Oil

Introduction

Today 1,056 barrels of oil are consumed every second worldwide, i.e. 167,000 litres. At present oil is the most important source of energy and for some applications it is irreplaceable, but till when will it be able to satisfy the growing demand of energy? The day will come when the production of oil shall reach a peak, after which it shall inexorably decrease with a consequent increase in prices. Some believe that the peak in production shall be reached in about thirty years, others instead believe that it has already been reached in the years between 2005 and 2010, and some believe in the existence of large quantities of oil at increasingly great depths, and others believe in the exploitation, for example, of tar sands.

The distribution of the main oil basins around the world is not uniform, however it is not even random. In fact it depends on the geological conditions that are necessary for the formation of large deposits and the difficulty encountered to explore and search for oil in isolated scarcely known areas, as for example areas characterized by environmental conditions that are particularly severe (vast areas in Siberia, the rain forest area in South America and deep offshore areas). The geological history of our country is very complex and has given the peninsula a complicated and not very “tranquil” structural and sedimentary order. This has not favoured the formation of large extensive oil basins but has created local situations that are favourable for the formation of a number of oil provinces that are quite important, even though their extension is not great.

Oil knowledge

What is it?

Oil is a fossil fuel, just like coal and natural gas. Such fuels derive from the rests of plants and animals which died hundreds of million years ago, when mankind had not yet appeared on Earth. Those plants and animals, as it happens today, have accumulated the energy coming from the Sun and, after their death, have remained buried for millions of years until they have turned into oil and coal. Prehistoric animals and plants today return the solar energy they accumulated in the past as heat and electric energy. Great part of the energy we use today comes from fossil fuels, especially oil. However, it is a non-renewable energy source which is bound to depletion sooner or later.
More specifically, oil is a natural mixture of liquid hydrocarbons and other substances of fossil origin contained in sedimentary rocks and associated to smaller quantities of gaseous (natural gas) and solid (bitumen) hydrocarbons.
All the molecules of the existing hydrocarbons include two types of atoms only: carbon and hydrogen atoms. According to the quantity of carbon atoms included in the molecule, hydrocarbons can be in gaseous (up to 4 atoms), liquid (from 5 to 16 atoms) or solid state (over 16 atoms).

Origins of oil

The most favourable environment for the formation of new hydrocarbons includes areas marked by a limited circulation at the bottom and constant accumulation of debris by rivers (ancient seas or lakes), as well as sedimentary basins where the Earth’s crust is lowered gradually or quickly following natural geological processes (see image).
Those areas are inhabited by numerous organisms which, when they die, lye at the bottom and are constantly covered by the debris (soil and minerals). The layers of mud rich in organic substances (mother-rock) slowly sink owing to the pressure of new layers. At a given depth and temperature the organic substance “ripens”, at first turning into “Kerogen” (approximately 1000 metres and 50°C), then into actual hydrocarbons. The length of the process ranges from 10 to 100 million years according to the temperature.
If the organic substances are abundant, remarkable fields of coal and natural gas can result. If the kerogen does not ripen, and its concentration exceeds 8%, liquid oil can be obtained by heating it artificially. At greater depth methane and

light hydrocarbons are produced. Several kilometres away from the surface and at a temperature ranging from 150 to 200°C, kerogen turns into pure crystal carbon (graphite).

Oil fields

Once it has formed, oil is squeezed out of the mother rock (compressed by the layers lying on top) and it first moves through the microfractures (primary migration) and then into the small channels in the permeable adjacent rocks (secondary migration). In some cases hydrocarbons reach the earth's surface and disperse. In others, their migration is blocked by impermeable rocks. In this case the hydrocarbons are trapped and they accumulate. An accumulation of hydrocarbons, in a quantity that can be exploited economically is known as a field.
A trap consists of two elements: below, a reservoir rock that holds the petroleum and above, a cap rock that forms a barrier. Cap rocks are convex on the upper side and are impermeable, so that they prevent the hydrocarbons from escaping. On the contrary the reservoir rocks must be permeable and porous like sponges in order to enable the hydrocarbons to move within, and to make the extraction procedures easy. The size of a deposit depends on the amount of the original reserve – from the over 11 billion tons in the Ghawar deposit (Saudi Arabia) to a few hundred tons in the smaller fields.

What is for?

Many products can be obtained from oil, ranging from some of the most common fuels (petrol, gas-oil and other by-products of oil) to many of the plastic materials used by mankind. The simple hydrocarbons that compose oil are, in fact, the main raw materials needed to produce plastic materials with specific features: resilience, plasticity, hardness, flexibility, biodegradability, sturdiness, adherence, water-proof characteristics, malleability, etc.
The four most commonly used hydrocarbons are ethylene, propylene, butadiene and benzene. Their molecules make them particularly suitable for composing long organized chains. The complex nature of petrochemical substances is reconstructed through numerous passages and different production processes to achieve a very wide range of products.
Ethylene is the raw material most widely used in the world (5 million tonnes per year). It is used alone to make fruit ripen more quickly and produce detergent marked by a limited foam production.
Polymerization leads to polythene (PE), contained in numerous packages, prints, and linings. The combination of ethylene with water leads to the creation of ethylic alcohol, a solvent for perfumes, cosmetic products, varnish, soap, dyes, textiles and plastic products.
The combination of ethylene and benzene leads to polystyrene (PS), an insulating material used in the building industry and as a raw material to package fragile things and toys. The combination with chlorine leads to polyvinyl chloride (PVC), a widely used material in the building sector and to manufacture waterproof textiles.
Propylene is the starting point of numerous chemical products, including isoprene, glycerine and acetone. The mutual combination of thousands of propylene molecules leads to polypropylene (PP), an ideal substance to manufacture packages and other resilient products. Butadiene is especially used to treat synthetic rubber, leather succedaneum and as solvent.
Finally, benzene, is the starting point to obtain important by-products, such as phenol, aniline, styrene and chlorobenzene, all used in dyes, fibres, resins, plastic, synthetic rubber, pharmaceuticals, insecticides, detergents, textiles. Oil by-products are used as fuels in thermoelectric plants for the production of electric energy, as well as for household heating and the production of hot water.

The reserves

In 2012 oil production covers approximately 31.4% of the world energy consumption (the percentage increases to 52.7% if natural gas is considered). The reserves of that energy source are not distributed in a uniform way in the world; on the contrary, they concentrate in some countries: the Middle East alone has 48%, South and Central America has 20%

(Venezuela has 18% of the world oil reserves), North America has 13%, Russia and Central Asia has 7%, Africa has 8%, Asia-Pacific has 3% and Europe only 1%. The comparison between the annual oil production levels and the currently identified reserves shows that Middle East countries produce little as compared to their capacity, whereas the United States and Western Europe exploit their reserves at a fast pace. In fact, the countries that consume more oil are the ones that own less oil. Europe each year consumes 16% of the world production. This means that if the current production level remains unchanged and no new discoveries are made, Europe and North America will deplete their reserves in a few years and will be forced to resort to imported oil only. The reserves identified so far worldwide will be depleted in 52 years if the current annual consumption levels are maintained. The age of oil is probably bound to last for several years still. However, the level of the world energy consumption is expected to grow in the future (the world population will grow as well as the per capita energy consumption), thus reducing the oil reserves at a faster pace than now. The possibility of avoiding new oil and energy crises (i.e. a situation marked by a limited quantity of oil available on the market to meet an increasing demand leading prices to soar) in the future will depend upon the oil industry's ability to find new fields and above all on mankind's ability to achieve an optimum exploitation of the currently available oil and develop alternative, possibly renewable, energy sources.
(*Source: eni, World Oil & Gas Review 2014*)

