Shell Global Solutions

Centrifugal Pump Selection and Sizing

2009 Calgary Pump Symposium

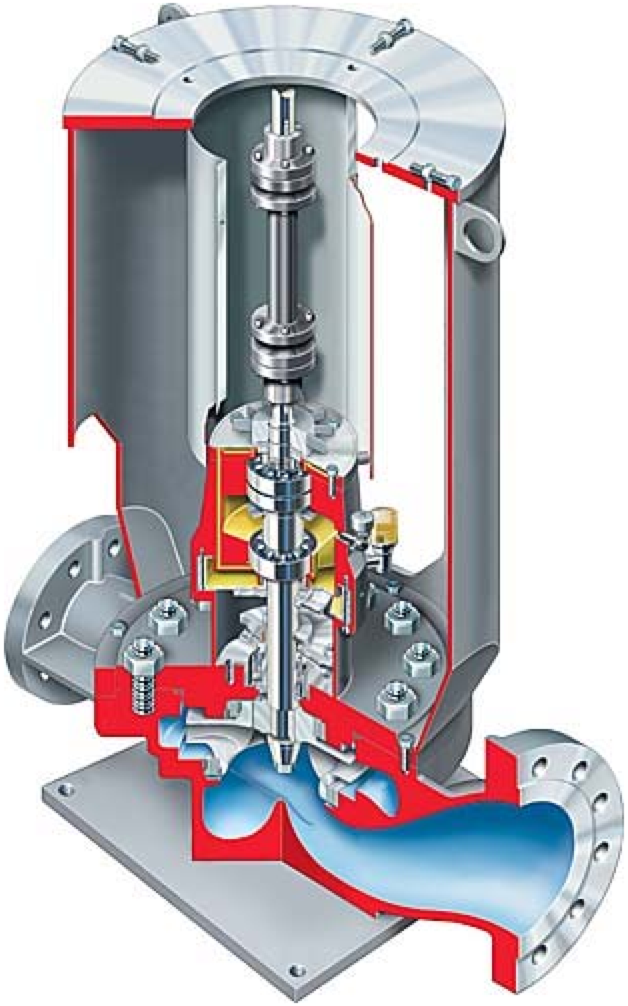
Chris Gilmour, P.Eng.

Pump types being Considered

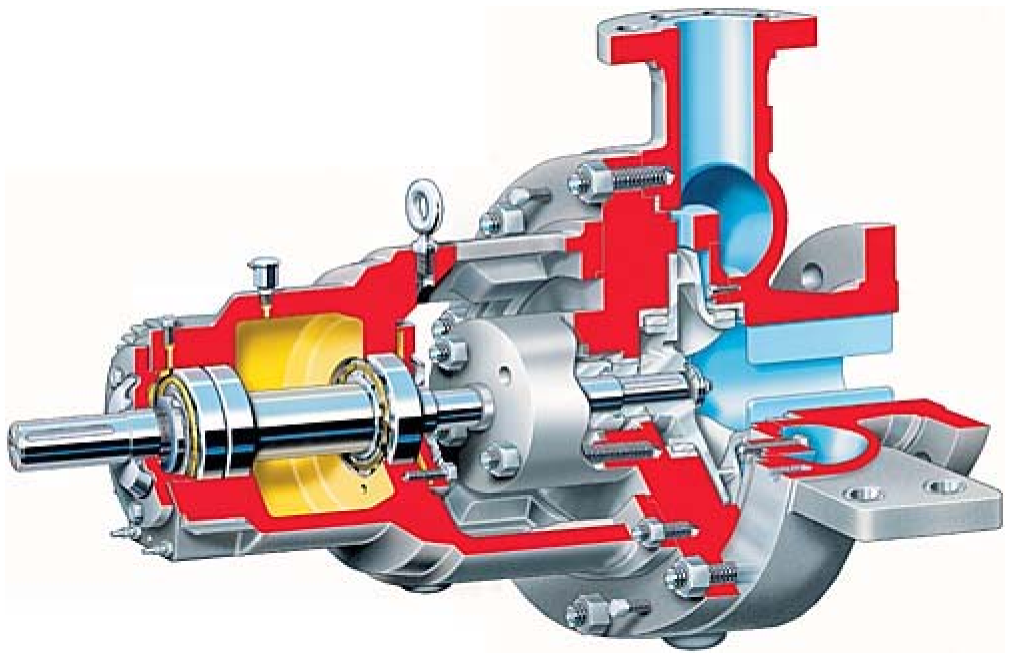
- One and two stage centrifugal pumps
  - OH2, OH3/4, BB1, BB2
  - most common pumps used

- Pumps not considered in this presentation:
  - OH5 close-coupled VIL
  - OH6 high-speed integral gear VIL
  - vertically-suspended pumps
  - multi-stage centrifugal pumps
  - low-flow pumps (Ns < 500)

