

PUMP SYSTEM ANALYSIS AND SIZING

BY
JACQUES CHAURETTE p. eng.

5th Edition
February 2003
Published by Fluide Design Inc.
www.fluidedesign.com
© Copyright 1994

TABLE OF CONTENTS

Introduction

Symbols

Chapter 1 - An Introduction to pump systems

1.0 Hydrostatic pressure and fluid column height	1.1
1.1 The three forms of energy	1.2
1.2 The relationship between elevation, pressure and velocity in a fluid	1.4
1.3 The difference between pressure and head	1.7
1.4 Fluid systems	1.8
1.5 The driving force of the fluid system	1.9
1.6 The components of Total Head	1.10
1.7 Negative (relative) pressure	1.13
1.8 The siphon effect.....	1.17
1.9 Specific gravity	1.22

Chapter 2 - The application of thermodynamics to pump systems

2.0 Energy and thermodynamic properties	2.1
2.1 Closed systems and internal energy	2.2
2.2 Closed systems, internal energy and work	2.3
2.3 Open systems and enthalpy	2.4
2.4 Open systems, enthalpy, kinetic and potential energy	2.5
2.5 Work done by the pump	2.6
2.6 Fluid and equipment friction loss.....	2.6
2.7 The control volume	2.7
2.8 The determination of Total Head from the energy balance	2.9
2.9 System or Total Head equation for a single inlet-single outlet system	2.9
Example 2.1-Calculate the Total Head for a typical pumping system.....	2.13
2.10 Method for determining the pressure head at any location	2.18
Example 2.2 Calculate the pressure head at the inlet of the control valve	2.21
2.11 System or Total Head equation for a single inlet-double outlet system	2.26
2.12 General method for determining Total Head in a system with multiple inlets and outlets.....	2.29
2.13 General method for determining Total Head in a system with multiple pumps, inlets and outlets	2.31
2.14 General method for determining the pressure head anywhere in a system with multiple pumps, inlets and outlets.....	2.34

Chapter 3 - The Components of Total Head

3.0 The Components of Total Head	3.1
3.1 Total Static Head (ΔH_{TS}).....	3.1
3.2 Suction Static Head (ΔH_{SS})	3.2
3.3 Net Positive Suction Head Available (N.P.S.H.A.)	3.3
Example 3.1-Calculate the Net Positive Suction Head Available	3.12
3.4 Pump intake suction submergence	3.13
3.5 Discharge Static Head (ΔH_{DS})	3.16
Example 3.2 – Calculate the Suction & Discharge Static Head	3.17
3.6 Velocity Head Difference (ΔH_V)	3.18
3.7 Equipment Pressure Head Difference (ΔH_{EQ})	3.18
3.8 Pipe Friction Head Difference for newtonian fluids (ΔH_{FP})	3.20
3.9 Fitting Friction Head Difference for newtonian fluids, K method and 2K method (ΔH_{FF})	3.23
3.10 Pipe Friction Head Difference for wood fiber suspensions (ΔH_{FF})	3.28

Chapter 4 - Pump Selection, Sizing, Interpretation of Performance Curves

4.0 Pump classes	4.1
4.1 Coverage chart for centrifugal pumps	4.2
4.2 Performance curve chart	4.2
4.3 Impeller diameter selection	4.5
4.4 System curve	4.6
4.5 Operating point.....	4.7
4.6 Safety factor on Total Head or capacity	4.9
4.7 Pump operation to the right or left of Best Efficiency Point (B.E.P.)	4.11
4.8 Pump shut-off head	4.14
4.9 Pump power	4.15
4.9 Affinity laws	4.16

Chapter 5 - Field Measurements

5.0 Real live measurements	5.1
5.1 Total Head	5.1
5.2 Net Positive Suction Head Available (N.P.S.H.A.)	5.4
5.3 Shut-off head	5.5
5.4 Equipment head difference	5.7
5.5 Flow measurement	5.8
5.6 Calculating flow based on power consumed by the motor	5.9

Glossary**Bibliography****Appendix A**

Useful equations (metric and imperial systems)
The definition of viscosity
Rheological (viscous behavior) properties of fluids

Appendix B

The Newton-Raphson iteration technique applied to the Colebrook equation

Appendix C

The determination of slurry density based on the volume and weight concentration of the solid particles

Appendix D

The use of imperial system (FPS) units

Appendix E

Power factors and efficiency values for ABB electric motors

Introduction

The purpose of this book is to describe how pressure can be determined anywhere within a pump system. The inlet and outlet of a pump are two locations where pressure is of special interest. The difference in pressure head (the term pressure head refers to the energy associated with pressure divided by the weight of fluid displaced) between these two points is known as the Total Head. A system equation will be developed based on fundamental principles from which the Total Head of the pump can be calculated, as well as the pressure head anywhere within the system. These principles can be applied to very complex systems.

