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(71) Demandeur/Applicant:
ENI S.P.A., IT
(72) Inventeurs/Inventors:
ANDREI, MARIA, IT;
DELBIANCO, ALBERTO, IT
(74) Agent: FETHERSTONHAUGH & CO.

(54) Titre : PROCESSUS INTEGRE AVAL-AMONT D'AMELIORATION DE PETROLE BRUT LOURD AVEC CAPTURE DE CO₂ ; INSTALLATION CONNEXE POUR LA MISE EN ŒUVRE DUDIT PROCESSUS
(54) Title: UPSTREAM-DOWNSTREAM INTEGRATED PROCESS FOR THE UPGRADING OF A HEAVY CRUDE OIL WITH CAPTURE OF CO₂ AND RELATIVE PLANT FOR THE EMBODIMENT THEREOF

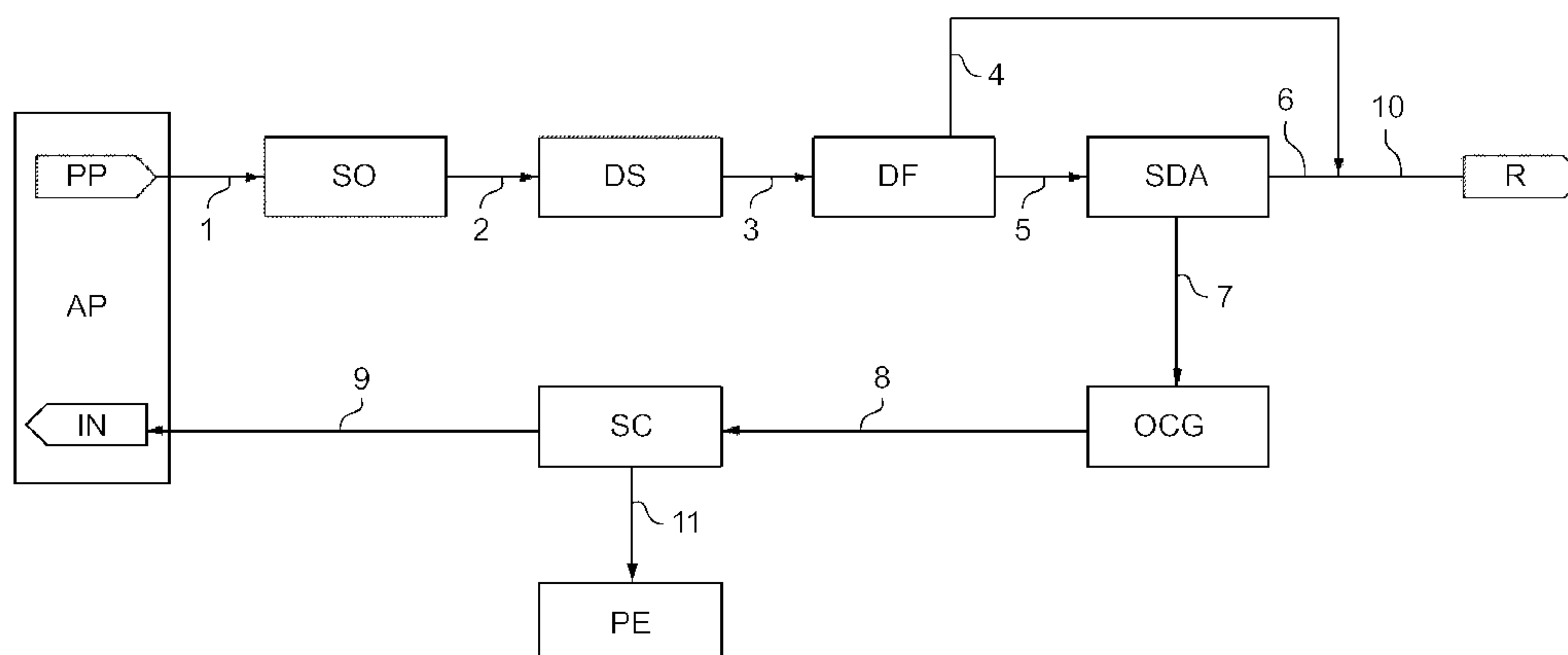


Fig. 1

(57) **Abrégé/Abstract:**

The present invention relates to an upstream-downstream integrated process for the upgrading of a heavy crude oil with the capture of CO₂, comprising the following operative steps: a) production of a heavy crude oil from a reservoir; b) distillation of said heavy crude oil, at atmospheric pressure or under vacuum, with the separation of a distilled fraction and a hydrocarbon residue containing asphaltenes; c) solvent deasphalting of said hydrocarbon residue containing asphaltenes with the formation of a precipitate of asphaltenes and a deasphalted oil (DAO); dl) oxy-combustion of said precipitate of asphaltenes in pure oxygen with the formation of a stream of exhausted gases comprising CO₂ and water vapour; d2) as an alternative to said oxy- combustion, gasification of said precipitate of asphaltenes in pure oxygen with the formation of a stream of syngas which is subsequently transformed into a gas stream comprising CO₂ and H₂; e) separation of a substantially pure gaseous stream of CO₂ from said stream of exhausted gases or from said gas stream comprising CO₂ and H₂; f) injection of said gaseous stream of CO₂ into the subsoil in order to recover oil or gas, by displacement, from a reservoir and/or to permanently sequester said gaseous stream of CO₂ in a geological formation. The present invention also relates to a plant for the embodiment of the above integrated process.



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(71) Applicant (for all designated States except US): ENI S.P.A. [IT/IT]; Piazzale E. Mattei, 1, I-00144 Roma (IT).

(72) Inventors; and

(75) Inventors/Applicants (for US only): ANDREI, Maria [IT/IT]; Via Carro Maggiore, 6, I-20060 Mediglia (MI) (IT). DELBIANCO, Alberto [IT/IT]; Via Adua, 5, I-20087 Robecco Sul Naviglio (MI) (IT).

(74) Agent: BOTTERO, Carlo; c/o Barzano' & Zanardo S.P.A., Via Borgonuovo, 10, I-20121 Milano (IT).

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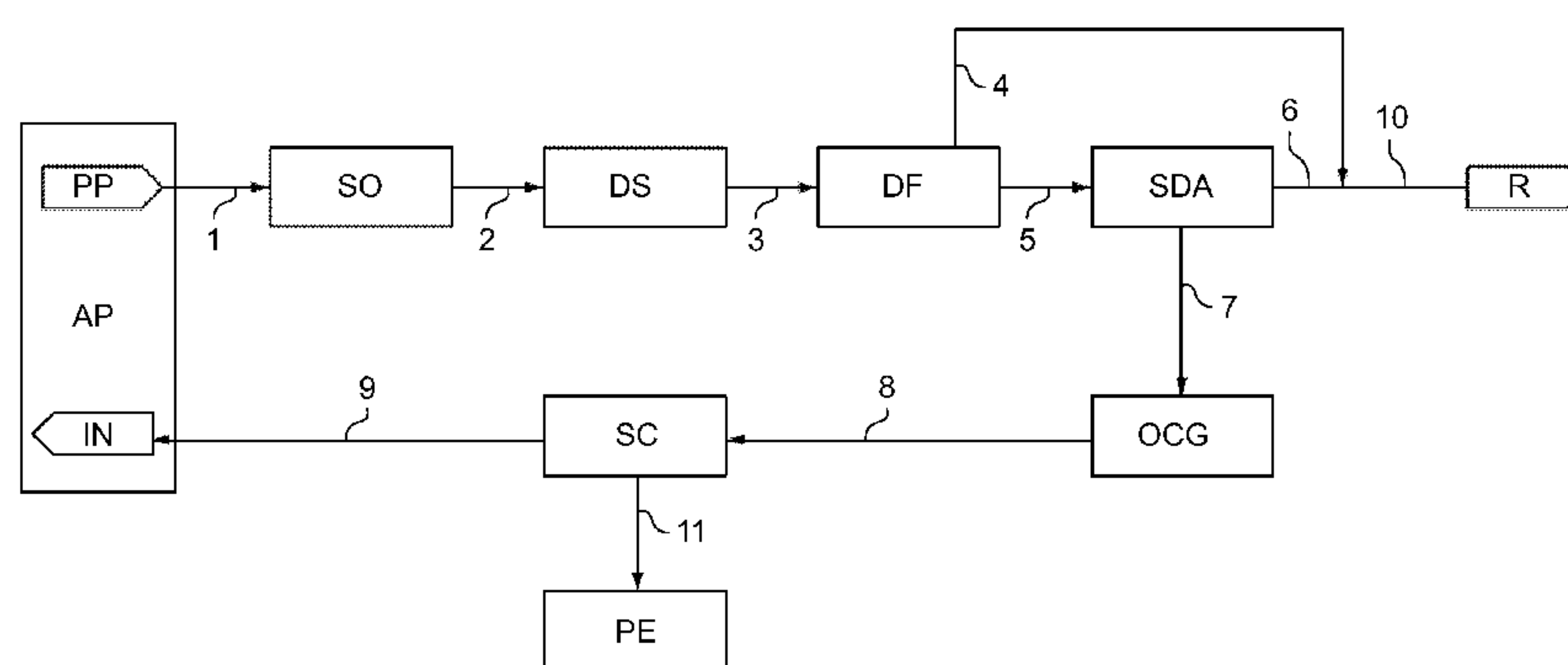


