Equipment for Plant Processing Coal into Diesel Fuel & Associated Petroleum Products

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NPZ-DT500

Package

NPZ-DT500 Package Intended Use

NPZ-DT500 is a refinery package designed to liquefy coal to produce synthetic crude oil for further processing mainly into diesel fuel and gasoline and fuel oil residues.

NPZ-DT500 Package Design Concept

The **NPZ-DT500** design concept comprises an open architecture and using of large-size factory-preassembled modules that are nearly finished.

The open architecture, eventually, contributes to both the package capacity and functionality due to potential expanding the range of petroleum products along with improving specifications (refining extent and operational properties). In addition, this concept makes it possible to adhere to different options in terms of processing the ash left after the coal is liquefied.

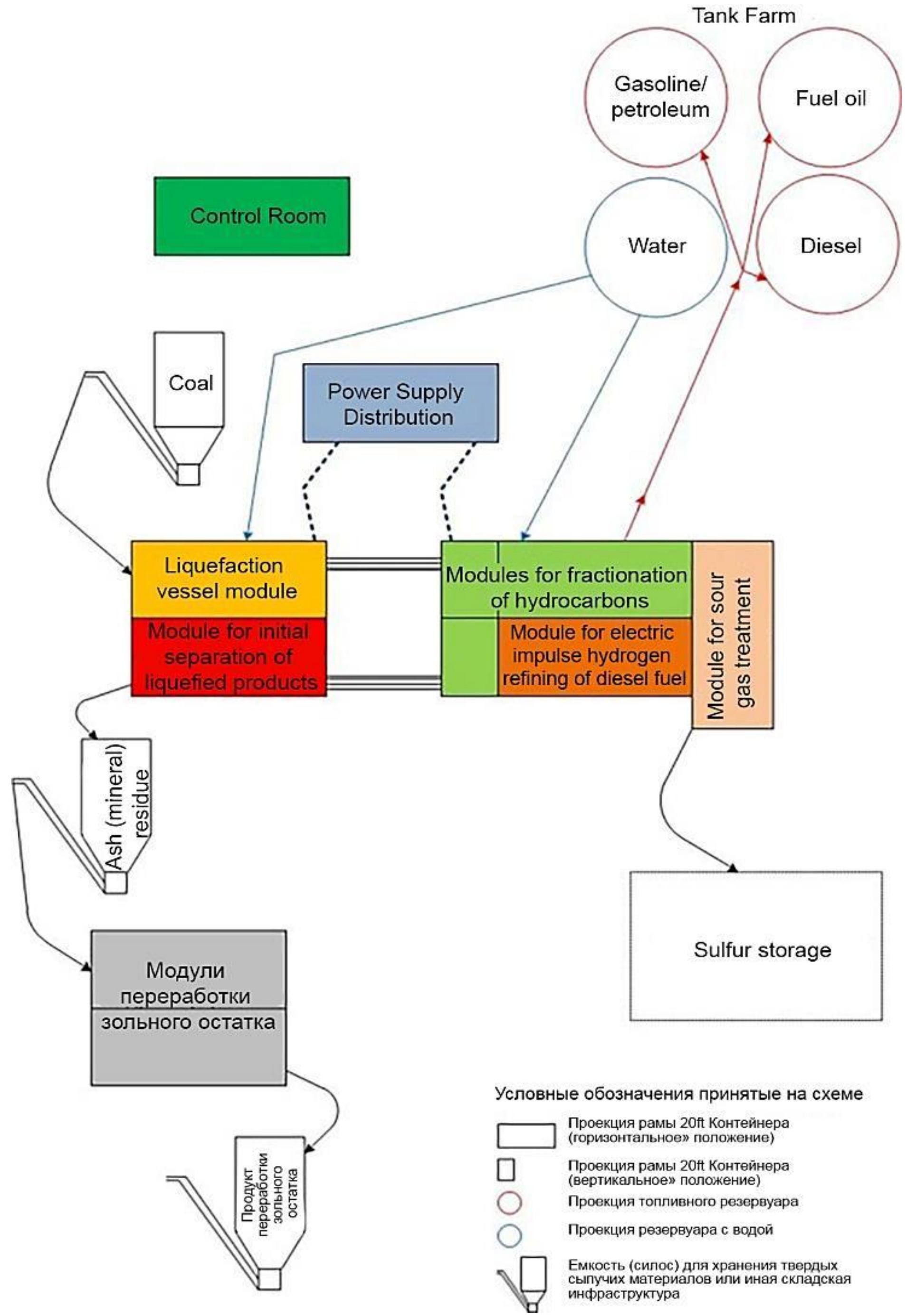
The use of large-scale factory-preassembled modules is a way to minimize the time and costs to install and commission the package.

