

Absorption cleaning of fuel gases in an activated carbon production plant

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Abstract. Today, waste recycling in Russia is becoming increasingly important, since new, in-demand products are obtained during their recycling. But for many enterprises, recycling of production waste is becoming impossible due to many constraints, the key one being environmental pollution during the recycling of this waste. The most effective and environmentally friendly method of recycling waste is its thermochemical decomposition into coal, combustible gas and liquid fuel. But even with pyrolysis, which is quite safe for the environment, emissions of harmful substances occur that pollute the atmosphere. The solution to the problem of emissions of harmful impurities is sorption gas purification systems. During adsorption purification, gas with harmful impurities is passed through a solid material with a high specific surface area, during absorption purification, the gas is purified using a liquid component that absorbs harmful particles of gas emissions. The price of adsorbents is quite high and requires frequent replacement due to rapid saturation, therefore this paper presents an absorption system for cleaning flue gases, implemented in a pyrolysis waste processing plant. The principle of the absorber is to repeatedly pass the absorbent through gas emissions. The purified gas is harmless to the environment and can be safely released into the atmosphere.

1 Introduction

To organize pyrolysis processes, thermal energy is generated in combustion devices, the operation of which is accompanied by the release of toxic emissions into the atmosphere. At the Department of Wood Materials Processing of the Kazan National Research Technological University, an energy- and resource-saving continuously operating installation designed for the production of activated carbon was developed. The manufacturing process in the installation includes a full cycle of activated carbon production from waste grinding to carbon capping [1-6].

Energy and resource conservation in the installation is achieved through the repeated use of steam-gas mixtures obtained at various stages of activated carbon production. Mixtures of vapors and gases contain harmful impurities, the release of which into the atmosphere will harm the ecology of the planet and entail huge fines [7-35].

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In this regard, the task in this work is to study the formation of a steam-gas mixture and a method for purifying this mixture using process water condensed during the production of activated carbon.

2 Methods and materials

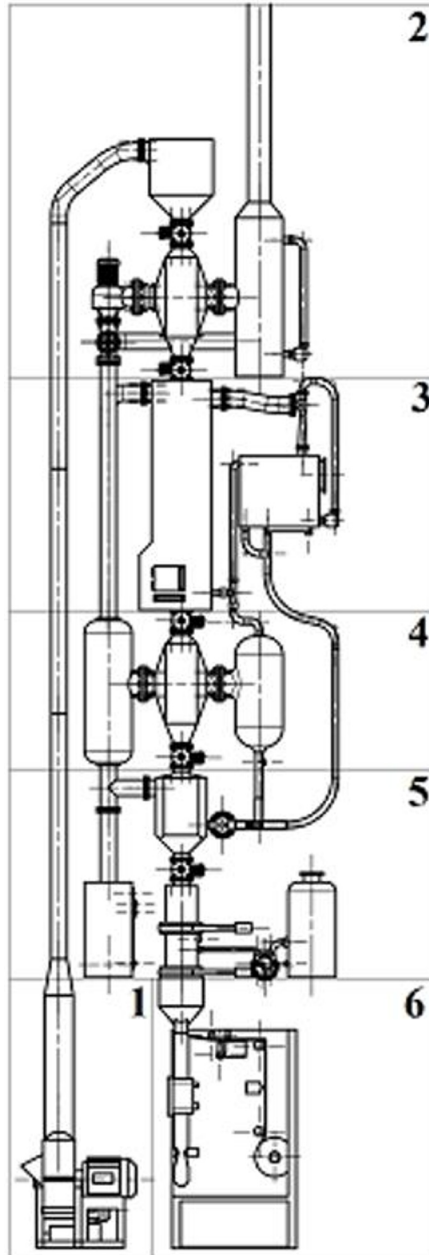


Fig. 1. Plant for the production of activated carbon.

The installation is based on the principle of conductive pyrolysis. The fuel for the installation is gas obtained during the decomposition of waste. Figure 1 shows the scheme of the installation for processing waste into activated carbon.

Structurally, the activated carbon production unit is a vertical retort, where the waste crushed in zone 1 continuously moves from top to bottom and as it passes through drying zones 2, pyrolysis 3, activation 4, cooling 5, and capping 6, it is converted into activated carbon. In units 2-5, due to high temperatures, heat and mass transfer occurs in the processed raw materials. During the processing of the initial raw materials, combustible gases and water vapor are formed.

