A SunCam online continuing education course

Chemical Feed System Design

by

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Course Outline:

Overview of Chemical Feed Systems

A chemical feed system is a group of components that work together to inject a chemical solution into a destination fluid, such as a tank, pipe, or channel. The chemical feed rate is typically paced, or metered, at an adjustable flow rate based on achieving a target dosage, concentration, or another parameter (e.g. pH, chlorine residual, etc.) in the destination fluid.

The chemical may be in any of the following forms:

- Liquid solution (the focus of this course)
- Dry powder, granules, pellets, or tabs (volumetric or gravimetric feed)
- Gaseous (pressurized cylinders or canisters)
- On-site generation (chemical mixing and reactions)

A liquid chemical feed system typically includes the following components:

- Chemical unloading station
- Storage tanks and day tanks
- Feed pumps
- Piping, valves, and instruments
- Injection locations

See Figure 1 for a schematic of an example chemical feed system.

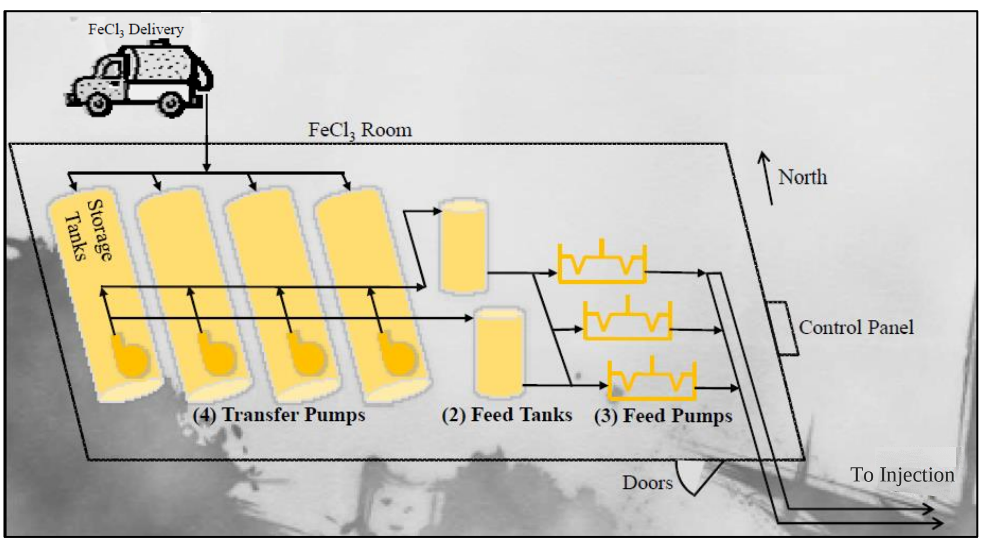


Figure 1: Schematic of a ferric chloride ($FeCl_3$) chemical feed system.

Industries

Chemical feed systems are commonly used in many industries around the world, including the following:

- Biomedical
- Chemical
- Consumer Products
- Food & Beverage
- Heating, Ventilation, and Air Conditioning
- Manufacturing
- Oil & Gas
- Water & Wastewater

Each industry has a variety of applications. For example, the following are common chemical feed applications at a water treatment plant:

- Coagulation
- Corrosion Control
- Disinfection
- Flocculation
- Fluoridation
- Odor Control
- pH Adjustment
- Sludge Conditioning
- Softening

Many types of engineers regularly encounter chemical feed systems, including:

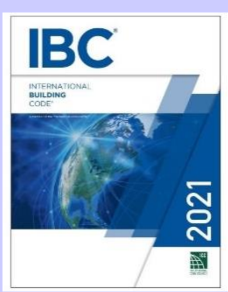
- Chemical Engineers
- Environmental Engineers
- Industrial Engineers
- Mechanical Engineers
- Nuclear Engineers
- Petroleum Engineers
- Process Engineers

Engineers are expected to design chemical feed systems that are sized to handle the range of design conditions, that meets regulations, and that can be operated safely. This course will help prepare you for these tasks.

Regulatory Requirements

Chemical feed systems have many regulatory requirements due to the safety hazards involved with chemical handling. Table 1 lists common regulations that are likely to apply to any chemical feed system design:

Table 1: Regulations and Standards for Chemical Feed Systems	
Federal Regulations	
OSHA	• 29 CFR 1910 Subpart H entitled “Hazardous Materials” including: ○ Standard 1910.106 entitled “Flammable Liquids” with the following design topics: ▪ Chemical categories ▪ Storage tanks ▪ Piping, valves, and fittings ▪ Containment ▪ Loading and unloading ▪ Ventilation
EPA	• 40 CFR 264 entitled “Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities” including: ○ Subpart I (264.170 – 264.179) entitled “Use and Management of Containers” ○ Subpart J (264.190 – 264.200) entitled “Tank Systems”
State Regulations	
State Environmental Agency	Vary by State
Building Codes	Vary by State
Adopted Codes	Commonly Adopt NFPA, IBC, Ten States Standards, and other standards
Local Regulations (Vary by Municipality)	

Standards	
NFPA	• NFPA 1 entitled "Uniform Fire Code" including: ○ Division IV, Section 80.402, entitled "Spill Control, Drainage Control, and Secondary Containment" • NFPA 30 entitled "Flammable and Combustible Liquids Code" • NFPA 395 entitled "Standard for the Storage of Flammable and Combustible Liquids at Farms and Isolated Sites" • NFPA 400 entitled "Hazardous Materials Code" • NFPA 401 entitled "Recommended Practice for the Prevention of Fires and Uncontrolled Chemical Reactions Associated with the Handling of Hazardous Waste" • NFPA 430 entitled "Code for the Storage of Liquid and Solid Oxidizers" • NFPA 432 entitled "Code for the Storage of Organic Peroxide Formulations" • NFPA 497 entitled "Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas" • NFPA 820 entitled "Standard for Fire Protection in Wastewater Treatment and Collection Facilities"
IBC 	• Section 414 entitled "Hazardous Materials" • Section 415 entitled "Groups H-1, H-2, H-3, H-4 and H-5"

The following are important regulatory requirements that apply to most chemical feed system designs:

- Incompatible chemicals should not be stored in the same containment area or piped together to prevent chemical reactions and safety hazards.
- Chemical hazard warning signs shall be placed on tanks. See Figure 2.
- Chemical feed lines should be labeled or color coded.
- Storage tanks, mixing tanks, and pumps shall be above the base flood elevation.
- Heating, ventilation, and dehumidification shall be provided in chemical rooms for worker respiration and equipment longevity.
- Fire suppression type and size shall be in accordance with the room classification and compatible with the chemicals present.
- Emergency (standby) power shall be provided.
- Include alarms for overflows, spills or equipment failures
- Provide spill containment to contain accidental spills of chemicals:
    - Tanks:
        - Available methods:
            - Containment curbs,
            - Walls with barriers at doorways,
            - Double walled tanks, or
            - Floor drains with drain piping to a buried tank.
        - Indoors: Containment volume shall be sufficient to contain 110 percent of the volume of the largest chemical storage tank plus the volume of fire sprinkler water for a period of 20 minutes.
        - Outdoors: Containment volume shall be sufficient to contain 110 percent of the volume of the largest chemical storage tank plus the volume of a 24-hour rainfall from a 25-year storm.
    - Piping:
        - Double contain the following piping:
            - Piping not in a contained area to prevent environmental release.
            - Overhead piping to prevent dripping on people below.
            - High-pressure piping to prevent sprays on people.
    - Chemical unloading stations:
        - Provide containment at hose connections as needed to prevent the environmental release of leaks and drips.

- Provide protective equipment such as:
    - Emergency eyewash stations
    - Deluge showers (often combined with an eyewash)
    - Dust collectors (for dry chemicals)
    - Exhaust fans and ducting
    - Leak monitoring and detection equipment
    - Adequate lighting
- For potable water applications:
    - Overfeeding of chemicals shall be prevented with a day tank and/or flow switches at metering pumps.
    - Wetted materials shall be certified to NSF/ANSI Standard 61 or FDA-approved food grade.

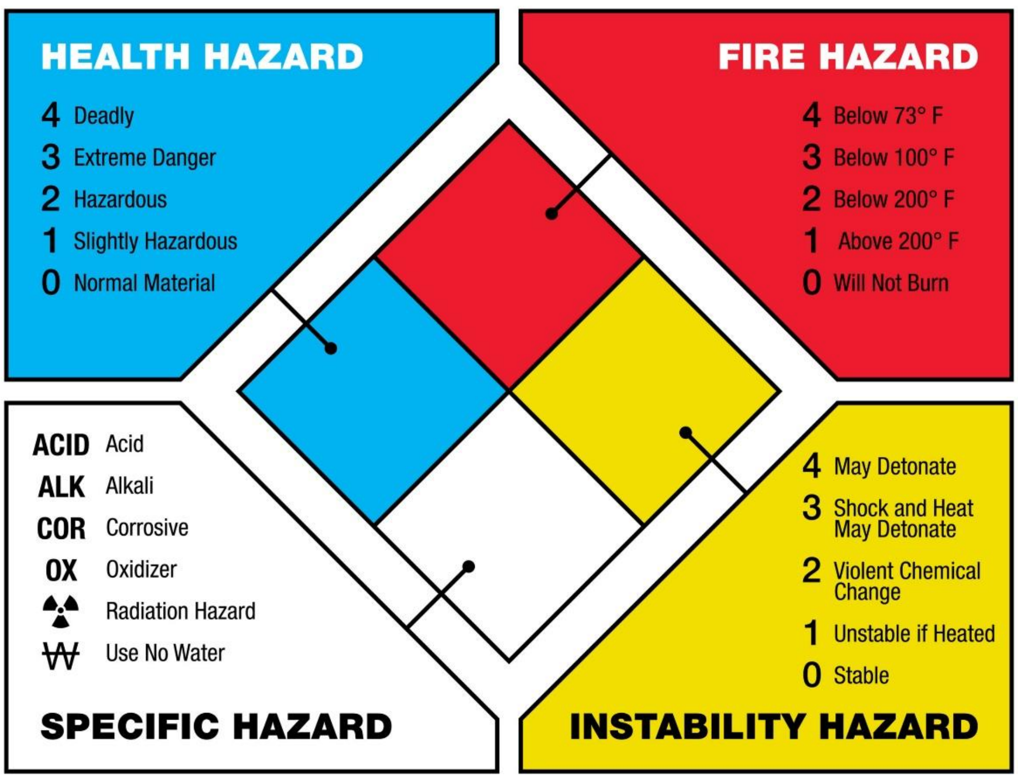
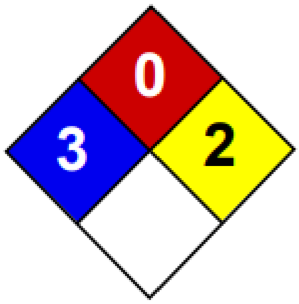


Figure 2: NFPA Fire Rating Label with options listed for each of the four quadrants. This label is commonly called a Fire Diamond

Example Problem 1

Construction superintendent Randy unloaded two chemical tanks to be installed, one for ferric chloride and one for sodium hypochlorite. The fire diamond signs (shown below) were shipped loose, and Randy is not sure which sign is for which tank.



a)

b)

He checks the safety data sheets which indicate the following hazards:

- Ferric chloride: extreme danger health hazard, no fire hazard, potential violent chemical changes.
- Sodium hypochlorite: extreme danger health hazard, no fire hazard, stable, oxidizer.

Help Randy figure out which fire diamond is for which chemical.

Solution:
Fire diamond (a) is for ferric chloride because the yellow 2 indicates “potential violent chemical changes”.

Fire diamond (b) is for sodium hypochlorite because the yellow 0 indicates stable and the white “OX” indicates oxidizer.

Safety Data Sheets

A Safety Data Sheet (SDS) should be obtained for each chemical being considered in the design. The document was formerly called a Material Safety Data Sheet (MSDS). Chemical manufacturers create a unique SDS for every chemical. An SDS contains chemical ingredients, characteristics, hazards, and other relevant information.

Engineers should review the SDS and note important details such as those highlighted in Figure 3. The stability and health hazard sections help to determine the appropriate protective equipment required for the storage and conveyance of the chemical. Often the chemical supplier is not known at the time of design. In that case, SDS from a variety of potential suppliers should be used to ensure the chemical feed design is compatible with chemicals from all the potential suppliers.

Material Safety Data Sheet

Section 1 - Chemical Product and Company Identification

Product/Chemical Name: Aluminum Sulfate, Liquid
Chemical Formula: $Al_2(SO_4)_3 \bullet 14(H_2O)$
CAS Number: 10043-01-3
General Use: Water Treatment Chemical
Emergency Contact: **800-424-9300** Chemtrec

Manufacturer:
Delta Chemical Corporation,
2601 Cannery Avenue,
Baltimore, MD 21226-1595,
Phone 410-354-0100, (7:00am 5:00pm)
FAX 410-354-1021

HMIS	
H	1
F	0
R	0
PPE†	

†Sec. 8

Section 2 - Composition / Information on Ingredients

Ingredient Name	CAS Number	% wt
Aluminum Sulfate	10043-01-3	27.8
Water	7732-18-5	72.2

Toxicity Data:

Section 3 - Physical and Chemical Properties

Physical State: liquid
Appearance and Odor: colorless, clear amber or light green
Odor Threshold: negligible odor
Vapor Pressure: NA
Vapor Density (Air=1): NA
Density:
Specific Gravity (H_2O=1, at 4 °C): 1.32
pH: 2.1 ± 0.5

Water Solubility: Complete
Other Solubilities:
Boiling Point: 109° C/228° F
Freezing/Melting Point: -13° C/9° F
Viscosity:
Surface Tension:
% Volatile: NA

Section 5 - Stability and Reactivity

Stability: Aluminum Sulfate, Liquid is stable at room temperature in closed containers under normal storage and handling conditions.
Polymerization: Hazardous polymerization cannot occur.
Chemical Incompatibilities: Alkalies and water-reactive materials.
Conditions to Avoid: N/A
Hazardous Decomposition Products: Thermal oxidative decomposition of Aluminum Sulfate occurs at temperatures greater than 1400°F and can produce sulfur oxides.