NPZ-DT500 Package Arrangement

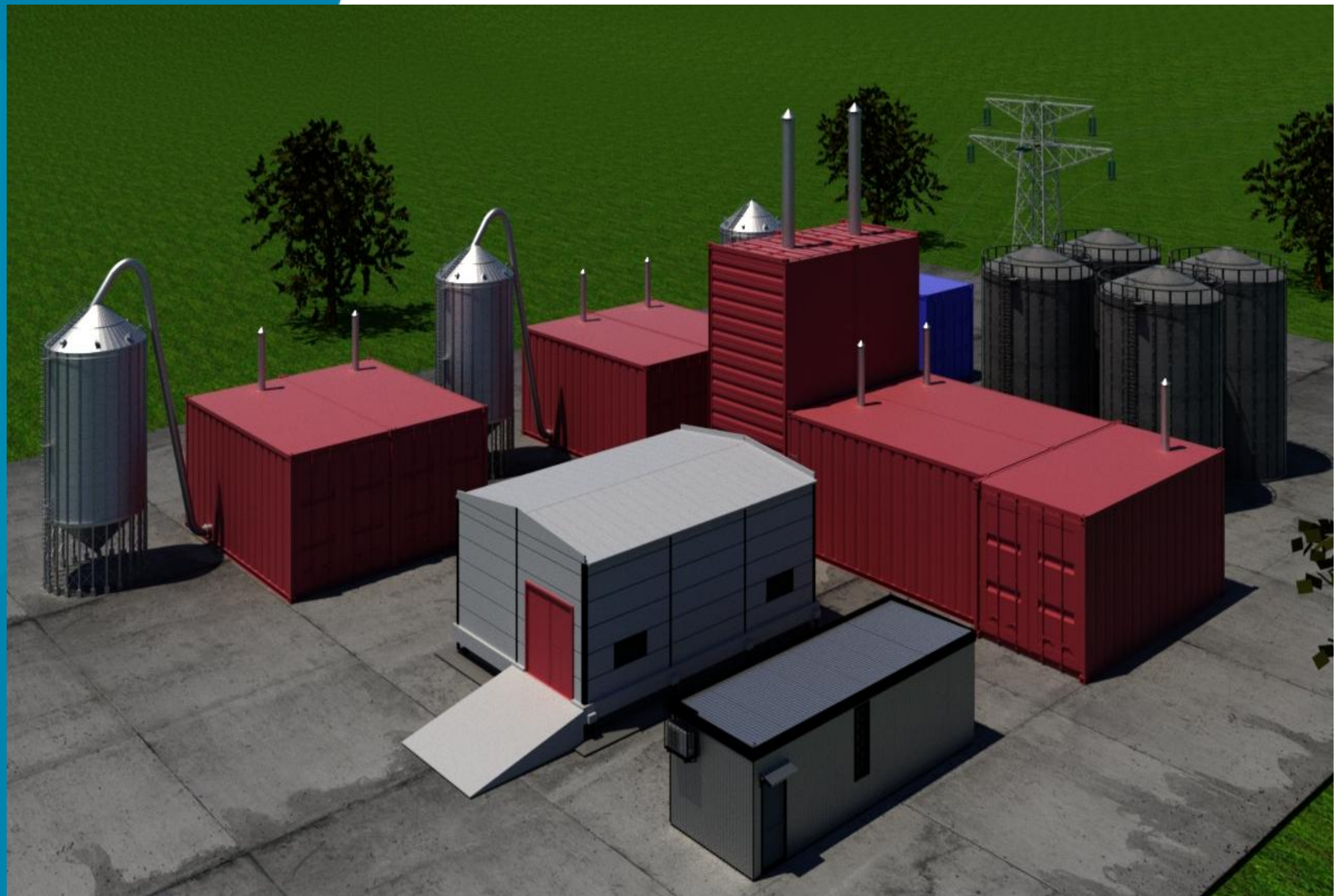
The package mainly consists of large-sized factory-preassembled modules whose dimensions are equal to 20ft sea containers. Some of the modules form a single space, while their frames are bolted one to another. A slab foundation is required to install the modules.

In addition to the process modules, the package includes storage tanks for the oil products, storage facilities (for coal, ash residue, ash residue conversion products (as an option), and sulfur), and a water tank. The infrastructure composition is agreed with the Customer, while the packages are set out at certain sites when designing field installation approach.

NPZ-DT500 Package Arrangement



NPZ-DT500 Package Arrangement



Yields of Petroleum Products. Key Specifications

Approximate yields for black and brown coals with about 43% ash content

Oil Production Stage

- Oil yields from brown coal and black coal is 36-52 (40)%;
- Yield of gases from brown coal is 5-16%;
- Yield of gases from black coal is 3-9%;
- The yield of mineral residue from brown and black coals is 98-104% of the dry mineral residue.

Oil Refining Stage (t)

- Diesel fuel yield from produced oil is 0.7
- Gasoline fraction yield from produced oil is 0.12
- Gasoline Ai92 yield from gasoline fraction is 0.96 (the rest covers propane-butane fractions)
- Fuel oil yield from produced oil is 0.14
- Gas yield from produced oil is 0.04
- Yield of low-viscosity marine fuel (marine gas oil) from produced fuel oil is 0.87 (the rest covers gases for in-plant combustion use)

Yields of Petroleum Products.
Key Specifications

Example of balance for the liquefaction and primary fractionation unit and the fractionation and cracking unit

Feedstock	Products
Liquefaction initial separation of liquefied products	
Total **2,16t** Coal **1t** Fuel oil **1t** including — Recycle bottoms from the fractionation and cracking unit for provisional previous liquefaction cycles –0.96t; — Bottoms formed from coal from the previous provisional cycle — 0.04t	Total **2.16t** Mineral residue **0.42t** Mix of liquid hydrocarbons **1.47** including — remained bottoms upon recycling 0.96 — bottom fraction formed from the coal of the current cycle 0.12t — diesel fraction 0.27 (including diesel fraction formed from recycle bottoms 0.035) — gasoline fraction 0.07 (including gasoline fraction formed from recycle bottoms 0.0012) — gases **0.12** (including gases formed from recycle bottoms 0.0038)
Water (including recycle water 0.15t) **0.16t**	Water **0.15**
Fractionation and cracking	
Total **1.47t** Mix of liquid hydrocarbons **1.47**	Total **1.47t** — Bottoms **1.04t** (including bottoms to recycle 1t, and bottoms to be realeased from the Package 0.04t) — Diesel **0.33t** (including straight-run one 0.22t and cracking 0.11t) Gasoline fraction **0.065t** (including straight-run one 0.041t and cracking 0.024t) Gases **0.035** (all from cracking)

Yields of Petroleum Products.
Key Specifications

Properties of gasoline fraction: IBP87-CC180C; other properties are not rated.

