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800.0 Appendix

801.0 *Nomenclature*

Term	Symbol	Customary Units	S.I. Units
Area	A	ft^2	m^2
Impeller Diameter	*D*	inches	m
Voltage	*E*	volts	V
Pump Efficiency	Eff	%	%
Local Gravitational Acceleration	g	ft/sec^2	m/sec^2
Total Head	H	feet of liquid	m of liquid
Total Discharge Head	h_d	feet of liquid	m of liquid
Discharge Friction Head	h_{fd}	feet of liquid	m of liquid
Suction Friction Head	h_{fs}	feet of liquid	m of liquid
Total Suction Lift	h_{gs}	feet of liquid	m of liquid
Power	*Hp*	horsepower	kW
Pressure Head	h_p	feet of liquid	m of liquid
Suction Surface Pressure	h_{ps}	feet of liquid	m of liquid
Suction Surface Pressure Absolute	h_{psa}	psia	kPa
Total Suction Head	h_s	feet of liquid	m of liquid
Static Discharge Head	h_{sd}	feet of liquid	m of liquid
Static Suction Head	h_{ss}	feet of liquid	m of liquid
Velocity Head	h_v	ft of liquid	m of liquid
Discharge Velocity Head	h_{vd}	feet of liquid	m of liquid
Vapor Pressure	h_{vpa}	psia	kPa
Suction Velocity Head	h_{vs}	feet of liquid	m of liquid
Current	I	amps	A
Length	*L*	ft	m
Speed of Rotation	*n*	rpm	rad/sec
Net Positive Suction Head Available	$NPSH_A$	ft of liquid	m of liquid
Net Positive Suction Head Required	$NPSH_R$	ft of liquid	m of liquid
Suction Pressure	P_1	psig	kPa
Discharge Pressure	P_2	psig	kPa
Power Factor	*Pf*	dimensionless	dimensionless
Gauge Pressure	P_g	psig	kPg
Hydraulic Power	*Pw*	horsepower	kW
Capacity of Pump	*Q*	gpm	m^3/sec
Specific Gravity	s	dimensionless	dimensionless
Temperature	T	° F	° C
Velocity	v	ft/sec	m/sec
Work	W	ft lb/ lb	Joules/ Kg
Datum Correction Discharge	Z_d	feet of liquid	m of liquid
Datum Correction Suction	Z_s	feet of liquid	m of liquid
Specific Weight (Mass)	γ	lb/ft^3	kg/m3
Viscosity	μ	centipoise	Pa

802.0 *Sample Test Results*

The example problem is shown to demonstrate calculations needed to establish various pump characteristics at a single operating point. When complete performance curves are required, several points must be determined.