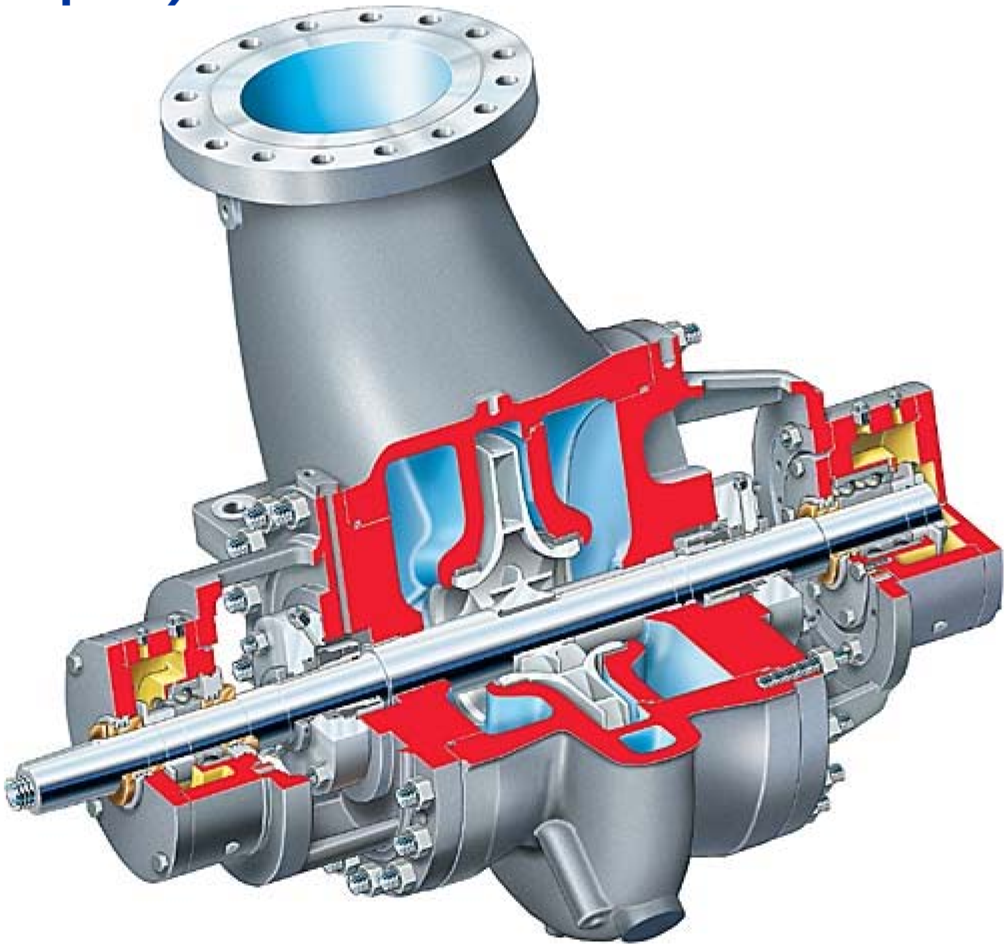
Pump types – Vertical In-line Pump



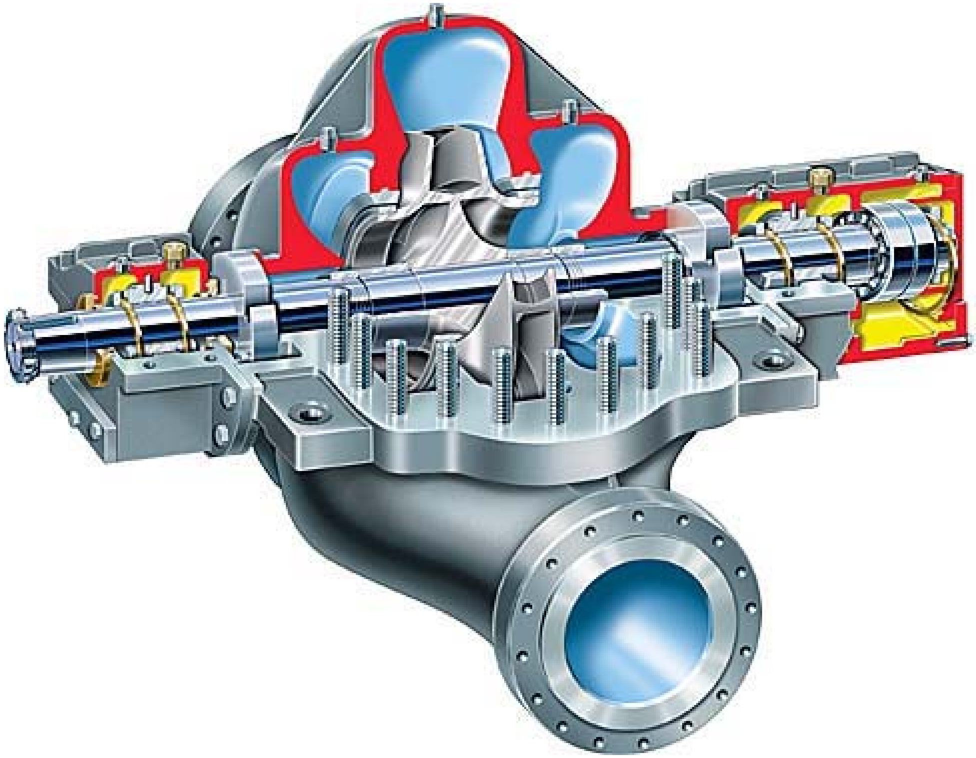
Pump types – Horizontal Overhung



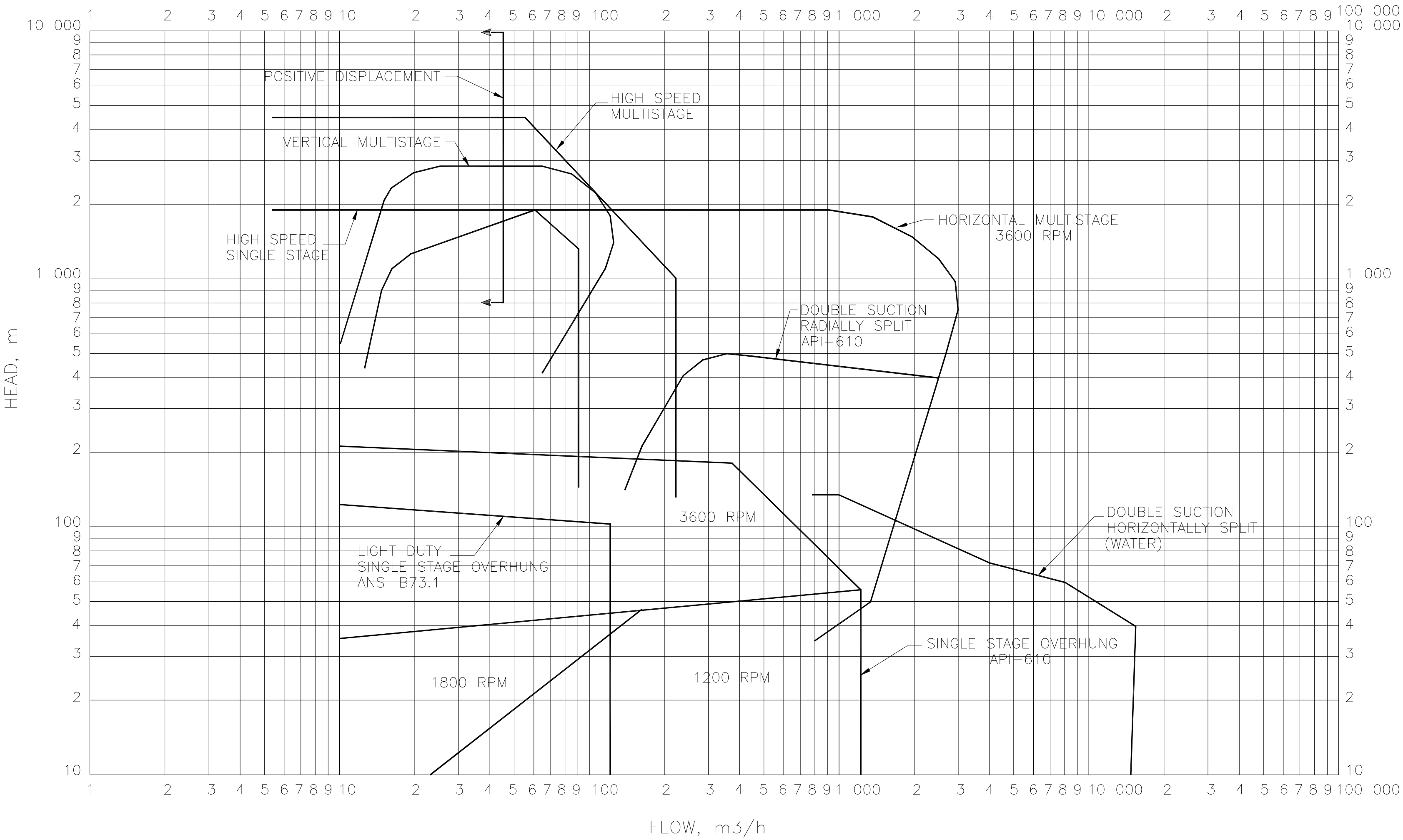
Pump types – Between-Bearing Pump (radially split)



