OPTIMIZATION OF THERMAL LIQUIDATION PARAMETERS AND KINETIC MODELING OF THE PROCESS OF DELAYED COKING OF OIL RESIDUES

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Abstract. *This work investigates mechanisms for increasing the efficiency of delayed coking technology, which is a destructive-thermal process of deep oil refining. The main goal of the study is to scientifically substantiate the relationship between the dispersed state of the raw material and the kinetics of polycondensation of asphaltene-resin compounds, as well as to develop a mathematical model of the process. The kinetic patterns of coke yield and gas formation were approximated using the linear regression method depending on the degree of coke formation (K) of the raw material. The developed mathematical model and the identified kinetic parameters allow for high-precision forecasting in the design of slow-cooking units, the modernization of existing ones, and the automatic control of technological modes. The research findings are of strategic importance in increasing the productivity of energy resources through the deep processing of oil residues.*

Keywords: *delayed coking, deep oil rafining, thermochemical mechanism, kinetic dependence, tar, oil residues, asphaltene-resin compounds, distillate product regression equation.*

Introduction

In deep oil refining technology, the delayed coking process relies on thermochemical mechanisms for the formation of coke and distillate products. The efficiency of this process is determined by the dispersed state of the raw material and the kinetics of the condensation of asphaltene-resin compounds within it. The general equation of the coking process can be expressed as follows.

$$Raw\ material \xrightarrow{k_1} Steam + Gaz + Coke \quad (1)$$

The empirical mathematical model of the process regarding coke yield is linearly dependent on the coke-forming property of the raw material (K) and is characterized by the following approximation equation:

$$W_k = a + b * K \quad (2)$$

Literature Review and Theoretical Explanation

In the study, a high-precision coke yield forecast was developed using coefficients a=2 and b=1.66. To model the polytropic process in industry under laboratory conditions, it is necessary to determine the equivalent temperature. Based on the nomogram of A.I. Zinovieva and D.I. Orochko, an equivalent temperature (te) is calculated, which is more accurate than the arithmetic mean temperature:

$$t_e \approx \frac{t_{inlet} + t_{outlet}}{2} + \Delta t_{polytropic} \quad (3)$$

In the coking chamber, the transformation of the liquid phase into a foamy mass and the formation of the coke skeleton are characterized by the swelling coefficient (SCO). Based on experimental data, the influence of temperature on this parameter was expressed by the following regression equation:

$$K_{VS}=4.5+0,11(486-t) \quad (4)$$

Analysis of Contemporary Trends

It shows how the yield of final products changes as the coke-forming components (Coke level, K) in the raw material increase. This relationship is linear in nature.

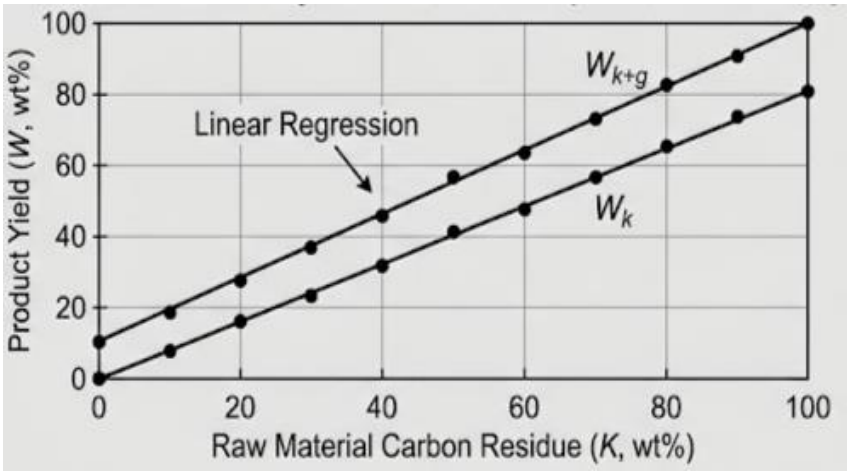


Fig 1. Raw material quality and product yield (Kinetic dependence)

