Report of Cooperative Education

Cost Estimation of Pumping System Through Its Life Cycle

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Abstract

This project generated the calculation templates for economic cost estimation of pumping system through its life cycle from design, procurement, installation, operation and maintenance by using Microsoft Excel 2013. Pumping system included pumps, motors, pipes, valves, and fittings. The detail cost data and cost estimation methods were collected and recorded in the calculation templates to acquire cost estimation of the pumping system. The calculation templates consisted of 6 algorithm steps, i.e., hydraulic calculation to estimate pressure drop and total dynamic head by using the Bernoulli's equation; variables screening by using equation ranges of equipment purchase cost and criteria; equipment purchase cost calculation from cost data sources; installation cost calculation; energy consumption cost calculation; and maintenance cost of about 8.05% of total depreciation cost, respectively. The installation cost of the pumping system considered 2 categories: pump and piping installation based on man-hour method; and essential bulk materials for pump installation by using the AACE factors method. However, the limitations of calculation templates are lack of some data on equipment purchase cost, installation cost, and maintenance cost, e.g., pipe supports and pipe racks. The obtained calculation templates for cost estimation of pumping system was validated with the selected a case study. It was found that the 3-inch pipe showed the reasonable fixed investment cost, while 4-inch pipe showed the reasonable cost of pumping system life cycle for 2 years.

Keywords: Pumping system, Life cycle, Cost estimation, Cost data, AACE factors method

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Pavarint Owatranporn

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NOMENCLATURE

B = Constant for the mechanical energy balance

B' = Constant independent of inside diameter

$C'_{pumping}$ = Pumping cost when laminar flow (USD/year/m)

C_{ECC} = Energy consumption cost (USD/year)

C_{EPC} = Equipment purchase cost (USD)

C_{FIC} = Fixed investment cost (USD)

$C_{fitting}$ = Fitting cost (USD/kg)

C_{INS} = Total installation cost (USD)

$C_{INS,bulk}$ = Bulk material installation cost (USD)

$C_{INS,piping}$ = Piping installation cost (USD)

$C_{INS,pump}$ = Pump installation cost (USD)

C_{LCC} = Life cycle cost (USD)

C_{MAN} = Maintenance cost (USD)

C_{motor} = Motor purchase cost (USD)

c_{pipe} = Pipe purchase cost (USD/kg)

C_{pipe} = Total pipe purchase cost (USD)

$C_{pipe,annual}$ = Cost for the installed piping system (USD/year/m)

$c_{pipe\text{-}0.0257}$ = Pipe 0.0257-m purchase cost (USD/m)

C_{piping} = Total piping cost (USD)

C_{pump} = Pump purchase cost (USD)

C_{pumping} = Pumping cost (USD/year/m)

C_{TDC} = Total depreciation cost (USD)

C_{valve} = Total Valve cost (USD)

c_{valve} = Valve cost (USD/each)

C_{var} = Variable cost (USD/year)

$C_{var,total}$ = Total variable cost (USD)

C_{wage} = Wage for labor (USD/h)

$D_{i,opt}$ = Economic pipe diameter (m)

D_{inside} = Pipe inside diameter of the pipe (m)

D_n = Annual depreciation charge (USD/year)

$D_{outside}$ = Pipe outside diameter (m)

E = Quality factor of pipe

f = Fanning friction factor

F = the ratio of the total cost for fittings and installation

J = Equivalent length (m)

K = Electricity rate (USD/kWh)

K_F = Fraction of initial cost for the completely installed pipe

L = Actual pipe length (m)

L_{US} = Actual pipe length (ft)

$m_{erection}$ = Pipe erection man-hour (h/ft)

$M_{erection}$ = Total pipe erection man-hour (h)

$m_{painting}$ = Pipe painting man-hour (h/ft)

$M_{painting}$ = Total pipe painting man-hour (h)

$m_{pipe,con}$ = Pipe connection man-hour (h/each)

$M_{pipe,con}$ = Total pipe connection man-hour (h)

M_{piping} = Total piping man-hour (h)

m_{pump} = Pump setting man-hour (h/HP)

M_{pump} = Total pump setting man-hour (h)

$m_{valve,con}$ = Valves and fitting connection man-hour (h/each)

$M_{valve,con}$ = Total valve connection man-hour (h)

n = Constant whose value depends on the type of pipe selected

N_{con} = Number of connections (each)

N_{Re} = Reynolds number

$N_{valve,fitting}$ = Number of valves and fittings

P_1 = Upstream pressure (kg/cm^2)

P_2 = Downstream pressure (kg/cm^2)

$P_{B,HP}$ = Power requirement (horsepower)

$P_{B,kW}$ = Power requirement (kW)

$P_{H,HP}$ = Hydraulic power (horsepower)

$P_{H,kW}$ = Hydraulic power (kW)

P_{design} = Internal design gage pressure (kPa)

Q_{gpm} = Volumetric flow rate (gpm)
Q_{SI} = Volumetric flow rate (m^3/h)
q_{SI} = Volumetric flow rate (m^3/s)
S = Size factor
S_t = Stress value for material (MPa)
t_m = pressure design thickness (mm)
$T_{operating}$ = Total pump operating time (year)
$t_{operating}$ = Pump operating time (h/year)
$t_{useful\ life}$ = Pump useful life (h/year)
v = Average velocity of fluid (m/s)
W = Weld joint strength reduction factor
W_{pipe} = Weight of pipe (kg)
$W_{fitting}$ = Weight of fitting (kg)
W_s = Mechanical work.
Y = Pipe wall thickness coefficient
Z = Elevation change (m)
ε = Pipe roughness (mm)
η_M = Motor efficiency
η_P = Pump efficiency
ρ = Fluid density (kg/m^3)
μ = Viscosity (Pa·s)

CHAPTER I

INTRODUCTION

1.1 Background

TTCL Public Company Limited has experience and expertise in providing an integrated EPC (Design and engineering, procurement of machinery and equipment, and construction) of turnkey projects for industrial and process plants, mainly in energy, petrochemical, chemical, and power industries.

Pumping system is one of trade-off design which is common in optimization capture between cost and benefits. Pumping system benefits or better performance in terms of reduced energy consumption of pumping liquid usually comes at the higher piping purchase cost and installation cost. Consequently, trade-off design of pumping system should be considered. In fact, process engineers of TTCL Co. Ltd. design pumping system after having project specification without economic consideration due to insufficient data, i.e., cost data and cost estimation method for pumping system. Therefore, cost data and cost estimation methods are given in the calculation templates for economic consideration of pumping system through its life cycle.

The life cycle of pumping system divided into 5 steps consisting of design, procurement, equipment installation, operation, and maintenance. The design step has not cost because it is company profits. In procurement step, the company purchases equipment in pumping system including pump, motor, pipe, valves, and fittings. Next, labor or contractors are hired for equipment installation. After that, pumping system is started-up, operated and maintained depending on schedule. According to life cycle of pumping system, cost in each step consists of equipment purchase cost from procurement step, installation cost from equipment installation step, energy consumption cost from operation step, and maintenance cost from maintenance step. The operation cost and maintenance cost are included in life cycle because sometimes TTCL Co. Ltd. have to study and train the customer's staff to operate plant which have to pay these costs during depending on contract.

1.2 Objective

1.2.1 Provide the calculation templates having cost data and cost estimation method for economic consideration of pumping system through its life cycle.

1.3 Scope of works

1.3.1 Create calculation templates for pumping system cost including equipment purchase cost, installation cost, energy consumption cost, and maintenance cost.

1.3.2 Provide cost data and cost estimation in the calculation templates for economic evaluation of pumping system design in relating to pumping system cost consisting of pump, motor, pipe, valves, and fittings.

1.4 Outputs

1.4.1 The calculation templates can estimate cost through life cycle of pumping system which consists of equipment purchase cost, installation cost, energy consumption cost, and maintenance cost.

1.4.2 The calculation template implies the pipe size which is minimum fixed investment cost and variable cost

CHAPTER II

LITERATURE REVIEW

2.1 Terms and definitions

2.1.1 Butt-weld joint (Perry, R.H. and Green, D.W., 2018)

The butt-weld joint widely used joint in piping system. In all ductile pipe metals are available in all sizes and wall thicknesses. Joint strength equal to the original pipe (except for work-hardened pipes which are annealed by the welding), unimpaired flow pattern, and generally unimpaired corrosion resistance more than compensate for the necessary careful alignment, skilled labor, and equipment required.

2.1.2 Pipe (ASME B16.5, 2013)

A pressure-tight cylinder used to transmit a fluid pressure, ordinarily designated “pipe” in applicable material specifications.

2.1.3 Piping (ASME B16.5, 2013)

Assemblies of piping components used to convey, distribute, mix, separate, discharge, meter, control, or snub fluid flows.

2.1.4 Piping components (ASME B16.5, 2013)

Mechanical elements suitable for joining or assembly into pressure-tight fluid-containing piping systems. Components include pipe, tubing, fittings, flanges, gaskets, bolting, valves, and devices such as expansion joints, flexible joints, pressure hoses, traps, strainers, inline portions of instruments, and separators.

2.1.5 Newtonian fluids (Perry, R.H. and Green, D.W., 2018)

Newtonian fluid rheogram is a straight line passing through the origin as shown in Figure 2.1. The slope of the line is the viscosity. The viscosity is independent of shear rate and may depend only on temperature and perhaps pressure. The Newtonian fluid is the largest class of fluid of engineering importance.

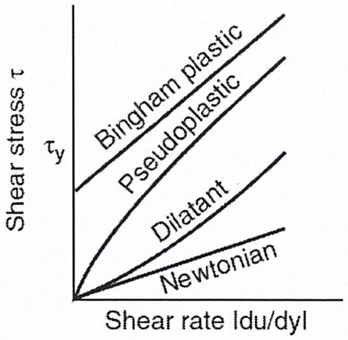


Figure 2.1 Shear diagram

(Perry, R.H. and Green, D.W., 2018)

2.1.6 Salvage value (Max, S.P. and Klaus, D.T., 2003)

The salvage value is the amount of recovered through sale, trade-in at the end of asset life. It normally is estimated at about 10% or less than of the asset purchase cost following federal regulation.

2.1.7 Useful life (Max, S.P. and Klaus, D.T., 2003)

The useful life is the service life of an asset. Determining the service life of the asset was often very difficult, and uncertainty which led to disputes between taxpayers and the Internal Revenue Service (IRS). Consequently, the IRS provided the guidelines for estimating the useful life which knew as asset depreciation ranges, or ADRs. These guidelines specify a range of useful life for assets, based on historical data. The taxpayers are allowed to choose a useful life within the guidelines. The water transportation systems are ranged between 14.5 years to 21.5 years.

2.2 Pumps (Brian, N., 2006)

2.2.1 Horizontal single-stage double suction axially split pump

A generally design with a large impeller between two bearings, two stuffing boxes and axial-split pump casing with the pipe connections in the lower half. The design is generally used large and very large water services pump. The impeller speed is less than the similar single suction pump. The standard cast iron casing can hold the water temperature about 120 °C. The small pump can handle 1200 m^3/h and lifts about 100 m. The larger pump can handle 40,000 m^3/h and lifts about 40 m.

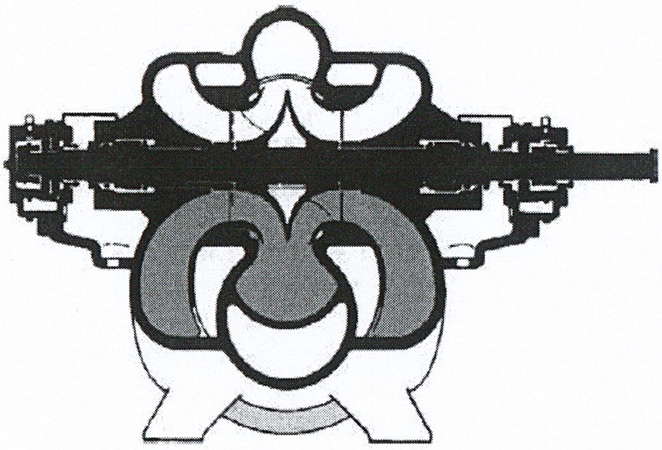


Figure 2.2 Double suction axially split pump with sleeve bearings

(Brian, N., 2006)

2.2.2 Horizontal single-stage double suction radially split pump

A horizontal single-stage radially pump has some design similar to the horizontal single-stage axially spilt pump, but the casing is different. The radially split casing is located to center line. Rolling bearings are commonly used, sliding bearings and various lube oil systems can be made to order. The mechanical seal can be serviced by removing the coupling and bearing housing. The double entry impeller is located between two bearings which normally is rolling bearing. The flow is proper over 5,000 m^3/h and the head is up to 500 m.

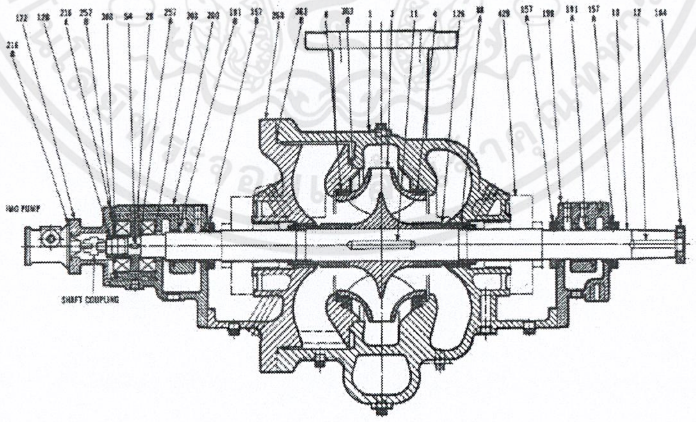


Figure 2.3 Double suction radially split pump accordance with API 610

(Brian, N., 2006)

2.2.3 Horizontal two-stage axially split centrifugal pump

A two-stage pump is used for the extra differential head. Suction and discharge connections are located at the bottom half. The top half simplifies to remove the connections without disturbing pipe. Impellers are usually located back-to-back. This pump design is usually larger than the end-suction two-stage pump and requires impellers to be located between bearings. Impellers usually have a front wear ring which reduces leakage between the stages. The center bush also acts as the bearing and give some shaft stiffness. A double-suction first stage can be used when NPSHa is low, but the cost is increased significantly. The increased cost should be less than providing a separate booster pump and driver which associated electrics and controls. Generally, a two-stage pump can handle flow up to about 2,000 m^3/h and can pump up to 600 m differential head.

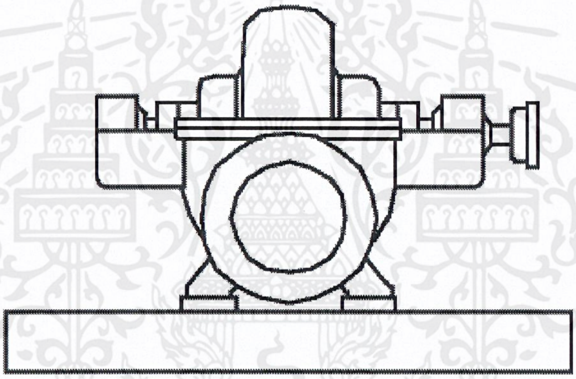


Figure 2.4 Axially split one- and two-stage between-bearings pump

(API STD 610, 2003)

2.2.4 Horizontal two-stage radially split centrifugal pump

A radially spilt design is recommended for hazardous liquid. The advantage of the radially split casing is found in application and maintenance. Thermal growth problems can be removed by centerline-mounted therefore this design is suitable for high-temperature applications. A two-stage pump is usually larger than the end-suction two-stage pump. Impellers are located between bearings and are usually mounted back-to-back to minimize axial thrust. A double-suction first stage can be used when NPSHA is low, but the cost is increased significantly. The increased cost should be less than providing a separate booster pump and driver which associated electrics and control. The two-stage pump can usually handle flow up to about 2,000 m^3/h and can pump up to 800 m differential head. Operating temperatures up to 425 °C are typical.

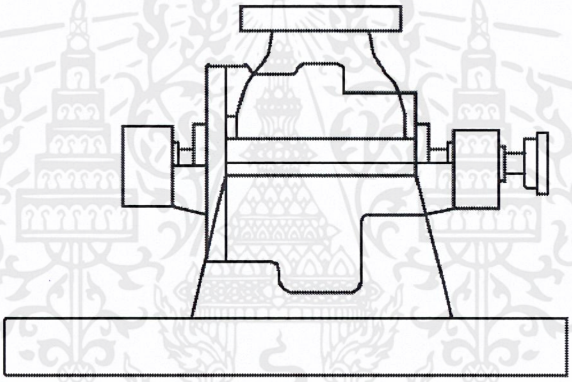


Figure 2.5 Radially split one- and two-stage between-bearings pumps (API STD 610, 2003)

2.2.5 Horizontal multi-stage axially split centrifugal pump

A large multi-stage axially spilt pump has a widely application. It is used in refining, petrochemical industries, and oil field production. A small multi-stage pump has 50 or 100 stages and a large multi-stage pump depends on shafts deflection and critical speeds, but it rarely exceeds 15 stages. The pump can handle 2,400 m^3/h at heads over 1,400 m when runs at speed 2,900 rpm. The casing design is available for pressure ratings up to 280 barg.

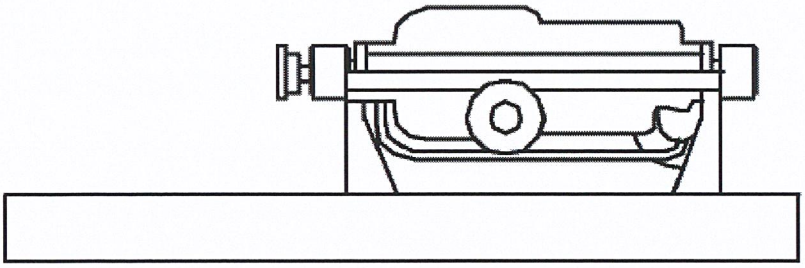


Figure 2.6 Axially split multistage between-bearings pumps

(API STD 610, 2003)

2.2.6 Plunger pumps

Plunger pumps are available from single cylinder hand pumps to nine-cylinder vertical pumps and are built with 1, 3, 4, 5, 6, 7 or 9 cylinders. Increasing the number of cylinders increases the pump capacity, tends to smooth the flow variations, and reduces pressure pulsations and torque variations at the crankshaft. The plunger pump has suction valve unloaders fitted and would be driven by an external gear box or V-belt drive. Liquid ends can be built in different configurations for various applications. The mono-block liquid end general for standard pumps on non-corrosive applications. Plunger pumps are capable of pressure over 300 bar and consume power over 3,000 kW.

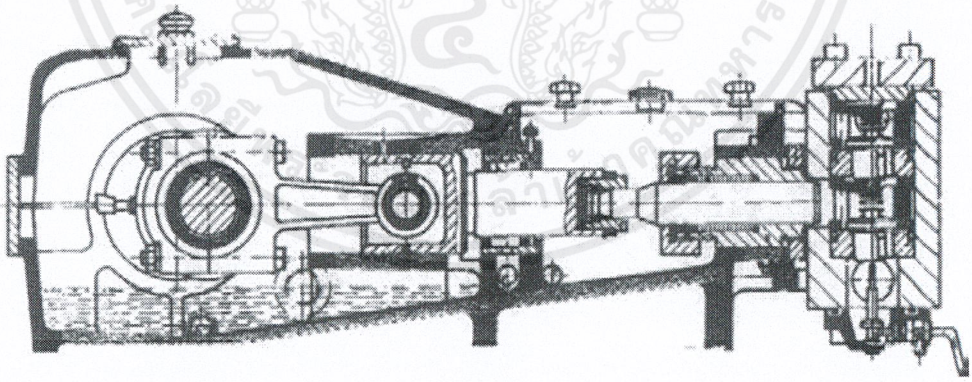


Figure 2.7 Plunger pump with monoblock liquid end and wing guided valves

(Brian, N., 2006)

2.3 Efficiency of pump and motor (Warren, D.S., et al., 2017)

The efficiency of pump and motor can be determined by using Eq (2.1) and Eq (2.2). The efficiency of pump is a function of the volumetric flow rate and is applicable in the range of 50 to 5,000 gpm. The motor efficiency depends on horsepower and is applicable in the rage of 1 to 1,500 HP.

$$\eta_P = -0.316 + 0.24015[\ln(Q_{gpm})] - 0.0119[\ln(Q_{gpm})]^2 \tag{2.1}$$

$$\eta_M = 0.8 + 0.0319[\ln(P_{H,HP})] - 0.0182[\ln(P_{H,HP})]^2 \tag{2.2}$$

2.4 Pump selection

2.4.1 Selection type of pump

When pump type is not available in a project specification, Table 2.1 is given to guide pump selection in accordance with rotation speed and volumetric flow rate. In addition, this table provides equation ranges of pump purchase cost. When the flow ranges are apart from Table 2.1, Table 2.2 gives wide range and provides the suitable differential head or pressure for each pump types.