Section 6 - Health Hazard Information

Potential Health Effects

Primary Entry Routes: Ingestion
Target Organs: N/A
Acute Effects No unusual
Eye: May cause a burning feeling.
Skin: May cause a skin rash or burning feeling.

Figure 3: Example first page of an SDS for Alum (Aluminum Sulfate), with important information for design highlighted in red.

Source: https://files.dep.state.pa.us/Water/BSDW/OperatorCertification/TrainingModules/ww07_chem_feed_wb.pdf, deltachemical.com

Design Steps

The design of a chemical feed system can be accomplished in the following steps:

1. Define design criteria
2. Jar testing (if required)
3. Chose an arrangement
4. Create a process flow diagram
5. Design storage tanks
6. Design piping
7. Chose pump type
8. Pump selection
9. Design of ancillary features
10. Detailed design (calculations, plans, specifications, cost estimate, etc.)

The order of these design steps can be modified. Chemical feed design often requires an iterative approach. For example, the pump type (step 7) and pump selection (step 8) may require modifying the process flow diagram (step 4) and piping design (step 6). These inter-dependencies increase the chance for oversights and mistakes and make a final quality review of high importance. Calculations and design decisions should be documented and kept organized for a quality review.

The following sections address the above design steps. Additional guidance can be found in the reference documents in the Helpful References section.

Design Criteria

Defining the design criteria is the first step in ensuring a successful chemical feed design. Design criteria are specific goals for the system. The following are example design criteria to consider:

1. Overall Criteria:
    a. Meet regulatory and safety requirements
    b. Allow future expansion of the system
    c. Minimize footprint
    d. Minimize capital and lifecycle costs
    e. All wetted materials to be compatible with chemicals handled
2. Storage Tank Criteria:
    a. Provide a minimum of 30 days of storage
    b. Provide a minimum of 110% containment volume
3. Pump Criteria:
    a. Pump flow and pressure capacity meets or exceeds demands
    b. Pump type and materials suitable for the chemical
    c. Speed control, stroke control, and minimum turndown allow for minimum flow
    d. Meet lift and NPSH requirements
    e. Locate pumps close to storage tanks
    f. Provide an installed spare pump
4. Piping Criteria:
    a. Double contained except inside tank or pump containment areas
    b. Keep above freezing temperature
    c. Provide interconnecting piping so any pump can feed any injection point

Project stakeholders can provide valuable input when defining design criteria. Stakeholders may include staff from management, operations, maintenance, and consultants. Although the design criteria should be defined at the start of the design process, it is important to review the criteria throughout the design process to confirm nothing is forgotten or neglected, and to avoid redesign.

Design Flow Rates

It is critical to define the required flow and pressure of the system. The required flow rates are often called flow demands or design flow rates. When combined with pressure requirements at the chemical injection points, these are called the system demands or design conditions.

Each pumping system has a unique combination of flow sources and discharge requirements that should be identified and reviewed when defining the design conditions. The design flow rates should be defined for the overall pumping system, regardless of the number of pumps. After deciding the number of pumps and the piping arrangement, the flow rates per pump can be specified.

Common flow rates to define are as follows:

- Minimum design flow, or minimum hourly flow (MHF): This is the smallest flow rate expected to be maintained by the pumping system.
- Average design flow (ADF), or average daily flow (ADF): This is the average flow calculated as the volume of fluid divided by the time period (such as the number of hours or days).
- Maximum design flow (MDF), or maximum day design flow (MDDF): This is the largest of the various calculated or measured flow rates.
- Peak design flow (PDF), peak hourly flow (PHF), or instantaneous peak flow (IPF): This is the highest flow rate (measured in a short interval) to be maintained by the chemical feed system. Often this value is estimated by multiplying the average design flow by a peak factor.
- Ultimate design flow (UDF), ultimate average flow (UAF), or ultimate peak flow (UPF): This is the estimated flow rate to be experienced in the future. Often the system is designed with the flexibility to easily be upgraded to meet the ultimate design flows.

Example Problem 2

Engineer Monica is asked to list the design criteria for feeding a solution of 93% ferric chloride into a water tank to lower the pH. The feed system must reliably pump a peak flow of 4 gph, an average flow of 3 gph, and a minimum flow of 0.2 gph. The injection point is 10 feet below the water surface. Two motor-driven diaphragm pumps with speed control are to be utilized, with an installed spare. Chemical is to be delivered and stored in totes with a volume of 350 gallons, with a minimum of 30 days of storage, assuming feed operations for 6 hours per day. Each tote is to sit on a containment pallet with a minimum of 110% volume. Piping is to be PE tubing with a maximum velocity of 0.5 fps.

Solution:

Monica creates the following Table 2 to summarize the design criteria.

Table 2: Ferric Chloride Feed System Design Criteria	
Storage	
Chemical	93% ferric chloride
Totes	2 x 350 gallons
Containment Pallet Size	385 gallons (minimum)
Pumps	
Pump Type	Motor-driven diaphragm
Number of Pumps	3 (2 duty + 1 standby)
Drive Type	Variable frequency
Flow Range, per Pump	0.2 to 2 gph
Turndown	10:1
Max. Pressure	Static: 4.3 psi (10 ft) Dynamic: TBD
Piping and Injection	
Material	PE Tubing
Inner Diameter (in)	0.25
Flow Range	0.2 to 4 gph

The minimum storage volume is 3 gph x 6 hrs/day x 30 days = 540 gallons. Therefore, two 350-gallon totes would be sufficient at 700 gallons.

The minimum inner diameter is calculated as follows:

D_{min}(in) = sqrt(0.408 * Q(gpm) / V(fps))
= sqrt(0.408 * 4 gph * 1hr/60 min / 0.5 fps)
= 0.23 in (rounded up to 0.25 inches)

Chemical Dosing

Common applications for chemical delivery include:

- Feeding into a flow of water in a pipe, channel, or structure
- Feeding a specified volume into a mixing tank with various ingredients
- Feeding into a storage tank to achieve a specified concentration
- Feed rate adjusted based on instrument readings, such as pH, temperature, oxidation-reduction potential (ORP), residual concentration, etc.

Three different dosing/feed rate formulas can be used: volumetric, liquid weight, or dry weight.

1a. Volumetric, flow:

$$\text{Feed rate (gph)} = \frac{\text{Volumetric Dose (ppm)} * \text{Water Flow Rate (gph)}}{10^6}$$

1b. Volumetric, volume:

$$\text{Feed volume (gal)} = \frac{\text{Volumetric Dose (ppm)} * \text{Water Volume (gal)}}{10^6}$$

2a. Liquid weight, flow:

$$\text{Feed rate (gph)} = \frac{\text{Liquid Weight Dose (ppm)} * \text{Water Flow Rate (gph)}}{\text{Specific Gravity} * 10^6}$$

2b. Liquid weight, volume:

$$\text{Feed volume (gal)} = \frac{\text{Liquid Weight Dose (ppm)} * \text{Water Volume (gal)}}{\text{Specific Gravity} * 10^6}$$

3a. Dry weight, flow:

$$\text{Feed rate (gph)} = \frac{\text{Dry Weight Dose (ppm)} * \text{Water Flow Rate (gph)}}{\text{Specific Gravity} * \text{Chemical Feed Concentration (\%)}/100 * 10^6}$$

3b. Dry weight, volume:

$$\text{Feed volume (gal)} = \frac{\text{Dry Weight Dose (ppm)} * \text{Water Volume (gal)}}{\text{Specific Gravity} * \text{Chemical Feed Concentration (\%)}/100 * 10^6}$$

The formulas express the target chemical concentration in "parts per million" (ppm), which can be defined as follows:

- Volumetric ppm: **volume** parts of chemical per million **volume** parts of solution
- Liquid weight ppm: **weight** parts of chemical per million **volume** parts of solution
- Dry weight ppm: **weight** parts of chemical per million **weight** parts of solution

Note that a 1% concentration solution is 10,000 ppm. A 1% by liquid weight solution is 10,000 mg/L. It is important to check the chemical data sheets to determine if the chemical concentration is expressed in volumetric, liquid weight, or dry weight. The specific gravity can be used to convert from liquid weight ppm to dry weight ppm. Jar test results are most commonly expressed as a liquid weight ppm or mg/L concentration of the chemical constituent (not the overall solution), as different chemical supplier concentrations can be accommodated.

As an example, if you want to dose a flow of water with 5 ppm by volume of sodium hypochlorite, use the volumetric, flow formula (1a). For 5 ppm by liquid weight, use the liquid weight flow formula (2a). If you want to dose a tank of water to achieve 5 ppm by liquid weight of phosphoric acid, use the liquid weight, volume formula (2b).

Example Problem 3

Engineer Dalton is designing an aluminum sulfate (alum) feed system. He performs jar testing of different amounts of an alum solution (15% aluminum sulfate by dry weight, specific gravity of 1.3) and determines the optimal dosage for the overall chemical solution is 20 ppm by volume. The alum is to be injected into a water pipe flowing at 2,000 gpm. What is the required flow rate of the alum solution?

Solution:

Dalton uses the volumetric-based feed rate formula to calculate the flow rate of the chemical solution:

$$\text{Feed rate (gpm)} = \frac{\text{Volumetric Dose (ppm)} * \text{Water Flow Rate (gpm)}}{10^6}$$

$$= \frac{20\text{ ppm} * 2{,}000\text{ gpm}}{10^6} = 0.06\text{ gpm} = \mathbf{3.6\ gph}$$

Dalton expressed the flow rate in gallons per hour (gph), as this is conventional for chemical metering pumps.

Example Problem 4
Continuing problem 3, how many pounds per day of aluminum sulfate will be added?

Solution
The following "pounds formula" can be used to convert concentration to load.

Load (lb/d) = conc. (mg/L) * flow (MGD) * 8.34

The actual aluminum sulfate concentration is 15% by dry weight, which is 150,000 mg/L. Thus the load is calculated using the pounds formula:

Alum sulfate (lb/d) = 150,000 mg/L * (3.6 gph * 24 hr/d * 1 MG/10^6 gal) * 8.34

= **108 lb/d**

Arrangements

The design engineer should consider alternative arrangements for the chemical feed system and pick the arrangement that best fits the design criteria. Creating block flow diagrams is a good first step for visualizing and choosing an arrangement. Figure 4 shows example block flow diagrams.

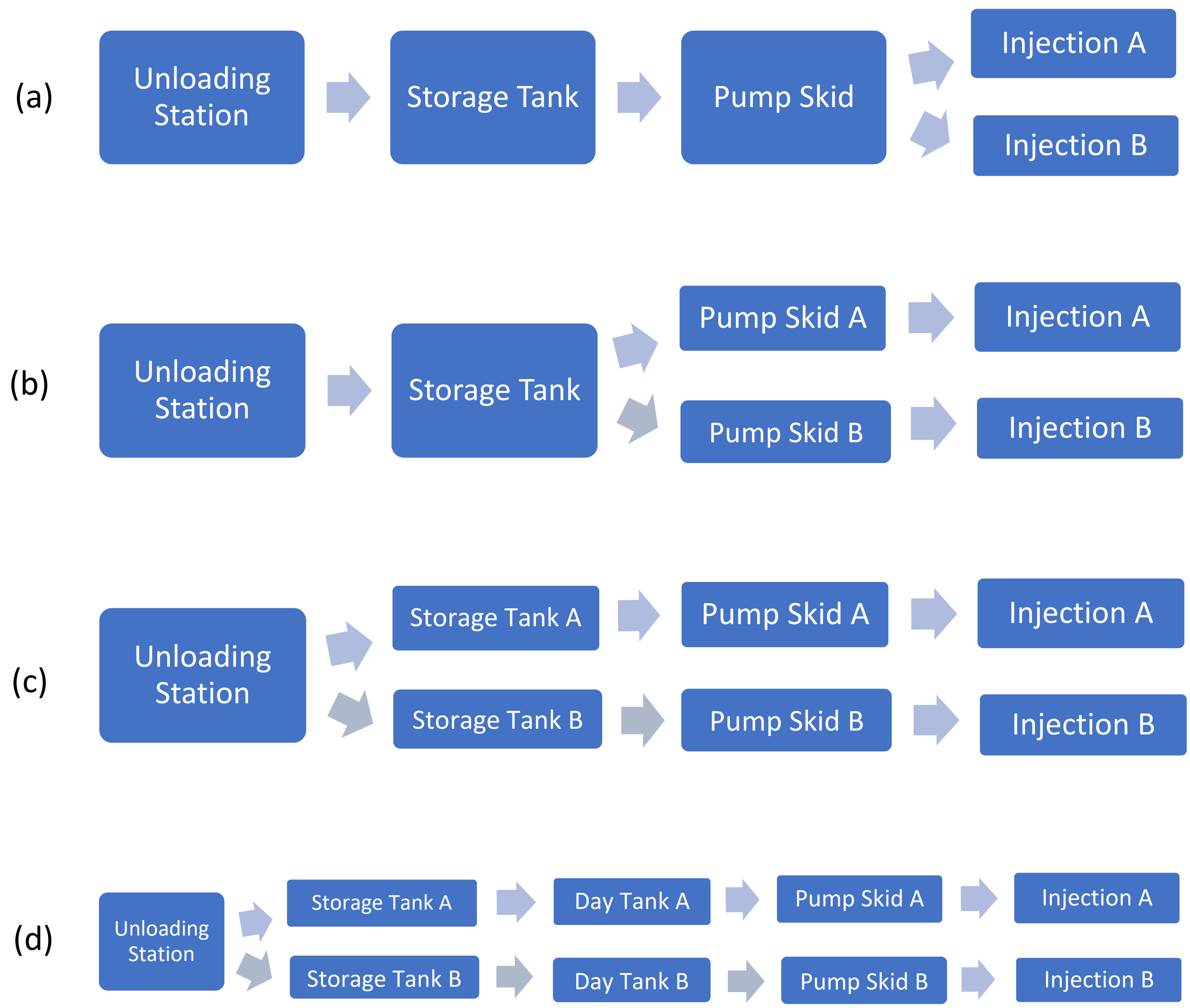


Figure 4: Four possible block flow arrangements for a chemical feed system with two injection points, in order from least redundancy (a) to most redundancy (d).