A bit of history

For thousands of years, hunting and collecting vegetables were the main resources of mankind. Human beings could only consume energy, since they were unable to produce it.
Approximately 7000 years ago, mankind discovered agriculture and eventually learned how to produce energy: it was food and muscle energy (produced by human beings and animals helping them), wind and water power (wind and water mills). Crafts, trade, transports were developed along with the exploitation of slaves, a new labour source to support economic development.
The first contact between mankind and oil dates back to that period of history. Oil rarely emerges on the earth's surface spontaneously: 5000 years ago Egyptians discovered its therapeutic virtues and used it to treat rheumatisms and circulation disorders, and to foster the conservation process of corpses (mummification). On the other hand, Persians and Romans used oil for illumination purposes and to manufacture firebombs. However, the use of oil remained episodic for many centuries and played a minor economic role.
During the 17th century England went through en energy crisis owing to the excessive exploitation of wood as fuel and the price growth ensuing therefrom. Thus the energy potential of pit coal – in which England was rich - was discovered. The "Industrial Revolution" started in 1709, when Abraham Darby used pit coal instead of charcoal for the first time. After a little longer than a century, pit coal became the most widely used energy source and new technologies simplified its extraction. .
History speeded up. Starting from the second half of the 19th century, mankind started exploiting new resources: oil, natural gas, waterpower and atomic energy.
The discovery of new energy resources accompanied the population growth and economic development.
Over thousands of years mankind lived off hunting and collecting the fruits of the Earth, almost exclusively using the energy of muscles: under those circumstances the planet could only support a population of 20 millions approximately. With the development of agriculture and the discovery of new energy sources, the population grew rapidly. 16 centuries were necessary to reach the figure of 500 million inhabitants, but only two centuries (1600-1830) to reach the first billion. At present the world population amounts to approximately 6 billions, and hydrocarbons, together with the development of the electric energy, provided a vital contribution to the development of human civilisation during the 20th century, and will continue doing so during the 21st century. However, the other side of the coin is inevitable: the large production of pollution and waste and the growing gap in terms of available raw materials and energy between the Northern and the Southern hemispheres. Only during the last decades of the 20th century did mankind start caring for the planet's health,

endeavouring to minimise the impact of its presence on Earth. As regards the gap between North and South, the Governments of the world will need to endeavour very hard to find a solution for a very difficult problem.

Oil fields distribution

When analyzing the list of major producers of hydrocarbons in the world, the differences in the various countries are immediately highlighted. However it must be borne in mind that production is influenced by a vast series of factors, among which the potential of the reserves is only one of the main ones; technical factors can make extraction more or less difficult even in the presence of large reserves and economic factors may lead to an increase in the production depending on the demand. For example, the production of the USA is very high compared to the estimated reserves, while in the Middle East, which has enormous reserves, the production/reserves ratio is very low. Therefore it is important not to confuse production with the size of the reserves. The largest producers are not necessarily the countries with the largest reserves. 48% of the oil reserves is localized in the Middle East. Most of the oil reserves are in Veneziela, accounting for 18%; the countries that follow are Saudi Arabia, Canada, Iran, Iraq, Kwait, United Arab Emirates, Russia, Libya and Nigeria. Most of the gas reserves, instead, are in Rusia, accounting for 24% of the world reserves, followed by the Middle East, Iran and Qatar, which together account for 29% of the total.

Giants in the world

The reserves are classified according to their size and the amount of hydrocarbons they contain, in millions of barrels (for oil) or billions of m3 (for gas), according to a classification made by API (American Petroleum Institute). Till date, in the world, 2 megagiant, 40 supergiant and 330 giant reserves have been discovered. The largest reserve is the Ghawar megagiant field in Saudi Arabia (83 billion barrels), followed by Greater Burgan in Kuwait (70 billion barrels) and by Costanero Bolivar in Venezuela. Out of the 20 largest oil and gas reserves in the world, 15 are in the Middle East (6 in Saudi Arabia, 4 in Iran, 3 in Iraq , 1 in Kuwait, 1 in Abu Dhabi), 2 in Russia, 1 in South America (Venezuela) and 2 in North America (1 in USA-Alaska, 1 in Mexico). Out of the 20 most important gas reserves, 12 are in countries of the former Soviet Union, 7 in the Middle East and 1 in North Africa (Algeria).

(*Source: eni, World Oil & Gas Review 2014 and “Enciclopedia degli idrocarburi”*)

Oil fields in the world

The distribution of the principal oil fields in the world is not uniform, but neither is it random, and it depends on particular geological conditions that are necessary for the formation of large reserves and the difficulty of exploring and researching oil in isolated areas that are not well known, such as areas characterized by particularly severe environmental conditions (the vast areas of Siberia, the areas of the rain forest in South America and the deep offshore areas). The more important oil fields have geological characteristics that are very different from each other, but they have some common elements.
According to the above stated considerations, the first areas in which to search for hydrocarbons are the areas in which sea sediments are present, where the seas are not very deep and are rich in organic substances developing in anoxic environments, which are the ideal mother rocks for hydrocarbons. These conditions are to be found in the fields that are near to stable continental areas (the so-called cratons), where detritus sediments coming from the emerged lands form powerful and thick deposits of permeable material (reservoir rock) covered with fine marine deposits (cap rock). For this reason, many of the more productive fields are to be found along the borders of the continents: in the North American fields in Texas and Louisiana, in the Gulf of Mexico, in the Mexican fields in Tampico-Misantla and Sureste, in the Central African fields of the Niger delta and the Congo Basin and the enormous fields in Western Siberia.
Similar situations with longer, narrower fields also form in the rifts along the borders of subduction areas. In these areas the tectonic deformations can create efficacious structural traps, as in the Venezuelan fields along the Andes mountain range or as in the Sumatra field. Also deep fields characterized by a rapid sedimentation are favourable regions for the formation of important reserves, as for example in Europe in the small province of the Rhine basin or in Graben in the North Sea, that are the most important reserves in Western Europe. Also the large Sirte field in Libya has a similar origin.
However, it is in the continental collision areas, that lead to the formation of mountain ranges, that the more favourable situations for the formation of numerous and important structural traps are generally found. In these areas the reserves

are very often numerous and their volume is large. The enormous oil fields in the Middle East, that are the most extensive and important in the world, follow the trend of the mountain ranges that were formed from the collision of the Euro-Asiatic plate and the Arabian plate.
Also the large fields of the Volga and the Urals, are in a continental suture area, but they belong to a more ancient orogenetic cycle. The collision of the African plate and the European plate in the Mediterranean area, created numerous mountain ranges, among which the Pyrenees, the Alps and the North-African ranges. Near these areas, in particular in the accumulation reservoirs on the front of the mountain range, we find the largest Mediterranean oil fields, such as the Sahara field, but also the largest Italian oil provinces (such as the Po valley, the Adriatic coast, South East Sicily and the Sicily Channel).Important reserves are also to be found, all over the world, in areas where the presence of levels of evaporitic rocks has led to the formation of diapiric salt as for example in many reserves in Central Europe and in the area around the Gulf of Mexico.

Hydrocarbons in Italy

The geology of our country (Italy) is very complex and the peninsula consequently has a complicated sedimentary and structural order, that is not very calm. This has not favoured the formation of large and extensive oil fields, but has created local situations that are favourable for the formation of numerous oil provinces that are reasonably important, even though their extension is not great.
Our country can, from a tectonic point of view, be subdivided into **4 "districts"**. These are all tied to the presence of the mountain ranges of the Alps and Apennines:

- a "rear-arch" field , an area that is not greatly deformed, consisting in the Tyrrhenian Sea;
- a mountain range area, that consists in the big "arch" that stretches from the Alps to the Apennines, and that forms the backbone of the Calabria and Sicily regions;
- a "fore-rift" area, a depressed field that is not greatly deformed, that is located in front of the mountain ranges advancing on the so-called "fore-country", consisting of the borders of the Adriatic Sea, the Ionian Sea and the Sicily Channel;
- the "fore-country" area, an area that is still not deformed, towards which the mountain ranges that are forming move, which consists in the Po Valley, the Adriatic Sea, South East Sicily and the Sicily Channel.

The most important Italian provinces for oil are the Northern area of the Adriatic Sea, the Po Valley (gas and oil), the Pescara field (oil and gas) the Southern Area of the Adriatic (oil and gas), the Southern Apennines (oil), the Fossa Bradanica in the Puglia region (gas and oil) the off-shore platforms of the Calabria region (gas), Central Sicily (gas) and the Pelagic fields (oil).
The most important oil reserves are in Val d'Agri (Potenza) and Villafortuna-Trecate (Novara). Val d'Agri is the province with the greatest oil reserves in Italy. Hydrocarbons are to be found in the anticline folds of the Mesozoic calcareous areas of the Apulian Platform, covered by the slopes of the Apennines in the Campania and Basilicata regions. The presence of oil and gas on the surface have been reported in Tramutola. These escaped from deeper traps following the tectonic deformations in the Apennine mountain range. In the Villafortuna-Trecate fields, hydrocarbons are in Mesozoic carbonate rocks that were fractured due to the Alpine deformations buried below the Po Valley, with one of the deepest liquid hydrocarbon fields in the world (6,200 m).
The distribution of the principal oil provinces in Italy, clearly reflects the geological situation: the comparison between a structural map of our country and a map of the main fields, in fact, shows that approximately 40% of the reserves are in mountain range areas (like the reserves of the Southern Apennines and Central Sicily), while the remaining 60% are in the fore-rifts and fore-country areas - the reserves in the Northern Adriatic Sea and the Po Valley, closed between the front of the Alps and the front of the Apennines that are moving towards each other; the Pescara field and the Southern Adriatic field are closed between the Apennines; and the Dinaridi around the Dinara Mountain area to the East, and the

off-shore platforms of the Calabria region, South-Eastern Sicily and the Sicily Channel. From a simple comparison of the two maps, it is quite easy to see the controlling influence of the geological and structural order of a region on the distribution and importance of the hydrocarbon reserves we may hope to find therein.