Properties of diesel fuel: sulfur content is not more than 50 ppm; the intended use is motor fuel. Lubricity, cetane number, and tar content are according to EN 590:2009 for summer diesel.

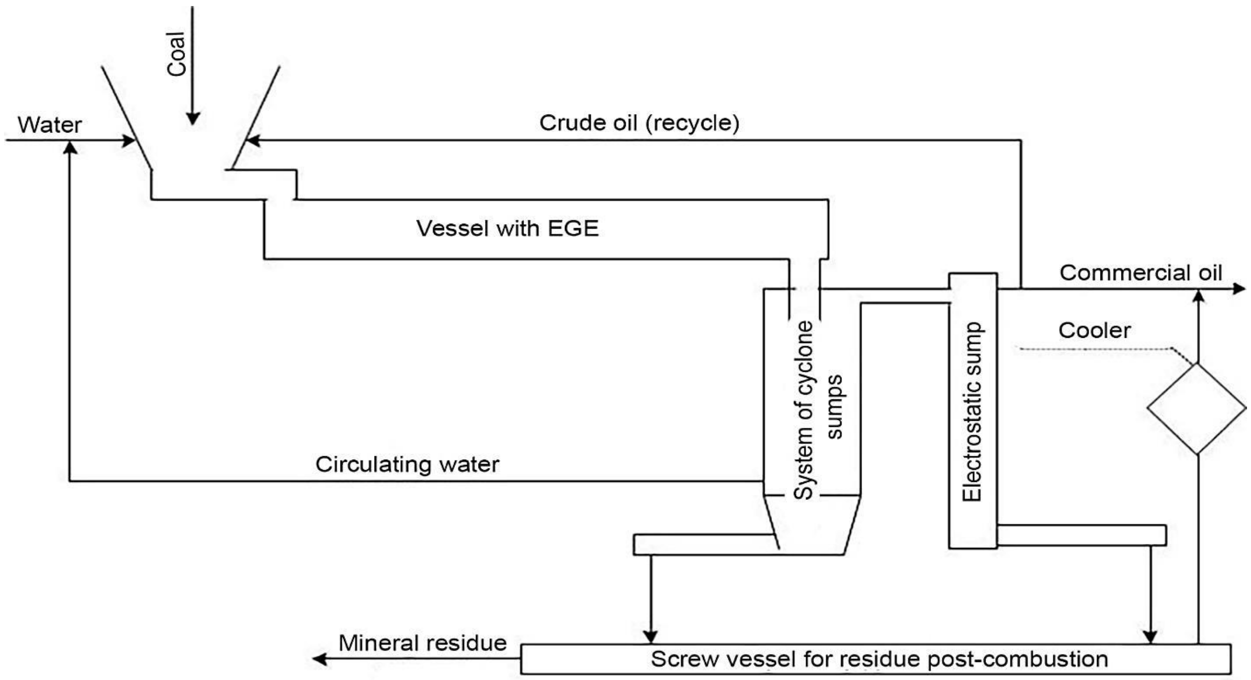
Properties of fuel oil: no-flow point is not higher than + 5°C. Coking ability is not more than 4%$ other parameters are not rated.

Properties of synthetic oil before its refining (Example)

Parameter	Value
Yields of fractions (%) boiled out up to temperature:	
- 200^0C	13,8
- 300^0C	34,7
- 350^0C	87,5

