

# CHAPTER 1

## FUELS

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## Introduction

1. The search for more suitable fuels for all types of internal combustion engines is continually going on in the research laboratories of all the fuel producing companies. This chapter will deal very briefly with the origin, sources, specific requirements and production of fuels for piston and gas turbine engines.

## PRODUCTION OF CRUDE OIL

### Origin

2. The exact origin of crude oil or petroleum is unknown. Three main theories claim that it is of mineral, vegetable or animal origin; the last being the most widely accepted i.e., that it originated from the decomposed remains of marine life. This theory is supported by the fact that considerable quantities of salt water are frequently found immediately below oil-bearing strata.

3. Petroleum is found at depths varying from 1,000 ft. downwards in strata of sand or porous rock. It is necessary that the underlying and overlying strata should be non-porous or the oil would drain away and there would be no means of preventing the gases, usually present with the oil at considerable pressure, from escaping. Drillings to 15,000 ft. and below have revealed the presence of petroleum at these depths.

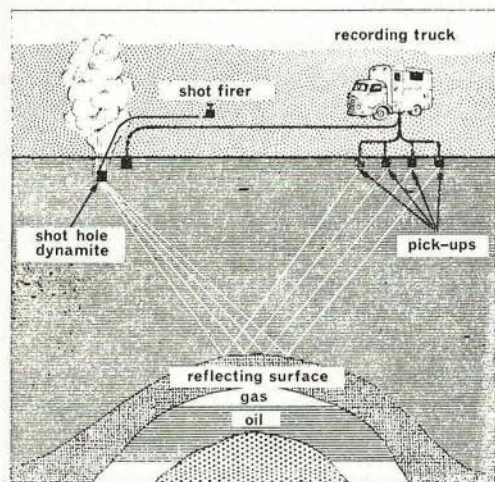


Fig. 1. Rock location.

### Location

4. Geologists decide upon a drilling location by mapping an area, studying surface rock formations and checking their findings with instruments that predict if likely rock structures lie underground, as shown in Fig. 1.

### Drilling

5. The modern method of drilling for oil uses various types of rotating bits which bore through the rock in a manner similar to a carpenter's bit boring through wood. The drill pipe collects samples of the strata and the drill hole is lined with a steel casing to prevent the hole collapsing. A stream of mud is pumped down the casing to carry away the cuttings and to lubricate and cool the drilling bit.

6. When the oil bearing stratum is reached there is usually enough gas pressure to force the oil to the surface. When this natural gas pressure gives out, compressed air may be pumped into the stratum to keep up the oil flow. Another method is to lower a surface driven pump into the well. The oil lines, controlled by valves, lead to chambers where the natural gases are separated from the oil which is then pumped to field storage tanks.

## SOURCES AND CHARACTERISTICS

### Petroleum

7. Almost all motor gasoline is of petroleum origin and is composed of one or more of the following:

- a. Straight-run gasoline which is obtained by distillation.
- b. Natural and "casing-head" gasolines, used in blending to produce easy starting.
- c. Cracked or re-formed spirits, made by heat and pressure treatment of certain petroleum fractions.
- d. Spirit made by special methods such as the direct combination of hydrogen and cracked residues from heavy petroleum fractions to form lighter spirits; or polymerization, in which gaseous compounds in cracker and refinery gases are made to react so that light molecules combine to form heavier liquid molecules thus producing gasoline.

### Shale Gasoline

8. Although at present a very subsidiary fuel, owing to the high cost of production, gasoline obtained by the distillation of oil shale may assume increasing importance as the world's petroleum reserves diminish.

### Benzole

9. Motor benzole is a very valuable light fuel. It is obtained during the high temperature carbonization of coal in gas ovens and to a lesser extent at gas works. Because of its limited supply and usage in the manufacture of drugs, dyes and explosives it is a very expensive fuel.

### Alcohol

10. Some alcohol is manufactured from coke oven gas and cracker gas but the greater part is ethyl alcohol which is made by fermentation of residues derived from vegetable matter such as sugar beet.

### Manufactured Fuels

11. There are also relatively small quantities of fuels which are made by chemical processes; they include:

- a. Gasoline made by the addition of hydrogen to bituminous coal or brown coal.
- b. Gasoline made by the addition of hydrogen to some coal tar products.
- c. Gasoline made from "synthesis" gas, for example, from the mixtures of carbon monoxide and hydrogen.
- d. Methyl alcohol made from a gas containing carbon monoxide and hydrogen.
- e. Ethyl alcohol made from petroleum gases.
- f. Hydrocarbon compounds such as iso-octane, iso-decane and triptane, made by special cracking processes.

