PUMP SIZING CALCULATOR

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Contents

Introduction

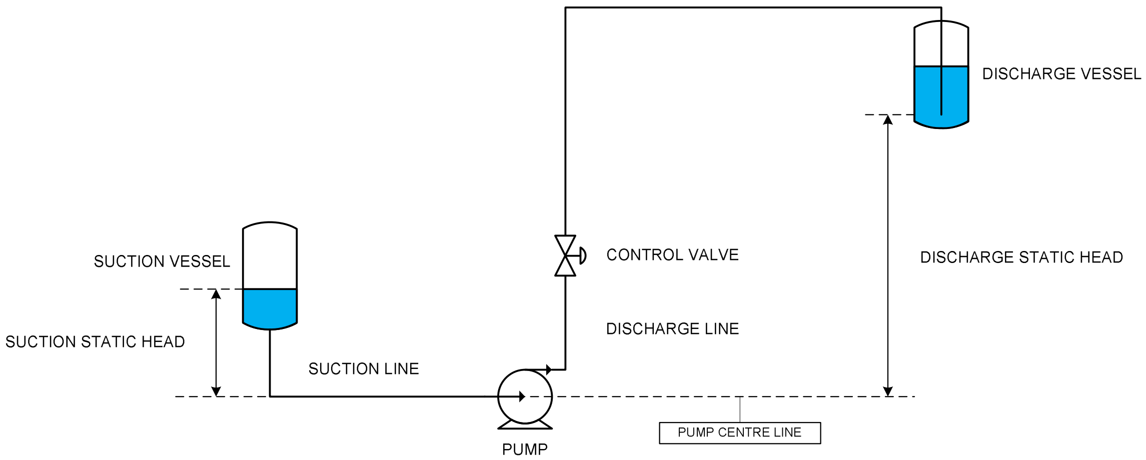
This document describes the basis and operation of the Blackmonk Engineering Pump Sizing Calculator.

The calculation methodology is based on that described in Crane Technical Paper 410M "The Flow of Fluids Through Valves, Fittings and Pipes" and "Process Pump Selection – A Systems Approach", IMechE Guide for the Process Industries, John Davidson.

The calculator determines the pump total differential head and absorbed power given the required liquid flow rate and details of the piping system.

The calculator determines the static head loss and frictional head loss of the system. It also calculates the net positive suction head available at the pump suction.

System Diagram



Calculation Inputs

The following parameters are user specified inputs to the calculation:

Pump Details

Input	Description	Units
Pump tag number	Optional user specified equipment tag number	N/A
Suction vessel tag number	Optional user specified equipment tag number	N/A
Discharge vessel tag number	Optional user specified equipment tag number	N/A
Barometric pressure	Mandatory user specified barometric pressure at pump	bara

	location	
NPSH available margin	Mandatory user specified NSPH margin (can be zero)	m
Pump efficiency	Mandatory user specified pump efficiency	%

Fluid Properties

Input	Description	Units
Fluid	Optional user specified name of fluid	N/A
Phase	Optional user specified phase of fluid	N/A
Flowrate	Mandatory user specified flow rate	kg/hr
Density	Mandatory user specified fluid density	kg/m^3
Viscosity	Mandatory user specified fluid viscosity	cP
Vapour pressure	Mandatory user specified fluid vapour pressure at pumping temperature	bara

Vessel Gas Pressures

Input	Description	Units
Suction vessel gas pressure	Mandatory user specified pressure in the suction vessel gas space	barg
Discharge vessel gas pressure	Mandatory user specified pressure in the discharge vessel gas space	barg

Static Heads

Input	Description	Units
Suction static head	Mandatory user specified static head of suction side liquid above the centre line of the pump	m
Discharge static head	Mandatory user specified static head of discharge side liquid above the centre line of the pump	m

Pipelines

Input	Description	Units
Pipe nominal diameter	Mandatory user specified pipe nominal bore (nominal diameter)	inch
Pipe schedule	Mandatory user specified pipe schedules. Selected from a drop down list of valid values for the specified pipe nominal bore	N/A
Pipe length	Mandatory user specified pipe length	m
Absolute roughness	Mandatory user specified absolute roughness of the inside of the pipe	mm