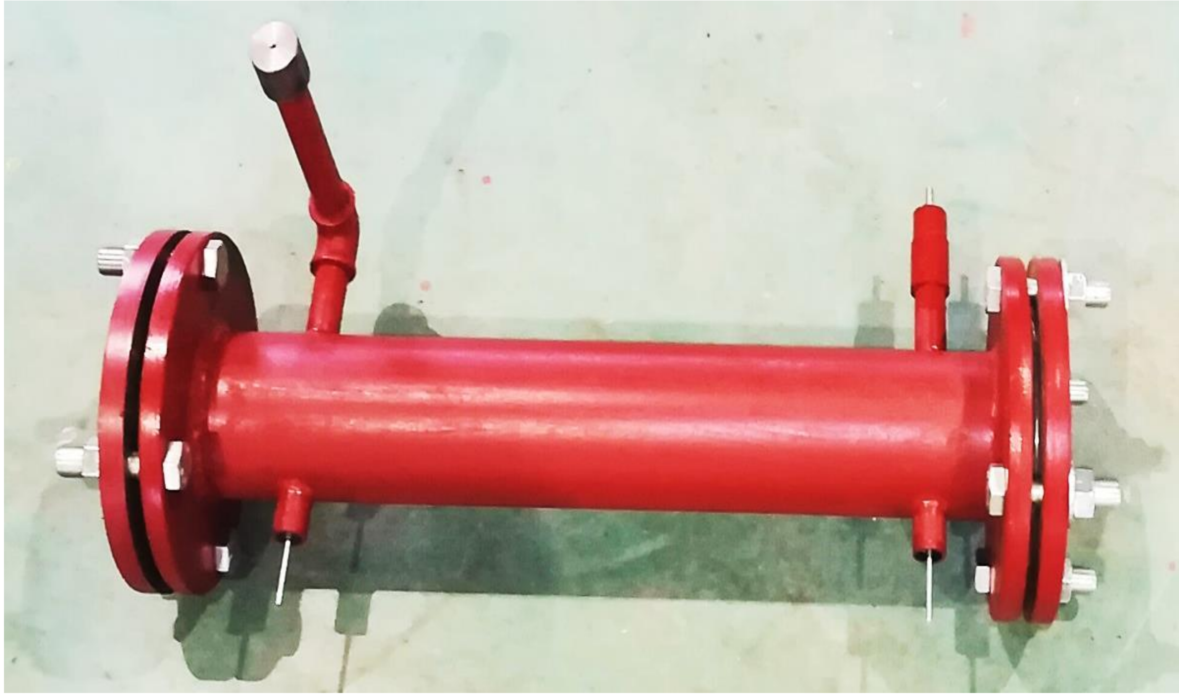
Coal Liquefaction
Module Solutions

Coal is liquefied due to the exposure of the mix of coal, water and black oil recycle to high-voltage electrical pulse discharges. The coal liquefaction module is connected
to the module designed for initial separation of liquefied products.



Coal Liquefaction
Module Solutions

The vessel consists of individual modular cells, the number of which depends on the required (design) capacity
of the vessel.



Coal Liquefaction
Module Solutions

The vessel design has a number of features such as:

Module Design is a way to unify the vessel design to switch over between various coal capacities and to simplify its maintenance and repair.

Multi-Discharge Electrode contributes to increasing discharge lengths at the same intensity, which is a way to reduce the power consumption for liquefaction due to the larger contact area between the discharge surface and raw materials and due to less loss of active particles for recombination.