### Chemical Physical Properties

12. Some confusion arises when referring to the various hydrocarbon compounds, because certain trade names are similar to the names used by the chemists. The chemical series to which

these compounds belong have some distinguishing molecular structure, or grouping of the atoms, to which their characteristic properties are due. Two compounds of different series and molecular structure, although having the same proportion of hydrogen to carbon atoms, may have quite different characteristic properties because of different grouping of the atoms in the molecule.

13. The four main series of hydrocarbons, the paraffins, olefines, naphthenes and aromatics all occur in petroleum at some stage or other. The simplest compound is methane or marsh gas, the lightest of the paraffin series, being a gas at normal atmospheric temperatures. The series continues through the gases propane, butane and liquids of increasing density, to solids such as paraffin wax.

14. Paraffinic base crude oils are so called because the residue after distillation is paraffin wax. The liquid that is commonly called paraffin contains members of other series as well as "fractions" of the paraffin series and is now more correctly called kerosine.

15. The composition of petroleum varies with its source; the preponderance of any chemical series depending upon the geographical origin of the crude oil. Pennsylvanian straight-run gasoline is typically paraffinic; Russian gasoline, naphthenic; Borneo crude petroleum contains a high percentage of aromatics; Iranian crude petroleum has a high sulphur content as an impurity.

## REQUIREMENTS OF A FUEL

### General

16. The internal combustion engine derives its heat from the burning of a fuel-air mixture in the combustion chamber. Efficiency of burning is only one of the requirements of the fuel. While in the tank the fuel must not undergo any physical or chemical change. It must not form any gummy deposits which might block the fuel system. It must not be corrosive to any part of the fuel system and it must not be so volatile that any appreciable amount could be lost by evaporation through the fuel tank vent system.

17. Excessive volatility can cause fuel to stop flowing in hot weather or at high altitudes. This is caused by the fuel boiling in the pipe line, so producing sufficient vapour to produce what is known as "vapour lock".

18. When the fuel-air mixture reaches the cylinder or combustion chamber its ability to resist knocking or pinking when burnt, outweighs all other factors. The power that can be obtained from an engine of given size, or the efficiency with which the air it consumes can be burnt, depends largely upon the volatility of the fuel and its anti-knock rating.

## SPECIFIC REQUIREMENTS

### Anti-Knock Rating

19. **Detonation.** After the fuel-air mixture has been ignited, ideally the flame spreads evenly across the combustion chamber causing a rise in temperature and pressure of the unburnt portion of the fuel-air mixture. If the fuel is not sufficiently knock-resistant, then at a temperature and pressure critical to that particular fuel, spontaneous combustion starts at many points in the unburnt portion of the mixture, and this occurs with such rapidity that there is an audible explosion. This explosion is what is meant by the term "knock" or "detonation" and the critical

temperature and pressure at which this takes place is determined mainly by the chemical composition of the gasoline.

20. Quite apart from the noise effect the violence with which the explosion occurs is so great that it has effects, such as causing the crown of the piston to burn and collapse, that materially shorten the life of many components of the engine.

21. **Causes of Detonation.** Contributory causes of detonation are:

- a. Incorrect mixture strength.
- b. Any design feature which has any influence on the temperature and pressure of the mixture at the time that it is ignited, or the time taken by the flame point to travel through the combustion chamber.
- c. Fuel with poor anti-knock value.

22. By using fuel of a higher knock rating the compression ratio of the engine may be increased without the occurrence of detonation; this results in increased thermal efficiency and consequent economy with slightly increased power output. Thus, high compression ratio high efficiency engines need good anti-knock fuels.

23. There is no advantage to be gained by using a fuel of higher anti-knock value than the engine needs to maintain steady knock-free burning of the mixture. Above this limit a higher knock rating fuel has no effect whatsoever provided the best ignition setting is being used.

23. **Tetra-Ethyl Lead.** Apart from the choice of hydrocarbons with high anti-knock ratings, the anti-knock rating of gasoline is effectively increased by the use of metallic compounds. Of these, tetra-ethyl lead, commonly known as T.E.L., is the most powerful and widely used. T.E.L. affects various types of fuels differently and the amount which can be added is limited, because the anti-knock rating of the fuel does not improve steadily with increasing quantities of the additive. T.E.L. is poisonous, even when diluted in gasoline and if in constant contact with the skin causes dermatitis.

### Volatility

24. **Definition.** A volatile liquid is one which is capable of changing readily from the liquid to the vapour state by the application of heat, or by contact with a gas into which it can evaporate.

25. The following properties of a fuel are related to volatility; efficiency of distribution, oil dilution, startability, and vapour locking tendencies. Some of these factors depend upon the presence of low and others of high boiling fractions, therefore volatility cannot be expressed as a single figure.