802.1 *System Configuration* See Figure 802.1

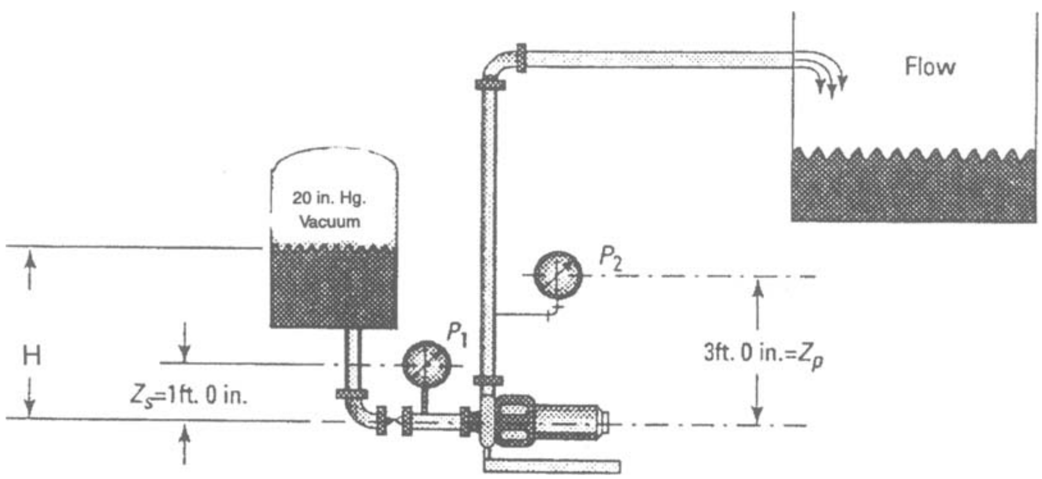

Figure 802.1 System Schematic

802.2 *Sample Data Log Sheet* Figure 802.2.1 is an example of a log sheet used to assemble data, which will be used in the sample calculation. Sample calculation is based on only one flow condition (1000 gpm). All other flow conditions will be taken from Figure 802.2.2.

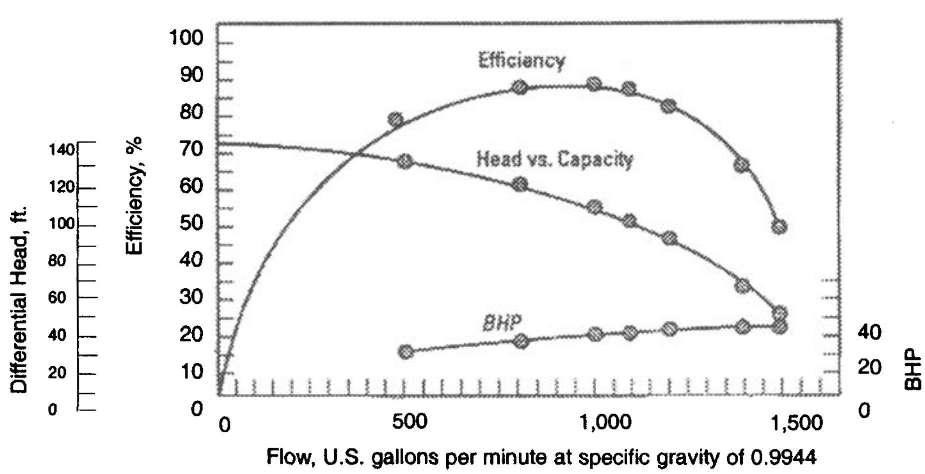

Figure 802.2.1 Vendor Supplied Pump Curve

802.3 Flow Measurement was determined by measuring the difference in level in the discharge tank over a time period.

802.4 *Power for Sample Problem* The power factor shown in the data was obtained from the motor manufacturer's typical values for the type and size motor. The motor efficiency was obtained in the same manner.

RECORD OF PUMP TEST

Mark each pump with test number

MANUFACTURER BRAND X	DISCHARGE DIAMETER 3"	SUCTION DIAMETER 4"	IMPELLER DIAMETER 12"	TEST NO. 1
MODEL DESCRIPTION	LIQUID TEMP. 100° F	BAROMETRIC PRESSURE 14.7	SPECIFIC GRAVITY 0.9944	DATE 11-17-2001
MANUFACTURER SERIAL NO.	G.P.M. AT 1000	FT. TOTAL HEAD 98	VAPOR PRESSURE 0.947 / VISCOSITY 1 cp	TESTED BY
MOTOR (DRIVER) 40.0 HP MOTOR		MOTOR SPEED 1750 RPM		LINE VOLTAGE 460 VOLTS
EFFICIENCY % 90	POWER FACTOR 0.875	CYCLES/HERTZ 60	PHASE 3	