Fig. 1

(57) Abstract: The present invention relates to an upstream-downstream integrated process for the upgrading of a heavy crude oil with the capture of CO₂, comprising the following operative steps: a) production of a heavy crude oil from a reservoir; b) distillation of said heavy crude oil, at atmospheric pressure or under vacuum, with the separation of a distilled fraction and a hydrocarbon residue containing asphaltenes; c) solvent deasphalting of said hydrocarbon residue containing asphaltenes with the formation of a precipitate of asphaltenes and a deasphalted oil (DAO); d1) oxy-combustion of said precipitate of asphaltenes in pure oxygen with the formation of a stream of exhausted gases comprising CO₂ and water vapour; d2) as an alternative to said oxy-combustion, gasification of said precipitate of asphaltenes in pure oxygen with the formation of a stream of syngas which is subsequently transformed into a gas stream comprising CO₂ and H₂; e) separation of a substantially pure gaseous stream of CO₂ from said stream of exhausted gases or from said gas stream comprising CO₂ and H₂; f) injection of said gaseous stream of CO₂ into the subsoil in order to recover oil or gas, by displacement, from a reservoir and/or to permanently sequester said gaseous stream of CO₂ in a geological formation. The present invention also relates to a plant for the embodiment of the above integrated process.

UPSTREAM-DOWNSTREAM INTEGRATED PROCESS FOR THE
UPGRADING OF A HEAVY CRUDE OIL WITH CAPTURE OF CO₂ AND
RELATIVE PLANT FOR THE EMBODIMENT THEREOF

The present invention relates to an upstream-
5 downstream integrated process for the upgrading of a
heavy crude oil with capture of CO₂ and the relative
embodiment plant.

In particular the present invention relates to an
upstream-downstream integrated process for the
10 upgrading of a heavy crude oil which can be used in an
upstream applicative context of marginal fields having
a medium-small production capacity (1,000-5,000
barrels/day) wherein the by-products of the upgrading
process are conveniently used in tertiary recovery
15 processes for the production of additional oil.

The CO₂ produced in the integrated process of the
present invention is captured and used in Enhanced Oil
Recovery (EOR) or Enhanced Gas Recovery (EGR) processes
and/or is sequestered in the subsoil.

20 For the same purpose, in EOR assisted oil recovery
processes, the vapour produced in the oxy-combustion
process can be used. In particular, vapour can be used
in Steam Assisted Gravity Drainage (SAGD), Steam
Flooding or Cyclic Steam Stimulation (CSS) processes.

25 Furthermore, the power produced by the vapour can
be conveniently used in alternative EOR thermal
recovery processes, for feeding Electrical Heaters,
electric cables which are lowered into the well and are
capable of reducing the viscosity of the crude oil,

enhancing its recovery (EEOR, Electrically Enhanced Oil Recovery).

In the present description, the terms "crude oil" and "oil" are used interchangeably with one another.

5 The decrease in the availability of high-quality light crude oils (characterized by an API density > 34°, a low sulfur and heavy metals content) has led to an ever-increasing interest towards the exploitation of heavy oil, ultra-heavy oil or bitumen reservoirs (heavy
10 oils: °API < 22; bitumens: °API < 10).

Heavy crude oils are characterized by a high viscosity (from 100 to 10,000 cP), a factor which strongly limits their mobility and transportation in pipelines. Heavy crude oils can, in many cases, be
15 produced spontaneously or with the assistance of pumps, exploiting the high temperature of the field which guarantees a low viscosity under reservoir conditions; once the oil has reached the surface, however, the temperature of the oil decreases and the viscosity
20 consequently increases at the well head to such an extent as to not satisfy the specifications for transportability in pipelines. The viscosity of the crude oil therefore represents a limiting factor for transportation in pipelines: with an increase in the
25 viscosity, the transportation costs increase, for example as a result of the higher consumption of energy due to the pumping systems.

Numerous methods are known for improving the transportability of heavy crude oil, such as, for

example:

- use of a diluent/fluxing agent: this consists in the addition of a light hydrocarbon fraction (gas oil, naphtha, etc..) to the heavy oil, in volumes in the order of 10-50% with respect to the volume of the crude oil to be transported, which allows a reduction in the viscosity of the heavy oil. This system leads to a reduction in the transporting capacity of crude oil in the pipelines. Mixing and separation stations are also required, together with specific transporting ducts for the diluent;
- thermal methods: these exploit the decrease in viscosity associated with an increase in the temperature. Insulated pipelines and heating stations are used. The methods are demanding from an energy and economic point of view. In addition, they can be applied in limited sections of the pipeline and, preferably, *on-shore*;
- chemical methods: these consist of the addition of emulsifiers or dispersants. In this case, the choice of chemicals to be used can be quite laborious as the emulsion or dispersion must be stable during the transporting phase, but they must also allow an easy recovery of the crude oil at the end of the transportation (breakage of the emulsion and/or dispersion). In this case, the amount of water to be added can be extremely high, reducing the transporting capacity of the crude oil in the pipeline. The water must then be recovered and

recycled;

- thermal methods for partial upgrading at the well head: these are partial crackings (for example, mild-visbreaking processes) which can be applied at the well head, demanding from an energy point of view.

In the state of the art, solvent deasphalting processes have long been used for separating the heavier fractions from a crude oil, thus contributing to a decrease in the viscosity of the oil and to its transportability.

Typically, in solvent deasphalting (SDA) processes a hydrocarbon stream is put in contact with a solvent (or mixture of solvents) at a certain temperature. The contact with the solvent generates a deasphalted oil (DAO), mainly composed of saturated and aromatic hydrocarbons with a low condensation degree and a precipitate of asphaltenes containing the heaviest, polar hydrocarbon fractions, which is separated from the DAO. The solvents used in SDA processes are light paraffin compounds, such as propane, butane, pentane, hexane. The process temperature is selected so as to allow the dissolution of the residue in the solvent.

The DAO fraction obtained from the deasphalting process has a lower viscosity with respect to the starting oil and can be suitably transported in pipelines to the final destination (to the refinery, for example, where it can be processed for the production of fuels and lubricants).

The application of the SDA process in the upgrading of heavy oils, ultra-heavy oils and bitumens has led to the development of technologies *ad hoc* in which the classical extraction unit is often combined with other processes. This is the case of the OrCrudeTM process, specifically developed for the upgrading of Canadian bitumens by ORMAT Industries Ltd. In fact, the process provides for: i) distillation of the bitumen (atmospheric and vacuum), ii) deasphalting treatment of the residue through which the asphaltenes are removed, iii) Thermal Cracking of the DAO, and finally iv) recycling of the cracking products charged to the process in order to recover the distillates and separate the asphaltene component produced with the thermal treatment. Analogously to a coking process, the OrCrudeTM process produces distillates and a heavy residue (asphaltenes) which is used as feedstock for gasification plants which produce synthesis gas for the generation of energy and vapour necessary for the extraction of bitumens by means of the Steam Assisted Gravity Drainage (SAGD) technique, in addition to the hydrogen necessary for the further upgrading of the products.

OPTI Canada Inc. and Nexen Petroleum Inc. are following this path; the two companies are developing a project (Long Lake Project) for the recovery and treatment of 70,000 bbl/d of bitumen in the state of Alberta. The application of the process to this type of feedstock will allow the production of a liquid having

a density of 22.3°API with a yield of 78% with respect to the bitumen as such, whereas the remaining 3,100 t/d of asphaltenes form the feedstock for the gasification unit.

5 The main advantages of the SDA process consist in the low investment and operating costs, whereas the main limit is linked to the fact that in order to obtain DAO with a low content of pollutants (metals, nitrogen, CCR, etc..) the yields must be limited, which
10 implies the separation of significant amounts of by-products (asphaltenes).

According to the present invention, the asphaltene stream can be suitably upgraded.

In the state of the art, the fraction of
15 asphaltenes separated from the DAO is used in various ways. It can be used, for example, as fuel for producing energy (energy upgrading), it can be used for the preparation of road tars, it can be subjected to gasification processes (partial oxidation with oxygen
20 deficiency) to produce synthesis gas or it can be used in coking processes.

The use of asphaltenes as fuel in conventional combustion processes using air as comburent, however, creates considerable problems of environmental impact.
25 As these processes produce high amounts of polluting emissions, they can only be effected by adopting expensive technologies for the purification of the combustion fumes.

As an alternative to conventional combustion

processes in air, the use of asphaltene residues within integrated gasification processes and the production of energy in so-called Integrated Gasification Combined Cycle (IGCC) plants, is also known in the state of the art. The IGCC technology is considered as being one of the most promising technologies currently available for energy recovery from asphaltene residues.

In IGCC processes, the oil refinery residues are subjected to gasification in air (oxygen) with the production of hydrogen and carbon monoxide (synthesis gas) which can be used, after abatement of the H_2S present, in combined cycle power plants for the generation of electric energy.

Although highly efficient, IGCC processes have the disadvantage of being complex to run, not very reliable, in addition to having high plant investment costs.