Table 2.1 Pump selection from flow ranges (Warren, D.S. et al., 2017)

Pump types	Number of stages	Casing orientation	Rotation speed (rpm)	Flow ranges (m^3/h)
Centrifugal pump	1	VSC	3,600	10 – 200
			1,800	10 – 794
	1	HSC	3,600	23 – 340
			1,800	57 – 1,140
	2		3,600	10 – 250
	2+		3,600	23 – 340

Table 2.2 Pump selection from pump flow ranges and pressure ranges (Robert, C.R., 2004)

Pump types	**Number of stages**	**Casing orientation**	**Flow ranges (m^3/h)**	**Differential head or pressure**
Centrifugal pump	1	VSC	< 1,200	< 100 m
			< 40,000	< 40 m
	1	HSC	< 5,000	< 500 m
	2		< 2,000	< 600 m
	2+		< 2,400	< 1,400 m
Reciprocating plunger pump	-	-	< 500	< 100 barg

2.4.2 Selection material of pump

The material of pump should not be contaminated during handled liquid by the pump. Table 2.3 provides the materials of pump which is suitable for each fluid conditions.

Table 2.3 Materials for centrifugal pumps and their main areas of application (Brian, N., 2006)

Materials	**Applications**
Cast iron	Has good resistance to many liquids assuming the graphite film is not damaged by high velocities, aeration, cavitation or solids.
Ductile iron	Better resistance to corrosion at high liquid velocities than cast steel but not as good as cast iron
Cast steel	De-aerated hot water, boiler feed pumps
Bronze	Saltwater, seawater, brine and other moderately corrosive water solutions. AI bronze and NiAI bronze better than tin bronze in seawater. NiAI bronze for higher pressures
Stainless steel	Boiler feed water, general corrosive applications, poor in chloride solutions
Hastelloy C	Very resistant to corrosion. For H_2SO_4 at all concentrations and moderate temperatures. Dilute HCI, strong chloride solutions at higher temperatures
Monel	Seawater, Brines
Nickel	Hot, Seawater
Titanium	Chloride solutions, chlorine dioxide and other liquids for bleach manufacture

2.5 Pump purchase cost (Warren, D.S., et al, 2017)

2.5.1 Centrifugal pump purchase cost

The most common radial centrifugal pump type has been published purchase cost data. The pump purchase cost often includes a pump, a base plate, and a direct-drive coupling. In some cases, an electric motor drive is included. The size factor of pump, S, recognizes the fact that a given centrifugal pump can operate over a range of flow rate and head combinations. There is no general agreement on the equipment size factor to be used for correlating purchase cost. Most common are brake horsepower and, product of the capacity and the total dynamic head (or pressure increase). The size factor can be calculated by using Eq (2.3). In addition to the size factor, the purchase cost of a centrifugal pump depends on its rotation speed, number of stages and pump orientation spilt case. The configuration of a base cost pump is a single-stage centrifugal pump with vertical spilt case construction of caste iron and operating at 3,600 rpm. Eq (2.4) is provided size factor is valid between from 400 to 100,000.

$$S = 7.93 Q_{SI} (h_{TDH})^{0.5} \tag{2.3}$$

$$C_{B,pump} = \exp\{12.1656 - 1.1448[\ln(S)] + 0.0862[\ln(S)]^2\} \tag{2.4}$$

For other types of centrifugal pump and other materials of construction are given by:

$$C_{pump} = C_{B,pump} F_{Type\ factor,pump} F_{M,pump} \tag{2.5}$$

Table 2.4 Typical types of radial centrifugal pump and type factors (Warren, D.S., et al, 2017)

No. of stages	Shaft speed (rpm)	Case-split orientation	$F_{Types\ factor,pump}$
1	3,600	Radially spilt case	1
1	1,800	Radially spilt case	1.5
1	3,600	Axially spilt case	1.7
1	1,800	Axially spilt case	2
2	1,800	Axially spilt case	2.7
2+	1,800	Axially spilt case	8.9

Table 2.5 Materials of construction factors for centrifugal pump (Warren, D.S., et al, 2017)

Materials	$F_{M,pump}$
Cast iron	1.00
Ductile iron	1.15
Cast steel	1.35
Bronze	1.90
Stainless steel	2.00
Hastelloy C	2.95
Monel	3.30
Nickel	3.50
Titanium	9.70

2.5.2 Reciprocating plunger pump purchase cost

The plunger type is the most demanding applications and provides a wide range of flow rates. A purchase plunger pump cost includes the pump and a driver coupling for a motor or a V-belt drive. The size factor for corelating purchase cost is based on brake horsepower and flow capacity. Typically, the efficiency of this pump type is 90%. In addition to the size factor, the reciprocating pump purchase cost depends on the material of construction. A reciprocating plunger pump of ductile iron construction is calculated by using Eq (2.6). It is applicable over the range of 1 to 200 HP. For the other material of construction purchase cost, the based cost is multiplied to materials factor in Table 2.6.

$$C_{B,pump} = \exp\{7.9361 - 0.26986[\ln(P_{B,HP})] + 0.0862[\ln(P_{B,HP})]^2\} \tag{2.6}$$

$$C_{pump} = C_{B,pump} F_{M,pump} \tag{2.7}$$

Table 2.6 Materials of construction factors for reciprocating plunger pump (Warren, D.S., et al, 2017)

Materials	$F_{M,pump}$
Ductile iron	1.00
Ni-Al-Bronze	1.15
Carbon steel	1.50
Stainless steel	2.20

2.6 Motor enclosure selection

The motor enclosure type is selected from the best suitable for an application. Table 2.8 provide the selection guidelines by application.

Table 2.7 Selection enclosure according to environment (Brian, N., 2006)

Condition or application	**Drip-proof**	**Totally enclosed**	**Explosion-proof**
Fumes			
Explosive	-	-	✓
Nonexplosive	-	✓	-
Corrosive	-	✓	-
Liquids			
Acid or alkali	-	✓	-
Dripping water	✓	-	-
Explosive	-	-	✓
Nonexplosive	-	✓	-
Paint	-	-	✓
Petroleum, oil	-	-	✓
Splashing water	✓	✓	-
Solvent			
Corrosive, nonexplosive	-	✓	-
Noncorrosive, nonexplosive	-	✓	-
Noncorrosive, explosive	-	-	✓

2.7 Electric motor purchase cost

The electric motor is used to drive a centrifugal pump and its cost is added to the pump cost. There have three common motor types provide in the calculation template including an open drip-proof enclosure, a totally enclosed fan-cooled (TEFC) enclosure, and an explosion-proof enclosure. The open drip-proof enclosure is designed to prevent the liquid and dirt particle entrance but not airborne moisture, dust, and corrosive fumes into the internal working motor parts. The totally enclosed fan-cooled enclosure is designed for prevention of any air getting inside. The explosion-proof enclosure is used against explosion hazards from combustible gases, liquids, and dust by pressurizing the enclosure with a safe gas. The electric motor purchase cost depends on its power consumption. Eq (2.8) gives the purchase cost of an electric motor operating at 3,600 rpm with an open, drip-proof enclosure. The equation applies the power consumption between 1 to 700 HP. For the other motor speed and types purchase cost, the base cost is multiplied by type factor in Table 2.7.

$$\begin{aligned} C_{B,motor} = \exp\{&5.9332 + 0.16829[\ln(P_{B,HP})] - 0.110056[\ln(P_{B,HP})]^2 \\ &+0.071413[\ln(P_{B,HP})]^3 - 0.0063788[\ln(P_{B,HP})]^4\} \end{aligned} \qquad (2.8)$$

$$C_{motor} = C_{B,motor} F_{Type\ factor,motor} \qquad (2.9)$$

Table 2.8 Type factors of typical motor enclosure (Warren, D.S., et al, 2017)

Types of motor	$F_{Type\ factor,motor}$	
	3,600 rpm	**1,800 rpm**
Open, drip-proof enclosure	1.0	0.9
Totally enclosed, fan-cooled	1.4	1.3
Explosion-proof enclosure	1.8	1.7

2.8 Straight pipe wall thickness (ASME B31.3, 2017)

The required thickness of straight sections of pipe shall be determined in accordance with Eq (2.10).

$$t_m = \frac{P_{deisgn} D_{outside}}{2(S_t EW + P_{design} Y)} \tag{2.10}$$

Where $D_{outside}$ = Outside diameter of pipe (m)

E = Quality factor is 0.8.

S_t = Stress value for material from Table B.6

P_{design} = Internal design gage pressure (kPa)

t_m = Pressure design thickness (m)

W = Weld joint strength reduction factor from Table B.7

Y = Coefficient from Table F.8

2.9 Economic pipe diameter (Max, S.P. and Klaus, D.T., 2003)

2.9.1 Pumping cost

For any given operating conditions which involves an incompressible fluid flow through a constant pipe size, the total mechanical energy balance can be reduced to Eq (2.11).

$$W_s = \frac{2fv^2 L(1+J)}{D_{inside}} + B \tag{2.11}$$

For the turbulent flow, fanning fiction may be approximated for new steel pipes by using Eq (2.12).

$$f = \frac{0.04}{N_{\mathrm{Re}}^{0.16}} \tag{2.12}$$

Adding the friction factor and the mechanical work and applying the necessary conversion factors, the annual pumping cost is provided in Eq (2.13) for turbulent flow and Eq (2.14) for laminar flow.

$$C_{pumping} = \frac{1.248\times10^{-4} Q_{SI}^{2.84} \rho^{0.84} \mu^{0.16} K(1+J) t_{operating}}{D_{inside}^{4.84} \eta_P \eta_M} + B' \tag{2.13}$$

$$C'_{pumping} = \frac{0.0407 Q_{SI}^{2} \mu K(1+J) t_{operating}}{D_{inside}^{4} E} + B' \tag{2.14}$$

2.9.2 Fixed charges for piping system

A plot of the logarithm of the pipe diameter versus the logarithm of the purchase cost per meter pipe is a straight line. Therefore, the purchase cost for pipe may be presented by Eq (2.15).

$$c_{pipe} = c_{pipe,0.0254-m} (\frac{D_{inside}}{0.0254})^{n} \tag{2.15}$$

The annual cost for the installed piping system may be expressed as Eq (2.16).

$$C_{pipe,anuual} = (1+F) c_{pipe,0.0254-m} (\frac{D_{inside}}{0.0254})^{n} K_F \tag{2.16}$$

2.9.3 Optimum economic pipe diameter

The total annual cost for the piping system and pump can be calculated by adding Eq (2.11) and Eq (2.16) or Eq (2.12) and Eq (2.16). The only pipe purchase cost varies in the total cost expressions therefore the optimum economic pipe diameter can be found by taking the derivation of the total annual cost with respect to pipe diameter, setting the result equal to zero, and solving for the diameter. This procedure gives Eq (2.17) for turbulent flow and Eq (2.18) for laminar flow.

$$D_{i,opt} = [\frac{6.04\times10^{-4}(0.0254)^{n} Q_{SI}^{2.84} \rho^{0.84} \mu^{0.16} K(1+J) t_{operating}}{n(1+F) c_{pipe,0.0254-m} \eta_P \eta_M K_F}]^{1/(4.84+n)} \qquad (2.17)$$

$$D_{i,opt} = [\frac{0.1628(0.0254)^{n} Q_{SI}^{2} \mu K(1+J) t_{operating}}{n(1+F) c_{pipe,0.0254-m} \eta_P \eta_M K_F}]^{1/(4.0+n)} \qquad (2.18)$$

Where n = 1.5 for pipe diameter is 0.0254 m or larger and 1 for diameter less than 0.0254 m.

F = Ranging from 1.5 to 6.75

K_F = 0.2

J = 0.35

Therefore, for turbulent flow in steel pipe and $D_{i,opt} \geq 0.0254$ m;

$$D_{i,opt} = Q_{SI}^{0.448} \rho^{0.132} \mu^{0.025} [\frac{1.63\times10^{-6} K(1+J) t_{operating}}{(1+F) c_{pipe,0.0254-m} \eta_P \eta_M K_F}]^{0.158} \qquad (2.19)$$

For turbulent flow in steel pipe and $D_{i,opt} < 0.0254$ m;

$$D_{i,opt} = Q_{SI}^{0.487} \rho^{0.144} \mu^{0.027} [\frac{1.53\times10^{-5} K(1+J) t_{operating}}{(1+F) c_{pipe,0.0254-m} \eta_P \eta_M K_F}]^{0.171} \qquad (2.20)$$

For laminar flow in steel pipe and $D_{i,opt} \geq 0.0254$ m;

$$D_{i,opt} = Q_{SI}^{0.364} \mu^{0.182} [\frac{4.39\times10^{-4} K(1+J) t_{operating}}{(1+F) c_{pipe,0.0254-m} \eta_P \eta_M K_F}]^{0.182} \qquad (2.21)$$

For laminar flow in steel pipe and $D_{i,opt} < 0.0254$ m;

$$D_{i,opt} = Q_{SI}^{0.40} \mu^{0.20} \left[\frac{4.14 \times 10^{-3} K (1+J) t_{operating}}{(1+F) c_{pipe,0.0254-m} \eta_P \eta_M K_F} \right]^{0.20} \qquad (2.22)$$

2.10 Valves (Robert, C.R., 2004)

2.10.1 Ball valves

The ball valves are the cheapest, but most widely used of all valve types. The basic geometry involves a spherical ball, which has a hole through one axis, located by two resilient sealing rings in a simple body form. The fluid can through the valve when the ball hole is aligned with the axis of the valve. Body forms and matching ball hole may give straight-through (full-bore parallel), reduced flow, or venturi flow. The ball valves are recommended for quick opening and minimum flow resistance requirements. Its advantages are including low cost, high capacity, bidirectional shutoff, straight-through pattern, low leakage, self-cleaning, low maintenance, no lubrication requirement, compact, tight sealing with low torque, and good throttling characteristics with special trim. Its disadvantages are including poor throttling characteristics with standard ball designs, susceptible to seal wear with soft seats, and prone to cavitation with standard ball designs.

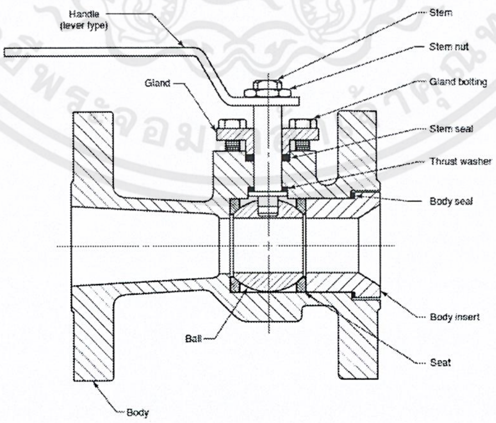


Figure 2.8 Standard ball valve and its component

(API STD 608, 2002)

2.10.2 Butterfly valve

The butterfly valves use a flat disc rotation to adjust a liquid flow. The butterfly valves movement require only 90° rotation for full movement. With a high flow capacity, butterfly valves enable lower weight and space requirements which attractive cost-saving. The butterfly valve generally is applied in high-temperature, high-pressure applications or those involving toxic or corrosive fluid. Its disadvantages are restricting the flow through the pipe and solids catching on the disc which causes a blockage or prevents the valve from closing.

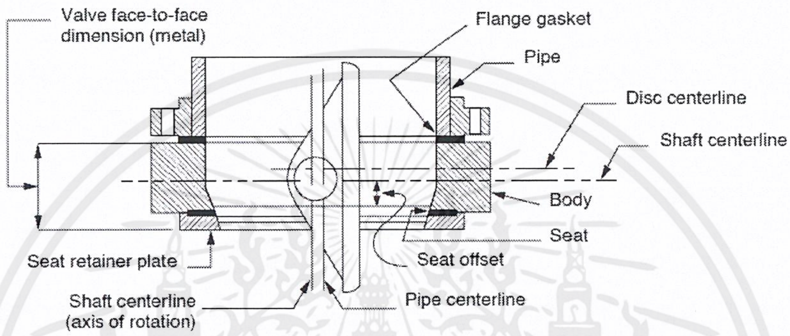


Figure 2.9 Butterfly valve top view

(API STD 609, 2004)

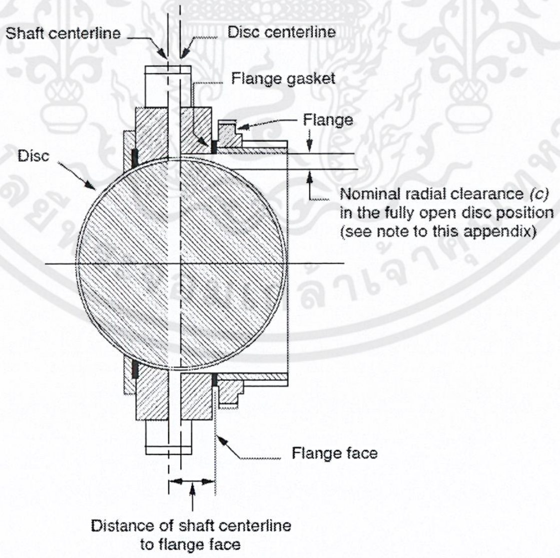


Figure 2.10 Butterfly valve side view

(API STD 609, 2004)

2.10.3 Swing check valve

The check valve is used to prevent reverse flow. The disc inside the check valve hinges upward to permit flow through the valve and closes to prevent reverse flow. The check valves are recommended for the vertical lines having upward flow. The general application for this type is high-temperature service, cryogenic service, and steam service. Its advantages are self-actuating, unobstructed flow path, and resistant to debris. Its disadvantage is a slam due to flow conditions.

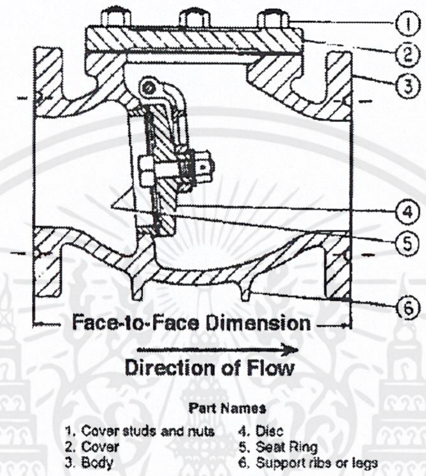


Figure 2.11 Check valve

(Louis, G.L., 1984)

2.10.4 Globe valve

The globe valve is characterized by a baffle or partition separating the two halves of the body. An interconnecting part at the center opened and closed by a screw-down/screw-up disc or plug mounted at right angles to the body. The globe valve is used for regulation characteristics but high resistance because of the tortuous flow path. The globe valves have a variety of discs or plugs and seals. The solid deposits forming on the seat can destroy the discs contract with the seat, so the globe valve is suitable only for the clean fluid.

