

REACTORS**JGS 210-120-1-20E**

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1. SCOPE

This standard practice covers basic design of reactors used in refineries, petrochemical plants, and other similar plants.

The following reactors are considered in this Basic Design Manual.

- (1) Fixed bed reactor
- (2) Trickle bed reactor
- (3) Bubble column reactor
- (4) Fluidized bed reactor

Descriptions are focused to basic design of (2) Trickle bed reactor. However with regard to the above items (1), (3) and (4), only major application examples and design considerations are described in this practice.

2. WORK PROCEDURE

2.1 Process Conditions

The data to be used for the design of REACTOR will be obtained from, but not limited to, the following documents;

- Process Flow Diagram (PFD), including material and heat balances
- Basic Engineering Design Data (BEDD)
- Piping & Instrument Diagram (P&ID)
- Plot plan
- Piping material specification
- Material Selection Basis

2.2 Input Data

- (a) Heat and material balances around reactors, with specified conversions and selectivities of reaction.
- (b) Equilibrium data and physical properties of reactants and products
- (c) Catalyst volume required.

2.3 Output from Design

- (a) Sizing result of Reactors
- (b) Dimensions of Internals
- (c) Considerations to prepare data sheet

The following information should be described on a data sheet for mechanical design of such internals as catalyst support grids.

- Liquid density under the operating condition
- Liquid height in the reactor
- Catalyst density, each bed height, and voidage*

*: Usually, voidage is given from a catalyst manufacture.

However, voidage can be assumed to be 0.39, when it is not supplied.

It is noted that pressure drop is significantly affected by catalyst bed voidage.

- ΔP of each bed

It should be noted that the ΔP is the difference of static pressure between the inlet and the outlet of the reactor, but ΔP is not frictional pressure loss. ΔP is defined as follows(refer to Fig. 2.3.1).

$$\Delta P = (P_1 - P_2) = \Delta P_f - \rho \cdot g \cdot h$$

where ρ : average density of fluid [kg/m³]
 g : acceleration of gravity [m/s²]

Static head and catalyst weight are added to ΔP when mechanical design is required.

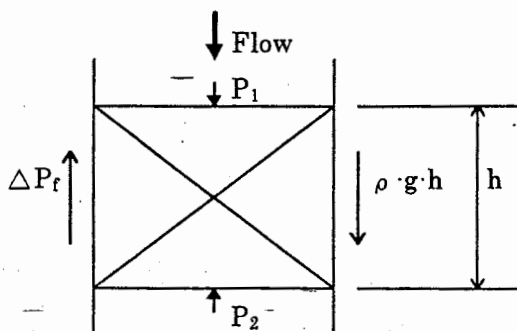


Fig.2.3.1 Definition of pressure drop

- Depressuring

- Pressure drop

- Pressure drop should be calculated by dynamic simulation in accordance with the philosophy stipulated in API 520 and 521.

- Possibility of reverse flow.

- Details

- Others

- Other important information pertinent to design, should be described on a data sheet clearly. For example, if catalyst are regenerated, temperature and pressure conditions for catalyst regeneration shall be described.

2.4 Work Steps

(1) Prepare input data in accordance with section 2.2

(2) Design reactors

There are following of design to be done ;

(a) by licenser

(b) by client

(c) by JGC

(d) by JGC with licenser or client

In case of (a) and (b), the reactor designs shall be checked and reviewed in accordance with section 3.

In other cases, (c) and (d), reactors and internals shall be designed in accordance with section 3.

2.5 Computer Programs

The following JAPETS PROGRAMS (J3G) can be available.

#FIXBED : Temperature and composition profiles in a Tubular Fixed Bed Reactor can be obtained.

#RXDELP : Pressure drop in a Fix Bed Reactor are calculated.

3. DESIGN

3.1 Selection Procedure

Types and features of practical reactors are shown in Table 3.1.

3.2 Bubble Column Reactor

(1) Feature

The liquid phase in a bubble column reactor is stirred by the gas introduced continuously through a gas distributor installed at the bottom of the reactor. Reactant are transferred from gas phase to liquid phase. In particular, when the catalyst particles are contained in the liquid, the reactor is called Bubble Column Slurry Reactor.

