DEVELOPMENT PHASE OF HYDROCARBON FIELDS
5.1.1 Introduction

The development phase of a field starts at the end of the exploration phase, including the geological and geophysical surveys and the drilling of exploratory wildcat and appraisal wells, which provided the data and information necessary to assess with sufficient accuracy, through specialist studies, the extent of the field and its potential.

The field development phase entails large-scale investments, the amount and duration of which depend primarily on two factors: the logistics and environmental situation; and the technical solutions adopted for drilling and for bringing the wells into production, which depend on the type of reservoir, the hydrocarbons composition, the field pressure and temperature, and the technical solutions regarding the gathering, treatment and storage of the fluids produced, as well as the disposal of those undesired.

For the development of onshore fields it can be assumed that, excluding certain areas with particularly hostile climatic conditions, if a scrupulous assessment is made of all the conditioning elements, the technical and logistical problems no longer present any great difficulties due to the fact that consolidated standardized solutions now exist.

With regard to the approach to the optimal technical solutions, it must be considered that the final objective is that of achieving the maximum recovery of the hydrocarbons reserves within a time frame compatible with the rational development of the field and with the lowest possible investment. Of the various feasible solutions, the best one is that which enables a balance to be found between the greatest quantity of recoverable reserves, the shortest possible time and the lowest cost. In fact, high daily production requires high investments as a larger number of wells are necessary together with a greater capacity of the gathering and treatment plants. These elements, apart from increasing the unit cost of the product, can diminish the recovery of the hydrocarbons; in fact, for reasons linked to the physical characteristics of the field (permeability, porosity, type of fluid contained, etc.), accelerated development can cause irreparable damage to the field, when large amounts of recoverable hydrocarbons are yet to be extracted.

However, a low production level, while on the one hand means investment is reduced and minimizes the possibilities of damage to the field, will have an impact on revenue long term. This could be uneconomic for operators who need to quickly recuperate their capital investment and make adequate profits to finance their ongoing activities.

The production of a field can spin out for several decades and will stop when revenues can no longer cover operating costs. The life of a field can be lengthened by carrying out projects of secondary recovery by injecting water and gas into the deposit (see Chapter 4.6), or projects of tertiary recovery (see Volume 3, Chapter 4.2). However, these techniques entail complex solutions and large-scale investments; in this case, an in-depth knowledge of the field can help the operator, having observed its behaviour during its productive life.

It is also important to stress that for the development phases of a field it is necessary to maintain a tight technical co-ordination in order to amalgamate contributions from various areas of competence.

Field study area. It provides – also on the basis of other areas, such as laboratories – the basic information on knowledge of the field and, in particular: assessment of reserves, drive mechanisms,
chemical-physical characteristics of the fluids, number of development wells, their location on the target, the rate, pressure, GOR (Gas/Oil Ratio), etc.

Drilling area. It defines the type of drilling rig or rigs for the development wells and, with reference to the geological targets and any directional parameters, defines the areas for locating the wells or groups of wells (clusters) and the drilling programmes.

Production technology area. It defines the types of well completion (simple or multiple), the surface safety control equipment and the technologies for future operations on the wells (workover).

Engineering area. It defines the gathering system, the process plants for treatment of the fluids produced, storage, control and telemetry systems, auxiliary structures (such as possible accommodation for personnel), etc.

Environment and safety area. It ensures the respecting of regulations regarding safety, health and environment in both the design phase and the construction and management phase.

All the areas of competence listed above together make up the preparation of the feasibility study for the development project.

The accuracy of a feasibility study depends, to a large extent, on the reliability of the data obtained from the reservoir study and from the level of information. To assess the incidence of any uncertain factors, a very common technique applied is called sensitivity analysis, and consists of varying a given parameter and verifying the influence of this variation on the other parameters, in particular on the economic indicators.

A prime example of this application is the optimization of the number of wells necessary for developing a field; in terms of both investment and operating costs, this is often one of the most important considerations. Spacing the wells in fact determines, on the one hand, the distribution of production over time and, on the other, the amount of initial investment and operating costs. In any case, an increase in the number of wells means an earlier production and, therefore, increased profitability up to a maximum value. Hence, this assessment, though based on technical considerations (e.g. the characteristics of the hydrocarbons that can be produced, the drive mechanism, the reserves, the type of secondary recovery if necessary, etc.), is predominantly of an economic nature.

At times, in order to reduce the risks stemming from uncertainty of field data, it is best to conduct long-term tests whenever possible (taking anything from a few months to a year), termed early production. This solution usually consists of bringing a limited portion of the field into production, so as to acquire or consolidate the information necessary for full development.

The adoption of this technique offers obvious advantages, such as: acquiring field data that is far more reliable than those obtainable from a mere test carried out on single wells; and earlier production, although partial, with reduced initial investments, in this way improving the overall profitability of the field development project.