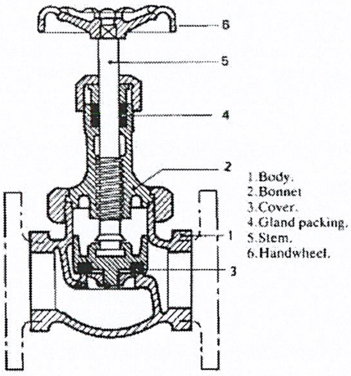


Figure 2.12 Globe valve

(Louis, G.L., 1984)

2.10.5 Gate valve

Generally, a gate valve is used for on-off throttling service by using the flat face or vertical disc or slides in a track or seat which can be lifted in a direction at right angles to the valve until clear of the flow path. Large gate valves tend to be power operated. The gate valves are classified depending on the design of the gate and its seating faces.

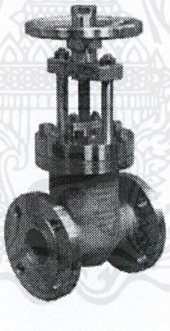


Figure 2.13 Gate valve

(Louis, G.L., 1984)

2.11 Flanges (Louis, G.L., 1984)

2.11.1 Welding neck flange

The welding neck flange has a long-tapered hub and gentle transition of thickness in the region of the butt weld joining it to the pipe. The long-tapered hub gives an important reinforcement of the flange from a strength standpoint and resistance to dishing. The decline of taper provides a smooth transition from the flange thickness to the pipe wall thickness. An endurance strength of welding neck flange equal to butt welded joint therefore this flange type is preferred for several service conditions. The welding neck flange is suitable for handling explosive, flammable or high-value liquid.

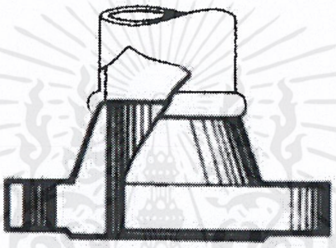


Figure 2.14 Welding neck flange

(Louis, G.L., 1984)

2.11.2 Slip-on flange

A slip-on flange has an installation cost and a strength less than a weld neck flange. The strength under design internal pressure is two-thirds of the weld neck flange and its life under fatigue is about one-third of the latter.

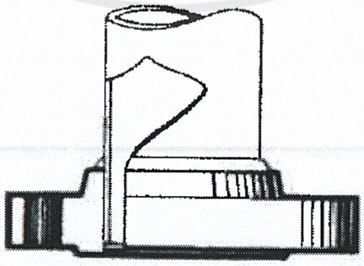


Figure 2.15 Slip-on flange

(Louis, G.L., 1984)

2.12 Hydraulic calculation (Perry, R.H. and Green, D.W., 2018)

The fluid mechanic is fluid behavior study at rest and motion. It used to calculate the pumping system variable which is a total dynamic head. The total dynamic head which is calculated by using the Bernoulli equation is used to identify the pump specification and to estimate pump energy consumption. Fluid velocity is calculated from Eq (2.23)

$$v = \frac{4Q}{\pi D_{\text{inside}}^2} \tag{2.23}$$

2.12.1 Reynolds number

The Reynolds number is the ratio between the inertial forces in a fluid and the viscous forces which is an important dimensionless quantity. It is used to predict flow patterns. The Reynolds number is calculated by using Eq (2.23).

$$N_{\text{Re}} = \frac{Dv\rho}{\mu} \tag{2.24}$$

The Reynolds number below 2,100, it is called the laminar flow regime. The particle in this regime is smooth paths in a layer. The Reynolds number which is between 2,100 and 4,000 is called the transition regime. It is a combination flow between the laminar and turbulent flow. The Reynolds is number over 4,000, it called the turbulent flow regime. In this regime, particle velocity and direction are chaotic.

2.12.2 Bernoulli equation

The Bernoulli equation is derived from mechanical energy balance which is the sum of the kinetic energy, the static pressure, and potential energy. It is used for the incompressible fluid based on Newton's second law of motion. When head loss is included, the Bernoulli equation is modified into Eq (2.25).

$$\frac{P_1}{\rho} + \frac{v_1^2}{2} + gz_1 = \frac{P_2}{\rho} + \frac{v_2^2}{2} + gz_2 + \sum h_f \tag{2.25}$$

The total dynamic head is the total equivalent height in which a fluid is to be pumped. It is calculated by using Eq (2.25) which is derived from the Bernoulli's equation.

$$h_{TDH} = \frac{P_2 - P_1}{\rho g} + \Delta z + \sum h_f \tag{2.26}$$

2.12.3 Head loss

The head loss refers to the total loss due to friction. It is calculated by using Eq (2.27). The head loss in a pipe is divided into 2 causes. The first cause is a head loss from the pipe which depends on size and length. In a rough pipe, the friction factor is a function of the Reynolds number and the relative roughness.

$$h_f = 4f(\frac{L}{D_{inside}})(\frac{v^2}{2g}) \tag{2.27}$$

2.12.3.1 Major head loss

The major head loss is friction loss in a pipe which depends on pipe size and length. The friction factor is a function of the Reynolds number and the relative roughness. For the Reynolds number is below 2,100, which is called laminar flow, the friction factor is calculated by using Eq (2.28). The Reynolds number more than 4,000, which is called turbulent flow, the friction factor is calculated by Eq (2.29). This equation gives a good approximation for the entire turbulent flow range.

$$f = \frac{16}{N_{\mathrm{Re}}} \tag{2.28}$$

$$\frac{1}{\sqrt{f}} = -4\log[\frac{\varepsilon}{3.71D_{inside}} + \frac{1.26}{N_{\mathrm{Re}}\sqrt{f}}] \tag{2.29}$$

2.12.3.2 Minor head loss

The minor head loss is friction loss from valves and fittings. The friction factor from valves and fitting is calculated by using an equivalent length method. The equivalent length is the losses due to valves and fitting which reports as a ratio of straight pipe length, which has the same head loss. Table 2.9 shows the equivalent length ratio of widely usage valves and fittings.

Table 2.9 Equivalent length (Crane Co., 2013)

Valves and fittings	**L_e/D**
Gate vale	8
Globe valve	340
Ball valve	3
Check valve	145
Butterfly valve	20
45° L-Elbow	16
90° L-Elbow	30
TEE Branch	60
TEE Thru	20

2.12.4 Power and brake horsepower calculation

A pump may raise the liquid to a higher elevation, force it into a vessel at higher pressure, provide the head to overcome pipe friction, or perform any combination of these. Regardless of the service required of a pump, all energy imparted to the liquid in performing this service must be accounted for; consistent units for all quantities must be employed in arriving at the work or power performed. A pump power output is determined by using Eq (2.31).

$$P_{H,kW} = \frac{Q\rho g h_{TDH}}{(3,600)(1,000)} \tag{2.31}$$

Power input is usually greater than pump input due to internal loss resulting from friction which is defined as Eq (2.32).

$$P_{B,kW} = \frac{P_{H,kW}}{\eta_P \eta_M} \tag{2.32}$$

2.13 Cost index (Warren, D.S., et al, 2017)

The cost index is used for adjusting the base cost to earlier cost. There have 4 commonly organizations which provide cost data including the Chemical Engineering (CE) plant cost index, the Marshall & Swift (MS) equipment cost index, the Nelson-Farrar (NF) refinery construction cost index and the Engineering News-Record (ENR) construction cost index. The CE and NF indexes account purchase and installation equipment. However, the NF index provides the cost index for petroleum industry whereas the CE index give the cost index for chemical processing industries. The ENR index is a more general index which provides the average of all industrial construction cost index.

Table 2.10 Comparison of annual average cost indexes (Warren, D.S., et al, 2017)

Years	CE	MS	NF	ENR	CPI
2006	500	1,365	2,008	722	201
2007	525	1,399	2,107	742	207
2008	575	1,478	2,251	774	215
2009	522	1,446	2,218	798	214
2010	551	1,477	2,338	819	218
2011	586	1,537	2,436	844	224
2012	585	-	2,465	867	229
2013	567	-	2,490	889	233

2.14 Estimation of man-hour (John, S.P. (1),1999)

The most important things before begins to calculate man-hour are productivity efficiency and productivity element. The five categories of productivity efficiency and the six groups of production element are classified by comparing the projects which vary the conditions. The five ranges of productivity efficiency are shown in Table 2.11. The six groups of production elements are including general economy, project supervision, labor relations, job conditions, equipment, and weather.

Table 2.11 Productivity efficiency classification (John, S.P. (1),1999)

Types	Ranges
Very low	10-40%
Low	41-60%
Average	61-80%
Very good	81-90%
Excellent	91-100%

2.14.1 General economic

Normally, the general economic depends on the nation or area in which a project is to be constructed. The three things that should be reviewed consist of business trends and outlooks, construction volume and employment situation. For example, after considering these items and estimating them to be very good or excellent. The productivity range will be much lower because the top supervision and craftsmen will be mostly employed so the employers who have to draw will be inexperienced personnel. Because of this reason, it will bring to a bad relationship between owner representatives, contract supervision, and the various craftsmen which are unfavorable job conditions. On the other hand, a fairly good average economic tents to raising productivity efficiency.

2.14.2 Project supervision

The project supervision has a concept the same as general economic. If the business is normal, the probability to obtain good supervision is high, but if the economic is excellent, the chance in which inexperience personnel hiring is high.

2.14.3 Labor relations

The labor relation depends on a labor relation in the organization, the craftsmen experienced and satisfies in the area. The things that need to be considered include experience, supply and pay.

2.14.4 Job conditions

There are many items could be considered dependent on the project; however, the most important items that should be analyzed are the scope of work, site conditions, material procurement, and manual and mechanized operation. The plan and the specification are carefully studied and analyzed for correctly estimating a productivity efficiency percentage.

2.14.5 Equipment

The equipment analyze is the simplest of all elements. The equipment to complete a project should be useable, work the right condition and be performed maintenance.

2.14.6 Weather

The estimator should check the past weather conditions for the area which a project is to be located. The weather is the worst of all elements to be considered.

2.14.7 Composite rate

The composite rate considers to correctly arrive at a total direct labor cost when the different labor performances available. Most organizations regard the cost of field personnel with a rating of a superintendent or greater to be a part of job overhead and that of general foreman or lower as direct job labor cost. Therefore, a composite rate should be used when converting the man-hours to direct labor dollars. Table 2.12 provides the pipefitter craft composite rate calculation example. The example assumes that a certain pipe project will need four 10-man crews and that only one general foreman will be needed to head the four crews. General foreman and foreman are dead weight because they do not work with their tools; however, they must be considered and charged to the composite crew.

Table 2.12 Example of composite rate calculation (John, S.P. (1),1999)

Crew	**Number of crews**	**Work (hours)**	**Total work (hours)**	**Wages (USD/hours)**	**Total wages (USD)**
General foreman	1	2	2	23.75	47.50
Foreman	1	8	8	23.50	188.00
Journeyman	9	8	72	23.00	1,656.00
Fifth-year apprentice	1	8	8	18.00	144.00
Total	12	26	80	25.44	2,035.50

2.15 Estimation of fixed investment cost (Perry, R.H. and Green, D.W.,2008)

2.15.1 Order-of-magnitude method

A rule-of-thumb method based on cost data from similar processes type. The probable accuracy is -30 percent to +50 percent. An exponential method, known as the seven-tenths rule, is used to obtain a rapid capital cost by using Eq (2.33). The exponents usually range from 0.6 to 0.8 but 0.7 is used when the exponent cannot estimate.

$$\text{Cost of plant B} = \text{Cost of plant A}\left(\frac{\text{Capacity of plant B}}{\text{Capacity of plant A}}\right)^{x} \qquad (2.33)$$

2.15.2 Preliminary estimate method

A preliminary estimate requires information about the process and equipment design. The probable accuracy of this method is -20 to +25 percent. The Lange method is an estimation equipment installation cost by multiplying a factor with the purchased equipment cost. The factors are grouped into categories that depend on plant types. The Lange factors are shown in Table 2.13. A refinement of the Lange factor method is the Hand method. The Hand method provides the factors which depend on equipment types. The Hand factors are provided in Table 2.14.

Table 2.13 Lange factors (Perry, R.H. and Green, D.W.,2008)

Equipment types	**Factors**
Fractionating column	4.0
Pressure vessels	4.0
Heat exchanger	3.5
Fired heater	2.0
Pump	4.0
Compressor	2.5
Instrument	4.0
Miscellaneous equipment	2.5

Table 2.14 Hand factors (Perry, R.H. and Green, D.W.,2008)

Plant types	**Lange factors**	
	Fixed capital investment	**Total capital investment**
Solid processing	4.0	4.7
Solid-fluid processing	4.3	5.0
Fluid processing	5.0	6.0

2.15.3 Definitive estimate method

A modular method is an extension of the factor method. The Guthrie method which is one of the modular methods includes materials and labors cost for installation equipment. It is one of the most comprehensive. The material cost is a bulk material essentially for supporting installation equipment and the labor cost is a cost for erection and setting equipment. Besides, indirect costs for freight, insurance, engineering, and field expenses are added if applicable. The summation of purchase equipment and installation cost is called a bare module cost. The factors are used to multiply with the purchase equipment cost. After applying to all factors, they are summed for estimating the bare module cost. Unfortunately, the factors and data are old, but the concept is useful. The Guthrie method factors for the pump are shown in Table 2.15. The accuracy of this method is probably -10 to +15 percent.

Table 2.15 Guthrie factors (Perry, R.H. and Green, D.W.,2008)

Details	**Factors for pump and driver**
Purchase equipment	1.00
Piping	0.30
Concrete	0.04
Instruments	0.03
Electrical	0.31
Insulation	0.03
Paint	0.01
Erection and setting	0.70
Freight, insurance, taxes, engineering	0.08
Overhead or field expense	0.97

2.15.4 AACE method (AACE International, 2004)

This method is adapted from the Lange method. It provides the factors for calculation essential bulk materials cost for the installation pump. The installation bulk materials consist of foundations, structural steel, building, insulation, instruments, electrical, piping, painting and miscellaneous. An incompressible fluid is operated in a pumping system. Therefore, the factors for the liquid system are provided in Table 2.16.

Table 2.16 AACE factors (AACE International, 2004)

Details		**Pressure (psig)**	
		$P \leq 150$ psig	**$P > 150$ psig**
Foundations	Material	0.050	0.060
	Labor	0.066	0.080
Structural steel	Material	0.040	0.050
	Labor	0.020	0.025
Buildings	Material	0.030	0.030
	Labor	0.030	0.030
Insulation	Material	0.010	0.030
	Labor	0.015	0.045
Instruments	Material	0.060	0.070
	Labor	0.024	0.028
Electrical	Material	0.080	0.090
	Labor	0.060	0.0675
Piping	Material	0.300	0.350
	Labor	0.150	0.175
Painting	Material	0.005	0.005
	Labor	0.015	0.015
Miscellaneous	Material	0.040	0.050
	Labor	0.032	0.040
Setting and erection	Labor	0.250	0.250

2.16 Estimation of maintenance (Warren, D.S., et al., 2017)

The maintenance cost is an annual charge for keeping the equipment in acceptable working by repairing and replacement of parts as needed. It includes maintenance wages and benefits (MW&B), salaries and benefits and maintenance overhead. The maintenance wages and benefit accounts for 3.5% of total depreciable capital. The salaries and benefits for the engineers and supervisory personnel are accounted for about 25% of MW&B. The materials and services for maintenance are estimated at 100% of MW&B, and maintenance overhead is accounted for 5% of MW&B. The total depreciable capital is calculated by using a depreciation rate.

2.16.1 Straight-line method (Chan, S.P., 2013)

The straight-line (SL) method is calculated the depreciation rate in a uniform model. The depreciation cost is depending on the useful life, and the salvage value. It is calculated by using Eq (2.34).

$$D_n = \frac{C_{asset} - C_{salvage}}{T_{useful\ life}} \tag{2.34}$$

2.16.2 Declining-balance method (Chan, S.P., 2013)

The declining balance method implies the depreciation cost over time. The depreciation cost in the first year is greatest and least in the last year because the mechanical efficiency of assessment in the first year is high and tends to decline with age. Eq (2.35) is provided to calculate the depreciation rate of the declining-balance method.

$$\alpha = \frac{1}{N}(\text{multiplier}) \tag{2.35}$$

The general multiplier used in the United States are 1.5 (called 150%DB) and 2.0 (called 200% DDB, or double-declining-balance). The 200% declining balance method recognizes that the depreciation rate will be 200% of the straight-line rate.

2.16.3 Units-of production method (Chan, S.P., 2013)

The units-of production method is used when amount of the operation time each year is not uniform or full-time operation. The annual depreciation charge is calculated similar to the straight-line method but the fractional of the operation time to total service units is applied as shown in Eq (2.36). In the fact, the depreciation depends on production volume therefore the method provides a more precious picture of machine usage which is advantage of this method.

$$C_{TDC} = \frac{t_{operating}}{t_{useful\ life}}(C_{FIC} - C_{salvage}) \tag{2.36}$$

CHAPTER III

RESEARCH METHODOLOGY

Calculation templates is design intent to estimate costs of pumping system through its life cycle consisting of procurement, installation, operation, and maintenance. Design steps of calculation templates is divided into main 4 steps including selection of cost data and cost estimation method, design algorithm of calculation templates, macro and VBA design, and recording related equation and data in calculation templates, respectively. In addition, calculation templates assumptions are used to simplify in hydraulic calculation step and details requirement should be general gathered from project specification such as process details, equipment specification, and isometric drawing.

3.1 Selection of cost data and cost estimation method

The selection cost data and cost estimation methods for recording in calculation templates is important during design calculation templates, it implies accuracy cost estimation of pumping system. The selection them depends on their limitations, reasonable, and validation when using the currency of Thailand.

3.1.1 Selection of estimation method for pump and motor purchase cost

The order-of-magnitude method is a rule of thumb method to estimate the similar processes type. In addition, it can be used for estimation purchase cost of pump and motor, but purchase cost of the similar equipment type is necessary. Due to insufficient cost data, therefore the correlation of pump and motor purchase cost is applied in calculation templates.

3.1.2 Selection of factors for estimation cost of bulk materials

Bulk materials cost consists of foundation, structural steel, buildings, insulation, instruments, electrical, piping, painting, and miscellaneous. The labor cost is for bulk materials installation. There are 4 methods for estimation cost of bulk materials cost consisting of Lange method, Hand method, Guthrie method, and AACE method. The comparing factor between 4 methods is shown in Table 3.1.

Table 3.1 Comparison factors for estimation cost of bulks material installation

Methods		**Factors**		
		Bulk materials	**Labor cost**	**Indirect cost**
Lang		4.00		
Hand		4.00		
Guthrie		0.72	0.70	1.05
AACE	P ≤ 10 barg	0.62	0.66	-
	P > 10 barg	0.74	0.76	-

Form Table 3.4, Lange factors and Hand factors include equipment purchase cost, bulk materials installation cost, labor cost, and indirect cost. The Guthrie factors implies net labor factor for pump and bulk materials installation. Some bulk materials are excluded because they are apart from the scope of work, i.e. building, foundation, and piping. Therefore, Lange factors, Hand factors, Guthrie factors is not appropriate in this case. AACE factors are applied in calculation templates because it is treating materials and labor separately for allowing the estimator to make an additional check on the reasonableness of estimation. Consequently, the AACE factors are proper to apply in the calculation template.

3.1.3 Selection of estimation method for total depreciation cost

The depreciation cost estimation is provided several methods including straight-line method, declining balance method, and unit of production method. The straight-line method and declining balance method give the same total depreciation cost because they assume that pumping system is operated full time. The unit of production method depends on the amount of usage which is reasonable for having shift work operation. Therefore, the unit of production method is applied in the calculation templates.

3.2 Assumptions of calculation templates

The calculation templates assume that pumping system is steady state, fluid is incompressible fluid and classifies in Newtonian. The steady state is variables state unchanging in time. This concept is provided to simplify pumping system problems and design calculation templates. The two-phase liquid is cause of huge pressure drop in the pipe which is complex problem therefore the incompressible fluid assumption is essential reducing complexity of the calculation template. The Newtonian fluid is usually used in the chemical processes and the largest class of fluid type.

3.3 Calculation templates algorithm

The algorithm of calculation template divided into 4 steps (See Figure 3.1) which are including input specification, hydraulic calculation, variables screening, life cycle cost calculation and showing the results in graph and table.

