ELECTRIC SEPARATORS AND THEIR FIELD OF APPLICATION

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Recently, a dc electric field has been widely used abroad for refining distillates and petroleum end-products. Development of these processes has been accompanied by comparatively rapid improvement in the design of electric separators, which are the main equipment in refining installations. In the Soviet Union several institutes are currently developing Soviet electric separators. Experimental plants for refining fuels, lubricants, and paraffin wax are already in operation at several refineries.

The article briefly describes the electric separation process, the practical operation of electric separators, and the experience of the American firm "Petreco."

The operation of an electric separator is based on the electrophoresis effect in which an external dc electric field causes charged particles of the disperse phase to move towards one or the other electrode.

The principal advantage of electrophoretic refining of petroleum products is that the refining reagent can be finely dispersed in the petroleum product; the emulstion is converted to practically colloidal state in a mixer; it is then passed through an electric field which rapidly coagulates the dispersed particles which settle by gravity. The effectiveness of the process largely depends on the fineness of the emulsion.

Indeed, in the mixer the reagent is broken down into very fine drops; the area of contact between reagent and petroleum product is very great, so that reaction is rapid and reagent is used economically. On the other hand, very fine particles take longer to coagulate than larger particles, and this reduces throughput [1].

Accordingly, in each particular case the optimal dispersion is that which combines adequate throughput with economy of reagent.

Let us briefly consider the electrical properties of heterogeneous systems. All electrokinetic effects in colloidal solutions, including electrophoresis, depend on the charges of the dispersed and dispersing phase being of opposite sign. During electrophoresis, colloidal particles become charged because a double electric layer is present on their surface. When an external electric field is superposed on the field of the double electric layer the mycelle ceases to be electrically neutral and conditions become suitable for electrophoresis.

On the surfaces of the nuclei the external electric field induces charges which were formerly bound together; ions and counter ions move relative to one another in the direction of the applied field; part of the counter ions in the diffusion layer become separated from the system and move towards the electrode of opposite sign.

Under these conditions negatively charged particles of the dispersed phase start to move towards the positive electrode, and the counter ions of the diffusion layer move towards the negative electrode; and only part of the counter ions which are held in the "closely adjacent layer" by comparatively strong electrical and adsorption forces move together with them.

If the disperse phase is positively charged its particles move towards the negative electrode and the counter ions towards the positive electrode.

The electrophoretic transfer rate is given by Smolukhovskii's equation [2]

$$v = \frac{\xi \cdot \varepsilon \cdot E}{4\pi\eta L \cdot 300^2},$$

where v is the electrophoretic speed, cm/sec; ξ is the zeta-potential, V; E is the voltage applied to the electrode;
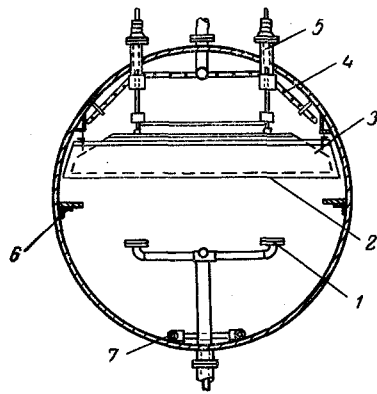
Fig. 1   Fig. 2

Fig. 1. Cross section through horizontal electric separator with plate electrodes:
1) distributor; 2) negative electrode; 3) positive electrode; 4) upper mother
liquor; 5) insulator chamber; 6) guide plates; 7) collector for extraction of
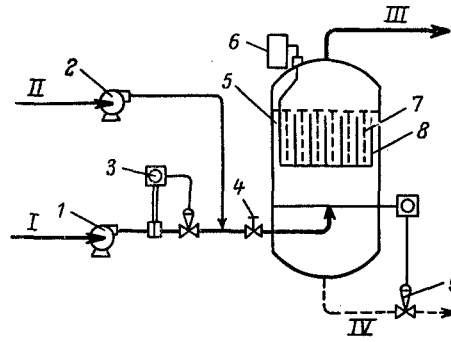heavy phase.

Fig. 2. Schematic diagram of single-stage electric separator: 1, 2) pumps; 3)
flow regulator; 4) mixer; 5) electric separator; 6) rectifier; 7) earthed elec-
trode; 8) positive electrode; 9) interphase level regulator; I) unrefined distil-
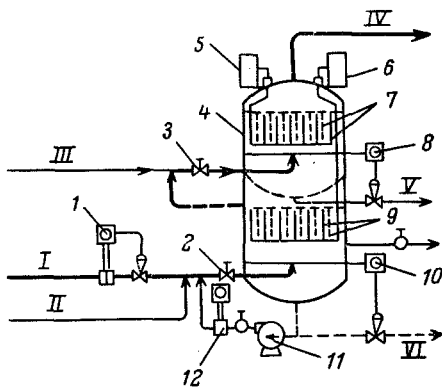late; II) reagent; III) refined distillate; IV) used reagent.