Extraction and uses

The search for new fields

The search for new field is very expensive, and therefore it must be carried out with great care. The initial information is obtained by studying aerial photographs made from planes or satellites, which provide a map of the surface rocks, using the Geographic Information System (GIS) mapping to integrate the data, and for the reconstruction of digital models of the ground. Subsequently, geochemistry, micropaleontology and petrography provide all the information that is required with regard to the physical and chemical characteristics of the rocks, their age and composition.
When a potentially interesting area is located, a series of inquiries are necessary in order to classify the nature of the rocks and their geological structure in the deeper layers underground, many thousands of metres in depth. In particular, the scope of the inquiries is to identify the presence of rocks containing hydrocarbons (reservoirs) and traps that enclose them. For this, geophysical investigation is carried out, and in particular reflection seismology. Shock waves are generated using small explosive charges and using systems that make the land vibrate (on the earth’s surface) or with a rapid expansion of compressed air (in the sea). The waves spread in the ground or in the water, and are reflected differently, depending on the layers they meet. When they return to the surface they are recorded by suitably positioned geophones. The elaboration of the recordings provides a sort of “map” of the composition of the underground layers, and from which the presence of any traps may be deduced. The final scope of the preliminary inquiries is to calculate the volume of hydrocarbons present in the field. This is calculated by studying the structure and size of the traps with the help of sophisticated software that can manage all the data collected in the research phase. For this three-dimensional models of the structures are created, in order to calculate the volume, and these models are subsequently used to decide the number and optimum locations of the exploration wells. Not all the traps, in fact, contain oil and only by drilling wells, the presence of oil in the traps can be confirmed.

Drilling of onshore oil wells

Before becoming petrol and plastic, oil needs to undergo a very complex artificial production process which starts with the search for oil fields and, through the extraction, processing and transportation stages (often taking place in countries very far away from each other), it ends with the petrol available at the local gas station or the rubber hose at the shop round the corner. Drilling wells is the only way to assess the value of a field, i.e. the type and quantity of the hydrocarbons contained therein. Drilling a well is a long and expensive, albeit simple, operation.
Rocks are drilled with a rotating bit mounted at the end of a series (battery) of mutually screwed steel pipes (rods), which is extended as the well becomes deeper. The rods are supported by a 50-meter tall tower (derrick) and their rotation is ensured by a rotating plate operated by means of a dedicated electric engine. The bit is made of very hard material and, in some cases, equipped with components of synthetic diamond.
The rod battery is as long as the well is deep. In some cases an extension of 6/7,000 metres is reached, whereas the weight supported by the derrick can reach 500 tonnes. The rods are empty to ensure the circulation of an ad hoc mud which greases and cools the bit supports the well walls and, when it goes back to the surface, removes the debris resulting from drilling the rocks. At pre-defined depth, the hole is covered with steel pipes (casting) to reduce its diameter gradually from 75 to 15/20 centimetres. Modular drilling plants transported by truck are used on the mainland. A 1,000 metre well is drilled in less than a month, but in the case of wells exceeding 6,000 metres, over 45 million Euro and one year of constant round-the-clock drilling are needed.
Off shore drilling techniques are the same although the plant features vary. Up to a 100-metre depth, mobile self-lifting platforms (jack-up) including a hull supported by a sliding scaffolding (legs) are used. The legs of the structure stand on

the sea bottom and keep the hull 15-20 metres above the sea surface to avoid the impact of waves and tides. In the case of 6/700 metre wells, floating platforms are used. After they are fixed to the sea bottom, they float above undersea hulls. If the well is deeper (up to 2,500 metres), drilling ships are necessary, featuring a hole in the hull to operate the telescopic pipes (riser).
During the drilling, the debris produced is continuously analysed, in order to evaluate if the quantity and quality of extractable hydrocarbons is sufficient to pay the production costs back. During this stage, before going on with the actual well development and production stages, other "perimeter wells" are drilled. The drilling stage is one of the most critical and delicate of the petroleum life cycle and can cause strong environmental impacts. In fact, during drilling a lot of rock fragments are produced which are covered with the so-called "drilling mud". Drilling mud is a complex mixture made up of water-based and oil-based chemical additives, utilised to prevent the borehole from collapsing during drilling. In the past, drilling mud was accumulated and abandoned on the site. Nowadays, disposal techniques have changed and the mud is treated and then properly disposed of in order to reduce the environmental impact to zero. First, depending on the composition of the mud, the water- or oil-based fluid is separated from the mud and all the potentially harmful substances are eliminated. Both the base oil and water are recovered and recycled, while the solid decontaminated component can follow three different courses: it can be taken to the dump, it can be reused as building material, for roads or bricks for example, or lastly it can be incorporated into the soil.

Offshore drilling

The need to transfer drilling and production facilities off the coasts, with the consequent difficulties in setting up a plant capable of enduring particular environmental conditions, has resulted in innovative and state-of-the-art offshore research and engineering as far as technological development is concerned.
Offshore facilities are of different types and differ depending on the seabed, water depth and the prevailing climatic conditions. Up to a depth of 100 metres, movable jack-up rigs are used. These consist of a hull supported by retractable structures (legs). These rest on the sea floor, leaving the hull 15-20 metres above the water surface so waves and tides cannot affect it. For depths up to 1,500 metres, floating platforms are used. These, once moored, rest on submerged hull structures. For greater depths (up to 3,300 metres) drillships are utlised. These are equipped with an opening in the hull through which telescopic pipes (risers), which connect the floating structure to the wellhead, pass. Drillships can operate without fixed moorings, maintaining their position using dynamic systems with numerous computer-controlled propellers that generate thrust in different directions.

Oil rigs

The first offshore drilling operations took place in the Gulf of Mexico in the late 1930s. The first predecessors of modern offshore platforms were installed at the beginning of the Fifties, but it was not until the Seventies that the offshore industry really started booming. In the Eighties, there were advances in drilling technology for moderately deep sea exploitation, while in the Nineties, more attention was focused on oilfields of small dimensions (but not economically attractive) and on the search for deep sea hydrocarbon reserves.
An offshore platform is equipped with the following components:

- machinery for drilling and maintenance of oil wells;
- machinery for extracting hydrocarbons;
- oil, gas and water separation system;
- security and emergency systems;
- systems that transport hydrocarbons ashore;
- laboratories, staff accommodation and common rooms;

- gas flares to burn gases during emergencies or when activating the facilities.

These different components can be found on a single platform or on interconnected, independent structures. The drilling unit is usually separate and can be removed at the end of the operations for reuse in another extraction site.
Since offshore drilling and extraction are very delicate operations, offshore rigs are equipped with state-of-the-art security systems designed to minimise the environmental impact of the activity. The security systems present on an offshore platform are the following:

- emergency generator system: activated in the case of malfunction of the main power supply;
- UPS (Uninterruptible Power Supply): security system activated in case of failure of the emergency generator system;
- emergency shutdown system: steps in to shutdown production in case of an accident;
- detection systems: detectors are installed on the platform in order to detect the presence of fires, smoke or gas;
- fire extinguishing systems: the facilities are equipped with fire-fighting systems installed on the platform that use water, which is pumped directly from the sea, foam, carbon dioxide and inert gases. Moreover, the platform itself is made of high temperature-resistant materials to avoid the collapse of the structure in case of a fire. In particular, the area of the wells is isolated from other areas of the platform with blast-resistant walls;
- safety and evacuation systems are located in strategic positions on the platform;
- alarm and communication systems: required to signal an emergency situation both internally and externally, and ask for help in case of an accident.

