ORGANIZATION OF MATERIAL AND ENERGY FLOWS BY DIRECTED GRAPH METHODS IN PRODUCTION OF LUBRICATING OILS

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The assigned task of the present work has been the use of a directed flow graph method to select the uniquely possible optimal hydrodynamic and temperature regimes for the operation of different items of apparatus included in a processing scheme.* The optimality criteria that were chosen were minima in the material (G, L) and energy (H) consumptions.

In accordance with the graph method, we obtained the tree of the graph (Figs. 1 and 2), the number of recycles, the rank of the graphs, the number of arcs, the number of unconstrained independent variables, and the cyclomatic matrix [1].

As a result of calculating the process parameters in accordance with the cyclomatic matrix, it became possible to make an optimal selection of (m-n) unconstrained variables, where m is the number of process parameters and n is the number of equations. The independent variables were selected by a bipartite graph method [2, 3], whereupon it became possible to obtain the following numerical values:

a) For the material independent flows:

$$L_1 = 18 \text{ m}^3/\text{h}; \quad G_3 = 0{,}5 \text{ m}^3/\text{h};$$
$$L_2 = 19 \text{ m}^3/\text{h}; \quad G_4 = 4{,}5 \text{ m}^3/\text{h};$$
$$L_5 = 1{,}3 \text{ m}^3/\text{h}; \quad G_8 = 1 \text{ m}^3/\text{h};$$
$$L_8 = 38{,}4 \text{ m}^3/\text{h}; \quad G_9 = 0{,}65 \text{ m}^3/\text{h};$$
$$L_9 = 1{,}26 \text{ m}^3/\text{h}; \quad T_2 = 3{,}3 \text{ m}^3/\text{h};$$
$$G_2 = 0{,}7 \text{ m}^3/\text{h}; \quad T_3 = 34 \text{ m}^3/\text{h}.$$

b) For the energy dependent flows:

$$H_1 = 324\,000 \text{ kcal/h}; \quad H_{18} = 118\,000 \text{ kcal/h};$$
$$H_2 = 890\,000 \text{ kcal/h}; \quad H_{19} = 162\,000 \text{ kcal/h};$$
$$H_3 = 1\,010\,000 \text{ kcal/h}; \quad H_{20} = 240\,000 \text{ kcal/h};$$
$$H_5 = 695\,000 \text{ kcal/h}; \quad H_{22} = 45\,500 \text{ kcal/h};$$
$$H_6 = 1\,190\,000 \text{ kcal/h}; \quad H_{23} = 187\,000 \text{ kcal/h};$$
$$H_7 = 2\,225\,000 \text{ kcal/h}; \quad H_{24} = 57\,000 \text{ kcal/h};$$
$$H_8 = 1\,480\,000 \text{ kcal/h}; \quad H_{26} = 1\,550\,000 \text{ kcal/h};$$
$$H_{10} = 142\,000 \text{ kcal/h}; \quad H_{30} = 1\,575\,000 \text{ kcal/h};$$
$$H_{11} = 77\,500 \text{ kcal/h}; \quad H_{31} = 1\,940\,000 \text{ kcal/h};$$
$$H_{13} = 5\,450\,000 \text{ kcal/h}; \quad H_{33} = 92\,000 \text{ kcal/h};$$
$$H_{14} = 680\,000 \text{ kcal/h}; \quad H_{35} = 55\,000 \text{ kcal/h};$$
$$H_{16} = 85\,000 \text{ kcal/h}; \quad H_{37} = 210\,000 \text{ kcal/h};$$
$$H_{17} = 84\,000 \text{ kcal/h}; \quad H_{38} = 260\,000 \text{ kcal/h}.$$

For the commercial object of this investigation, the amount of raffinate obtained (L_{11}) amounts to 12.46 m^3/h; the amount of extract (L_{12}) is 4.95 m^3/h; the takeoff of water (G_7) is 2.24 m^3/h; the quantity of raffinate solution (L_3) leaving the extractor K-2 is 15.9 m^3/h; the quantity of raffinate with low phenol content (L_4) entering the stripping tower K-4 is 13.56 m^3/h (including 0.676 m^3/h phenol); the quantity of extract solution (L_6) passing from the drying tower K-6 to the extraction tower K-5 is 35.7 m^3/h; the quantity of extract (L_7) with low phenol content passing from

*N. I. Chernozhukov, Technology of Petroleum and Gas Processing [in Russian], Part 3 (1967), p. 135.

