2 Conveying Equipment for Fluids

Classification:

- According to fluids:
  - liquid: pump
  - gas: ventilator, blower, air compressor, vacuum pump
- According to the mechanism:
  - impeller (turbine): centrifugal, axial-flow, …
  - positive displacement: reciprocating, rotary, …
  - others: jet, …

2.1 Introduction

General energy equation:

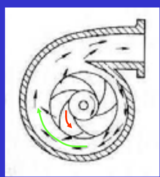
$$z_1+\frac{u_1^2}{2g}+\frac{p_1}{\rho g}+H_e=z_2+\frac{u_2^2}{2g}+\frac{p_2}{\rho g}+H_f \qquad (1\text{-}48)$$

H_e – head of delivery

$$H_e=\Delta z+\frac{\Delta u^2}{2g}+\frac{\Delta p}{\rho g}+\sum H_f \qquad (2\text{-}1)$$

2.2 Centrifugal pump

2.2.1 Mechanism



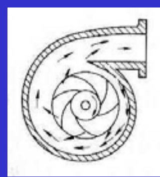
Main parts:

- rotating impeller
- volute

The kinetic energy is converted into pressure energy when liquid passes through the gradually increasing cross-section:

- between curved vanes
- in the chamber of volute

Angle of impeller blades:



- forward inclined
- backward inclined : for larger potential energy

The magnitude of centrifugal force depends on

- speed of rotation n
- diameter of impeller D
- liquid density ρ

Pockets of gas:

If there is some air in the pump, because $\rho_g << \rho_l$, the pressure developed is insufficient to drive the liquid out and suck in the liquid.

Therefore, the pump and suction pipe should be full of liquid before start.

2.2.2 Operating characteristics

Main operating parameters:

- head H_e
- rate of flow q_v
- axial power P_a
- efficiency η
- Operating characteristics:

  plot of H_e, P_a, and η against q_v

1. Power and efficiency

Effective power – the mechanical energy of liquid acquired from the pump per unit time.

$$P_e = \rho g q_v H_e \quad \text{[J/s] or [W]} \qquad (2\text{-}19)$$

Efficiency

$$\eta = P_e / P_a \qquad (2\text{-}20)$$

离心泵内的各种损失：

容积损失：由于流体漏回吸入口处，容积效率η_v与叶轮形式有关；

水力损失：由于流体的涡旋、撞击和粘性摩擦，水力效率η_h一般为0.8-0.9；

机械损失：由于机械摩擦和粘性摩擦，机械效率η_m一般为0.96-0.99。

离心泵总效率 $\eta = \eta_v \eta_h \eta_m$

2. Operating characteristics of a pump

The **operating characteristics are determined experimentally** and provided in the catalog by manufacturer.

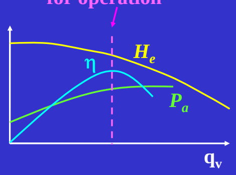
$H_e \sim q_v$

$\eta \sim q_v$

$P_a \sim q_v$

Corrections:

for μ, n



2.2.3 Adjustment of flow rate and operation with pumps

1. The characteristic curve of pipelines and duty point of pump

The head loss of pipelines is

$$\Sigma H_f = \sum \left[\left(\lambda \frac{l}{d} + \zeta \right) \frac{u^2}{2g} \right] \qquad (2\text{-}2)$$

With the relation of u and q_v, we obtain

$$\Sigma H_f = K q_v^2 \qquad (2\text{-}3)$$

where $K = \sum \dfrac{8\left(\lambda \dfrac{l}{d} + \zeta\right)}{\pi^2 d^4 g}$

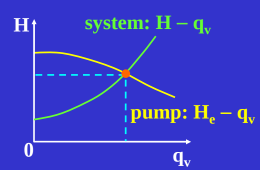
If Re is large enough, K is constant.

The **characteristic curve of pipelines** is

$$H = \Delta z + \frac{\Delta u^2}{2g} + \frac{\Delta p}{\rho g} + K q_v^2 \qquad (2\text{-}4)$$

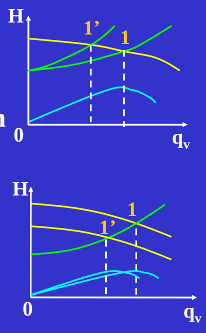
Duty point:

satisfies the two characteristic curves.