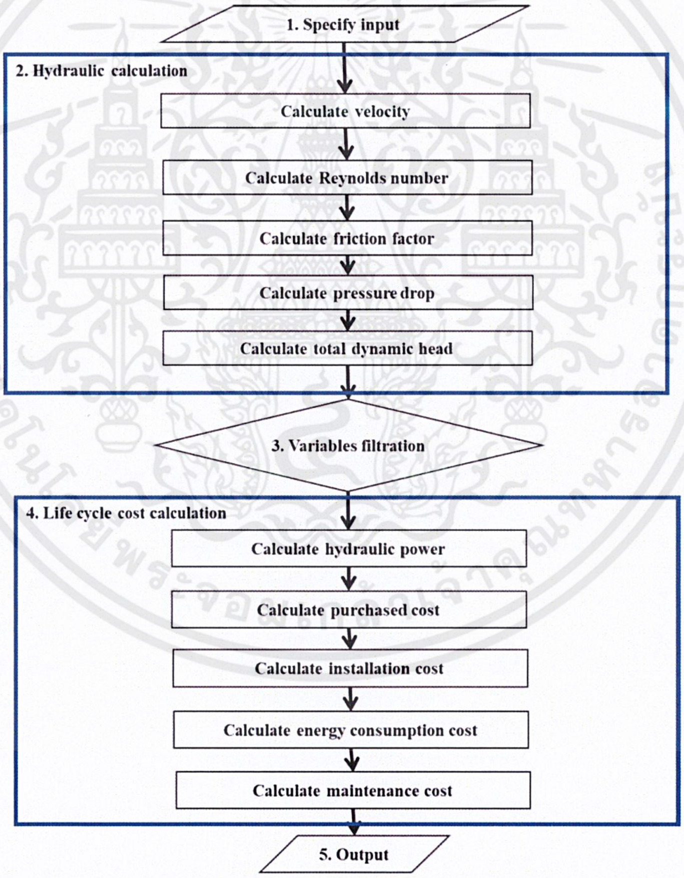


Figure 3.1 Calculation templates algorithm

3.4 Macro and VBA algorithm

In macro and VBA design, varying pipe length is not considered because it is fixed following isometric drawing which is reasonable the shortest pipeline. Therefore, varying pipe size is more interesting than varying pipe length.

The macro and VBA (Visual Basic for Applications) proceed in accordance with blue line as shown in Figure 3.2. the blue lines proceed macro and VBA script. First, they specify the inner diameter of ½-inch pipe into the hydraulic calculation template. If flow regime of this pipe size is turbulent, macro and VBA will activate the goal and seek function for friction factor calculation. Then, pressure drop and velocity are screened by using criteria, and are recorded results within table. After obtaining total dynamic head and brake horsepower, the equipment purchase cost of ½-inch pipe size is provided. Macro and VBA specify next pipe size, repeat the script and stop when total dynamic head of the 24-inch pipe size obtains.

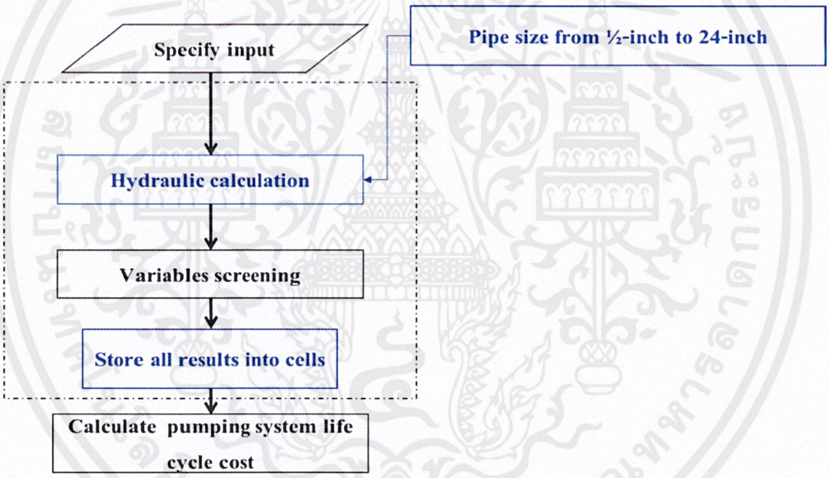


Figure 3.2 VBA and macro algorithm

3.5 Details requirement for calculation templates

3.5.1 Details for calculations

The process details and criteria are gathered from a project specification. The details, which need to be specified in the calculation template, are separated into two groups. The first group is details for hydraulic calculation, and the second is details for the life cycle cost calculation. The details for hydraulic calculation include volumetric flow rate, density, elevation change, actual pipe length, number of valves and fitting, internal design gauge pressure, allowable pressure drop, and velocity. The details for life cycle cost calculation consist of pump capacity, pump types, pump materials of construction, motor types, pipe materials of construction, operating time, and labor wage.

3.5.2 Details for filtration variables

In addition to details for hydraulic calculation and life cycle cost calculation, the allowable pressure and velocity should specify in calculation templates. The allowable pressure drop is an acceptable pressure loss from piping per 100 m and the allowable velocity is the permitting fluid speed to flow through a pipe. The design criteria are usually specified on a project specification. In case the project specification is unavailable, the design criteria are depending on the company criteria or the engineer's experience. Apart from allowable pressure and velocity, the pipe diameter from estimation method of economic pipe size creates the boundary by varying the ratio of the total cost for fittings and installation from 1.5 to 6.75 (Towler, G. and Sinnott, R., 2013). For pump and motor criteria, the size factor implies the range of purchase equipment cost.

3.6 Calculation cost of pumping system

3.6.1 Equipment purchase cost

3.6.1.1 Pump and motor purchase costs

A pump purchase cost is a product of volumetric flow rate and total dynamic head following Eq (2.6) and Eq (2.7). The specifying details step provides the volumetric flow rate, and the hydraulic calculation step gives total dynamic head. The purchase motor cost is a function of brake horsepower following Eq (. For a reciprocating plunger pump, the efficiency is about 90% (Warren, D.S, et al., 2017).

3.6.1.2 Piping purchase cost

The pipe and fittings purchase costs are reported a ratio of purchased weight to purchase cost. The pipe and fittings materials of construction, which available in the calculation template, consist of carbon steel, stainless steel and plastic. The weight of carbon steel pipe and flange is provided in Table B.3 to Table B.5. The pipe and fittings costs data are reported in Table B.9 and the valves cost data provides in Table B.10.

1) Pipe cost

$$C_{pipe} = c_{pipe} W_{pipe} \tag{3.1}$$

2) Fitting cost

$$C_{fitting} = c_{fitting} W_{fitting} \tag{3.2}$$

3) Valve cost

$$C_{valve,type} = c_{valve,type} N_{valve,type} \tag{3.3}$$

4) Total piping cost

$$C_{piping} = C_{pipe} + C_{valve} + C_{fitting} \tag{3.4}$$

3.6.1.3 Total of equipment purchase cost

Before calculation of total equipment purchase cost, pump and motor costs need to be updated their cost from 2013 to 2019 by using Eq (3.5) and Eq (3.6). After that, pump, motor, and piping purchase costs are added for giving total equipment purchase cost.

$$C_{pump,update} = C_{pump,2013} \left(\frac{I_{update}}{I_{2013}}\right) \tag{3.5}$$

$$C_{motor,update} = C_{motor,2013} \left(\frac{I_{update}}{I_{2013}}\right) \tag{3.6}$$

$$C_{EPC} = C_{pump} + C_{motor} + C_{piping} \tag{3.7}$$

3.6.2 Installation cost

The pump installation cost calculation is divided into two parts. The first part is an estimation cost of pump and pipe installation by using the man-hour method, and another part is an estimation cost of bulk materials.

$$C_{INS} = C_{INS,pump} + C_{INS,piping} + C_{INS,bulk} \tag{3.8}$$

3.6.2.1 Man-hour method

The man-hour method is time that a person can perform the work in an hour. It uses to estimate the labor for erection, connection, and setting equipment. The man-hour for pump setting depends on pump types, number of stages, and brake horsepower. The man-hour for piping is in accordance with pipe schedule, actual pipe length, and pressure rating. Besides, it depends on the materials of construction, in which carbon steel is a base material. Therefore, the man-hour percent additives apply for other materials of construction. The man-hour data is reported in Appendix C.

1) Pump installation cost

$$C_{INS,pump} = m_{pump} P_{B,HP} C_{wage} \tag{3.9}$$

2) Piping erection man-hour

$$M_{erection} = m_{erection} L \tag{3.10}$$

3) Pipe connection man-hour

$$M_{pipe,con} = m_{pipe,con} N_{con} \tag{3.11}$$

4) Valves and fittings connection man-hour

$$M_{valves,con} = m_{valve,con} N_{valves,fittings} \tag{3.12}$$

5) Pipe painting man-hour

$$M_{painting} = m_{painting} L C_{wage} \tag{3.13}$$

6) Total piping man-hour

$$M_{piping} = M_{erection} + M_{pipe,con} + M_{valves,con} + M_{painting} \tag{3.14}$$

7) Piping installation cost

$$C_{INS,piping} = M_{piping} C_{wage} \tag{3.15}$$

3.6.2.2 Bulk materials installation cost

After unnecessary bulk materials in AACE factors are removed, the bulk materials installation cost is determined in accordance with Eq (3.16) and Eq (3.17) for pressure equal or below than 10 kg/cm^2 and higher than 10 kg/cm^2.

$$C_{INS,bulk} = 0.4575(C_{pump} + C_{motor}) \tag{3.16}$$

$$C_{INS,bulk} = 0.5803(C_{pump} + C_{motor}) \tag{3.17}$$

3.6.3 Fixed investment cost

Equipment purchase cost and installation cost are added for calculation of fixed investment cost.

$$C_{FIC} = C_{EPC} + C_{INS} \tag{3.18}$$

3.6.4 Maintenance cost

The total depreciation cost estimation in accordance with Eq (3.23). The maintenance cost is estimated about 8.05% of total depreciation cost and is shown in Eq (3.24). The liquid transportation system has useful life about 14.5 to 21.5 years following ADR (Asset Depreciation Range) which TTCL Co. Ltd., use 20 years. Salvage value is estimated 10% or less than of the asset cost.

$$C_{TDC} = \frac{T_{operating}}{T_{useful\ life}}(C_{FIC} - C_{salvage}) \tag{3.19}$$

$$C_{MAN} = 0.08C_{TDC} \tag{3.20}$$

3.6.5 Energy consumption cost

An energy consumption cost is one of the variable costs which is a function of pump brake power, fractional pump to motor efficiency, operating time, and electricity rate. The pump brake power can be determined following Eq (2.32). If the centrifugal pump and motor efficiency is not specified, they will be calculated by using Eq (2.1) and Eq (2.2). For the reciprocating plunger pump, the efficiency assumes 90% (Warren, D.S, et al, 2017).

$$C_{ECC} = KP_{B,kW}t_{operating} \tag{3.21}$$

3.6.6 Variable cost

The variable cost is total annual charges per year. Normally, the variable cost cannot add in a fixed investment cost directly therefore the equipment lifetime period prescription requires for life cycle cost calculation. The life cycle cost for 2 years is considered because sometimes the company needs studying and training customer's staff about operation for 2 years.

$$C_{var} = C_{ECC} + C_{MAN} \tag{3.22}$$

$$C_{var,total} = C_{var}T \tag{3.23}$$

3.6.7 Life cycle cost

The life cycle cost is a summation of fixed investment cost and variable cost for a total lifetime which is expressed in accordance with Eq (3.24).

$$C_{LLC} = C_{FIC} + C_{var,total} \tag{3.24}$$

3.7 Outputs from calculation templates

In the calculation templates, results are shown in a graph and a table. According to Figure 3.3, the graph is a function of pipe diameter, fixed investment cost, and variable cost. The X-axis is pipe diameter in inch and the Y-axis is cost in USD. The fixed investment cost increases during the variable cost decreases. This pattern occurs, during pipe size increases until a head loss is close to zero which affects the pump purchase cost and the variable cost are almost constant.

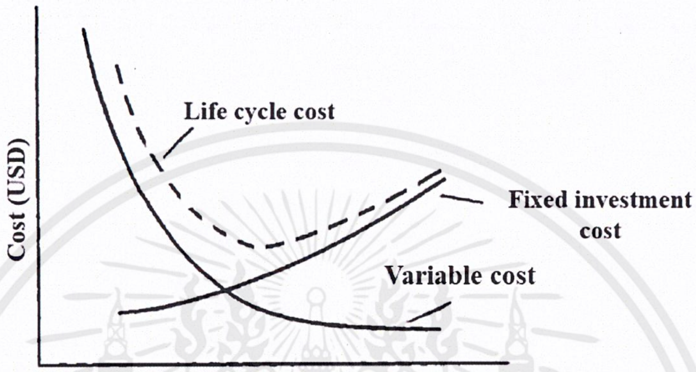


Figure 3.3 Effects on pipe diameter to life cycle cost

(Brian, N, 2006)

For the table, the calculation templates give results for all cost calculation and colors. The green color means the lowest cost, the yellow color is a fair, and the red is the highest cost.

Figure 3.4 Example of results table in summary sheet with color tab

CHAPTER IV

RESULTS AND DISCUSSION

A case study is used to show example of calculation templates. The calculation templates are divided into 4 steps consisting details specification, hydraulic calculation, filtration the parameters and calculation of life cycle cost. The case study assumes that elevation change is negligible, labor wage is minimum wage in Thailand, life cycle cost is considered for 2 years. The consideration of life cycle cost is for 2 years, because in some cases TTCL needs to study operation plant and to train customer staffs. Therefore, the operation cost belongs to TTCL.

4.1 Examples of calculation templates

4.1.1 Calculation templates component

Normally, Excel has calculation templates within sheets as shown in Figure 4.1. The essential process details are specified in the input sheet. After that, macro and VBA take all details to the calculation sheet which has hydraulic calculation and pipe data templates. The pipe data template is connected inner diameters form ANSI sheet which has details following ASME B16.5. After obtaining total dynamic head and brake horsepower from hydraulic calculation template, life cycle cost is calculated in summary sheet. The calculation template of installation cost, which is in summary sheet, takes pump and piping man-hour data from piping man-hour and pump setting man-hour sheets.

Figure 4.1 Component of calculation templates

4.1.2 Node specification

The node specification is the most important section because it defines a scope of cost calculation. For the case study, the process flow diagram is drawn manually to be specified the node which includes the pump and discharge pipe. The suction pipe of this process is excluded because it assumes that the suction pipe is short and can ignore.

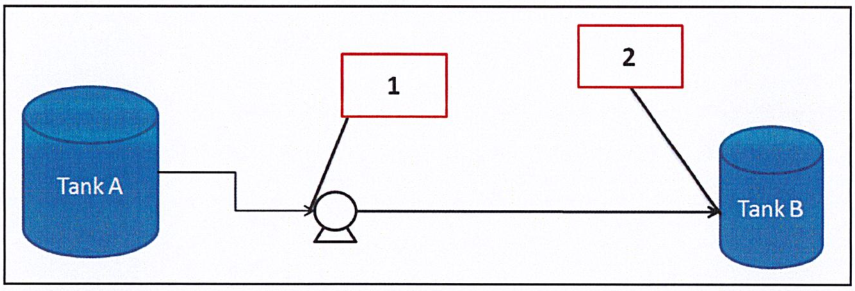


Figure 4.2 Node specification

4.1.3 Pump and motor enclosure type specification

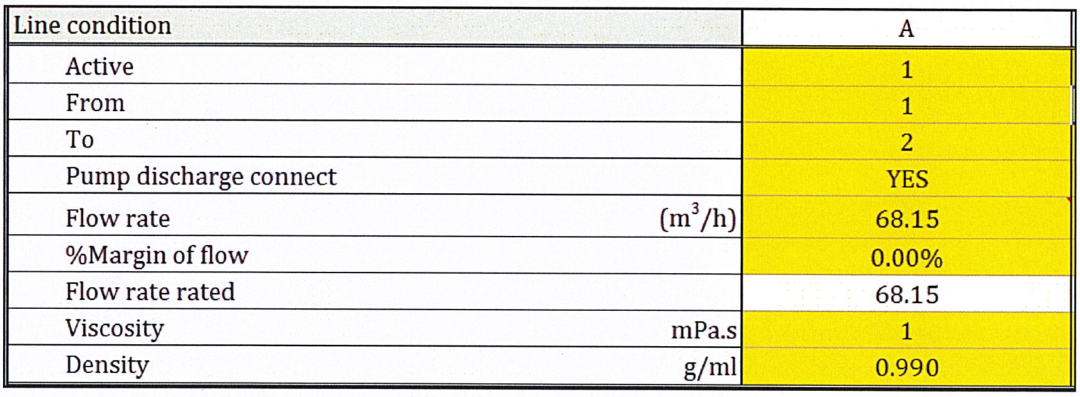
The elevation changing from the case study is not specified therefore the total dynamic head depends on the head loss from pipe directly. From the case study, 68.15 m^3/h of water is pumped by the pump which operates with the rotation speed 1,800 rpm motor. There are 2 types of the pump in conditional including single-stage centrifugal pump combined with vertical spilt casing, or horizontal spilt casing. The pump type is selected by the most economic. From Table 4.1, the type factor of vertical spilt casing is lower about 25%, therefore the centrifugal pump with vertical spilt case is selected. For the enclosure type, the one drip proof is selected due to environment condition and fluid handling.

Table 4.1 Comparison type factor of radial centrifugal pump

Pump types	**Number of stages**	**Casing types**	**Rotation speed (rpm)**	$F_{type\ factor}$
Centrifugal	1	VSC	1,800	1.5
Centrifugal	1	HSC	1,800	2

4.1.4 Input template

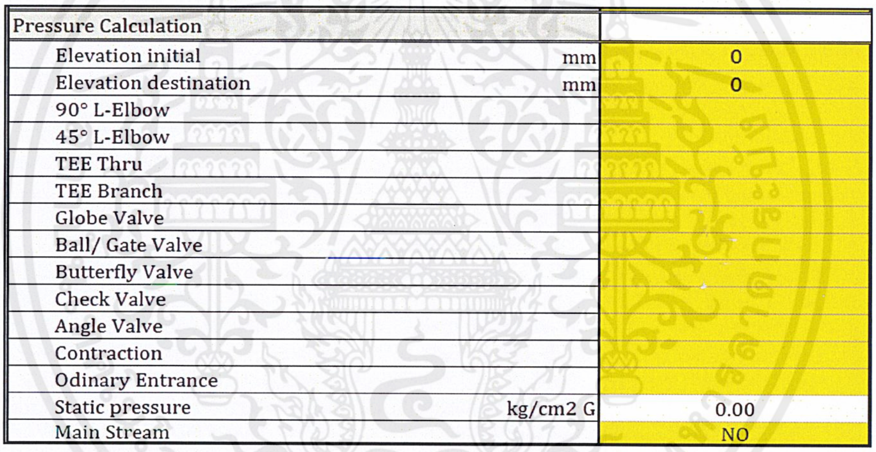
As shows in Figure 4.3, the fluid properties are filled in yellow cells. The white cell is the result from calculation. The first row is a node name. The “Active” is filled 1 for allowing the macro and VBA activated in this column. The pump discharge connect cell is filled “YES” for calculation of pump and motor purchase cost.



Line condition		A
Active		1
From		1
To		2
Pump discharge connect		YES
Flow rate	(m³/h)	68.15
%Margin of flow		0.00%
Flow rate rated		68.15
Viscosity	mPa.s	1
Density	g/ml	0.990

Figure 4.3 Fluid properties details specification

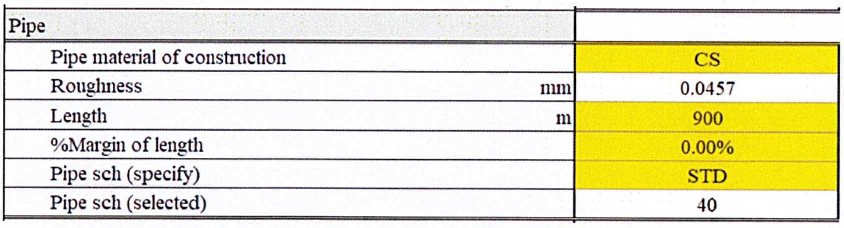
From the case study, elevation change, number of valve and fitting are not available, therefore zero and blank are specified as shown in Figure 4.4.