### Efficiency of Distribution

26. After leaving the carburettor, the fuel/air mixture is heated at the exhaust-heated hot spot and then passes to the engine cylinders. The efficiency with which the air is mixed with the gasoline in the carburettor is largely determined by the volatility of the gasoline; however, the time involved is so small that much of the gasoline remains in the form of minute unevaporated droplets, the evaporation of which is largely completed at the hot spot.

27. If a large proportion of the gasoline is not evaporated at the hot spot, as will be the case if the gasoline volatility is low and its maximum boiling point is high, there will be a tendency for these unevaporated droplets to congregate at each end of the inlet pipe rather than to be distributed evenly between the various cylinders. This means that the fuel/air ratio of the charge in the individual cylinders will vary, with consequent variations in the power developed, resulting

in poor performance and rough running. Experience has proved that a certain minimum percentage of gasoline must boil at 100°C. if this condition is to be avoided.

### **Startability**

28. A mixture of fuel and air vapour is not inflammable unless it contains between about 1½ per cent. and 6½ per cent. of fuel vapour. Hence a sufficient proportion of the fuel must be vapourized at the time the spark occurs otherwise the mixture will not burn and the engine will not start. The ability of a gasoline to give easy starting depends upon the number of volatile fractions it contains.

### **Vapour Lock**

29. If a gasoline is very volatile, not only will it be lost by evaporation from the tank, but it will tend to boil rapidly on the depression side of the fuel pump. This condition, which is known as vapour lock, has been experienced by many motorists, for instance in very hot weather or at high altitudes in mountains. The tendency for vapour locking can be predicted in the laboratory by determining the vapour pressure of the gasoline.

### **Cold Starting**

30. The volatility of a gasoline has a most marked effect on the cold starting ability and speed of warm-up of an engine. For good starting and quick warm-up and in order to reduce the time element which is necessary to establish good distribution to the cylinders, high volatility at the low temperature part of this range is most necessary. This must be balanced however against the fact that too much volatility tends to cause vapour lock.

### **Oil Dilution**

31. Oil dilution will occur if the final boiling point of the fuel is too high. This is because unburnt fuel will get into the engine when incompletely evaporated fuel reaches the cylinders, and it will escape past the piston rings into the crankcase. The viscosity of the lubricating oil will be reduced, and so lubrication will become ineffective. The oil on the cylinder walls may also be washed away, with consequent serious damage to the engine. Oil dilution is controlled by the 90 per cent. distillation temperature and the final boiling point.

### **Stability**

32. A number of hydrocarbon compounds which are used in motor gasoline have a considerable attraction for the oxygen in the air. When they come into contact with the air, they oxidize and undergo other chemical changes (polymerization) to form heavy resinous gummy compounds and corrosive bodies.

33. Motor gasoline contains a large proportion of fuel obtained by "cracking", and cracked fuels, when stored, form more gum than straight-run fuels. Once gum formation starts, it proceeds rapidly and affects hydro-carbons which otherwise would be stable. It shows in the form of a colourless or yellow sticky deposit. Less frequently, deterioration shows as a white precipitate of the lead compounds in the fuel.

### **Corrosive Properties**

34. The corrosive effects of gasoline are caused by its sulphur and additive contents. Sulphur that would cause corrosion before combustion is known as corrosive sulphur. Sulphur that

would cause corrosion after combustion is known as total sulphur; this also includes the corrosive sulphur.

**35. Combustion of Sulphur.** Sulphur and sulphur compounds, when burnt in air form sulphur di-oxide, and this, when mixed with the water content of the exhaust products, forms sulphurous acid. This will be corrosive to the exhaust system.

#### **Cleanliness**

36. Even with the most modern manufacturing techniques it is not easy or cheap to make a gasoline of high anti-knock quality that will burn cleanly in the engine. The higher the anti-knock level, the more difficult it becomes to achieve satisfactory cleanliness. Unless the gasoline is properly refined, gummy, resinous compounds may form during the compression stroke, and appear as deposits on the pistons and in the crankcase. The presence of these is frequently ascribed to the use of poor quality lubricating oil.

#### **Contamination**

37. Conscientious observation of instructions laid down in the appropriate Air Publications during servicing and refuelling, will ensure that contamination of fuel and deterioration of the fuel system are prevented as far as possible.

## **MANUFACTURE OF GASOLINES**

### **Introduction**

38. The only economical way to make gasoline is to refine it from crude petroleum, and the petroleum technologist must ensure that the gasoline meets the specific requirements dealt with earlier in this chapter.