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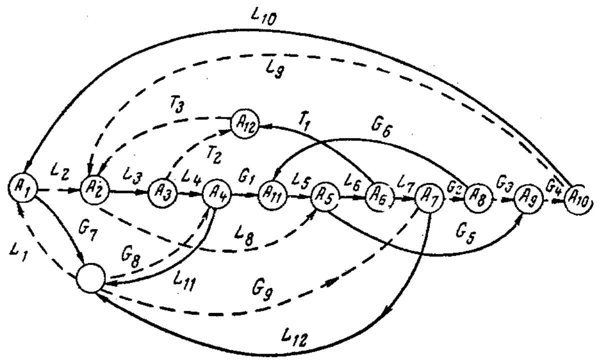

Fig. 1

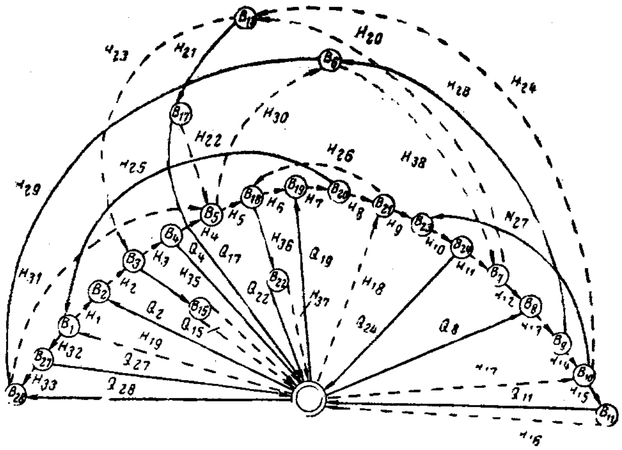

Fig. 2

Fig. 1. Graphical representation of material flow paths: A_1 – absorber K-1; A_2 – extractor K-2; A_3 – vaporizer tower K-3; A_4 – stripping tower K-4; A_5 – drying tower K-5; A_6 – extraction tower K-6; A_7 – stripping tower K-7; A_8 – point of mixing C_1; A_9 – point of separating C_2; A_{10} – point of mixing C_3; A_{11} – point of separating C_4; A_{12} – dry phenol storage E_4; L_1 – feedstock; L_2 – phenol-containing feedstock after K-1; L_3 – raffinate solution after K-2; L_4 – raffinate with small amount of phenol entering K-4; L_5 – mixture of phenol and water entering K-5; L_6 – solution of extract with major part of phenol entering K-6; L_7 – extract with small content of phenol entering K-7; L_8 – solution of extract passing from K-2 to K-5; L_9 – phenolic water entering K-2; L_{10} – vapors of phenol and water entering K-1; L_{11} – raffinate; L_{12} – extract; G_1 – mixture of phenol and water leaving K-4; G_2 – mixture of phenol and water leaving K-7; G_3 – mixture of phenol and water entering C_2 from K-7; G_4 – mixture of phenol and water entering C_3; G_5 – uncondensed vapors and gases together with azeotropic mixture of vapors leaving K-5; G_6 – mixture of phenol and water vapors (recalculated as liquid); G_7 – water from K-1; G_8 – vapors entering K-4; G_9 – vapors entering K-7; T_1 – phenol leaving K-6 and entering E-4; T_2 – phenol entering E-4 from K-3; T_3 – phenol entering K-2.

Fig. 2. Graphical representation of energy flows: B_3 – absorber K-1; B_5 – extractor K-2; B_7 – drying tower K-5; B_9 – extraction tower K-6; B_{10} – stripping tower K-7; B_{20} – vaporizer tower K-3; B_{21} – stripping tower K-4; B_{13} (C_2), B_{23} (C_4) – points of separation; B_{18} (T-6), B_1 (T-1), B_6 (T-10) – heat exchangers; B_4(T-4), B_{22}(T-7), B_{15}(T-9), B_{27}(T-8), B_{24}(T-12), B_{17}(T-13), B_{11}(T-14) – coolers; B_2(T-2), B_{28}(T-5) – steam heaters; B_{13}(C_2), B_{23}(C_4) – points of mixing; B_{19}(F-1), B_8(F-2) – furnaces; H_1 – heat in feedstock after T-1; H_2 – heat in feedstock after steam heater T-2; H_3 – heat in phenol-containing feedstock after absorber K-1; H_4 – heat in phenol-containing feedstock entering extractor K-2; H_5 – heat contained in raffinate solution leaving extractor K-2; H_6 – heat in raffinate solution after heat exchanger T-6; H_7 – heat in raffinate solution entering vaporizer tower K-3; H_8 – heat transferred by raffinate solution from vaporizer tower K-3 to stripping tower K-4; H_9 – heat of phenol and water passing to point of mixing C_4 from stripping tower K-4; H_{10} – heat of phenol–water mixture entering cooler T-12; H_{11} – heat of phenol–water mixture entering drying tower K-5; H_{12} – heat of extract solution leaving drying tower K-5; H_{13} – heat of extract solution entering extraction tower K-6; H_{14} – heat of extract entering stripping tower K-7; H_{15} – heat of extract leaving stripping tower K-7; H_{16} – heat of extract; H_{17}, H_{18} – heat of vapor entering stripping towers K-7 and K-4; H_{19} – heat of feedstock entering treatment; H_{20} – heat of mixture of vapor and gases leaving drying tower K-5; H_{21} – heat of stream from mixing point C_2 to cooler T-13; H_{22} – heat contained in phenolic water entering extractor K-2; H_{23} – heat of phenol and water vapors entering absorber K-9; H_{24} – heat passing from K-7 to C_2; H_{25} – heat contained in phenol vapor leaving vaporizer tower K-3; H_{26} – heat in raffinate leaving stripping tower K-4; H_{27} – heat passing from K-7 to C_4; H_{28} – heat in phenol vapors leaving extraction tower K-6; H_{29} – heat in phenol after T-10; H_{30} – heat contained in extract solution leaving extractor K-2; H_{31} – heat in phenol entering extractor K-2; H_{32} – heat contained in phenol after T-1; H_{33} – heat contained in phenol after cooler T-8; H_{34} – heat in water vapors leaving absorber K-1; H_{35} – heat in waste water; H_{36}, H_{37} – heat contained in raffinate before and after cooler T-7; H_{38} – heat contained in extract solution entering drying tower K-5; Q_8, Q_{19} – heat obtained by material streams in furnaces F-2 and F-9, respectively; Q_2, Q_{28} – heat obtained by material streams in steam heaters T-2 and T-5, respectively; Q_4, Q_{11}, Q_{17}, Q_{15}, Q_{27}, Q_{22}, Q_{24} – heat given up by material streams in coolers T-4, T-14, T-13, T-9, T-8, T-7, and T-12, respectively.