Day Tanks

Day tanks can be added between large storage tanks (also called bulk tanks) and chemical feed pumps, as shown in arrangement (d) in Figure 4. The benefits of adding a day tank are as follows:

- Comply with regulations for feeding chemicals in potable water systems
- Prevent overfeeding of chemicals
- Allow for more precise measurement of chemical usage
- Adds redundancy for tanks

Day tanks are commonly sized to hold a volume equal to one day of average chemical usage. Day tanks are often avoided by utilizing modern controls and instrumentation features that can prevent overfeeding and precise flow measurements.

Quantity of Pumps

Early in the design process, it is helpful to choose the number of pumps. The assumed number of pumps can be used to make an initial layout and process flow diagram. In later design steps, a pump selection is made and the quantity of pumps can be modified as needed.

A duplex pump arrangement is the simplest design. There is one duty (or lead) pump and one standby (or lag) pump. Each pump is the same and each pump can operate at the peak flow. Chemical feed pumps nearly always have speed control to allow dosing down to the minimum flow required.

A duplex pump arrangement has the following advantages:

- Simplicity in design, construction, and maintenance,
- Easier to calculate the flow/dosing rate and adjust the pump speed,
- Lowest construction cost, and
- Smallest footprint.

Duplex arrangements are common for pumping fluid out of a single storage tank. If there are multiple tanks, either a common suction pipe feeds multiple pumps or each tank can have two pumps. See Figure 5 for alternative pump and tank arrangements.

Using three (triplex) or more pumps is generally beneficial under the following conditions, although this is highly dependent on the type of pump:

- High flow rates (beyond the largest model pump),
- Large flow range (beyond pump turndown ratio),
- Large pressure range, such as greater than 40 psi, and
- Need for additional redundancy (more than one standby pump).

Three or more pumps offer the following benefits:

- Ability to cover a greater range of flows and pressures,
- Better ability to maintain a fixed water level in a tank (suction or discharge),
- If two pumps are out of service, can still pump at average flow, and
- Increase in pumping efficiency with associated energy savings.

For chemical feed systems, it is best to have all the pumps the same size. Having different size pumps adds complexity and is not commonly required since positive displacement pumps are commonly used. Positive displacement pumps can provide a large flow range (turndown ratio) through speed and/or stroke control.

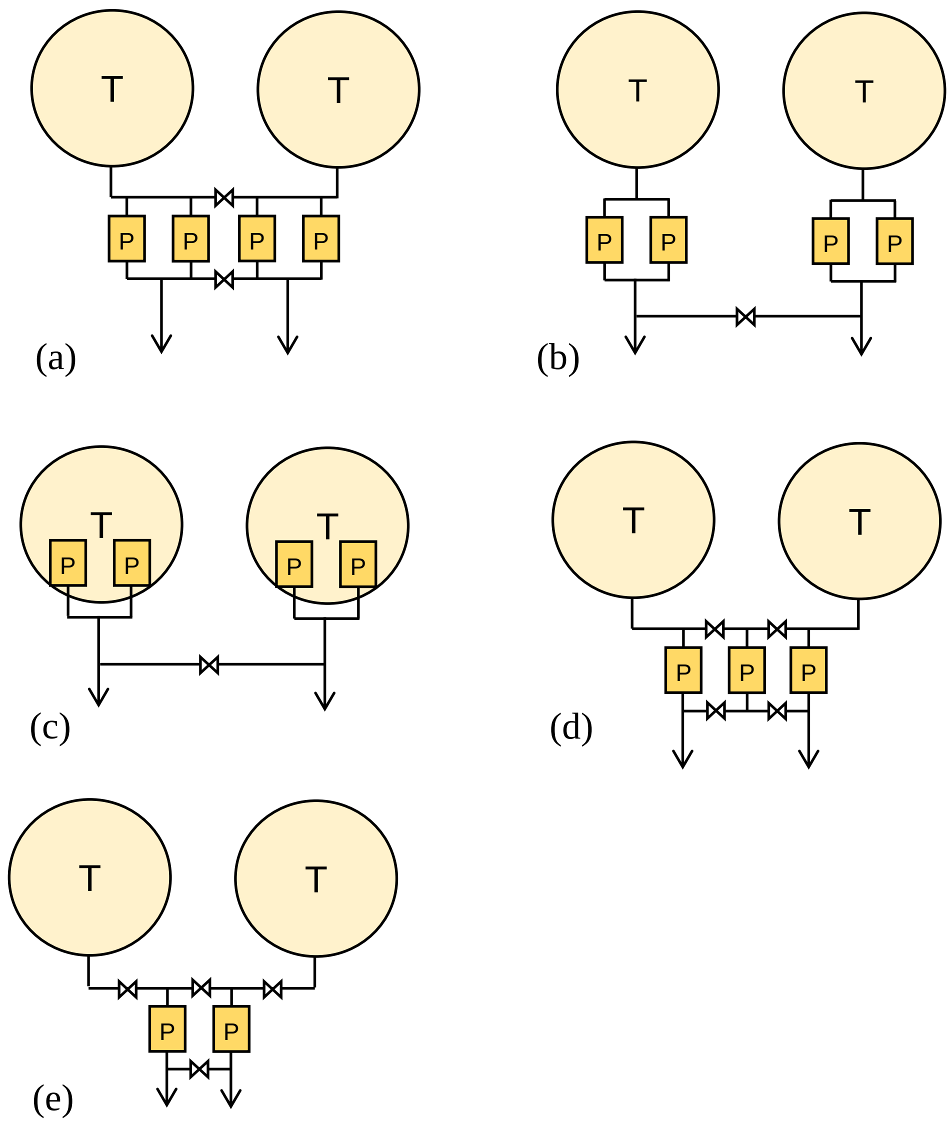


Figure 5: Alternative tank (T) and pump (P) arrangements to provide for redundancy of tanks, pumps, and piping. For (c), the pumps are mounted on top of the tanks. The level of redundancy decreases from (a) highest to (e) lowest. The capital cost also decreases from (a) highest to (e) lowest.

Source: Author

Process Flow Diagram

Early in the design process, it is important to make a schematic drawing of the overall chemical feed system. This may start as a back-of-the-envelope sketch with boxes and lines, similar to the tank and pump configurations in Figure 5. As the design develops, a more formal diagram should be developed and drawn in CAD. A process flow diagram (PFD) is a simple schematic showing major components such as pumps and tanks, and lines representing the piping.

See Figures 6 to 8 for example PFDs. Note that these examples have valve and instrument details that would normally be developed later in the design.

PFDs are often used by electrical and controls engineers to create instrumentation and controls diagrams (P&IDs). P&IDs include symbology for controls features, such as instrumentation, control panels, and communications. See Figure 9 for an example P&ID.

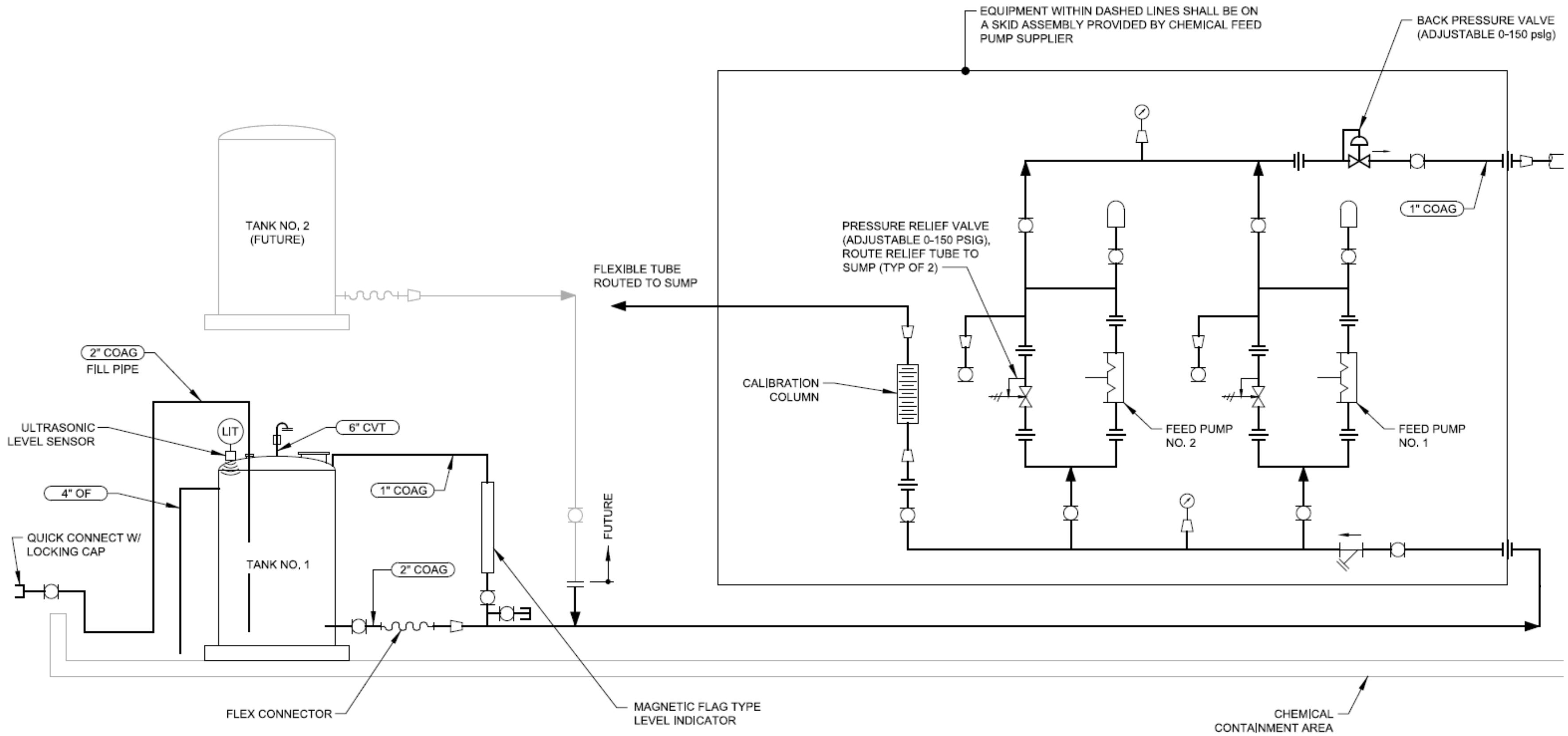


Figure 6: Example PFD for a chemical feed system with two diaphragm pumps, one storage tank, and a pipe connection for a future tank (in grey).

Source: Author

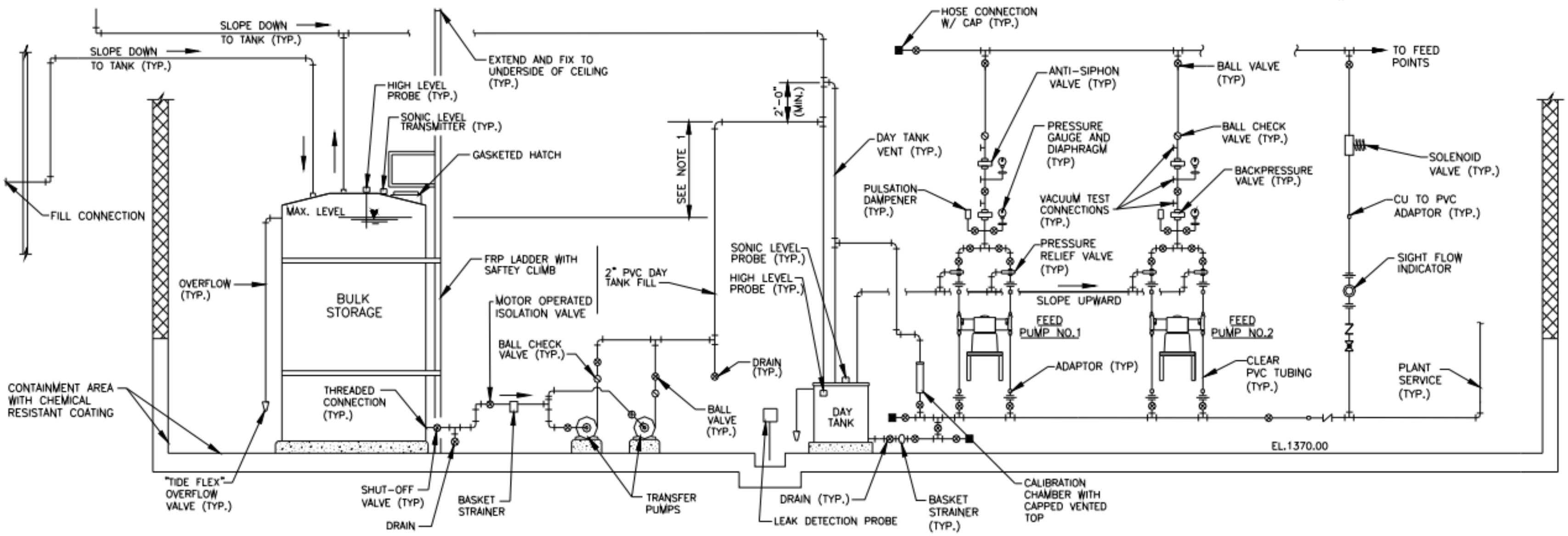


Figure 7: Example PFD for a chemical feed system with transfer pumps and a day tank, followed by two feed pumps.

