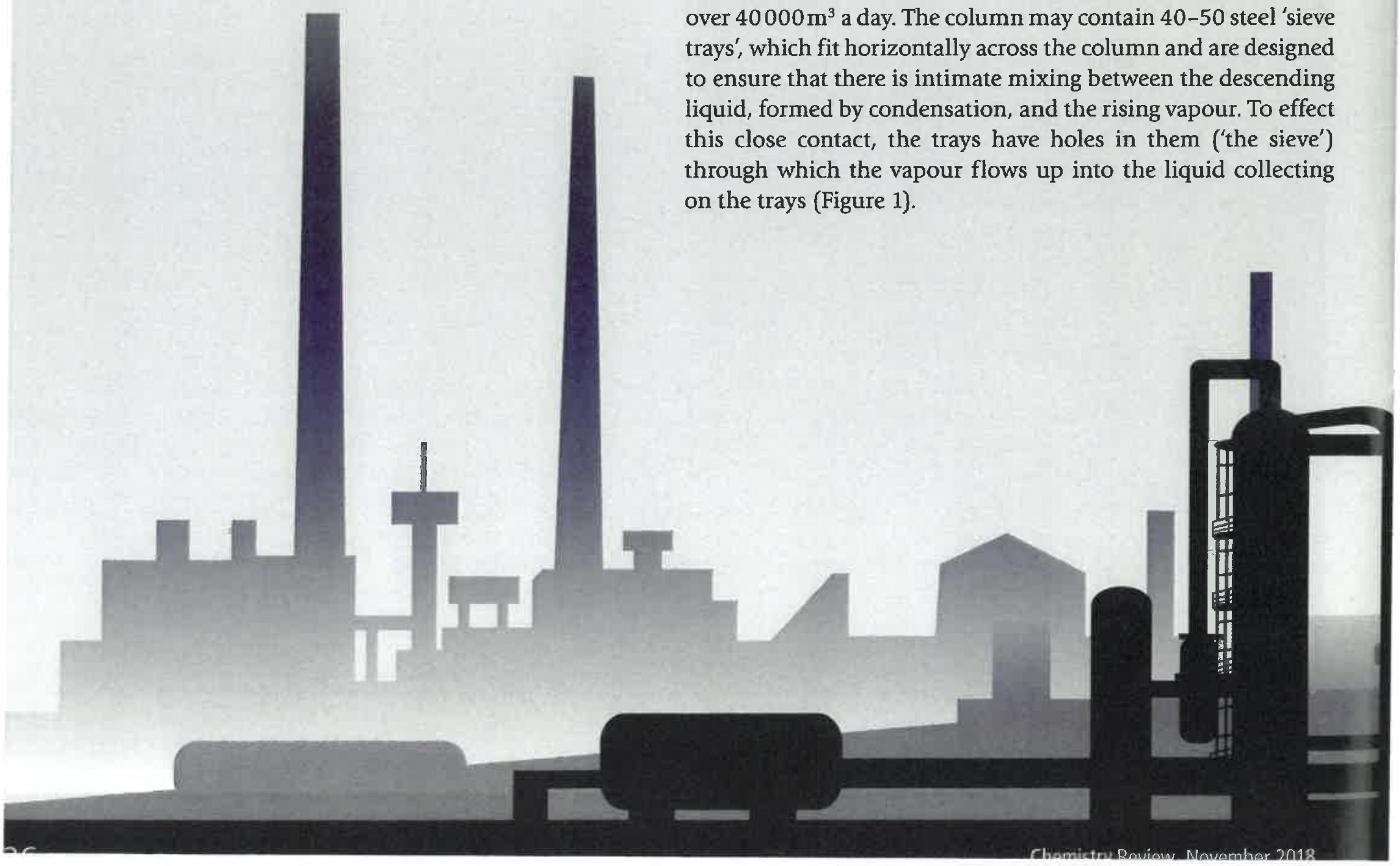
Distillation is used to separate mixtures of liquids by exploiting differences in the boiling points of the different components. The technique is widely used in ndustry, for example in the manufacture and purification of ıitrogen, oxygen and the rare gases from liquid air.

One of its best known uses is the refining of crude oil into ts main fractions, including naphtha, kerosine and gas oil (see ℑHEMISTRY REVIEW, Vol. 5, No. 3, pp. 16–17 and Vol. 5, No. 1, ɔp. 2–5). This is the first stage of converting oil into compounds, vhich are used to manufacture everything from plastics to nedicines.