39. Gasoline is a mixture of hydrogen and carbon, and these combine in hundreds of different proportions and ways to form many varied hydrocarbon products. The smallest complete particle of a compound is called a molecule, and a molecule consists of varying numbers of atoms of each of the two basic substances. Not only do hydrocarbons have varying numbers of hydrogen and carbon atoms in different molecules, but also in some, which superficially appear to be very similar, the atoms are arranged differently.

40. Some hydrocarbons have a suitable volatility for use in motor gasoline but are deficient in knock rating. Others have adequate knock rating but are deficient in volatility, stability or other characteristics. Few which occur naturally have all the desired properties.

41. A further complication is that the demand for motor gasoline in relation to the total amount of crude petroleum produced is much greater than the proportion of suitable hydrocarbons which occur naturally in the crude oil. The petroleum refiner therefore has three problems:

- a. To increase the octane number of the naturally occurring hydrocarbons of suitable volatility in the gasoline range.
- b. To decrease the volatility and increase the octane number of a proportion of the hydrocarbons which would otherwise be too volatile for use in gasoline.

c. To increase the volatility and increase the octane number of a proportion of the natural hydrocarbons which are insufficiently volatile for use in gasoline. In this way the demand for high octane motor gasoline can be met.

42. The crude petroleum when received at the refinery is a dark oily liquid. The first step is to effect a partial separation into portions such as gasoline, kerosine, gas oil (high speed diesel oil), fuel oil, etc., by the process of distillation. This process means that the liquid is converted to vapour by the application of heat, and then back to a liquid by cooling.

### Fractional Distillation

43. This process is carried out in a fractionating column which has a series of trays as shown in Fig. 2. The effect of the superheated steam on the heated crude petroleum is to cause the lighter fractions to rise up the column. When rising, the vapour cools and a certain amount condenses on each tray until the tray is full of liquid to the overflow. Thus, each tray is a little cooler than the one below it, and therefore, lighter and lighter fractions will be present on each tray, as the vapours pass up the column. The temperature is controlled at the bottom of the column by the temperature of the crude oil, and at the top of the column by taking a certain amount of the product as it leaves, condensing it and pumping it back into the top of the column. This is known as the reflux.

44. A certain amount of material will condense, which has a lower boiling point than the bulk of the liquid on a particular tray. To enable separation of these fractions the liquid from a selected tray is drawn into a smaller auxiliary column, called a "side-stripper". Here it is treated with steam which causes the lightest fractions to vapourize and pass along with the steam into the main column.

45. The use of these side-strippers enables kerosine and gas oil to be obtained direct from the plant. Lubricating oil distillate, if such is present, can usually be drawn direct from a tray without the use of a side-stripper, while gasoline leaves the top of the column as a vapour and must be cooled to condense it to liquid gasoline.

### Flash Distillation

46. In this method the crude petroleum is under pressure and heated to a certain temperature before introduction into the fractionating column. In the column, owing to the reduction of pressure together with the addition of superheated steam, the crude petroleum is vapourized

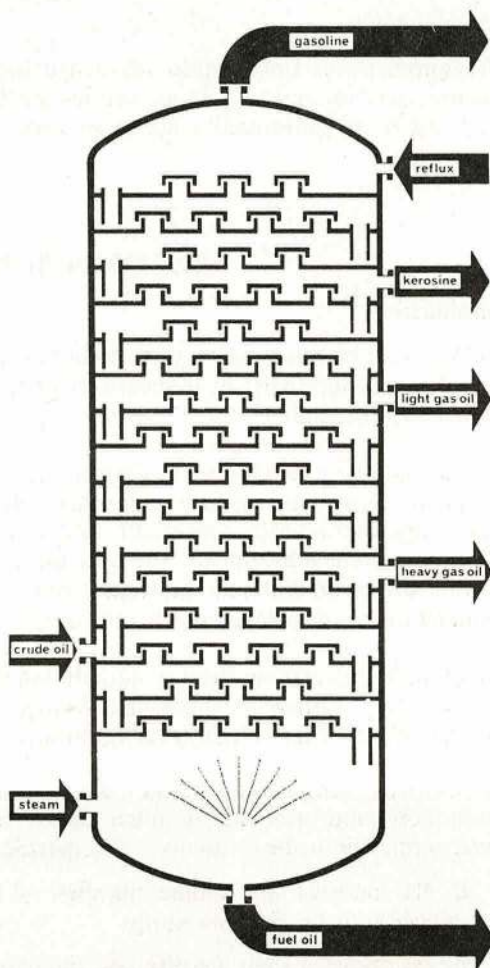


Fig. 2. Fractionating column.