Pressure Calculation		
Elevation initial	mm	0
Elevation destination	mm	0
90° L-Elbow		
45° L-Elbow		
TEE Thru		
TEE Branch		
Globe Valve		
Ball/ Gate Valve		
Butterfly Valve		
Check Valve		
Angle Valve		
Contraction		
Odinary Entrance		
Static pressure	kg/cm2 G	0.00
Main Stream		NO

Figure 4.4 Valves and fitting details specification

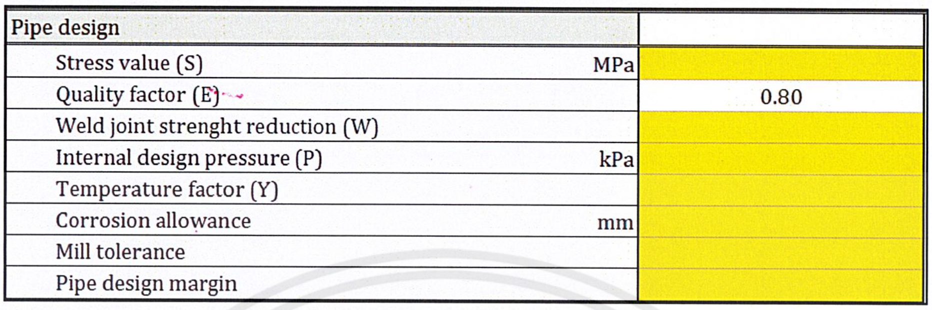
After that, the pipe material of construction is specified. If pipe schedule is not specified in a project specification, pipe wall thickness will be calculated in accordance with ASME 31.3.



Pipe		
Pipe material of construction		CS
Roughness	mm	0.0457
Length	m	900
%Margin of length		0.00%
Pipe sch (specify)		STD
Pipe sch (selected)		40

Figure 4.5 Pipe details specification

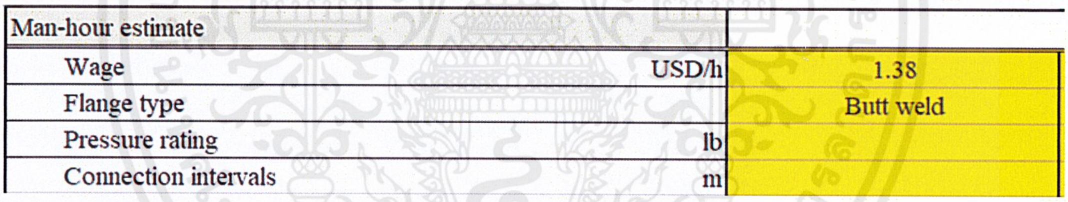
Internal pressure design gauge is specified at input template as shown in Figure 4.6. The other variables are gathered in pipe material data sheet in the same calculation templates or ASME 31.3.



Pipe design		
Stress value (S)	MPa	
Quality factor (E)		0.80
Weld joint strenght reduction (W)		
Internal design pressure (P)	kPa	
Temperature factor (Y)		
Corrosion allowance	mm	
Mill tolerance		
Pipe design margin		

Figure 4.6 Pipe wall thickness calculation

The minimum wage in Thailand is about 330 baht/day or 1.38 USD/h so it is specified in wage cell. The butt weld connection is used for unknown flange type. The connection span depends on the vendor which common is 6 m.

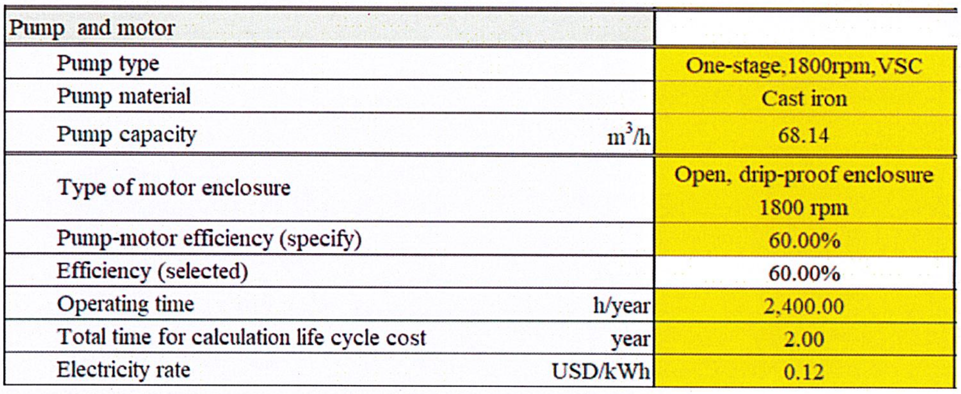


Man-hour estimate		
Wage	USD/h	1.38
Flange type		Butt weld
Pressure rating	lb	
Connection intervals	m	

Figure 4.7 Man-hour details specification

The pump type and material of construction are specified in yellow cells as shown in Figure 4.8. The pump capacity, which is from pump specification, is used to determine pump purchase cost.

The one, drip-proof enclosure motor with rotation speed 1,800 rpm is specified. The pump and motor efficiencies are calculated when they are not specified in an equipment specification. The product of pump to motor efficiency in the case study specifies 60%, so it is filled in "Pump-motor efficiency (specify)".

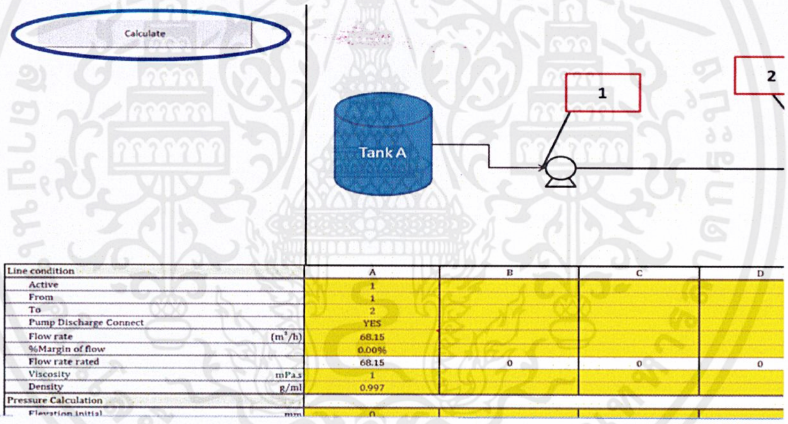


Pump and motor		
Pump type		One-stage,1800rpm,VSC
Pump material		Cast iron
Pump capacity	m^3/h	68.14
Type of motor enclosure		Open, drip-proof enclosure 1800 rpm
Pump-motor efficiency (specify)		60.00%
Efficiency (selected)		60.00%
Operating time	h/year	2,400.00
Total time for calculation life cycle cost	year	2.00
Electricity rate	USD/kWh	0.12

Figure 4.8 Motor, efficiency, operating time and electricity rate details specification

4.1.5 Hydraulic calculation template

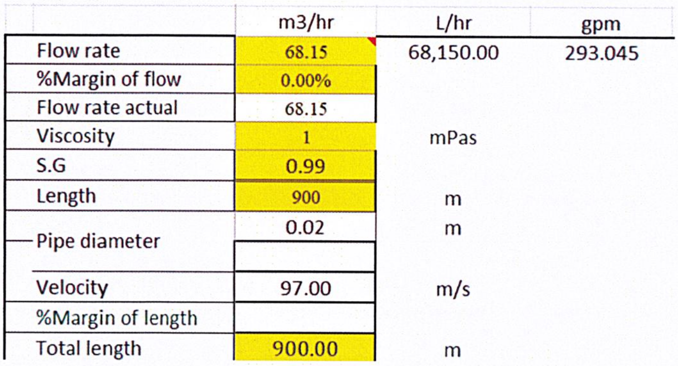
After specifying all inputs in yellow cells, the macro and VBA is activated in calculation button in input template as shown in Figure 4.9.



Line condition		A	B	C	D
Active		1			
From		1			
To		2			
Pump Discharge Connect		YES			
Flow rate	(m^3/h)	68.15			
%Margin of flow		0.00%			
Flow rate rated		68.15	0	0	0
Viscosity	mPa.s	1			
Density	g/ml	0.997			
Pressure Calculation					
Elevation initial	mm	0			

Figure 4.9 "Calculate" button for activating macro and VBA

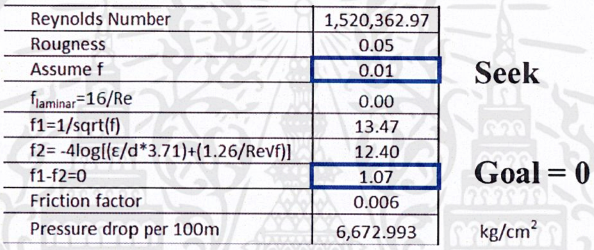
The fluid properties are taken to the hydraulic calculation template and the volumetric flow rate is converted units to the liter per hour and gallons per min. Then, macro and VBA specified ½ inch pipe in pipe diameter cell.



	m3/hr	L/hr	gpm
Flow rate	68.15	68,150.00	293.045
%Margin of flow	0.00%		
Flow rate actual	68.15		
Viscosity	1	mPas	
S.G	0.99		
Length	900	m	
Pipe diameter	0.02	m	
Velocity	97.00	m/s	
%Margin of length			
Total length	900.00	m	

Figure 4.10 Hydraulic calculation template

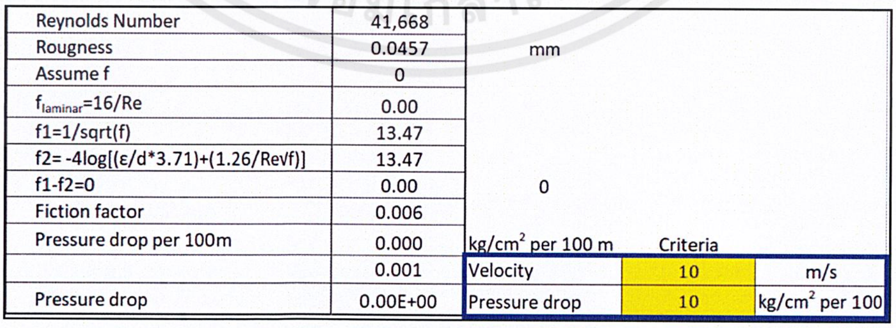
After that, macro and VBA activate goal and seek function for friction factor calculation and stores results in pressure drop results Table.



Reynolds Number	1,520,362.97	
Rougness	0.05	
Assume f	0.01	**Seek**
$f_{laminar}$=16/Re	0.00	
f1=1/sqrt(f)	13.47	
f2= -4log[(ε/d*3.71)+(1.26/Re√f)]	12.40	
f1-f2=0	1.07	**Goal = 0**
Friction factor	0.006	
Pressure drop per 100m	6,672.993	kg/cm^2

Figure 4.11 Friction factor calculation

The velocity and the pressure drop criteria are linked form the input sheet. For the velocity and pressure drop are more than the specifying criteria, the total pressure drop is specified zero. In this case, the calculation template gives the total pressure drop in all pipe sizes.



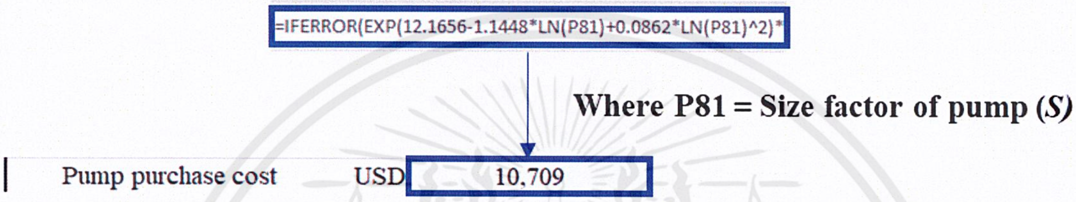
Reynolds Number	41,668			
Rougness	0.0457	mm		
Assume f	0			
$f_{laminar}$=16/Re	0.00			
f1=1/sqrt(f)	13.47			
f2= -4log[(ε/d*3.71)+(1.26/Re√f)]	13.47			
f1-f2=0	0.00	0		
Fiction factor	0.006			
Pressure drop per 100m	0.000	kg/cm^2 per 100 m	Criteria	
	0.001	Velocity	10	m/s
Pressure drop	0.00E+00	Pressure drop	10	kg/cm^2 per 100

Figure 4.12 Pressure drop and velocity criteria

Finally, total dynamic head is calculated and macro and VBA repeat script until obtaining total dynamic head of 24-inch pipe.

4.1.6 Calculation templates of life cycle cost

The life cycle cost calculation template can be divided into 2 calculation patterns. The first pattern is equations or factors specified in cells, this pattern is used when cost estimation is equations or factors, i.e., pump and motor purchase costs, bulk materials installation cost, energy consumption cost, maintenance cost.



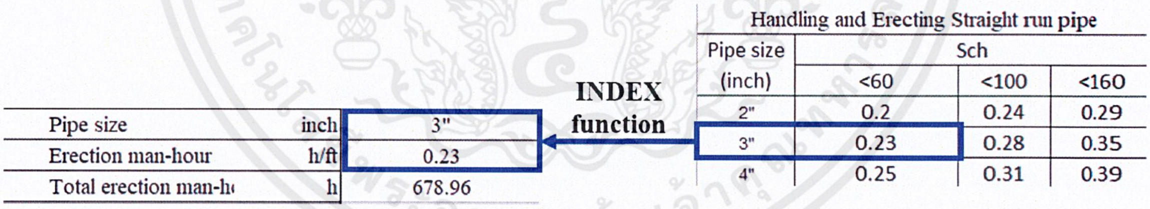
```
=IFERROR(EXP(12.1656-1.1448*LN(P81)+0.0862*LN(P81)^2)*
```

Where P81 = Size factor of pump (*S*)

Pump purchase cost	USD	10,709

Figure 4.13 Example of calculation template for pump purchase cost

The second pattern is taking cost estimation data from other templates by using INDEX function, i.e., man-hour data and pipe details.



Pipe size	inch	3"
Erection man-hour	h/ft	0.23
Total erection man-h	h	678.96

INDEX function

Handling and Erecting Straight run pipe

Pipe size (inch)	Sch		
	<60	<100	<160
2"	0.2	0.24	0.29
3"	0.23	0.28	0.35
4"	0.25	0.31	0.39

Figure 4.14 Example of calculation template for pipe installation

4.1.7 Results and discussion

From Figure 4.15. The most economic of pumping system for 2 years is 4-inch pipe. The fixed investment cost increases during pipe size increases. The variable cost decreases significantly when pipe size increases from 3-inch to 4-inch due to decreasing head loss.

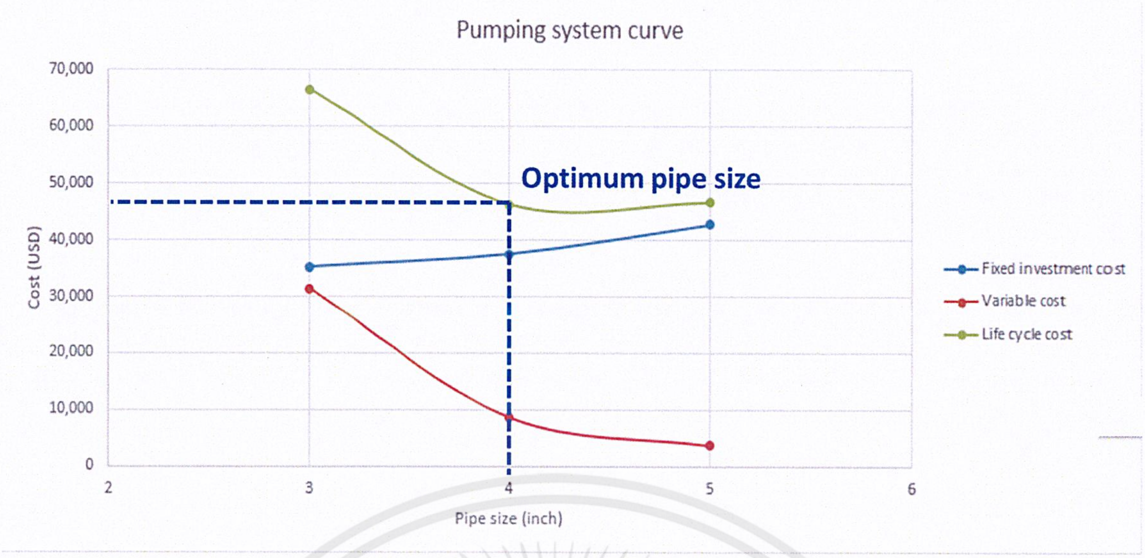
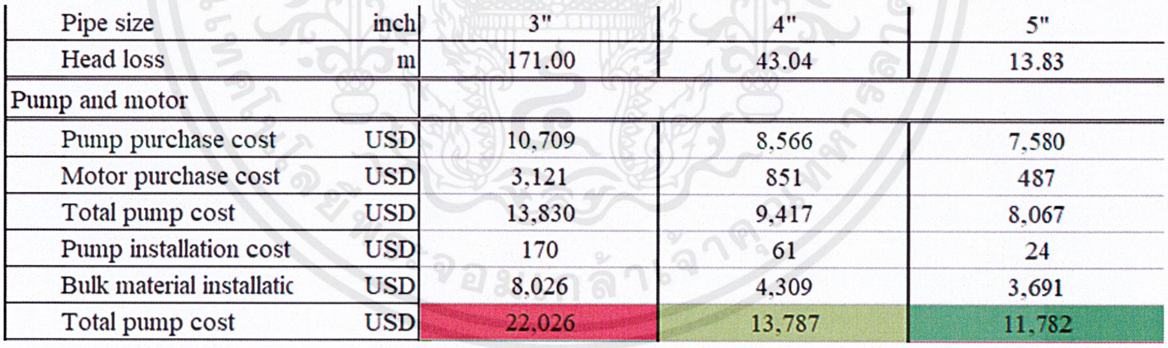


Figure 4.15 Correlation between cost and pipe size

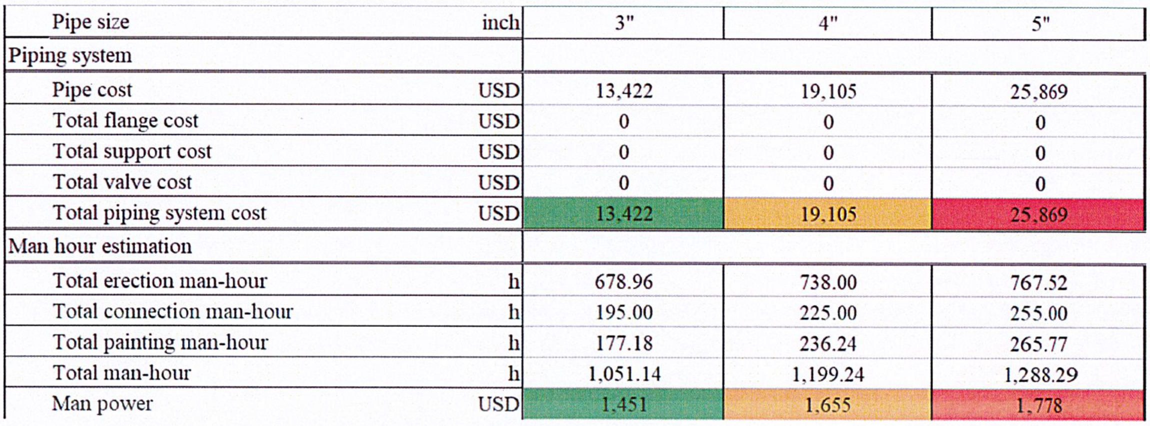
Form the Darcy Weisbach's equation, the head loss is a fraction of velocity to diameter. Consequently, the pipe diameter increasing cause of velocity decreases, and head loss is greatly reduced as shown in Figure 4.16. In this case, the volumetric flow rate is constant, and static pressure equals zero. Therefore, the total dynamic head depends on only head loss.