Pump types – Between-Bearing Pump (axially split)



Pump Selection – Old School



Pump Selection

The Goal

- We want to select and purchase pumps that are:
  - Reliable
  - Reasonably priced
  - Efficient

What type of plant?

- Class of Plant
  - Class 1 : low first cost, lower on-stream factor
  - Class 2: a Class 1 plant with selective upgrades
  - Class 3: higher first cost, higher on-stream factor
- Construction (wrt pumps)
  - Modularized or not modularized

Pump Selection – order of preference

- 1. Vertical inline pump
- 2. Horizontal Overhung Pump
- 3. Between Bearing Pump

Pump Selection

- The smallest, least expensive, most efficient pump is an overhung pump (vertical inline, or horizontal overhung) running at 3600 rpm
  - higher speed = smaller diameter for same head
  - higher speed = higher Ns = higher efficiency
  - smaller diameter = smaller casing size = less $

Relative Costs – example 1

- 200 m3/h @ 150 m w/ >7m NPSHa (880 gpm @490 ft w/ > 23 ft NPSHa)
  - 150 HP motor, single seal

Pump	size	rpm	eff	rel $	+ Install $
OH3	4x6x13	3600	78%	1.00	base support
OH2	4x6x13	3600	78%	1.35	+ fdn, grouting
BB2	4x6x13	3600	70%	2.30	+fdn, grouting

Relative Costs – example 2

- 200 m3/h @ 150 m w/ 4m NPSHa (880 gpm @490 ft w/ 13 ft NPSHa)
  - 150 HP motor, single seal

Pump	size	rpm	eff	rel $	+ Install $
OH3	6x8x23	1800	66%	1.00	base support
OH2	6x8x23	1800	66%	1.07	+ fdn, grouting
BB2	4x6x13	3600	70%	1.04	+fdn, grouting

Relative Costs – example 3

- 200 m3/h @ 150 m w/ 4m NPSHa (880 gpm @490 ft w/ 13 ft NPSHa)
  - 150 HP motor, dual seal w/ Plan 53a

Pump	size	rpm	eff	rel $	+ Install $
OH3	6x8x23	1800	66%	1.00	base support
OH2	6x8x23	1800	66%	1.06	+ fdn, grouting
BB2	4x6x13	3600	70%	1.33	+fdn, grouting

Why not always buy a 3600 rpm O/H pump?

- An O/H pump is not always available in the size required
- An O/H pump is not always an appropriate selection
- 3600 rpm may not be an appropriate speed for the process conditions

Overhung Pumps – Typical Coverage

Pump				Impeller Diameter (inches)							
Size											
(Dis x Suc)		7	9	11	13	15	17	20	23	27	30 *
1-1/2x3		2									
2x3		2	2,4	2,4	2,4						
3x4		2	2,4	2,4	2,4	2,4					
4x6		2	2,4	2,4	2,4	2,4	4,6	4,6			
6x8			2,4	2,4	2,4	2,4	4,6	4,6	4,6	4,6	
8x10						4	4,6	4,6	4,6	4,6	
10x12							4,6	4,6	4,6	4,6	
12x16		3600 rpm (2-pole)						4,6	4,6	4,6	6
16x20 *		1800 rpm (4-pole)								4,6	6
20x24 *		1200 rpm (6-pole)									6
		* OH2 only									

Overhung Pumps – Typical Limits

- Tip Speed
  - u = RPM/60 x PI x Diameter , units – m/s, m
  - Issue is vibration
  - Typical limit is 62 m/s (205 ft/s) for Class 3 plant
    - 13" diameter impeller at 3550 rpm
    - 27" diameter impeller at 1750 rpm
  - Consider increasing for Class 1 plant

VIL Pumps – Typical Limits

- Tip Speed: issue is vibration
  - Typical limit is 62 m/s (205 ft/s) for Class 3 plant
    - 13" diameter impeller at 3550 rpm
    - 27" diameter impeller at 1750 rpm
- Power: issue is vibration, reliability
    - Typical limits for Class 3 plant are:
      - 200HP at 3600 rpm
      - 400HP at 1800 rpm
      - 600HP at 1200 rpm
- Process Fluid Temperature: issues are shaft sealing, bearing cooling, and motor cooling
  - Typical upper limit is 200 C (400F) for Class 3 plant

VIL Pumps: Bearing-bracket (OH3) type – Other considerations

- How to lubricate the bearing bracket?
  - best is oil mist, if available
  - using oil in a vertical bearing bracket hasn’t always worked well, depends on the arrangement
  - grease is an option for cooler services, but requires regular monitoring

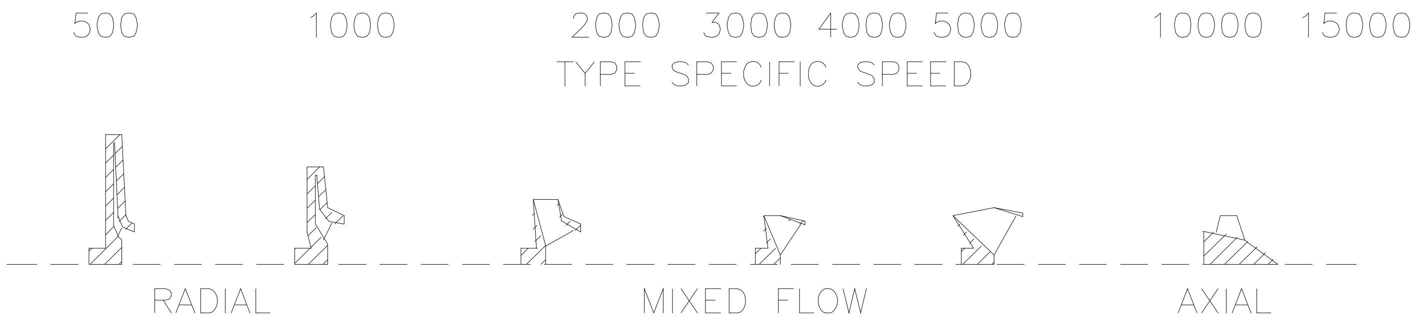
VIL Pumps: Rigidly-coupled (OH4) type – Other considerations