For the type of bubble column reactor, refer to Technical Report [2]

(2) Design considerations

Typical superficial gas velocities in bubble column reactors are follows;

- bubble column reactors ... 0.01 - 0.3 m/s
- bubble column reactors with draft tubes ... 0.01 - 0.25 cm/s
- multistage bubble column reactor ... 0.06 - 0.11 cm/s
(when the gas velocity is within this range, channeling of gas is prevented and degree of liquid backmixing is decreased)

For calculation methods of gas hold-up and bubble diameter, refer to Technical Report [2]

(3) Design of gas distributor

Sparger and perforated plate are frequently used as gas distributors. Spargers shall be designed as follows; the diameter and number of holes are determined to keep following limited, hole pitch or distance of hole shall be larger than 0.05 m, gas velocities through each hole shall be larger than 15m/s, pressure drop shall be larger than 20 mmH₂O. A typical configuration of a sparger is shown in Fig. 3.2.

Diameter and number of holes of a perforated plate shall be determined so that pressure drop shall be greater than 20 mmH₂O.

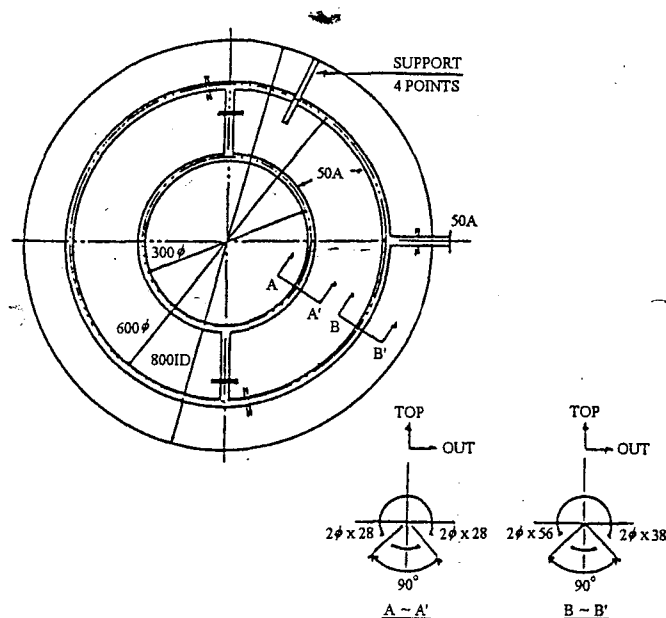


Fig. 3.2 Typical Sparger

(4) Applications

Bubble column reactor : Typical application examples of bubble column reactors are shown in Table 3.2 .

Bubble column slurry reactor : In general, catalyst particles are suspended in a bubble column without or with draft tubes. Coal liquefaction, oxo processes and oil fats hydrogenation have been applied.

When slurry concentration is lower than 5 vol%, flow patterns of bubbles are almost same as in case of without particle.

3.3 Fluidized Bed Reactor**(1) Feature**

In a Fluidized Bed Reactor, the catalyst particles are fluidized by gas and liquid. Mainly fluidized bed reactors are commonly used for gaseous catalytic reactions.

(2) Design considerations

The most important design item for fluidized bed reactors is a gas distributor. The required considerations to design a gas distributor are as follows ;

- (a) uniform gas distribution by generating small bubbles
- (b) preventing to cause dead space above the distributor, good particle circulation in the reactor is required
- (c) preventing to particles from leaking through the distributor holes.
- (d) support the total weight of the particles and withstand thermal stress under high temperature reaction condition.

(3) Design of distributor

The distributor shall be designed in view of the following considerations;

- (a) pressure drop of the distributor
- (b) hole pitch
- (c) gas jet velocity

For detailed calculation procedures of these items (1) to (3), refer to Technical Report [2].

Concerning minimum fluidizing velocity (U_{mf}) and pressure drop of fluidized bed, also refer to Technical Report [2].

(4) Applications

Typical applications are shown in Table 3.3 .

3.4 Fixed Bed / Trickle Bed Reactors

Fixed bed reactor is a cylindrical vessel loaded with solid catalysts. In this reactor, the solid catalysts are retained and fixed by a grating, wire mesh, perforated plate, and so on, Reaction fluids flow through voids among the catalyst particles. There are two cases of reactive fluids: one case is a single phase of gas or liquid and the other case is two phases of gas and liquid.