Source: https://files.dep.state.pa.us/Water/BSDW/OperatorCertification/TrainingModules/ww07_chem_feed_wb.pdf

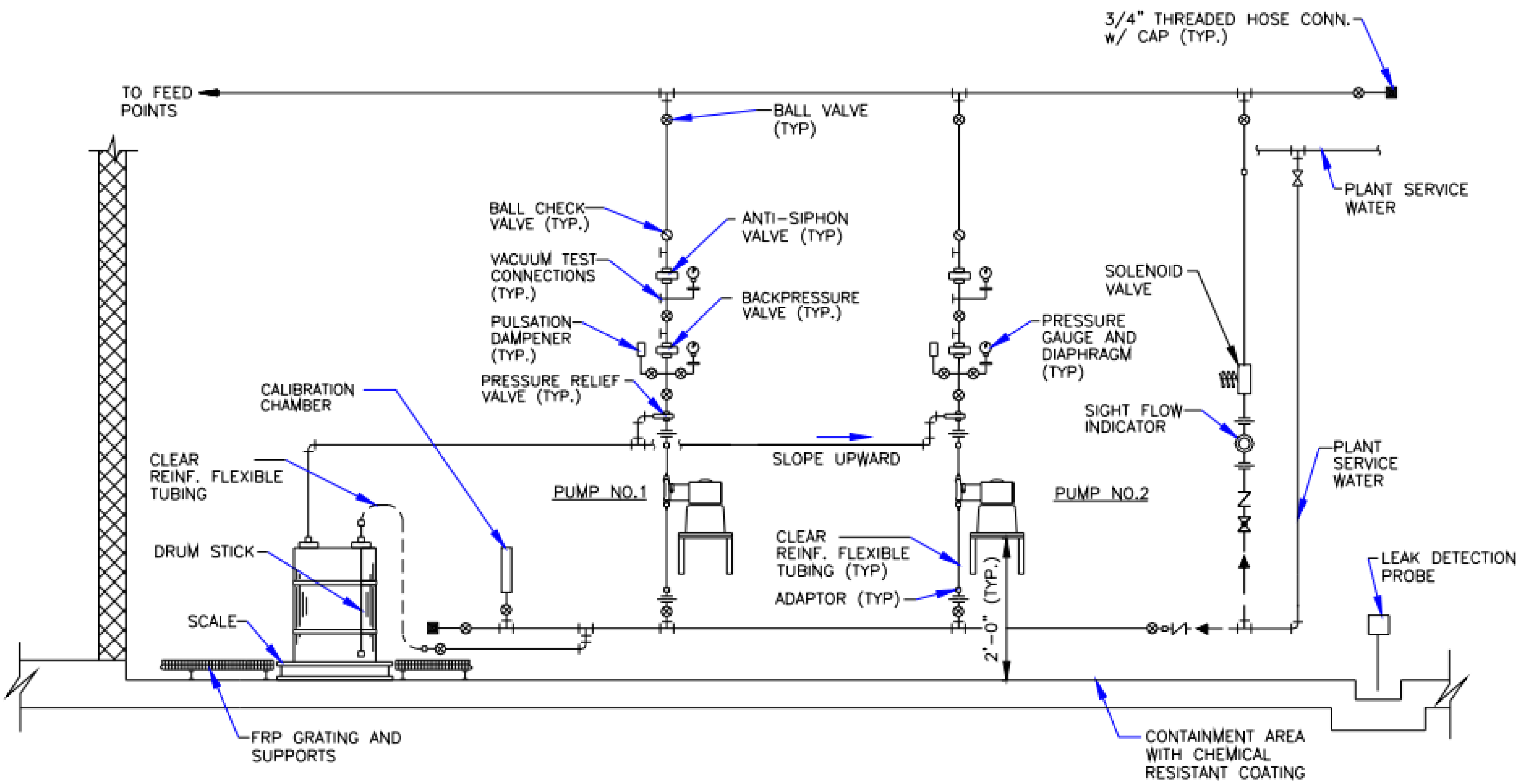


Figure 8: Example PFD for a chemical feed system with a drum (similar to a tote) and two feed pumps.

Source: https://files.dep.state.pa.us/Water/BSDW/OperatorCertification/TrainingModules/ww07_chem_feed_wb.pdf

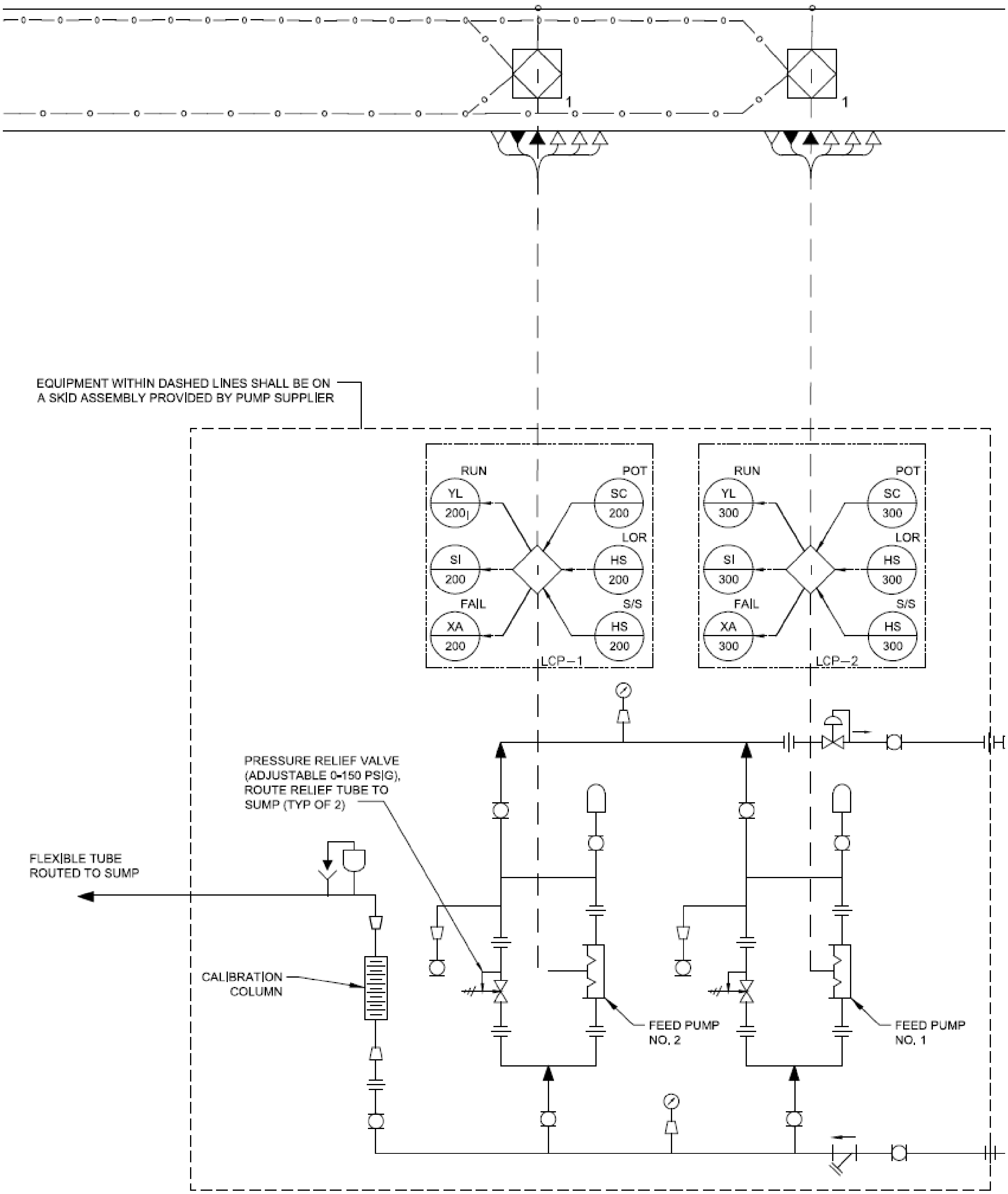


Figure 9: Example P&ID for two pumps, with symbols indicating the controls design.

Source: Author

Chemical Storage Tanks

Chemical storage tanks are also called "bulk tanks". Table 3 summarizes the common types of tanks for liquid chemical storage. For gas chemicals, compressed gas cylinders are common. For dry chemicals, silos and cone bottom batch tanks are common.

Table 3: Common Types of Storage Tanks

Tank Type	Example
Vertical Cylindrical	 Source: Public Domain

Vertical on Legs	 Source: Public Domain
Vertical Rectangular	 Source: Author

Horizontal Cylindrical	 Source: https://commons.wikimedia.org/wiki/File:20,000-gallon_Fuel_Tanks_(39126798444).jpg, Tony Webster, CC-BY-2.0
Drums or Barrels	 Source: https://commons.wikimedia.org/wiki/File:Fuel_Barrels.JPG, Trevor MacInnis, CC-BY-SA-2.5
Totes	 Source: commons.wikimedia.org/wiki/File:Pueblo_Chemical_Agent-Destruction_Pilot_Plant_ Immobilized_Cell_Bioreactor_Area_(10022064684).jpg, PEO ACWA, CC-BY-2.0

Buried	 Source: Public Domain

Engineers are to specify a tank material that is compatible with the chemical being stored. Example tank materials are as follows:

- Fiberglass (FRP)
- High-Density Polyethylene (HDPE)
- Polypropylene (PP)
- Steel with Interior Coating/Lining (e.g. high solids epoxy)
- Stainless Steel (304L, 316L, or duplex)

Tank mixing is required for some chemicals such as coagulants. Mixing options include:

- Side entry mechanical mixer
- Top mounted mechanical mixer
- Submersible mechanical mixer
- Jet mix system with flow recirculation
- Aeration mixing

The following are common design practices for chemical storage tanks:

- Size for total volume for 30 days at average dosage
- Clearly label with chemical name and NFPA fire diamond.
- Cover tanks to prevent items from falling inside.

- Chemical storage tanks are generally not buried (except for fuel tanks) due to the risk of leaking and groundwater contamination.
- Indoor tanks to have vents routed outside with an insect screen.
- Provide an overflow routed to a containment area. For indoor tanks, the overflow pipe shall have a liquid trap filled with mineral oil to avoid evaporation.
- Provide a valved drain at the bottom of the tank, routed to a containment area.
- Either check valves or "fail to closed position" valves are used to prevent overfeeding of chemicals and to prevent fluid from traveling from the injection stream backwards into the storage tank.
- Include redundant liquid level indicators or float switches.
- Outlets shall be flush with tank floor when possible, with integrally molded fittings for FRP, HDPE, and PP tanks.
- For chemicals that may crystallize, tank outlets shall be at least 6 inches above the tank bottom.
- Outlets shall have a flexible connection to avoid load transfer to the tank nozzle.
- Locate feed pumps close to storage tanks to avoid suction problems and simplify the arrangement.
- Provide containment with a volume of 110% of the largest tank plus 20 minutes of fire flow or stormwater flow, as explained in the Regulatory Requirements Section.
- A double wall tank often complies with tank containment requirements.
- Containment surfaces to have a chemically compatible coating.
- Containment shall have a level sensor or leak detector to alert staff of a chemical spill.

Chemical unloading stations shall include the following:

- Containment at fill connections to capture leaks
- Lockable cap at fill connection
- Fill connection is typically a Camlock quick-connect type fitting with a cover
- Shut off valve and/or check valve close to fill connection
- Tank level indication visible to filling operator
- Tank high-level alarm including an audible horn

Chemical Feed Pumps

The feed pumps are “the heart” of a chemical feed system. The pump design is often the most challenging aspect of a chemical feed system design. The following guidance and examples are to help tackle this challenge.

Pump Selection

The pump type, model, and size should be chosen to meet the design criteria, namely fluid type, flow, and pressure. This is known as pump selection or pump sizing. The design engineer is expected to confirm the proper pump selection.

The following are typical steps for the pump selection process:

1. Review pump design criteria
2. Select the type of pump
3. Define operating points with hydraulic calculations, if applicable
4. Review pump manufacturer literature including pump curves
5. Make a preliminary pump selection
6. Compare and choose a pump
7. Plot pump curve on the system curve, if applicable
8. Confirm pump capacity at different pump conditions
9. Review net positive suction head (NPSH)
10. Select motor HP, if applicable
11. Design pump connections, mounting, etc.
12. Quality review of the entire pumping system

Examples of pump selection techniques are provided in this section. For further details, consult the Helpful References Section.