The extraction

In terms of extraction and processing, during the production stage a sufficient number of wells is drilled to maximise the exploitation of the oil field. Every day, over a period of approximately 20-30 years, a well produces between 500 and 1,000 tonnes of oil (a few thousand barrels) and a few hundred thousand cubic metres of natural gas.
Initially, the oil flows up the pipes owing to the pressure of the water and the gas contained in the field. Thus, 30% of the oil and 90% of the natural gas are extracted. An additional 10-15% can be extracted by keeping up the pressure and adding more water or gas. Finally, an additional 10-15% can be extracted by injecting emulsions, steam or solvents washing the rocks and removing more oil.
Approximately 1/5 of the world production of oil comes from the sea, a percentage bound to increase in the next years. In this case, during the first stages many wells are drilled a few meters away from each other. Then, to drain all the fields, also horizontally, the wells are deviated to reach locations up to a few kilometres away from each other. If the sea bottom is more than 400-metre deep, undersea plants are necessary and the opening of the well is on the sea bottom.
During the petroleum production phases, hydrocarbons are extracted along with large quantities of liquid wastes. These effluents must be treated adequately to avoid contamination of the environment. The liquids produced during the drilling phase consist mainly of produced water and injection water. The former is extracted together with the hydrocarbons; in fact, in deposits, oil and natural gas are associated with a large amount of water, much saltier than ocean water. Moreover, as the reservoir reaches depletion, the amount of hydrocarbons extracted decreases and the volume of produced water increases, until, at the completion of the production stages, the volume of water extracted is greater than the volume of hydrocarbons. Produced water contains organic and inorganic compounds, often toxic, that must be treated before the water is disposed of.
Injection water is the water that returns to the surface after having been pumped into the reservoir to maintain adequate pressure. In the majority of cases, the water is injected back into the well; in the case of offshore oil activities, it can be discharged into the sea, but only if it does not contain pollutants, in other cases it can be reused for other purposes,

such as agriculture.

Disposal of sulphur-containing compounds in associated gas

Associated gas that is found associated with petroleum fields can contain large amounts of sulphur compounds (mainly H_2S). In this case, the associated gas is treated in specific desulphurisation plants that can eliminate up to 99.9% of the H_2S present. A waste product of desulphurisation plants is solid sulphur (S_8); however, after having been protected by an adequate moisture barrier, it can be reused or stored at the production site for future use. One of the main uses of solid sulphur is the production of fertilisers, but there are other applications: for example, it can be used to make sulphur concrete. The latter is more resistant than regular concrete and has a double advantage: it uses waste material that would be taken to the dump and it reduces the consumption of fresh raw materials.

Treatment and storage

On extraction, crude oil contains a mixture of hydrocarbons along with water, dissolved natural gas, salts, sulphur and inert substances such as sand and heavy metals. Prior to being introduced into the pipelines, crude oil must undergo a number of processes such as degasification, dehydration, desalting and desulphurisation.

During the degasification stage, crude oil is separated from associated gas. In order to do this, crude oil is made to pass through a series of separators (3 or 4); separators are particular pressure vessels. This separation process in different stages allows the maximum recovery of liquid hydrocarbons.

During the dehydration stage, water is removed from crude oil. Water in oil can be free or emulsified. In the former case, water can be separated easily due to differences in specific gravity, using a separator; in the latter, separation is more complex and can be carried out with the help of chemical emulsifiers (tensio-active agents) or by heating the mixture.

Often crude oil must undergo another important refining process, desulphurisation. Very often, in fact, crude oil contains hydrogen sulphide, a very corrosive and toxic gas, which must be removed. The most commonly used process is “stripping”, which consists in bringing crude oil into contact with a sweet natural gas within special vertical, cylindrical vessels (stripping towers) in counterflow with the gas. In this way the stripping gas removes hydrogen sulphide from crude oil.

Lastly, a desalting process is carried out to remove sodium chloride and possible sediments present in crude oil. This process also allows the removal of other contaminants which are soluble in water, such as carbonates or sulphates along with heavy metal chlorides.

After having undergone the different processes, crude oil is generally stored in cylindrical steel tanks, which are fire resistant and equipped with a cooling system and containment basins in case of rupture of the tank, until it is transported to refineries by oil tankers and transmission pipelines.

The transport

Oil is present in sufficient quantities to start production only in certain areas of the world, therefore most of it needs to be transported to reach refineries and the place of consumption. Italy, for example, imports 91.4% of the oil it consumes (*Source: eni, World Oil & Gas Review 2014*).

In terms of transport, there are two complementary ways to transport oil: pipelines and oil tankers. Pipelines include a system of 10-12 metre long steel pipes electrically welded together. They are generally buried at a depth of 3-15 metres or positioned on the sea bottom. The flow of crude oil along the pipeline is ensured by large pumps distributed along the route at distances ranging from 50 to 250 km according to the characteristics of the territory to be crossed. Control and safety stations distributed along the route ensure transportation to ports and refineries.

The oil transportation stage is particularly delicate by sea, since it can turn into one of the main pollution sources of seas and oceans if shipwrecks occur.

A modern tanker is equipped with separate double hull storage compartments (i.e. equipped with a double metal shell to protect the oil being transported) and other complex failure prevention systems to minimize the risk of oil spills in the sea. Before the oil crisis in the 1970s, oil tankers were huge (450 m long, 500 tonnes of tonnage), but this trend was changed by the re-opening of the Suez canal (which called for smaller ships crossing it), the changed market conditions and, during the last years, environment preservation and safety considerations. To reduce the environmental impact of those ships, new tank cleaning systems were introduced which allow the collection of the oil residues to be treated in plants on the mainland instead of discharging them into the sea.

Refining

Crude oil includes a large range of hydrocarbons with different quantities of carbon atoms. The ratio of the components varies according to the place of origin. For example, the oil of Venezuela is rich in long molecules making it thicker, whereas the crude oil from the North Sea is more liquid. To subdivide crude oil into its components, while providing its optimum exploitation, a fractioned distillation (or refining or cracking) is necessary.

The various hydrocarbons are separated according to their different boiling temperature. Liquid crude oil is heated up to 400° C at the base of the refining tower and turns into a gas mixture rising up. While they rise, the gases cool down and, according to different condensation temperatures, are separated. Heavier hydrocarbons condensate immediately and are deposited at the bottom. The others rise up and liquefy again at different levels, where they are collected.

Residues contain over 20 carbon atoms, condensate first and can be further separated by means of vacuum distillation to produce lubricants, paraffin, wax and bitumen.

Gas-oil contains 14/20 carbon atoms and condensates at a temperature of 250/350°C. It is an oil fuel used to propel diesel engines and for household heating purposes.

Kerosene contains 10/15 carbon atoms and condensates at 160/250°C. It is an oil fuel used to propel jet planes and heating systems.

Naphtha contains 8/12 carbon atoms and condensates at 70/160°. It is a yellow liquid used as fuel and processed to manufacture plastic materials, pharmaceuticals, pesticides and fertilisers. It is also a solvent to treat rubber.

Petrol contains 5/10 carbon atoms and condensates at 20/70°. It is used as fuel for cars and planes but also to manufacture plastic materials and detergents.

At 20° C only methane, ethane, propane and butane remain gaseous. Most of them are used as energy sources and to produce petrochemical substances and plastic materials. Butane and propane in particular are used in the production of the fuel called liquid natural gas.

Vapour plants

In particular, thermoelectric plants exploit vapour energy, which is produced by a “boiler” that burns a liquid fuel, such as fuel oil and naphtha or methane (usually modern boilers can burn the three types of fuel without distinction). Usually large thermoelectric power plants are installed close to big consumption centres and need suitable water supplies for vapour production and fuel storage. The combustion occurs in a part of the boiler that is called “combustion chamber”, with the walls made up of a series of pipes where water heats and gradually converts into vapour. The combustion chamber receives the fuels by means of adequate openings through which air passes, pushed by special ventilators. According to a determined route, the gases resulting from the combustion release a part of their heat and, at the boiler exit, they pass through the pre-heaters that release the air, which will enter the boiler. Then, they pass through a series of treating filters and finally they get to the chimney, that disperses them into the air. The vapour turns the blades of a turbine, which is connected to an alternator for the production of electric power. Vapour turbines are approximately similar to hydraulic ones, but they differ a lot because they do not work with water, but with superheated vapour, with all the subsequent temperature and resistance problems deriving from it.

Pollution abatement

Flue gas of thermoelectric power plants contains pollutants produced from fuel oil combustion. These include:

- sulphur dioxide (SO_2): arises from the oxidation of the sulphur contained within fossil fuels;
- nitrogen oxides (NO_x): arise from the oxidation of the nitrogen contained within fossil fuels and present in air;

- dust particles: produced during the complex physical and chemical processes which the fuel particles undergo inside the combustion chamber;
- carbon dioxide (CO_2): produced in all combustion reactions.