In order to avoid the disadvantages of combustion and gasification in air, the oxy-combustion process (also called oxy-fuel process) has been proposed in the state of the art. In this process the comburent is represented by pure oxygen instead of air.

Oxy-combustion is characterized by the high thermal combustion yield of asphaltenes, the improved flame characteristics which lead to a reduced production of unburned (ashes). With oxy-combustion, moreover, the amount of exhausted fumes emitted into the atmosphere is significantly reduced.

The greater efficiency of the oxy-combustion

process is mainly due to the absence of nitrogen in the comburent.

From an environmental point of view, the absence of nitrogen also implies a reduction in the amount of
5 nitrogen oxides (NOx) produced by the combustion process and emitted into the atmosphere.

Oxy-combustion processes, however, have the disadvantage of having to be effected in relatively complex, voluminous plants, and with high investment
10 costs. Oxy-combustion plants, in fact, require, in their immediate vicinity, the presence of a plant for the production of oxygen (normally by means of cryogenic separation from the air), whose dimensions are proportional to the power of the oxy-combustion
15 plant. An oxy-combustion plant, for example, for the production of 500 MW, requires the production of 10,000 t/day (tons per day or tpd) of oxygen, thus necessitating the installation of at least two air fractioning units.

20 The objective of the present invention is to overcome the drawbacks revealed in the state of the art.

A first object of the present invention relates to an upstream-downstream integrated process for the
25 upgrading (refining) of a heavy crude oil with the capture of CO₂, comprising the following operative steps:

- a) production of a heavy crude oil from a reservoir;
- b) distillation of said heavy crude oil, at atmospheric

pressure or under vacuum, with the separation of a distilled fraction and a hydrocarbon residue containing asphaltenes;

- c) solvent deasphalting of said hydrocarbon residue
5 containing asphaltenes with the formation of a precipitate of asphaltenes and a deasphalted oil (DAO);
- d1) oxy-combustion of said precipitate of asphaltenes in pure oxygen with the formation of a stream of exhausted gases comprising CO₂ and water vapour;
- 10 d2) as an alternative to said oxy-combustion, gasification of said precipitate of asphaltenes in pure oxygen with the formation of a stream of syngas which is subsequently transformed into a gas stream comprising CO₂ and H₂;
- 15 e) separation of a substantially pure gaseous stream of CO₂ from said stream of exhausted gases or from said gas stream comprising CO₂ and H₂;
- f) injection of said gaseous stream of CO₂ into the subsoil in order to recover oil or gas, by
20 displacement, from a reservoir and/or to permanently sequester said gaseous stream of CO₂ in a geological formation.

The above process preferably also includes a phase g) for mixing the DAO obtained in phase c) with at
25 least a part of the distilled fraction obtained in phase b) with the formation of a reconstituted crude oil and/or a phase h) for the production of power through the water vapour generated in the oxy-combustion phase for possibly feeding electric cables

lowered into the well/formation (*Electrical Heaters*) for EOR purposes EEOR, Electrically Enhanced Oil Recovery).

The above process can possibly comprise the
5 following phase:

i) injection of water vapour into the subsoil for oil displacement from a reservoir.

A second object of the present invention relates to a plant for implementing the upstream-downstream
10 integrated process for the upgrading of a heavy crude oil according to claim 1, comprising:

I) a production well for producing a heavy crude oil from a reservoir;

II) a distillation unit for distilling, at
15 atmospheric pressure or under vacuum, said heavy crude oil with the separation of a distilled fraction and a hydrocarbon residue containing asphaltenes;

III) a solvent deasphalting unit for treating said hydrocarbon residue containing asphaltenes with the
20 formation of a precipitate of asphaltenes and a deasphalted oil;

IVa) a combustion unit for subjecting said precipitate of asphaltenes to oxy-combustion with the formation of a stream of exhausted gases comprising CO₂
25 and water vapour;

IVb) or, alternatively to the unit defined in IVa), a combustion unit for subjecting said precipitate of asphaltenes to a gasification process in pure oxygen with the formation of a stream of syngas which can be

subsequently transformed into a gas stream comprising CO₂ and H₂;

V) a separation unit for separating a substantially pure gaseous stream of CO₂ from said
5 exhausted gas stream, or from said gas stream comprising CO₂ and H₂;

VI) an injection unit for injecting said gaseous stream of CO₂ or the vapour separated by IVa into the subsoil to recover oil or gas, by displacement, from a
10 reservoir and/or for permanently sequestering said gaseous CO₂ stream in a geological formation.

The Applicant has found an integrated process which allows the transportability of a heavy crude oil to be enhanced, through the separation of the asphaltene
15 stream, allowing the transportability specifications in pipelines, to be reached. At the same time, the process allows the asphaltene stream separated from the process to be upgraded.

For the purposes of the present invention, the
20 expression "heavy crude oil" means a crude oil having a density lower than 22 °API and a viscosity within the range of 100-10,000 cP or bitumen, i.e. a mixture of hydrocarbons extracted from natural deposits or obtained from asphaltic rocks or oil sands, having a
25 density lower than 10°API and a viscosity higher than 10,000 Cp. Unlike heavy crude oils, bitumens are not mobile under reservoir conditions.

The process comprises sending the heavy crude oil to an extraction unit (Solvent DeAsphalting, SDA) in

order to separate the high-quality fraction of the crude oil (DeAsphalted Oil, DAO) from the remaining stream of residual asphaltenes, reaching, for this high-quality fraction, viscosity characteristics which
5 ensure its pumpability into the pipeline. In this way, the poison content (heavy metals, nitrogen, CCR) in the deasphalted oil DAO is reduced and this fraction can be processed in the refinery (in Fluid Catalytic Cracking (FCC) units or hydrocracking units) without particular
10 expedients.

The asphaltenes, which in this type of heavy crude oil are typically present in a quantity in the order of 20-40% by weight, separated from the SDA process, are then subjected to combustion in a pure oxygen
15 atmosphere (process known as oxy-combustion) in order to generate power and an off-gas stream containing pure CO₂ and SO₂. The pure CO₂ can, in specific contexts, be used for assisted recoveries of the EOR/EGR type or sequestered in the reservoir. Oxy-combustion therefore
20 allows the production of carbon-free electric energy, i.e. without input of CO₂ into the atmosphere.

The process is particularly versatile and applicable in various operative contexts, as the choice of the solvent with which the deasphalting process is
25 effected allows the yield to deasphalted oil or the yield to asphaltenes to be maximized, in contexts in which the energy requirement is high.

In both cases, pure CO₂ (together with SO₂, whose volume depends on the characteristics of the oil) is

produced from the oxy-combustion process of asphaltenes, which can be used for the recovery of oil or gas by means of EOR or EGR treatments or sequestered in specific geological formations. Analogously the
5 vapour produced and the energy produced by the vapour (totally or partially) can be used in specific contexts for assisted recoveries of the EOR type.

The application of the process scheme according to the present invention could be particularly interesting
10 especially for medium-small heavy oil fields (reduced specific investment costs), whose production can be increased with EOR treatments with CO₂ and/or N₂ (nitrogen can also be a by-product of the process scheme) with EOR treatment with vapour (steam Flooding,
15 SAGD, CSS) or thermal recovery by means of electrical heating (EEOR, Electrical Enhanced Oil Recovery). The advantages offered by the present invention are:

- Upgrading of the heavy crude oil using an extraction process (SDA) for producing a
20 deasphalted oil which can be easily transported and refined in traditional refineries;
- Production of carbon-free electricity from a heavy oil residue and rich in pollutants;
- Production of a stream of pure CO₂ which can be
25 used for EOR treatments to favour the additional production of oil itself and which is partially sequestered permanently in the formation.
- Production of a vapour stream which can be used for EOR treatments for favouring the additional

production of the oil itself.

- Production of electric energy from the vapour stream (totally or partially) and feeding of electric cables (electrical heaters) for EOR treatments to favour the additional production of oil (EEOR, Electrically Enhanced Oil Recovery)

The process of the present invention integrates a solvent deasphalting process (SDA) of a hydrocarbon residue deriving from a heavy crude oil with an oxy-combustion process of the residue containing asphaltenes deriving from the same SDA process.

The oxy-combustion of the asphaltene precipitate produces vapour and/or energy with a high yield and provides a substantially pure gaseous stream of CO₂, which can be advantageously exploited for the assisted recovery of oil or gas from a reservoir by means of EOR or EGR treatment and/or sequestered in a geological formation, thus preventing its dispersion into the atmosphere.

In an alternative embodiment of the present invention, the oxy-combustion phase of asphaltenes is substituted by a gasification phase in the presence of pure oxygen.

The integration of the SDA and oxy-combustion processes applied to a heavy crude oil, on the one hand allows to realize their upgrading, improving their transportability characteristics, and on the other, exploits the residual asphaltene fraction of the upgrading treatment, in a particularly advantageous

way, from both an economic and also environmental point of view.

A particular advantage of the present invention lies in the unexpected fact that the production of
5 additional quantities of oil and/or gas from a reservoir, made possible by the use of the CO₂ deriving from the oxy-combustion of the asphaltene fraction, vapour or energy deriving from the same process, can adequately compensate the energy and plant investment
10 costs associated with the use of oxy-combustion.