Pump Type

Pumps are mechanical devices that move fluids. Chemical feed pumps are typically positive displacement pumps (not centrifugal pumps) for the following main reasons:

- Fewer moving parts touching the chemical
- Greater chemical compatibility
- More consistent flow rate
- Pressure fluctuations have minimal impact on flow rate
- Greater flow rate range

A positive displacement pump has chambers that repeatedly fill (suction) and empty (discharge) to displace (move) fluid, as depicted in Figure 10. This results in the discharge of a known amount of fluid for each fill and empty cycle.

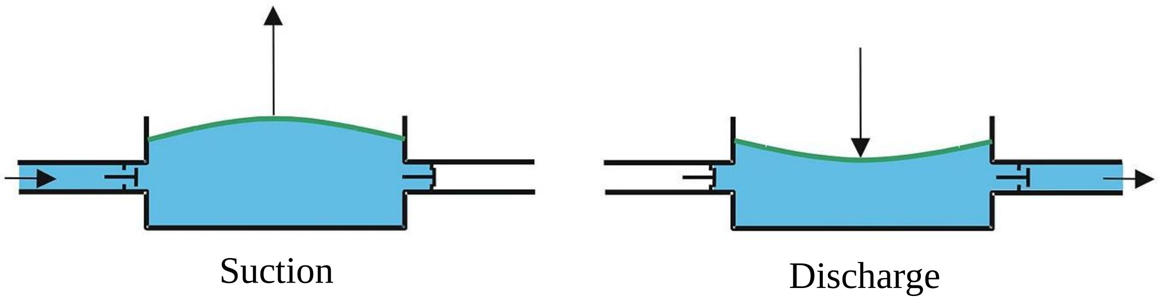


Figure 10: A reciprocating positive displacement pump head during the fill cycle (left) and discharge cycle (right). In this case, a diaphragm moves up to pull in fluid from the left, then moves down to push out fluid to the right. There are check valves to ensure flow only moves to the right.

Source: https://commons.wikimedia.org/wiki/File:Membranpumpe_Pumpen.jpg, Schorschi2, CC BY-SA 3.0

Positive displacement (PD) pumps deliver a constant flow rate regardless of the suction and discharge pressures. This differs from centrifugal/rotodynamic pumps which use spinning impellers to move fluid. A centrifugal pump delivers different flow rates at different pressures.

Positive displacement pumps are grouped into two main categories:

- Reciprocating Pumps:
    - Uses back and forth (oscillating) motion to move fluid.
    - Accelerates the fluid with each cycle (a.k.a. pulsation).
    - Requires check valves on each end of the pump head.
    - The example in Figure 10 is a reciprocating pump.
    - Common pump types for chemical feed:
        - Air Diaphragm Pumps
        - Controlled-Volume Diaphragm Pumps

- Rotary Pumps:
    - Uses rotating motion to move fluid.
    - Delivers a more consistent flow of fluid.
    - Common pump types for chemical feed:
        - Peristaltic Pumps
        - Gear Pumps
        - Rotary Lobe Pumps

The following are other pumps common for high chemical feed rates:

- Eductor Jet Pumps
- Centrifugal Pumps

The following tables provide details for each of these types of pump.

Air Diaphragm Pumps		
Function	**Configurations**	**Common Applications**
Compressed air moves a diaphragm back and forth, drawing fluid in and pushing fluid out.	• Single diaphragm • Double diaphragm	• Low to medium viscosity • Medium to high flow rates • Food grade sanitary • Variety of chemicals

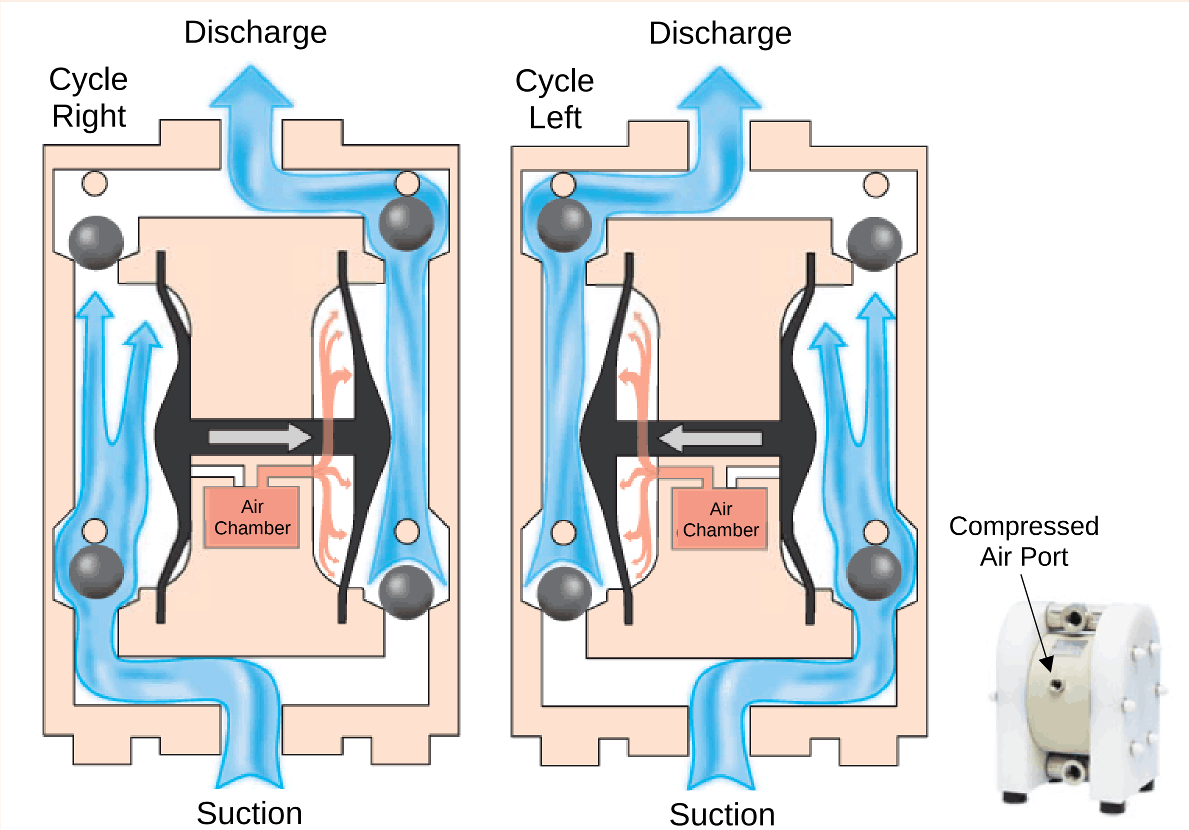


Figure 11: Pump head of an air-operated double diaphragm pump (AODD) showing the operation of the two chambers. The result is a relatively consistent discharge of fluid.

Source: commons.wikimedia.org/wiki/File:Pompe_pneumatique_membrane_tapflo.png, Delange.mobi, CC-BY-SA-3.0

Controlled-Volume Diaphragm Pumps (Most common type of chemical feed pump)		
Function	**Configurations**	**Common Applications**
A motor moves a rod and diaphragm back and forth, drawing fluid in and pushing fluid out. The liquid chamber is designed to pass a precise volume of fluid with each stroke.	• Single diaphragm • Multiplex diaphragm • Solenoid or motor driven • Mechanically coupled • Hydraulic	• A.k.a.: metering pumps, proportioning pumps, or dosing pumps • Low flow, high accuracy • High hazard chemicals • High concentrations • Self-priming • High viscosity

Figure 12: Examples of mechanically actuated diaphragm pumps.
Left: Small metering pump with built-in speed control, control screen, and a standard outlet plug.
Right: Large metering pump with a vertical motor designed for pressures up to 15,000 psi. The wheel is for manual stroke adjustment.

Sources: commons.wikimedia.org/wiki/File:LMI%27s_EXCEL_XR,_Chemical_Metering_Pump.jpg, LaurelBloch, CC-BY-SA-4.0
commons.wikimedia.org/wiki/File:Milton_Roy%27s_Primeroyal_X_Chemical_Metering_Pump.jpg, LaurelBloch, CC-BY-SA-4.0

Peristaltic Pumps		
Function	**Configurations**	**Common Applications**
Moves fluid by squeezing a flexible tube/hose while rotating in a circular or linear casing. The fluid does not touch the pump.	• Hose (with shoes) • Tube (with rollers) • Liner, Microfluidic • Linear (Infusion)	• Chemical metering/dosing • Food grade sanitary • Reactive or unstable chemicals • Self-priming • Low flow (high turndown)

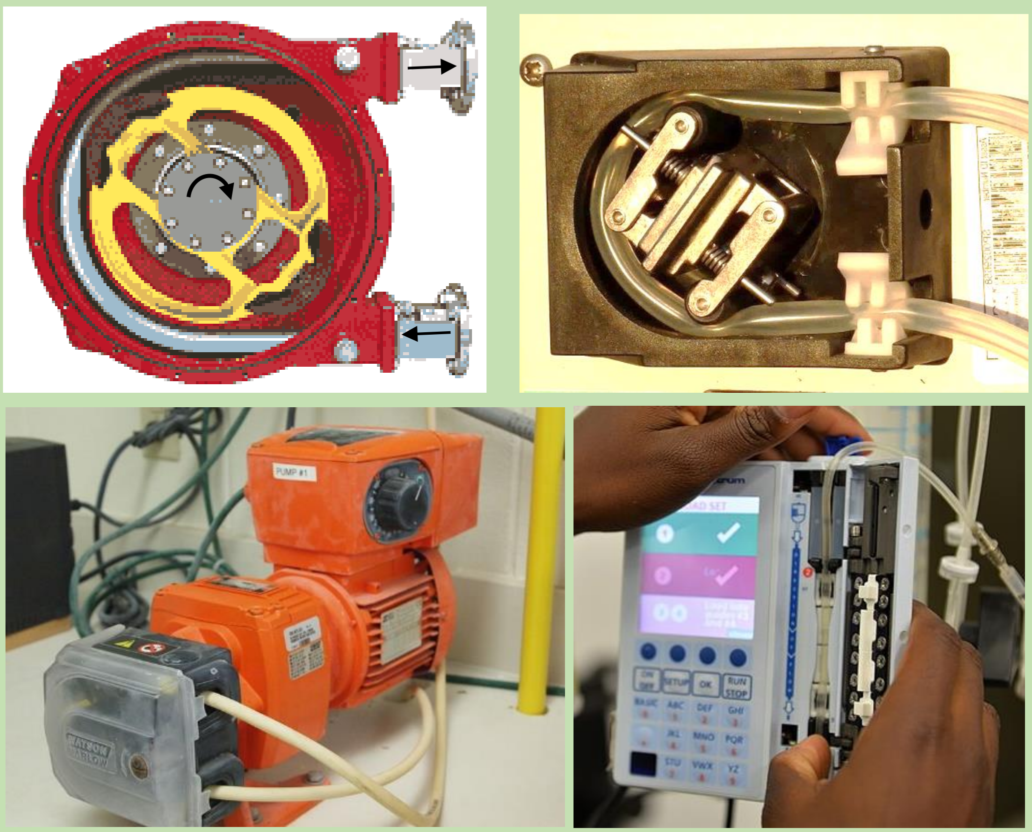


Figure 13: Top left: Hose pump internals with two shoes in black.
Top right: Tube pump internals with two rollers squeezing the clear tubing.
Bottom left: Example of a chemical metering tube pump with a speed control knob.
Bottom right: Linear IV infusion pump for injecting fluids into a patient.

Sources: commons.wikimedia.org/wiki/File:Bredel_Werkingsprincipe_animatie.gif (public domain)
commons.wikimedia.org/wiki/File:Peristaltic_pump_head.jpg, Andy Dingley, CC-BY-SA-3.0
commons.wikimedia.org/wiki/File:Watson-Marlow_Peristaltic_Pump.JPG, Z22, CC-BY-SA-3.0

Lobe Pumps (a.k.a. Rotary Lobe Pumps)		
Function	**Configurations**	**Common Applications**
Moves fluid by two tri-armed rotors rotating in opposite directions. The rotors create growing chambers when passing the inlet and shrinking chambers when passing the outlet.	• Horizontal • Vertical • Stainless or EPDM lobes	• Solids, slurries, pastes • Food, dairy & beverage • Food grade sanitary • Pharmaceutical • Biotechnology • Medium to high flow rates

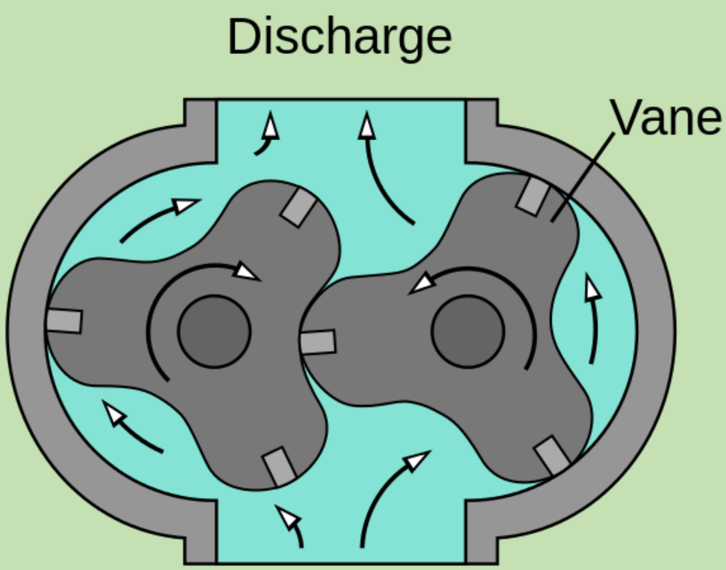


Figure 14: Section of a lobe pump with labels and flow direction arrows.