RATE OF FLOW	P_1 SUCTION PRESSURE GA.	P_2 DISCHARGE PRESSURE GA.	Z_d DISCHARGE GA. CORRECTION	Z_s SUCTION GA. CORRECTION	TOTAL HEAD	POWER INPUT	BRAKE H.P.	PUMP SPEED	CORRECTED FLOW	CORRECTED HEAD	CORRECTED B.H.P.	WATER H.P.	PUMP EFF.
GPM	PSIA	PSIA	FEET	FEET	FEET	AMPS	HP	RPM	GPH	FEET	HP	WHP	%
0	11	68	3.0	1.0	135	18	15	1750	None	None	None	0	0
500	10.5	63			125	26.2	21.6	1745				15.8	73
800	10	57			112	31	27.6	1749				22.6	82
1000*	9.0	49			96	36	30	1750				24.9	83
1100	8.5	46			90	37	30.8	1747				25	81
1200	8	42			80	37.3	31.1	1752				24.3	78
1400	7	30			55	39	32.4	1750				19.4	60
1500	6.3	22			40	41.5	34.4	1753				15.1	44

REMARKS: Piping:

Suction — 6" SCH 40 STEEL

Discarge — 6" SCH 40 STEEL

* Condition used in sample calculation, Sec. 803.0

Figure 802.2.2 Recording Sheet for Pump Test

803.0 *Sample Calculations (Dual Units)*

U.S. Customary Units

Pressure Head

$$h_p = \frac{P_g \frac{\text{lb}_f}{\text{ft}^2} \; 32.2 \; \frac{\text{lb}_m \text{ft}}{\text{lb}_f \sec^2}}{\gamma \frac{\text{lb}_m}{\text{ft}^3} \; g \; \frac{\text{ft}}{\sec^2}}$$

(144) P_g (PSIA) = P_g (lb_f / ft^2)

(62.4) s = γ (lb_m / ft^3)

g = 32.2 (ft / $\sec^2$)

$$h_p = 2.31 \frac{P_g(\text{PSIA})}{s} \text{ft}$$

Flow Rate

Q = 1000 gal / min

Static Suction Head, h_{ss}

P_1 = 9 PSIA

$$h_{ss} = 2.31 \frac{P_1(\text{PSIA})}{\text{s}} \text{ft}$$

s = 0.9944

h_{ss} = 2.31 (9) / (0.9944)
= 20.91 feet

Static Discharge Head, h_{sd}

P_2 = 49.3 PSIA

$$h_{sd} = 2.31 \frac{P_2(\text{PSIA})}{\text{s}} \text{ft}$$

h_{sd} = 2.31 (49.3) / (0.9944)
= 114.52 ft

S.I. Units

Pressure Head

$$h_p = \frac{P_g \frac{\text{N}}{\text{m}^2} \; 1 \; \frac{\text{kg m}}{\text{N} \sec^2}}{\gamma \frac{\text{kg}}{\text{m}^3} \; g \; \frac{\text{m}}{\sec^2}}$$

(1000) P_g (kPa) = P_g (N / m^2)

(1000) s = γ (kg / m^3)

g = 9.807 (m / $\sec^2$)

$$h_p = 0.102 \frac{P_g(\text{kPa})}{\text{s}} \text{meters}$$

Flow Rate

$$Q = 1000 \frac{\text{gal}}{\text{min}} \frac{0.003785 \text{ m}^3}{\text{gal}} \frac{60 \text{ min}}{\text{hr}}$$