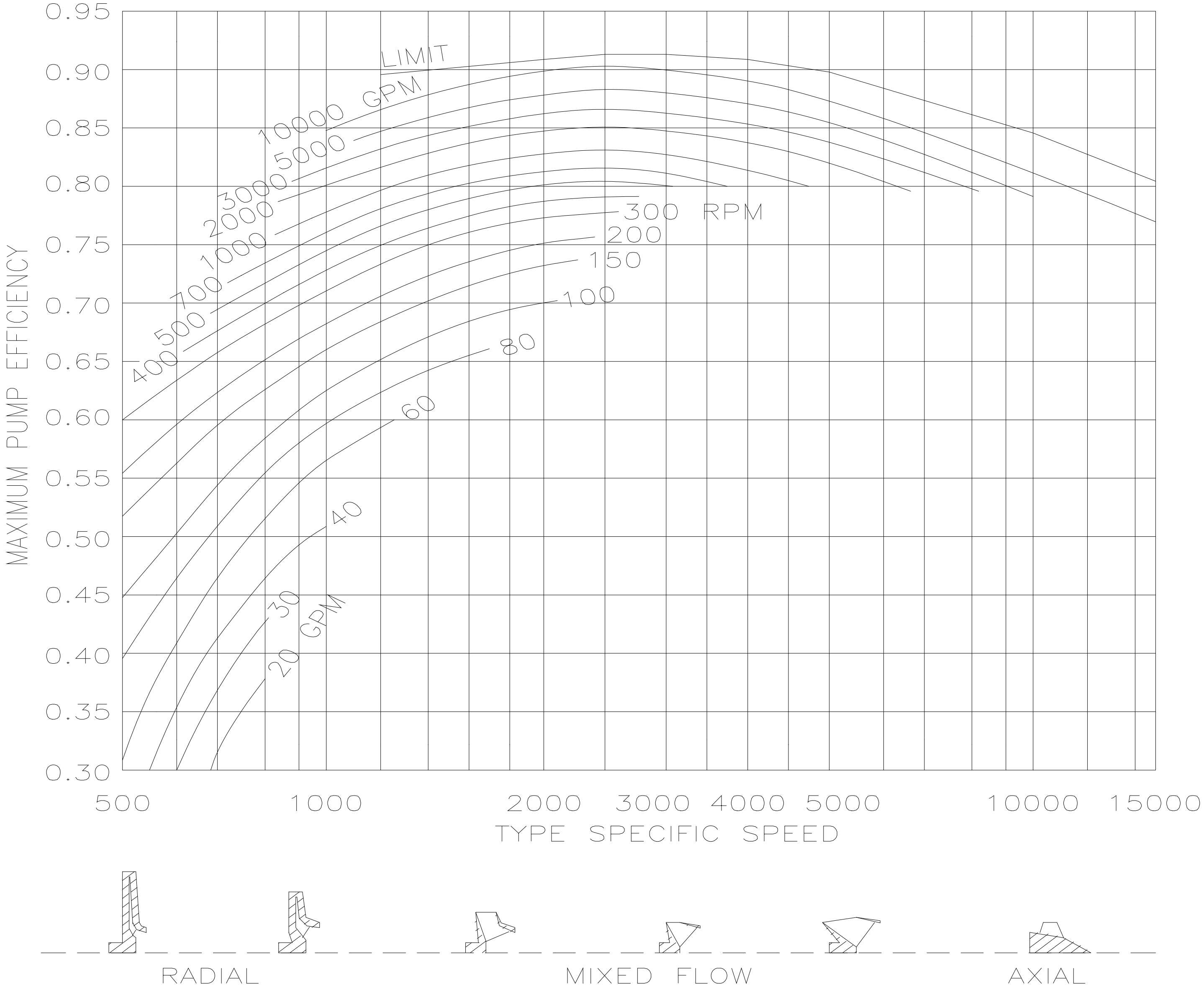
- Fluid-lubricated radial bearing
  - need to consider the cleanliness and lubricating properties of the fluid
- Motor shaft runout
  - requires tight tolerance on motor shaft runout
- Reliability / seal life ?
  - some companies have had poor seal MTBR with these pumps
  - Shell Canada experience has been reasonably good

Pump Sizing

Specific Speed (Ns)

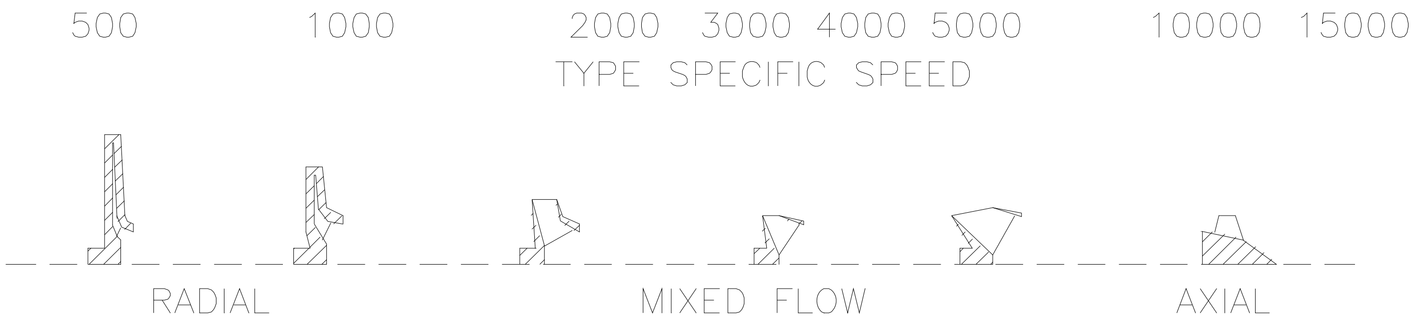
- a ‘dimensionless’ parameter describing geometric similarity
- evaluated at BEP, maximum diameter
- Ns = rpm x gpm^0.5 / ft^0.75 , use ½ Q for double suction
- useful for sizing/selecting pumps




