Distillation Column Dynamics with the Use of the Pulse Technique

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Dynamic response information for a complex chemical process may be found either theoretically, by computing the relationship between some arbitrary input and the corresponding output from a mathematical description of the system, or experimentally, by upsetting the process with some forcing function and measuring the output signals as a function of time. At the present time, it is not possible to write the mathematical model for most real systems, and as a result one must resort to experimental techniques. Of the numerous types of forcing functions which may be used experimentally, the most commonly used are sinusoidal forcing, pulsing techniques, and transient forcing. The steady state frequency response has as its principal disadvantage that the test period is lengthy and therefore uneconomical. Transient forcing has the disadvantage of changing the outputs to new values which may be undesirable and result in off quality products. Pulse techniques are desirable in that they may be designed so that they disturb the system less than the other two types.

The application of the pulse technique shows that theoretically any one pulse yields the dynamic response information. In this communication, the effect on response dynamics from varying pulse widths on a distillation column is compared with results of standard sinusoidal forcing.

An experimental study was performed on a bubble cap distillation column to determine whether pulse techniques could be used in place of sinusoidal forcing for determining the column dynamics.

The history of the pulse technique starts with Fourier, who derived the original equations for use in the analysis of mathematical topics. The procedure was applied at first to aircraft performance characteristics and in 1956 Lees and Hougen (*1*) and later Morris (*2*) both showed that the pulse technique was a reliable method for obtaining frequency response data.

In 1960 Hougen and Walsh (*3*) summarized the known material on pulse testing in a paper which described how the width of the pulse influenced the excitation of the system. They also showed that experimental pulse testing was a useful and reliable tool.

The most complete set of reference material on this subject is by Draper, McKay, and Lees (*4*), who offer a discussion of theoretical concepts and criteria for processing time history data. In 1961 Dreifke (*5*) investigated the pulse technique largely on an analytical basis.

All the dynamic response information obtained through sinusoidal testing can be obtained by pulse testing. Experimentally, it is necessary that the pulse have enough energy to produce measurable outputs. These pulse functions can be handled through an extension of the Fourier or Laplace transforms. If Fourier transforms are used, the transform for a single pulse can be defined as

$$FT\left[f(t) = \int_{-a}^{+a} f(t)e^{-j\omega t}\,dt = F(j\omega)\right.$$

where $2a$ is the time period of the pulse and is based upon linear behavior.

Fortunately, other investigators, as well as the experimental data of this investigation, indicate that this is a reasonably accurate approximation of a distillation process in the range of compositions in which the equilibrium data are approximately linear.

The experimental runs, which included both sinusoidal and pulse tests, were performed on an experimental distillation unit consisting of a 24-plate stainless steel column 8 in. in diameter, fitted with five bubble caps on each plate.

The input pulses and continuous sine waves were introduced into the reflux return line through a linear ½-in. control valve. The electrical signal from the generator was converted to a 3 to 15 lb./sq. in. gauge pneumatic signal to the valve by an electropneumatic transducer. Because of the time lag and stiction in the valve, the variation of valve position was measured by an external circuit containing a Sanborn 7DCDT transducer. This signal from the transducer was used in all computations as the input pulse to the system. Thus, these input pulses consisted of changes in flow rates caused by the opening and closing of this valve corresponding to a predetermined time-position relationship.

Inputs were generated by means of a Hewlitt-Packard low frequency function generator adapted by a pulse-forming circuit which allowed single pulses to be generated. Outputs were temperatures measured by thermocouples located on plates 4, 12, and 20 from the top of the column. All pulses were rectangular in nature and varied in width from 26 to 84 sec. in length. The height of all pulses was the same and corresponded to an operational maximum of the opening and closing of the valve. All experimental runs were made at constant reflux conditions.

The material distilled in the column was a solution of benzene-acetone. This system was selected because it has a temperature difference of 43°F. representing a large temperature change per plate and the equilibrium relationship is nearly linear. The composition range used in this study was limited to a linear portion of this equilibrium relationship.