The integrated process of the present invention is also particularly versatile and can be easily adapted to different operating contexts of the oil industry. In particular, the integrated process, object of the
15 present invention, is suitable for the upgrading of heavy crude oils in an applicative context of oil fields having small-medium dimensions, in the order of 1,000-5,000 barrels/day (1 barrel = 159 l).

In these fields, in fact, the limited production
20 volumes of oil do not generally justify the use of traditional assisted recovery techniques of oil or gas.

The integrated process, object of the present invention, therefore represents a promising technological alternative for upgrading heavy crude
25 oils making them transportable, by means of the deasphalting process, exploiting the asphaltene stream for producing energy/vapour and a stream of pure CO₂ which can be suitably used for EOR.

Asphaltenes are hydrocarbons insoluble in solvents

of the n-alkane type, for example n-heptane or n-pentane, and soluble in aromatic solvents such as benzene and toluene. Asphaltenes comprise a wide variety of molecular structures. The composition of
5 asphaltenes can vary significantly in relation to the nature of the residue subjected to SDA.

The integrated process, object of the present invention, is applied in the context of the upgrading of heavy crude oils. In particular, the process
10 according to the present invention exploits hydrocarbon residues containing asphaltenes deriving from fractionation processes of these crude oils.

Phase a) of the integrated process according to the present invention comprises the extraction of heavy
15 crude oil from a reservoir. Once produced at the well head, the heavy crude oil is subjected to the usual preliminary treatment (oil separation, washing, etc.) before being sent for distillation (phase b). The distillation of the heavy crude oil, which can be
20 effected at atmospheric pressure or under vacuum, separates a distilled fraction and a hydrocarbon residue containing asphaltenes.

The subsequent phase c) of the process comprises a SDA treatment of the hydrocarbon residue (feedstock).
25 The SDA treatment is effected according to the techniques and with the equipment known to experts in the field.

In the SDA process, the feedstock is put in contact with a solvent inside an extractor. The solvents used

are C₃-C₆ alkanes, such as propane, butane (and its isomers), pentane (and its isomers), hexane or mixtures thereof. The solvent/heavy crude oil ratio in the SDA process ranges from 4:1 to 13:1.

5 The solvent extraction produces a first fluid phase consisting of a deasphalted oil (DAO) and a second phase, which is separated from the first, consisting of a mass containing the asphaltenes precipitated (hereafter, asphaltene precipitate).

10 In the asphaltene precipitate, in addition to asphaltenes, there are also polluting compounds, such as metals, compounds based on sulfur, nitrogen and aggregates of high-molecular-weight molecules having a high tendency towards the formation of coke.

15 The DAO obtained in phase a) has a lower density, viscosity, carbonaceous residue and concentration of S, N and metals with respect to the starting feedstock and it is therefore easier to move and be further processed. Furthermore, it is more valuable from an
20 economic point of view.

 The yield and composition of the DAO and that of the asphaltene precipitate depend on the operating conditions adopted for the SDA process.

 The choice of solvent to be used in the SDA process
25 plays a fundamental role in determining the yield and quality of the DAO, as the nature and quantity of components of the hydrocarbon residue which can be extracted depends on the solvent or mixture of solvents used. In an SDA process, an increase in the quantity of

DAO produced generally corresponds to a deterioration in its quality, as a greater quantity of aromatic components and impurities, such as sulfur, nitrogen and metals, is also extracted from the hydrocarbon residue.

5 The solubility of the feedstock in the solvent, under the same operating conditions, depends on the density of the solvent used. By increasing the density of the solvent (passing for example from propane to butane and pentane) the dissolution capacity of the
10 resins and pollutants contained in the feedstock increases.

 The yield and quality of the DAO which can be obtained also depends on the temperature at which the extraction is carried out. In the case of C_3 - C_6 alkanes,
15 the solubility of the hydrocarbons of the feedstock having a higher molecular weight decreases with an increase in the temperature. With an increase in the temperature, moreover, the paraffinic hydrocarbons present in the feedstock become more soluble in the
20 extraction solvent with respect to the aromatic hydrocarbons.

 The possibility of acting on numerous operating parameters makes the SDA process particularly versatile, as it allows the quality and quantity of DAO
25 to be controlled together with that of the asphaltene precipitate. This makes the integrated process according to the present invention particularly adaptable to the specific requirements of the applicative context in which it is inserted.

In applicative contexts characterized by a high energy requirement, for example, it is preferable to maximize the quantity of asphaltene precipitate that can be produced in phase c), in order to increase the amount of energy that can be obtained in the subsequent phases. If, on the other hand, the energy requirement is less significant, phase c) is preferably carried out under such conditions as to maximize the yield to DAO; in this case, the yield to DAO is in relation to the characteristics of the DAO to be obtained in terms of viscosity for transportation and properties required for the possible subsequent refining step.

The asphaltene precipitate is separated from the solvent at the outlet of the extractor. The separation of the solvent can be effected in various ways known to experts in the field. The separation is typically effected by stripping at a temperature slightly above the critical temperature of the solvent. At the critical temperature, the oil (DAO) and part of the resins are separated from the solvent, which is thus recovered. By operating under supercritical conditions, it is possible to recover over 85% of the solvent.

Various types of treatment of the SDA type which can be used for effecting phase c) of the process according to the present invention, are known in the state of the art.

Examples of SDA processes are the DEMEX[®] process of UOP and the ROSE process of (Kellog Brown & Root, Inc.).

Both of the above processes recover the solvent under supercritical conditions.

Other SDA processes known in the art and which can be used for the purposes of the present invention are
5 the PASD[®] process of Petrobras and the SOLVAHL[®] process of Axens.

In a preferred embodiment of the present invention, the process envisages a phase g) for mixing the DAO obtained in the solvent deasphalting phase c) with at
10 least a part of the distilled fraction from the heavy crude oil obtained in phase b) with the formation of a reconstituted crude oil (also called *Synthetic Crude Oil*).

According to a first preferred embodiment, the
15 integrated process according to the present invention comprises a phase d1) for the oxy-combustion of the asphaltene precipitate obtained in phase c).

Oxy-combustion (or oxy-fuel combustion or oxy-firing) is a combustion process which uses pure oxygen,
20 instead of air, as primary oxidant.

The oxy-combustion of phase d1) can be effected according to the techniques and with the equipment known to experts in the field.

The oxy-combustion process is characterized by a
25 high recirculation of discharge gas. As combustion in pure oxygen would in fact produce an excessively high temperature in the combustion chamber, the pure oxygen is previously diluted with a stream of recirculated discharge gas. The use of a comburent mixture formed by

the combination of a stream of pure oxygen and a dilution stream of exhausted gases allows the combustion of the asphaltene precipitate to be effected within a wide temperature range (600-1200°C).

5 The pure oxygen used in phase d1) is typically produced in a specific air separation unit, for example a cryogenic distillation unit.

For the purposes of the present invention, the term "pure oxygen" indicates gaseous oxygen having a purity
10 degree equal to or higher than 95% by volume.

The oxy-combustion is effected by putting the fuel in contact with the comburent mixture containing oxygen in a high-pressure combustion chamber (30-100 bar).

The oxy-combustion produces a stream of exhausted
15 gases substantially comprising vapour and CO₂. The presence in the asphaltene precipitate of compounds based on nitrogen and sulfur can produce small quantities of sulfur oxides (SO_x) and nitrogen oxides (NO_x) in the stream of exhausted gases.

20 With respect to conventional combustion processes in air, the oxy-combustion of phase d1) produces much lower volumes of discharge gas (up to 75% less), it is characterized by reduced heat losses and produces much lower quantities of NO_x and SO_x.

25 In an alternative embodiment of the present invention, instead of phase d1), the process envisages a gasification phase d2) of the asphaltene precipitate in pure oxygen, instead of in air, and the subsequent transformation of this into a stream of gas comprising

CO₂ and H₂.

Gasification allows organic materials (coal, biomasses, residues of distillation processes of oil products, etc.) to be converted into carbon monoxide and hydrogen (so-called synthesis gas or syngas), which can be used as fuel or as a base for the production of chemical products. Syngas can be burnt directly in internal combustion engines, used for producing methanol or hydrogen, or converted by means of the Fischer-Tropsch process into synthetic fuel.

The process is carried out at high temperatures (higher than 700-800 °C) and pressures of 20-30 bar, in the presence of a substoichiometric percentage of oxygen.

Syngas generally contains pollutants whose concentration must be reduced to levels which depend on the final use of the gas. For this purpose, the syngas is treated in a conditioning section which typically provides: 1) a cooling system of the syngas which allows the vapour to be condensed, with the production of energy; 2) a purification system of the syngas to remove particulate, sulfur and other pollutants present; 3) a transformation system of the syngas which depends on the type of application for which the syngas is destined. The CO₂ to be used in EOR/EGR treatment or to be sequestered in a geological formation is obtained from the CO-Shift process which converts syngas into CO₂ and H₂.

Gasification in oxygen is preferred with respect to

oxy-combustion in contexts in which use is made of the H_2 produced (for example, refineries or integrated upstream-downstream complexes).

