Design and Layout of Pumping Systems

An Online Continuing Education Course for Engineers

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Design and Layout of Pumping Systems

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INTRODUCTION

Pumping systems are used extensively throughout the world to transport liquids from one location to another. Pumping systems are used in a wide variety of applications, including water treatment, distribution, transmission, sewage conveyance and treatment, flood control, agriculture, energy production, and industrial manufacturing. This course focuses on the design and layout of municipal water and wastewater pumping systems. The purpose of this course is to give the reader an introductory understanding of the major design standards, performance criteria, hydraulics, pump and piping orientation, and intake arrangements for water and wastewater pumping stations.

Course Organization

This course is arranged into 15 different topics. A summary of the contents of each of the different topics is provided below:

- Introduction: course overview and outline, design development for a typical pumping system.
- Pipe Sizing and Arrangement: pump suction and discharge pipe sizing, recommended piping layout upstream and downstream of pumps.
- Hydraulic Calculations: an overview of continuity and Bernoulli equations for pump hydraulics, pump total dynamic head, static head types, friction, and minor losses.
- System Head Curves: system versus station losses, maximum and minimum system head envelopes, current and future system headloss considerations.
- Pump Performance Curves: reading and understanding manufacturer-published pump performance curves, variable impeller diameter and variable motor speed curves, pump power, and efficiency.
- Combining Pump and System Curves: plotting pump and system curves, pumps in parallel and series, best efficiency point, design rating point, and minimum and maximum operating points.
- Pump Selection Criteria: selecting a suitable pump, pump performance coverage and overlap, number of duty and standby pumps, pump operating range, and reliability.
- Submergence and NPSH Considerations: understanding and calculating minimum submergence and NPSH, effects of cavitation, recirculation, and air entrainment, and how to mitigate.

- Motor and Drive Selection Criteria: motor type, speed, horsepower, and a summary of different pump drive types.

- Material Selection Criteria: advantages and disadvantages of different pump and piping materials.

- Pump Types: types of rotodynamic and positive displacement pumps, typical applications, advantages and disadvantages of each.

- Pumping System Layout: summary of different pump intake configurations and sizing, piping arrangement, valve selection, and lifting equipment.

- Performance Testing: factory and performance testing guidelines and acceptance criteria.

- Design Resources: listing of resources for designers.

- Summary: course overview and summary.

Basic Design Development

Before moving into the technical subject matter of the course it is important to understand how a pumping system design is typically developed for municipal water and wastewater applications. The following provides a general overview of the major steps in the development of a pumping system design.

- Define the properties of the liquid to be pumped to determine piping material and pump type.
- Define the system operating conditions and any issues/constraints with parallel systems.
- Determine the need for preliminary treatment and select the type if required.
- Develop a Process Flow Diagram (PFD) showing how the system is configured.
- Develop a Piping and Instrumentation Diagram (P&ID) showing how the system operates.
- Develop a hydraulic profile for the system.
- Select the piping materials, linings, coatings, and valve types.
- Develop system head curves for the system operating conditions.
- Select the pump type and make a preliminary pump selection, including the number of pumps, rating points, arrangement and motor size and speed, constant or variable speed, and the number of standbys.
- Develop a comprehensive equipment list for the entire system listing key design parameters.
- Select and size the type of wet well or intake structure for the pumps.
- Develop layout drawings of the system showing equipment, piping, and valve arrangements, as well as required structure size and depth.

When defining the liquid properties of water pumping systems it is important to consider the source of the water (i.e., ground, river, lake, reservoir, tank, ocean, etc.), whether the water is raw, treated, brackish, or seawater, the presence of any chlorides, temperature, sediment and/or debris type, algae growth, and fish or other aquatic life to be handled. When defining the liquid properties of wastewater pumping systems it is important to consider the source of the wastewater (i.e., sanitary sewer, combined sewer storm drain, industrial, commercial, etc.), the type of solids and debris, chlorides, temperature, pH, hydrogen sulfide, abrasive solids (i.e., grit), chemicals and corrosives, and grease and oil.

System operating conditions should be developed for both the initial and future conditions of the system and should consider minimum, average, and peak flow conditions. In determining the design rating point of the system, it is advantageous to consider flow rates at which the system would operate most frequently, as well as the expected flow range over the life of the system and an understanding of how frequent the outer limits of that flow range will occur. Other important criteria to consider when defining system operating conditions include pressure requirements, intake and discharge conditions, hydraulic constraints, water level elevations and variations, site conditions (i.e., altitude, temperature, flood level, indoor or outdoor installation, topography), and physical constraints.

PIPE SIZING AND ARRANGEMENT

The pump intake geometry, pump suction sizing, and valve and fitting locations are critical to the proper design and operation of a pumping system. Unbalanced hydraulic loads to the pump impeller and shaft can cause excessive vibration and cavitation of the pump, so it is imperative that the pump intake components be designed appropriately. The pump intake and suction piping sizing and arrangement can affect several important pumping system characteristics, including overall system performance, longevity, noise, vibration, vortex formation, minimum submergence, operating levels, and maximum pumping depth.