It goes without saying that the effects on the environment of the above-mentioned substances depend on their concentration. To reduce polluting emissions modern thermoelectric power plants are equipped with systems which are based on different technologies:

- denitrification: nitrogen oxides are converted to water and molecular nitrogen (not polluting) through a reaction with ammonia and oxygen;
- dust precipitators: thanks to the effect of electrical fields or filtration devices, solid particles are trapped and are not released into the atmosphere (currently precipitators collect 99.9% of the dust);
- flue gas desulphurisation: an operation which allows the removal of up to 97% of the sulphur compounds present in fossil fuel power plant flues;
- water treatment: there are different uses of water in power plants; in all cases, however, before being discharged, water must be treated in order to eliminate possible polluting substances, and it can be released among the flue gases or into the sea only when the concentration of hazardous substances and the temperatures comply with legal regulations.

Ultimately all substances are filtered and treated by the pollution abatement systems present in the power plants. In order to favour the dispersion at higher altitudes of the remaining flue gas components and hence avoid soil pollution, flue stacks are very tall, in some cases over 200 metres high.

Turbogas plants

Another type of plant uses a gas turbine instead of a boiler. The gas turbine is a rotating thermal machine that converts the heat into work, by directly using combusted gases as working fluid, supplying mechanic power on a rotating shaft. The air sucked by the compressor is compressed and sent to the combustion chamber where the fuel is burnt (gas oil, “benzinone”, or methane) and the high temperature air and gas mixture is directly sent into the turbine, where thermal energy is converted into mechanic energy. A part of the mechanic energy is converted by the alternator, together with the turbine, into electric energy. The other part is used to activate the compressor. In a few words, a turbogas plant is based on the same principle as reaction plane propellers, with the difference that in planes the turbine only produces that part of the energy required to activate the compressor, while the remaining part is exploited as pressure gas to provide the necessary propelling force to fly.
This type of system has several advantages: reduced costs, possibility to start also in absence of network energy, simplicity and rapidity of construction and finally it does not need cooling water (as a consequence it can be positioned anywhere, even without water supply).

Decommissioning

When an oil field is depleted, the decommissioning of the production facilities follows. The activities carried out during the decommissioning phase include the safe removal of the pre-treatment plant, the platform structures, the compression structures and the hydrocarbon dispatch facilities and the removal of the wellheads and the pipelines that connect to the collection points. Following the dismantling of the production facilities, there is the environmental restoration phase. The areas where the wells and the treatment facilities were located are reclaimed and restored to pre-mining conditions, with the planting of grasses and trees. As far as the decommissioning of offshore facilities is concerned, operations to safely plug and abandon the well must be carried out and the installations and pipelines that connected the platform to treatment facilities on land must be removed. These operations are very delicate and require specialised personnel in order to avoid adverse environmental impacts. Once the installations have been removed, suitable sites must be identified for materials that cannot be reused and for the disposal of potentially polluting products. An alternative to the dismantling and removal of offshore installations envisages the reuse of disused platforms in-situ as artificial barriers, for example. In fact, it has been observed that many artificial structures placed in open water are soon colonised by benthic macrofauna and by a large number of fish species that find a suitable habitat to reproduce. Another alternative is the installation of offshore wind turbines on the disused platforms. In fact, these offshore platforms can support wind turbines with the advantage that they are far from the coast, where the winds are strong and constant, and where there they do not have a negative effect on the landscape. The option of leaving disused offshore platforms in place must be carefully evaluated from an environmental and a legislative point of view.

The oil system

Badly distributed wealth

If one observes the distribution of hydrocarbons in the world, it is quite clear that it is not uniform all over the planet, but there are areas in which hydrocarbons are much more abundant and others that are totally devoid: the imbalance between the quantity of hydrocarbons contained in the reserves of the different world oil-yielding provinces is very clear. What conditions and determines the distribution of natural gas and oil in the subsoil?

Geology helps us to understand

The factors that determine the quantity of hydrocarbons present in a region are manifold and all of a geological nature: to understand why one region is richer than another and to evaluate the potential of an oil-yielding province it is necessary to know its geology very well, both in terms of the different types of rock you can find and in terms of its geological history. This knowledge, that is not always easy to obtain, is very important to be able to implement a preliminary evaluation on areas that have not yet been explored as far as hydrocarbon research is concerned and to determine their productive potential. It is a fundamental step when an exploration is being carried out.

The oil system

The set of all the characteristics that lead to the formation of an oil field make up the so-called ‘oil system’. This system is made up of the following fundamental elements that will be dealt with in detail in the subsequent paragraphs:

- the presence of a mother rock (source rock);
- the presence of a reservoir rock;
- the presence of a cap rock (seal);
- the formation of traps with a suitable structure.

The necessary processes comprise:

- the generation of hydrocarbons (conditions to reach the ‘oil window’);
- the expulsion and migration of the hydrocarbons from the mother rock to the reservoir rock;
- the accumulation of hydrocarbons in a reservoir rock within a trap.

The areas that produce the most hydrocarbons are divided into ‘oil fields’ according to their geological and structural characteristics; these in turn are subdivided into smaller provinces characterized by a uniform geological situation and by similar characteristics of the reservoir rocks and of the structure of the traps. The task of the person who is engaged in exploring for hydrocarbons is to locate the areas that have the above-mentioned geological characteristics, those that are the most favourable to the formation of important reserves.

The mother rock

Hydrocarbons are formed due to the transformation of organic material scattered in rocks. Organic substances provide the two elements essential to the constitution of hydrocarbons: carbon and hydrogen. For the formation of a significant quantity of hydrocarbons, the source rock must contain more than 0.5% of its weight in organic carbon. Hence, the first prerequisite condition for the formation of an important oil field is the presence of rocks that are rich in organic substances.

Organic substances derive from animal and plant organisms that, when dead, accumulate in sediments and detritus that deposit at the bottom of sedimentation basins. Accumulation can take place in both a marine or a continental environment and in both cases the organic substances are generally decomposed rapidly and only a small part (about one per thousand) avoids the attack of bacteria and the oxidation processes. Organic substances can therefore accumulate in great quantities only in sedimentary rocks that form in basins that have been stable for a long time.

The accumulation of organic material also depends on the production rate of the same, that is conditioned by environmental factors such as the availability of food and nutritious substances, light intensity and temperature. The sites that are more favourable to a high accumulation of organic material (remains of marine and land organisms) are warm, relatively shallow seas and those off the coast. In deep sea environments organic material is less, due to a scarce supply, while on land it decomposes very rapidly. The first places to look for hydrocarbons are therefore those areas in which shallow water marine sediments that are rich in organic material are present: the ‘mother rocks’ from which hydrocarbons originate.

It is also necessary that the organic substances should be preserved and protected from the decomposition processes as much as possible. This can be accomplished in regions of quick sedimentation, where the material is rapidly buried or in environments deprived of oxygen. Anoxic conditions can be found in closed basins with limited or no water circulation, as in lakes or lagoons with scarce communication with the open sea, in relatively shallow seas within emersed lands or in very deep oceanic basins. Anoxic basins are so tightly connected to the presence of noteworthy hydrocarbon deposits that they are considered among the most important generators of mother rocks and are therefore the object of exhaustive studies by those working on gas and oil exploration.

Mother rocks formed in closed anoxic basins have been identified in all the main oil yielding provinces: Venezuela, Colombia, Gulf of Mexico, Saudi Arabia and Alaska, while mother rocks that have formed due to rapid sedimentation have been found in the oil-yielding provinces of Argentina, West Africa, the North Sea, USA and Italy (the Po basin).

Transformation of organic material

The sediments that are progressively deposited bury the ones below, that are therefore covered by growing layers of material that accumulate in time. As they are pushed deeper and deeper in the Earth’s crust, the sediments slowly loose the water that they contained originally, become denser and more compact and are subjected to growing temperature and pressure. The ‘oil window’ is defined as the set of particular pressure and temperature conditions that are required for the transformation of organic material into hydrocarbons. For an important oil-yielding province to be formed, it is also necessary that the mother rock should reach the conditions of an ‘oil window’.

The transformation can take place at low temperatures but over a long lapse of time (as in older rocks) or in a short time but with higher temperatures (as in younger rocks): the age of the mother rock is not a determining factor in the production of hydrocarbons but the temperature it reaches is. The initial characteristics of the organic substance in addition to the conditions and the time required to reach the ‘oil window’ can be decisive to determine a greater production of gas rather than oil. The researchers carry out a series of tests on the possible mother rocks to establish whether these have reached the conditions that are necessary for transformation, or not, by checking some specific ‘indices’: the reflecting power of vitrinite (an organic substance that increases, reflecting the higher the temperature to which it is subjected) and the colour of pollen spores (that become darker as the temperature rises).