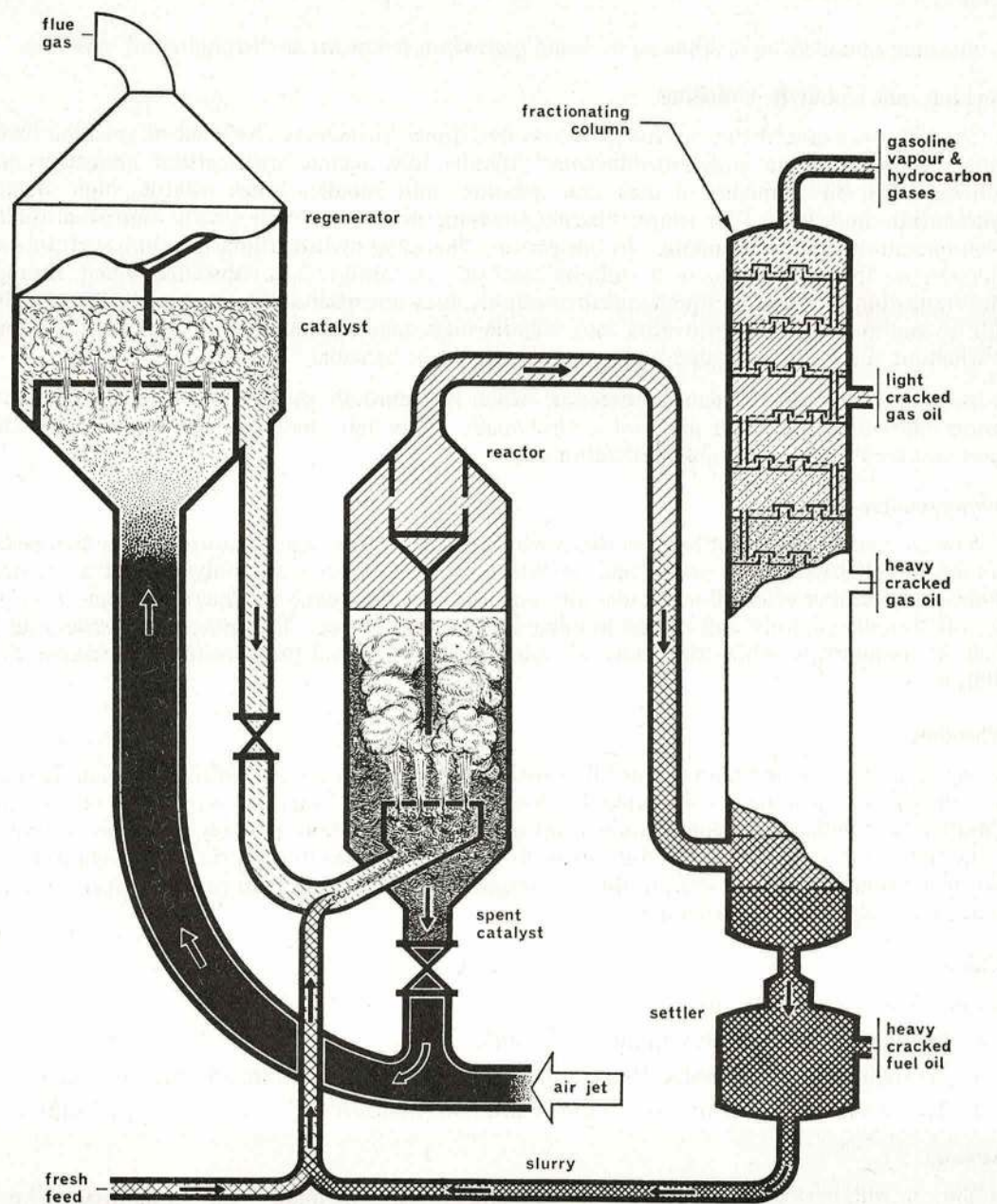


Fig. 3. Catalytic cracking plant.

instantaneously (except for the residue). The process then proceeds as for fractional distillation.

47. Gasoline obtained by distillation of crude petroleum is known as "straight-run" gasoline.

### **Cracking and Catalytic Cracking**

48. Cracking was one of the earliest processes developed to increase the yield of gasoline from crude petroleum. The large, insufficiently volatile, low octane hydrocarbon molecules are broken, under the influence of heat and pressure, into smaller, more volatile, high octane hydrocarbon molecules. The simple thermal cracking process has been greatly improved by the development of catalytic cracking. In this process the heavy hydrocarbons are subjected to heat and pressure in the presence of a suitable catalyst. A catalyst is a substance which, though either retarding or speeding up chemical reactions, does not itself suffer chemical change. The bulk of the molecules are converted into volatile high octane gasoline-type compounds, many of which are aromatic in nature, and generally similar to benzole.