Fittings

Input	Description	Units
90° LR bends	Mandatory user specified quantity of 90° long radius bends (can be zero)	N/A
90° Std elbows	Mandatory user specified quantity of 90° standard radius elbows (can be zero)	N/A
45° LR bends	Mandatory user specified quantity of 45° long radius bends (can be zero)	N/A
45° Std elbows	Mandatory user specified quantity of 45° standard radius elbows (can be zero)	N/A
Straight tees (flow thro' run)	Mandatory user specified quantity of straight tees with the fluid flow through the tee (can be zero)	N/A
Straight tees (flow thro' branch)	Mandatory user specified quantity of straight tees with the fluid flow through the branch of the tee (can be zero)	N/A
Pipe entrances	Mandatory user specified quantity of pipe entrances (can be zero)	N/A
Pipe exits	Mandatory user specified quantity of pipe exits (can be zero)	N/A
Pipe contractions	Mandatory user specified quantity of pipe contractions (can be zero)	N/A
Pipe expansions	Mandatory user specified quantity of pipe expansions (can be zero)	N/A
Gate valves	Mandatory user specified quantity of gate valves (can be zero)	N/A
Globe valves	Mandatory user specified quantity of globe valves (can be zero)	N/A
Swing check valves	Mandatory user specified quantity of swing check valves (can be zero)	N/A
Lift check valves	Mandatory user specified quantity of lift check valves (can be zero)	N/A
Tilting disc check valves	Mandatory user specified quantity of tilting check valves (can be zero)	N/A
Stop check valves	Mandatory user specified quantity of stop check valves (can be zero)	N/A
Poppet foot valves (with strainers)	Mandatory user specified quantity of poppet foot valves (can be zero)	N/A
Hinged disc foot valves (with strainers)	Mandatory user specified quantity of hinged disc foot valves with strainers (can be zero)	N/A
Ball valves	Mandatory user specified quantity of ball valves (can be zero)	N/A
Butterfly valves	Mandatory user specified quantity of butterfly valves (can be zero)	N/A
Plug valves	Mandatory user specified quantity of plug valves (can be zero)	N/A
Miscellaneous losses	Mandatory user specified quantity of miscellaneous velocity head losses (can be zero)	N/A
Fittings factor	Mandatory user specified design factor to be applied to the total number of fittings velocity head losses	N/A

Discharge Control Valve

Input	Description	Units
Control valve differential pressure	Mandatory user specified differential pressure across a control valve in the pump discharge line (can be zero)	bar

Calculation Outputs

The following parameters are calculated by the software and displayed to the user:

Output	Description	Units
Pipe internal diameter	The pipe internal diameter determined from the selected pipe nominal diameter and schedule	mm
Volumetric flow rate	Volumetric flow rate of fluid calculated from the specified mass flow rate and the fluid density	m^3/hr
Relative roughness	Ratio of absolute pipe roughness to pipe internal diameter	N/A
Flow area	Cross sectional area of the inside of the pipe	m^2
Velocity	Fluid velocity through the pipe based on the flow area	m/s^2
Reynolds No.	Fluid Reynolds number based on the pipe internal diameter	N/A
Flow regime	Laminar, transition or turbulent based on the Reynolds number	N/A
Friction factor	Darcy friction factor	N/A
Pipe velocity head loss	Velocity head loss resistance coefficient for the pipe excluding fittings	N/A
Fittings total velocity head loss	Total velocity head loss resistance coefficient for the pipe fittings	N/A
Frictional pressure loss	Frictional pressure drop through pipe	bar
Frictional head loss	Frictional head loss through pipe	m
Pump suction pressure	Absolute pressure at the pump suction expressed as a pressure	bara
Pump suction head	Absolute pressure at the pump suction expressed as a head	m
Pump discharge pressure	Absolute pressure at the pump discharge expressed as a pressure	bara
Pump discharge head	Absolute pressure at the pump discharge expressed as a head	m
Net positive suction pressure available	Net positive suction pressure available with allowance for user specified margin	bara
Net positive suction head available	Net positive suction head available with allowance for user specified margin	m
Pump total differential pressure	Difference between pump discharge pressure and pump suction pressure	bara
Pump total differential head	Difference between pump discharge head and pump suction head	m
Pump absorbed power	The power absorbed by the pump at the shaft allowing for the user specified pump	kW