As seen from the graph, as the coking capacity of the raw material increases, the total yield of coke and gas (Wk+g) increases linearly. This is an important indicator for the industry, as it allows for the assessment of coke oven efficiency and the level of raw material processing. An increase in temperature above 500 °C reduces the viscosity of the dispersed system, which leads to a decrease in the K_{VS} and an increase in the coke density. For a device with a daily capacity of G = 1100 t/day, the geometric parameters were optimized by correlating the effective volume (v_r) of the chamber with the volumetric velocity (w = 0.14 s^{-1}. Based on the given K_{VS} = 4.5 + 0.11 (486 - t) equation, the influence of temperature on the coke mass structure during the coking process is as follows:

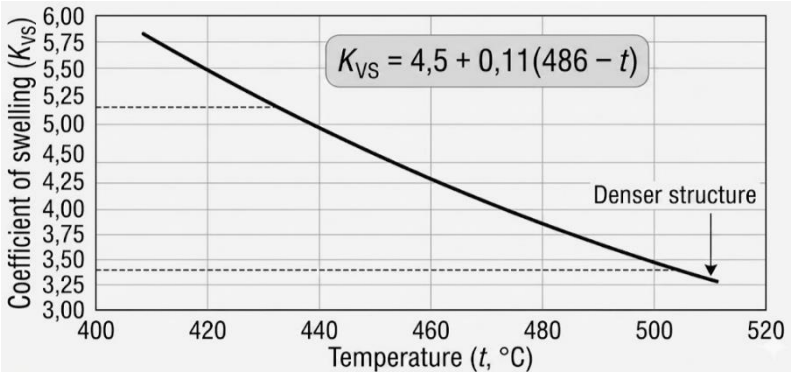


Fig 2. Effect of temperature on swelling coefficient (K_{VS})

An increase in temperature reduces the swelling capacity of the coke mass. The decrease in the K_{VS} on the graph (for example, approaching 2.0 above 500°C) indicates that at higher temperatures, the coke structure becomes denser and porosity decreases. This is a necessary condition for increasing the mechanical strength of coke.

The height of the cylindrical part of the chamber is determined by the following integral relation.

$$H_{st}=\frac{V_h \cdot \tau}{F \omega} \quad (5)$$

In this case, F is the cross-sectional area of the chamber (18 m2). As a result of the calculations, it was scientifically substantiated that the total height of the chamber is 25 m, and the diameter is 4.8 m. The diagram in Figure 3 depicts the process of filling the reaction chamber (coke drum) with coke and foam mass over a 24-hour operating cycle depending on time.

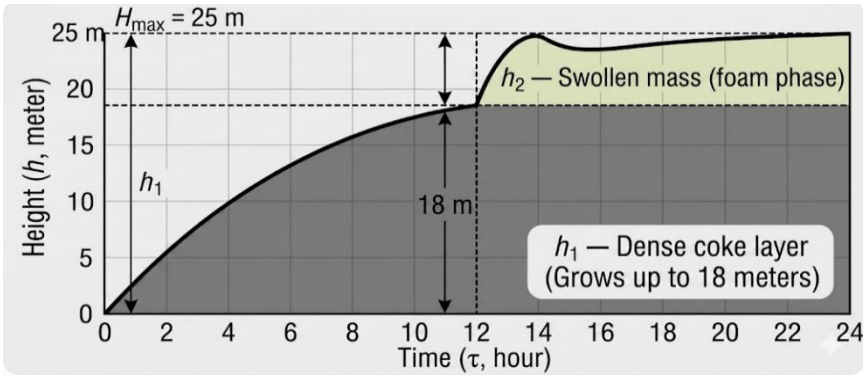


Fig 3. Dynamics of reaction chamber filling by height

At the beginning of the process (0-8 hours), a dense coke layer (h1) grows rapidly, and above it, the swollen mass (h2) foams and approaches the upper part of the chamber (Hmax). During this period, there is a risk of the chamber becoming full. In the second half of the cycle (12-24 hours), the coke layer continues to grow and stabilizes at 18 meters, while the swollen mass transforms into coke, and its height decreases.