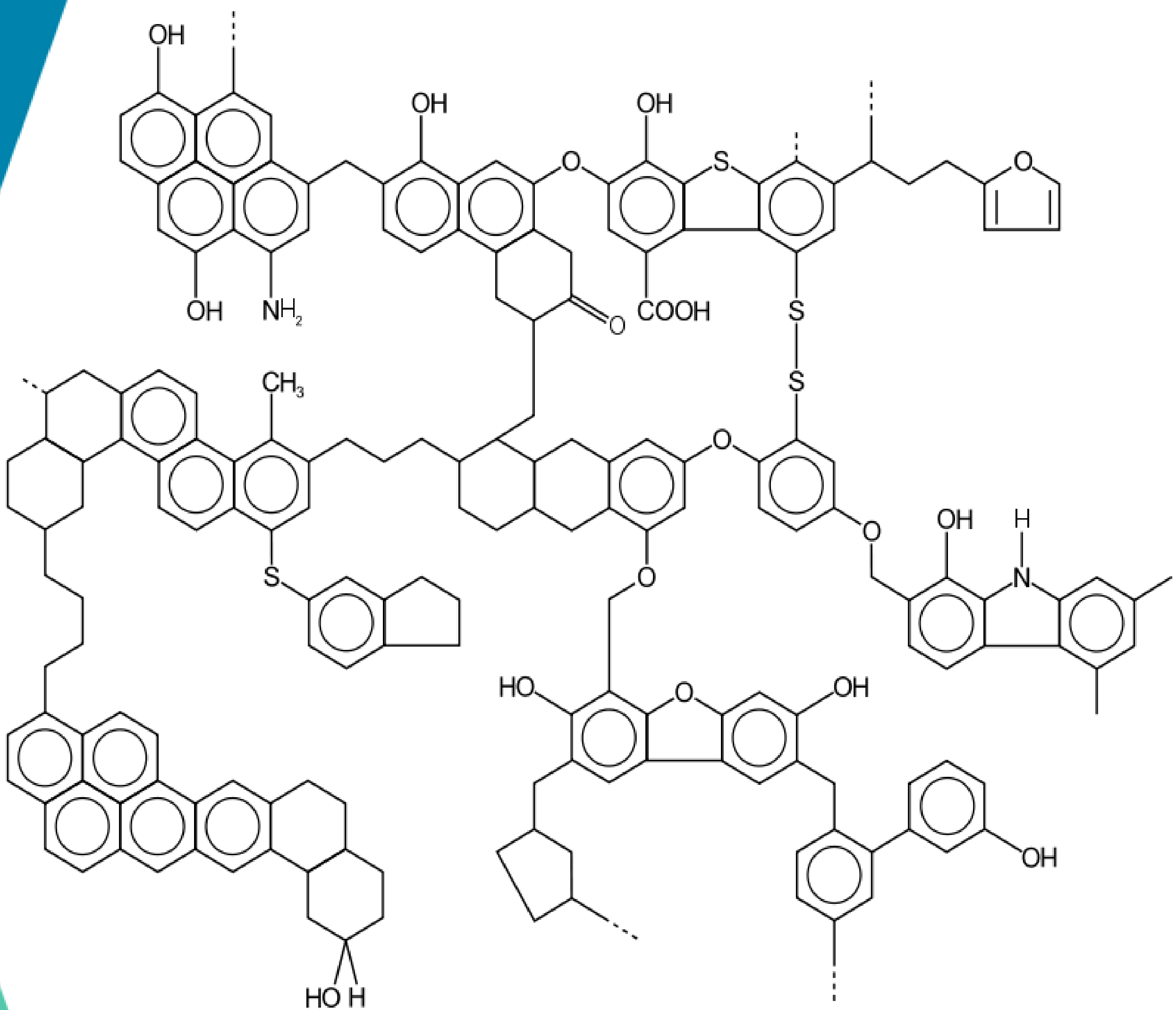
Gas Discharger Process Solutions

To generate a pulse discharge the circuit diagram should include a kind of discharger. There are two options: adding a discharger as a stand-alone element outside the vessel (vacuum discharge element) or placing it into a vessel compartment. The proper option depends on the vessel capacity. The first option is preferable when capacity is up to 3 tons per hour, the second one is when capacity is higher than 3 tons per hour. The approach significantly improves the energy performance of the process.

Coal Liquefaction

Module Solutions

Liquefaction Mechanism and Features



Organic matter of coal is represented mostly by solid polymers such as condensed conjugated compounds of cyclic and aromatic nature, interconnected by intermolecular interaction forces.

Coal Liquefaction

Module Solutions

Liquefaction Mechanism and Features

The liquefaction process requires reactions of depolymerization of the condensed substance and further hydrogenation of the depolymerization products. Being exposed to high-voltage pulse discharge, the mix of coal, organic solvent (still bottoms — high-boiling hydrocarbon fraction), and water demonstrates the following processes:

The substance is heated to hundreds of thousands of Kelvin degrees in the discharge channel, and then sudden expansion occurs. The sudden expansion of the substance provokes high pressures up to several thousand MPa inside the discharge channel and in the local area around. The result is emission of fast electrons along with formation of active particles, namely: fast electrons themselves (e) whose energy is more than 5 keV and whose lifetime is up to 400 μs;
and particles of radicals: *O, *H, *OH. The active particles interact with the solid organic coal substance due to the radical mechanism and electron impact mechanism, which results in formation of low-molecular liquid organic products.

Coal Liquefaction

Module Solutions

Liquefaction Mechanism and Features

Due to the rapid expansion of the substance inside the discharge channel, a shock wave arises, which, in turn, causes cavitation phenomena in the reaction mixture.
The cavitation is featured with formating of steam microcavities which is followed by rapid collapsing of such cavities. When collapsing the cavitation cavities, extremely high pressures and temperatures occur and a local part of the substance achieves the supercritical state. In turn, a certain amount of supercritical substance is prone to coal liquefaction without exposure to the active particles (e, *O, *H, *OH).

The provoked shock wave and relevant cavitation phenomena also resulted in the processes that are not parts of the organic coal liquefaction but contribute to it such as crushing, intensification of diffusion of the substance
of the reaction mixture towards the middle part of the coal particle and liquefied products and back

Coal Liquefaction

Module Solutions

Liquefaction Mechanism and Features

The key point in the coal liquefaction process is a liquid medium for passing high-voltage pulse discharges. A mixture of water and heavy hydrocarbons (bottoms) is the best option for such a medium.

<u>Water is required mainly for the following:</u>

Water delivers active radical particles: *O, *OH, *H. Oxygen radicals and the most long-living hydroxyl radical along with electron impact trigger the depolymerization of the organic coal substance, while atomic hydrogen is involved in
the hydrogenation reaction, including hydrogenating of low molecular weight compounds at the time of their formation.
Water is also required as a component of the supercritical fluid that is locally formed during the cavitation process.

Water significantly reduces the dielectric constant of the medium and facilitates high-voltage discharge in a fluid layer with particles of liquefied coal.