Friction loss due to fluid flow in pipes is the most difficult component of Total head to calculate. The methods used to calculate friction loss for different types of fluids such as water and viscous fluids of the Newtonian type and wood fiber suspensions (or stock) will be explained.

The fluids considered in this book belong to the categories of viscous and non-viscous Newtonian fluids. Wood fiber suspensions are a special type of slurry. There is an excellent treatment on this subject by G.G. Duffy in reference 2. For the reader's benefit, a condensed version is provided. Slurries, which are an important class of fluids, are not considered. I recommend reference 7, which provides a complete treatment of the subject. However, all the principles for Total Head determination described in this book apply to slurry fluid systems. The only exception is the methods used to calculate pipe friction head.

Centrifugal pumps are by far the most common type of pump used in industrial processes. This type of pump is the focus of the book. The challenge in pump sizing lies in determining the Total Head of the system, not the particular pump model, or the materials required for the application. The pump manufacturers are generally more than willing to help with specific recommendations. Information on models, materials, seals, etc., is available from pump manufacturer catalogs.

Often when approaching a new subject, our lack of familiarity makes it difficult to formulate meaningful questions. Chapter 1 is a brief introduction to the components of Total Head. I hope it proves as useful to you as it did to me.

Symbols

Variable nomenclature		Imperial system (FPS units)	Metric system (SI units)
A	area	in ² (inch square)	mm ² (mm square)
C _w	solids concentration ratio by weight in a slurry	non-dimensional	
C _v	solids concentration ratio by volume in a slurry	non-dimensional	
D	pipe diameter	in (inch)	mm (millimeter)
F	force	lbf (pound force)	N (Newton)
f	pipe friction factor	non-dimensional	
g	acceleration due to gravity: 32.17 ft/s ²	ft/s ² (feet/second squared)	m/s ² (meter/second squared)
<i>E</i>	energy	Btu (British Thermal Unit)	kJ (kiloJoule)
\bar{E}	specific energy	Btu/lbm	kJ/kg
ΔE_n	enthalpy variation of the system	Btu	kJ
H	head	ft (feet)	m (meter)
ΔH_P	Total Head	ft	m
ΔH_{DS}	discharge static head	ft	m
ΔH_{EQ}	equipment head difference	ft	m
ΔH_F	friction head difference	ft	m
ΔH_{SS}	suction static head	ft	m
ΔH_{TS}	total static head	ft	m
ΔH_v	velocity head difference	ft	m
ΔKE	kinetic energy variation of the system	Btu	kJ
L	length of pipe	ft	m
m	mass	lbm (pound mass)	kg (kilogram)
M	mass flow rate	tn/h	t/h
ΔPE	potential energy variation of the system	Btu	kJ
p	pressure	psi (pound per square inch)	kPa (kiloPascal)
P	power	hp (horsepower)	W (watt)
R _e	Reynolds number	non-dimensional	
SG	specific gravity; ratio of the fluid density to the density of water at standard conditions	non-dimensional	
T	temperature	°F (degrees Fahrenheit)	°C (degrees Celsius)
Q	heat loss	Btu	kJ
q	volumetric flow rate	ft ³ /s	m ³ /s
ΔU	internal energy variation of the system	Btu	kJ
V	volume	ft ³	m ³
v	velocity	ft/s	m/s
W	work	Btu	kJ
z	vertical position	ft	m

Variable nomenclature		Imperial system (FPS units)	Metric system (SI units)
Greek terms			
Δ	delta: the difference between two terms		
ε	epsilon: pipe roughness	ft	m
ν	nu: kinematic viscosity	SSU (Saybolt Universal Second)	cSt (centiStoke)
η	eta: efficiency	non-dimensional	
μ	mu: dynamic viscosity		cP (centiPoise)
ρ	rho: density	lbm/ft ³	kg/m ³
γ	gamma: specific weight	lbf/ft ³	N/m ³

Note: A dot above the symbol (i.e. \dot{m} , \dot{Q} , \dot{W}) indicates the rate of change of the variable.

A term with multiple subscripts such as ΔH_{EQ1-2} means the total or sum of all equipment head between points 1 and 2.

*FPS: Foot-pound-second system (Imperial) used in the U.S. and anglophone countries.

**SI: Système internationale, the metric system.