For a description of how oil and natural gas are formed and how they are extracted see CHEMISTRY REVIEW, Vol. 28, No. 1, pp. 28–30. Crude oil is a mixture of many hundreds of liquid hydrocarbons. Dissolved in it are many other hydrocarbons, some of which are solids and some of which are gases (the lower members of the alkane family, predominantly methane and ethane, but often with some propane and butane). There may also be some hydrocarbon gases trapped above the oil, as for example in some of the oil fields in the North Sea. In the refineries the oil is distilled in distillation towers into liquid fractions with different boiling point ranges, which are then further processed.

Fractionating towers

The crude oil is heated in a furnace (at about 650 K) and the resulting mixture fed as a vapour into a fractionating tower, which can have a height of 20–100 metres, handling volumes of over 40 000 m^3 a day. The column may contain 40–50 steel 'sieve trays', which fit horizontally across the column and are designed to ensure that there is intimate mixing between the descending liquid, formed by condensation, and the rising vapour. To effect this close contact, the trays have holes in them ('the sieve') through which the vapour flows up into the liquid collecting on the trays (Figure 1).



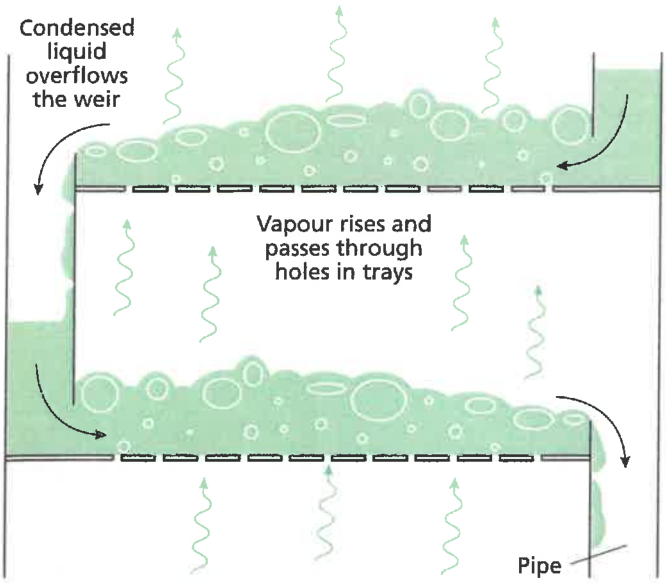


Figure 1 Sieve trays in a fractionating column