= 227.1 m^3 / hr

Static Suction Head, h_{ss}

$$P_1 = 9 \text{ PSIA} \frac{6.894 \text{ kPa}}{\text{PSIA}}$$

= 62.05 kPa

$$h_{ss} = 0.102 \frac{P_1(\text{kPa})}{\text{s}} \text{meters}$$

s = 0.9944

h_{ss} = 0.102 (62.05) / (0.9944)
= 6.36 meters

Static Discharge Head, h_{sd}

$$P_2 = 49.3 \text{ PSIA} \frac{6.894 \text{ kPa}}{\text{PSIA}}$$

= 339.87 kPA

$$h_{sd} = 0.102 \frac{P_2(\text{kPa})}{\text{s}} \text{meters}$$

h_{sd} = 0.102 (339.87) / (0.9944)
= 34.86 meters

U.S. Customary Units

Suction Velocity Head, h_{vs}

$$h_{vs} = \frac{V^2}{2g} \text{ for 6" line}$$

V = 11.1 ft / sec

$$h_{vs} = \frac{(11.1 \text{ft / sec})^2}{2\,(32.17 \text{ ft / sec}^2)}$$

= 1.91 ft

Discharge Velocity Head, h_{vs}

$$h_{vd} = \frac{V^2}{2g} \text{ for 6" line}$$

V = 11.1 ft / sec

$$h_{vd} = \frac{(11.1 \text{ ft / sec})^2}{2\,(32.17 \text{ ft / sec}^2)}$$

= 1.91 ft

Datum Correction Suction, Z_S

$Z_S = 1$ ft

Datum Correction Discharge, Z_d

$Z_d = 3$ ft

Vapor Pressure, h_{vpa}

$h_{vpa} = 0.947$ PSIA

$$h_{vp} = 2.31 \frac{P_{vpa}\text{(PSIA)}}{\text{s}} \text{ ft}$$

$h_{vp} = 2.31\ (0.947)\ /\ (0.9944)$
= 2.199 ft

Total Suction Head, h_S

$h_S = h_{SS} + Z_S + h_{VS}$
= 20.91 + 1.0 + 1.91
= 23.82 ft

S.I. Units

Suction Velocity Head, h_{vs}

$$h_{vs} = \frac{V^2}{2g}$$

$V = 11.1$ (ft / sec) (0.3048 m / ft)
= 3.38 m / sec

$$h_{vs} = \frac{(3.38 \text{m / sec})^2}{2\,(9.807 \text{ m / sec}^2)}$$

= 0.584 m

Discharge Velocity Head, h_{vs}

$$h_{vd} = \frac{V^2}{2g}$$

$V = 11.1$ (ft / sec) (0.3048 m / ft)
= 3.38 m / sec

$$h_{vd} = \frac{(3.38 \text{m / sec})^2}{2\,(9.807 \text{ m / sec}^2)}$$

= 0.584 m

Datum Correction Suction, Z_S

$Z_S = 1$ ft (0.3048 m / ft) = 0.3048 m

Datum Correction Discharge, Z_d

$Z_d = 3$ ft (0.3048 m / ft) = 0.91 m

Vapor Pressure, h_{vpa}

$h_{vpa} = 0.947$ PSIA (6.894 kPa/PSIA)
= 6.529 kPa

$$h_{vp} = 0.102 \frac{P_{vpa}\text{(kPa)}}{\text{s}} \text{ meters}$$

$h_{vp} = 0.102\ (6.529)\ /\ (0.9944)$
= 0.670 m

Total Suction Head, h_S

$h_S = h_{SS} + Z_S + h_{VS}$
= 6.36 + 0.3048 + 0.548
= 7.248 m

U.S. Customary Units

Total Disharge Head, h_d

$h_d = h_{sd} + Z_d + h_{vd}$
$= 114.52 + 3 + 1.91$
$= 119.43$ ft

Total Head, H

$H = h_d - h_s$
$= 119.43 - 23.82$
$= 95.61$ ft

Driven Horsepower

$$Hp = \frac{\sqrt{3}\ \text{E I Pf Eff}}{746\ \text{W hp}}$$

$$= \frac{\sqrt{3}(460)(36)(0.875)(0.90)}{746\ \text{W hp}}$$

$= 30.28$ hp

Hydraulic Horsepower

$P_w = Q\,H\,\gamma$

$Q = 1000$ gal / min (ft^3 / 7.48 gal)

$= 133.7$ ft^3 / min

$= 2.228$ ft^3 / sec

$H = 95.51$ ft

$\gamma = 0.9944$ (62.4 lb / ft^3)