The stream of exhausted gases leaving phase d1) or
5 the stream of gas comprising CO_2 and H_2 leaving phase d2) is subjected to a separation process of the CO_2 (phase c).

When the process comprises the oxy-combustion phase, a part of the stream of exhausted gases is
10 preferably recycled as dilution stream for forming the comburent mixture fed to the oxy-combustion of phase d1).

Before proceeding with the separation of the CO_2 , the stream of exhausted gases leaving phase d1) is
15 generally subjected to conventional purification treatment to remove possible impurities of SO_x and NO_x .

In phase e) the separation of the stream of CO_2 can be effected according to various treatment techniques.

As a stream of high-purity CO_2 (from 80% to 90% by
20 volume) is generated in the process of the present invention, by means of oxy-combustion and gasification in pure oxygen, the separation and purification process of this stream is considerably simplified. When phase d) is an oxy-combustion phase, for example, the
25 separation of CO_2 from the stream of exhausted gases can be effected by cooling the exhausted gases to remove the water and subsequently removing the inert gases possibly present. Once separated, the CO_2 can be compressed.

In phase f) of the process according to the present invention, the stream of CO₂ leaving phase e) is injected into the subsoil.

The objective of injection into the subsoil can be
5 the assisted recovery of oil (EOR) or gas (EGR) from a reservoir. Alternatively, the injection of CO₂ into the subsoil can have the purpose of permanently sequestering this gas in a geological formation.

The assisted recovery of oil or gas (hydrocarbon
10 fluids) in a reservoir is an extraction technique which allows the displacement of the hydrocarbon fluid from the reservoir exceeding the volumes which can be obtained with conventional primary recovery processes. These processes are also known as tertiary recovery
15 processes and are effected by the injection of a fluid containing chemical additives or polymers (chemical/polymer injection), gases such as CO₂, N₂ or hydrocarbon gases (gas injection) or by means of thermal recovery with the injection of vapour (steam
20 flooding) or again with electrical heaters.

In phase i) of the process according to the present invention, the vapour stream leaving phase d1) is injected into the subsoil for EOR purposes. Vapour can be used in Cyclic Steam Stimulation (CSS) process, in
25 Steam Assisted Gravity Drainage (SAGD) process and in Steam Flooding process.

In phase h) of the process according to the present invention, the electric energy produced by the vapour (totally or partially), can be used for feeding

electric cables (*electrical heaters*) for EOR purposes (EEOR, Electrically Enhanced Oil Recovery).

In these processes, the objective is to push (displace) the hydrocarbon fluid towards the production
5 wells. For this purpose, wells are excavated in the oil field for the injection of the immiscible fluid (also called displacement fluid) which are arranged so as to create a thrust front in the subsoil, of the hydrocarbon fluid which is as uniform as possible.

10 Furthermore, in the case of oil fields, the injection of gas or vapour into the reservoir and/or electrical heating, contribute to the recovery of the oil present, reducing its viscosity and consequently increasing its mobility within the rock formation.

15 In a preferred embodiment of phase f), the gaseous stream of CO₂ leaving phase d1) or d2) is injected into a coal bed methane reservoir, where it produces a displacement effect with respect to the methane present, allowing its production at the surface.

20 In an alternative embodiment of the present invention, the above stream of CO₂ is permanently sequestered in suitable geological formations, such as exhausted oil or gas reservoirs or deep saltwater reservoirs.

25 The sequestering of CO₂ in underground reservoirs, also called geological storage, can be effected with the equipment and according to techniques known in the field.

The integrated process of the present invention

also preferably comprises a phase h) for feeding the water vapour stream obtained in phase d1), once separated from the CO₂, to a thermal and/or electric energy production process.

5 The stream of water vapour produced in the oxy-combustion and gasification phases can also be used for EOR treatments, such as SAGD, CSS, Steam Flooding processes or for oil recovery processes by means of thermal methods.

10 The advantages of the integrated process of the present invention are particularly evident in the case of its application in oil fields having a low production capacity, such as for example oil fields in an advanced state of production. In these fields, in
15 fact, the availability of CO₂ produced, vapour and electric energy by oxy-combustion of asphaltenes allows the implementation on the same fields of EOR and EGR assisted recovery processes, which would otherwise not be effected as this would not be economically
20 convenient.

When, on the other hand, the CO₂ produced in phase e) is destined for sequestering in geological formations, the implementation of the integrated process of the present invention on the same oil fields
25 is in any case advantageous, as the overall environmental impact of the extraction of oil from the reservoir is significantly reduced.

With reference to the block scheme of figure 1, which shows a schematic representation of a possible

embodiment of the integrated process of the present invention, an example of a possible application of the process is described hereunder.

The oil 1 extracted from a production well PP is fed, from the wells area AP, to the oil separation unit SO, and subsequently to the desalination unit DS, where the saline compounds contained therein are removed by washing with water. The oil, free of saline compounds 3, is fed from the desalination unit DS to the fractionated distillation unit DF. In the unit DF, separation of the lighter hydrocarbon fractions is effected by distillation. A distillate 4, containing light hydrocarbon fractions, leaves the distillation unit DF, together with a hydrocarbon residue containing asphaltenes 5. The distillate 4 can be further processed in the refinery in order to obtain hydrocarbon products having a commercial value. The hydrocarbon residue containing asphaltenes 5 is subjected to a deasphalting process in a deasphalting unit SDA. The solvent extraction effected in this unit produces a DAO 6 and an asphaltene precipitate 7.

In the process illustrated in figure 1, the DAO 6 leaving the SDA unit is mixed with at least a part of the distillate 4 in order to obtain a reconstituted crude oil 10 having the density and viscosity specifications necessary for allowing it to be easily moved towards the subsequent processing phases in a refinery R.

The asphaltene precipitate 7 leaving the

deasphalting unit SDA is fed as fuel to a combustion unit OCG, in which the oxy-combustion of the asphaltene precipitate 7 is effected (or its gasification in pure oxygen followed by transformation of the syngas by means of the CO-Shift reaction), with the production of vapour/energy and a stream of exhausted gases 8 substantially comprising CO₂ and H₂O. The stream of exhausted gases 8 is fed to a separation and compression unit of the CO₂ SC, in which a stream of high-purity CO₂ 9 is obtained, together with a stream of water vapour 11. The stream of high-purity CO₂ 9 is recycled to the well area AP, into an injection unit IN, where it can be exploited for the assisted recovery of gas or oil from the reservoir or it can be injected into the subsoil in order to permanently sequester it in a geological formation. The stream of water vapour 11 is fed to an energy production unit PE, for generating thermal and/or electric energy, which can be used for the feeding of electric cables (electrical heaters) for EOR purposes. This technique is particularly convenient in relatively shallow reservoirs, in which the EOR techniques with vapour cannot be typically applied due to the lack of the mineralogical coverage necessary for preventing the discharge of the vapour injected.

The stream of water vapour can be used, alternatively to or combined with the production of energy, in an injection unit IN, where it can be exploited for assisted oil recovery from the reservoir.

In order to allow it to be injected into the subsoil, the CO₂ is compressed in a specific compression unit (not shown in figure 1) generally comprising five compression steps, each with a liquid vapour separator
5 (knock-out drum) in suction and air cooling in supply.

An embodiment example of the integrated process of the present invention is provided hereunder for purely illustrative purposes, which should not be considered as limiting the protection scope defined by the
10 enclosed claims.

EXAMPLE

The effectiveness of the integrated process, object of the present invention, was evaluated considering two different types of starting heavy crude oil, indicated
15 with the names "Crude oil 10" and "Crude oil 15". The characteristics of the two crude oils are indicated in Table 1.

20

25

Table 1 - Characteristics of the crude oils

	Crude oil 15	Crude oil 10
Presence of flushing agent	no	yes
Density at 15°C (g/cm ³)	1.0205	0.9879
°API	7.2	11.7
Kinematic viscosity at 15°C (cSt)	133524	2080
Kinematic viscosity at 40°C (cSt)	13263	624
Asphaltenes C ₅ (% by weight) ¹	13.6	12.0
S (% by weight)	5.79	4.07
CCR (% by weight) ²	11.2	10.7
Ni (ppm by weight)	85	37.5
V (ppm by weight)	73	77
Mo (ppm by weight)	17.2	16.2
Fe (ppm by weight)	0.9	10
H ₂ O (% by weight)	21.3	38.4
<i>Dynamic Viscosity</i> <i>η (mPa.s) at 100 s⁻¹</i>		
T=15 °C	136262	2055
T=40 °C	13183	607
T=50 °C	6457	361
T=60 °C	2677	257
<i>Density (g/cm³)</i>		
T=15 °C	1.0205	0.9879
T=40 °C	0.994	0.9725
T=50 °C	0.9864	0.9665
T=60 °C	0.9735	0.9602
Notes: 1) Asphaltenes insoluble in C5 solvents 2) Conradson carbonaceous residue		

Table 2 indicates the water content of the two
5 crude oils tested and the weight percentage of the
different hydrocarbon fractions obtained by atmospheric
distillation (percentages referring to the overall
weight of the starting heavy crude oil).