5.1.2 Feasibility study

The final document summarizing the work in this phase is the feasibility study, which outlines the feasibility of the project in both technical and economic terms. It is set up on the basis of the value of the exploitable reserves within a pre-established time frame, for a minimum number of wells, defined by means of field studies. It evaluates technically the various alternatives for developing the field in terms of location of wells, choice of drilling rig or rigs, and definition of both fluid gathering and treatment plants as well as of storage plants. It also takes into consideration the most technically viable and economic solutions, while respecting safety and the environment.

The feasibility study also takes into account logistical problems regarding the construction of roads, offices, technical rooms and laboratories, common rooms, stores, canteens, sickbays, eventual staff accommodation, and any other plants to be used for secondary recovery projects.

The conditions that significantly influence the feasibility study in its various components are represented by local factors such as the presence of existing facilities, the location of the field and environmental conditions, the country’s administrative constraints, the import embargoes or restrictions, contract terms and tax systems, etc., which have to be accurately assessed as they can be of fundamental importance for the profitability of the project. These variable elements, by and large, mean that various technical solutions are proposed, each with its particular strong point, because a single satisfactory technical solution hardly ever exists.

It is important to point out that the decision to put a feasibility study into practice may also include considerations that are not of an economic character, such as company policy, the country’s geopolitical situation, the geographical area where the field is situated and the possibility that other companies may participate in a joint venture. To sum up, it can therefore be stated that the information essential for
carrying out a feasibility study is of a strategic as well as a technical and economic nature.

To enable an economic evaluation of the feasibility study, a relatively limited number of elements is sufficient, such as knowledge of the production forecasts and the characteristics of the extractable hydrocarbons, an estimate of the investments, the start and end date of the investments, an estimate of operating costs and the forecast scenario of hydrocarbons prices.

Knowledge of these elements means that all the field data relating to its development must be known and that the plants for producing and processing the hydrocarbons and the necessary support logistics have been defined (in terms of processing capacity, type, storage, and so on). In order to obtain this level of detail, the feasibility study must provide both general information on the area involved in carrying out the project and the information provided by specific investigations on the single places identified for installing the main plants (well sites, gathering system, processing units, etc.) and logistics facilities (roads, various buildings, etc.).

Once the feasibility study has been approved, the next phase is the final design of the single structures, followed by their construction.

5.1.3 Construction design of the structures

General
The design and construction of the works necessary for developing a field for the production of hydrocarbons, regarding both the plant aspects (well sites, gathering system, processing units, etc.) and the logistics facilities (roads, various buildings, etc.), entail the carrying out of three basic activities: a feasibility study integrated with the basic design together with project data and the targets to be reached; a general local survey of the area concerned in implementing the project, and a specific survey of the places identified as plant sites.

General local survey
The data obtained for the location of the plants includes: elements of specific evaluation, the meteorological conditions of the area, information on legislation and technical regulations, market and various other surveys.

Such information is indispensable for rationally and economically preparing the designs, the cost estimates and the work contracts.

Elements of specific evaluation. On the basis of the indications given by topographic maps of the area concerned, and taking a typical general layout as a point of reference, a reconnaissance is carried out of both the actual sites for the works and adjacent areas that could condition the overall project due to their configuration. The following elements are therefore ascertained and assessed:
a) morphological features of the surface area; b) nature, mechanical and geological characteristics of the soil; c) presence of areas covered by crops and their extent; d) existence of surface water and underground streams, stagnant or flowing, aggressive or otherwise, springs and water wells; e) areas liable to periodic flooding; f) presence of watercourses affecting the area, their characteristics and regimes, normal and exceptional flood and low-water levels, their frequency and periodicity, bank erosion and build-up, existing hydraulic defence works; g) apparent signs of natural soil movements, in or around the area, and their possible trend; h) residential and/or industrial areas in the zone; i) location of the nearest roads and motorways, railway lines, airports and ports; j) presence of gas and oil pipelines, aqueducts, drains and sewers, electric and telephone lines in the area; k) presence of any military works. For all the utilities available in the area, the possibilities of connection, present and future potential and offtake points have to be checked.

Meteorological conditions. The following data are obtained for the whole of the area concerned, covering the longest possible time span:
a) temperature and relative humidity with monthly and exceptional maximum and minimum values; b) rainfall with the number of rainy days a month, total monthly precipitation, maximum annual 24-hour rainfall and maximum annual hourly rainfall, and rainfall intensity in relation to time; c) maximum normal snowfall rates, maximum exceptional precipitation and its duration; d) wind rose illustrating wind intensity and duration percentage throughout the year and for every direction.

Legislation and technical regulations. All information must be obtained on the country’s legislation and local technical regulations, by means of checks with ministries, local agencies and specific offices. This information is very important for designs and for relevant building permits and tests. Information on antiseismic, fire-prevention and accident-prevention regulations, the need for any specific authorizations and the procedures for testing works are particularly important.
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*Market surveys.* The market for the supply of materials must be assessed as a function of: quality and productive capacity of suppliers, as well as logistics situations and costs. The local labour market is of particular importance and must be assessed verifying the levels of available skill possessed, the trend of worker availability and basic costs. As far as contracting firms are concerned, their degree of knowledge and experience, personnel, availability of offices, equipment and mobile and fixed machinery must be ascertained.