According to hydrodynamic stability, the foaming process is associated with an acceleration of gas release during the coking stage of asphaltens. To eliminate this, the use of silicone-based anti-foaming agents was analyzed from a kinetic perspective. The introduction of water vapor (turbulization) serves to maintain the Reynolds number (Re) of the flow above the critical value so that coke does not settle in the coils of the heat-exchange furnace. This bar chart shows the distribution (mass fraction) of all distillates (liquid and gaseous products) obtained as a result of the coking process by distillation temperature.

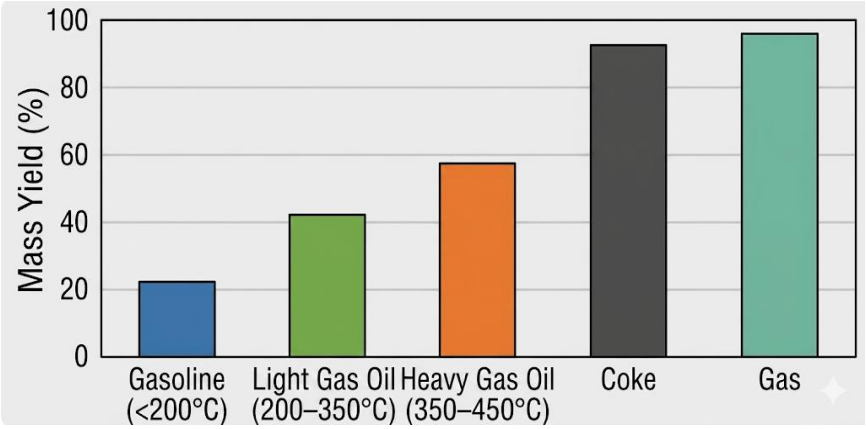


Figure 4. Fractional composition of products (Material balance)

Research findings indicate that to effectively manage the slowing-down coking process, it is necessary to optimize the raw material recirculation coefficient and maintain the temperature gradient of the reaction chamber at a minimum level. The developed mathematical model allows for high-precision calculations during the design of industrial installations and the modernization

of existing ones. The presented four graphs analyze various technological and kinetic parameters of the coking process.

Conclusion

The common scientific basis uniting them is that coking is a complex thermochemical decomposition process, the efficiency of which and the nature of the final products depend nonlinearly but predictably on the composition (quality) of the initial raw materials and the thermal regime of the process. The presented graphs show that the kinetics of coke formation strongly depend on the quality of the raw materials. As the degree of coking of the raw material increases (K, % by mass), i.e., as the proportion of heavy, aromatic, and coke-forming components in the raw material increases, the final yield of the coke itself (Wk) and the coke+gas mixture (Wk+g) increases linearly. This relationship is based on the thermochemical nature of the coke formation process. Raw materials with a high degree of coking contain a large amount of heavy hydrocarbons (e.g., asphaltenes), which, upon decomposition at high temperatures, primarily form a solid phase (coke). The linear trend in the graph confirms that the process follows stable kinetic laws at specific temperatures and pressures. This set of four graphs provides a comprehensive analysis necessary for managing and optimizing the coking process. It combines the kinetic effect of raw material quality (Fig. 1), the influence of temperature on structural density (Fig. 2), the dynamics of temporary chamber filling (Fig. 3), and the material balance of final products (Fig. 4). The interdependence between these parameters allows for the correct selection of process conditions (temperature, pressure, raw material composition, and time) to achieve the desired coke quality and maximum product yield.

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