49. In addition, some still heavier material, which is eventually disposed of as fuel oil, and a certain amount of very light material is also made. This light material, which is a gas, is the major source of feed to the polymerization plant.

### **Polymerization**

50. This process makes use of hydrocarbons which are initially so light that they are in fact gases, and would otherwise go to waste and be burnt in the flare so commonly seen at a modern refinery. A number of small molecules are joined together to make a reduced number of larger ones of suitable volatility and octane number for use in gasoline. The process is carried out in reaction chambers, in which the gases are submitted to heat and pressure in the presence of a catalyst.

### **Reforming**

51. The naphtha obtained from the distillation of the crude oil has poorer anti-knock qualities than the straight-run gasoline. Consequently these hydrocarbon fractions which are of suitable volatility, but inadequate octane number, are subjected to heat and pressure in a process known as thermal reforming. This does not break down the molecules but rearranges the carbon and hydrogen atoms in them, so that, in the rearranged form the octane number is increased and the volatility is substantially unchanged.

### **Refining**

52. The objects of refining are:

- a. To remove undesirable sulphur compounds.
- b. To remove unstable bodies (unsaturated hydrocarbons) which deteriorate in storage.
- c. To obtain a product of good colour and odour, conforming to the given specification.

### **Blending**

53. Thus it will be seen that four types of hydrocarbons are made; the straight-run simply distilled product, the catalytically cracked, the polymerized and the reformed. These are appropriately blended to make the required gasoline.

54. Some manufacturers may also make use of benzole and alcohol, as has been previously stated, and tetra-ethyl-lead may be added because of its anti-knock qualities.