*Miscellaneous surveys.* It is necessary to ascertain the availability and technical level of laboratories for carrying out tests on materials, of firms specialized in geotechnical or topographic surveys, and consulting engineering firms specialized in structural calculations and designing.

**Specific survey**

The specific survey of each site consists in acquiring information of a geotechnical character which, after the local surveys and laboratory results, can supply the requisite design data for each area where it is envisaged setting up a new plant and/or constructing new works. This information concerns above all the foundation works for plants and the laying of pipelines, but also problems regarding excavation.

The in-situ operations and tests to be carried out concern:

• Boreholes to determine the stratigraphy, description of types of soil traversed, and collection of soil samples to be subjected to laboratory tests; when making the boreholes the watertable level must be measured and water samples collected for analysis; piezometers will be placed for measuring the elevation of the watertable.

• Resistance tests (penetration tests, cone tests, vane tests, etc.).

• Permeability tests.

• Bearing capacity tests for road works and general paving.

• Collection of samples for determining grain size characteristics in quarries located close to the plant area.

On the basis of the data obtained and of the analyses and laboratory tests carried out on soil samples, the geotechnical report is drawn up, generally dealing with questions regarding elements needed for planning excavation and for designing and dimensioning the foundations and defence, soil and water protection and pollution-prevention works.

**Planning of excavation.** Programming adequately and rationally the movement of earth excavated and added for the preparation of areas for surface structures is very important, and includes the following actions:

• Identification of the various types of materials concerning the works, delimiting the extent of each type, and rock in particular.

• Identification of materials from excavations that can be reused as fill, as foundation backfill, for retention works for water basins or suchlike, as foundation layers for storage tanks, for road embankments, as sub-base for flexible (road) and rigid paving (paving in reinforced concrete), and other possible uses (aggregates, etc.).

• Identification of materials from excavations to be dumped or reused as topsoil.

• Identification of foreseeable settlements and possible needs for control and in-situ measurement of subsidence (for foundations of storage tanks the installation of instruments to measure settlements should be foreseen).

**Design and dimensioning of foundations.** For the construction of foundations and especially those intended for the sites of particularly heavy structures (storage tanks) or particularly stressed structures (compressors, turbines, etc.) it is necessary to establish the following: a) conformation, thickness and materials to be used for foundations of storage tanks, in relation to settlements and foreseen preloading times, with indication of the possible need for control and in-situ measurement of subsidence; b) types, relevant lengths, bearing capacity of vertical and tangential load of foundation piles, if necessary; c) criteria of dimensioning of foundations for equipment, indicating the bearing capacity of the foundation soil; d) foreseeable settlements for major items of equipment and times of any hydraulic testing operations; e) parameters for dimensioning and/or verifying foundations for compressors; f) criteria for dimensioning direct reinforced-concrete foundations of buildings, pointing out any need and the frequency of joints for avoiding differential subsidence; g) criteria for dimensioning simple or anchored reinforced-concrete retaining walls, indicating whether back-drains and subsidence joints are advisable; h) bearing capacity of subgrade for paving in general; i) aggressiveness or otherwise of soil and/or groundwater, and counter-measures to be taken.

**Defence, soil and water protection and pollution-prevention works.** As far as these works are concerned, it is necessary, first and foremost, to know the permeability of the soil, also regarding the possibility of adopting cesspools and/or seepage pits for non-polluted waters. It is also important to define the criteria of choice and of dimensioning linings.
and erosion-prevention works for road embankments, banks, earth-containing basins, excavation slopes, ditches, drainage channels and suchlike.

**Topographic and horizontal/vertical surveys**

Topographic and horizontal/vertical surveys should be carried out in sufficient detail to permit the preparation of general layouts and the design of civil works in particular. These surveys can be carried out with operations performed wholly on the ground or, if the area is vast and without extensive vegetation, the necessary topographic data may be obtained by means of an aero-photogrammetric survey.

The field work should be carried out by running a horizontal/vertical survey of the points of a square grid (sides of 25 m), as well as measuring any other outstanding point on the ground, so as to define the morphology of the terrain correctly, identifying the various areas of uniform slope and the lines of minor and major slope and saddle points.

Surveys of the areas concerned should be carried out by means of closed traverses and/or first-order – and possibly second-order – triangulations, tied into the local geodetic system, taking as a reference one or more trigonometric points of such a system.

**5.1.4 Areas for field structures**

The structures necessary for developing a field may be subdivided, for an area of competence, into plant areas, general services areas and residential areas. The first one contains mainly processing plants and accessory plants, and the second one concerns the complex of items of civil and industrial use that form part of the infrastructure directly serving the processing plants. The residential area has to be constructed in cases where all the facilities to house the personnel employed in constructing and in the subsequent phase of operating the plants are not available locally. Naturally the residential area must be situated at a safe distance from the plant area, if possible to the windward side.