Pipe size	inch	3"	4"	5"
Head loss	m	171.00	43.04	13.83
Pump and motor				
Pump purchase cost	USD	10,709	8,566	7,580
Motor purchase cost	USD	3,121	851	487
Total pump cost	USD	13,830	9,417	8,067
Pump installation cost	USD	170	61	24
Bulk material installatic	USD	8,026	4,309	3,691
Total pump cost	USD	22,026	13,787	11,782

Figure 4.16 Pump cost results

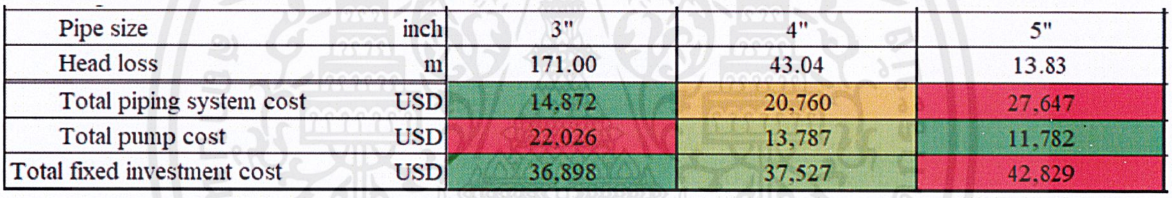
The valves and fittings are not available, so their costs equal to zero. The pipe purchased cost is calculated from its weight. The piping installation cost is calculated by using the man-hour method which varies on pipe size and length. Therefore, the total pipe cost varies directly with only the pipe size when length is constant.



Pipe size	inch	3"	4"	5"
Piping system				
Pipe cost	USD	13,422	19,105	25,869
Total flange cost	USD	0	0	0
Total support cost	USD	0	0	0
Total valve cost	USD	0	0	0
Total piping system cost	USD	13,422	19,105	25,869
Man hour estimation				
Total erection man-hour	h	678.96	738.00	767.52
Total connection man-hour	h	195.00	225.00	255.00
Total painting man-hour	h	177.18	236.24	265.77
Total man-hour	h	1,051.14	1,199.24	1,288.29
Man power	USD	1,451	1,655	1,778

Figure 4.17 Piping cost results

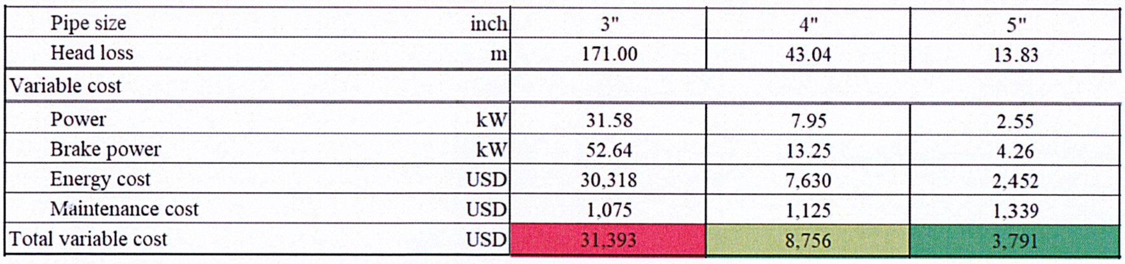
The total pump cost and piping cost are added to determine the fixed investment cost. The total pump cost of pipe size 3-inch is costly, but the pipe cost is the lowest, so the total fixed cost is the minimum.



Pipe size	inch	3"	4"	5"
Head loss	m	171.00	43.04	13.83
Total piping system cost	USD	14,872	20,760	27,647
Total pump cost	USD	22,026	13,787	11,782
Total fixed investment cost	USD	36,898	37,527	42,829

Figure 4.18 Fixed investment cost results

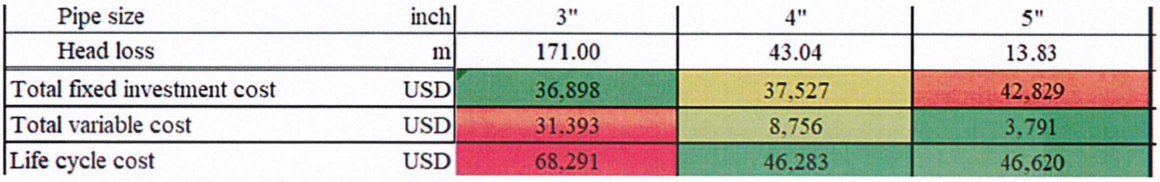
The energy consumption cost is a function of volumetric flow rate and the total dynamic head. The total dynamic head depends on only head loss and volumetric is constant. Consequently, the energy consumption cost is decreased when pipe size is increased. The maintenance cost increases because equipment purchases cost increases.



Pipe size	inch	3"	4"	5"
Head loss	m	171.00	43.04	13.83
Variable cost				
Power	kW	31.58	7.95	2.55
Brake power	kW	52.64	13.25	4.26
Energy cost	USD	30,318	7,630	2,452
Maintenance cost	USD	1,075	1,125	1,339
Total variable cost	USD	31,393	8,756	3,791

Figure 4.19 Variable cost results

The 3-inch pipe is the highest energy consumption cost, but the fixed investment cost of 3-inch and 4-inch pipe is not different significant. Therefore, the 4-inch pipe is the most economical of pumping system for 2 years.



Pipe size	inch	3"	4"	5"
Head loss	m	171.00	43.04	13.83
Total fixed investment cost	USD	36,898	37,527	42,829
Total variable cost	USD	31,393	8,756	3,791
Life cycle cost	USD	68,291	46,283	46,620

Figure 4.20 Life cycle cost results

4.2 Comparison life cycle results between calculation templates and case study

From Table 4.2, the fixed investment cost from case study is more than the calculation templates due to piping installation cost. The piping installation cost from calculation template is in accordance with labor wage which is minimum wage in Thailand. Generally, the engineers or foremen wage should be included.

Table 4.2 Fixed investment cost from calculation templates and a case study

Nominal pipe size (inch)	**Fixed investment cost (USD)**	
	Calculation template	**Case study**
3	36,898	37,067
4	37,527	45,463
5	42,829	60,169

The case study equipment annual cost estimation is more than the calculation template maintenance cost. Therefore, the variable cost and life cycle cost of case study are higher. The life cycle cost for 2 years from the calculation templates is lower due to estimation method of maintenance cost. The annual charge of equipment from the case study is 20% of piping purchase cost, but the maintenance cost estimation in the calculation templates bases on total usage time until end of useful life so the maintenance cost from calculation templates is estimated only 2.19% of equipment purchase cost.

Table 4.3 Variable cost from calculation templates and a case study

Nominal pipe size (inch)	Variable cost for 2 years (USD)	
	Calculation template	Case study
3	31,393	36,851
4	8,756	16,365
5	3,791	14,281

Table 4.4 Life cycle cost from calculation templates and a case study

Nominal pipe size (inch)	Life cycle cost for 2 years (USD)	
	Calculation template	Case study
3	68,291	71,704
4	46,283	60,995
5	46,620	74,000

4.3 Comparison labor wages and salaries

The wage is used to compare including minimum wage in Thailand, minimum wage in USA, and wage estimation from textbook. The fraction of pipe installation cost to pipe purchase cost when using minimum wage in Thailand is shown in Table 4.5.

Table 4.5 Fraction of pipe installation cost to pipe purchase cost in calculation templates

Nominal pipe size (inch)	Pipe purchase cost (USD)	Pipe installation cost (USD)	Fraction of pipe installation cost to pipe purchase cost
3	13,422	1,451	0.10
4	19,105	1,655	0.09
5	25,869	1,778	0.07

The case study estimates pipe installation about 100% of pipe purchase cost, but the calculation template estimates only 7-10% of pipe purchase cost. The minimum wage in USA, which is 7.25 USD/h, is specified in the calculation templates and results are shown in Table 4.6.

Table 4.6 Fraction of pipe installation cost to pipe purchase cost when using minimum wage in USA

Nominal pipe size (inch)	Pipe purchase cost (USD)	Pipe installation cost (USD)	Fraction of pipe installation cost to pipe purchase cost
3	13,422	7,621	0.56
4	19,105	8,694	0.46
5	25,869	9,340	0.36

From Table 4.6, The fraction is increased significantly but lower than estimation from case study. The man-hour for pipe project is estimated wage about 25.44 USD/h (John S.P.(1), 1999). This wage includes general foreman, foreman, journeyman, and fifth-year apprentice.

Table 4.7 Fraction of pipe installation cost to pipe purchase cost when including foremen salaries

Nominal pipe size (inch)	**Pipe purchase cost (USD)**	**Pipe installation cost (USD)**	**Fraction of pipe installation cost to pipe purchase cost**
3	13,422	26,741	1.99
4	19,105	30,509	1.60
5	25,869	32,774	1.27

From Table 4.7, the fraction is more than estimation from case study, therefore the fixed investment cost from case study and calculation template is different due to specifying wage in calculation templates.

Table 4.8 Comparison pipe installation cost when using minimum wage in USA and salaries including foremen

Nominal pipe size (inch)	**Pipe installation cost from calculation templates (USD)**		**Pipe installation cost from case study (USD)**
	Minimum wage in USA	**Wage from John S.P. (1)**	
3	7,621	26,741	15,766
4	8,694	30,509	21,690
5	9,340	32,774	29,523

The estimation cost of pipe installation about 100% of pipe purchase cost is reasonable when including foremen wage and salaries, therefore the minimum wage in Thailand mainly makes fixed investment cost between calculation templates and case study different.

4.4 Maintenance cost from each estimation methods of total depreciation cost

Because energy consumption cost from the calculation templates and the case study are estimated similar electricity rate, therefore different in life cycle cost for 2 years causes from maintenance cost.

The total depreciation is used to compare consisting of units of productions method, declining method, straight-line rate method. From the case study, annual charges for equipment is estimated 20% of installed equipment. The declining and straight-line rate give the same total depreciation cost because the pump is assumed full time operated (Chan, S.P, 2013). The maintenance cost is 8.05% of total depreciation cost (Warren, D.S, et al, 2017). The maintenance cost is 10% of fixed investment cost (Perry, R.H. and Green, D.W., 2018).

Table 4.9 Comparison maintenance cost from each estimation method of total depreciation cost

Nominal pipe size (inch)	**Maintenance cost (USD/yr)**		
	Total deprecation cost from declining method	**Maintenance cost bases on fixed investment cost**	**A case study**
3	2,180	4,379	3,153
4	2,282	4,546	4,338
5	2,715	5,115	5,905

From Table 4.8, maintenance cost bases on fixed investment cost is reasonable for this case study, but the maintenance cost should depend on equipment usage.

CHAPTER V

CONCLUSION

The calculation template implies that the pipe size 3-inch is the saving fixed investment cost and the pipe size 4-inch is the most economic for 2 years. For case study, minimum wage in Thailand cause the fixed investment cost of 4-inch and 5-inch in calculation templates is low when compare with a case study.

LIMITATIONS

- Most costs are calculated depending on EPC provider perspective therefore the calculation template is not covered the annual cost, for example, labor operation cost, property tax and total production cost.
- Pipe support cost and pipe rack cost will be further calculated in equipment purchase cost, installation cost, and maintenance cost.

SUGGESTIONS

- For equipment purchase cost providing in the calculation template, it can be estimated by order-of-magnitude method, which is provided in Section 2.15.1, but the accuracy is lower.
- The AACE method is estimation costs of bulk materials and labor for pumping system by applying factors. From comparison labor wages and salaries section, the labor wages and salaries including foremen in United State is reasonable, therefore the labor factors for each bulk materials installation should be rechecked with actual installation cost of bulk materials in Thailand.

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APPENDIX A

CASE STUDY DATA

A 900 m pipeline must be installed to handle 68.15 m^3/h at 20 °C. The cost of the pump may be assumed to be approximately constant regardless of pipe size. The charges for installing the pipe can be assumed to be 100% of the cost of the pipe and the annual charges against the other equipment are 20% of the installed cost. The pump is to operate 8 hours per day, 300 days per year, and the cost of power $0.12 per kW hour. The pump-motor combination has an overall efficiency of 60%. The pump operates with the 1750 rpm motor. Cost of carbon steel pipe schedule 40 is 0.40 USD/lb.

Table A.1 Pump motor cost data from case study

$P_{B,HP}$ (HP)	Cost (USD/HP)
1	222.0
1.5	174.0
2	156.0
3	114.0
5	96.0
7.5	73.8
10	70.2
15	55.8
20	49.8
25	46.2
30	52.2
40	46.8
50	45.6

Table A.2 Pipe weight from case study

Nominal pipe size (inch)	Weight (lb/ft)
1/2	0.85
1	1.68
2	3.66
3	7.85
4	10.80
5	14.70
6	19.00
8	28.60
10	40.50
12	53.60
14	63.30
16	82.80

Table A.3 Case study results

Nominal pipe size (inch)	Pump motor cost (USD)	Pipe cost (USD)	Pipe installation cost (USD)	Fixed investment cost (USD)	Annual equipment cost (USD/year)	Energy consumption cost (USD/year)	Life cycle cost for 2 years (USD)
3	5,536	15,766	15,766	37,067	3,153	36,851	73,919
4	2,082	21,690	21,690	45,463	4,338	16,365	61,828
5	1,123	29,523	29,523	60,169	5,905	14,281	74,449

APPENDIX B

PIPE DATA

Table B.1 Pipe wall thickness (ASME B16.5, 2013)

Pipe size (inch)	Outside diameter (mm)	Wall thickness (mm)									
		Schedule number									
		10	20	30	40	60	80	100	120	140	160
½"	21.3	...	...	...	2.77	...	3.73	...	...	...	4.78
¾"	26.7	...	...	...	2.87	...	3.91	...	...	...	5.56
1"	33.4	...	...	...	3.38	...	4.55	...	...	...	6.35
1 ¼”	42.2	...	...	...	3.56	...	4.85	...	...	...	6.35
1 ½"	48.3	...	...	...	3.68	...	5.08	...	...	...	7.14
2"	60.3	...	...	...	3.91	...	5.54	...	...	...	8.74
2 ½"	73.0	...	...	...	5.16	...	7.01	...	...	...	9.53
3"	88.9	...	...	...	5.49	...	7.62	...	...	...	11.13
3 ½"	101.6	...	...	...	5.74	...	8.08	...	...	...	...
4"	114.3	...	...	...	6.02	...	8.56	...	11.13	...	13.49
5"	141.3	...	...	...	6.55	...	9.53	...	12.70	...	15.88
6"	168.3	...	...	...	7.11	...	10.97	...	14.27	...	18.26
8"	219.1	...	6.35	7.04	8.18	10.31	12.70	15.09	18.26	20.62	23.01
10"	273.0	...	6.35	7.80	9.27	12.70	15.09	18.26	21.44	25.40	28.58
12"	323.8	...	6.35	8.38	10.31	14.27	17.48	21.44	25.40	28.58	33.32
14"	355.6	6.35	7.92	9.53	11.13	15.09	19.05	23.83	27.79	31.75	35.71
16"	406.4	6.35	7.92	9.53	12.70	16.66	21.44	26.19	30.96	36.53	40.49
18"	457	6.35	7.92	11.13	14.27	19.05	23.83	29.36	34.93	39.67	45.24
20"	508	6.35	9.53	12.70	15.09	20.62	26.19	32.54	38.10	44.45	50.01
24"	610	6.35	9.53	14.27	17.48	24.61	30.96	38.89	46.02	52.37	59.54

Table B.2 Pipe inside diameter (ASME B16.5, 2013)

Pipe size (inch)	Inside diameter (mm)									
	Schedule number									
	10	20	30	40	60	80	100	120	140	160
½"	…	…	…	15.76	…	13.84	…	…	…	11.74
¾"	…	…	…	20.96	…	18.88	…	…	…	15.58
1"	…	…	…	26.64	…	24.3	…	…	…	20.7
1 ¼”	…	…	…	35.08	…	32.5	…	…	…	29.5
1 ½"	…	…	…	40.94	…	38.14	…	…	…	34.02
2"	…	…	…	52.48	…	49.22	…	…	…	42.82
2 ½"	…	…	…	62.68	…	58.98	…	…	…	53.94
3"	…	…	…	77.92	…	73.66	…	…	…	66.64
3 ½"	…	…	…	90.12	…	85.44	…	…	…	…
4"	…	…	…	102.26	…	97.18	…	92.04	…	87.32

Table B.2 Pipe inside diameter (Cont.) (ASME B16.5, 2013)

Pipe size (inch)	Weight of carbon steel pipe (kg/m)									
	Schedule number									
	10	20	30	40	60	80	100	120	140	160
5"	...	...	...	21.77	...	30.97	...	40.28	...	49.12
6"	...	...	...	28.26	...	42.56	...	54.21	...	67.57
8"	...	33.32	36.82	42.55	53.09	64.64	75.92	90.44	100.93	111.27
10"	...	41.76	51.01	60.29	81.53	95.98	114.71	133.01	155.10	172.27
12"	...	49.71	65.19	79.71	108.93	132.05	159.87	186.92	208.08	238.69
14"	54.69	67.91	81.33	94.55	126.72	158.11	194.98	224.66	253.58	281.72
16"	62.65	77.83	93.27	123.31	160.13	203.54	245.57	286.66	333.21	365.38
18"	70.57	87.71	122.38	155.81	205.75	254.57	309.64	363.58	408.28	459.40
20"	78.56	117.15	155.13	183.43	247.84	311.19	381.55	441.52	508.15	564.85
24"	94.53	141.12	209.65	255.43	355.28	442.11	547.74	640.07	720.19	808.27

Table B.3 Weight of carbon steel pipe

Pipe size (inch)	Weight of carbon steel pipe (kg/m)									
	Schedule number									
	10	20	30	40	60	80	100	120	140	160
½"	...	...	...	1.27	...	1.62	...	...	...	1.95
¾"	...	...	...	1.69	...	2.20	...	...	...	2.90
1"	...	...	...	2.50	...	3.24	...	...	...	4.24
1 ¼”	...	...	...	3.39	...	4.47	...	...	...	5.61
1 ½"	...	...	...	4.05	...	5.41	...	...	...	7.25
2"	...	...	...	5.44	...	7.48	...	...	...	11.11
2 ½"	...	...	...	8.63	...	11.41	...	...	...	14.92
3"	...	...	...	11.29	...	15.27	...	...	...	21.35
3 ½"	...	...	...	13.57	...	18.64	...	...	...	...
4"	...	...	...	16.08	...	22.32	...	28.32	...	33.54

Table B.3 Weight of carbon steel pipe (Cont.)