Source: https://commons.wikimedia.org/wiki/File:LobePump_en.svg, public domain

Gear Pumps		
Function	**Configurations**	**Common Applications**
Moves fluid by the meshing of two gears. The gears create growing chambers when passing the inlet and shrinking chambers when passing the outlet.	• External ○ Spur, helical, herringbone • Internal Gerotor • Internal Cresent	• Adhesives • Food and Beverage • Paint and ink • Petrochemicals • Pulp and paper • Medium flow rates

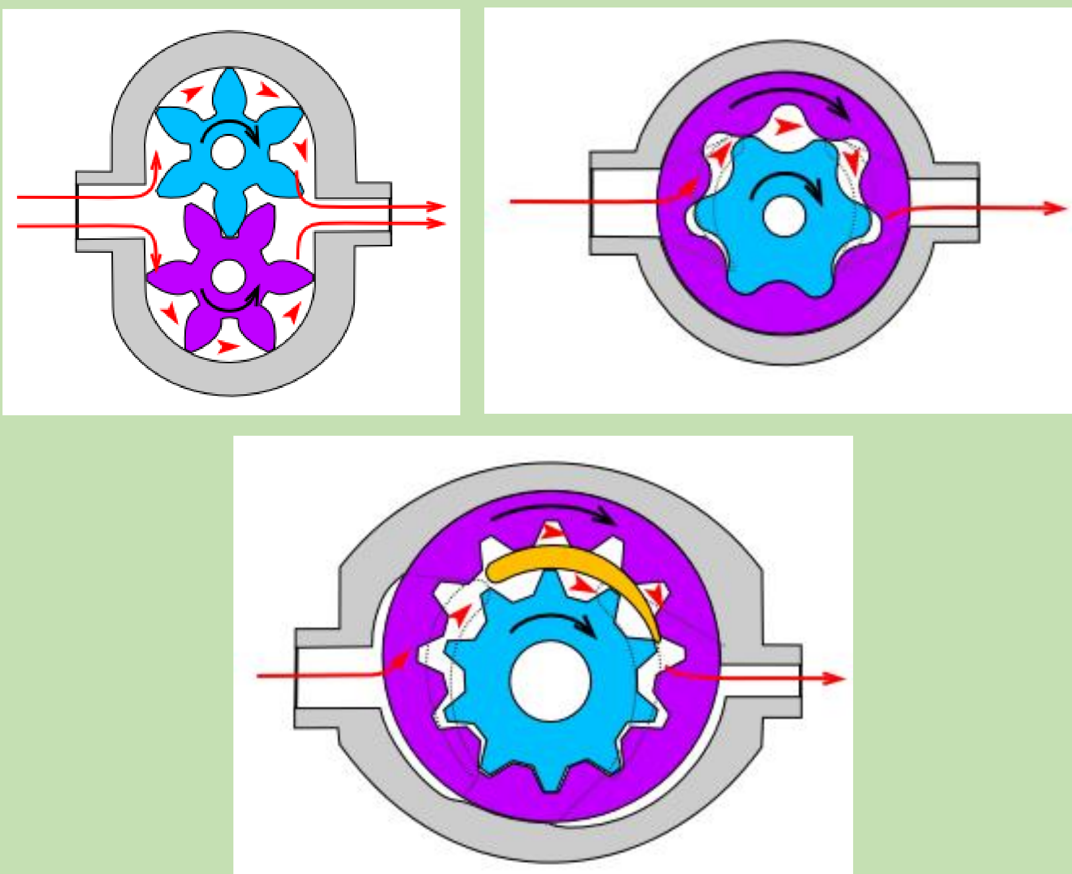
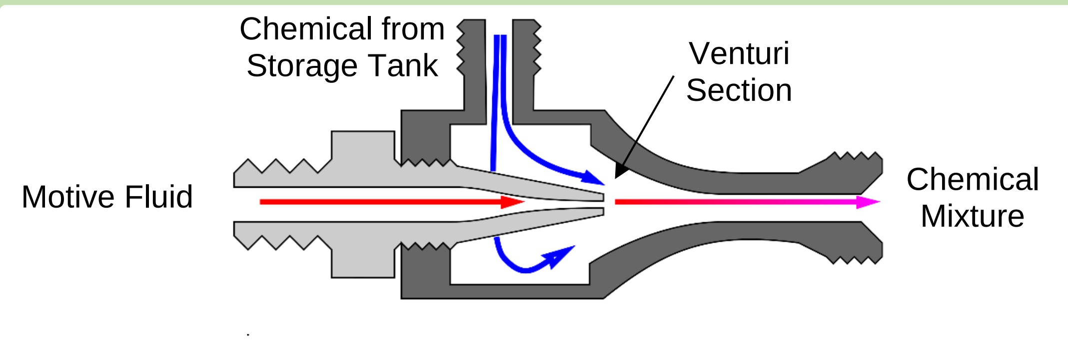


Figure 15: Sections of gear pumps with driver gear in cyan and driven gear in purple. Upper left: External gear. Upper right: Internal Gear Gerotor, Bottom: Internal Gear Crescent.

Source: commons.wikimedia.org/wiki/File:Gear_pump.png, Gear_pump_2.png, Gear_pump_3.png, me, CC-BY-SA-4.0

Eductor Jet Pumps		
Function	**Configurations**	**Common Applications**
Motive liquid (typically water) is pumped at high pressure through the venturi section of the eductor, which is a high velocity, low-pressure zone that draws in the chemical and discharges a mixture of the chemical and the motive liquid.	• Hopper eductor • Solid mixing eductor • A.k.a. venturi pumps, ejectors, or hydro eductors, eductor nozzles	• Lime slurry injection • Aeration of wastewater • Combined chemical injection and mixing • Stable chemicals • Self-priming



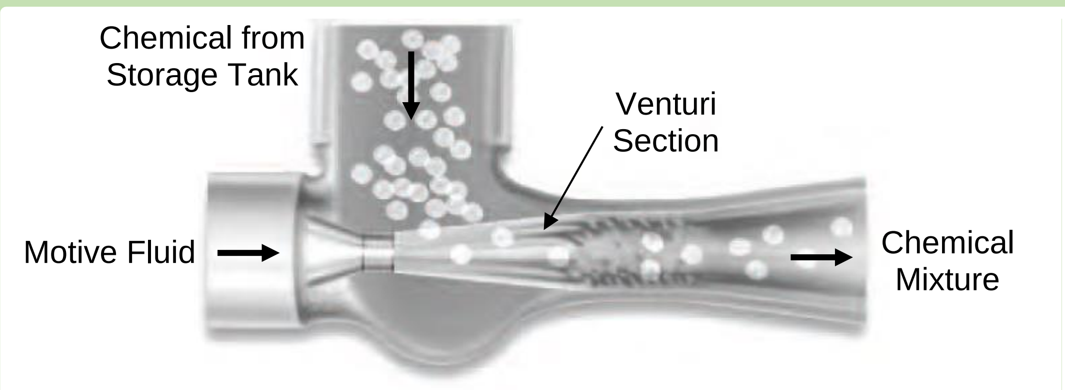


Figure 16: Section views of eductor jet pumps (nozzles).

Source: commons.wikimedia.org/wiki/File:Gear_pump.png, Gear_pump_2.png, Gear_pump_3.png, me, CC-BY-SA-4.0

Centrifugal Pumps		
Function	**Configurations**	**Common Applications**
Fluid enters the pump near the center of the impeller and is accelerated outward (radially) by the spinning impeller to a discharge outlet.	• Vertical sump, vertical suspended column • Sanitary stainless steel	• Clean-in-place (CIP) • Chemical room sumps • Tank recirculation for chemical mixing • Low concentration, high flow chemical feed

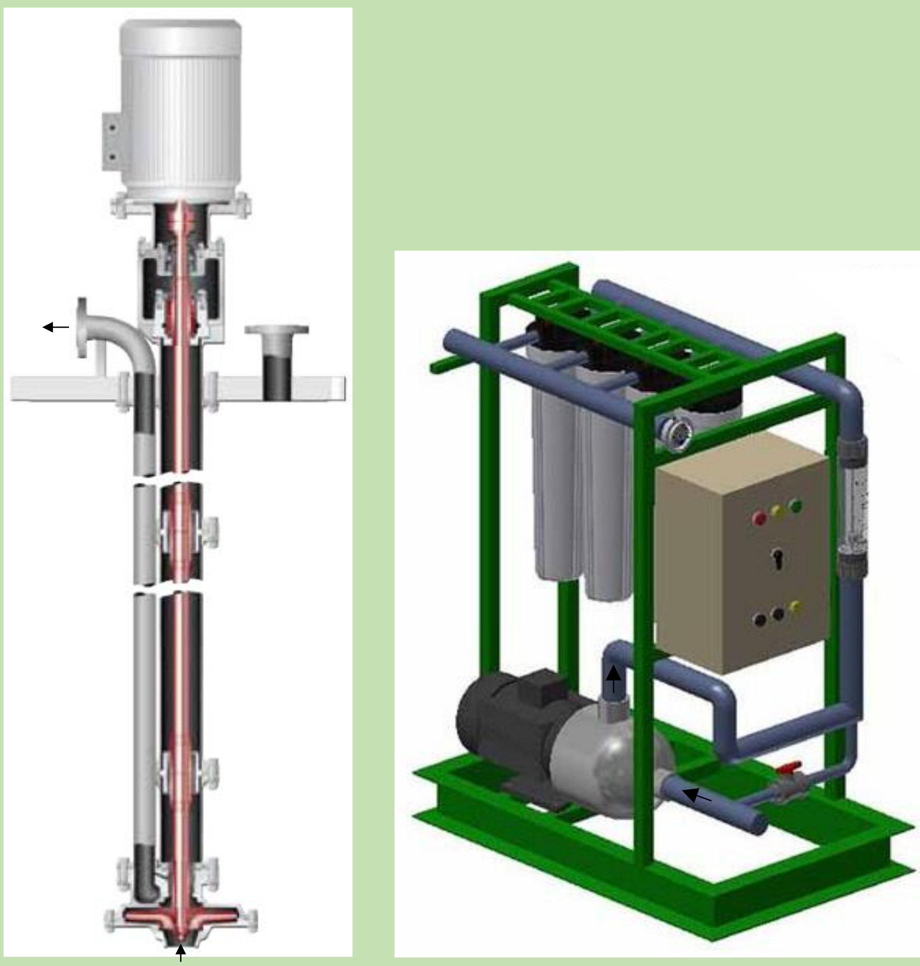


Figure 17: Left: a vertical suspended column centrifugal pump which sits on top of a storage tank. Right: A clean-in-place (CIP) pump skid for chemical cleaning of manufacturing processes.

Source: commons.wikimedia.org/wiki/File:Alat_Cleaning_Membrane_Reverse_Osmosis.jpg, mapurnautama, CC-BY-SA-4.0

Rated Pressure

For positive displacement (PD) pump applications, pressure is often treated differently than for centrifugal pumps. This is because changes in the suction or discharge pressure have minimal impact on the flow rate through most PD pumps. Each PD pump model has a maximum pressure, also called a rated pressure. The rated pressure needs to be greater than the actual delivery pressure at the outlet of the pump.

The anticipated discharge pressures should be listed with the design criteria. For example, if a chemical feed system is to inject a chemical into a pipe with a pressure range of 60 psi to 80 psi, then the design criteria would be an injection pressure of 60 psi (minimum) to 80 psi (peak) at all flow rates.

The pressure at the pump discharge would need to be calculated based on the piping details, however, pipe losses are likely to be small (1 to 3 psi) compared to the injection pressure. Chemical pipe design velocities are often 1 fps or less, compared to 5 fps or more for water applications. This means that pipe friction and fitting losses are relatively small.

Flow Control

Virtually every type of pump can have the flow rate controlled by adjusting the pump speed. For reciprocating pumps, there are two ways to control the flow rate:

1. Stroke Length: By adjusting the distance the piston/plunger/diaphragm moves, the volume of liquid displaced per stroke of the pump is changed.
2. Stroke Speed: By adjusting the speed of the strokes. For example, with a variable frequency drive (VFD).

Positive displacement pumps are often designed to accurately control the flow rate to a 10:1 turndown ratio, which is 10% of the design capacity. Many metering pumps (controlled-volume diaphragm pumps) are designed for a turndown of 100:1 (1%) to 1000:1 (0.1%). Note that for centrifugal pumps, the common turndown ratio is 2:1, or 50% speed.

Pump Speed Control

Chemical feed pumps usually have speed control capabilities to control the dosing. This is often achieved by adjusting the pump speed in small increments based on instrument readings and/or programming. Several types of variable speed pumping equipment are available, including variable frequency drives (VFDs), variable voltage drives, eddy current couplings, and mechanical variable speed drives. Many positive displacement pumps come with integral speed adjustment features and a control screen or buttons. Speed adjustment equipment adds a small amount of energy loss, typically 3% to 5%. It is usually wise to include speed control features, in case they are needed or helpful.

Positive displacement pumps typically have a linear speed to flow relationship: if the speed is reduced in half, the flow is reduced in half. The same is true of the stroke length for reciprocating pumps. The formula is as follows:

$$\text{Actual Pump Flow} = \text{Max Pump Flow} * \frac{\%\ \text{Speed}}{100} * \frac{\%\ \text{Stroke}}{100}$$

Example Problem 5

Engineer Tiffany is to determine the pump speed required to deliver 3 gph with a diaphragm pump with a maximum flow of 6 gph and the stroke length set at 80%.