2. Adjustment of flowrate

- adjust the valve on the delivery pipe of pump:
  - → change ΣH_f of the system
  - → change $H - q_v$ curve of the system
  - → change the duty point
- change n or reduce D
  - → change $H_e - q_v$ curve of pump



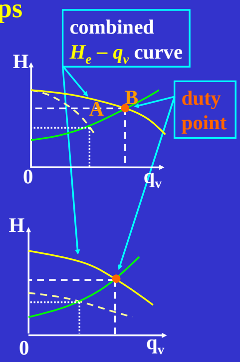
3. Operation with pumps

(1) Pumps in parallel

(the same pumps and suction pipes)

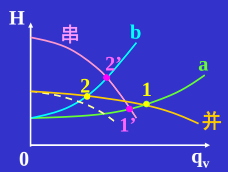
(2) Pumps in series

(the same pumps)



(3) Selection of operation

– dependent on the characteristics of pipe



- Low friction pipe (a), in parallel.
- High friction pipe (b), in series.

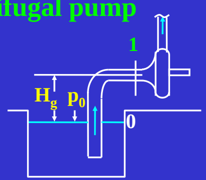
Exercises:

2 – 1, 6, 7

2.2.4 Suction head of centrifugal pump

Problem 1-25:

$$\frac{p_0 - p_1}{\rho} = Hg + \frac{u_1^2}{2} + h_f$$



Near the center of impeller, the pressure p_1 is lower than p_0, so that the liquid is sucked into the pump.

For certain value of p_0, $H\uparrow$, $p_1\downarrow$.

$\therefore$ the suction head H_g depends on p_1.

(1) Cavitation

Phenomenon: If $p_1 \le p_v$ (vapor pressure), vaporization will occur. The vapor bubble condenses suddenly as it moves to the position with higher pressure, resulting in a local vacuum. The surrounding liquid will fill in quickly and cause impact.

Onset: a marked increase in noise and vibration.

Result: mechanical damage and loss of head.

(2) Suction head

We must guarantee that

mechanical energy $\frac{p_1}{\rho g}+\frac{u_1^2}{2g}>\frac{p_v}{\rho g}$ saturated vapor pressure head

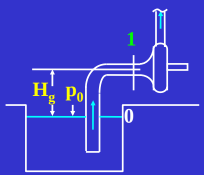
or $$\text{NPSH}=\frac{p_1}{\rho g}+\frac{u_1^2}{2g}-\frac{p_v}{\rho g} \qquad (2\text{-}32)$$

NPSH (net positive suction head)
— 实际汽蚀余量

- 临界汽蚀余量$(\text{NPSH})_c$:
  When $p_1 \to p_{1,\min}$, the liquid evaporates. $(\text{NPSH})_c$ is determined experimentally by manufacturer.
- 必需汽蚀余量$(\text{NPSH})_r$:
  $(\text{NPSH})_r = (\text{NPSH})_c$ + allowance
  It is given in the catalog.
- 实际汽蚀余量(NPSH):
  $\text{NPSH} \ge (\text{NPSH})_r + 0.5$ m

(3) Allowable suction head

The energy balance between 0-1 is



$$H_g=\frac{p_0-p_1}{\rho g}-\frac{u_1^2}{2g}-\sum H_f$$

As $p_1 \to p_{1,\min}$, $H_g \to H_{g,\max}$ (the maximum suction head). The practical suction head should be less than $H_{g,\max}$ by a safety factor.

NPSH has included the allowance. Solving Eq. (2-32) for p_1 and substituting it into above equation, we have

the maximum allowable suction head

$$[H_g]=\frac{p_0-p_v}{\rho g}-\sum H_f-\text{NPSH}$$

or

$$[H_g]=\frac{p_0-p_v}{\rho g}-\sum H_f-[(\text{NPSH})_r+0.5] \qquad (2\text{-}34)$$

If the values of p_0 , p_v , ΣH_f , and $(\text{NPSH})_r$ are known, $[H_g]$ may be calculated.

2.2.5 Types of centrifugal pump and selection for applications

Types:

- clarified water pump (IS, D, Sh)
- oil pump (Y, YS)
- anticorrosive pump (F)
- submerged pump (FY)
- canned-motor pump
- slurry pump (P)
  such as
  sewage pump (PW)
  sand pump (PS)
  sludge pump (PN)
- in-line pump
- cryogenic pump

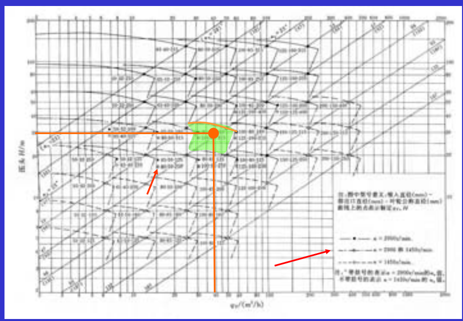
The specifications and characteristics are given in catalogs.