Table 2 - Composition of the hydrocarbon fractions obtained by atmospheric distillation

Weight %	Gela 10	Gela 15
H ₂ O	38.4	21.3
PI÷60°C	0.2	0.6
60÷250°C	8.1	5.4
R250°C+ ^{**}	53.4	72.7

5 * PI÷60°C: mixture of the hydrocarbon products distilled from PI (initial distillation point, in this case room temperature) to 60°C.

10 ** R250°C+: hydrocarbon fraction of the crude oil which does not distil at atmospheric pressure up to a temperature of 250°C.

The results of the characterization of the fraction PI250°C- (corresponding to the mixture of hydrocarbon products distilled at a temperature lower than 250°C) and that of the residue R250°C+ are indicated in Table 3 (Crude oil 15) and in Table 4 (Crude oil 10).

15 3 (Crude oil 15) and in Table 4 (Crude oil 10).

Table 3 - Characterization of the fractions
PI250°C- and R250°C+ of Crude oil 15

	PI250°C-	R250°C+
Yield ¹	7.6	92.4
Density at 15°C (g/cm ³)	0.792	1.032 ²
°API	47.2	5.6
Kinematic viscosity at 40°C (cSt)	3.8 ³	90143
S (% by weight)	2.69	7.70
CCR (% by weight)	--	17.2
Ni (ppm by weight)	--	130
V (ppm by weight)	--	112
Fe (ppm by weight)	--	18.1
Mo (ppm by weight)	--	25.3
Dynamic Viscosity η (mPa.s) at 100 s ⁻¹	--	
T=15 °C	3	1363243
T=40 °C	--	83635
T=50 °C	--	28184
T=60 °C	--	11920
Density (g/cm ³)		
T=15 °C	0.792	1.032
T=40 °C	--	1.008
Notes:		
1) Expressed as weight % referring to the weight of the anhydrous crude oil		
2) value determined at 25 °C		
3) value determined at 15 °C		

Table 4 - Characterization of the fractions PI 250°C⁻ and R250°C⁺ of Crude oil 10

	PI250°C ⁻	R250°C ⁺
Yield	13.3	86.7
Density at 15°C (g/cm ³)	0.7981	1.0181
°API	45.8	7.5
Viscosity at 40°C (cSt)	2 ²	1979
S (%by weight)	1.65	6.9
CCR (% by weight)	--	14.8
Ni (ppm by weight)	--	66.6
V (ppm by weight)	--	139
Fe (ppm by weight)	--	26.9
Mo (ppm by weight)	--	27.8
Dynamic viscosity η (mPa.s) at 100 s ⁻¹		
T=15 °C	1.7	13737
T=40 °C	--	1983
T=50 °C	--	967
T=60 °C	--	517
Density (g/cm ³)		
T=15 °C	0.7981	1.0181
T=40 °C	--	1.0023
T=50 °C	--	0.9958
T=60 °C	--	0.9896
Notes:		
1) Expressed as weight % with respect to the weight of the anhydrous crude oil		
2) value determined at 15 °C		

5 The distilled fractions up to 250°C (PI250°C⁻) were separated from the residue (R250°C⁺), to allow subsequently mixing, if necessary, with the DAO

deriving from the solvent deasphalting of the residue R250°C+. The viscosity and density specifications of the DAO can be adjusted to the minimum acceptable conditions for its transportation (250 cSt at 40°C), by
5 mixing with the distillates.

Deasphalting tests on the residue R250°C+

The deasphalting tests (SDA) were carried out on the residue R250°C+ deriving from the distillation of Crude oil 15 and Crude oil 10 (anhydrous).

10 The solvent extraction on the residues R250°C+ of the two oils was effected using n-pentane or n-butane as solvent.

In the case of n-pentane, the solvent was mixed with the hydrocarbon residue (feedstock) in a flask at
15 room temperature and atmospheric pressure.

The feedstock was mixed with an excess of solvent.

The asphaltene precipitate was separated from the liquid phase (mixture DAO-solvent) through vacuum filtration. The solvent was subsequently separated from
20 the DAO by distillation in a rotating evaporator at 55°C.

The feedstock, the separated asphaltene fraction and DAO were quantified for determining the material balance.

25 In the case of n-butane, the solvent extraction was effected in batch, in a stirred autoclave, heated by two electric coils. The feedstock was mixed with an excess of solvent (mass ratio 1:5). The separation of DAO was effected by decanting the asphaltenes

flocculated at a temperature of about 60°C.

At the end of the decanting, the supernatant liquid was poured, through a plunged pipe and a heated line, into a second autoclave, where the solvent was
5 separated from the DAO by evaporation at about 55°C and degassing to atmospheric pressure.

In order to optimize the extraction, due to the lower solvent-feedstock ratio with respect to the laboratory tests with n-pentane, the decanted
10 asphaltene precipitate was subjected to a second solvent extraction treatment. At the end of the second solvent extraction, the asphaltene precipitate was discharged and recovered from the first autoclave, whereas the DAO was discharged and recovered by
15 drainage from the bottom of the second autoclave.

Deasphalting process of the residue of Crude oil 15

Table 5 indicates the yields of the SDA process applied to R250°C+ of Crude oil 15, in terms of DAO and asphaltene precipitate, and also the results of the
20 characterization of the products obtained.

Table 5 - Results of the SDA process (in n-pentane and n-butane) of the residue R250°C+ of Crude oil 15

	DAO (n-butane)	PA ³ (n-butane)	DAO (n-pentane)	PA ³ (n-pentane)
Yield ¹	43.3	49.1	67.7	24.6
Yield ²	46.9	53.1	73.3	26.7
Density at 15°C (g/cm ³)	0.959	1.055	0.991	
°API	16.0	2.6	11.3	
Cinematic viscosity 40°C (cSt)	249		2072	
S (% by weight)	6.10	8.43	6.92	8.7
CCR (% by weight)	1.73		6.44	
Ni (ppm by weight)	12.2	263	64.3	298
V (ppm by weight)	5.3	189	36.0	297
Fe (ppm by weight)	<0.5	50.7	2.4	52.2
Mo (ppm by weight)	<0.5	55.9	<0.5	89.0
Dynamic viscosity η (mPa.s) a 100 s ⁻¹				
T=15 °C	1576	290369153	18315	--
T=40 °C	234	--	2019	--
T=50 °C	--	--	--	--
T=60 °C	--	--	--	--
T=120 °C	--	102330	--	--
T=130 °C	--	64565	--	--
T=140 °C	--	35662	--	--
Density (g/cm ³)				
T=15 °C	0.9593	1.0554	0.9909	--
T=40 °C	0.9407	--	0.9745	--
T=50 °C	--	--	--	--
T=60 °C	--	--	--	--
Notes: 1) % by weight with respect to the weight of the anhydrous residue R250°C+, subjected to SDA; 2) % by weight with respect to the overall weight of Crude oil 15 (anhydrous) from which R250°C+ was obtained, subjected to SDA; 3) PA: Asphaltene precipitate.				

The results of Table 5 show that in the DAO
5 obtained by deasphalting with n-butane, there are

significant reductions in viscosity, density, Conradson carbonaceous residue (CCR) and metal concentrations with respect to the starting residue R250°C+, but substantially low reduction in the sulfur content.

5 In the DAO obtained from deasphalting with n-pentane smaller reductions in viscosity, CCR and metals and sulfur content can be observed with respect to deasphalting with butanes.

The results of Table 5 show that the DAO obtained
10 by deasphalting with butane of the R250°C+ fraction of Crude oil 15, has viscosity and density characteristics suitable for its transportation (250 cSt, at 40 °C). These characteristics are not reached by deasphalting with pentane; in this case the transportation
15 specifications can be improved by mixing the distilled fraction PI250°C- with DAO. The viscosity is reduced from 2,072 cSt (at 40°C) to 656 Cst, without reaching however the transportability specifications.

The example shows the importance in the selection
20 of solvent deasphalting, which must be effected according to the type of application and DAO characteristics expected.

Table 6 show the characteristics of Crude oil 15, reconstituted by mixing DAO (obtained by means of SDA
25 with n-pentane and n-butane) with 7.6% by weight of the corresponding distilled fraction PI250°C- (percentage referring to the weight of the (anhydrous) feedstock subjected to SDA).

Table 6 - Characterization of the reconstituted

Crude oil 15

	SDA (n-butane)	SDA (n-pentane)
% weight of distillate P<250°C- in the reconstituted Crude oil ¹	7.6	7.6
DAO kinematic viscosity (cSt at 40 °C)	249	2072
°API DAO	16.0	11.3
Kinematic viscosity DAO reconstituted (cSt at 40 °C)	95	656
°API reconstituted	20.0	14.2

1) percentage of distillates obtained from the
5 initial fractioning of the crude oil with respect
the weight of the initial Crude oil.

Deasphalting process of the residue of Crude oil 10

Table 7 shows the yields of the SDA process applied
to the residue R250°C+ of Crude oil 10, in terms of DAO
10 and asphaltenes, and also some characteristics of the
products obtained. The tests were carried out following
the same procedures illustrated in the case of Crude
oil 15.