	efficiency	

Pump Total Differential Head

The total differential head to be delivered by the pump is determined from the following equations:

$$H_{pump} = H_{discharge} - H_{suction}$$ **Equation 1**

$$H_{discharge} = \frac{P_{dis.\_vessel}}{\rho g} + H_{dis.\_static\_head} + H_{dis.\_friction\_head}$$ **Equation 2**

$$H_{suction} = \frac{P_{suc.\_vessel}}{\rho g} + H_{suc.\_static\_head} - H_{suc.\_friction\_head}$$ **Equation 3**

Net Positive Suction Head Available

The net positive suction head available at the pump suction is determined using the following equation:

$$NPSHa = H_{suc.\_static\_head} - H_{suc.\_friction\_head} + \left(\frac{P_{suc.\_vessel} + P_{atm} - P_{vap}}{\rho g} \right) - H_{margin}$$

Equation 4

The equation includes an allowance for a design margin over the basic NPSH to account for uncertainties in the calculation data.

Pump Absorbed Power

The power absorbed by the pump is given by the following equation:

$$E = \frac{Q \times H_{pump} \times \rho g}{\eta}$$ **Equation 5**

This equation gives the power requirement at the pump shaft allowing for the pump efficiency.

Frictional Head Loss

The total friction head loss in a system is the sum of the frictional head loss in the pipe and the frictional head loss in the fittings.

$$H_{friction\_head\_total} = H_{friction\_head\_pipe} + H_{friction\_head\_fittings}$$ **Equation 6**

Frictional head loss through a pipe is calculated using the Darcy-Weisbach formula (Ref: Crane Technical Paper 410M, Page 1-6):

$$H_{friction\_head\_pipe} = f\frac{L}{d}\frac{u^2}{2g}$$ **Equation 7**

This relationship can also be expressed in terms of velocity head loss resistance coefficient:

$$H_{friction\_head\_pipe} = K_{pipe}\frac{u^2}{2g}$$ **Equation 8**

Where

$$K_{pipe} = f\frac{L}{d}$$ **Equation 9**

Pipe Friction Factor

For laminar flow (Re<2000) the friction factor is given by (Ref: Crane Technical Paper 410M):

$$f = \frac{64}{\text{Re}}$$ **Equation 10**

For turbulent flow (Re>4000) the friction factor is calculated using the Churchill equation (Ref: Perry's 7th Ed, Page 6-11):

$$f^{-0.5} = -4\log\left[\frac{0.27\varepsilon}{d} + \left(\frac{7}{\text{Re}}\right)^{0.9}\right]$$ **Equation 11**

In the transition zone between 2000 < Re < 4000 the friction factor is indeterminate and has lower limits based on laminar flow conditions and upper limits based on turbulent flow conditions. To produce a conservative value for the calculated friction factor, the turbulent flow friction factor equation is used throughout the transition zone in this calculation.

Fittings Frictional Head Loss

Frictional head loss through pipe fittings is calculated using the "resistance coefficient" version of the Darcy-Weisbach equation (Ref: Crane Technical Paper 410M, Page 2-8):

$$H_{friction\_head\_fittings} = K_{fittings} \frac{u^2}{2g}$$ **Equation 12**

The resistance coefficient of the various pipe fittings used in the calculator are based on data from Crane Technical Paper 410M. In general the resistance coefficient for each type of fitting is dependent on the nominal size of the pipe fitting.

In these cases, the resistance coefficient for each type and size of fitting is calculated from the following equation:

$$K_{fitting} = C \times f_T$$ **Equation 13**

Where C is a constant representing the equivalent length:diameter of the particular fitting and f_T is the friction factor for the appropriate size of the fitting.