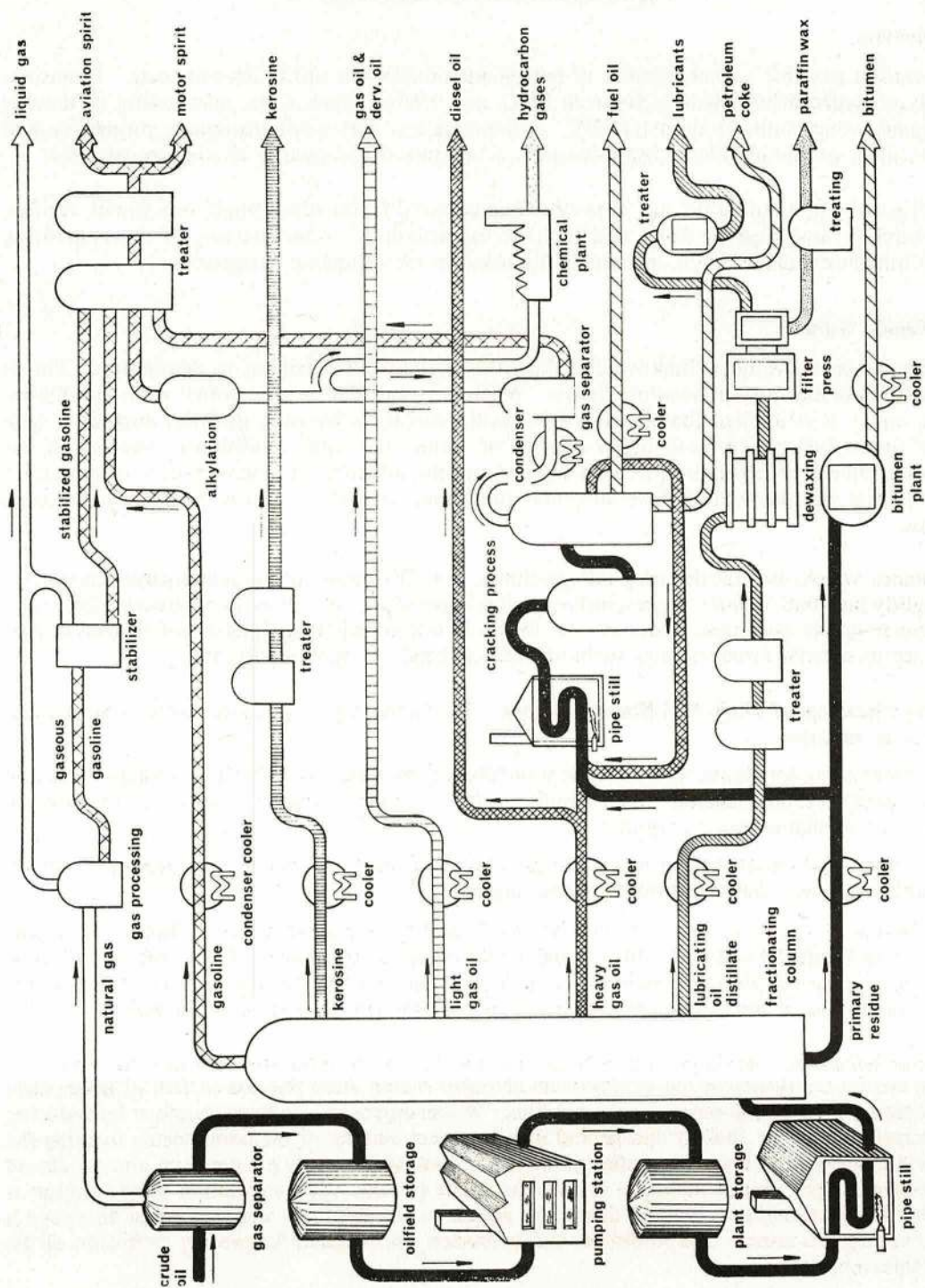


Fig. 4. Processing of crude oil.

## AVIATION GASOLINES

### Introduction

55. Aviation gasoline is that fraction of petroleum suitable for use in aero-engines. It consists mainly of hydrocarbons boiling between 35°C. and 150°C. One of the most useful of these is iso-octane, which boils at about 117.3°C. Iso-octane has very good anti-knock properties, and the so called octane number is in this respect, a measure of the quality of aviation gasoline.

56. All gasolines, suitable for use in piston-engined aircraft, must have high anti-knock ratings, high stability, low freezing point and high overall volatility. Some aspects of these qualities, which influence engine design, are briefly discussed in the following paragraphs.

### Anti-Knock Value

57. The anti-knock value of fuel is defined as, the resistance the fuel has to detonation. This is a comparative and not an absolute figure. When it is said that a certain fuel has a good anti-knock value, it is implied that the fuel has good detonation resisting qualities compared with several other fuels being used under exactly the same operating conditions. Because of the disastrous effects of detonation in aero-engines and the difficulty of detecting it, it is imperative that aviation gasoline should have adequate anti-knock properties, that is to say, a high rating or value.

58. Engines which use the lower grade gasolines, e.g. 73 Grade, are either unsupercharged or very lightly boosted. Under these conditions, it is necessary to specify weak mixture ratings only. For higher grade gasolines, however, the above is not sufficient safeguard and therefore it is necessary to specify knock ratings for both weak and rich mixture conditions.

59. **The Advantage of High Anti-Knock Ratings.** The higher the anti-knock rating of a fuel, the better it is, because:

- a. Increase in knock rating means the possibility of increased compression ratio and hence of increased thermal efficiency. This would result in a gain in economy and at the same time an increase of engine power output.
- b. Increase in knock rating means the possibility of increased boost pressure and hence of greatly increased power output from the engine.

*Note.* Increased knock rating does not by itself lead to increased power. Merely changing from Grade 73 to Grade 100/130 fuel would make no difference. Power output will only be increased if the compression ratio and/or boost pressure are increased, i.e., the running conditions of the engine are altered to suit the changed properties of the fuel.

60. **Water Injection.** Although not truly an anti-knock, the injection of water into the induction system creates conditions in the combustion chamber which allow the use of fuel of lower anti-knock rating than would otherwise be possible. Water injection produces its effect by reducing the temperature of the fuel/air charge and also by direct cooling of the components forming the combustion chamber. Its cooling effect is similar to, but considerably greater than, that produced by a rich mixture. Water injection is used for short periods when maximum power output is required from an engine. Methyl alcohol is added to the inhibited distilled water to create a "non-freezing" mixture. The inhibitor, anti-corrosion oil, is added to prevent corrosion of the water injection system.

**Joint Service Nomenclature—Fuels**

61. The symbols shown in the second column of the table that follows indicate broadly the composition of the items against which they appear and are the agreed Joint Service designation. The use of these designations enables the Services to obtain standard petroleum products from each other without other means of identification being necessary. For example:

- AVTUR/50 — Aviation Turbine Fuel minus 50°C., freeze-point
- AVTAG — Aviation Turbine Gasoline
- NLAVGAS — Aviation Storage Gasoline (NL indicates "NO LEAD").
- AVGAS — Aviation Gasoline (Prefixed by octane and rich mixture ratings, e.g. 73 AVGAS or 100/130 AVGAS)

**Aviation Gasoline Grades and Identification**

62. The grades of gasoline now in use for piston-engined aircraft in the Royal Air Force can be identified by their distinctive colour as follows:

N.A.T.O. Code Number	Joint Service Nomenclature	Colour of Fuel	Remarks
F13	73 NLAVGAS	Colourless	This is a lead free grade used for running engines prior to storage and as an aviation fuel for certain small piston engines.
F18	100/130AVGAS	Green	Used in aviation piston engines and certain marine craft.
F22	115/145AVGAS	Purple	Alternative fuel for aviation piston engines.