Coal Liquefaction

Module Solutions

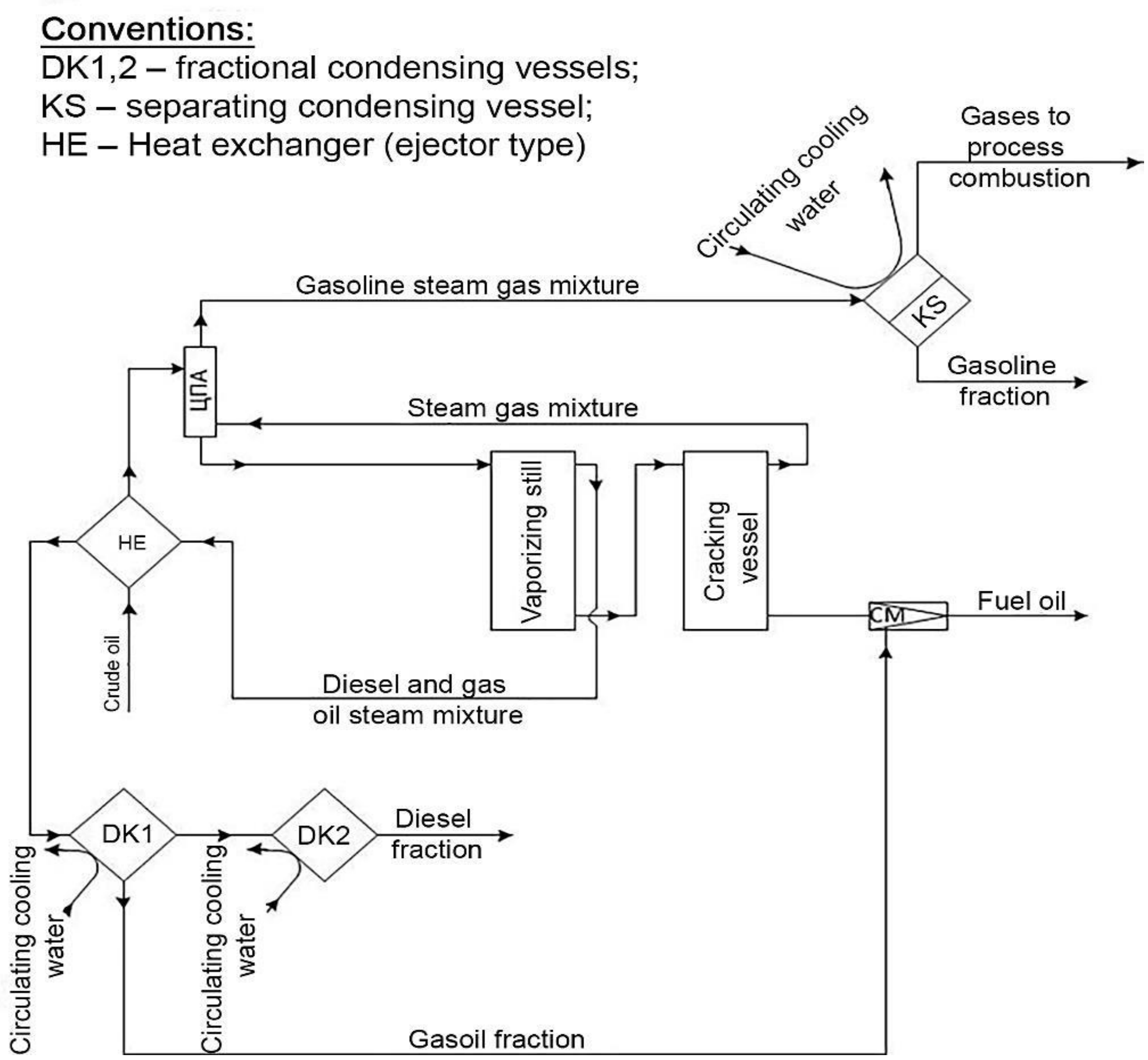
Liquefaction Mechanism and Features

<u>The role of heavy hydrocarbons is as follows:</u>

Heavy hydrocarbons are an additional source of hydrogen; their recycling ensures better H:C ratio for the produced products and minimizes the content of unsaturated compounds and tars that deteriorate motor fuels.

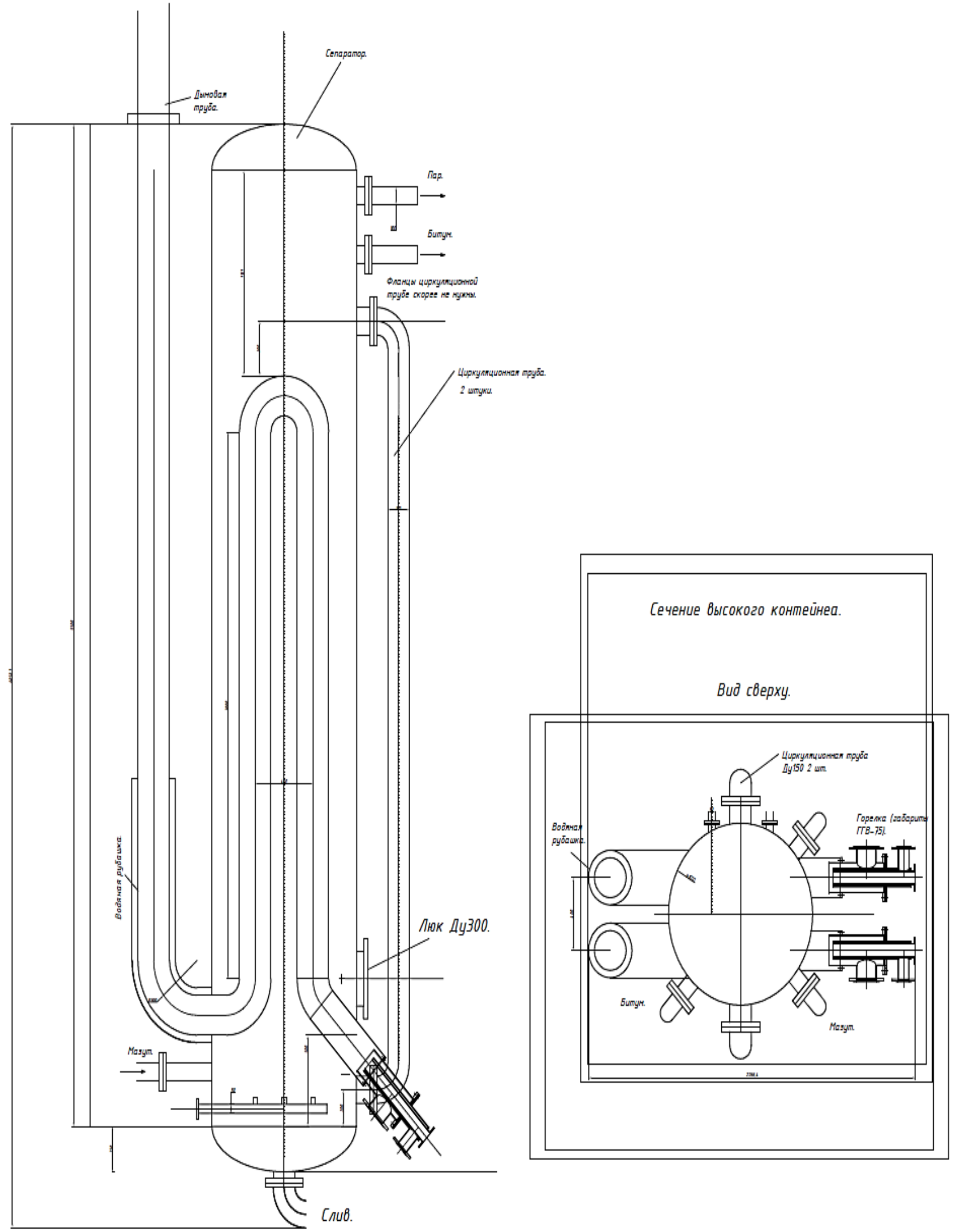
Heavy hydrocarbons, the same as water, act as a component of supercritical fluid that is locally formed due to cavitation. The liquefaction in the supercritical medium demonstrates the best performance in the presence of organic hydrocarbons and water; the process is possible only
in the water or hydrocarbon medium being
in a supercritical state.