Fig. 3. Schematic diagram of two-stage
electric separator: 1) flow regulator; 2)
first stage mixer; 3) second stage mixer;
4) electric separator; 5) second stage rec-
tifier; 6) first stage rectifier; 7) second
stage electrodes; 8) second stage inter-
phase level regulator; 9) first stage elec-
trodes; 10) first stage interphase level
regulator; 11) circulating pump; 12)
flow regulator; I) unrefined product; II)
fresh reagent; III) washing water inlet;
IV) refined distillate; V) separated water;
VI) used reagent.

V; L is the distance between neighboring components of electrodes
of different polarity, cm; η is the viscosity of the medium, kg ·
sec/m^2; ε is the permittivity of the medium.

The first layer forms on the surface of the particles by selec-
tive adsorption on the boundary of phase separation of one of the
ions that is present in the system. As the dispersed particles are of
identical nature and always adsorb a particular ion they all acquire
a charge of the same sign.

A particle together with ions, which are called potential-
forming ions, uniformly adsorbed on its surface forms a nucleus.
The nucleus has either positive or negative charge, depending on
the sign of the adsorbed ions.

Part of the counter ions contained in the disperse phase to-
gether with the potential-forming ions form the so-called "closely
adjacent layer." The remaining counter ions are diffused through-
out the dispersing medium.

This complex, called a mycelle, remains electrically neutral
because the total charges of potential-forming ions on the surfaces
of the nucleus and of the corresponding counter ions in the disperse
medium are the same. It should be emphasized that the presence
of charges in a double electric layer is a property of the particular
solution and does not depend on the external electric field.

Now consider the influence of an external electric field on
an individual drop. The electrophoretic velocity can be expressed
in terms of the external field strength:

$$v = \frac{\xi \cdot \varepsilon \cdot H}{4 \pi \eta \cdot 300^2},$$

where H is the field strength, equal to E/L, V/cm.

By increasing or reducing the voltage applied to the electric separator we can produce the required electro-
phoretic velocity and so alter the throughput. Hence it follows that electric separators should be equipped with rec-

TABLE 1. Operating Conditions of Electric Separators on a Refinery

Notation, on diagram (Fig. 4)	Distillate	Type of refining and concentration of reagent	Refining operation	Temperature, °C	Volume of reagent recirculated
a, c	Straight run gasoline or naphtha	NaOH from 10 to 20° Baume	Removal of H_2S	27-38	5-10% by volume
b, d	The same	Used acid after alkylation, NaOH 5° Baume	Removal of sulfur	28-38	15% by volume NaOH
g	Kerosene	The same	Removal of mercaptan sulfur, color improvement	28-49	15% by volume NaOH
e, f, h	Diesel fuel, jet fuel, kerosene	NaOH from 3 to 7° for naphthenic acid and up to 20° Baume for H_2S	Removal of naphthenic acids and H_2S	49-54	None for naphthenic acids, 10% by volume for H_2S
i	Gas oil	Used after alkylation, NaOH 5° Baume	Removal of metals	49-54	NaOH 15% by volume

tifiers with a wide range of controlled output voltage. For example, electric separators of Giproneftmesh design are equipped with rectifiers type VTM-8/30, and the rectified voltage can be smoothly varied in the range 8-30 kV.

In addition to the charge that is induced by the external electric field, particles of the dispersed phase may acquire their own charge, for example by contact with a metallic electrode. The charge is given approximately by the formula [3]

$$q \approx 1,4 \cdot H \cdot r^2,$$

where H is the strength of the external electric field; r is the particle radius.

In this case the recharged particles begin to move at high speed to the opposite electrode and collide with other particles on the way. If the colliding particles have sufficient kinetic energy to overcome the potential barrier due to their protective envelopes, the envelopes break down at the point of contact and the particles join together.

In the last fifteen years the "Petreco" company and a number of foreign manufacturers have suggested and constructed numerous designs of horizontal and vertical electric separators with plate, concentric chamber, and other types of electrodes.

A cross section through a horizontal electric separator with plate electrodes located in the upper part of the equipment perpendicular to its longitudinal axis is shown in Fig. 1.* The individual flows of emulsion are treated in the electric field between each pair of plates of positive and negative (earthed) electrodes.

A schematic diagram of a single-stage vertical electric separator is shown in Fig. 2. Unrefined distillate and reagent in the required proportions are passed through a mixer in which they are emulsified to the required fineness and the refining reaction takes place. The emulsion is then admitted to the separator through the lower distributor and flows uniformly upwards to the electrodes, each of which is a set of concentric shells. An electric field which treats the rising flow of emulsion is applied between successive positive and negative electrode shells. The positive shells are all connected through a bushing to the appropriate pole of the rectifier, and the negative shells are earthed to the equipment frame.