15

20

Table 7 - Results of the SDA process (in n-pentane)
of the residue R250°C+ of Crude oil 10

	DAO (n-pentane)	PA (n-pentane)
Yield ¹	64.5	22.2
Yield ²	74.4	25.6
Density at 15°C (g/cm ³)	0.9482	--
°API	17.7	--
Kinematic viscosity at 40°C (cSt)	102	--
S (% by weight)	6.39	8.02
CCR (% by weight)	5.58	
Ni (ppm by weight)	18.7	169
V (ppm by weight)	33.4	354
Fe (ppm by weight)	0.75	96.2
Mo (ppm by weight)	<0.5	93.9
Dynamic viscosity η (mPa.s) a 100 s ⁻¹		
T=15 °C	355	--
T=40 °C	95	--
T=50 °C	58	--
T=60 °C	38	--
T=120 °C	--	--
T=130 °C	--	--
T=140 °C	--	--
Density (g/cm ³)		
T=15 °C	0.9482	--
T=40 °C	0.9327	--
T=50 °C	0.9264	--
T=60 °C	0.9203	--
Notes:		
1) % by weight with respect to the weight of the anhydrous residue R250°C+, subjected to SDA;		
2) % by weight with respect to the overall weight of Crude oil 15 (anhydrous) from which R250°C+ was obtained, subjected to SDA		
3) PA: Asphaltene precipitate		

The results of table 7 show that the DAO obtained by
5 deasphalting with n-pentane of the fraction R250°C+ of

Crude oil 10 has viscosity and density characteristics suitable for its transportation.

Table 8 indicates the characteristics of Crude oil 10 reconstituted by mixing DAO (obtained by means of SDA with n-pentane) with 13.3% by weight of the corresponding distilled fraction PI250°C- (percentage referring to the weight of the anhydrous feedstock subjected to SDA).

Table 8 - Characterization of the reconstituted Crude oil (Crude oil 10)

	SDA (n-pentane)
Distillates (PI250°C-) in the reconstituted crude oil ¹	13.3
Kinematic viscosity of DAO (cSt a 40 °C)	102
°API DAO	17.7
Kinematic viscosity of reconstituted crude oil (cSt a 40 °C)	35
°API (DAO reconstituted)	21.9

1) weight percentages referring to the anhydrous weight of the feedstock subjected to SDA.

Oxy-combustion process of the asphaltene precipitate obtained by means of SDA of the residue of Crude oil 15.

On the basis of the experimental results described

above, the energy recovery which can be obtained by oxy-combustion of the asphaltene precipitate deriving from the deasphalting with n-butane of the residue R250°C+ of Crude oil 15, was estimated as follows.

5 The treatment was assumed of the residue R250°C+ deriving from the atmospheric distillation of 15,000 barrels/day (barrel-per-day, bpd) of crude oil 15 corresponding to 2433 t/day (tpd) of stock tank.

10 The atmospheric distillation of 2433 tpd of crude oil, produces.

- distillates (PI250°C-) in an amount equal to 7.6% by weight of the Crude oil treated (185 tpd);
 - hydrocarbon residue (R250°C+) in an amount equal to 92.4% by weight of the crude oil treated
- 15 (2248 tpd).

By subjecting the residue R250°C+ to an SDA process with n-butane, the following products are obtained:

- 1054 tpd of DAO, equal to 43.3 by weight of the starting Crude oil and 46.9% by weight of the
- 20 residue R250°C+;
- 1193 tpd of asphaltene precipitate, equal to 49.1% by weight of the starting crude oil and 46.9% by weight of the residue R250°C+.

25 The DAO can be mixed with the distillate fraction PI250°C- to form 1239 tpd of reconstituted Crude oil.

The oxy-combustion of 1193 tpd of asphaltene precipitate is effected using 3722 tpd of pure oxygen which can be obtained by separation of 15510 tpd of air (nitrogen separated: 11800 tpd).

The following products are obtained with the oxy-combustion of the asphaltene precipitate:

- 14050 tpd of vapour (the amount of vapour produced was obtained by assuming a thermal conversion yield on the pci of the asphaltene precipitate equal to 90%); the vapour produced can be suitably transformed (totally or partially) into electric energy, for a maximum of 152 MW of electric energy (assuming an electric generation yield equal to 35% on the lower calorific power (pci) of the asphaltene precipitate);
- 3935 tpd of CO₂ + SO₂;
- 3.35 tpd of ashes.

By subtracting the consumptions of electric energy necessary for running the process from the overall amount of electric energy produced, the amount of the electric energy available (for use or for sale) is equal to electric 106 MW.

The vapour produced can be used in EOR processes such as SAGD, CSS and Steam Flooding, wherein the ratio between the volume of vapour to be injected and the volume of additional oil that can be produced (SOR, Steam to Oil Ratio) can vary within the range of 3-5 (for 3-5 volumes of vapour injected, 1 volume of additional oil can be produced).

The electric energy available can also be used for EOR purposes for feeding electrical heaters. In this case, the power density varies within the range of 200-300 W/m of electric cable.

The energy recovery obtainable through oxy-

combustion of the asphaltene precipitate deriving from deasphalting in n-pentane of the residue R250°C+ of the Crude oil 15, was calculated in the same way.

When 2248 tpd of the residue R250°C are subjected
5 to an SDA process with n-pentane, the following products are obtained:

- 1648 tpd of DAO, equal to 67.7% by weight of the starting Crude oil and 73.3% by weight of the residue R250°C+;

10 - 600.3 tpd of asphaltene precipitate, equal to 24.6% by weight of the starting Crude oil and 26.7% by weight of the residue R250°C+.

The DAO can be mixed with the distillate fraction PI250°C- of the previous example, to form 1833 tpd of
15 reconstituted Crude oil.

For the oxy-combustion of 600.3 tpd of asphaltene precipitate, 1872 tpd of pure oxygen are consumed, obtained by separation of 7800 tpd of air (nitrogen separated: 5930 tpd).

20 Through the oxy-combustion of the asphaltene precipitate, the following products are obtained:

- 7069 tpd of vapour (the amount of vapour produced was calculated by assuming a thermal conversion yield on the pci of the asphaltene
25 precipitate equal to 90%); the vapour produced can be suitably transformed (totally or partially) into electric energy for a maximum of 76.4 MW of electric energy (assuming an electric generation yield equal to 35% on the lower calorific power (pci) of the

asphaltene precipitate);

- 1980 tpd of CO₂ + SO₂;
- 1.68 tpd of ashes.

By subtracting the consumptions of electric energy
5 necessary for running the process from the overall
amount of electric energy produced, the amount of the
electric energy available for other uses (or for sale)
is equal to electric 53.5 MW.

The use of CO₂ resulting from the oxy-combustion for
10 EOR recoveries can favour the additional production of
oil, quantifiable as 1 t. of oil per 1-5 t of CO₂
injected, depending on whether the mechanism is of the
miscible type (1 t oil per 1-3 t of CO₂ injected) or
non-miscible type (1 t oil per 3-5 t of CO₂ injected).

15

CLAIMS

1) An upstream-downstream integrated process for the upgrading of a heavy crude oil with the capture of CO₂, comprising the following operative steps:

5 a. production of a heavy crude oil from a reservoir;

b. distillation of said heavy crude oil, at atmospheric pressure or under vacuum, with the separation of a distilled fraction and a hydrocarbon
10 residue containing asphaltenes;

c. solvent deasphaltation of said hydrocarbon residue containing asphaltenes with the formation of a precipitate of asphaltenes and a deasphalted oil (DAO);

d1. oxy-combustion of said precipitate of
15 asphaltenes in pure oxygen with the formation of a stream of exhausted gases comprising CO₂ and water vapour;

d2. alternatively to said oxy-combustion, gasification of said precipitate of asphaltenes in pure
20 oxygen with the formation of a stream of syngas which is subsequently transformed into a gas stream comprising CO₂ and H₂;

e. separation of a substantially pure gaseous stream of CO₂ from said stream of exhausted gases or
25 from said gas stream comprising CO₂ and H₂;

f. injection of said gaseous stream of CO₂ into the subsoil in order to recover oil or gas, by displacement, from a reservoir and/or to permanently sequester said gaseous stream of CO₂ in a geological

formation.

- 2) The process according to claim 1, characterized in that said process comprises a mixing step g) of said DAO with at least a part of said distilled fraction
5 with the formation of a reconstituted crude oil.
- 3) The process according to claim 1 or 2, characterized in that said process comprises a power production step h) (electric and/or thermal energy) by means of the water vapour generated in the oxy-
10 combustion step.
- 4) The process according to any of the previous claims, characterized in that said process comprises a phase i) for the injection of water vapour into the subsoil for the displacement of oil from a reservoir.
- 15 5) The process according to any of the previous claims, characterized in that the water vapour produced in the oxy-combustion and gasification steps is used for EOR treatment, such as steam-assisted gravity drainage processes (SAGD), Cyclic Steam Stimulation (CSS)
20 processes, Steam Flooding processes) or oil recovery processes by means of thermal methods.
- 6) The process according to any of the previous claims, characterized in that the power produced by the water vapour generated in the oxy-combustion phase, is used
25 for EOR treatment, such as thermal recovery processes by means of electrical heaters (EEOR, Electrically Enhanced Oil Recovery).
- 7) The process according to any of the previous claims, characterized in that said gaseous stream of CO₂ (9) is

injected as displacing fluid into a carbon-bed methane reservoir.