Pipe size (inch)	Weight of carbon steel pipe (kg/m)									
	Schedule number									
	10	20	30	40	60	80	100	120	140	160
5"	...	...	...	21.77	...	30.97	...	40.28	...	49.12
6"	...	...	...	28.26	...	42.56	...	54.21	...	67.57
8"	...	33.32	36.82	42.55	53.09	64.64	75.92	90.44	100.93	111.27
10"	...	41.76	51.01	60.29	81.53	95.98	114.71	133.01	155.10	172.27
12"	...	49.71	65.19	79.71	108.93	132.05	159.87	186.92	208.08	238.69
14"	54.69	67.91	81.33	94.55	126.72	158.11	194.98	224.66	253.58	281.72
16"	62.65	77.83	93.27	123.31	160.13	203.54	245.57	286.66	333.21	365.38
18"	70.57	87.71	122.38	155.81	205.75	254.57	309.64	363.58	408.28	459.40
20"	78.56	117.15	155.13	183.43	247.84	311.19	381.55	441.52	508.15	564.85
24"	94.53	141.12	209.65	255.43	355.28	442.11	547.74	640.07	720.19	808.27

Table B.4 Weight of carbon steel slip-on flange in kilogram (Grath Industrial, n.d)

Pipe size (inch)	Service pressure rating (Lb)						
	150	300	400	600	900	1500	2500
½"	-	-	-	-	-	-	-
¾"	-	-	-	-	-	-	-
1"	0.50	0.90	0.90	0.90	-	2.30	3.20
1 ¼”	0.90	1.40	1.40	1.80	-	2.70	3.60
1 ½"	0.90	1.80	1.80	1.80	-	4.10	5.40
2"	1.40	2.30	2.30	2.70	-	4.50	7.70
2 ½"	1.40	3.20	3.20	3.60	-	5.90	11.30
3"	2.30	4.10	4.10	5.40	-	11.30	19.00
3 ½"	3.20	5.40	5.40	8.20	-	16.30	23.60
4"	3.60	6.80	6.80	10.40	14.10	21.80	42.60
5"	5.00	8.20	8.20	11.80	-	-	-
6"	5.90	11.30	11.30	19.00	23.10	33.10	65.80
8"	6.80	14.50	14.50	31.00	39.00	59.00	111.00
10"	8.60	19.00	19.00	36.70	49.90	75.00	172.00
12"	13.60	30.40	30.40	54.40	79.40	125.00	263.00
14"	19.50	41.30	41.30	86.20	118.00	206.00	448.00
16"	29.00	63.50	63.50	102.00	147.00	313.00	692.00
18"	41.00	81.60	81.60	127.00	181.00	426.00	-
20"	44.50	113.00	113.00	177.00	225.00	567.00	-
24"	59.00	145.00	145.00	215.00	308.00	737.00	-

Table B.5 Weight of carbon steel welding neck flange in kilogram (Grath Industrial, n.d)

Nominal size (inch)	Service pressure rating (Lb)						
	150	300	400	600	900	1500	2500
½"	-	-	-	-	-	-	-
¾"	-	-	-	-	-	-	-
1"	0.05	0.90	0.90	0.90	-	1.80	3.20
2"	0.90	1.40	1.40	1.40	-	2.30	3.60
2 ½"	0.9	1.40	1.40	1.80	-	3.60	5.00
3"	1.40	1.80	1.80	2.30	-	4.10	7.30
3 ½"	1.40	2.70	2.70	3.20	-	5.40	10.00
4"	2.30	3.20	3.20	4.10	-	11.30	17.20
5"	3.20	4.50	4.50	5.90	-	16.30	24.90
6"	3.60	5.90	5.90	7.30	14.10	21..8	37.60
8"	5.00	7.70	7.70	9.50	-	-	-
10"	5.90	10.00	10.00	16.80	24.00	33.10	56.70
12"	6.80	12.70	12.70	28.60	37.60	59.00	95.30
14"	8.60	17.70	17.70	36.30	49.90	75.00	147.00
16"	13.60	26.30	26.30	52.20	77.10	118.00	220.00
18"	19.50	36.70	36.70	77.10	111.00	197.00	422.00
20"	29.00	52.20	52.20	90.70	147.00	263.00	499.00
24"	41.00	74.80	74.80	104.00	181.00	-	-

Table B.6 Basic allowable stress (ASME B31.3, 2017)

Nominal composition	Product Form	Spec No.	Type/ Grade	Basic Allowable Stress, S, MPa, ate Metal Temperature, °C					
				40	65	100	150	175	200
Carbon steel	Pipe & tube	API 5L	A	110.00	110.00	110.00	110.00	…	110.00
Carbon steel	Pipe & tube	API 5L	A25	103.00	103.00	103.00	102.00	…	98.50
Carbon steel	Pipe & tube	API 5L	B	138.00	138.00	138.00	138.00	…	138.00
Carbon steel	Pipe & tube	API 5L	X42	138.00	138.00	138.00	138.00	…	138.00
Carbon steel	Pipe & tube	API 5L	X46	145.00	145.00	145.00	145.00	…	145.00
Carbon steel	Pipe & tube	API 5L	X52	152.00	152.00	152.00	152.00	…	152.00
Carbon steel	Pipe & tube	A53	A	110.00	110.00	110.00	110.00	…	110.00
Carbon steel	Pipe & tube	A53	B	138.00	138.00	138.00	138.00	…	138.00
Carbon steel	Pipe & tube	A106	A	110.00	110.00	110.00	110.00	…	110.00
Carbon steel	Pipe & tube	A106	B	138.00	138.00	138.00	138.00	…	138.00
Carbon steel	Pipe & tube	A672	C60	138.00	138.00	134.00	130.00	…	126.00
Stainless steel	Pipe	A358	304	138.00	138.00	138.00	138.00	134.00	129.00
Stainless steel	Weld pipe	A358	316	138.00	138.00	138.00	138.00	138.00	134.00

Table B.6 Basic allowable stress (Cont.) (ASME B31.3, 2017)

Nominal composition	Product Form	Spec No.	Type/ Grade	Basic Allowable Stress, S, MPa, ate Metal Temperature, ^{o}C					
				425	450	475	500	525	550
Carbon steel	Pipe & tube	API 5L	A	64.00	55.80	43.90	31.70	21.40	14.20
Carbon steel	Pipe & tube	API 5L	A25	…	…	…	…	…	…
Carbon steel	Pipe & tube	API 5L	B	79.50	62.60	45.00	31.70	21.40	14.20
Carbon steel	Pipe & tube	API 5L	X42	…	…	…	…	…	…
Carbon steel	Pipe & tube	API 5L	X46	…	…	…	…	…	…
Carbon steel	Pipe & tube	API 5L	X52	…	…	…	…	…	…
Carbon steel	Pipe & tube	A53	A	64.00	55.80	43.90	31.70	21.40	14.20
Carbon steel	Pipe & tube	A53	B	79.50	62.60	45.00	31.70	21.40	14.20
Carbon steel	Pipe & tube	A106	A	64.00	55.80	43.90	31.70	21.40	14.20
Carbon steel	Pipe & tube	A106	B	79.50	62.60	45.00	31.70	21.40	14.20
Carbon steel	Pipe & tube	A672	C60	79.50	62.60	45.00	31.70	21.40	14.20
Stainless steel	Pipe	A358	304	105.00	103.00	101.00	99.10	97.30	95.50
Stainless steel	Weld pipe	A358	316	110.00	109.00	108.00	107.00	106.00	105.00

Table B.6 Basic allowable stress (Cont.) (ASME B31.3, 2017)

Nominal composition	Product Form	Spec No.	Type/ Grade	Basic Allowable Stress, S, MPa, ate Metal Temperature, °C					
				625	650	675	700	725	750
Carbon steel	Pipe & tube	API 5L	A	…	…	…	…	…	…
Carbon steel	Pipe & tube	API 5L	A25	…	…	…	…	…	…
Carbon steel	Pipe & tube	API 5L	B	…	…	…	…	…	…
Carbon steel	Pipe & tube	API 5L	X42	…	…	…	…	…	…
Carbon steel	Pipe & tube	API 5L	X46	…	…	…	…	…	…
Carbon steel	Pipe & tube	API 5L	X52	…	…	…	…	…	…
Carbon steel	Pipe & tube	A53	A	…	…	…	…	…	…
Carbon steel	Pipe & tube	A53	B	…	…	…	…	…	…
Carbon steel	Pipe & tube	A106	A	…	…	…	…	…	…
Carbon steel	Pipe & tube	A106	B	…	…	…	…	…	…
Carbon steel	Pipe & tube	A672	C60	…	…	…	…	…	…
Stainless steel	Pipe	A358	304	51.60	41.60	32.90	26.50	21.30	17.20
Stainless steel	Weld pipe	A358	316	65.00	50.40	38.60	29.60	23.00	17.40

Table B.7 Weld joint strength reduction (ASME B31.3, 2017)

Steel group	Component Temperature, T_i						
	427 (800)	454 (850)	482 (900)	510 (950)	538 (1,000)	566 (1,050)	566 (1,100)
CrMO	1	0.95	0.91	0.86	0.82	0.77	0.73
CSEF	…	…	…	1	0.95	0.91	0.86
CSEF	…	…	1	0.5	0.5	0.5	0.5
Autogenous welds in austenitic stain-less grade, 3xx and N088xx and, N066xx nickel alloys	…	…	…	1	1	1	1
Austenitic stainless grade 3xx and N088xx nickel alloys	…	…	…	1	0.95	0.91	0.86
Other materials	…	…	…	…	…	…	…

Table B.7 Weld joint strength reduction (Cont.) (ASME B31.3, 2017)

Steel group	Component Temperature, T_i						
	621 (1,150)	649 (1,200)	677 (1,250)	704 (1,300)	732 (1,350)	760 (1,400)	788 (1,450)
CrMO	0.68	0.64	…	…	…	…	…
CSEF	0.82	0.77	…	…	…	…	…
CSEF	0.5	0.5	…	…	…	…	…
Autogenous welds in austenitic stain-less grade, 3xx and N088xx and, N066xx nickel alloys	1	1	1	1	1	1	1
Austenitic stainless grade 3xx and N088xx nickel alloys	0.82	0.77	0.73	0.68	0.64	0.59	0.55
Other materials	…	…	…	…	…	…	…

Table B.8 Value of coefficient (ASME B31.3, 2017)

Material	Temperature, ^{o}C (^{o}F)							
	482 (900) or below	510 (950)	538 (1,000)	566 (1,050)	593 (1,100)	621 (1,150)	649 (1,200)	677 (1,250) and above
Ferritic steels	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
Austenitic steels	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
Nickel alloys UNS Nos. N06617 N08800, N08810 and N08825	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
Gray iron	0	…	…	…	…	…	…	…
Other ductile metals	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Table B.9 Pipe and fittings purchase cost data

Construction materials	Price (USD/kg)	
	Pipe	Fittings
Carbon steel	1.39	2.34
Stainless steel	2.47	9.88
Plastic	1.24	1.32

Table B.10 Valve purchase cost data

Valve size (inch)	Cost (USD/each)					
	Check Valve			Ball valve		
	CS	SS	Plastic	CS	SS	Plastic
½"	55	215	44	62	242	50
¾"	57	224	46	96	376	78
1"	68	265	55	115	452	93
1 ¼”	89	349	72	173	679	140
1 ½"	100	393	81	231	906	187
2"	209	820	169	386	1,512	312
2 ½"	256	1,002	207	540	2,118	438
3"	302	1,185	245	684	2,680	554
3 ½"	296	1,161	240	867	3,400	703
4"	417	1,634	338	1,051	4,121	851
5"	497	1,947	402	1,588	6,226	1,286
6"	760	2,980	616	2,167	8,496	1,756
8"	1,567	6,142	1,269	3,507	13,746	2,840
10"	2,396	9,393	1,941	5,186	20,328	4,201
12"	3,491	13,686	2,828	7,185	28,167	5,820
14"	4,797	18,806	3,886	9,505	37,261	7,699
16"	6,315	24,754	5,115	12,146	47,611	9,838
18"	8,043	31,530	6,515	15,106	59,217	12,236
20"	9,983	39,134	8,086	18,387	72,079	14,894
24"	14,496	56,826	11,742	25,911	101,570	20,988

Table B.10 Valve purchase cost data (Cont.)

Valve size (inch)	Cost (USD/each)					
	Butterfly Valve			Gate valve		
	CS	SS	Plastic	CS	SS	Plastic
½"	79	309	64	79	309	64
¾"	81	316	65	81	316	65
1"	84	331	68	84	331	68
1 ¼”	97	378	78	97	378	78
1 ½"	115	452	93	115	452	93
2"	127	499	103	127	499	103
2 ½"	141	552	114	141	552	114
3"	292	1,144	236	292	1,144	236
3 ½"	450	1,764	364	450	1,764	364
4"	608	2,384	493	608	2,384	493
5"	710	2,784	575	509	4,485	412
6"	812	3,184	658	699	5,807	566
8"	1,382	5,418	1,120	1,187	8,673	962
10"	1,910	7,487	1,547	1,823	11,837	1,476
12"	1,954	7,658	1,582	2,605	15,300	2,110
14"	2,633	10,319	2,132	3,533	19,061	2,862
16"	3,539	13,872	2,866	4,608	23,1120	3,732
18"	4,487	17,588	3,634	5,829	27,477	4,721
20"	6,228	24,415	5,045	7,197	32,132	5,829
24"	10,722	42,031	8,685	10,372	42,338	8,401

APPENDIX C.

MAN-HOUR DATA

Table C.1 Centrifugal pump installation man-hour (John, S.P. (1), 1999)

Prime mover or motor horsepower range	Single-stage		Two-stage		Multi-stage		Vertical in line single stage	
	1	2	1	2	1	2	1	2
0-15	3.00	20.00	3.30	22.00	3.60	24.00	3.00	20.0
16-30	2.50	50.00	2.75	55.00	3.00	60.00	2.50	50.0
31-50	2.00	75.00	2.20	82.50	2.40	90.00	2.00	75.0
51-75	1.75	110.00	1.90	121.00	2.10	132.00	1.75	110.0
76-100	1.50	150.00	1.65	165.00	1.80	180.00	1.50	150.0
101-125	1.50	155.00	1.65	170.00	1.80	186.00	1.50	155.0
126-300	1.25	200.00	1.38	220.00	1.50	240.00	-	-
301-500	-	-	0.90	270.0	0.98	295.00	-	-
501-5,000	-	-	-	-	0.60	310.00	-	-
5,001-7,500	-	-	-	-	0.10	510.00	-	-

Code:

1-Unit manhours per horsepower.

2-Minimum manhours per pump.

Table C.2 Power pump installation man-hour (John, S.P. (2), 1999)

Motor horsepower range	Light duty (h/HP)		Heavy duty (h/HP)	
	1	2	1	2
0-15	1.50	10.00	1.80	12.00
16-30	1.25	25.00	1.50	30.00
31-50	1.00	37.50	1.20	45.00
51-75	0.90	55.00	1.10	66.00
76-100	0.75	75.00	0.90	90.00
101-125	-	-	0.90	94.00
126-300	-	-	0.78	120.00

Code:

1-Unit manhours per horsepower.

2-Minimum manhours per pump.

Light-duty power pumps include forged steel pump cylinder, 410 stainless steel plungers, valves and seats, and are mounted on a fabricated steel base plate with V-belt drive and belt guard attached. These pumps are designed for petroleum and industrial applications with a capacity of 10 to 170 gallons per minute and weigh 850 to 2,500 pounds each.

Heavy-duty power pumps are of the direct connection type and are designed for petroleum, oil field, chemical, petrochemical, hydraulic, and industrial applications. Pumps are mounted on fabricated steel base plates and consist of forged steel pump head, integral gear and pinion with hardened 410 stainless steel plungers, valves and seats. These pumps are capable of pumping 6 to 500 gallons per minute and weigh 2,450 to 13,880 pounds each.

Table C.3 Handling and erection straight run carbon steel pipe man-hour (hours per foot) (John, S.P. (2), 1999)

Pipe sizes (inch)	Schedule numbers		
	10 to 60	**80 to 100**	**120 to 160**
¼"	0.16	0.17	0.18
⅜"	0.16	0.17	0.19
½"	0.16	0.18	0.20
¾"	0.17	0.19	0.21
1"	0.17	0.20	0.23
1 ¼”	0.18	0.21	0.24
1 ½"	0.19	0.22	0.27
2"	0.20	0.24	0.29
2 ½"	0.21	0.26	0.32
3"	0.23	0.28	0.35
3 ½"	0.24	0.30	0.38
4"	0.25	0.31	0.39
5"	0.26	0.34	0.43
6"	0.28	0.38	0.50
8"	0.34	0.48	0.65
10"	0.43	0.60	0.82
12"	0.52	0.73	1.00
14"	0.64	0.87	1.19
16"	0.75	1.02	1.39
18"	0.88	1.17	1.6
20"	1.03	1.32	1.81
24"	1.15	1.49	2.04

Table C.4 Manual carbon steel pipe butt welds man-hour (hour per each) (John, S.P. (2), 1999)

Pipe sizes (inch)	**Schedule numbers**								
	20	**30**	**40**	**60**	**80**	**100**	**120**	**140**	**160**
¼"	-	-	0.60	-	0.60	-	-	-	-
⅜"	-	-	0.60	-	0.70	-	-	-	-
½"	-	-	0.60	-	0.70	-	-	-	-
¾"	-	-	0.70	-	0.80	-	-	-	-
1"	-	-	0.70	-	0.80	-	-	-	1.00
1 ¼”	-	-	0.80	-	0.80	-	-	-	1.10
1 ½"	-	-	0.80	-	0.90	-	-	-	1.30
2"	-	-	1.00	-	1.00	-	-	-	1.60
2 ½"	-	-	1.20	-	1.30	-	-	-	1.80
3"	-	-	1.30	-	1.40	-	-	-	2.10
3 ½"	-	-	1.40	-	1.60	-	-	-	-
4"	-	-	1.50	-	1.80	-	-	-	3.00
5"	-	-	1.70	-	2.10	-	-	-	3.80
6"	-	-	2.00	-	2.50	-	-	-	4.90
8"	2.60	2.60	2.60	3.00	3.30	4.60	6.00	7.50	8.60
10"	3.10	3.10	3.10	4.00	5.10	6.80	9.40	11.40	13.10
12"	3.60	3.60	4.10	5.20	6.60	9.90	12.20	15.30	17.90
14"	4.30	4.30	5.00	6.80	9.60	13.20	16.20	19.20	22.70
16"	5.00	5.00	6.60	8.40	12.40	19.50	20.70	25.00	27.70
18"	5.90	6.80	8.60	11.20	16.40	21.80	25.60	29.90	33.70
20"	6.30	8.40	9.40	13.80	19.50	26.00	31.90	37.00	40.80
24"	6.90	9.40	13.30	20.10	25.20	35.80	43.50	49.30	59.30

Manhours include set-up of welding equipment, welding, grinding where necessary, and stress relieving where necessary.