MAXIMUM PUMP EFFICIENCY
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
LIMIT
10000 GPM
5000
3000
2000
1000
700
500
400
300 RPM
200
150
100
80
60
40
30
20 GPM
500
1000
2000
3000
4000
5000
10000
15000
TYPE SPECIFIC SPEED
RADIAL
MIXED FLOW
AXIAL

Specific Speed - Guidelines

- typical process pumps have Ns between 500 and 1,800
  - limited choices of supplier below 500
- pumps with Ns 1,800 – 2,400 are less desirable (reduced range of acceptable operation)
- Pumps with Ns > 2,400 should be avoided



Suction Specific Speed (Nss)

- a ‘dimensionless’ parameter describing impeller eye geometry
- evaluated at BEP, max diameter
- Nss = rpm x gpm^0.5 / NPSHr^0.75 , use ½ Q for double suction impeller
- consider this example: 500 gpm pump at 3550 rpm
  - Nss = 9,000 when NPSHr = 18.2 ft
  - Nss = 11,000 when NPSHr = 13.9 ft
  - Nss = 13,000 when NPSHr = 11.2 ft
- for the same pump, lower NPSHr achieved by one or more of:
  - sharpening the impeller inlet edges
  - increasing the impeller inlet area by: decreasing # of blades; and /or, increasing blade inlet angle; and /or, increasing inlet area

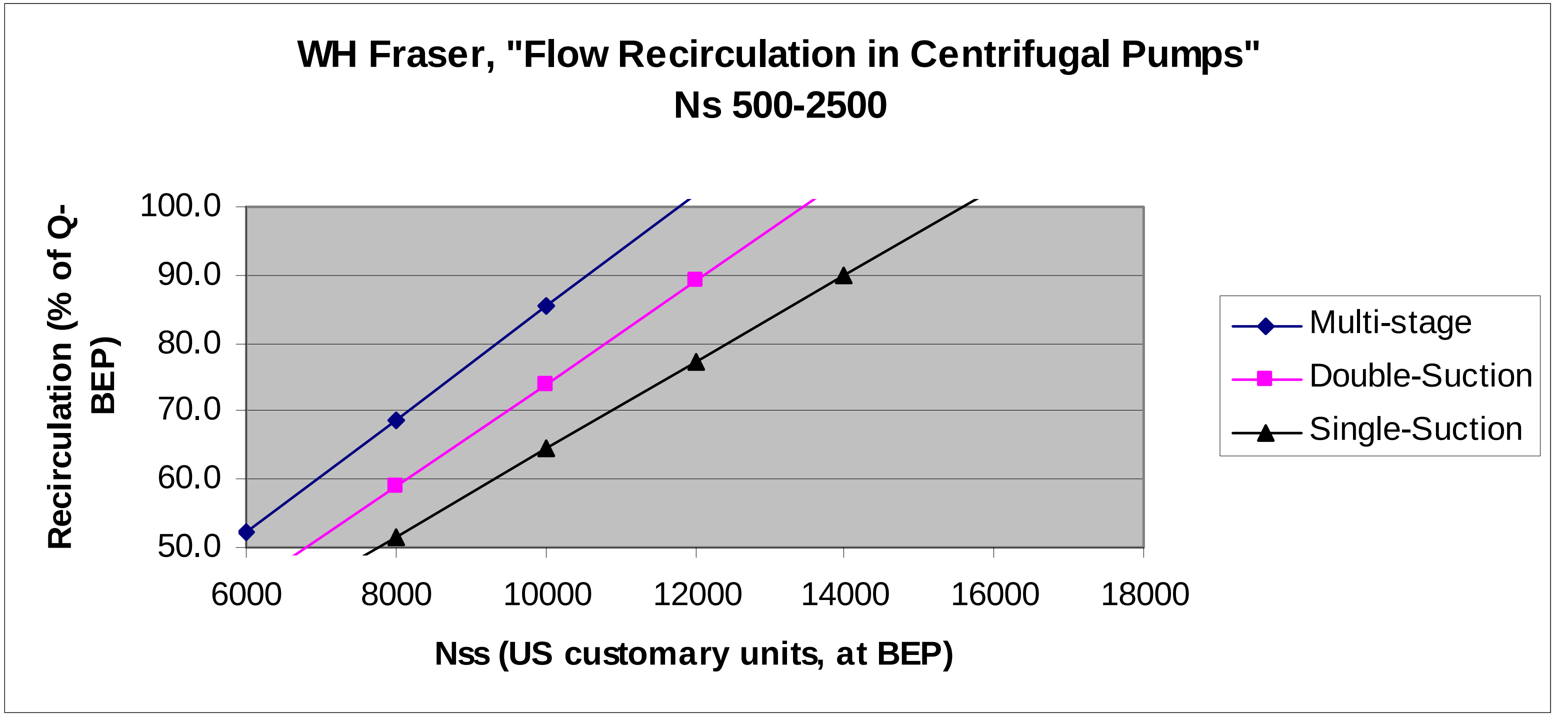
Suction Specific Speed (Nss) - Guidelines

- typical range is 7,000 to 16,000 (and higher)
- higher Nss results in restricted range of acceptable operation
- for pumps with Ns 500 –1800, max Nss up to 11,000 is acceptable
- for pumps with Ns 1,800 – 2,400, max acceptable Nss should be reduced to about 9,000
- pumps with Ns above 2,400 should be avoided