Hydrocarbons Fractionation
Module Solutions

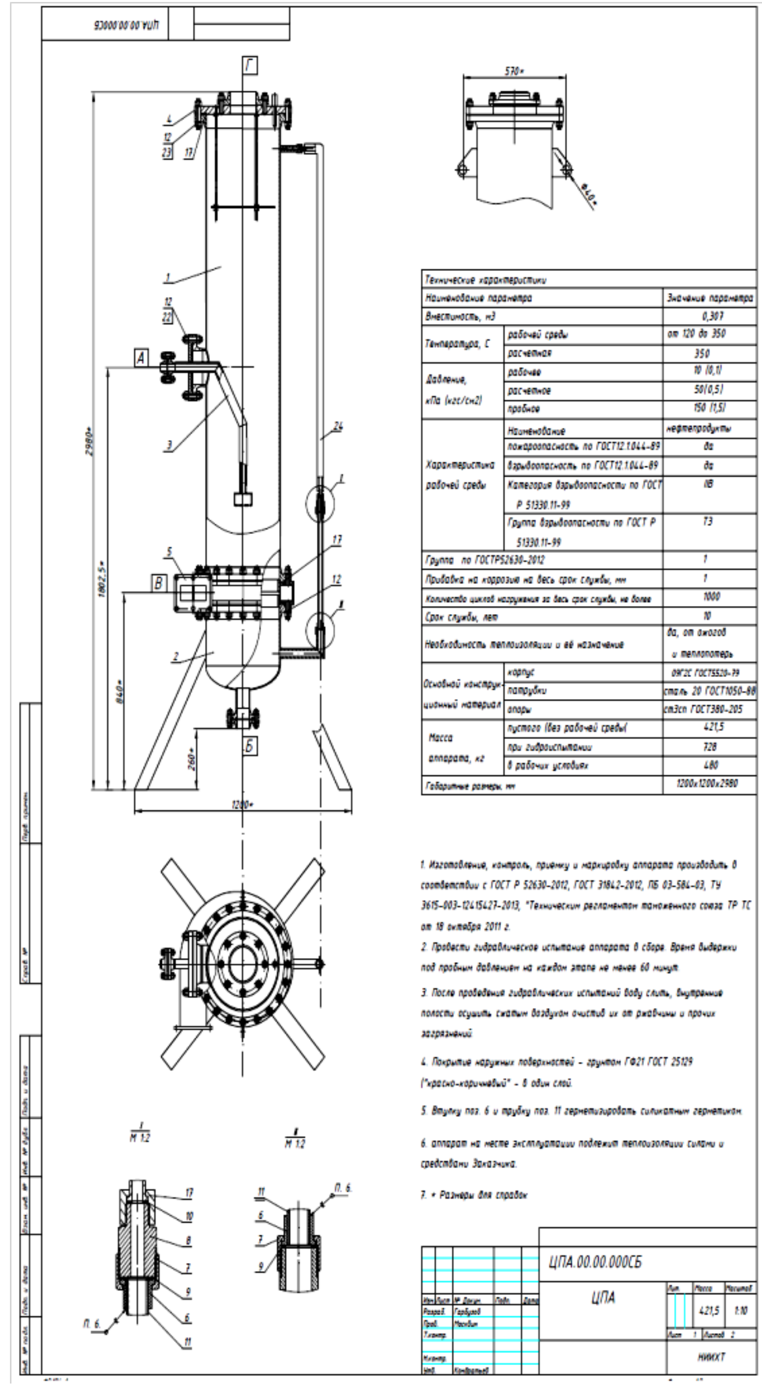


The hydrocarbons of produced synthetic oil is fractionated simultaneously with light visbreaking of the heaviest hydrocarbon fractions.

Hydrocarbons Fractionation
Module Solutions
Designs of Vessels



Hydrocarbons Fractionation
Module Solutions
Designs of Vessels



Pulse Hydrotreating of Diesel Fuel

Module Solutions

The pulse hydrotreating vessel consists of separate compartments whose structural design is similar to the liquefaction vessel compartments; the approach contributes to the equipment unification and simplifies its maintenance.

