PACKED COLUMN HYDRAULICS

OBJECTIVE

The objective of this experiment is to characterize a packed column for an air-water system in terms of the hydraulics and mass transfer. Experimentally determine the following parameters:

- Effective packing diameter
- Packing factor
- Packing constant
- Flooding conditions
- Gas phase mass transfer coefficient
- Recommend a range of operating conditions for the laboratory column

APPARATUS

Koch-Glitsch FLEXRING random packing (koch-glitsch.com)

- Nominal Packing Size = 5/8 in
- Void Fraction = 87%
Acrylic Column

- Packing Height = 57 in
- Column inside diameter = 13 in

Air is blown into the column below the packing. A valve and rotameter are used to control and measure the airflow rate. The inlet air temperature and pressure are measured with a thermocouple and manometer, respectively. A relative humidity meter and probe located at the top of the column are used to measure the relative humidity and temperature of the exiting air. The ambient pressure in the laboratory is measured with a barometer.

Water is circulated to the top of the column with a centrifugal pump. The water flow rate is controlled with a valve and measured with a rotameter. A thermocouple is located in the pump inlet line to measure the water inlet temperature.

**HYDRAULICS**

Investigate laboratory column flooding-velocities for an air-water system in the lab column by generating a plot similar to the following graph.
Figure 2. Example of pressure drop vs. superficial gas velocity plot to locate flooding velocities (Seader and Henley, 1996).

Plot the gas flooding velocity versus liquid mass velocity in a log-log plot.

![Diagram](image)

Gas flooding velocity, lb/ft$^2$·h

Liquid mass velocity, lb/ft$^2$·h

Figure 3. Example of gas flooding velocity verses liquid mass velocity.

Calculate the effective diameter ($D_p$) for the packing using dry-gas pressure drop according the Ergun equation:

$$\text{Ergun:} \quad \frac{\Delta P}{l_T} = \frac{150 \mu u}{D_p^2 \varepsilon^3} \left(1 - \varepsilon\right)^2 + \frac{1.75 \rho u^2}{D_p \varepsilon^3} \left(1 - \varepsilon\right)$$

(1)
Alternatively, determine the effective diameter ($D_p$) and packing constant ($C_P$) from the Billet-Schultes dry-gas correlation.

\[
\frac{\Delta P}{l_T} = f \frac{a}{\varepsilon^3} \frac{\rho u^2}{2}
\]  

(2)

where $a/\varepsilon^3$ is the dry-packing surface area per unit volume of bed void space:

\[
a = \frac{6}{D_p} \left(1 - \varepsilon\right)
\]  

(3)

in addition, $f$ is a modified friction factor:

\[
f = \frac{C_P}{K_w} \left(\frac{64}{Re} + \frac{1.8}{Re^{0.08}}\right)
\]  

(4)

where the Reynolds number is corrected for bed porosity and wall effects:

\[
Re = \frac{\rho u D_p K_w}{1 - \varepsilon \mu}
\]  

(5)

\[
\frac{1}{K_w} = 1 + \frac{2}{3} \left(1 - \varepsilon\right) \frac{D_p}{D_T}
\]  

(6)

$C_P$ = packing constant  
$D_p$ = effective packing diameter, m  
$D_T$ = diameter of the tower, m  
$K_w$ = wall factor  
$l_T$ = height of packing in the tower, m  
$u$ = superficial gas velocity, m/s  
$\Delta P$ = pressure drop, Pa  
$\varepsilon$ = void fraction in the packed column  
$\rho$ = gas density, kg/m$^3$  
$\mu$ = dynamic viscosity of the gas, Pa·s

Calculate the packing factor, $F_p$, from the generalized pressure drop correlation (GDPC):
**Figure 4.** Generalized pressure drop correlation (GDPC) for randomly packed towers (Seader and Henley, 1996).

**MASS TRANSFER**

Use the HTU-NTU method to calculate the specific gas film mass transfer coefficient, $k_y a$, from the change in humidity of the gas phase:

$$ l_T = HTU \cdot NTU $$

(7)

where

$$ HTU = \frac{G}{k_y a} $$

(8)

$$ NTU = \int_{y_{in}}^{y_{out}} \frac{dy}{y_i - y} = \ln \left( \frac{y_i - y_{in}}{y_i - y_{out}} \right) $$

(9)

$a = \text{specific area of mass transfer, m}^2/\text{m}^3$

$G = \text{gas molar flow rate, kmol/m}^2\cdot\text{s}$

$HTU = \text{height of a transfer unit, m}$

$k_y = \text{gas phase mass transfer coefficient, kmol/m}^2\cdot\text{s}$

$l_T = \text{height of packing in the tower, m}$

$NTU = \text{number of transfer units}$

$y = \text{bulk gas phase mole fraction of water}$

$y_i = \text{interface gas phase mole fraction of water}$
Correlate the mass transfer coefficient with the gas flow rate using the dimensionless Sherwood and Schmidt numbers:

\[ Sh = b \text{ Re}^n \text{ Sc}^{1/3} \]  \hspace{1cm} (10)

Use your experimental results to determine b and n.