Regarding the layout, for practical reasons the area for the general services containing the buildings for technical, administrative and management purposes should be located close to the entrance to the plant, and in any case outside of the danger limit determined by the equipment and identified by the classification of dangerous areas and by risk analyses. The areas of competence of the plants are subdivided into plant typology sub-areas: arrival

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![Fig. 1. Skid-mounted prefabs: examples of standardised single blocks.](image-url)
manifolds (manifolds for the collection and distribution of production pipes), separators, apparatus for stabilization, etc. The flares or the blower are normally positioned opposite the entrance, while the oil storage tanks occupy a peripheral position, far from both the buildings and the flare.

**Plant area**

The realization of the plant area involves various teams of specific competences as it can be defined as the ensemble of processing plants, storage tanks, electro-instrumental equipment, pipes and structures of various types.

It is important to remember that not only accessory plants, e.g. those for fire-fighting, production and transportation systems for electric power generation, compressed air, steam, etc., but also roads and all the hydrocarbons gathering systems, are included in the plants area.

**General services area**

This area contains the facilities directly supporting the processing equipment, such as the civil buildings for various uses (gatekeeper’s lodge, offices, changing rooms, sickbay, canteen), buildings of an industrial type (workshops, store, laboratories, radio services, etc.) and the structures supporting the operating units responsible for plant maintenance.

There is no fixed typology of buildings, as choice generally depends on local construction characteristics. In any case, for given buildings for industrial use (workshops, store, etc.), the most common practice is to use prefabricated units of steel or reinforced concrete, while, for other buildings, the tendency is to use masonry, on the basis of local architecture and types of construction.

**Residential area**

The design of the residential area, or more specifically the staff accommodation structures, is required, in the majority of cases, for areas far from large inhabited centres (mostly desert areas). In this case, too, local architecture is adopted, using materials available at the site.

Generally all the housing units consist of skid-mounted prefabricated buildings, prefabs anchored to foundations or brick-built prefabs.

It should be noted that for some types of activity (drilling sites, pipe-laying locations, etc.) skid-mounted prefabs are used (Fig. 1) because, being easily transportable and adaptable to all projects with, they are the most convenient choice from the standpoint of construction times.

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**5.1.5 Well locations (clusters or single locations)**

Traditionally, the wellheads of onshore fields correspond approximately to the position in depth of the target identified in the productive horizon (vertical wells) and may be spaced from a few hundred metres up to more than one kilometre apart, according to the development mesh adopted.

During the development of an oil field, however, it might prove more convenient, and is often the case, to have the wellheads and their production equipment in the same area. This facilitates and optimizes all the operations, both in the initial well drilling/completion phases and in the subsequent phases of the productive life of the field, with a considerable saving in operating costs.

The ensemble of development wells in a field, drilled from a single position (Fig. 2), thus forms a cluster. At the surface of the cluster, the wells are lined up and spaced out approximately 4 m from each other. This solution, apart from the advantages from a plant engineering standpoint, permits considerable savings in terms of times and costs of using the rigs, as clusters enable the wells to be drilled by shifting certain kinds of rigs on skids specifically designed for this purpose, avoiding the need to dismantle them and reassemble them on the new wellhead (moving out, moving in).

In this way it is possible to carry out, during the first skidding operation, only the drilling of the wells, and then in the return phase to run the completion strings and to perform any special operations (e.g. gravel packing), with further savings and optimized operations typical of working in series.

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![Fig. 2. Cluster well area.](image-url)
Naturally, wells drilled from a cluster must be of a directional type entailing a consequent higher cost for drilling each single well and the greater risk of problems linked with this deviation (greater likelihood of the drillstring getting stuck, breakages, etc.). However, if the deviation angle of the wells can be limited to between 15° and 50°, these risks are amply offset by the advantages obtainable, i.e. the considerable saving in rig moving times and simplified plant engineering and operation.

The choice of the site on which to locate the cluster is generally made in relation to the geological targets, so as to reduce the degrees of well deviation to a minimum. In substance, the cluster or clusters must be placed in a barycentric position relevant to the geological targets to be reached.

Where drilling wells in a cluster is not possible, single vertical wells have to be drilled; in any case these enjoy a number of advantages, such as fewer drilling problems (drillstring getting stuck), smoother running-in of the well casing and the completion strings, and greater ease of operation during the running-in of the well casing.

From a plant engineering standpoint, the cluster offers the possibility of concentrating the first processing plants over a single area, but also of optimizing their use by installing only two separators, for example, to serve a number of wells. The first one can function as a production separator while the second can act as a test separator to receive the production of each single flowline through a manifold and with cadence fixed beforehand, in order to monitor flow, any production of water, and so on.

5.1.6 Equipment installed in wellhead area

The equipment in the well sites, whether clusters or single locations, has to serve a variety of purposes, which may be basically summed up as follows: wellhead and plant safety and control devices; and initial processing plants, installed to regulate the flow and pressure of the hydrocarbons produced, and to remove products (formation water, solids, etc.) that could prejudice running or make transport to the processing centre a problem. Prior to marketing.