Minimum Flow

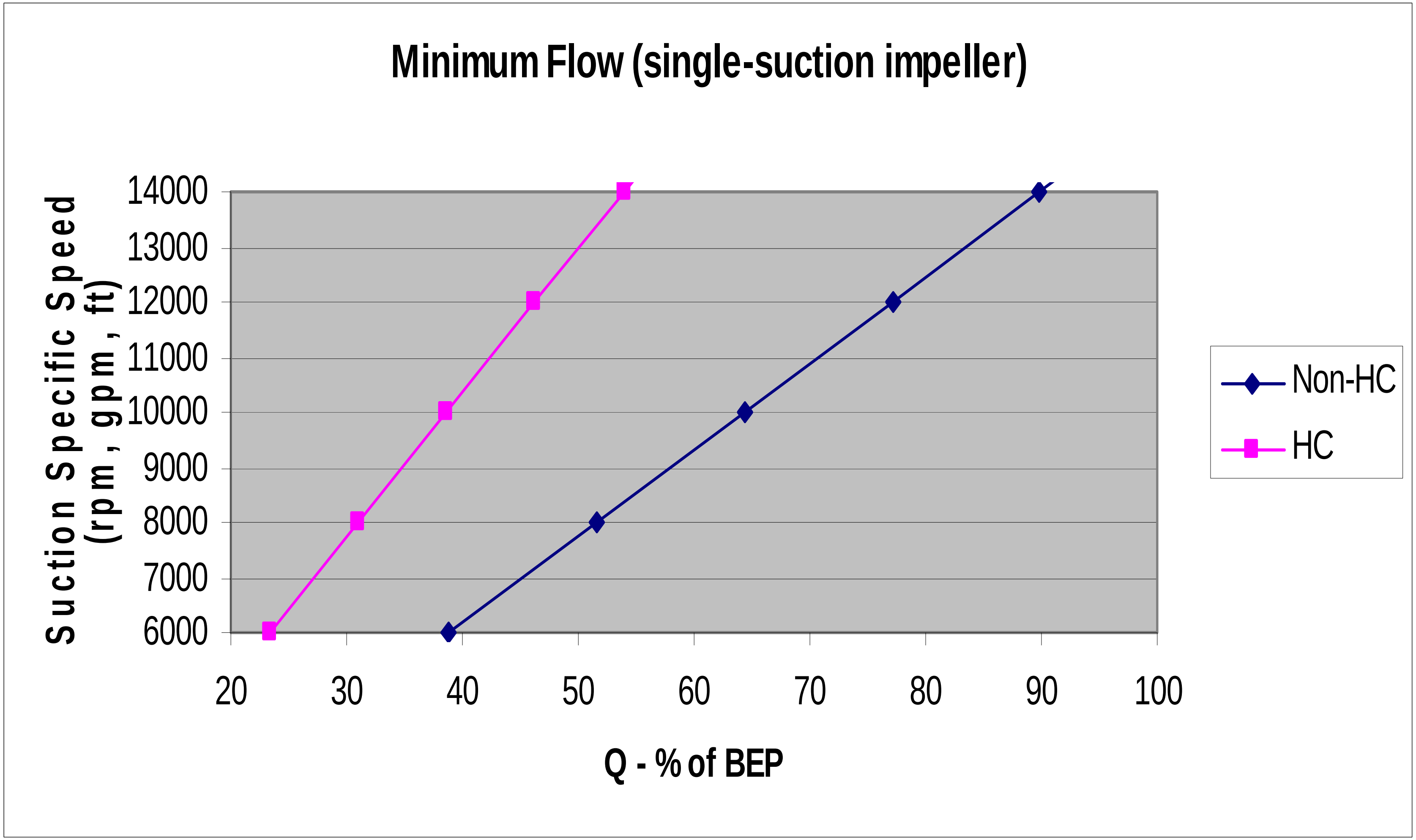
- Minimum flow issues:
  - temperature rise
  - internal recirculation
  - increased flow separation
  - increased pressure fluctuation
  - increased vibration levels (both radial and axial)
- Avoiding these issues
  - method from WH Fraser (ref: “Flow Recirculation in Centrifugal Pumps”, 1981 Texas A&M Turbomachinery Symposium), ensure pump selection has acceptable range (ie. operation at flows above onset of recirculation)

Minimum Flow - Guidelines



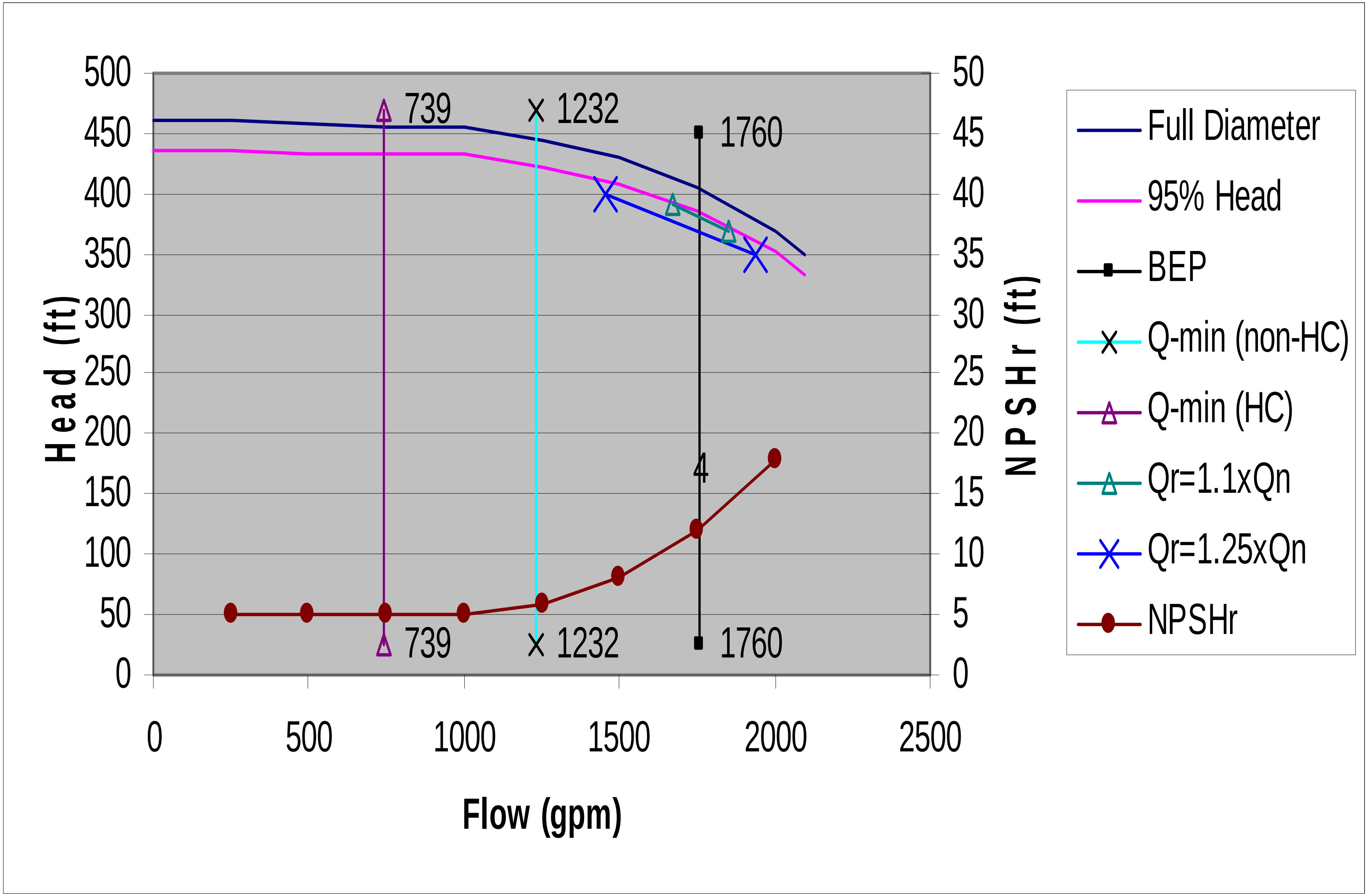
- for Q<2500 gpm and Hd<150 ft, use 50% of curve for continuous and 25% for intermittent operation
- for HC service, use 60 % for continuous and 25% for intermittent operation