*Notes.* 1. When a fuel has an anti-knock rating above 100 octane, it is given a performance number. All knock rating numbers up to 100 are octane numbers, and all numbers above 100 are performance numbers. Therefore a Grade 73 fuel would be an anti-knock rating, and Grade 115/145 a performance number or numbers.

2. Dyes are added to aviation gasoline with the T.E.L. to provide identification colour.

**AVIATION TURBINE FUELS****Current Service Fuels**

63. At present, the octane value or performance number of a fuel has no significance with a gas turbine engine, and the range of a turbine-engined aircraft is directly proportional to the heating value of the fuel used.

64. Kerosine, which is a refined petroleum distillate, normally with a boiling range of 150° C. to 300°C., proved at one stage of development to be the best fuel for gas turbine engines, but wide-cut gasoline turbine engine fuel (Joint Service designation AVTAG) is now more generally used. However, aviation turbine kerosine AVTUR/50 can be used as an alternative for AVTAG subject to a re-adjustment of fuel pump (density sensitive) overspeed governors or acceptance of a loss of power at take-off. Where density compensated fuel governors are fitted, no adjustments are necessary.

**General Requirements**

65. A gas turbine fuel should have the following requirements:
- Be "pumpable".
  - Permit quick starting of the engine.
  - Give good and complete combustion under all conditions.
  - Have as high a calorific value as possible.
  - Be non-corrosive to the fuel system.
  - Lubricate efficiently certain moving parts of the engine.
  - The products of combustion should have no harmful effects on such parts as flame tubes, turbine blades.
  - Fire hazards should be reduced to a minimum.

**Pumpability**

66. The fuel must be capable of flowing easily and of being pumped under all operating conditions. This quality can be adversely affected at low temperatures by the deposition of absorbed water, either as water droplets or ice crystals, and heavy hydrocarbons as waxy solids (cloud point). The presence of either or both of these solids can, by obstructing the fuel system, cause the engine to stop.

**High Calorific Value**

67. The heat of combustion of a fuel is an expression of the amount of heat and hence energy, which a quantity of the fuel produces on combustion in a given engine. For hydrocarbons, calorific value is usually related to specific gravity. As specific gravity decreases there is a reduction in the heat of combustion per unit volume and an increase in heat of combustion per unit weight, for example:

FUEL	Heat of Combustion		Specific Gravity
	In B.Th.U.s. per lb.	In B.Th.U.s. per gal.	
Gasoline 100/130 Grade .. .. .	18,940	136,600	.720
Aviation Kerosine (AVTUR) .. .. .	18,560	150,400	.810
Typical Gas Oil .. .. .	18,260	155,200	.850

*Notes.* 1. The fuel tanks of a high speed fighter aircraft are necessarily limited in size and in consequence a fuel is required which provides the greatest heat of combustion per unit volume. Typical gas oil has an even greater heat of combustion per unit volume than AVTUR but, at low temperatures, pumping and vapourizing difficulties prevent its use in turbine-engined aircraft.

2. The fuel contents gauges of certain aircraft are now calibrated in "Mass Units". The flow meter readings of the refuelling vehicles are converted into Mass Units by reference to graphs or tables in accordance with the S.G. of the fuel supplied. The results obtained are entered in F.700 as pounds of fuel in the aircraft tanks.

**Corrosive Properties**

68. The tendency of a kerosine turbine fuel to corrode the aircraft's fuel system depends upon two factors:

- a. Water content.
- b. Sulphur compounds.

69. The presence of free, or undissolved water is always possible in the kerosine fuel systems. The corrosive effects can be serious where control valves, or similar components having sliding parts and small clearances, are concerned. The addition, by refiners, of small quantities of engine lubricating oil to the fuel has considerably reduced this source of corrosion. The total sulphur compound content of kerosine is generally much higher than gasoline; as this content must be accepted, due to refining difficulties, it is kept as low as possible.

**Identification of Turbine Fuels**

70. At present two grades of turbine fuel have been approved for general use in the service. A third grade is for use by Royal Navy carrier-borne aircraft. A special fuel is provided for turbine engine starters.

N.A.T.O. Code Number	Joint Service Nomenclature	Colour of Fuel	Remarks
F34	AVTUR/50	Colourless	Aviation turbine engines.
F40	AVTAG	Colourless to pale straw	Aviation turbine engines.
F42	AVCAT	Colourless	Aviation turbine engines in R.N. carrier-borne aircraft.
S746	AVPIN		Aviation turbine engine starter fuel.

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