In the case of gas-producing well areas, the typical process carried out is the following: the gas produced by the production string in the wells is conveyed through the production lines, each fitted with a stop cock, to a heater. In the heater, the temperature of the gas is raised to such a level that its subsequent cooling due to pressure reduction by means of pressure/flow rate choke valves does not lead to the formation of hydrates in the pipes.

The gas is then conveyed to the separators, where the free water coming from both the formation and that condensed during expansion is separated and, after being metered, is fed into the gathering network to be sent to the processing centre.

The water produced, separated and collected from the separators, is conveyed to a liquids gathering pond for temporary storage and subsequent disposal. This liquid (containing faint traces of hydrocarbons) is periodically removed by tanker trucks for disposal or re-injected after filtration into the subsoil through dedicated injection wells into the reservoir or into other water bearing horizons which, in this case, have to be accurately selected so as to avoid any problems of pollution.

Above the liquid gathering pond there is a flare, in the form of a vertical pipe with a diameter of between 6" to 18" and of appropriate height. Its function is to convey any vapours present in the liquid to a safe level. The gas from the plant will also flow to the flare, following the switching on of emergency devices.

The plant engineering sequence described above, namely wellhead → heater → pressure reducer → separator, is adopted mainly with high wellhead pressures. In the case of flowing pressures indicatively of less than 20 Mpa, it is preferable to adopt the sequence wellhead → separator → heater → pressure reducer, which enables the liquids to be removed directly.

In oil wells, pumps are used to lift the liquids produced by the wells that do not come spontaneously up to the surface, and separators (to separate oil, gas and water).

Safety and control devices

In order to guarantee the safety of the personnel, the safeguarding of the environment and protection of the plants, the well areas are equipped with various safety and control systems, which come into play both in the case of a fire emergency and for anomalies in the processing parameters.

The first system encountered in the production process is constituted by the valve shut-down system installed in the string inside the well. This consists of two safety devices: one of the tubing safety valves or storm chokes which come into play with excess of flow if there is an accident at the wellhead and/or to the plants. The other one consists of hydraulic valves, located at a depth of between 30-100 m, having a control line in steel tubing with a diameter of approximately 10 mm. The valve, normally closed, is kept open by the hydraulic pressure transmitted by a...
special sub-unit located at the surface. If an accident occurs at the wellhead, the control line is interrupted and the loss of pressure causes the automatic closure of the valve.

As far as the plants are concerned, the tendency is to protect them by installing devices that prevent the occurrence of any dangerous events. Fundamental among these are the PSVs (Pressure Safety Valves), which are positioned on the various items of apparatus to protect them against excess pressure, and the high- and low-pressure detection systems, consisting of groups of pressure sensors located on the processing lines, detecting any variations in the normal values of the parameters caused by operating anomalies or line breakage.

Systems to detect fire or the presence of an explosive mixture are also essential for the safety of the plants. These normally consist of pneumatic or electronic detectors which signal the event to control devices: the PLC (Programmable Logic Controller), a dedicated unit which, through specific software, controls and actuates a sequence of programmed operations), pneumatic panels, etc.

The recognition of dangerous events results in the subsequent automatic initiation of the action sequences which, depending on the gravity of the situation that determined them, actuate various levels of shutting-down of the plants.

**Shut-down levels**

The shut-down levels normally present on the plants are ESD, PSD and LSD. The sequence of the operations they actuate, described below, is arranged according to the various levels of gravity.

ESD (Emergency Shut-Down), the emergency level with top priority, is actuated by the fire detection systems (plug fuses, infrared detectors, heat-sensitive cables, etc.), as well as manually through a series of pushbuttons located in strategic positions (entrances, operator posts, etc.). This is associated with the complex of all the processing units and services and entails the general shut-down of the process and, in sequence, the general depressurization of the whole plant, segregation of the liquids present, and disconnection of the electricity supply to the units, with the exception of those considered priority such as fire-fighting and emergency lighting plants, communication systems, etc. The depressurization gas is sent to the flares and to the cold flares which dispose of it in safe areas and guarantee its dilution to concentration levels that are not dangerous.

PSD (Process Shut-Down) involves the shut-down of the treatment process and is associated with homogeneous plant sections (e.g. oil section and gas section). It is automatically actuated by the anomalous variation of the values of the main parameters governing the operation of the process, such as for example: high or low pressure on the treatment lines, high temperature of heaters, very high level of the separators, high or low pressure measured on the feed lines of the pneumatic instruments, etc.

For some items of the plant (e.g. gas separators and heaters) there is also an LSD (Local Shut-Down) which, actuated by the instruments positioned on the apparatus controlled, determines a limited, reversible shut-down, without interfering with the overall functions of the plants present in the area.

**Fire detection systems**

To detect any fires in the well area, various devices are installed (with plug fuses, infrared detectors, heat-sensitive cables, etc.), sometimes with backup.