Solution:

Tiffany rearranges the following formula and calculates the pump speed:

$$\text{Pump Flow} = \text{Max Pump Flow} * \frac{\%\ \text{Speed}}{100} * \frac{\%\ \text{Stroke}}{100}$$ rearranged:

$$\%\ \text{Speed} = \frac{\text{Pump Flow} * 100 * 100}{\text{Max Pump Flow} * \%\ \text{Stroke}} = \frac{3\ \text{gph} * 10{,}000}{6\ \text{gph} * 80} = \mathbf{62.5}\%$$

Example Problem 6

Continuing with Example Problem 5, the plant manager informs Tiffany that there are two extra diaphragm pumps in the warehouse with nameplate model/size "E36". Tiffany finds the below data sheets for this pump model. Can these pumps provide the required feed rate of 6 gph with redundancy? If so, at what speed?

Capacity/Pressure Rating

Size	Max Output Capacity		Max output per stroke	Max Pressure		Power Index
	GPH	mL/min	mL	PSI	MPa	GPH x PSI
E31	5.5	340	0.94	150	1.0	825.0
E36	8.5	520	1.44	105	0.7	892.5
E46	12.0	750	2.08	60	0.4	720.0
E56	20.0	1250	3.47	30	0.2	600.0

Solution:

Tiffany finds row E36 in the table and compares the max output capacity of 8.5 gph to the required feed rate of 6 gph. Since the pump capacity is larger, it will work for the application. Since there are two pumps available, there can be one standby pump, thereby providing redundancy. Tiffany calculates the required pump speed as follows, assuming the stroke length will be kept at 100 percent:

$$\%\ \text{Speed} = \frac{\text{Pump Flow} * 100 * 100}{\text{Max Pump Flow} * \%\ \text{Stroke}} = \frac{6\ \text{gph} * 10000}{8.5\ \text{gph} * 100} = \mathbf{70.6}\%$$

Lift

A ***lift*** is when a pump is higher than the suction water level, so the pump must suck up the fluid. ***Self-priming*** is when the pump must pull a lift when the suction pipe is empty. Centrifugal pumps commonly struggle in these situations. Meanwhile, most types of progressive cavity pumps can pull a high lift and be self-priming, as shown in Figure 18.

Pump manufacturers will often provide a maximum lift height. Some positive displacement pumps can achieve a lift of 22 feet. The maximum lift height listed in pump literature makes certain ideal condition assumptions, such as pure water, the pump mounted directly over the tank, no pipe joints, ideal inlet, and ideal pipe diameter. Engineers can check the achievable lift for a particular application by checking the net positive suction head (NPSH).

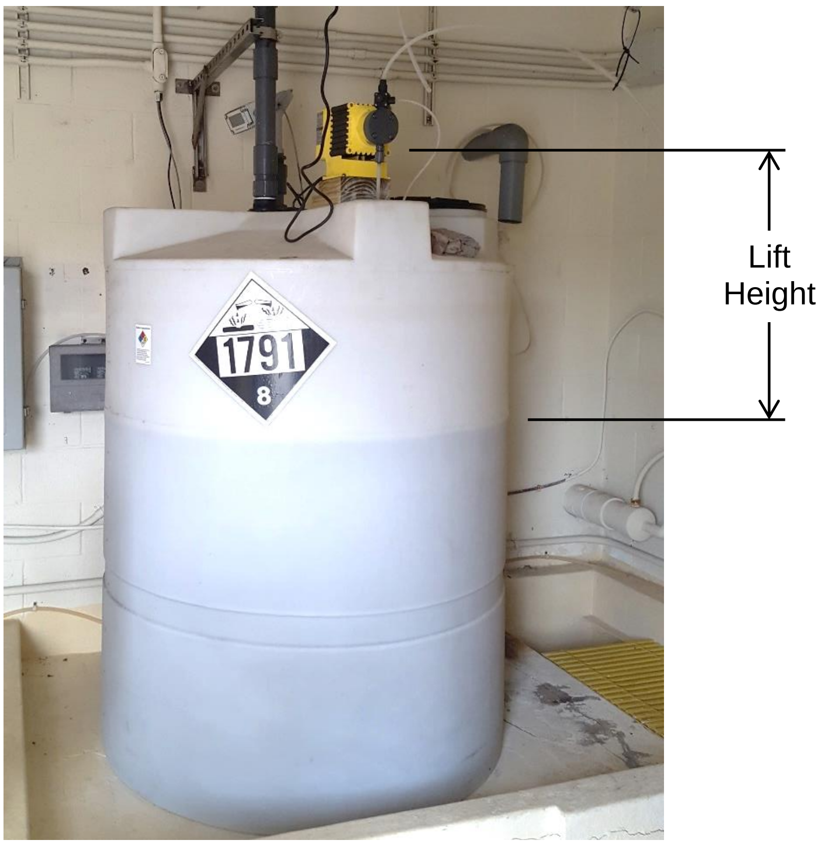


Figure 18: Chemical metering (diaphragm) pump mounted on a tank.
The suction pipe (clear tube) drops straight down into the tank to near the bottom, where there is a foot valve on the inlet (not shown) to keep the tube full of fluid and thereby avoid self-priming. This pump can pull a lift of 7 feet to empty the tank.

NPSH
To avoid cavitation and related pumping problems, the net positive suction head available (NPSHa) should be greater than the net positive suction head required (NPSHr). The NPSHa is based on the details of the intake design, while the NPSHr is from the pump manufacturer.

The design engineer should confirm that the NPSHr value at the maximum flow rate for the selected pump is less than the calculated NPSHa. If the NPSHr is greater than NPSHa, the following options are available to correct the issue:

- Lower the elevation of the pump or increase the water level,
- Increase suction pipe size and eliminate elbows,
- Add pulsation dampeners, or
- Choose a different pump.

The NPSHa formula is as follows, with definitions and an example in Table 4:

$$NPSHa = H_{bar} + h_s - h_{vap} - h_{fs} - h_m - h_{vol} - h_a - FS$$

Table 4: NPSHa Definitions and Calculation

Term	**Example (ft)**	**Definition**
H_{bar}	+33.96	Atmospheric pressure, which is 14.7 psi (33.96 ft) at sea level.
h_s	+2.50	Minimum static head at the pump. Measure the height from pump intake to low water level.
H_{vap}	-1	Vapor pressure of water, at 75 deg F, expressed in feet.
h_{fs}	-0.50	Suction pipe friction losses at the max pump operating flow rate. Perform hydraulic calculations as needed.
Σh_m	-1.96	Suction pipe minor losses at max pump operating flow rate. Perform hydraulic calculations as needed.
h_{vol}	-2	Partial pressure of dissolved gases. For example, air in water (customarily ignored as insignificant) and organics in wastewater (estimated at 2 ft).
h_a	-0	Acceleration head for reciprocating pumps (zero for centrifugal pumps and most rotary pumps). See the formula below.
FS	-5	Factor of Safety, which can range from 2ft to 5ft, or 20% to 35% of NPSHr.
NPSHa	**26.0**	**Sum the above terms**

The acceleration head, h_a, accounts for the cyclic flow from reciprocating pumps such as diaphragm pumps. It is calculated as follows:

$$h_a = \frac{L * v * n * C * SG}{K * g}$$

where:

h_a = Acceleration head (ft), to be subtracted in the NPSHa calculation
L = Length of suction line (ft)
v = Velocity in suction line (fps)
n = Pump speed in rpm
C = Cycle constant for reciprocating pump type (min/s):
- C = 0.4 for simplex, single-acting
- C = 0.3 for simplex, double-acting
- C = 0.1 for simplex double disc
- C = 0.2 for duplex, single-acting
- C = 0.115 for duplex, double-acting
- C = 0.06 for duplex double disc
- C = 0.066 for triplex (three pumps)
- C = 0.04 for quintuplex (four pumps)

SG = Specific gravity of liquid (1.0 for water)
K = Fluid factor:
- K = 2.5 for hot oil and compressible liquids such as ethane
- K = 2.0 for hydrocarbons (crude oil, diesel, fuel oil, lubricating, oil)
- K = 1.5 for water, amine, glycol, most common chemicals
- K = 1.4 de-aerated water
- K = 1.2 wastewater sludge
- K = 1.0 urea and liquids with entrained gases

g = gravitational constant (32.2 ft/s^2)

Example Problem 7

Engineer Dustin is tasked with calculating the acceleration head for two diaphragm pumps in parallel with a common suction tube, for transferring sodium hypochlorite (bleach). The pumps run at 100 rpm. The suction tube is 3/8" diameter and 10 feet in length. The design flow is 10 gph. Help Dustin calculate the acceleration head with one pump in operation and two pumps in operation.

Solution:

First, Dustin calculates the velocity in the pipe, in fps:

$$v = \frac{flow}{area} = \frac{10\ gph * \frac{1gpm}{60gph} * \frac{1\ cfs}{448.8\ gpm}}{\pi\left(\frac{0.375}{12}\right)^2/4} = \frac{0.00037\ \frac{ft^3}{s}}{0.00077\ ft^2} = 0.48\ fps$$

Next, he calculates the acceleration head with one pump running (simplex, single acting):

$$h_a = \frac{\mathrm{L}*v*\mathrm{n}*\mathrm{C}*\mathrm{SG}}{\mathrm{K}*g} = \frac{10\ \mathrm{ft} * 0.48\frac{ft}{s} * 100\mathrm{rpm} * \mathbf{0.4} * 1.0}{1.5 * 32.2\frac{ft}{s^2}} = \mathbf{4.0}\ \boldsymbol{ft}$$

And, with two pumps running (duplex, single acting):

$$h_a = \frac{10\ \mathrm{ft} * 0.48\frac{ft}{s} * 100\mathrm{rpm} * \mathbf{0.2} * 1.0}{1.5 * 32.2\frac{ft}{s^2}} = \mathbf{2.0}\ \boldsymbol{ft}$$

Define Operating Points
At each design flow rate, the pump needs to provide energy, expressed as total dynamic head (TDH), to overcome the energy losses in the piping system and to move the fluid to a higher elevation or pressure at injection. Hydraulic calculations are often required to define the head/pressure requirements at one or more design flows. Note that most positive displacement pumps provide a nearly constant flow rate at all pressures (up to a maximum/rated pressure of the pump).

For centrifugal pumps, TDH is expressed in feet or meters. For positive displacement pumps, the TDH is often expressed as pressure in psi, bar, or MPa. The conversion is 1 ft TDH = 2.31 psi.

For reciprocating pumps and peristaltic pumps, it is not necessary to calculate the TDH at various flows nor to develop a system curve (as is done for centrifugal pumps). Instead, the *delivery pressure* at the pump outlet/discharge needs to be lower than the *rated pressure* of the pump. The delivery pressure is the sum of the pressure at the injection point plus the head losses through the discharge piping at the peak/maximum flow rate.

For rotary pumps and centrifugal pumps, it is common to calculate the TDH at multiple flow rates and plot the resulting system curve and the pump curve.

The formula for TDH is as follows:

$$\mathbf{TDH} = H_{Static} + H_{Lm} + H_{Lf}$$

H_{Static} = Static head (elevation and/or pressure difference from inlet to outlet)
H_{Lm} = Minor losses from fittings, valves, etc.
H_{Lf} = Friction losses from the pipe walls

For further instructions on how to calculate TDH and develop a system curve, see the SunCam course entitled “Centrifugal Pump Selection”.

Pump Model and Size

The design engineer should review tables or charts of the capacity and pressure ranges of various pump models, as shown in Figure 19. This allows choosing a pump model. It is good practice to contact the pump supplier to request pump information and to confirm the pump is a good fit for the application.

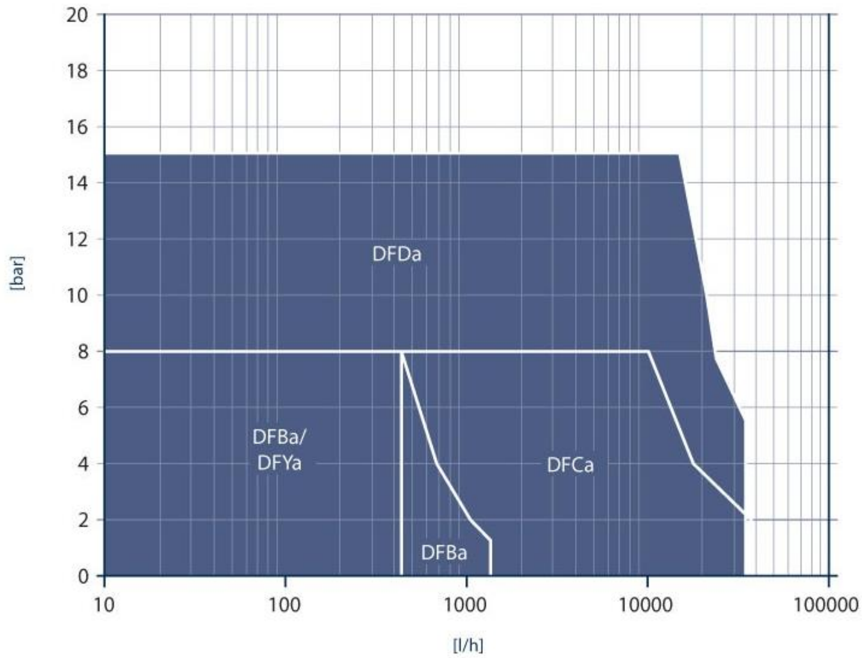


Figure 19: Example chart of capacity and pressure ranges for various diaphragm pump models. Note that 1 liter per hour (l/h) = 0.2642 gph and 1 bar = 14.5 psi.