The migration of hydrocarbons

The hydrocarbons that form within the mother rock are generally scattered in the sediments and must have the possibility of migrating and concentrating to build up economically significant deposits. It has been calculated that only 5% of the hydrocarbons that form accumulate in oil fields of a certain importance.
Migration takes place in two phases. **Primary migration** allows the expulsion of hydrocarbons from the mother rock with a mechanism similar to the one that provokes the alienation of the water originally present in the sediments due to the growing pressure to which they are subjected.
Oil and gas are lighter and less dense than water so during secondary migration they tend to rise through pores and fractures in the rock.
For migration to take place, it is necessary that the surrounding rocks should be permeable, i.e. that they should have pores and fractures wide enough to allow the passage of oil drops and gas bubbles. The higher the permeability of the surrounding rocks, the higher the possibility that a great quantity of hydrocarbons can accumulate. Permeability depends on the geological history of the region and is conditioned by two important factors:

- **initial permeability** depends on the kind of rock and on the conditions of its formation; it is very high in gravel and sand, lower in sandstone and very low in limestone and in igneous and metamorphic rock;
- **secondary permeability** is created by fractures and faults that form in the rock as a result of tectonic deformations or hollows that develop as a consequence of karstification processes.

The more productive oil-yielding provinces must therefore be sought for in places where the geological history has increased the probability of finding rocks with the characteristics of mother rocks surrounded by permeable rocks. Less permeable rocks, such as clay, act as an impermeable barrier that stops hydrocarbon migration and forms the 'cap rock'.

Elements that form an oil field

Hydrocarbons, being light and not very dense, tend to rise while they migrate. If they do not find obstacles on their ideal pathway, they scatter in the overlying rocks until they reach the surface and give rise to spontaneous evidence: the so-called oil seepage that remains on the surface. In short, for an important oil field to form it is necessary that the rock formations that surround the mother rocks should be able to trap and accumulate hydrocarbons within, and require three indispensable conditions:

- the presence of a rock that can contain the hydrocarbons, the so-called reservoir;
- the reservoir rock must be bounded by an impermeable rock, called 'cap rock', capable of stopping the migration of fluids and of confining them within the reservoir;
- the disposition and configuration of the reservoir and cap rocks must be such that they form a rather capacious container with a shape suited to hold the maximum amount of hydrocarbons and constitute the so-called 'trap'.

Capacious reservoirs

Reservoir rocks must have an elevated porosity and permeability: the higher these values are, the greater the quantity of hydrocarbons that the reservoir rock can contain and the easier it will be to extract oil and gas. Naturally, the greater the volume of the reservoir rock, the greater the volume of the oil field.
The most efficient reservoir rocks are the 'silicoclastic' ones, made up of granules and fragments of pre-existent rocks (sand, sandstone, conglomerate). These rocks are characterized by an elevated porosity and form high quality basins. It has been calculated that 60% of the oil fields discovered up to now are contained in rocks of this type.
Even carbonate rocks (calcareous and dolomite) are good reservoir rocks when they are intensely fractured or of organic origin (such as coastal calcareous rocks), when karst processes are active and create big underground void spaces. A

little less than 40% of the world oil fields is contained in rocks of this kind.
All other kinds of rocks make good reservoirs only when they are intensely fractured: generally, they contain very small oil fields that are therefore practically irrelevant, Important fields in fractured granite rock can only be found in the area between Kansas and Texas (Anadark basin), in the Egyptian field of Ashrafi, in the Gulf of Suez and in the off-shore field of Bach-Ho, in Vietnam.

A suitable 'cap'

For the hydrocarbons to remain confined within the reservoir rock it is necessary that it should be surrounded by rocks that prevent the hydrocarbons from moving away. Cap rocks must therefore have characteristics that are in contrast to those necessary for a rock to be a good reservoir: in fact, they have to be as impermeable as possible. Usually they are made up of fine-grained sedimentary rock (such as clay, marl, clayey limestone) or of evaporite rocks (such as gypsum and halite) and must not be very fractured. 95% of the cap rocks of the world's main oil fields is made up of clays or evaporites.
Efficient traps
The above-mentioned characteristics of reservoir and cap rocks are conditions that are necessary but not sufficient for the formation of noteworthy oil fields. A decisive factor is the shape of the 'trap' that imprisons the hydrocarbons because it determines the shape and volume of the reservoir and the magnitude of the reserves that the latter can contain. Traps can be either structural or stratigraphic.
Structural traps are caused by tectonic deformations that have fractured and folded the rocks. The conformation that is most favourable is that of rocks deformed in anticline folds with the layers upwardly convex. These structures are therefore the most suitable to contain fluids that tend to flow upwards because they are less dense.
Even evaporite rocks can originate excellent traps: salt deposits, being lighter than the surrounding rocks, tend to flow upwards and curve the layers above forming structures called 'diapirs' that are favourable for the accumulation of hydrocarbons. Very many oil fields in the world are associated to the presence of salt diapers. (for example, in Central Europe).
Even tectonic structures, where fault systems create an alternation of low-lying basins and protruding areas (Horst and Graben), can constitute efficient trap systems like in the North Sea Basin and in the Rhine Trench between France and Germany.
Structural traps are the easiest to identify with geophysical surveys which explains why the majority of the world oil fields are contained in structures of this type.
Stratigraphic traps, instead, are formed due to sedimentary causes, when there are sudden changes in the permeability and porosity of the rock, such as in river and relatively shallow sea environments. Even though stratigraphic traps are very numerous, they contain only 15% of the world oil fields, not because they are less efficient than structural traps but because their identification with geophysical survey methods is much more problematic.
Within a trap, due to the difference in density of the various components, we find: at the top the lightest gas, below this, hydrocarbons and lastly, water. The surface that separates oil from water marks the lower limit of the oil field and its identification is fundamental to calculate the volume of hydrocarbons contained in the field.

Non-conventional hydrocarbons

Difficult recovery

The productivity of an oilfield depends on different factors, such as the permeability of the rocks of the reservoir, the pressure inside the oilfield , or the viscosity and density of the hydrocarbons that it contains: because of these limiting factors it is not possible to extract all the hydrocarbons in a reservoir, but only a percentage of the same. The "recovery factor" is an important index that makes it possible to evaluate the percentage of hydrocarbons that can be extracted in an economically profitable manner. Maybe not many people know that with the most well known and economical

technologies that are currently in use, the percentage of recovery is surprisingly low: it rarely exceeds 50%. This means that in the known fields there is more or less the same amount of hydrocarbons as the amount extracted in the history of oil exploitation: an enormous quantity that, if made available in some way, would enable us to shift further the dreaded moment in which the reserves of fossil fuels shall inevitably finish.
Furthermore, till date, hydrocarbons have been available in sufficient amounts to cater to the demand, and only the best quality hydrocarbons, which are lighter and more liquid, have been extracted and utilized: a very large part of the hydrocarbons does not have characteristics that are suited for the refining process, as they are too dense, too heavy, too viscous or rich in unwelcome impurities, such as sulphur or heavy metals. However our economy and our energy production are necessarily still based on fossil fuels, and the need to dispose of this (for the time being) essential source of energy has intensified research and development programmes, thus leading research institutes and the principal oil companies to pay attention to what some already define (light-heartedly, but not seriously...) the “bottom of the barrel”.

Non conventional reserves

It is not easy to estimate what lies underground, however it is believed that in the sedimentary rocks worldwide, there are probably 1.8 x 10^{12} cubic metres (approximately 12 x 10^{12}barrels) of liquid oil. Liquid hydrocarbons, even though they all belong to the same family, differ from one another. They are made up of compounds with different chemical and physical characteristics: oils, heavy oils, tar and very heavy oils. The oils of the best quality are the less viscous ones, and are called “conventional” oil (or petroleum): in fact these hydrocarbons can be extracted with conventional methods, with technologies that have already been developed, and that are widely utilized since decades all over the world, with relatively low costs, which are therefore very convenient.
However, out of all the estimated reserves, conventional oil is only a small part (approximately 0.5 x 10^{12} m^3): the more consistent part (approximately 1.3 x 10^{12} m^3) consists of oil with a high viscosity, that is less valuable and more difficult to extract. An analogous quantity of organic material, a potential source of hydrocarbons, is trapped in the form of kerogen (a precursor of petroleum) in particular rocks such as oil shale and tar sand, however this is mostly beyond our range of utilization, at least at present.
Since the reserves of conventional oil are inexorably decreasing, research is pointing towards the exploitation of the more viscous hydrocarbons. These are known as “non conventional” hydrocarbons because, in order to extract them, special techniques are required, such as extraction by mining, appropriate processing of the rocks that contain these hydrocarbons, or procedures to decrease their viscosity, so that it is easier to extract them. Furthermore, all these “special” hydrocarbons require prior processing before being sent for refining. Therefore there are potentially enormous reserves, but for the extraction and production of these hydrocarbons, much more complex technologies are required, and these are still in the developmental stage, and due to the additional costs these are not competitive as yet. However, the situation is rapidly changing and the future of oil research is increasingly oriented towards the “non conventional” hydrocarbons.