The most common device, is the network of plug fuses (with a melting point of around 70°C), located in the immediate vicinity of the main equipments which contain gas. These networks are kept under pressure (normally at 4-6 bar). In the event of fire, the plug fuses melt, causing the depressurization of the network, which is registered by a block panel that immediately actuates the depressurization sequence of the feeder lines for the pneumatic actuators of the automatic closing/opening valves, and subsequently causes the closure of the plant shutoff valve SDV (Shut-Down Valve), located at the wellheads and on the discharge manifold, and the opening of the plant BDVs (Blow-Down Valves).

The opening of the BDVs is actuated with a calculated delay with respect to the closing of the SDVs, to make sure that the plants will start to depressurise only when the SDVs are correctly closed. The activation of the PSD and the ESD shut-down levels is signalled on the block panel and usually actuates the telealarm devices to alert the emergency crews.

**First processing plants**

Below is a brief description of the plants installed in the wellhead area, of their functions and of the regulation system.

**Separators**

These separate liquids (production water and liquid hydrocarbons such as oil and condensates) from the gas. Separators may be horizontal or vertical. Horizontal separators are often used in fields which produce a considerable amount of liquids (oil, condensates or water), while vertical ones are being used more and more in cases of gas-liquid separation.
when there are small quantities of liquids or where the layout requirements of the apparatuses call for reduced spaces. Vertical separators are therefore the best solution when the amount of liquid treated is modest and the flow of gas to be treated is not very great.

Separators may be further subdivided into two-phase types, for separating gas from liquids in general, and three-phase types, able to separate gas from water and from hydrocarbons (oil and condensates), taking advantage of the fact that the latter have a different specific weight from water.

Both types of separators share the system of liquid level control, using devices provided with a float which, according to its position, determines the opening or closure of the discharge valve for the corresponding liquids (oil/condensates or water) or performs corrective actions, forming part of the control system (e.g. control when the level is very low).

The control devices normally present are:
- **LC** (Level Controller): level control device.
- **LSLL** (Level Switch Low Low): control device for a very low level of the internal liquid which determines the closure of the outlet (water or liquid hydrocarbons) in the event of the malfunctioning of the LC, actuating a special shut-off valve to prevent gas from escaping along the discharge line.
- **LSHH** (Level Switch High High): control device for a very high level which, to prevent the liquids from escaping from the separator, blocks its supply line.

Naturally, in three-phase separators LC devices exist which, when operating with duly calibrated floats, are able to recognize the density of the reference liquid and thus to keep two different interfaces inside the separator (between gas and liquid hydrocarbons and between liquid hydrocarbons and water).

Bearing in mind that the capacity to accumulate liquids is essential for correctly carrying out the function of separation, it follows that the minimum diameter of the separators, below which it is preferable not to go, must be assessed as a function not only of the mechanical separation of the drops, but also of the above-mentioned accumulation capacity.

Compartments, consisting of wire mesh pads and straightening vanes, are usually placed in the separators. Such devices are among those most used in hydrocarbons production as their separation efficiency is very high and they have negligible pressure losses.

For special applications it may be necessary to use multiple separation systems, which means the installation in series of two or more separation stages in the same recipient, to carry out both the necessary separation of the dispersed liquids and the elimination of the solids as well as the liquid cushions.

### Filters
Filters are installed for separating gas and solids. When this is necessary, it can have an appreciable impact on the global cost of the plant. In general, when it is necessary to use a different filtration unit from the gas-liquid separation unit, this entails higher installation and operating costs, as the need to periodically remove the cartridges necessitates the use of filtration units arranged in parallel, to ensure the continuous operation of the plant in periods of stoppage to replace the filter cartridges.

The filters are fitted with a removable quick-closing base and are quite costly for this reason, especially if dimensioned for high pressures and rates. It follows that the use of these units is limited to particular processing requirements. It should be observed that, to avoid frequent maintenance, and to maintain filter efficiency at a high level – in terms of pressure losses between gas inflow and outflow – where there are considerable quantities of dusts to be eliminated, a coarser screening system is necessary upstream of the cartridge filtration section.

### Heaters
Heaters are required to heat the gas produced, prior to the expansion phase which is necessary to reduce the FTHP (Flowing Tubing Head Pressure) before processing and transport. In fact, the expansion of gas causes considerable cooling due to the Joule-Thompson effect; as the gas is saturated with moisture, in this phase water condensation also takes place and it can therefore happen that, after expansion, the gas is capable of forming hydrates. This can be avoided if, prior to expansion, the gas is heated to a sufficiently high initial temperature to guarantee that in the ensuing cooling the final temperature will be higher than the hydrates formation point at this new pressure.

The heaters in use for current applications are of the indirect firing type, i.e. with a transmission medium, generally water (which is thus the intermediate fluid) between the fluid to be heated (gas produced) and the hot fluid. The system consists of a boiler, normally in the shape of a cylinder, containing one or two coils for the gas to be heated in (usually made of pipes 2"-4" in diameter) and a flame tube (about 12"-30" in diameter).