Table C.5 Attaching slip-on flanges type man-hour (hour per each) (John, S.P. (2), 1999)

Pipe sizes (inch)	Service pressure rating (lb)						
	150	300	400	600	900	1500	2500
¼"	-	-	-	-	-	-	-
⅜"	-	-	-	-	-	-	-
½"	-	-	-	-	-	-	-
¾"	-	-	-	-	-	-	-
1"	0.90	1.00	1.40	1.40	-	-	-
1 ¼”	1.00	1.20	1.40	1.40	-	-	-
1 ½"	1.00	1.30	1.40	1.40	1.80	2.10	2.30
2"	1.30	1.40	1.80	1.80	2.40	2.70	3.00
2 ½"	1.50	1.70	2.30	2.30	3.00	3.30	3.60
3"	1.80	2.10	2.90	2.90	3.60	4.00	4.40
3 ½"	2.20	2.40	3.30	3.30	-	-	-
4"	2.40	2.60	3.50	3.80	4.80	5.40	5.90
5"	3.00	3.30	4.50	4.80	6.10	6.70	7.40
6"	3.60	3.90	5.20	5.90	7.20	8.10	8.90
8"	5.10	5.40	7.30	8.00	9.90	11.00	12.00
10"	6.30	6.80	9.00	11.10	12.50	14.00	15.50
12"	7.70	8.30	11.00	13.70	15.30	17.20	19.00
14"	9.00	10.00	13.00	16.20	17.70	19.80	-
16"	10.50	11.30	15.00	18.40	20.10	22.40	-
18"	12.20	13.50	17.50	21.10	23.70	26.60	-
20"	14.60	16.00	21.10	23.70	27.50	30.80	-
24"	18.30	20.10	25.60	31.20	34.80	38.90	-

Table C.6 Attaching welding neck flanges type man-hour (hour per each) (John, S.P. (2), 1999)

Pipe sizes (inch)	Service pressure rating (lb)						
	150	300	400	600	900	1500	2500
¼"	-	-	-	-	-	-	-
⅜"	-	-	-	-	-	-	-
½"	-	-	-	-	-	-	-
¾"	-	-	-	-	-	-	-
1"	-	-	-	-	-	-	-
1 ¼"	-	-	-	-	-	-	-
1 ½"	-	-	-	-	-	-	-
2"	1.50	1.80	1.80	2.60	2.60	2.80	3.00
2 ½"	1.50	1.80	1.80	2.60	2.60	2.80	3.00
3"	2.00	2.30	2.30	3.40	3.40	3.60	4.20
3 ½"	2.00	2.30	2.30	3.40	3.40	3.60	4.20
4"	2.50	2.80	2.80	4.10	4.10	4.30	4.50
5"	3.20	3.50	3.50	5.00	5.00	5.60	5.80
6"	4.20	4.70	4.70	6.70	6.70	7.40	7.60
8"	5.40	6.00	6.00	8.60	8.60	9.80	10.20
10"	6.70	7.30	7.30	10.10	10.10	11.60	11.80
12"	7.30	7.90	7.90	10.50	10.50	12.30	13.30
14"	8.80	9.50	9.50	11.90	11.90	14.30	-
16"	9.60	10.20	10.20	12.30	12.30	16.10	-
18"	12.00	12.70	12.70	15.40	15.40	18.30	-
20"	13.30	14.00	14.00	16.90	16.90	21.60	-
24"	17.60	18.50	18.50	22.40	22.40	28.70	-

Table C.7 Making on screwed fittings and valves man-hour (hour per connection) (John, S.P. (2), 1999)

Pipe sizes (inch)	Plain (h/each)	Back welded (h/each)
¼"	0.10	0.40
⅜"	0.10	0.40
½"	0.10	0.40
¾"	0.10	0.50
1"	0.20	0.50
1 ¼"	0.20	0.60
1 ½"	0.30	0.70
2"	0.30	0.90
2 ½"	0.40	1.00
3"	0.40	1.20
3 ½"	0.40	1.40
4"	0.50	1.60
5"	0.60	1.95
6"	0.70	2.30
8"	0.90	2.80
10"	1.10	3.40
12"	1.20	3.90
14"	1.30	4.20
16"	1.40	4.50
18"	1.50	4.80
20"	1.60	5.10
24"	1.70	5.50

El-bow and valves = two connections

Tees = three connections

Table C.8 Pipe painting man-hour (hour per foot) (John, S.P. (2), 1999)

Pipe sizes (inch)	**Pipe painting (h/ft)**
¼"	-
⅜"	-
½"	-
¾"	-
1"	-
1 ¼”	-
1 ½"	-
2"	0.05
2 ½"	0.05
3"	0.06
3 ½"	0.07
4"	0.08
5"	0.09
6"	0.10
8"	0.13
10"	0.16
12"	0.18
14"	0.19
16"	0.22
18"	0.25
20"	0.28
24"	0.34

Table C.9 Percent additives for stainless steel (John, S.P. (2), 1999)

Pipe sizes (inch)	Erection	Attaching flange
1/4	0.318	0.475
3/8"	0.318	0.475
1/2"	0.318	0.475
3/4"	0.318	0.475
1"	0.318	0.475
1 ¼”	0.318	0.475
1 ½	0.318	0.475
2"	0.318	0.475
2 ½	0.318	0.560
3"	0.350	0.520
3 ½”	0.350	0.550
4"	0.380	0.570
5"	0.400	0.600
6"	0.420	0.635
8"	0.480	0.720
10"	0.540	0.810
12"	0.580	0.860
14"	0.620	0.930
16"	0.670	1.000
18"	0.710	1.120
20"	0.830	1.230
24"	0.880	1.390

Table C.10 Plastic pipe (PVC) man-hour (John, S.P. (2), 1999)

Pipe sizes (inch)	**Handle pipe (h/ft)**	**Cemented socket joint (h/each)**	**Saddles (h/each)**	**Handle valves PVC body (h/each)**
1/2"	0.07	0.20	0.38	0.13
3/4"	0.07	0.22	0.39	0.16
1"	0.07	0.25	0.40	0.17
1 ¼"	0.08	0.27	0.43	0.20
1 ½	0.08	0.29	0.45	0.25
2"	0.09	0.33	0.50	0.35
2 ½	0.09	0.38	0.55	0.58
3"	0.10	0.45	0.63	0.85
4"	0.11	0.55	0.73	1.25
6"	0.12	0.70	0.90	1.60
8"	0.14	0.80	1.00	1.95
10"	0.17	1.00	1.20	2.50
12"	0.20	1.25	1.40	3.00

Handle Pipe Units: Man-hours include handling, hauling rigging and aligning in place.

Cement Socket Joint Units: Man-hours include cut, square, ream, fit-up and make joint.

Saddle Units: Man-hours include fit-up, drill hole in header and cement saddle to header. Maximum hole size is assumed to be 1/2 inch. For larger branch lines the use of tees should be estimated. The size of the header not the size of the saddle determines the man-hours that apply.

Handle Valve Units: Man-hours include handling, hauling and positioning of valve only.

APPENDIX D

EXAMPLES OF CALCULATION

1. Unit conversion

1.1. Volumetric flow rate unit conversion

$$
\begin{aligned}
q_{SI} &= Q_{SI}\times\frac{1\ \text{s}}{3600\ \text{h}} \\
&= 68.15\ \frac{\text{m}^3}{\text{h}}\times\left(\frac{1\ \text{s}}{3600\ \text{h}}\right) \\
&= 0.019\ \text{m}^3/\text{s}
\end{aligned}
$$

1.2. Pipe actual length unit conversion

$$
\begin{aligned}
L_{US} &= L\times\frac{3.28}{1}\frac{\text{ft}}{\text{m}} \\
&= 900\ \text{m}\times\frac{3.28}{1}\frac{\text{ft}}{\text{m}} \\
&= 3{,}000\ \text{ft}
\end{aligned}
$$

1.3. Volumetric flow rate unit conversion

$$
\begin{aligned}
Q_{gpm} &= Q_{SI}\times\left(\frac{264.18}{1}\frac{\text{gal/h}}{\text{m}^3/\text{h}}\right)\times\left(\frac{1}{60}\frac{\text{h}}{\text{min}}\right) \\
&= (68.15\ \text{m}^3/\text{h})\times\left(\frac{264.18}{1}\frac{\text{gal/h}}{\text{m}^3/\text{h}}\right)\times\left(\frac{1}{60}\frac{\text{h}}{\text{min}}\right) \\
&= 300\ \text{gal/min}
\end{aligned}
$$

2. Hydraulic calculation

2.1. Velocity calculation

$$v = \frac{4Q}{\pi D_{inside}^2} \tag{2.31}$$

$$= \frac{4(0.019\ \mathrm{m^3/s})}{(3.14)(0.08\ \mathrm{m})^2}$$

$$= 3.97\ \mathrm{m/s}$$

2.2. Reynolds number calculation

$$N_{\mathrm{Re}} = \frac{D_{inside} v \rho}{\mu} \tag{2.24}$$

$$= \frac{(0.08\ \mathrm{m})(3.97\ \mathrm{m/s})(997\ \mathrm{kg/m^3})}{(1.00\times10^{-3}\ \mathrm{kg/m\cdot s})}$$

$$= 3.08\times10^{5}$$

2.3. Friction factor calculation

$$\frac{1}{\sqrt{f}} = -4\log[\frac{\varepsilon}{3.71 D_{inside}} + \frac{1.26}{N_{\mathrm{RE}}\sqrt{f}}] \tag{2.29}$$

$$= -4\log(\frac{(0.0457\ \mathrm{mm})}{3.71(77.92\ \mathrm{mm})} + \frac{1.26}{3.08\times10^{5}\sqrt{f}})$$

$$f = 0.0046$$

2.4. Head loss calculation

$$h_f = 4f(\frac{L}{D_{inside}})(\frac{v^2}{2g}) \tag{2.27}$$

$$= 4(0.0046)(\frac{900\ \mathrm{m}}{0.08\ \mathrm{m}})[\frac{(3.97\ \mathrm{m/s})^2}{2(9.81\ \mathrm{m/s^2})}]$$

$$= 170.72\ \mathrm{m}$$

2.5. Total dynamic calculation

$$h_{TDH} \qquad = \frac{P_2 - P_1}{\rho g} + \Delta z + \sum h_f \qquad (2.26)$$

$$= 0 \text{ m} + 0 \text{ m} + 170.72 \text{ m}$$

$$= 170.72 \text{ m}$$

2.6. Power calculation

$$P_{H,kW} \qquad = \frac{Q\rho g h_{TDH}}{(3,600)(1,000)} \qquad (2.31)$$

$$= \frac{(68.15 \text{ m}^3/\text{h})(997 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(170.72 \text{ m})}{(3,600)(1,000)}$$

$$= 31.58 \text{ kW}$$

2.7. Power unit conversion

$$P_{H,HP} \qquad = P_{H,kW} \cdot (\frac{1.34}{1}\frac{\text{HP}}{\text{kW}})$$

$$= 31.58 \text{ kW} \times (\frac{1.34}{1}\frac{\text{HP}}{\text{kW}})$$

$$= 42.32 \text{ HP}$$

2.8. Pump efficiency calculation

$$\eta_P \qquad = -0.316 + 0.24015[\ln(Q_{gpm})] - 0.01199[\ln(Q_{gpm})]^2 \qquad (2.1)$$

$$= -0.316 + 0.24015[\ln(300 \text{ gpm})] - 0.01199[\ln(300 \text{ gpm})]^2$$

$$= 0.66 \text{ or } 66\%$$

2.9. Motor efficiency calculation

$$\eta_M \qquad = 0.8 + 0.0319[\ln(P_{H,HP})] - 0.0182[\ln(P_{H,HP})] \qquad (2.2)$$

$$= 0.8 + 0.319[\ln(42.32 \text{ HP})] - 0.0182[\ln(42.32 \text{ HP})]^2$$

$$= 0.89 \text{ or } 89\%$$

2.10. Brake power calculation

$$P_{B,kW} = \frac{P_{H,kW}}{\eta_P \eta_M} \tag{2.32}$$

$$= \frac{31.58 \text{ kW}}{0.6}$$

$$= 52.63 \text{ kW}$$

3. Equipment purchase cost

3.1. Pump size factor calculation

$$S = 7.93 Q_{SI} (h_{TDH})^{0.5} \tag{2.3}$$

$$= 7.93(68.15 \text{ m}^3/\text{h})(170.72 \text{ m})^{0.5}$$

$$= 7.06\times10^3 \text{ m}^3/\text{h}\cdot(\text{m})^{0.5}$$

3.2. Base purchase pump cost calculation

$$C_{B,\text{pump}} = \exp\{12.1656 - 1.1448[\ln(S)] + 0.0862[\ln(S)]^2\} \tag{2.4}$$

$$= \exp\{12.1656 - 1.1448[\ln(7.06\times10^3 \text{ m}^3/\text{h}\cdot(\text{m})^{0.5})] + 0.0862[\ln(7.06\times10^3 \text{ m}^3/\text{h}\cdot(\text{m})^{0.5})]^2\}$$

$$= 6{,}572 \text{ USD}$$

3.3. Pump purchase cost

For single-stage centrifugal pump, vertical spilt casing, operate at 1,800 rpm, and construction of cast iron has type factor and material of construction factor 1.5 and 1 respectively following Table 2.4.

$$C_{pump} = C_{B,pump} F_{Type\ factor,pump} F_{M,pump} \tag{2.5}$$

$$= (6{,}572\text{USD})(1.5)(1)$$

$$= 9{,}859 \text{ USD}$$

3.4. Base motor purchase cost

$$C_{B,motor} \begin{aligned}[t] &= \exp\{5.9332 + 0.16826[\ln(P_{B,HP})] - 0.110056[\ln(P_{B,HP})]^2 \\ &+ 0.071413[\ln(P_{B,HP})]^3 - 0.0063788[\ln(P_{B,HP})]^4\} \\ &= \exp\{5.9332 + 0.16826[\ln(70.52\text{ HP})] - 0.110056[\ln(70.52\text{ HP}) \\ &+ 0.071413[\ln(70.52\text{ HP})] - 0.0063788[\ln(70.52\text{ HP})] \\ &= 3{,}192\text{ USD} \end{aligned} \qquad (2.8)$$

3.5. Motor purchase cost

From Table 2.8, the one-drip proof motor enclosure with 1,800 rpm has type factor about 0.9.

$$C_{motor} \begin{aligned}[t] &= C_B F_{\text{Type factor}} \\ &= (3{,}192\text{ USD})(0.9) \\ &= 2{,}872\text{ USD} \end{aligned} \qquad (2.9)$$

3.6. Pipe purchase cost

From Table F.3, the 3-inch pipe weight per meter is 11.3 kg/m.

$$C_{piping} \begin{aligned}[t] &= W_{pipe} L c_{pipe,carbon\ steel} \\ &= (11.3\text{ kg/m})(900\text{ m})(1.32\text{ USD/m}) \\ &= 13{,}424\text{ USD} \end{aligned} \qquad (3.1)$$

3.7. Pump purchase cost with cost index

$$C_{pump,2019} \begin{aligned}[t] &= C_{base,2013}\left(\frac{I_{2019}}{I_{2013}}\right) \\ &= (9{,}859\text{ USD})\left(\frac{615.90}{567}\right) \\ &= 10{,}709\text{ USD} \end{aligned} \qquad (3.5)$$

3.8. Motor purchase cost with cost index

$$C_{motor,2019} = C_{base,2013}(\frac{I_{2019}}{I_{2013}}) \quad (3.6)$$

$$= (2{,}872 \text{ USD})(\frac{615.90}{567})$$

$$= 3{,}120 \text{ USD}$$

3.9. Equipment purchase cost

$$C_{EPC} = C_{Pump} + C_{motor} + C_{piping} \quad (3.7)$$

$$= 10{,}709 \text{ USD} + 3{,}120 \text{ USD} + 13{,}424 \text{ USD}$$

$$= 27{,}253 \text{ USD}$$

4. Installation cost

4.1. Pump installation manpower

From Table C.1, the pump setting man-hour is 1.75 h/HP.

$$C_{INS,pump} = m_{pump} P_{B,HP} C_{wage} \quad (3.9)$$

$$= (1.75 \text{ h/HP})(70.52\text{HP})(1.38\text{USD/h})$$

$$= 170 \text{ USD}$$

4.2. Pipe erection man-hour

From Table C.3, the pipe erection man-hour is 0.23 h/ft.

$$M_{erection} = m_{erection} L_{US} \quad (3.10)$$

$$= (0.23 \text{ h/ft})(900 \text{ m})(\frac{3.28}{1}\frac{\text{ft}}{\text{m}})$$

$$= 678.96 \text{ h}$$

4.3. Pipe connection man-hour

From Table C.4, the pipe connection man-hour is 1.3 h/each.

$$M_{pipe,con} = m_{pipe,con} N_{con} \tag{3.11}$$

$$= (1.3\text{ h/each})(900\text{ m})(\frac{1}{6}\text{ m/each})$$

$$= 195\text{ h}$$

4.4. Pipe painting man-hour

From Table C.8, the pipe painting man-hour is 0.06 h/ft.

$$M_{painting} = m_{painting} L_{US} \tag{3.13}$$

$$= (0.06\text{ h/ft})(3000\text{ ft})$$

$$= 177.12\text{ h}$$

4.5. Pipe installation man-hour

$$M_{pipe,piping} = M_{erection} + M_{pipe,con} + M_{valves,con} + M_{painting} \tag{3.14}$$

$$= 678.96\text{ h} + 195\text{ h} + 0\text{ h} + 177.12\text{ h}$$

$$= 1{,}051.08\text{ h}$$

4.6. Piping manpower

$$C_{INS,piping} = M_{piping} C_{wage} \tag{3.15}$$

$$= (1{,}051.08\text{ h})(1.38\text{ USD/h})$$

$$= 1{,}450\text{ USD}$$

4.7. Bulk materials installation cost

The pressure of pumping system is 17.20 kg/cm^2 when pipe size is 3-inch, therefore Eq (3.19) is used.

$$C_{INS,bulk} = 0.5803(C_{pump} + C_{motor}) \tag{3.17}$$

$$= 0.5803(10,709 \text{ USD} + 3,120 \text{ USD})$$

$$= 8,026 \text{ USD}$$

4.8. Installation cost

$$C_{INS} = C_{INS,pump} + C_{INS,piping} + C_{INS,bulk} \tag{3.8}$$

$$= 170 \text{ USD} + 1,450 \text{ USD} + 8,026 \text{ USD}$$

$$= 9,646 \text{ USD}$$

5. Fixed investment cost

$$C_{FIC} = C_{EPC} + C_{INS} \tag{3.18}$$

$$= 27,253 \text{ USD} + 9,646 \text{ USD}$$

$$= 36,899 \text{ USD}$$

6. Energy consumption cost

$$C_{ECC} = KP_{B,kW}t_{operating} \tag{3.21}$$

$$= (0.12 \text{ USD/kWh})(52.64 \text{ kW})(2400 \text{ h/year})$$

$$= 15,160 \text{ USD/yr}$$

7. Maintenance cost

7.1. Total depreciation

$$C_{TDC} = \frac{T_{operating}}{T_{useful\ life}}(C_{EPC} - C_{salvage}) \tag{3.19}$$

$$= \frac{5.48\text{yr}}{20\text{ yr}}(27{,}253\text{ USD} - 2{,}725\text{ USD})$$

$$= 6{,}720\text{ USD}$$

7.2. Maintenance cost

$$C_{MAN} = 0.08C_{TDC} \tag{3.25}$$

$$= (0.08)(6{,}720\text{ USD})$$

$$= 538\text{ USD/year}$$

8. Total variable cost

$$C_{var} = C_{ECC} + C_{MAN} \tag{3.22}$$

$$= 15{,}160\text{ USD/yr} + 538\text{ USD/yr}$$

$$= 15{,}698\text{ USD}$$

9. Life cycle cost calculation

9.1. Variable cost for 2 years

$$C_{var,total} = C_{\text{var}}T \tag{3.23}$$

$$= (15{,}698\text{ USD/year})(2\text{years})$$

$$= 31{,}396\text{ USD}$$

9.2. Total life cycle cost for 2 year

$$
\begin{aligned}
C_{LCC} &= C_{FIC} + C_{var,total} \qquad (3.24)\\
&= 36{,}898\ \text{USD} + 31{,}396\ \text{USD}\\
&= 68{,}291\ \text{USD}
\end{aligned}
$$

10. Economic pipe diameter calculation

The flow regime is turbulent flow and the material of construction is carbon steel, so it is suitable with Equation 2.29.

10.1. Upper limit (F = 1.5)

$$
\begin{aligned}
D_{i,opt} &= Q_{SI}^{0.448}\rho^{0.132}\mu^{0.025}\left[\frac{1.63\times10^{-6}K(1+J)t_{operating}}{(1+F)c_{pipe,0.0254-m}\eta_P\eta_M K_F}\right]^{0.158} \qquad (2.19)\\
&= 0.019^{0.448}997^{0.132}(10^{-3})^{0.025}\left[\frac{1.63\times10^{-6}(0.12)(1+0.35)(2400)}{(1+1.5)(3.88)(0.6)(0.2)}\right]^{0.158}\\
&= 0.094\ \text{m or 3-inch}
\end{aligned}
$$

10.2. Lower limit (F = 6.75)

$$
\begin{aligned}
D_{i,opt} &= Q_{SI}^{0.448}\rho^{0.132}\mu^{0.025}\left[\frac{1.63\times10^{-6}K(1+J)t_{operating}}{(1+F)c_{pipe,0.0254-m}\eta_P\eta_M K_F}\right]^{0.158} \qquad (2.19)\\
&= 0.019^{0.448}997^{0.132}(10^{-3})^{0.025}\left[\frac{1.63\times10^{-6}(0.12)(1+0.35)(2400)}{(1+6.75)(3.88)(0.6)(0.2)}\right]^{0.158}\\
&= 0.11\ \text{m or 5-inch}
\end{aligned}
$$

BIOGRAHPY

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