Pump Intake Bell Sizing Criteria

Sizing criteria for pump intake bells are outlined in Rotodynamic Pumps for Pump Intake Design by the American National Standards Institute and the Hydraulic Institute (ANSI/HI 9.8-2018). The recommended target water velocity and acceptable water velocity range into the pump intake are presented in Table 1.

Table 1: Pump Intake Bell Recommended Velocity

Flow (gal/min)	Velocity Range (ft/s)	Target Velocity (ft/s)
< 5,000	2 to 9	5.5
5,000 to 20,000	3 to 8	5.5
> 20,000	4 to 7	5.5

ANSI/HI 9.8-2018 recommends a target velocity through the pump intake bell of 5.5 ft/s at the design flow rate. For wastewater pumping systems with solids present in the flow stream, it is recommended to reduce the target velocity to 3.5 ft/s at the design flow rate. The pump intake bell diameter “D” should be sized to achieve the target velocity at the design flow rate, while also being within the identified velocity range at the minimum and maximum flow rates for the system.

Pump Suction Piping Sizing and Arrangement Criteria

For typical clean water applications, the pump suction piping upstream of the pump intake bell should be sized for a velocity range of 4 to 6 ft/s. ANSI/HI 9.8-2018 recommends a maximum velocity of 8 ft/s in the suction piping, which may be increased at the pump suction flange through a gradual reducer. For wastewater pumping systems with high solids present, a minimum velocity of 3.0 ft/s is recommended to prevent sedimentation in the suction piping. This minimum velocity can be reduced to 2.0 ft/s depending on the characteristics of the solids present in the flow stream.

ANSI/HI 9.8-2018 recommends that there be no flow-disturbing fittings (i.e., valves, tees, elbows) on the suction piping for a specified distance upstream from the pump inlet flange. The recommended minimum straight pipe length upstream of the pump intake flange is provided in Table 2.

Table 2: Recommend Straight Pipe Length Upstream of Pump Intake Flange

Fitting	**Number of Pipe Diameters**	
	Long Radius	Short Radius
90° Elbow	4	5
Reducing Elbow with <30% Area Reduction	3	4
Reducing Elbow with 30% to 50% Area Reduction	2	3
Reducing Elbow with > 50% Area Reduction	0	1
Reducers	Concentric	Eccentric
1 Pipe Size Reduction	0	0
2 Pipe Size Reduction	0	1
3 Pipe Size Reduction	1	2
4 Pipe Size Reduction	2	3
5 Pipe Size Reduction	3	4
≤45° Elbow	4	-
>45°Elbow, Tee, Wye	5	-
Ball and Gate Valves (100% Open)	0	-
Plug Valve (80% Port)	4	-
Plug Valve (100% Port)	3	-
Butterfly Valve	2	-

Pump Discharge Piping, Mainline Piping, and Valve Sizing Criteria

For typical clean water applications, the pump discharge piping downstream of the pump discharge flange should be sized for a velocity range of 6 to 8 ft/s to minimize headloss. A maximum velocity of 10 ft/s is acceptable in designs where smaller valves and piping would result in significant cost savings while also adding negligible headloss to the overall system. For vertical piping in wastewater pumping systems with solids present, a minimum velocity of 5 ft/s is recommended to transport heavier solids.

Pipeline mains are defined as the portion of the discharge piping located downstream of the discharge manifold of the pumping system, which combines each of the smaller individual pump discharge piping runs into a single system discharge pipeline. Water mains should be sized for a velocity range of 4 to 6 ft/s to minimize headloss. A maximum velocity of 8 ft/s is acceptable considering the economics of the system piping and power costs, as well as the overall length of the water main. For wastewater force mains, a minimum velocity of 2 ft/s is required to maintain solids in suspension, while a velocity of 3.5 ft/s is required to re-suspended settled solids.

For most American Water Works Association (AWWA) compliant valves (i.e., butterfly, check, gate, and ball valves) a maximum velocity of 15 ft/s is recommended to prevent excessive vibration and cavitation at the valve and adjacent piping. Some valve manufacturers may allow for higher velocities depending on the application and period of use. Specialty valves are available, such as triple offset butterfly and ball valves, cone valves, or plunger valves, that are designed to handle velocities above 15 ft/s. Use of these valves should be coordinated closely with the valve manufacturer and the overall design of the pumping system to determine whether their application is practical and economical.