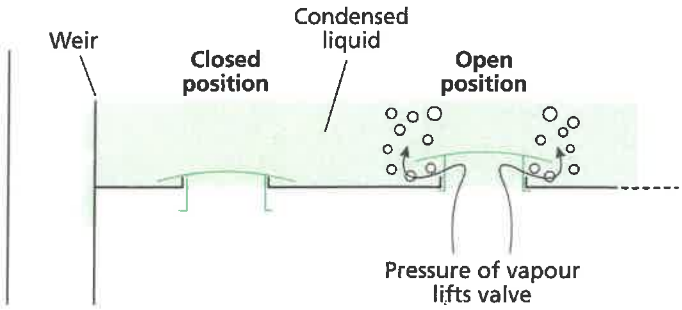
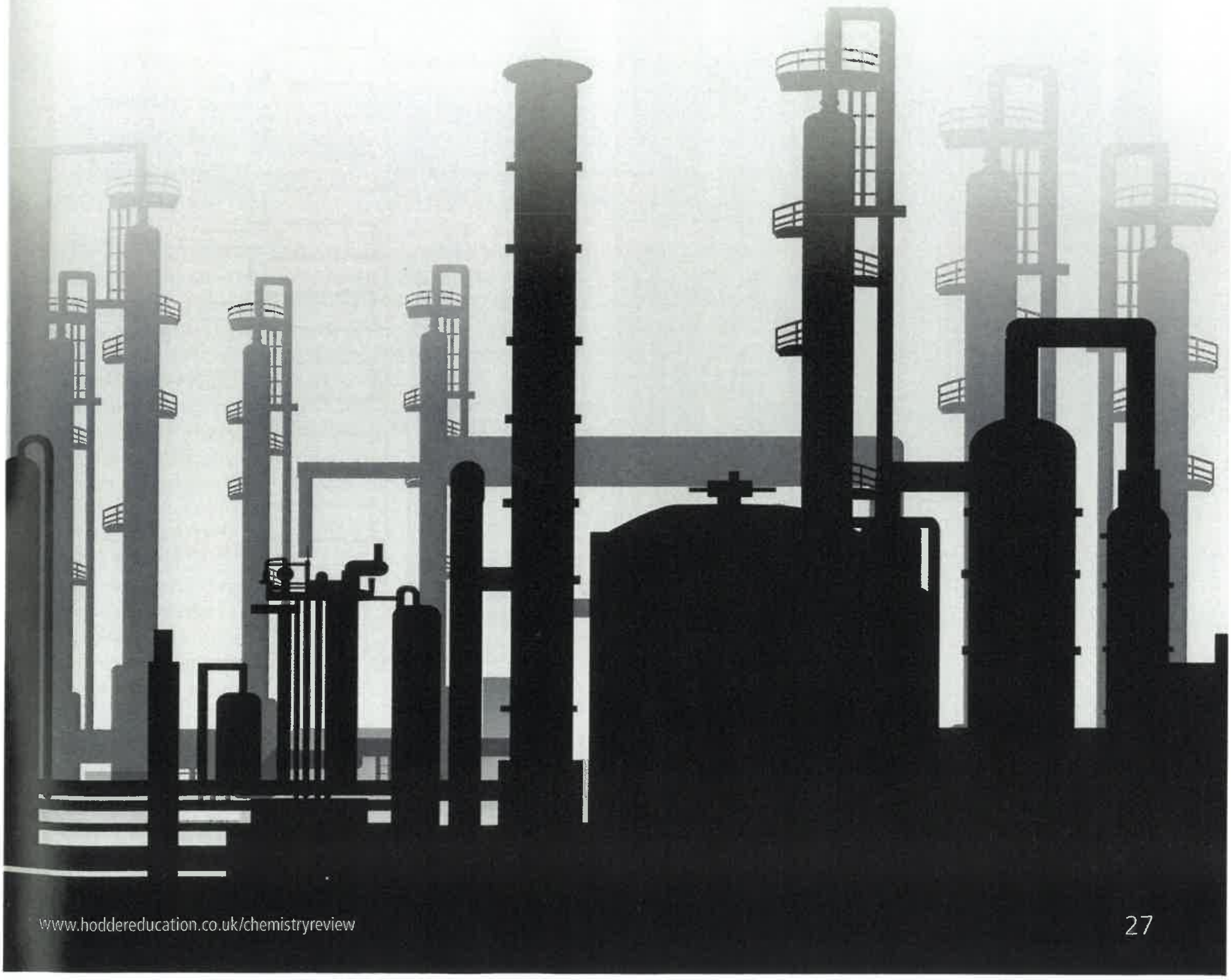


Figure 2 Valve trays

Alternatively, there may be valves fitted over the holes, which lift up when the pressure of the vapour below the tray is greater than the pressure on the tray (Figure 2). These are considered to be more efficient in fractionation than sieve trays without valves.

A temperature gradient exists in the tower, the top being cooler than the bottom. When the rising vapour reaches a tray containing liquid with a temperature below the boiling point (bp) of the vapour, it partially condenses. As some of the vapour condenses to a liquid, the dissipated **latent heat** then heats more liquid, and the more volatile components in the liquid evaporate, joining the remaining vapour and passing up the tower. The less volatile liquid flows across the tray and down a pipe to the tray below.



Products

This process occurs continuously in each tray, the least volatile vapour components condensing and the most volatile evaporating. This results in each tray containing products with a comparatively narrow boiling point range (called a 'close cut' of products). This leads to the low relative molecular mass products (low bp) accumulating near the top of the tower and high relative molecular mass constituents (high bp) collecting near the bottom (Figure 3).