REFERENCES


EQUIPMENT

1. Digital Thermometer
2. Humidity Meter
3. Stopwatch

CHEMICALS/MATERIALS

1. Water
2. Air

Prof. Davis, 9/09

EXPERIMENTAL PROCEDURE

A schematic of the experimental apparatus is shown in Figure 1. An image of the experimental packed column is shown in Figure 5 below.
The column consists of two 13” inside diameter columns. The lower section of the column is 3 feet tall and is the sump, which holds the water. The upper section of the column, which is 6 feet tall, holds the packing. The two sections are attached to each other with flanges. There is a stainless steel mesh screen between the two columns with 1/4” square openings that supports the packing in the upper column.

A centrifugal pump transfers the water from the sump to the top of the upper section. At the top of the column, water is distributed onto the packing through a 60-degree high volume, full cone, and clog-resistant spray nozzle. The water trickles down through the packing and drains back into the sump. The water flow is measured with a variable area rotameter.

A Gast Regenair blower supplies air to the column. The airflow to the column is set by manipulating one or two valves that release air to the lab. The airflow is measured with a variable area rotameter. Two different measuring devices measure the pressure drop across the column: a differential pressure meter and a water manometer.

A picture of the water pump and blower is shown in Figure 6.
1. Before starting the experiment check to ensure that the water control valve and the two air control valves are closed.
2. Check to ensure the drain valve on the right bottom side of the sump is closed.
3. Fill the sump with water to within two inches of the bottom of the air inlet on the left side of the column. Fill the sump with water using a water hose through the grey two-inch PVC pipe in front of the column.
4. Set the scale on the water manometer so the scale is at zero at the bottom of the meniscus on each tube.
5. Record the room temperature and barometric pressure.
6. If humidity meters are available record relative humidity and temperature measurements from the meter at the blower inlet and the upper column outlet.
7. Start the air blower by pressing the start button on the panel located on the wall behind the blower.
8. Open both air valves so the air entering the column is at a minimum.
9. If humidity meters are available record relative humidity and temperature measurements from the meters at the blower inlet and the upper column outlet. Record the temperature of the air entering the column (TC-1).
10. Start the water pump by turning the switch on the electrical strip to on.
11. Adjust the water flow so it is at the minimum flow (8 LPM).
12. Once steady state is reached at the minimum air and water flow record the relative humidity and temperature from the humidity meter if available. Record the temperature of the air entering the column (TC-1) and the temperature of the water at the pump inlet (TC-2). Record the differential pressure from the DP meter and the two liquid levels from the water manometer. Record any observations observed.
13. Increase the water flow by 2 LPM.
14. Once steady state is reached at this water flow record the data as requested in step #12 above.

Figure 6. Regenair blower and water pump.
15. Continue to increase the flow by 2 LPM each time and once steady state is reached, record the data as requested in step #12.

16. Once the maximum water flow is reached, reduce the water flow to the minimum flow (8 LPM). Increase the airflow by 20 to 25 SFM. After steady state is reached, record the data as requested in step #12. Continue to increase the water flow by 2 LPM until the maximum flow is reached recording the data at each water flow after steady state is reached.

17. Increase the airflow an additional 20 to 25 SCFM and record data at each of the water flows and then continue to increase the airflow by 20 to 25 SCFM until the maximum airflow is reached.

18. Sufficient sets of the data should be recorded so an error analysis can be performed on the data.

19. After all the data is collected and recorded, set the water flow to a minimum and turn off the water pump. Set the airflow to a maximum and shut off the air blower.

20. Turn off the digital thermometer and humidity meters.

21. Drain the water out of the sump. Run the flexible PVC tubing to the center-trough floor drain.

SAFETY NOTES

1. Personal Protective equipment shall include safety goggles and earplugs. The noise levels in the corner are approximately 80 decibels. Noise levels 8 feet away from the unit are approximately 60 decibels.

2. Water is used in this experiment. There is operating electrical equipment in close proximity. In case of a water spill be careful not to start up or shut down electrical equipment if standing in water.

WASTE DISPOSAL PROCEDURES

Water used in this experiment can be disposed down the drain to the sanitary sewer.
Department of Chemical Engineering

Stockroom Checkout slip

Packed Column - Hydraulics

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Lab No.: Lab 1  Tuesday 12:00 - 4:50 PM  Lab 2: Thursday 12:00 - 4:50 PM

Lab No.: Lab 3  Tuesday and Thursday morning (9:30 - 11:50 AM) (circle one)

Name: ____________________________  Date: __________________________
(print name)

Name: ____________________________  (Signature)