3 Results

During pyrolysis, a gas mixture is formed, which is continuously discharged from the pyrolysis chamber into a separator, where it is divided into distillate and combustible gas. From the separator, the combustible gas enters the pyrolysis zone furnace, where it burns out. Moving along the spiral chimney, the flue gas heats the outer walls of the pyrolysis chamber, then is discharged from the pyrolysis zone into a recuperative heat exchanger. The flue gases are cooled in the recuperative heat exchanger and fed to the drying zone. The activation zone and the cooling zone form a closed system through which water passes, turning into steam. Under the action of superheated steam in the activation zone, activation gases are released from the coal, after separation they become high-calorie combustible gases and are fed to the pyrolysis zone furnace.

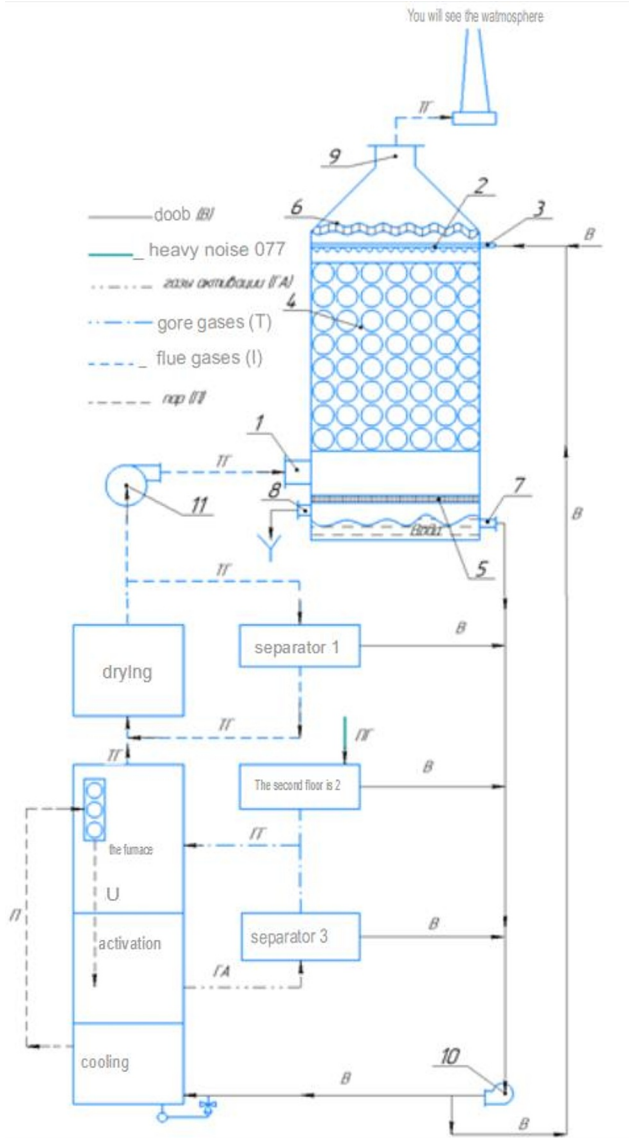


Fig. 2. Scheme of the flow of absorbent and flue gases in an activated carbon production plant.

In the gas cleaning unit, the exhaust flue gas enters the absorber through pipe 1. The absorbent (water) enters through pipe 3 and is sprayed through collector 2. The exhaust flue gas and water move towards each other through nozzle 4. The flue gas, having passed through the nozzle and filter 6, is cleaned and leaves the absorber through pipe 9. The movement of gas and the creation of excess pressure in the absorber is performed by gas blower 11. Water, having cleaned the gas, passes through filter 5. Through absorbent drain pipe 7, water is drained from the absorber to the cooling zone. Excess water is drained through pipe 8 into the sewer. The pressure of water for feeding to collector 3 and to the cooling zone is created by pump 10 (Figure 2).

The main characteristic of the absorber is the mass productivity for absorbed harmful impurities G [kg/s], determined by the expression [10]:

$$G = \frac{V \cdot y_H \cdot M \cdot \alpha}{k}$$

where V is the volumetric flow rate of the absorbed gas [m^3/s]; y_H is the initial concentration of harmful substances in the gas mixture, expressed in mole fractions. M is the molecular mass of the absorbed gas; k is the volume occupied by 1 kmol of gas, [m^3]; α is the coefficient of extraction of harmful gas, determined by the formula:

$$\alpha = \frac{y_{pH} - y_{pK}}{y_{pH}}$$

where: y_{pH} , y_{pK} – respectively, the initial and final concentration of harmful substances in the gas mixture, [%].