Limited Range at Higher Nss



Other Considerations

- Nozzle Velocities – typical limits
  - suction < 20 ft/s
  - discharge < 40 ft/s
- Q-rated & Q-normal relative to BEP
  - typically Q-rated = Q-normal x 1.1, but sometimes (eg. reflux service) Q-rated = Q-normal x 1.25
  - best is to straddle BEP with Q-normal and Q-rated, especially if Q-rated >> Q-normal
    - need to consider: NPSHa, min flow



500
450
400
350
300
250
200
150
100
50
0
Head (ft)
50
45
40
35
30
25
20
15
10
5
0
NPSHr (ft)
0
500
1000
1500
2000
2500
Flow (gpm)
739
1232
1760
4
739
1232
1760
Full Diameter
95% Head
BEP
Q-min (non-HC)
Q-min (HC)
Qr=1.1xQn
Qr=1.25xQn
NPSHr

Lets Size some pumps!

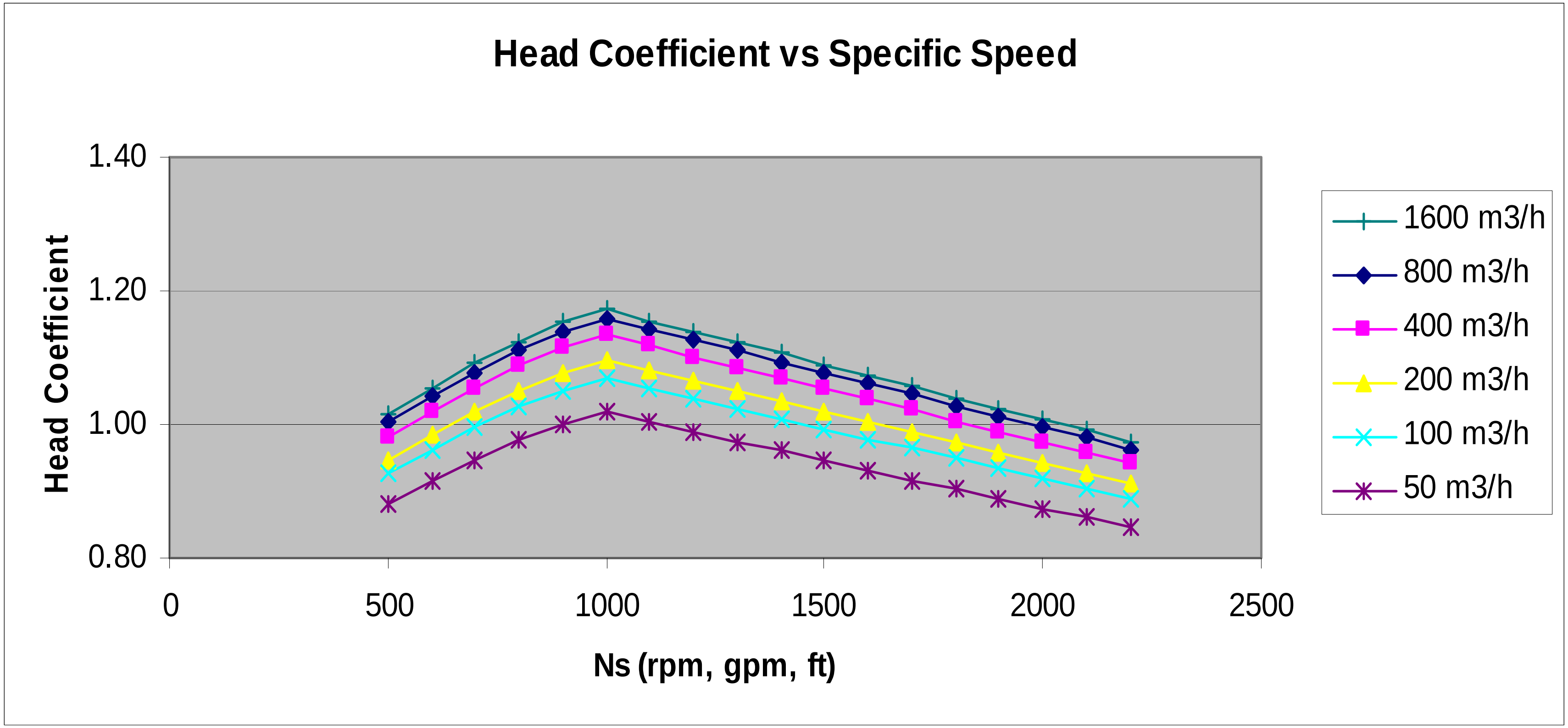
Equations & Correlations

- Head, $H = 2.31 \times dP / SG$, (ft, psi)
- Sp Speed, $Ns = N \times Q^{1/2} / H^{3/4}$, (rpm, gpm, ft)
- Suc Sp Speed, $Nss = N \times Q^{1/2} / NPSHr^{3/4}$, (rpm, gpm, ft)
- Head Coefficient, $HC = H / (u^2 / 2g)$, (ft, ft/s, ft/s^2)
  - methodology in "The Pump Handbook",
- Tip Speed, $u = (H \times 2g / HC)^{0.5}$, (ft/s, ft, ft/s^2)
- Diameter, $D = u \times 12 / PI / (RPM/60)$, (in, ft/s, rpm)
- Power, $P = H \times Q \times SG / (3960 \times n)$, (hp, ft, gpm)

- From Curves: efficiency, expected nozzle size, min flow

Estimating the Head Coefficient

- using the correlations in “The Pump Handbook”, 2nd edition, Karassik, et al, Ch 2.1



Required Information

- Require this info as a minimum:
  - flow, Q
  - head, H
  - NPSHa (or to know that it is ample)
- Also desirable to know:
  - SG (to calculate power; assume = 1 if not provided)
  - viscosity (to check if viscous corrections are reqd)
  - HC or non-HC (for minimum flow calculation)
  - continuous or intermittent service (for min flow calc)