Non-conventional characteristics

The non conventional hydrocarbon family includes compounds that differ greatly from one another, however they are all characterized by a high density and viscosity . The “heavy raw materials” are those oils whose density, according to the API (American Petroleum Institute) scale, is less than 25°, while the definition of viscous oils is a viscosity >50 cP (centiPoise; 10 Poise = 1 Pascal/s). Hydrocarbons with viscosity >10,000 cP and density <10° API (and therefore denser than water) are defined “extra heavy”. This latter category also includes tar extracted from sand and clay or oil shale.
Heavy hydrocarbons are also characterized by a significant content of foreign elements, such as sulphur (present in percentages up to 6-8%), nitrogen and heavy metals, in particular nickel and vanadium : all these components can create problems in the refining and manufacturing processes and can cause environmental pollution.
Non conventional hydrocarbons are generally found at modest depths (<1,000 m), and rarely below 3,000 m, because high temperatures decrease the viscosity; often the reservoirs are found in very porous sandstone. Heavy hydrocarbons are always on the bottom of the reservoirs, and they account for an important part of the reserves, however they can also

be found in concentrations when the hydrocarbons migrate from the mother rock where they were produced (in the so called “oil window” at depths from 3,500 to 4,500 m), and undergo degradation and alteration processes (for example due to bacteria) or evaporation and dissolving processes of the lighter more precious fractions. Very often these can be found in large quantities in the basins of rivers that flow on the Earth’s surface (as for example in the Orinoco river basin in Venezuela), and it is in these areas that research is now concentrated.

Where in the world

Exploiting non conventional hydrocarbons on a large scale began in the Eighties. These new fossil fuels initially contributed only small percentage amounts, but today they account for approximately 10-12% of the world production. Research began (actually even before the Eighties) in California, Venezuela and Canada, which are considered the pioneer countries for this kind of research.

Canada, for example, invested greatly in this type of research starting from the Seventies, and non conventional hydrocarbons account for 60% of the Canadian production of hydrocarbons And this is not a small amount if we consider that with a production of 3.4 Mbbl (million barrels), Canada is the sixth producer in the world of hydrocarbons after Russia, Saudi Arabia, USA, Iran and China. Also Venezuela is in the vanguard, with a production that amounts to 40% of the production of fossil fuels in the Country. More recently, other Countries have begun the production of viscous oils, such as Indonesia, the USA, Russia, Kazakhstan, Oman, China and Mexico.

Among the larger deposits and oilfields, the most important is the oilfield of Faja del Orinoco in Venezuela, where there is a production of oils with a viscosity ranging from 500 to 8,000 cP, high density (<10° API) and high sulphur content (>2%), from porous sand at depths between 400 and 900 m. Large quantities can also be found in Kazakhstan, Canada and Russia, however, all the oil reservoirs have rich deposits.

Some history

Asphalts, tar and heavy oils are not a recent discovery, on the contrary, it may be said that these were the first hydrocarbons to be used by man. Since the dawn of human civilization, in fact, these were used for the most varied purposes: as a sealing and waterproofing material for boats and the roofs of houses, as a glue, as fuel for oil lamps and lights, and as a medication for wounds.

From the very beginning of industrial exploitation of oil, it was noted that only a very small part of the hydrocarbons present in a reservoir could flow out naturally because of the pressure in the oilfield: which however decreased gradually as the contents of the oilfield were emptied out, and therefore from the very beginning, the need arose to study techniques that could artificially increase the pressure so as to facilitate the oil extraction procedures. The most common technique consists in injecting gas and water in the reservoir, that help to move the oils with a lower viscosity towards the wells.

However, notwithstanding these expedients, the heavier and more viscous oils cannot be moved and at least 50% of the hydrocarbons remains in the reservoir. For this reason a large number of oil reservoirs have been abandoned, because they were considered unproductive with the “normal” techniques, although these oilfields still contain a very large quantity of viscous hydrocarbons. Now that the conventional oil reserves are becoming depleted, at the end of the 20th century, research has been started to find techniques that enable the extraction and utilization of these “difficult” hydrocarbons.

Heavy hydrocarbons are not economical, but they are abundant and in the 21st century they will be a very important source of fossil fuel.

Experimental processes to distil hydrocarbons from rocks such as oil shale or tar sand were studied even far back in the 18th century, to extract asphalts, tar and oils for the lamps.

Of course there are a number of historical curiosities: for example, the so-called “saurolo” used to be extracted from a rocky formation known as “scisti bituminosi di Besano” (Besano tar shale), in the province of Varese. This area was well known for the discovery of perfectly preserved fossil remains of fish and large reptiles. The heavy Saurolo oil was thought to be some kind of “dinosaur distillation”, and was considered a very powerful, multipurpose medication! In the

second half of the 19th century Saurolo, which is very similar to Ichthyol (that was produced in Tyrol, which is now created artificially), was produced on an industrial scale and marketed by the pharmaceutical companies to cure skin diseases. In particular, it was used to cure cases of dermatitis reported by Italian soldiers who fought in the African campaigns. At the site, already in the 18th century, there was a mining activity to extract oil shale, that was used as fuel for lighting purposes. And starting from 1830, a new project was begun for the extraction of gas for public lighting of the city of Milan.
After this pioneering and experimental phase, researches on non conventional hydrocarbons started again in the Eighties, with an increasing allocation of funds . New technologies were used for the extraction, production and processing of the viscous oils, with important technological innovations that made exploitation of this resource increasingly profitable in terms of the percentages recovered and costs.

Bituminous sand

The terms bituminous sand, tar sand and oil sand refer to sand deposits that are not cemented together, and are very porous, and contain non mobile viscous oils. The largest known accumulation is in the region of Alberta (Canada), with an accumulation of oil that is over 60 m thick, at depths ranging from 0 to 600 m, in porous sand. The oil that is produced has a high content of sulphur and a very high viscosity level (2×10^6 cP). The tar sand of the surface deposits at Athabasca (one of the extraction sites in Alberta) have reserves amounting to 75-100 Gbbl. These have been exploited since 1963 with various active mines, and can produce 2.5 Mbbl per day, for 100 years (current production is 600,000 bbl a day). The largest reserves in tar sand are, in fact, in Canada (State of Alberta: Athabasca, Cold Lake, Peace River), in the Orinoco river basin in Venezuela and in Russia (The Siberian platform, Melekess). Other important deposits in tar sand are in China, India, Indonesia, Brazil and Ecuador. It is estimated that tar sand can contain reserves amounting to 5,000 Gbbl (billion barrels). Even if we consider that, at present, only 15-20% of these hydrocarbons can be extracted, these are however considerable amounts; for example, the Middle East has “conventional” reserves that are estimated to be 2,000 Gbbl, of which only 683 are considered extractable with the conventional methods.

Oil shale

Clays that are rich in organic substance are the most common mother rocks and many clays (oil shale) can contain large amounts of organic substance that has still not been completely transformed into hydrocarbons (kerogen), dispersed in small particles or concentrated in thin lenses or laminas: kerogen is typical in mother rocks that were never buried deep enough to generate hydrocarbons. If the kerogen content is greater than 8% of the weight, the rocks may be considered potential future reserves: this content guarantees a production of 40 l of oil per tonne of rock. In the richest oil shale, approximately 12-14% of the weight consists of oil: in the Green River Formation (Colorado, USA), exceptional values of 16% are reached. Kerogen is very abundant but it is difficult to extract; in fact it is scarcely mobile and it is not easy to separate it from the rock, and furthermore clays have a very low permeability therefore it is improbable that these hydrocarbons can account for more than 10% of the world resources. Tar shale and clay contain reserves amounting to 2,600 Gbbl, of which 2,000 are in the territory of the USA (Green River in Colorado, Uinta Basin in Utah and Washakie Basin in Wyoming), the rest is distributed between Brazil , Australia, China and Estonia.
In an international scenario, use of non conventional hydrocarbons should not only lead to an increase in the reserves but also to a greater diversification of the extraction sites (that are no longer prevalently concentrated in the Middle East) thus making the price of oil more stable, as it is less sensitive to the geopolitical scenarios and international crises. Serious environmental problems caused by “non conventional” extraction still have to be solved.

