EQUIPMENT

OPTIMIZATION OF PARAMETERS IN VACUUM DISTILLATION
OF ATMOSPHERIC RESID

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Vacuum distillation of atmospheric resid occupies a leading place among the various processes for cutting deeper into
the barrel of crude. Vacuum distillation is used either to obtain vacuum distillate as a feedstock for cat cracking or
hydrocracking, or to obtain lube fractions. Vacuum distillation is one of the major processes in petroleum refining in terms
of volume, and it is the process that consumes the most energy. Capacity may be as high as 3-4 million tonnes per year in a
single processing section. In comparison with atmospheric distillation, vacuum distillation requires at least twice the amount
of energy per unit of product. Hence, energy saving by optimizing the separation parameters is an extremely important matter.

In order to optimize the vacuum distillation process, it is necessary to examine and analyze the process chain of
equipment, from heating furnace to vacuum unit to condenser to vacuum system. Atmospheric resid as a feedstock for a
distillation process has one distinctive feature—its thermal instability. When atmospheric resid is heated in a furnace to a
temperature above 400°C, it decomposes to form gas and coke. The coke is deposited on the walls of the furnace coil and may
cause burnout of the coil. The gas produced by thermal decomposition requires the expenditure of additional energy in order
to evacuate it from the vacuum column.

Therefore, the basic strategy in calculating and designing vacuum distillation units for atmospheric resid consists of
performing the process with a lower temperature of feedstock heating in the furnace. In many cases, however, this strategy
conflicts with the demand for maximizing the yield of the desired fractions. A search for a compromise becomes the essential
feature in optimizing a vacuum distillation system for atmospheric resid.

The basic parameters of the optimization are as follows: residual pressure at the top of the vacuum tower; pressure
drop in the tower and furnace—tower transfer line; quantity of steam fed to the tower; type of vacuum system; parameters of
the steam and the cooling agent; and the temperature to which the feed is heated in the furnace. The tower-top residual pressure
is the prioritized parameter, on which all of the other optimization parameters depend to one degree or another. Naturally, the
lower the tower-top pressure, the lower will be the temperature to which the feed is heated in the furnace, with a
correspondingly lower energy consumption in heating. However, lower residual pressures call for increases in the diameter,
mass, and cost of the tower, in the energy and capital costs of the vacuum system, and so on.

It is fully evident that in order to find optimal parameters of the system, a series of calculations must be performed,
using as the global criterion the total prorated costs* of production of one unit of the desired product. These costs include the
capital and operating costs for heating the feed in the furnace, for distillation in the vacuum tower, in creating the vacuum,
and in pumping the condensate and water from the vacuum system.

In order to account more fully for the large number of interrelated parameters determining the total prorated costs, a
computerized calculation program was written. This program includes thermodynamic and hydraulic calculations of the transfer
line with a determination of the quantity of gases produced by thermal decomposition, a block of complete thermodynamic
calculations of the vacuum tower, a block of calculations of the condenser and vacuum system, and a block of calculations of
technoeconomic indexes.

*The "prorated costs" consist of the operating costs plus a fixed fraction of the capital costs — Translator.

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Fig. 1. Operating costs $O$ for steam fed to bottom of tower with various levels of steam consumption relative to feed (as indicated by numbers on curves), as a function of tower-top pressure $P_t$.

Fig. 2. Steam consumption in ejectors $G_s$ with various steam inputs relative to feed (as indicated by numbers on curves) as a function of tower-top pressure $P_t$.

The computer analysis was performed in the automatic mode by a method of stepwise variation of the consumption of steam fed to the bottom of the tower, from 0.15% to 1% by weight on feed. By means of the program that had been written, in the example of distillation of reduced crude with the primary objective of fuel production, we investigated the dependence of the consumption and cost of steam and cooling water on the residual pressure in the tower. The results of this analysis are presented in Figs. 1-3.

An extremal character of the dependence of costs on the tower pressure was established in [1, 2]. According to those studies, the minimum costs for ejector steam are obtained at a tower-top pressure of approximately 5.32 kPa. In [1], this conclusion was drawn on the basis of an analysis of tower operation with variation of the quantities of steam fed to the tower and to the ejectors.

An increase of steam feed to the tower, on the one hand, reduces the required degree of heating and hence reduces the costs of heat supply; on the other hand, it results in sharp increases of the consumption of ejector steam and condenser water. Analysis shows that the cooling water costs may account for more than 12% of the total costs, and the steam costs more than 4.5% of the total costs; within a certain range of variation of tower pressure, these costs may not be compensated by the saving of heat.

The costs for heating the feed in the furnace account for 60-80% of the total prorated costs. In performing the computer analysis, account was taken of only those costs for heating the feedstock in the furnace before it was fed to the tower, without any consideration of partial utilization of the heat supplied to the tower. With increasing tower pressure, the heat supply costs increase monotonically. Along with this, there is a corresponding increase in the fraction of these costs in the total separation cost.

The reason for this trend is the need for increasing the feedstock heating temperature with an increase in the tower-top pressure and hence an increase in the evaporation space in order to ensure the required fraction of overhead takeoff. At the same time, as the steam feed to the tower is increased, the feed inlet temperature can be lowered as a result of additional stripping of light components by reducing the partial pressure of the hydrocarbon mixture.

The feedstock heating temperature in the furnace determines the quantity of gas produced by thermal decomposition, which in turn has a substantial influence on the costs for creating the vacuum in the tower, mainly through an increase in the consumption of ejector steam and cooling water for condensing the vapor–gas mixture. The temperature to which the feed is heated in the furnace will also depend on the pressure drop in the transfer line.

Our analysis revealed an interesting dependence of the prorated costs on the residual pressure in the tower and the consumption of steam fed to the bottom of the tower (Fig. 4) — a dependence that had not been noted previously in studies.