Selection:

(1) determine the type of pump:
– according to the properties of liquid and operation condition

(2) determine the size:
– according to the head and flowrate

单级单吸式清水泵的系列特性曲线



Exercises:

2 – 9, 10, 11

2.3 Reciprocating Piston Pump

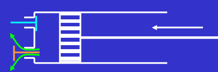
1. Mechanism

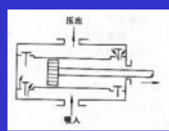
- **main parts:** cylinder, piston, suction valve and delivery valve (both are one-way valves).
- **mechanism:**

The piston moves forward and backward, the delivery and suction valves are opened in turn.

Types:

- single-acting pump
- double-acting pump



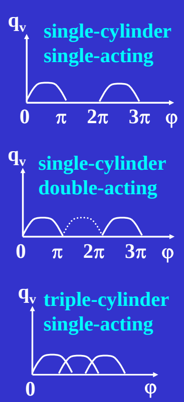


2. Head and flowrate

- **Flowrate:**

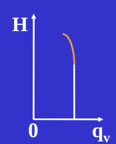
It is dependent on the swept volume of the cylinders and the number of strokes per unit time.

Therefore, it is a positive displacement pump.



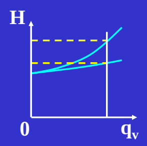
- **Head:**

Theoretical, it is independent of the geometry.



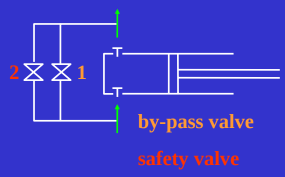
3. Adjustment of flowrate

The flowrate is independent of pipelines.



Adjustment of flowrate:

- by-pass
- change the speed and swept distance of piston.
- **No valve in the delivery pipe !**



2.4 Other pumps in chemical industries

2.4.1 Non-positive displacement type

- axial flow pump
- vortex pump

2.4.2 Positive displacement pump

- diaphragm pump
- metering pump
- gear pump
- screw pump

(gear pump, screw pump: rotary pumps)

2.4.3 Comparison of pumps

2.5 Equipment for Delivery of Gases

- **Mechanism:**

  similar to that for liquid delivery.

- **Main applications:**

  (1) deliver gases

  (2) develop high pressure

  (3) produce vacuum

Features of gases:

- compressible, low density

Characteristics of gas delivery:

(compared with liquid delivery):

- large volume and velocity

  ↓

- compression → changes in volume and T

  ↓

- different structure of conveying machine

Types of delivery machine for gases:

- According to the **structure of machine** and **mechanism**:
- centrifugal
- axial-flow
- reciprocating
- rotary

- According to the **outlet pressure**:
- **ventilator:** $p_{outlet} \le 15$ kPa (gage), compression ratio 1 ~ 1.15;
- **blower:** p_{outlet} = 15 kPa ~ 0.3 MPa (gage) , compression ratio < 4;
- **air compressor:** $p_{outlet} \ge 0.3$ MPa (gage) , compression ratio > 4;
- **vacuum pump:** p_{outlet} = 1 atm, p_{inlet} ~ vacuum.

2.5.1 Ventilators

1. Axial-flow ventilator

2. Centrifugal ventilator

- Mechanism:

  the same as that of centrifugal pump
- Structure: similar to centrifugal pump
- Characteristic parameters:

  flowrate (or 风量), m^3/h(inlet)

  head (or 风压, 全压) p_T, power, efficiency

Neglecting the potential and kinetic energy at the inlet, the head is

$$p_T = (p_2 - p_1) + \frac{\rho u_2^2}{2} \qquad (2\text{-}36)$$

static head p_S kinetic head p_K

The characteristic curves are determined experimentally by manufacture, with the air at 20°C and 0.1 MPa.

For other cases, conversion should be made.

2.5.2 Blowers

- Rootes blower

  rotary, positive displacement
- centrifugal blowers (turbine)

2.5.3 Compressors

- reciprocating piston compressor
- centrifugal compressor (turbocompressor)

2.5.4 Vacuum pumps

- reciprocating piston vacuum pump
- water ring vacuum pump
- liquid-ring pump (Nash Hytor pump)
- ejector

Exercises:

2 – 13

要求：

1. 离心泵

了解
- 工作原理及主要零部件
- 性能参数与特性曲线
- 气缚与汽蚀现象
- 安装高度的确定原则
- 类型

掌握
- 工作点
- 流量调节
- 选用方法

2. 往复泵

了解
- 工作原理及主要结构
- 性能参数
- 流量调节

3. 其它泵以及气体输送设备

了解
- 工作原理和流量调节
- 离心式通风机的主要性能与特性曲线。