Technologies for extraction

Sophisticated technologies

The basic concept for the recovery of non conventional oils is that the dense not very mobile hydrocarbons must be moved towards the extraction well. This is obtained in different ways: by increasing the permeability of the rock of the reservoir, by artificially creating pressure gradients in the oilfield, or by increasing the mobility of the oils by decreasing their viscosity. Various methods are used, and can be summarized as follows:

- “cold “extraction technologies that use physical and mechanical methods to increase the pressure in the oilfield and the permeability of the rock of the reservoir, while the viscosity of the oils is decreased by injecting chemical solvents.
- “thermal” methods that, instead, utilize heat to increase the mobility of the hydrocarbons in the reservoir.

Some technologies require wells, similar to the extraction wells, while others use mining techniques for the extraction (i.e. the collection) of the rocks (for example in the case of tar sand and shale, these are extracted or dug out and then processed at a later stage). With the use of the more modern technologies the percentage recovered from the reservoirs may increase to 70%.

Some methods, such as gravity drainage extraction, and mining and extraction of tar sands, date back to 100 years ago. However these methods have recently been reviewed and refined, and in the future it is believed that there will be a possibility of also using resources that are unheard of at present, such as methane hydrates or tar clay. These technologies, however, have some disadvantages: great energy consumption, the need to dispose of residues (such as shale and sand contaminated by the hydrocarbons produced in large quantities), a high level of CO_2 emissions and the production of sulphur and mud with a high content of toxic substances.

Other techniques

The first techniques utilized to produce viscous oils on a large scale date back to 1950 approximately, and these used steam. The countries that first started to study this technology were the USA, Canada, Indonesia, Romania, Russia, China and Kazakhstan, and at present with the thermal steam extraction technique, approximately 4-5 10^6 bbl/day are produced. Another technique that was initially used more often was in-situ combustion, in which combustion of a part of the hydrocarbons of the oilfield was used to heat and liquefy the remaining hydrocarbons, also the water flooding technique was used, and injection of solvents, polymer displacement and injection of inert gas (such as CH_4 or N_2) and other techniques that use a high pressure gradient to displace the oils and direct them towards the wells. A curiosity: the techniques that utilize repeated pressure impulses in order to make the hydrocarbons move towards the extraction wells were born in California, where it was observed that, after the vibrations of very strong earthquakes, the productivity of some of the oilfields increased spontaneously for some weeks.

In the Eighties new concepts were born that developed highly productive techniques, for example simultaneous use of the Cold Heavy Oil Production with Sand (CHOPS) method, to increase the thrust of the gas that is dissolved in the viscous oils, and Horizontal drilling techniques and gravity drainage extraction, that greatly increase the recovery coefficient. At present these are the more productive and more used techniques : with the CHOPS technique, 0.7 Mbbl/day are produced, in Canada alone; with the horizontal drilling technique 0.7 Mbbl/day are produced in Venezuela. Total production amounts to 4 Mbbl/day.

The more immediate development for the future is the thermal technique, using SAGD (Steam Assisted Gravity Drainage) that combines the steam injection thermal technique with recovery by means of horizontal drilling: a very efficient method that enables a recovery of up to 80% in 5-8 years, however it is still expensive.

There are many possible methods, however these are not always suited for all the occasions, therefore it is indispensible to begin accurately planning the interventions, according to the characteristics of the oilfields. Often a number of technologies are used, as a sequence or combined with one another.

For example, after having used the CHOPS method that simultaneously extracts sand and hydrocarbons, creating a remarkable increase in the permeability of the reservoir, it is possible to further increase the recovery coefficient by using a thermal method such as VAPEX or SAGD.

The recovery of oils from oil shale or tar sand is more complicated and involves the extraction of the material that cannot be processed in situ by mining. The production methods use heating processes (retorting, in special equipment called “retorts”) and destructive distillation, that destroys the rock leaving the hydrocarbons contained in it as residues. In some cases retorting can be carried out in situ, but prior to this the rock must be broken up by means of explosions. After thermal treatment, the extracted material is "washed" with hot water and emulsifiers in order to separate the hydrocarbons from the rock. The main disadvantage is the production of a large quantity of residual material, that must then be appropriately disposed of.

Treatments for special hydrocarbons

In Estonia, oil shale is burnt directly in thermoelectric power plants, however this is one of the few examples of direct utilization of non conventional oils. Normally, heavy hydrocarbons cannot be utilized in conventional refinery plants: they are too dense and viscous and contain large quantities of substances such as sulphur or heavy metals. These require a prior treatment, known as upgrading, that transforms them into lighter hydrocarbons, which also purifies them from the more harmful substances. Thus the large family of so-called "syncrude" oils (or SCO, synthetic crude oil) is born, the raw materials that are produced by synthesis (i.e. by chemical treatment) from other compounds and that, besides the products of the "non conventional" hydrocarbons, also include the raw materials produced from the liquefaction of coal or liquid hydrocarbons produced from the condensation of natural gas. A family that is rather costly at present, but which will give an ever increasing contribution to the production of our energy requirements and will be of great help in the difficult and long transition from fossil sources to renewable sources.
Since high viscosity oils are rich in carbon, and lack H, the upgrading processes to obtain low viscosity raw material that can be used in the conventional refineries imply three main phases: breaking up of the macromolecules (cracking) and elimination of excess carbon atoms, by means of a process called coking, addition of hydrogen to compensate the excess of carbon (hydrogenation) and removal of the sulphur, nitrogen and heavy metals.
In the coking process, the heated viscous oil is vaporized in a low pressure chamber, and the residues produced are coke, carbon mixed with various minerals (5%) and with sulphur (6-8%). The coke can be utilized as fuel (which is however not advisable as it is one of the "dirtiest" fuels) or in the steel production process. The coking process produces large amounts of CO_2 and therefore there is a trend to decrease its application in favour of hydrogenation.
All the more viscous hydrocarbons have a very high content of sulphur (a percentage that varies from 0.1 to 0.2 % up to 4 – 8 %) that is eliminated with the hydrogenation process which, besides producing lighter oils, extracts S, transforming it into H_2S.
This is again transformed later on into elementary S, and is then opportunely disposed of or stocked.
There are many processes that improve the characteristics of non conventional oils, transforming them into good quality syncrude, and these are rapidly evolving. In fact this is one of the research sectors of the oil industry in which investments and efforts are mostly focussed.
Even though non conventional hydrocarbons are not particularly abundant in Italy, it is in the vanguard in research in this field. In fact , ENI and SNAM research laboratories have obtained remarkable results, and have also developed interesting upgrading technologies with which it has become possible to eliminate the intermediate production of heavy fuel oils and coke: this process is known as the ENI Slurry Technology or EST.
The upgrading phase does not always take place at the extraction site, and for this reason the viscous oils must also be treated, by diluting them with lighter oils, so that it is possible to transport them in pipelines: in fact, products that are too viscous cannot be transported in pipelines.

Potential developments

The cost of extracting and treating non conventional hydrocarbons is about 10-20$ per barrel more than for conventional hydrocarbons: of these costs, approximately half are for improving the quality of the hydrocarbons (upgrading). Therefore this is not an economically profitable source, and its utilization will not make the price of oil drop. However there are abundant reserves that will guarantee a constant production of hydrocarbons in the near future, together with other sources that are also not very "conventional", such as the production of liquid hydrocarbons from coal liquefaction, from conversion of gas into liquid fuels (Gas To Liquid or GTL technology) and from the biomass, besides the possible exploitation of methane hydrates in the sediments of the ocean floors. While it is believed that the production of conventional hydrocarbons will reach its peak in the next 10 years, and will then inexorably decrease, it is estimated that the production of non conventional hydrocarbons should continue to increase for the next 50 years, and will reach 10% approximately of our energy requirements. Naturally the possibility of disposing of new unexpected reserves of fossil fuels, for a few more decades, must not lead us to forget that however it is necessary to reconvert our energy consumption and our production of energy, diversifying the sources, and favouring technologies that allow a production of energy that is as clean as possible and that respects the environment. For this reason non conventional hydrocarbons must not be considered a remedy for the oil crisis but a valid aid, and in the near future, these will become an increasingly important part of the so-called “Energy Mix” (together with clean coal, conventional oil, gas, nuclear power and alternative renewable sources): no more contrasts between the different sources of energy, but “team work” to develop technologies that are increasingly eco-compatible and sustainable.