In particular, when reactive fluids consist of two phases of gas and liquid, these fluids flow downward concurrently, this reactor is called a trickle bed reactor.

Typical application examples of fixed bed reactor are shown in Table 3.4.

A typical skeleton drawing of the Trickle Bed Reactor is shown in Fig. 3.4.

3.4.1 Dimensions

For much details, refer to Technical Report [1]

(1) Reactor diameter

Reactor diameter of a trickle bed reactor shall be determined from:

- appropriate aspect ratio, L/D (L:Reactor height, D:Reactor diameter)
- limitation due to pressure drop in a reactor, refer to Appendix 1 for calculation procedure of pressure drop.
- liquid mass velocity ensuring sufficiently high efficiency of contact catalysis
- flow pattern ensuring sufficient gas-liquid distribution

A smaller reactor diameter reduces the required wall thickness and leads to economy. However, it should be noted that a smaller reactor diameter raises the flow velocity of the fluid and the pressure drop, resulting in increasing the power of rotary equipment.

(2) Bed height

The total catalyst bed height shall be determined from the required quantity of catalyst and the reactor diameter.

However, the catalyst bed is sometimes divided, considering the quench point determined from the standpoint of reaction heat, or additionally gas-liquid distribution efficiency. In such a multistage reactor, a pipe must be provided to move the catalyst from the upper stage to the lower stage when the catalyst is unloaded, or a catalyst unloading nozzle must be provided in each stage.

3.4.2 Internals

(1) Distributor

(a) Inlet distributor

An inlet distributor shall be installed at the reactor inlet in order to prevent the reaction fluid from making direct impact on the liquid distribution or catalyst.

The construction of the inlet distributor is shown in Fig. 3.4.2a.

(b) Liquid distributor

In the gas-liquid distribution using the inlet distributor only, it is difficult to respond to changes in the flow rate when the reaction fluid forms a gas-liquid mixed-phase flow. Thus, a liquid distributor shall be jointly used to maintain a satisfactory gas-liquid distribution.

The liquid distributor has the following construction: many chimneys (pipes) are installed on a tray, and the liquid flows into side holes on the chimney pipe surfaces, and the gas flows through the upper openings of the chimney pipes. A roof is installed over each chimney to prevent the inflowing liquid from the reactor inlet from directly flowing into the chimneys. The construction of the liquid distributor is shown in Fig. 3.4.2b.

Liquid distribution depends on chimney arrangement; attention must be given to chimney arrangement so that the number of chimneys per cross-sectional area may be uniform. In particular, near the reactor shell where the number of chimneys is apt to become small, it is sometimes necessary to take measures such as changing the pitch of chimneys or the number of side holes.

Pressure drop in a liquid distributor can be estimated from the following equation.

$$P_{DIS} = (0.3) \cdot \rho_G \cdot u_G^2$$

where ΔP_{DIS} : pressure drop in a liquid distributor [Pa]
 ρ_G : gas density [kg/m³]
 u_G : gas velocity through the chimney [m/s]

$$= \frac{Q_G}{\frac{\pi}{4} D^2 \cdot N}$$

Q_G : gas flow rate [m³/s]
 D : diameter of chimney [m]
 N : number of chimney [-]

When a liquid distributor is installed as the redistributor and quench gas is supplied above the redistributor, the gas flow rate and gas density shall be taken account of the quench gas.

(2) Quench distributor

When the catalyst bed temperature excessively rises due to reaction heat, a cooling fluid such as recycle gas shall be introduced between the catalyst beds, using a quench distributor. The quench distributor must ensure swift and uniform mixing of the reaction fluid and the cooling fluid.

When the quench distributor is installed, it is necessary to install a catalyst supporting grid above the distributor and a redistributor tray under the quench distributor.

(3) Scale basket

Scale baskets shall be installed at the top of the catalyst bed to remove scale from the reaction liquid.

However, they are not always installed if the feed fluid contains only a very small quantity of scale.

The construction and locations of the baskets are shown in Fig. 3.4.3.

Scale baskets shall be 150 mm in inside diameter and 500 mm in length, and shall be laid out at a pitch of 250 mm on concentric circles whose diameter increases by 250 mm.