The vessel operation concept and process are as follows:

water with the raw materials are conveyed into the discharge chamber of the vessel, where the cavitation phenomena occurred due to the high-voltage discharge trigger water dispersion to the submicron level. The subsequent discharges invoke the following main processes in the raw materials
and water mixture:

Pulse Hydrotreating of Diesel Fuel

Module Solutions

Due to electron impact, UV radiation with a spectrum range of 16-270nm and, to a lesser extent, due to high temperatures, water is split as follows:

$$H_2O={}^{*}OH+{}^{*}H$$

The HO – H bond dissociation energy is 465 kJ/mol, which is
a bit greater than the dissociation energy for the H – H bond that is equal to 435 kJ/mol. The hydroxyl radical (*OH) oxidizes mainly a sulfur atom to form a sulfone molecule, which is followed by elimination of sulfur dioxide. Atomic hydrogen (*H) is involved in the treatment process by closing the hydrocarbon residues of the sulfone molecules. The high-voltage discharge passes along a route where the medium has the least resistance and dielectric constant. Thus, the discharge will tend firstly to pass through the microdroplets of water on its way through the inhomogeneous medium (the raw materials (hydrocarbons) plus water), which, first of all, results in the above described conversions.

Pulse Hydrotreating of Diesel Fuel

Module Solutions

Extremely high pressures in the spark channel area decompose sulfur-containing compounds at the C–S bond, since the dissociation energy for such a bond is 138 kJ/mol, which is less than the C–C and C–H bond energy values.
In addition, high pressures intensify hydrotreating processes.

The main factor of the electro-hydraulic effect is large emission into the space from the discharge channel of fast electrons, hard UV radiation, initial free radicals and ionized particles formed from the substance inside the discharge channel. The mechanical energy of the discharge (shock wave and cavitation of the discharge channel) is minimal, which is proved by tests involving various discharge pulse parameters; the higher the part of energy that is converted to radiation and not to mechanical energy, the higher is substance conversion.

Pulse Hydrotreating of Diesel Fuel

Module Solutions

Examples, balance yields of various products upon desulfurization

Properties of fuel oil before and after desulphuration. Mass Balance			
Input		**Output**	
Fuel oil M100 – 100%		Fuel oil M100 – 96,3%	
T, °C	% wt	T, °C	% wt
250-330	2,5	250-330	2,7
330-350	2,2	330-350	2,4
350-420	12,9	350-420	15,7
420-FBP	82,4	420-FBP	79,2
Sulfur content	2,5%	Sulfur content	0,08%
No-flow temperature	+6°C	No-flow temperature	+1°C

Pulse Hydrotreating of Diesel Fuel

Module Solutions

Examples, balance yields of various products upon desulfurization

Properties of diesel fraction before and after desulphuration. Mass Balance			
Input		**Output**	
Diesel fraction – 100%		Diesel fraction – 98.8%	
T, °C	% wt	T, °C	% wt
IBP	196	IBP	193
10	67	10	68
50	264	50	260
FBP	348	FBP	346
Sulfur content	0,12%	Sulfur content	8ppm
CN	50	CN	54
Pour point	-12,2°C	Pour point	-12,6°C

Pulse Hydrotreating of Diesel Fuel

Module Solutions

Examples, balance yields of various products upon desulfurization

Properties of gasoline fraction before and after desulphuration. Mass Balance			
Input		**Output**	
Gasoline fraction – 100%		Gasoline fraction – 99.1%	
T, °C	% wt	T, °C	% wt
IBP	36	IBP	35
10	68	10	67
50	112	50	115
90	178	90	179
FBP	215	FBP	212
Sulfur content	0,12%	Sulfur content	9ppm
Benzene content	2.3%	Benzene content	0.4%
ON	62	ON	61

Treatment of Sulfur-Containing Streams
Module Solutions

After desulfurization, sulfur is released as sulfur dioxide. Sulfur dioxide is recovered to elemental sulfur with cracking gases using one of the industrial commercial catalysts
such as Cu1-xMxCr2O4 (M-metal of the iron group).

$$SO_2+2H_2 = S+2H_2O$$
$$SO_2+2CO=S+2CO_2$$
$$2SO_2+CH_4=2S+CO_2+2H_2O$$

Option to Extract Other Minerals in the Course of Coal Processing

Depending on the composition, the mineral residue can be mixed with clay and roasted to produce natural cement.

Prior to processing the mineral residue into a mineral binder (natural cement) using additional modules (with electrochemical methods), various valuable inorganic components can be extracted.

Depending on the coal deposit, the content of such components is different and, first of all, should be evaluated. For example, brown coal at the Talovskoye deposit (Tomsk Region) contains: silver — 28 g/t — $ 1000/kg, scandium - 8.1 g/t — $ 20,000/kg, hafnium — 2.1 g/t, etc. (lanthanides — lanthanum, cerium, samarium, and europium).

Option to Extract Other Minerals in the Course of Coal Processing

As for liquefaction stage, Yutkin vessel can be equipped with modules to produce using non-reagent methods the following:

Montan wax — up to 8% (price in the market is up to $4000/t)

Option to Extract Other Minerals in the Course of Coal Processing

Humate-humic mixture is up to 2.7% (price in the market is up to $1000/t)