$= 62.05$ lb / ft^3

$P_w = (2.228)(95.51)(62.05)$

$$= \frac{13204\ \text{ft lb / sec}}{550\ \text{(ft lb / sec) / hp}}$$

$= 24.01$ hp

S.I. Units

Total Disharge Head, h_s

$h_d = h_{sd} + Z_d + h_{vd}$
$= 34.86 + 0.91 + 0.584$
$= 36.36$ m

Total Head, H

$H = h_d - h_s$
$= 36.36 - 7.248$
$= 29.11$ m

Driven Horsepower

Hp $= \sqrt{3}$ E I Pf Eff

$= \sqrt{3}(460)(36)(0.875)(0.90)$

$= 22588$ W $= 22.59$ kW

Hydraulic Power

$P_w = Q\,H\,\gamma\,g$

$Q = 227.1$ m^3 / hr (hr / 3600 sec)

$= 0.06308$ m^3 / sec

$H = 29.10$ m

$\gamma = 0.9944$ (1000 kg / m^3)

$= 994.4$ kg m^3

$g = 9.807$ m / s^2

$P_w = (0.06308)\ (29.10)\ (994.4)\ (9.807)$

$= 17901$ kg m^2 s^3

$= 17.90$ k W

U.S. Customary Units

Efficiency

$$Eff = \frac{P_w}{H_p}(100\%)$$

$$= \frac{24.01\text{ hp}}{30.28\text{ hp}}(100\%)$$

79.3%

NPSHA

NPSHA = $h_{ss} + Z_S - h_{vp}$

= 20.91 + 1 - 2.199

= 19.7 ft

S.I. Units

Efficiency

$$Eff = \frac{P_w}{H_p}(100\%)$$

$$= \frac{17.90\text{ kw}}{22.59\text{ kw}}(100\%)$$

79.3%

NPSHA

NPSHA = $h_{ss} + Z_S - h_{vp}$

= 6.36 + 0.3048 - 0.670

= 5.99 m

804.0 *Related Calculations*

The following calculations can be used to determine conditions, which affect pump performance.

804.1 *Net Positive Suction Head Available,* $NPSH_A$ should be compared with Net Positive Suction Head Required. $NPSH_R$ from the pump manufacturer's curve or data. Insufficient head can cause pumping problems.

804.2 *Effects of Speed and Impeller Diameter* The effects of minor changes in speed or impeller diameter can be computed when test conditions vary from published data.

804.2.1 Constant Speed Capacity varies in direct proportion to the impeller diameter:

$$Q_2 = Q_1\left(\frac{D_2}{D_1}\right)$$

Total Head varies as the square of the ratio of the impeller diameters:

$$H_2 = H_1\left(\frac{D_2}{D_1}\right)^2$$

Horsepower varies as the cube of the impeller diameter ratio:

$$Hp_2 = Hp_1\left(\frac{D_2}{D_1}\right)^3$$

804.2.2 *Constant Impeller Diameter* Capacity varies in direct proportion to the speed:

$$Q_2 = Q_1\left(\frac{n_2}{n_1}\right)$$

Total Head varies as the square of the ratio of the speeds:

$$H_2 = H_1\left(\frac{n_2}{n_1}\right)^2$$

Horsepower varies as the cube of the speed ratio:

$$Hp_2 = Hp_1 \left(\frac{n_2}{n_1} \right)^3$$

804.2.3 Where:

D = Impeller Diameter
H = Head
Q = Capacity
n = Rotational Speed
Hp = Power

805.0 *References*

805.1 *Hydraulic Institute Standards available from Hydraulic Institute, 9 Sylvan Way, Parsippany, NJ 07054-3802*

805.2 *Cameron Hydraulic Data, 18th Edition: Copyright 1996, Available from Ingersoll-Rand Co., Woodcliff Lake, NJ 07675.*

805.3 *American National Standards ASME Centrifugal Pumps Performance Test Code. PTC 8.2. available from American Society of Mechanical Engineers, United Engineering Center, 3 Park Avenue, New York, NY 10016-5901.*

805.4 *American National Standards ASME Centrifugal/ Vertical Pumps; Allowable Operating Region 9.6.3. Available from American Society of Mechanical Engineers, United Engineering Center, 3 Park Avenue, New York, NY 10016-5901.*