In the heater, water circulates by convection. Apart from permitting an even temperature regime, this increases the total transmission rate, appreciably improving the equipment’s efficiency. To provide greater safety during operation, the burner is located on the side opposite to the inlet, regulation and outlet points for the gas to be heated.

These units normally have burners with a pilot flame, their potential varying from 100,000 to
1,000,000 kcal/h. They have automatic instruments, which, apart from ensuring the thermostatic regulation of the intermediate fluid, actuate the process shutdown in the event of a low water level, a low/high pressure of the combustion gas and a high intermediate fluid temperature. In addition to the process gas exchange coil, there are also one or more coils of smaller diameter (1"-1.5"), their function being to preheat the amount of gas to be used as fuel gas for the heater or for wellhead plant services. The choke valves for reducing the pressure are located immediately downstream of the process gas exchange coils.

Plants for injection of chemical products
In the well area it is normally necessary to install equipment for injecting chemical products to act as inhibitors against the formation of hydrates (methyl and ethyl alcohol, glycol, etc.), or specific products to protect the tubes against aggressive corrosion (in particular due to the presence of SO2 and CO2). This action is performed using proportioning pumps driven by electric or gas engines, with the injection of the inhibitors at fixed points, usually through drip rings located downstream of the wellhead shut-off valve, upstream of the choke valve or at the flowline starting point.

Oil pumping systems
If the oil does not flow spontaneously from the wells, bottomhole pumping systems have to be installed (see Chapter 6.2).

The use of sucker-rod driven pumps, for onshore applications, is the most widespread pumping technique. It consists of a system formed by a crank-balanced (beam-balanced) pumping unit driven by an electric or internal-combustion engine and provided with counterweights, transmitting the energy necessary to actuate the submersible suction booster by means of a small-diameter string of sucker-rods, normally (5/8")-(9/8"). The main advantage of this is the tried and tested reliability of the system and the common possibility of supplying the internal-combustion engine actuating the pumping system with the gas produced from the well fuel gas, coming from the separator where the oil is separated from the dissolved gas.

Alternatively to the sucker-rod pump, other types of pumps can be used, the most common of which is of centrifugal type, known as an Electric Submersible Pump (ESP), which is lowered to the bottom of the well and is supplied from the surface by means of an electric cable. This pump needs a remarkable quantity of electric power, and when it is used the field generation system has to be upgraded.

Under particular conditions and as an alternative to the methods described above, it is possible to use the gas-lift technique to permit the production of oil, which consists in injecting gas into the well at a given depth, at a greater pressure than that of the fluid produced, through mandrel valves located along the tubing. Rising to the surface the gas reduces the hydrostatic pressure, also allowing the oil to rise. To use the gas-lift technique, a compressor has to be installed in order to compress the gas.

Gathering system
Gathering system consists of flowlines and other accessory equipment necessary to transport hydrocarbons (oil, gas, or both) from the well areas to the treatment plants. When they are of small diameter (2"-4") and intended to convey the production of each well to the main collectors, they are known as lease lines.

The specifications for the construction and operation of the materials used in gathering systems are contained in the API (American Petroleum Institute) standards, which define both the dimensions and the strength of the materials used.

A gathering system also includes the accessories necessary to ensure its functioning and operation, such as for example, valves (hand-operated or automatic), corrosion detection devices, intermediate plants for injecting inhibitors or other chemical products, cathodic protection plants, plants for launching and receiving the various pigs (see below and Chapters 5.3 and 7.1) for cleaning, maintaining or checking the pipelines, etc.

A gathering system is almost entirely made up of steel pipes. For particular uses, in the presence of corrosive agents or under special laying conditions, pipes and accessories of advanced-type synthetic materials (fibreglass, aromatic amine, aliphatic amine, etc.) have been developed, having the equivalent mechanical characteristics of those of steel pipelines.

Pipelines are normally buried, although in some cases they have to be laid on the surface, even for considerable distances. It follows that, without visual control of the lines, they have to be designed with ample safety coefficients and laid along secure routes. It is also necessary to install, along the route, a system of devices able to ensure monitoring of the pressures so as to avoid losses or spills in the event of breakages, and to arrange a regular surveillance service along the route.
The reliability of a gathering system consists in its capacity to maintain the original mechanical characteristics and dimensions unvaried in the course of time. The elements that can condition its reliability depend mainly on following factors:

- The choice of materials for the pipeline, which must be suitable for the type of fluid transported, to minimize any form of internal corrosion.
- The design criteria, applying safety factors in keeping with the reliability it is wished to obtain.
- The dimensioning of the plants, which must allow for the possibility of later extensions; for this purpose, at crossings or interferences with other services under critical conditions, it is a good rule to foresee the laying of a backup pipeline, to be used either if the main line is out of use, or for future rate increases.
- The choice of layout, which must ensure that the original laying conditions remain unvaried in time and avoid any sudden external stresses on the line; hence pipelines should not be laid in areas liable to landslides, in areas of topsoil erosion by external agents, across built-up areas or areas shortly to be urbanized, etc.
- The application of functional, long-lasting external coatings.
- The installation and maintenance of a cathodic protection plant, effective throughout the route.