HYDRAULIC CALCULATIONS

Conservation of Mass (Continuity Equation)

Mass is conserved within a steady-state, continuous flow regime in any closed system. This means that the flow rate of fluid weight that enters an upstream point in the conduit must equal the flow rate of fluid weight that exists in the conduit at a downstream point. Mathematically, the continuity equation between two points in a closed system can be described as

$$\rho_1 Q_1 = \rho_2 Q_2$$

where ρ is the fluid density and Q is the flow rate. Since water under normal operating conditions is essentially an incompressible fluid, its density from one point to another along a closed system is constant (i.e. $\rho_1 = \rho_2$). Furthermore, the flow rate, Q, can be expressed as the product of the fluid velocity and the cross-sectional area of the conduit. Given the foregoing, the continuity equation can be rewritten as

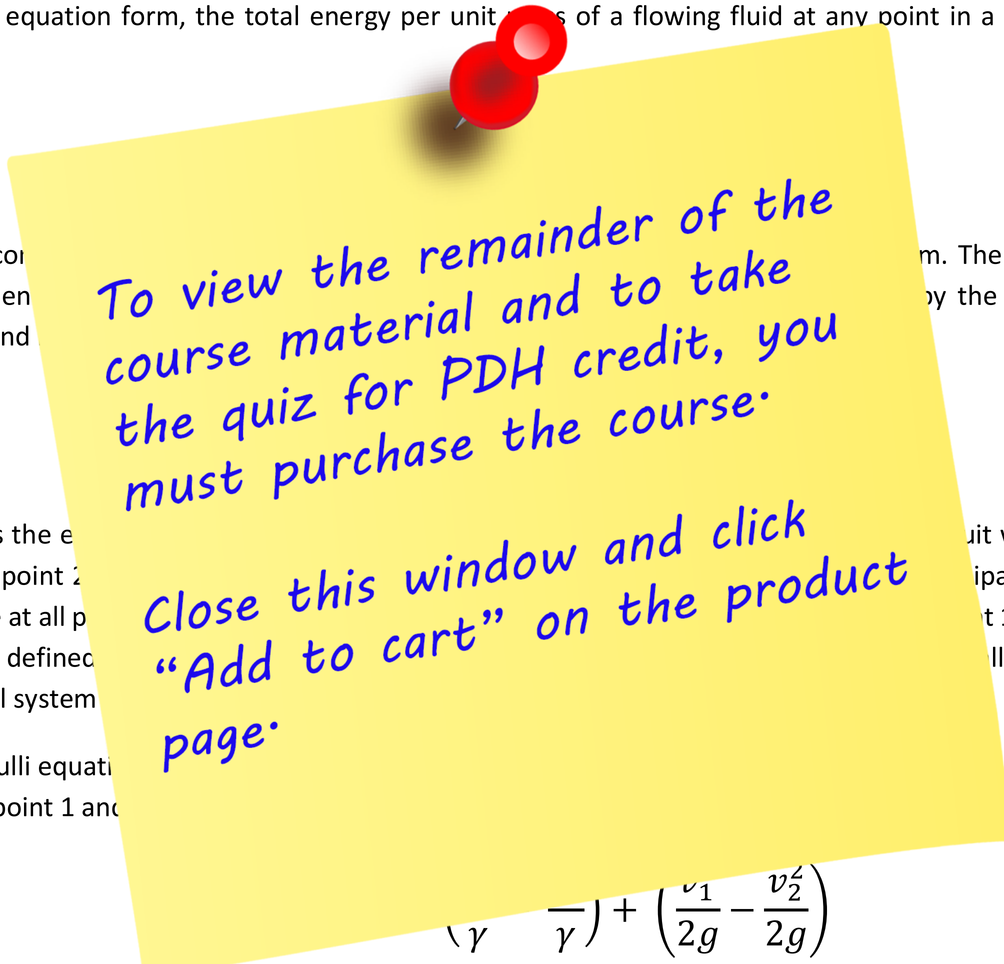
$$A_1 v_1 = A_2 v_2$$

where A is the cross-sectional area of the conduit and v is the velocity of the fluid.

Conservation of Energy (Bernoulli Equation)

Energy in the context of pumping systems consists of the summation of three components: elevation head, pressure head, and velocity head. Elevation head is defined as the height of the fluid in a conduit above a given datum, is expressed in feet, and is typically designated as "*z*". The pressure head is defined as the height to which the fluid in the conduit would rise in a piezometer that is attached to the top of the conduit and is also expressed in feet. The pressure head is defined mathematically as the pressure of the fluid in the conduit divided by the specific weight of the fluid (P/γ). Velocity head is defined as the height to which the fluid in the conduit would rise in a pitot tube that is attached to the inside of the conduit and is again expressed in feet. Velocity head is expressed mathematically as the square of the fluid velocity divided by two times the acceleration due to gravity ($v^2/2g$).

A visual representation of the three components of energy is illustrated in Figure 1. The summation of the elevation and pressure head is typically defined as the hydraulic grade line (HGL) of the system, while the summation of the elevation, pressure, and velocity head is defined as the energy grade line (EGL) of the system. In equation form, the total energy per unit ... of a flowing fluid at any point in a system is defined as



Energy is co... m. The resulting change in en... by the Bernoulli equation and ...

where h_f is the e... uit wall from point 1 to point ... ipated from turbulence at all p... t 1 to point 2, typically define... lly defined as the total system ...

The Bernoulli equat... the total energy at point 1 and ...

$$\ldots \frac{}{\gamma} - \frac{}{\gamma}\Big) + \left(\frac{v_1^2}{2g} - \frac{v_2^2}{2g}\right)$$

Visually, the total headloss can be illustrated as the reduction in height of the EGL from point 1 to point 2 as shown in Figure 1.