8) The process according to any of the previous claims, characterized in that said syngas stream is
5 transformed into a gas stream comprising CO₂ and H₂ by means of a CO-shift reaction.

9) The process according to any of the previous claims, characterized in that said solvent is a C₃-C₆ alkane and/or mixtures thereof, preferably n-pentane,
10 n-butane, or a mixture of butanes or pentanes and their isomers.

10) The process according to any of the previous claims, characterized in that said gaseous stream of CO₂
(9) is separated from said stream of exhausted gases
15 (8) by cooling the exhausted gas to remove the water present and, possibly, removing the inert gases present.

11) The process according to any of the previous claims, characterized in that said gaseous stream of CO₂
20 (9) is permanently sequestered in an exhausted oil or gas reservoir or in a deep reservoir of salt water.

12) The process according to any of the previous claims, characterized in that the H₂ generated in said gasification in pure oxygen of the precipitate of
25 asphaltenes is used in refineries or in upstream-downstream integrated complexes.

13) A plant for implementing the upstream-downstream integrated process for the upgrading of a heavy crude oil according to claim 1, comprising:

I) a production well (PP) for producing a heavy crude oil (1) from a reservoir;

II) a distillation unit (DF) to distil, at atmospheric pressure or under vacuum, said heavy crude oil (1) with the separation of a distilled fraction (4) and a hydrocarbon residue containing asphaltenes (5);

III) a solvent deasphaltation unit (SDA) for treating said hydrocarbon residue containing asphaltenes (5) with the formation of a precipitate of asphaltenes (7) and a deasphalted oil (6);

IVa) a combustion unit (C) for subjecting said precipitate of asphaltenes (7) to oxy-combustion with the formation of a stream of exhausted gases (8) comprising CO₂ and water vapour;

IVb) or, alternatively to the unit defined in IVa), a combustion unit (C) for subjecting said precipitate of asphaltenes (7) to a gasification process in pure oxygen with the formation of a stream of syngas which can be subsequently transformed into a gas stream comprising CO₂ and H₂;

V) a separation unit (SC) for separating a substantially pure gaseous stream of CO₂ (9) from said exhausted gas stream (8), or from said gas stream comprising CO₂ and H₂;

VI) an injection unit (IN) for injecting said gaseous stream of CO₂ (9) or the vapour produced in the process by oxy-combustion, into the subsoil to recover oil or gas, by displacement, from a reservoir and/or for permanently sequestering said gaseous CO₂ stream in a geological formation.

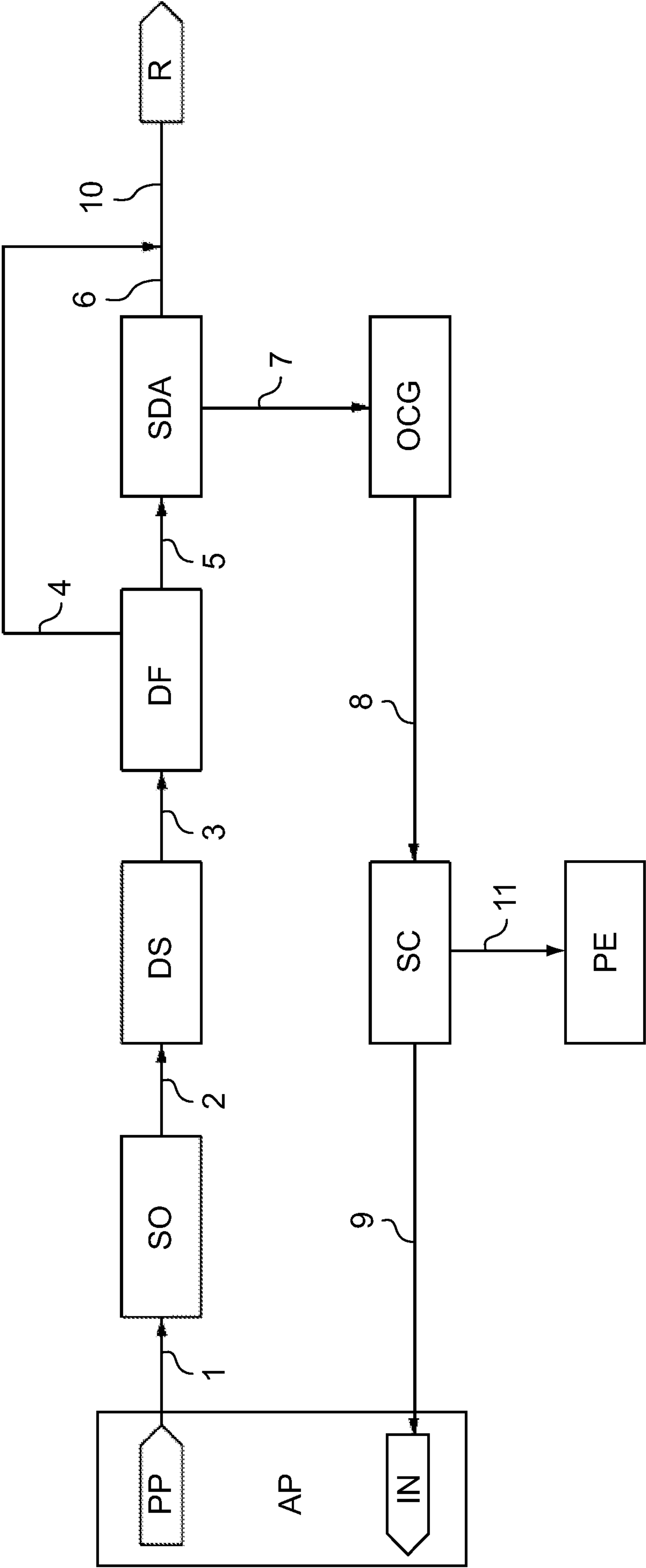


Fig. 1

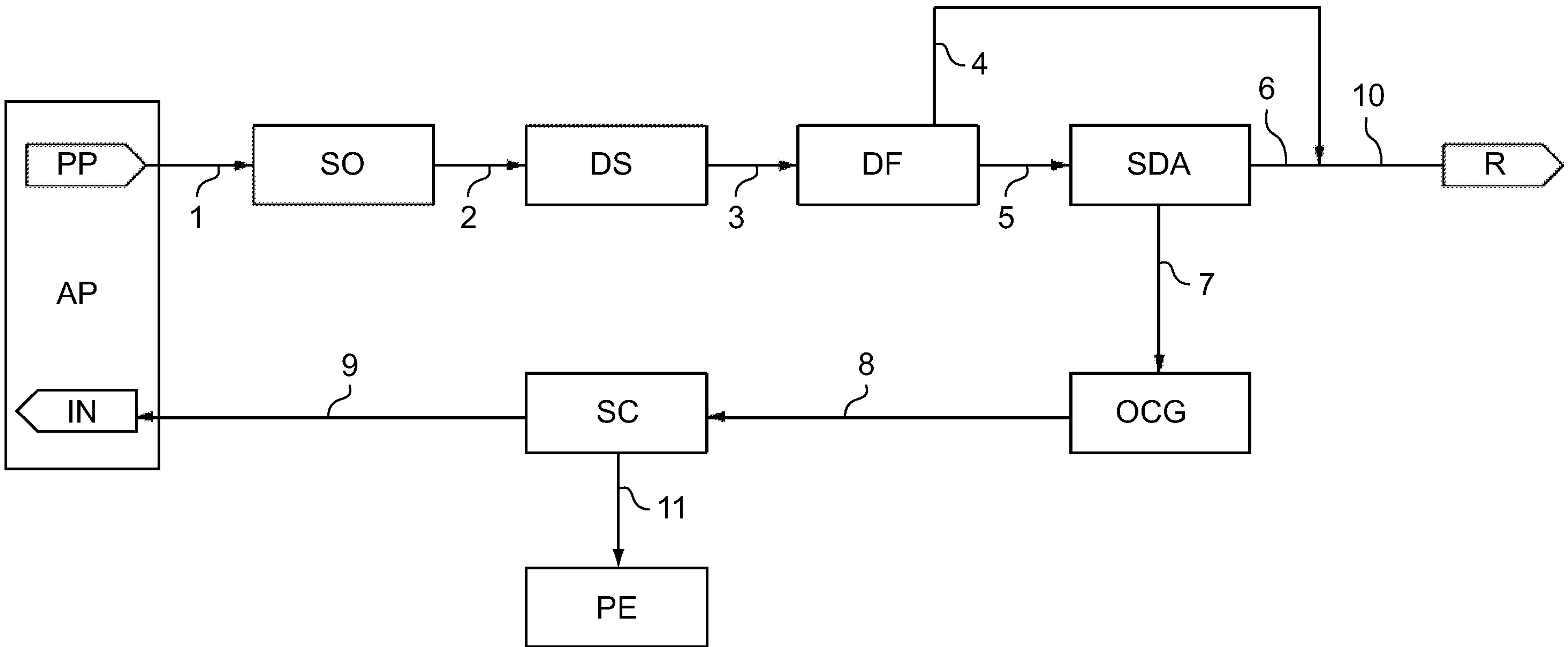


Fig. 1