The consumption of absorbent for gas purification L , [kg/s], is calculated using the formula:

$$L = \frac{G \cdot \varepsilon}{X_{pK} - X_{pH}}$$

where ε is the excess of the absorbent, [%], X_{pH} , X_{pK} are the initial and final concentrations of the harmful gas in the absorbent, [kg/kg].

To determine the absorber diameter, it is necessary to select the type of nozzle and material. The absorber operates in an aggressive environment, so ceramic Raschig rings will be the optimal choice for the nozzle.

Equivalent diameter of the Raschig ring d_3 , [m]:

$$d_3 = \frac{4V_{CB}}{\sigma}$$

where V_{CB} is the relative value of the volume of the absorber packing container to the total volume of the absorber container, [m^3/m^3]; σ is the specific surface area of the packing, [m^2/m^3].

$$w = \frac{Re_{CB} \cdot \mu_y}{d_3 \cdot \rho_y}$$

where μ_y is the viscosity of the gas mixture under operating conditions, [$\text{Pa}\cdot\text{s}$]; ρ_y is the average density of the gas phase under operating conditions, [kg/m^3]; Re_{CB} is the Reynolds number for the gas phase.

The diameter of the adsorber D [m] is determined by the flow rate of the flue gas Q [m^3/s] and its velocity in the adsorber [11]:

$$D = \sqrt{\frac{4Q}{\pi \cdot w}}$$

The absorber height consists of the height of: packing H_n [m], the upper part h_v , where the sprinkler and gas filter are located, and the lower part, where the water tank and filter for its purification are located. The height of the packed zone is determined taking into account the driving force in the column. In turn, the driving force at the bottom of the column ΔP_H is determined by the difference in the partial pressures of the gas at the absorber inlet and equilibrium with the liquid flowing out of the absorber, and the driving force at the top of the column ΔP_B is determined by the difference in the partial pressure in equilibrium with water and the pressure of the purified gas leaving the absorber pipe. The average driving force of absorption ΔP_{cp} is determined by the formula:

$$\Delta P_{cp} = \frac{\Delta P_H - \Delta P_B}{2,3 \cdot \lg \frac{\Delta P_H}{\Delta P_B}}$$

The height of the mounted column is determined by the expression:

$$H_H = \frac{G}{M \cdot 0,785 \cdot D^2 \cdot \sigma \cdot K_{\Delta P} \cdot \Delta P_{cp}}$$

where, $K_{\Delta P}$ is the mass transfer coefficient during absorption.

To determine the power of the gas blower, it is necessary to know the hydraulic resistance of the column with packing Δp , which is made up of the hydraulic resistance of the irrigated packing and the total pressure losses to overcome local resistances in the column.

The total pressure developed by the gas blower, [Pa]:

$$P = (k_p + k_{pc}) \cdot (\Pi - P_{atm} + \Delta p)$$

where k_p is the coefficient taking into account pressure losses in the supply gas pipelines (1.05-1.1); k_{pc} is the coefficient taking into account pressure losses during transitions from the chamber to the absorber (1.5-3) - used when the gas blower is located remotely from the absorber; P_{atm} is the atmospheric pressure; P is the absorption pressure.

Blower power, [W]:

$$N_{\Gamma} = (V \cdot P) / \eta$$

The pump power is calculated based on the costs of creating the flow rate in the pipeline Δp_{κ} using the formula:

$$N_H = (V_A \cdot \Delta p_{\kappa}) / \eta$$

where, V_A is the volumetric flow rate of the absorbent [m^3/s].

4 Conclusions

The presented scheme of absorption cleaning of flue gases for the activated carbon production plant allows to clean gases of different pollution levels without large financial costs for sorbents, since the sorbent is the formed process water. The use of return process

water, in accordance with the proposed scheme, reduces the consumption of external clean water and the amount of wastewater for regeneration. The proposed calculation method for the gas cleaning apparatus allows to calculate absorbers of different productivity and different configurations for plants operating on gas fuel.

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