Table 1: Fitting Friction Factors

Nominal Pipe Size (in)	Fitting Friction Factor f_T
0.125	0.036
0.25	0.031
0.375	0.028
0.5	0.027
0.75	0.025
1	0.023
1.25	0.022
1.5	0.021
2	0.019
2.5	0.018
3	0.018
4	0.017
5	0.016
6	0.015
8	0.014
10	0.014
12	0.013
14	0.013
16	0.013
18	0.012
20	0.012
22	0.012

24	0.012

Table 2: Equivalent Length:Diameter Constants for Various Fittings

Fitting	C	K
90° LR bends	14	-
90° Std elbows	30	-
45° LR bends	10	-
45° Std elbows	16	-
Straight tees (flow thro' run)	20	-
Straight tees (flow thro' branch)	60	-
Pipe entrances	-	0.5
Pipe exits	-	1
Pipe contractions	-	0.5
Pipe expansions	-	1
Gate valves	8	-
Globe valves	340	-
Swing check valves	50	-
Lift check valves	600	-
Tilting disc check valves	40	-
Stop check valves	400	-
Poppet foot valves (with strainers)	420	-
Hinged disc foot valves (with strainers)	75	-
Ball valves	3	-
Butterfly valves	45	-
Plug valves	18	-

Sometimes, the exact type and quantities of fittings in a line are undefined. In this case the length of the line is often multiplied by a “fittings factor” to provide some allowance for the head loss of the undefined fittings.

The calculator provides the facility to apply a “fittings factor” to each pipe length. By default, the fittings factor is 1. The “fittings factor” has the effect of modifying the pipe frictional head loss as follows:

$$K'_{pipe} = xK_{pipe}$$ **Equation 14**

Total Frictional Head Loss

The total frictional head loss of the pipe and fittings combined is given by the following equation:

$$K_{total} = K'_{pipe} + K_{fittings}$$ **Equation 15**

The total frictional head loss can then be calculated by:

$$H_{friction\_total} = K_{total} \frac{u^2}{2g}$$ **Equation 16**

Calculation of Fluid Velocity

Fluid velocity is calculated using the user specified mass flow rate, the fluid density and the internal pipe diameter defined by the selected nominal pipe size and schedule.

The flow area is given by:

$$A = \frac{\pi d^2}{4}$$ **Equation 17**

The volumetric flow rate is determined using:

$$Q = \frac{m}{\rho}$$ **Equation 18**

The fluid velocity is then determined by:

$$u = \frac{Q}{A}$$ **Equation 19**

Pipe Relative Roughness

The pipe relative roughness is the ratio of the absolute roughness of the inside of the pipe to the pipe inside diameter.

$$\text{Relative roughness} = \frac{\varepsilon}{d}$$ **Equation 20**

Reynolds Number

Reynolds number is determined using the relationship:

$$\mathrm{Re} = \frac{\rho u d}{\mu}$$ **Equation 21**

Flow Regime

The calculator classifies the flow regime as laminar, transition or turbulent based on the Reynolds number.

Table 3: Flow Regime Classification

Reynolds Number	Flow Regime
Re < 2000	Laminar
2000 < Re < 4000	Transition
Re > 4000	Turbulent

Pressure Drop and Head Loss

Pressure drop and head loss are related to each other via the following equation:

$$\Delta P = H\rho g$$ **Equation 22**

Calculation of Pump Size

The pump total differential head, suction and discharge pressures and absorbed power are calculated from the specified fluid properties, inlet conditions, pipe details and fittings details.