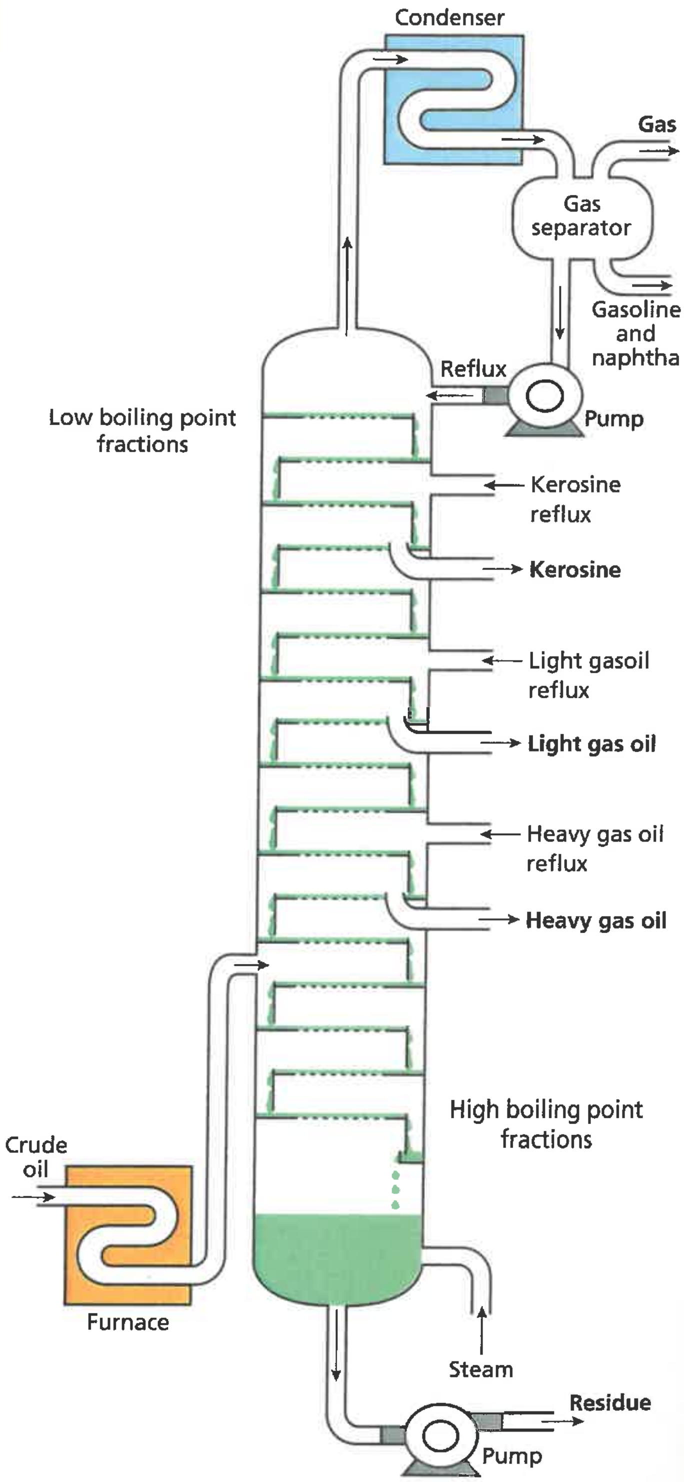
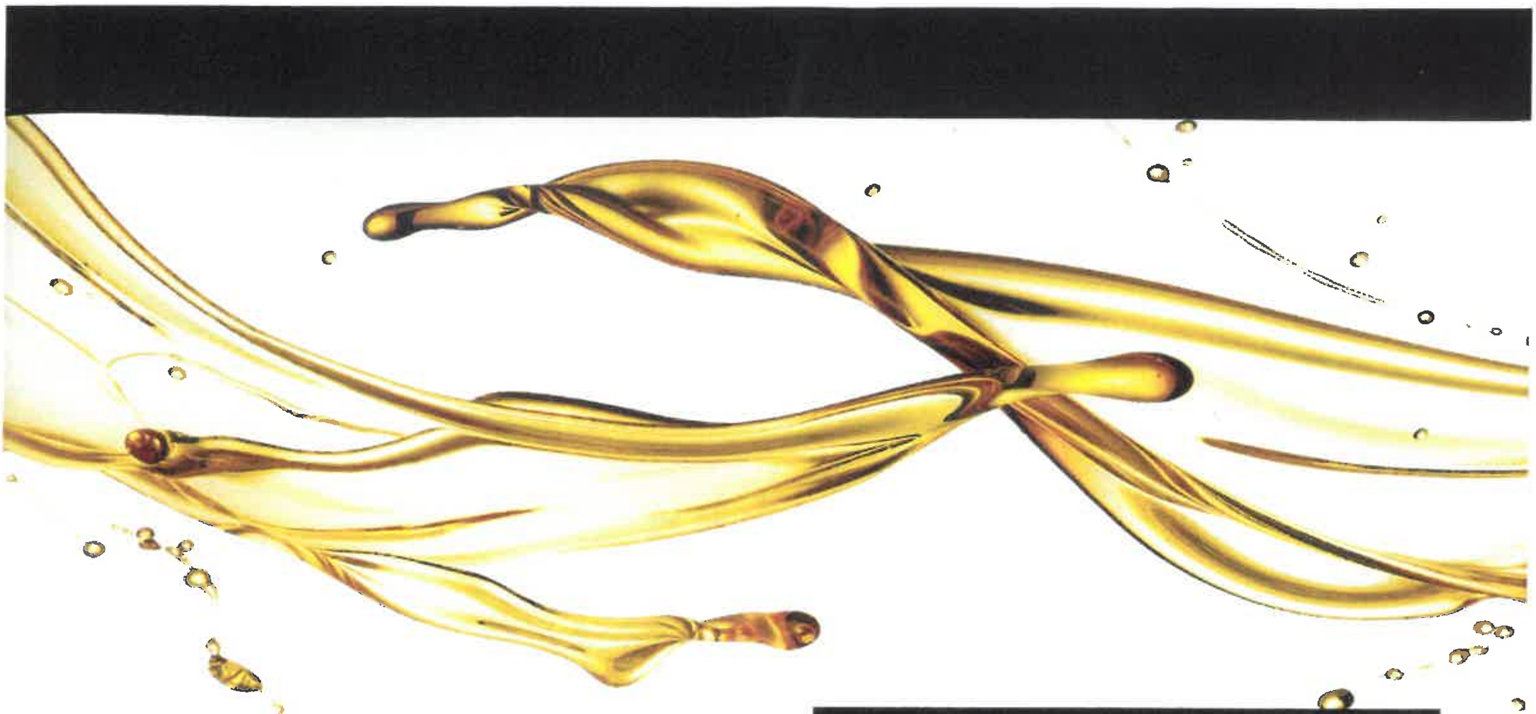