the extraction tower K-6 to the stripping tower K-7 is 5 m^3/h; the quantity of phenol and water vapors recalculated as liquid (L_{10}) entering the absorber K-1 is 3.11 m^3/h; the quantity of phenol–water mixture (G_1) leaving the stripping tower K-4 is 1.1 m^3/h; the quantity of uncondensed vapors and gases together with the azeotropic mixture of vapors (G_5) leaving the drying tower K-5 is 0.95 m^3/h (recalculated as liquid); the quantity of mixed phenol and water vapors (G_6) is 0.2 m^3/h (recalculated as liquid); and the quantity of phenol (T_1) passing to storage E_4 from the extraction tower K-6 is 30.7 m^3/h.

By means of the energy flow graph, all of the required heat flows of this process were calculated:

$H_4 = 390\,500$ kcal/h; $H_{29} = 3\,710\,000$ kcal/h;
$H_9 = 48\,000$ kcal/h; $H_{32} = 583\,000$ kcal/h;
$H_{12} = 2\,487\,500$ kcal/h; $H_{34} = 67\,000$ kcal/h;
$H_{15} = 495\,000$ kcal/h; $H_{36} = 67\,000$ kcal/h;
$H_{21} = 110\,000$ kcal/h; $Q_2 = 566\,000$ kcal/h;
$H_{25} = 745\,000$ kcal/h; $Q_4 = 6\,195\,000$ kcal/h;
$H_{27} = 94\,000$ kcal/h; $Q_8 = 2\,912\,500$ kcal/h;
$H_{28} = 5\,465\,000$ kcal/h; $Q_{11} = 442\,000$ kcal/h;

$Q_{17} = 64\,500$ kcal/h; $Q_{28} = 1\,764\,200$ kcal/h;
$Q_{19} = 1\,035\,000$ kcal/h; $Q_{24} = 64\,500$ kcal/h;
$Q_{15} = 72\,000$ kcal/h; $Q_{22} = 845\,000$ kcal/h.
$Q_{27} = 491\,000$ kcal/h;

From the quantities of heat that the material streams obtained in the heaters and gave up in the coolers, it became possible to calculate the water consumption in the coolers and the amounts of fuel or steam in the heaters that are required to maintain the optimal course of the process.

Assuming that the water temperature rises 15°C across the coolers, the water consumption rates can be calculated.

For the coolers, the water consumption is as follows: T-4 – 41.4 m^3/h, T-7 – 56.3 m^3/h, T-8 – 32.8 m^3/h, T-9 – 4.8 m^3/h, T-12 – 4.3 m^3/h, T-13 – 4.3 m^3/h, and T-14 – 29.5 m^3/h. The quantity of steam (pressure 1 kg/cm^2 and temperature 120°C) supplied to the heaters will be 566 m^3/h for T-2 and 1764.2 m^3/h for T-5.

The quantity of residual fuel oil burned in the furnaces is 29.1 kg/h for F-2 and 10.4 kg/h for F-1.

SUMMARY

1. A directed flow graph method has been used to set up a mathematical description of a process, calculating all optimal values of material and heat parameters of the process.

2. The required consumptions of water, fuel, and steam have been calculated for optimal processing, which opens up the possibility of a 25% increase in the yield of desired product (with residual feedstock).

3. It has been noted that variations in the amount of feedstock supplied to the extraction tower have little influence on the operation of the coolers or heaters in this process flow plan.

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