The calculation routine is described in the following steps:

1. Calculate the volumetric flow rate using Equation 18
2. Calculate pipe relative roughness for each specified pipe using Equation 20
3. Calculate flow area for the suction and discharge pipes using Equation 17
4. Calculate the fluid velocity for each the suction and discharge pipes using Equation 19
5. Calculate Reynolds number for the suction and discharge pipes using Equation 21
6. Determine flow regime for the suction and discharge pipes using Table 3
7. Calculate pipe friction factor for the suction and discharge pipes using Equation 10 for laminar flow and Equation 11 for transition and turbulent flow
8. Calculate pipe velocity head loss for the suction and discharge pipes using Equation 9

9. Calculate fittings velocity head loss for the suction and discharge pipes using Equation 13, Table 1 and Table 2 for each fitting
10. Calculate total velocity head loss for the suction and discharge pipes and fittings using Equation 15
11. Calculate the total frictional pressure and head loss for the suction and discharge pipes using Equation 16 and Equation 22
12. Calculate the pump suction pressure and head using Equation 3 and Equation 22
13. Calculate the pump discharge pressure and head using Equation 2 and Equation 22
14. Calculate the net positive suction pressure available and net positive suction head available using Equation 4 and Equation 22
15. Calculate the pump total differential pressure and head using Equation 1 and Equation 22
16. Calculate the pump absorber power using Equation 5

Nomenclature

H_{pump} = Pump total differential head (m)
$H_{discharge}$ = Head at pump discharge (m)
$H_{suction}$ = Head at pump suction (m)
$H_{dis.\_static\_head}$ = Static head of discharge side liquid over pump centre line (m)
$H_{dis.\_friction\_head}$ = Frictional head loss through discharge line and fittings (m)
$H_{suc.\_static\_head}$ = Static head of suction side liquid over pump centre line (m)
$H_{suc.\_friction\_head}$ = Frictional head loss through suction line and fittings (m)
H_{margin} = Allowance between basic net positive suction head and net positive suction head available (m)
$H_{friction\_head\_pipe}$ = Frictional head loss through pipe (m)
$H_{friction\_head\_fittings}$ = Frictional head loss through fittings (m)
$H_{friction\_head\_total}$ = Total frictional head loss through pipe and fittings (m)
$P_{dis.\_vessel}$ = Gas pressure in discharge vessel (Pa gauge)
$P_{suc.\_vessel}$ = Gas pressure in suction vessel (Pa gauge)
P_{atm} = Barometric pressure at pump location (Pa abs)
P_{vap} = Vapour pressure of pumped fluid at pump operating temperature (Pa abs)
P_{NPSHa} = Net positive suction pressure available (Pa abs)
ΔP_{CV} = Discharge control valve differential pressure (Pa)
ΔP_{pump} = Pump total differential pressure (Pa)
ρ = Density of pumped fluid (kg.m^{-3})
μ = Viscosity of pumped fluid (Pa.s)
g = Acceleration due to gravity (m.s^{-2})
f = Darcy friction factor (dimensionless)
f_T = Fitting friction factor (dimensionless)
L = Length of pipe (m)
d = Inside diameter of pipe (m)
u = Fluid velocity (m.s^{-1})
Re = Reynolds number (dimensionless)
ε = Absolute roughness of pipe inside wall (m)
K_{pipe} = Resistance coefficient of pipe (dimensionless)
$K_{fittings}$ = Resistance coefficient of pipe fittings (dimensionless)
$K_{fitting}$ = Resistance coefficient of a particular pipe fitting (dimensionless)
C = Equivalent length : diameter coefficient of a particular pipe fitting
$NPSHa$ = Net positive suction head available (m)
A = Flow area (m^2)
E = Pump absorbed power (W)
m = Mass flow rate through pump (kg.s^{-1})
Q = Flow rate through pump (m^3.s^{-1})
η = Pump efficiency (dimensionless)

Example

The following example was taken from Crane Technical Paper 410M “Flow of Fluids Through Valves, Fittings and Pipes” Example 4-15.

Description:

Water at 20C is pumped through a piping system at a rate of 400 litres per minute.