Figure 3 Fractional distillation of crude oil



The constituents in crude oil vary from one oil field to another

Table 1 Major fractions from the primary distillation of crude oil

Top ↑ (Temperature in tower decreasing) Bottom		Uses	Carbon chain length
	Gas 1–2% (bp <300 K)	Uncondensed vapour from top of tower. May be used as fuel on site or as liquefied fuel. Also feedstock for chemicals	1–4
	Naphtha 15–30% light (bp 300–470 K) 5–10% heavy (bp 403–493 K)	Petrol and chemicals feedstock by steam cracking	5–10
	Kerosine 10–15% (bp 450–530 K)	Feedstock for jet fuel, paraffin and domestic oil production	10–16
	Gas oil and heavy gas oil 15–20% (bp 530–620 K)	Diesel fuel and for blending fuel oil. Feedstock for chemicals (catalytic cracking)	14–20
	Residue from atmospheric distillation about 50%	For industrial heating and feedstock for vacuum distillation. This yields feedstock for catalytic cracking and lubricating oil. Waxes and bitumen	>20

The high boiling point residue from the crude oil is transferred to another column and distilled under vacuum. Lowering the pressure reduces the boiling point and ensures constituents distil at temperatures below their decomposition temperature. From this process, lubricating oils and waxes are obtained. The final residue from the process is bitumen.

Details of the fractionation are given in Table 1. The constituents in crude oil vary from one oil field to another (for example, the proportion of naphtha from North Sea oil is considerably greater than that from middle eastern oil), so the numbers given are approximate.

Other components

Crude petroleum does not just consist of hydrocarbons. Also present are a variety of organic sulfur-containing compounds and hydrogen sulfide. All these sulfur compounds must be removed during refining, otherwise they will poison the catalyst needed in the manufacture of synthesis gas (syngas, see CHEMISTRY REVIEW, Vol. 17, No. 3, pp. 2–5), which leads to many of the most important industrial compounds. In the desulfurisation unit, the organic sulfur compounds are often first converted into hydrogen sulfide, prior to reaction with zinc oxide. The feedstock is mixed with hydrogen and passed over a catalyst of mixed oxides of cobalt and molybdenum on an inert support (a specially treated alumina) at about 700 K.

$$R\text{–}SH(g) + H_2(g) \rightarrow R\text{–}H(g) + H_2S(g)$$

Then the gases are passed over zinc oxide at about 700 K and hydrogen sulfide is removed:

$$ZnO(s) + H_2S(g) \rightarrow ZnS(s) + H_2O(g)$$

Once separated by distillation in the refineries, into fractions with different boiling points, the fractions are further processed (by cracking, isomerisation, reforming and alkylation).

Glossary

Latent heat The heat absorbed or released when a substance changes phase at constant temperature (e.g. from liquid to gas at the boiling point).

Allan Clements, Mike Dunn, Valmai Firth, Lizzie Hubbard, John Lazonby and David Waddington. This article is adapted from **www.essentialchemicalindustry.org**, a resource on industrial processes and products for post-16 chemistry students. It is published by the CIEC, Department of Chemistry, University of York, **www.ciec.org.uk**