To analyze the data, both inputs and outputs were nondimensionalized before computer processing. Frequency response was calculated as the ratio of the output and input Fourier transforms and were nondimensionalized to compare the outputs, which were temperatures, with the input, which was a valve position as a function of time.

The outputs were recorded on strip charts and their Fourier transforms calculated on a digital computer through the use of a trapezoidal method. The resulting frequency responses were then plotted on a Bode diagram. The comparison of results showed that the rectangular pulses in general agreed with the results of sinusoidal forcing and predicted first-order behavior. The runs in which shorter pulse widths were used gave time constants closer in value to those of sinusoidal forcing. As pulse width became longer, these values were wider apart because of the introduction of nonlinearities in the system.

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For short pulses of widths of 26 to 84 sec., time constants of 50 to 45 sec., respectively, were found for the first-order systems as compared with 60 sec. found from sinusoidal forcing. These lie within the 25% limit which was proposed as a criterion by Dreifke (5). Pulses of larger widths fall outside of this criterion for this system. It was not possible to use shorter pulse widths than 26 sec. in this experimental study. Since the pulse heights used were constant and represented the maximum range of the valve opening, shorter pulse widths did not contain sufficient energy to produce measurable output signals.

Thus, in lieu of a mathematical model for a distillation process, the results of this study show that pulses may be used to determine the dynamic characteristics of the column used. However, pulse tests must be made on each new column, since the time constant, damping coefficient, natural frequency, and the order of the system will vary from column to column. In addition, some preliminary tests must be made to ascertain that the energy content of the input pulse is sufficient to energize the output signals.

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Development of a Two-Phase Contactor Without Pressure Drop

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Many operations in chemical engineering require the contact of two phases in multistage units under minimum pressure drop per stage. Low pressure drops are especially important for multistage reactors, distillators, or absorbers that handle heat sensitive materials under vacuum. Usually a compact multistage contactor is desirable from an economical point of view. To meet these requirements, a multistage contactor has been designed for gas-liquid contacting and a schematic cross section of the proposed unit is shown in Figure 1. The unit consists of contacting compartments and a common shaft with multiple impellers. As a result of the impeller action the gas is sucked from stage to stage through the openings provided in the trays. The impeller acts as an agitator for the dispersion and provides pumping for the gas. Thus, the gas is self-induced from the bottom of the vessel and is subdivided in each compartment into small size bubbles that are dispersed throughout the liquid phase. Consequently, the pressure drop across the liquid phase is eliminated and a negative pressure drop is established instead. By applying vacuum at the top, the lower pressure at the bottom of the unit allows heat sensitive materials to be handled under lower temperature conditions. Use of stators with radial vanes causes a very high shear on the liquid and incoming gas, resulting in a very small and relatively uniform diameter of bubbles with a high total surface area for diffusion. When entrainment problems are encountered and a compact unit is desirable, additional impellers may be installed between the stages to remove tiny drops from

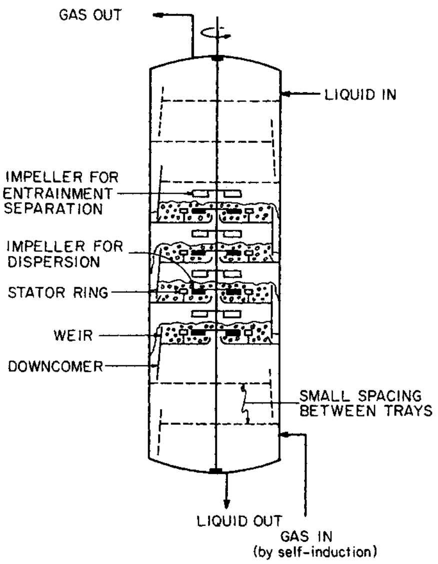

Fig. 1. Schematic cross section of proposed multistage contactor without pressure drop.