The pressure of the well flow can in itself be sufficient for transporting oil along short stretches of a few km. For transport over longer distances, pumping stations should be installed at the start of the pipelines, while intermediate booster stations are located along the line; the number and location of these depends on the length, the vertical profile of the route and the quantity of energy that has to be transferred to the liquid to enable it to be transported.

5.1.7 Hydrocarbons processing plants

Hydrocarbons must be processed in order to remove any fluid non-hydrocarbon components (water, carbon dioxide, hydrogen sulphide, nitrogen, etc.) or solids, and to bring the hydrocarbons (gas and oil) up to the required market standard.

The processing plants are designed to treat specific types of hydrocarbons (primarily gas, oil or both) and according to the type of compounds to be removed. In addition to separators, filtres, heaters, chemical-products injection systems, previously described, these plants are also composed of apparatus designed for the type of processing requested, in order to bring the hydrocarbons produced to comply with the current commercial specifications.

Where possible, these plants are assembled on skids of such a size and weight as to be easily transportable, reducing to a minimum the times and costs necessary for assembly at the field. This is particularly necessary for all equipment where the regulation and control devices form the main part of the plant installation.

The various processing plants depend on the type of process used, which is a function of the type of fluid and of its chemical, chemical-physical and thermodynamic properties. Below is a list of the types of treatment normally performed on gas and oil to meet required market standards (for details of the characteristics of the plants and their principles of functioning, see below).

Normal gas processing foresees (Fig. 3):
- dehydration for the removal of water, which is carried out through various systems such as refrigeration, adsorption and absorption; condensate removal, i.e. eliminating the higher hydrocarbons (propane, butane, etc.), by means of refrigeration and adsorption; desulphurisation-decarbonation, to remove hydrogen sulphide and carbon dioxide when present in unacceptable quantities.

For crude oil processing (Fig. 4), the normal procedures are:
- gas-oil separation;
- water-oil separation;
- desalting by various systems, to eliminate the saline content;
- desulphurisation to remove the hydrogen sulphide content;
- stabilisation to meet required market standards.

Fig. 3. Bhit Field (Pakistan, 2002): processing units for natural gas (courtesy of D. Vannini).
Stabilised crude oil is usually stored in tanks of various types and capacity before it is collected. This because collections cannot take place continuously, but at a frequency that varies from a few days to over a week, whereas production of the field is continuous and cannot be interrupted. The storage tanks are normally grouped in special areas (tank farms) located at a safe distance from the processing plants, and are constructed inside special containment basins that have a capacity at least equal to the volume of crude stored. The function of these basins is to contain the crude in the event of any spills and to segregate the areas in case of fire. The tanks are interlinked by a network of pipelines, which in turn are connected to pumping stations, for the carrying out of ordinary loading and discharge operations, and to drainage plants for the performance of maintenance operations (for details of the characteristics of the tanks, see below).

5.1.8 Treatment plants for secondary recovery projects

In the past, secondary recovery processes, based on artificial drive mechanisms, were applied to fields when the oil rate from primary recovery reached such low levels that it was no longer economically viable to continue production. The increase in oil prices in the last few decades has meant that currently these methods are already used in the initial stage of development, or at least taken into account in the development plan. Today, the most widespread methods are water flooding and gas injection. In the case of water flooding, peripheral injection wells are used, sometimes alternating with producer wells, whose position and spacing are defined by simulation with the numerical model of the field.

Water flooding consists in injecting water into the field in the oil zone or in the aquifer in contact with the oil. It should be noted that water injection is the least costly of the processes of oil recovery improvement, and the one that sometimes produces the best results.

For reinjection, it is necessary to have available a reliable and constant water supply (often coming, in the form of water disposal, from the oil treatment processes, water wells, rivers or from the sea, etc.).

The plant (Fig. 5) consists of various filtration units, tanks for storing filtered water and injection pumps, usually of supercharged positive-displacement type (piston type). This choice is justified to obtain the high injection pressures that is often necessary. Together with these basic plants, there are also accessory plants for the chemical-physical treatment of the water. This is essential to ensure injectivity, reducing corrosion to a minimum (one of the main
problems of these plants) and maintaining compatibility with the fluids present in the formation into which will be injected (avoiding for example reactions that create insoluble precipitates, that would lead to the gradual blocking of the formation into which the water is injected).

Secondary recovery with gas injection consists in injecting gas (usually that associated with oil or coming from a gas level) into the upper part of the reservoir, thus forming a gas-cap, maintaining the pressure of the field and exercising a displacement effect on the oil. This process is used almost exclusively in areas where marketing of the gas is not possible because of the long distance from the centres where gas is used. If the gas to be injected is associated with oil, the condensates are first removed to make it injectable, after which the gas is filtered and injected into the reservoir using compressors.

**Bibliography**


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