Source: https://www.prominent.com/en/Products/Products/Peristaltic-Pumps/pg-peristaltic-pumps.html

After a pump model is identified, capacity tables or curves should be reviewed for different pump sizes. Some pump manufacturers provide software or online tools that allow for a pump model and size selection.

Example Problem 8

Engineer Hayden is to select a pump size from the following capacity table. The pump draws from a tank and discharges into a nearby pipe with a maximum pressure of 120 psi. The pipe/tube length is short so friction & minor losses are negligible (less than 2 psi). The peak flow rate is 5.8 gph. The pump is to have a standard motor (60 hertz). Help Hayden pick a pump that meets the criteria and has the smallest stroke rate.

	Pump capacity at max. back pressure					
	with motor operating at 1,500 rpm at 50 Hz operation			Stroke rate	with motor operating at 1,800 rpm at 60 Hz operation	
Pump	bar	l/h	ml/stroke	Strokes/ min	psi	l/h
12017	12	17	3.8	73	174	20
12035	12	35	4.0	143	174	42
10050	10	50	4.0	205	145	60
10022	10	22	5.0	73	145	26
10044	10	44	5.1	143	145	53
07065	7	65	5.2	205	102	78

Solution:

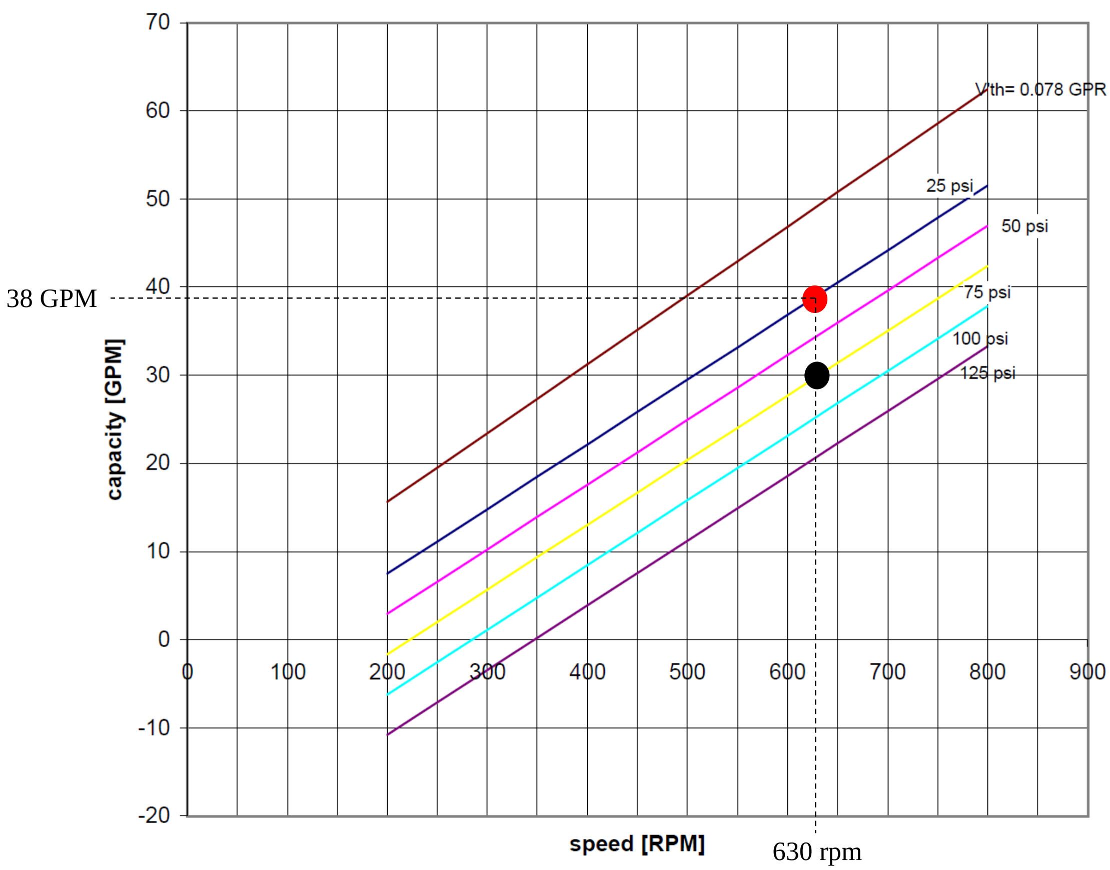
Hayden converts the flow to liters per hour (l/h) as follows:

Peak Flow = 5.8 gph * 1 l/h / 0.2642 gph = 22 l/h

Next, Hayden crosses out pumps that do not meet the maximum pressure or peak flow, as seen below. The pumps that meet the conditions are boxed in green. He selects **Pump No. 10022** since it has the slowest stroke speed at 73 strokes per minute.

	Pump capacity at max. back pressure					
	with motor operating at 1,500 rpm at 50 Hz operation			Stroke rate	with motor operating at 1,800 rpm at 60 Hz operation	
Pump	bar	l/h	ml/stroke	Strokes/ min	psi	l/h
12017	12	17	3.8	73	174	~~20~~
12035	12	35	4.0	143	174	42
10050	10	50	4.0	205	145	60
10022	10	22	5.0	73 ←	145	26
10044	10	44	5.1	143	145	53
07065	7	65	5.2	205	~~102~~	78

Example Problem 9
Engineer Colleen is to size a rotary lobe pump for pumping a chemical solution to a mixing tank. She calculates a delivery pressure of 75 psi (115 ft) at a peak flow of 30 gpm. Based on the below pump curve, Colleen must identify the required speed. Also, she must indicate how much the flow rate will change (percent change) when the discharge pressure drops by 50 psi.



Solution:
Colleen draws a **black** circle in the above pump curve at the operating point: 30 gpm on the 75 psi line in yellow. This point corresponds to a speed of approximately **630 rpm** (79%) on the x-axis.

For the case when the delivery pressure drops to 25 psi (75 - 50 = 25), the flow increases to approximately 38 gpm, as shown with the red circle on the chart. This is a **27% increase in flow** ((38 – 30) / 30 = 0.27) for a 67% drop in pressure.

Ancillary Items

Pump Skids

It is common for pumps to be supplied on a single "skid" with the needed accessories. See Figure 20 for an example with typical components. All valves and wetted surfaces should be of materials that are compatible with the chemical.

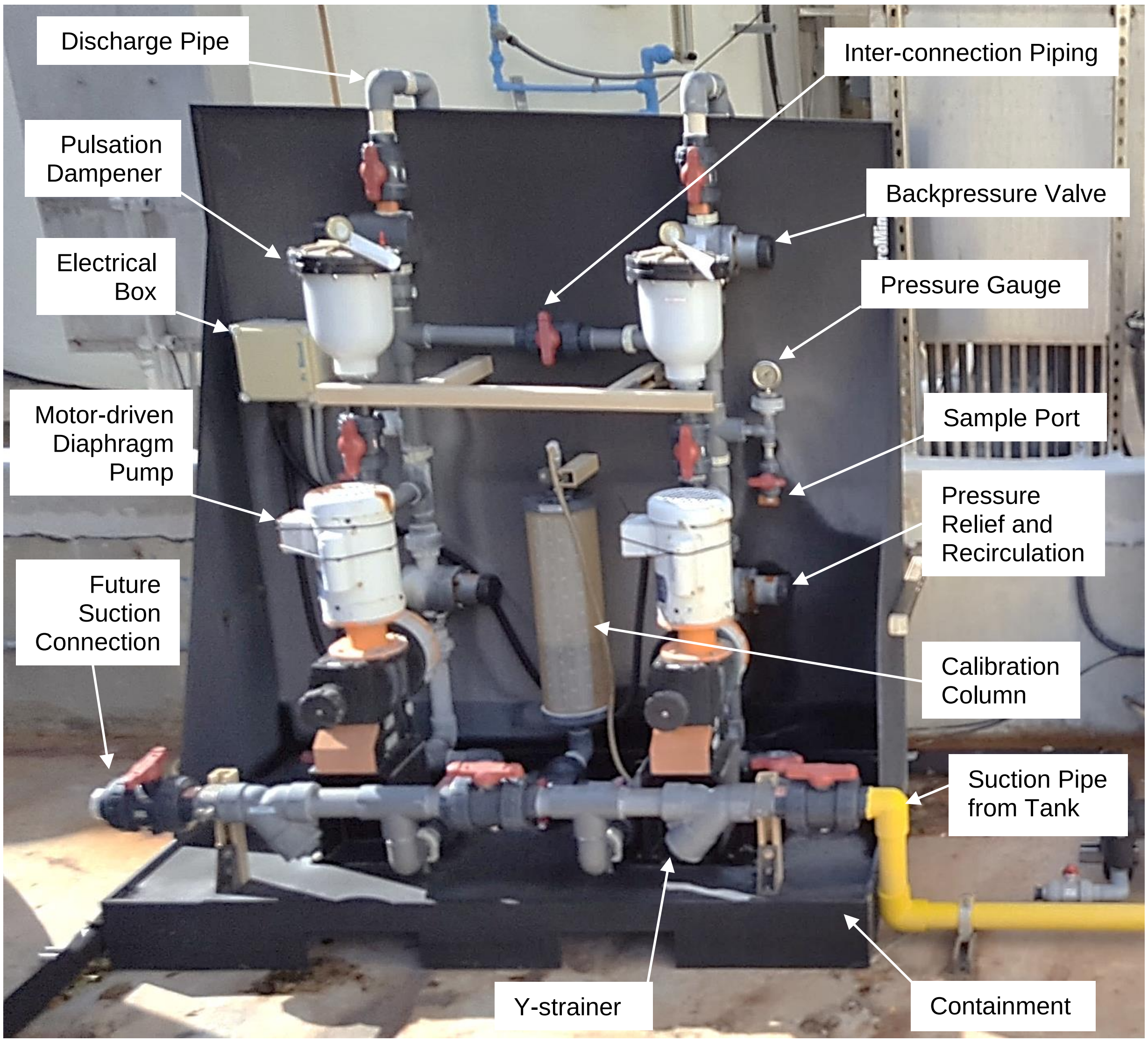


Figure 20: Example chemical feed skid with two pumps (one duty, one standby). Major components are labeled.

Valves

The following are common valves used in chemical feed systems:

- Anti-siphon Valve – Prevents the gravity flow of chemical to the injection/discharge location when the pump is not operating. An anti-siphon protection valve is normally installed just downstream of each metering pump. These valves are often required for potable water chemical feed systems, such as sodium hypochlorite for disinfection.
- Backpressure Valve – Maintains constant pressure at the discharge of the feed pump. This results in a more consistent flow and stable pump operation.
- Bleed Valve – A valve on a branch off the pump discharge pipe that is routed to drain or back to the chemical storage tank. This allows removing the pressure and draining the discharge pipe.
- Check Valve – Located after the pump head to prevent backflow. Diaphragm pumps have integral check valves on the inlet and outlet of the pump head.
- Foot Valves – Installed at the end of the suction pipe and near the bottom of the chemical storage tank. Used for metering pumps that pull a suction lift. The purpose is to keep the suction pipe flooded with chemical all the way to the pump head, to avoid self-priming.
- Off-gas Valve – Located after the pump to protect the pump and piping from air buildup and air binding. Off-gas valves are added when pumping chemicals that readily off-gas, such as sodium hypochlorite.
- Pressure Relief Valve – Located downstream of the pump. A pressure relief valve provides an upper limit on the discharge pressure of the feed pump which protects the pump and discharge piping. The valve has an outlet connection that should be piped back to the storage tank of the suction piping.
- Strainer – Provided on the metering pump suction pipes to prevent sand and grit from entering and damaging the pumps.

Pulsation Dampeners

Often pulsation dampeners are added to the discharge of reciprocating pumps to reduce pressure fluctuations and surges in the pipeline. Sometimes they are added to the suction side as well, to offset the acceleration head and thereby increase the NPSHa. Dampeners contain bladders that expand and contract to absorb and reduce peak flows. The pump and dampener manufacturer should be consulted to confirm the impact on the acceleration head calculation.

Water Conditioning
Many chemical solutions are prepared with make-up water. If the water is too "hard" a scale may buildup in the pump head and other components. The hardness can be removed with a water conditioning system, such as a water softener, ion exchange, or reverse osmosis.

Injection
The injection point refers to the location where the chemical is delivered/discharged into the receiving fluid. The following are injection options:

- Open channel diffuser, which is a pipe that spans the channel with small holes along the sides and bottom for chemical release, as shown in Figure 21.

Figure 21: Examples of open channel diffusers.

Source: Author.

- Static mixer assembly with integral chemical injection quills. Downstream of the injection location are elements to increase turbulence and thereby quickly mix the chemicals. The elements may be baffles, plates with openings, helical plates, or geometric grids. Figure 22 is a single plate or wafer-type mixer. Figure 23 is a geometric grid type mixer.

Figure 22: Static mixer with six chemical injection assemblies.
This mixer is installed as a wafer between two flanges.

Source: commons.wikimedia.org/wiki/File:Westfall_2800_Static_Mixer_with_multiple_injection_ports.jpg, Sageanne, CC-BY-SA-3.0

Figure 23: Static mixer with a geometric grid to increase turbulence.

Source: https://archive.epa.gov/apti/video/web/html/slide0143-3.html, public domain

- Injection quill that sticks into the receiving pipe, typically with the opening in the center of the flow stream. Injection quills can be removable through a ball valve. See Figure 22 for an example of removable injection quill assemblies.

- Tee into the receiving pipe.

- Drip into a tank or channel from an opened ended pipe located above the water line.

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