Lecture 25

Design of stack

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Key words: stack, chimney, draft, natural draft

What is stack effect

The phenomenon induced by the density difference between a hot and cold air column that creates a natural flow through a chimney is called stack effect or chimney effect.

The function of the stack is to disperse the hot gases, emissions and particles that leave the furnace. The gas temperature inside the stack is greater than the outside ambient air temperature. If these two air columns are connected at the bottom, dense air will push the light gases up the chimney. Higher is the temperature difference, greater will be the buoyancy force causing the lighter gases to move up.

Flow of gases in furnaces, stacks and other equipments operating at atmospheric pressures involve small difference in pressures $P_1 - P_2$ that should be used in mechanical energy balance equation (lecture 21, equation 7). This small pressure difference can be conveniently handled in terms of “draft”.

What is draft

Draft (d) at any point in the gas flow system is

$$d = [\text{Absolute pressure in the systems} - \text{absolute pressure of the surrounding atmosphere at the same level}]$$

Figure shows the chimney or stack in which hot gases are flowing at temperature $T$. We mount two water manometers at positions $Z = Z_1$ and $Z = Z_2$. One leg of the manometer is fixed with the chimney whereas the other leg is open to the atmosphere as shown in the figure.
At point 1 and 2 in the gas column

\[ d_1 = P_1^o - P_1 \quad \text{and} \quad d_2 = P_2^o - P_2 \]  

(1)

Where \( d_1 \) and \( d_2 \) represent draft at point 1 and 2 in the gas column. \( P_1^o \) and \( P_2^o \) are the atmospheric pressures and \( P_1 \) and \( P_2 \) absolute pressures at points 1 and 2 respectively.

Variations of pressure with height in a gas column are important. In a static column of fluid at constant temperature the pressure decreases with height due to gravity:

\[ dP = -\rho \, dZ \]  

(2)

Neglecting the effect of density with \( Z \), it follows for static systems

\[ P = P_0 - \rho Z \]  

(3)

\( P \) is pressure at height \( Z \) and \( P_0 \) is pressure at arbitrary datum plane of zero height. \( \rho \) is the gas density.

**Natural draft**

It is the draft produced by density difference between the two fluids. Consider the hot gas column shown in the figure. The hot gas column is surrounded by atmospheric cold air. A monometer mounted at point 1 and 2 reads the draft \( d_1 \) and \( d_2 \). The relation between draft and density difference can be obtained as follows:
\[ P_1 = P_{o1} - \rho_h Z_1 \quad (4) \]
\[ P_2 = P_{o2} - \rho_h Z_2 \quad (5) \]

By equation 1 and 4 and we get.

\[ d_2 - d_1 = \left( Z_2 - Z_1 \right) \left( \rho_a - \rho_h \right) \quad (6) \]

\( \rho_a \) is density of air and \( \rho_h \) is density of hot gas. Eq 6 is the draft produced in a static column of gas. If the chimney is open to atmosphere then \( d_2 = 0 \) so that draft or suction at the bottoms is

\[ d_1 = \left( Z_2 - Z_1 \right) \left( \rho_a - \rho_h \right) \quad (7) \]

Due to flow of gases, the draft is reduced by frictional losses, so that the static draft is the maximum draft which the stack of a given height can produce under limiting condition.

By using mechanical energy balance equation (equation 7 of lecture 21) and using equation 7 (express \( P_1 - P_2 \) in equation 7 in terms of \( d_1 \) and \( d_2 \)) we get the mechanical energy balance equation expressed in terms and draft:

\[ g \left( Z_1 - Z_2 \right) \left( 1 - \frac{\rho_a}{\rho_h} \right) + \frac{d_2 - d_1}{\rho_h} + \frac{V_2^2 - V_1^2}{2} + F - M = 0. \quad (8) \]

**Reference**

R. Schuhmann: Metallurgical Engineering, Volume 1 Engineering Principles