The piping system consists of:

- 150 metres of 3” Schedule 40 pipe
- 1 off 2.5” globe lift check valve with wing guided disc installed with reducers in 3” pipe having a total resistance coefficient of 27 velocity heads
- 1 off 3” gate valve
- 4 off 90° standard elbows
- 1 pipe exit
- Inlet elevation at pump centre line
- Outlet elevation 120 metres above pump centre line elevation

Fluid density = 998.2 kg/m^3
Fluid viscosity = 0.98 cP

Requirement:

Find the total discharge head at flowing conditions and the brake power required for a pump having an efficiency of 70%.

Solution:

Flow rate = 400 lpm = 24 m^3/hr = 23956.8 kg/hr

Total calculated discharge head = 126.97m (cf: Crane published result of 127 m)

Pump power required = 11.84 kW (cf: Crane published result of 11.84 kW)

Pump Sizing Calculator Screenshot:

PUMP DETAILS

Pump tag number		P-001	
Suction vessel tag number		V-001	
Discharge vessel tag number		V-002	
Barometric pressure	P_{atm}	1.013	bara
NPSH available margin	H_{margin}	1	m
Pump efficiency	η	70%	

FLUID PROPERTIES

Fluid		Water	
Phase		Liquid	
Flowrate	m	23956.8	kg/hr
Density	ρ	998.2	kg/m3
Viscosity	μ	0.98	cP
Vapour pressure	P_{vap}	0.02	bara

VESSEL GAS PRESSURES

Suction vessel gas pressure	$P_{suc.\_vessel}$	0	barg
Discharge vessel gas pressure	$P_{dis.\_vessel}$	0	barg

STATIC HEADS

Suction static head	$H_{suc.\_static\_head}$	0	m
Discharge static head	$H_{dis.\_static\_head}$	120	m

PIPELINES

		Suction Line	Discharge Line	
Pipe nominal diameter		6	3	inch
Pipe schedule		Sch 40	Sch 40	
Pipe internal diameter	d	154.1	77.9	mm

Pipe length	L	0	150	m
Absolute roughness	e	0.046	0.046	mm

FITTINGS

Quantities	**Suction Line**	**Discharge Line**
90° LR bends	0	0
90° Std elbows	0	4
45° LR bends	0	0
45° Std elbows	0	0
Straight tees (flow thro' run)	0	0
Straight tees (flow thro' branch)	0	0
Pipe entrances	0	0
Pipe exits	0	1
Pipe contractions	0	0
Pipe expansions	0	0
Gate valves	0	1
Globe valves	0	0
Swing check valves	0	0
Lift check valves	0	0
Tilting disc check valves	0	0
Stop check valves	0	0
Poppet foot valves (with strainers)	0	0
Hinged disc foot valves (with strainers)	0	0
Ball valves	0	0
Butterfly valves	0	0
Plug valves	0	0

Miscellaneous losses (no. velocity heads)	0	27

Fittings factor	1	1

DISCHARGE CONTROL VALVE

Control valve differential pressure	ΔP_{CV}	0	bar

OUTPUTS

Volumetric flow rate	Q	24.000	m3/hr

		Suction Line	Discharge Line	
Relative roughness	e:d	0.00030	0.00059	
Flow area	A	0.01865	0.00477	m2
Velocity	u	0.36	1.40	m/s
Reynolds No.	Re	56106	110987	
Flow regime		turbulent	turbulent	
Friction factor	f	0.02147	0.02055	
Pipe velocity head loss	K_{pipe}	0.000	39.575	
Fittings total velocity head loss	$K_{fittings}$	0.000	30.304	
Frictional pressure loss	$\Delta P_{friction}$	0.00	0.68	bar
Frictional head loss	$H_{friction}$	0.00	6.97	m

Pump suction pressure	$P_{suction}$	1.01	bara
Pump suction head	$H_{suction}$	10.34	m
Pump discharge pressure	$P_{discharge}$	13.45	bara
Pump discharge head	$H_{discharge}$	137.31	m
Net positive suction pressure available	P_{NPSHA}	0.90	bara
Net positive suction head available	NPSHa	9.14	m
Pump total differential pressure	ΔP_{pump}	**12.43**	**bar**
Pump total differential head	H_{pump}	**126.97**	**m**
Pump absorbed power	E	**11.84**	**kW**