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Acoustic detection of flooding in absorption columns and trickle beds

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Abstract

In countercurrent flow absorption columns and trickle beds, if either the liquid or gas flow is too high the column becomes flooded with the liquid. Flooding is accompanied by a dramatic increase in pressure, resulting in inefficient operation and potential damage to equipment. To optimize efficiency, however, it is desirable to operate as close to flooding as possible. This article discusses the feasibility of using acoustic emissions for a non-intrusive, in situ method of monitoring column operations. Six piezoelectric microphones were placed on the outside of a packed column and acoustic signals between 0 and 20,000 Hz were acquired over conditions ranging from non-flooded to flooded. The raw signals were then processed to obtain their standard deviation and entropy. Standard deviation and entropy were both found to increase at the onset of flooding. Entropy however, was more useful because it was not sensitive to the type of packing, air flow rate or water flow rate. Additionally, entropy began to increase sooner than standard deviation, providing an early warning. The results from both entropy and standard deviation proved acoustic detection can be used non-intrusively to monitor operations, allowing for better optimization and improved efficiency of absorption.

Keywords: Absorption columns; Trickle beds; Flooding; Acoustic monitoring

1. Introduction

1.1. Absorption columns and trickle beds

An absorption column is a packed column with a gas inlet at the bottom and a liquid inlet at the top. The countercurrent flow of the two fluids allows for the mass transfer operation known as absorption, where a component of the gas mixture is transferred to the liquid phase in which it is soluble [1]. The component from the gas mixture either forms a physical solution with the liquid or reacts with it chemically [2]. The packing in the column aids the transfer by increasing the surface area and contact time.

Absorption operations are also known as scrubbing operations and can be used for gas purification, product recovery or production of gas solutions [2]. Some common applications include, removing pollutants from plant emissions, purifying natural gas and recovering carbon monoxide in petrochemical production [3].

Trickle beds are used as multiphase reactors. The beds are composed of catalyst pellets, rather than ordinary packing and flow of the gas and liquid phases can be either co-current or countercurrent [4]. Some common applications using countercurrent flow include catalytic distillation, hydrodesulfurization and ultra clean diesel fuel production [5].

1.2. Flooding

Flooding occurs when either the gas or liquid flow is increased beyond the capacity of the column. In countercurrent operations, the gas inhibits the liquid flow and increased friction between the two fluids causes the liquid to backup [6]. The accumulation of liquid at the top of the packing acts as a visual indication of flooding.

Flooding is also accompanied by a rapid increase in pressure drop and liquid holdup [7]. The rapid increase in pressure drop and decrease in flow efficiency upon flooding makes the system inoperable [8]. The efficiency of interfacial mass transfer, however, is maximized near the flooding point [9]. Therefore, it is desirable to operate as close to flooding as possible, without actually reaching flooding and causing instability. Reliable

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online detection of flooding would make it possible to operate at optimal mass transfer conditions.

1.3. Flooding detection

Different methods have been used to detect flooding, including visual detection, measuring liquid holdup and monitoring pressure.

If the column being used is transparent, the "visual buildup of liquid on the upper surface of the packed bed," as described by Strigle [7], can be observed. The problem with visual observation is that there is often a delay in reaction and by the time flooding is noticed damage or loss has already taken place. In addition, hysteresis effects have been observed to delay column recovery by Celata et al. [10] and Shoukri [11]. With hysteresis, flooding persists until the flow rate is reduced to a level much lower than the critical flow rate [10], making restoration of normal column operation more difficult.

Flooding can also be identified by an increase in liquid holdup in the column. To measure liquid holdup, both gas and liquid flows must be stopped and the liquid remaining in the column must be drained [7]. Thus, using liquid holdup as an indicator of flooding disrupts operations and cannot be monitored online.

As flooding is accompanied by a dramatic increase in pressure, monitoring the pressure drop in a column or bed using sensors is a potential online method of flooding detection. It is not clear however, whether pressure sensors are capable of detecting flooding onset or simply flooding. Parthasarathy et al. [12] designed a neural network model based on pressure differential data as an indicator of flooding. The model predicts the differential pressure three minutes ahead, so adjustments can be made before flooding occurs [12]. The use of a predictive model suggests that real-time, online pressure measurements do not detect a change early enough to prevent flooding. In addition, monitoring pressure requires intrusive alterations to equipment in order to properly position sensors.

1.4. Acoustic detection

This article discusses the feasibility of using microphones as an inexpensive, non-intrusive, online method of detecting flooding onset. Piezoelectric microphones were attached to the outside of a packed column to monitor operations. Attachment and repositioning were simple and non-disruptive. Sound waves, which are simply propagations of pressure imbalances through fluid media, deformed the piezoelectric material generating a voltage signal [13]. The voltage signal could then be processed and analyzed using various statistical analysis techniques.

Similar acoustic monitoring techniques have been successfully employed by other members of The Western Fluidization Group. Albion et al. [14,15] applied passive acoustic monitoring to pneumatic transport and Daniher et al. [16] and Briens et al. [17] applied similar techniques to pharmaceutical granulation. Additionally, Briens et al. [18] has applied acoustic monitoring to solids drying.

1.5. Signal analysis

Several different types of advanced signal analysis were performed on the raw data obtained from the piezoelectric sensors. Standard deviation and entropy yielded the simplest and most informative results.

The standard deviation represents the fluctuations in a signal away from the mean:

$$s_N = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2} \tag{1}$$

where N is the sample size, x_i is a single value from the sample data and $\bar{x}$ is the mean of the sample data.

Entropy, in the context of information theory, is a measure of the information contained in a signal or event. The absence of information represents an uncertainty associated with the event; this uncertainty is known as the entropy of information or Shannon's entropy. The entropy of information, H, for an event, X, was defined by Claude E. Shannon as follows [19]:

$$H(X) = -\sum_{x} P(x)\log_2[P(x)] \tag{2}$$

where $P(x)$ is probability of an outcome, x, for the event, X. Therefore, the entropy of information is the negative summation of the probability of each possible outcome multiplied by its base 2 logarithm.

2. Apparatus and procedure

2.1. Apparatus

The apparatus, shown in Fig. 1, consisted of a clear, acrylic absorption column with a diameter of 0.10 m and a height of 1.46 m. The water inlet was at the top and the gas inlet was at the bottom. A metal perforated plate separated the bottom of the column from the downcomer.

Water from a holding tank was supplied to the top of the column using a pump with a gate valve and a rotameter to control and measure the flow rate. Compressed air was supplied to the bottom of the column with a gate valve and rotameter to control and measure the flow rate. Two ball valves on the water outlet pipe allowed the outlet liquid flow to be quickly stopped and water from the column to be easily drained and measured to enable liquid holdup measurements.

Six piezoelectric microphones were securely placed on the exterior surface of the column using holders and Velcro straps. The microphones were connected to signal conditioners, which fed into a data acquisition system connected to a computer for data storage and further analysis.

Three different types of packing were used in the column: 13 mm ceramic Raschig rings, 13 mm ceramic Intalox saddles and 13 mm glass marbles.