Accordingly, in this separator the emulsion is treated in individual small parallel flows in electric fields formed by pairs of electrodes of opposite sign. For treating light petroleum products the electrodes are 100 mm

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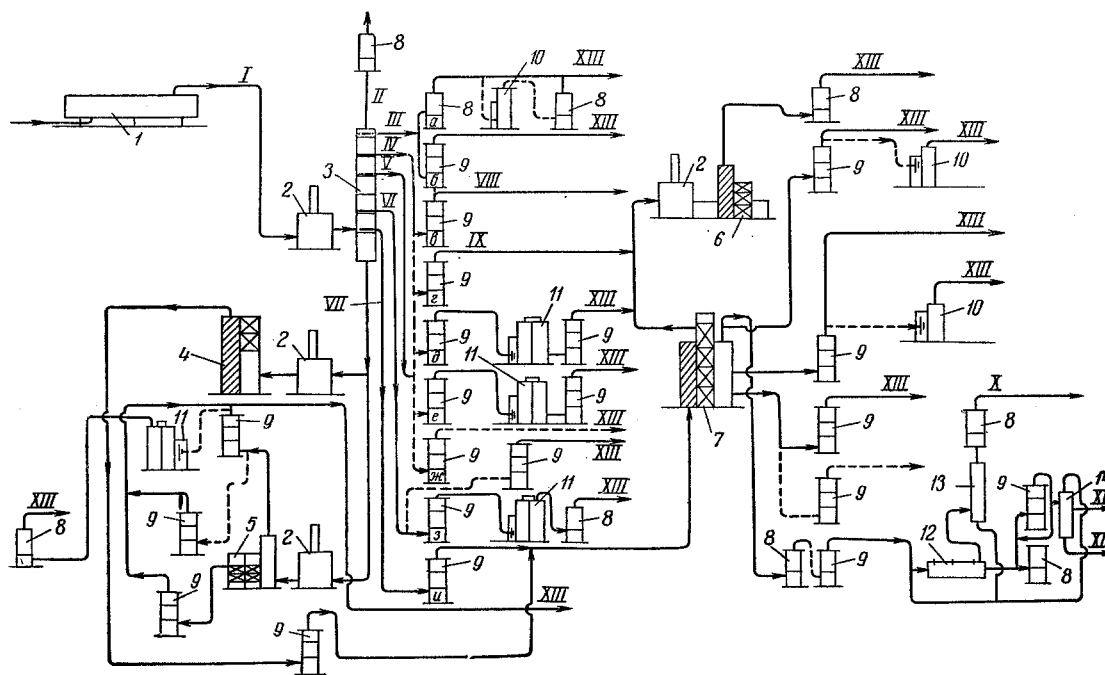* USA Patent No. 2,976,228 (March 21, 1961).

Fig. 4. Diagram of possible application of electric separator in a modern refinery: 1) electric dehydrator, or thermal-chemical settler; 2) furnace; 3) atmospheric distillation column; 4) vacuum distillation column; 5) thermal cracking; 6) reforming; 7) catalytic cracking; 8) single-stage electric separator; 9) two-stage electric separator; 10, 11) desulfurizing plants for light petroleum products (two different designs); 12) alkylation reactor; 13) depropanizer; 14) deisobutanizer. See Table 1 for notation of letters on electric separators. Streams: I) desulfurized crude; II) propane, butane; III) gasoline; IV) naphtha; V) kerosene; VI) diesel fuel; VII) gas oil; VIII) feed for reforming or to tank farm; IX) feed for reforming; X) propane for petrochemical production or to tank farm; XI) butane to tank farm; XII) alkylate to tank farm; XIII) to tank farm.

apart. The electric field breaks the emulsion into clearly defined phases by agglomerating fine particles of reagent into larger ones which are then precipitated.

The used reagent, free from distillate, is drained from the lower part of the equipment, and the refined distillate, free from reagent, is removed from the top of the equipment.

A schematic diagram of a two-stage electric separator working on the same principle is shown in Fig. 3.

In recent years designs of horizontal and vertical electric separators with vertical electrode chambers have been proposed. The chambers (of various shapes, round, square, hexagonal, etc.) are earthed and form the negative electrode. The positive electrode is formed by rods in the center of the chamber, which are connected together at top and bottom. According to published data these electric separators have very high throughput.

A special feature of electric refining processes is that they are continuous and very efficient. The principal advantages are: 1) the equipment is smaller than natural settlers; 2) smaller equipment saves space; 3) specific reagent cost is lower because mixing is thorough and surface of contact is large; 4) the finished petroleum product is free of reagent; 5) no petroleum product is lost with the used reagent; 6) the process is compeletely automatic and needs less staff; 7) labor conditions are better.

For electric separators to operate efficiently they should be equipped with flow regulators which automatically adjust emulsion residence times in the mixer and in the electric field, mixers which automatically control emulsion fineness, rectifiers which can vary the electric field strength over a wide range, interphase level regulators which automatically maintain the heavy phase at a set level, fluid level regulators which automatically disconnect electric power if gas collects in the top of the apparatus, and other instruments.

On the other hand, in refining any particular petroleum product the technological rules in respect to reagent quality, concentration, temperature, time, etc., must be strictly observed. These requirements should be worked out on pilot plants in research institutes.

Electric separators are now used with almost all petroleum products. Figure 4 shows a possible scheme of application of a refining plant, and Table 1 gives certain operating conditions.*

LITERATURE CITED

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3. G. M. Panchenkov and L. K. Tsabek, Zh. Fiz. Khim., 13, No. 9 (1968).

* From Leaflet No. 77001 of the Petreco Co.