Worked Example: H= 170 ft, Q= 2000 gpm, NPSHa= 20 ft, water

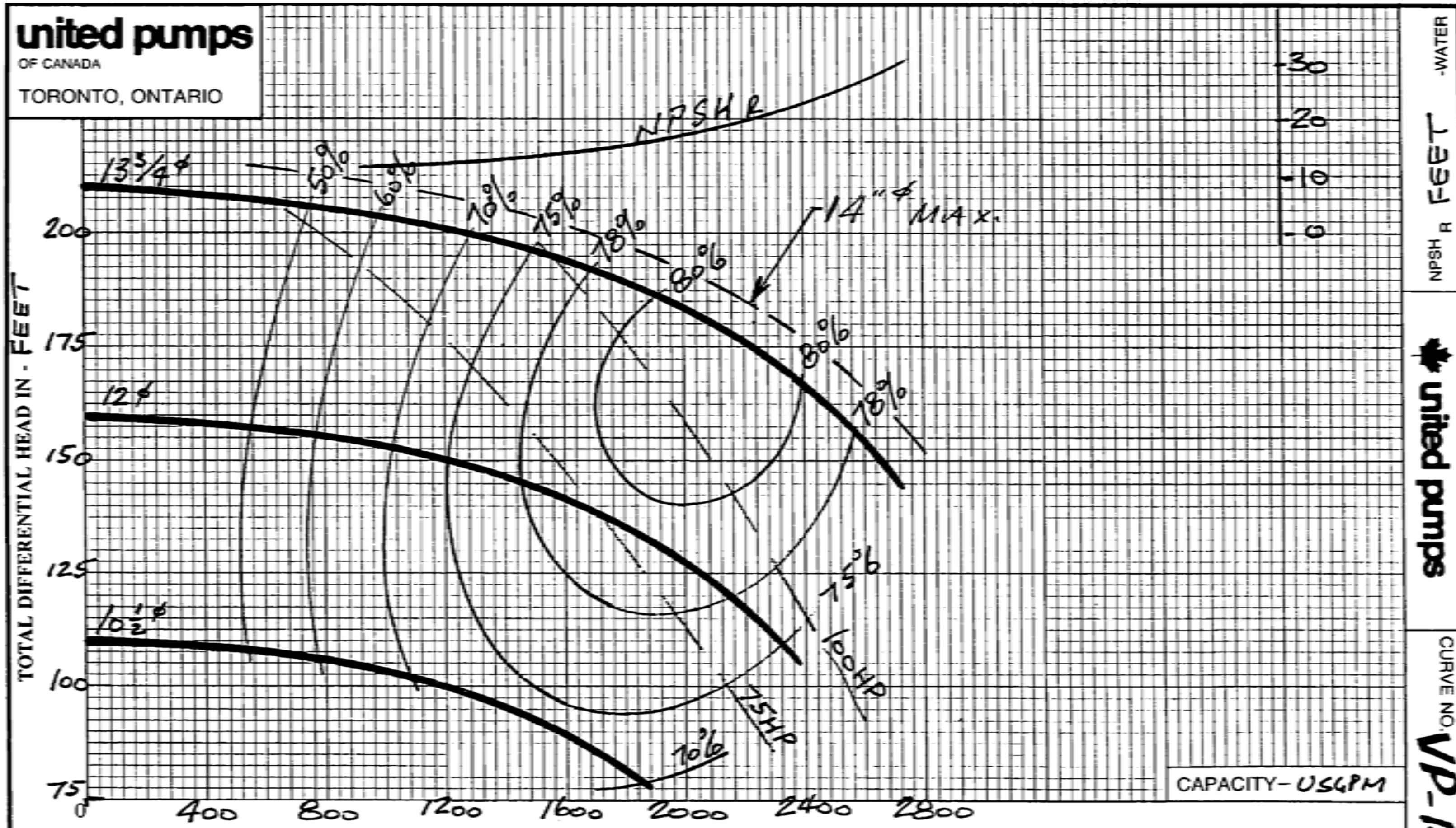
rpm	1780	3550	3550 / dbl
Ns (=RPM x gpm^0.5 / ft^3/4)	1,876	3,742	2,646
Nss (=RPM x gpm^0.5/NPSH^3/4)	< 9,000	17,800	12,586
efficiency, from curve	0.84		0.83
Head Coeff, from curve	0.93		0.83
Tip Spd, fps, = (H x 2g /HC)^0.5	108.2		114.6
Dia, in, = u x 12 / PI / (RPM/60)	13.9		15.7
HP = H x Q x SG / (3960 x n)	102		103
Min Nozzle (suc 20 fps, dis 40 fps)	6 x 8		6 x 8
Min Flow (non-HC, continuous op)	58%		88%

Typical Casing Sizes

	Pump Speed		
Q (GPM)	**1160**	**1780**	**3550**
0	3 x 4	2 x 3	1.5 x 2
100	3 x 4	2 x 3	1.5 x 2
200	4 x 6	3 x 4	2 x 3
300	4 x 6	3 x 4	3 x 4
500	4 x 6	4 x 6	4 x 6
700	6 x 6	6 x 6	4 x 6
1000	6 x 8	6 x 6	6 x 6
1500	8 x 8	6 x 8	6 x 6
2000	8 x 8	8 x 10	6 x 8
2500	8 x 10	8 x 10	8 x 10
3500	10 x 12	10 x 12	
4500	12 x 14	10 x 12	
5500	14 x 16	12 x 14	
7000	16 x 20	12 x 14	
10000	16 x 20	14 x 16	

Overhung Pumps – Typical Coverage

Pump Size (Dis x Suc)		Impeller Diameter (inches)									
		7	9	11	13	15	17	20	23	27	30 *
1-1/2x3		2									
2x3		2	2,4	2,4	2,4						
3x4		2	2,4	2,4	2,4	2,4					
4x6		2	2,4	2,4	2,4	2,4	4,6	4,6			
6x8			2,4	2,4	2,4	2,4	4,6	4,6	4,6	4,6	
8x10						4	4,6	4,6	4,6	4,6	
10x12							4,6	4,6	4,6	4,6	
12x16		3600 rpm (2-pole)						4,6	4,6	4,6	6
16x20 *		1800 rpm (4-pole)								4,6	6
20x24 *		1200 rpm (6-pole)									6
		* OH2 only									



RING CLEARANCE .021 ON 9 DIA	NS : 1800	ISSUE DATE: 10.31.69 7.30.90 12.20.91	IMPELLER 1591	VOLUTE 2483 6DV	CASE PATT. 2483	PUMP SIZE & TYPE B6x8x14 VP7
MAX. PART SIZE 1"	S.S. : 9100					R. P. M.- 1780
WET WR² LBS IN² 1125	EYE AREA : 40					

Worked Example: H= 500 ft, Q= 4500 gpm, NPSHa= 20 ft, hydrocarbon

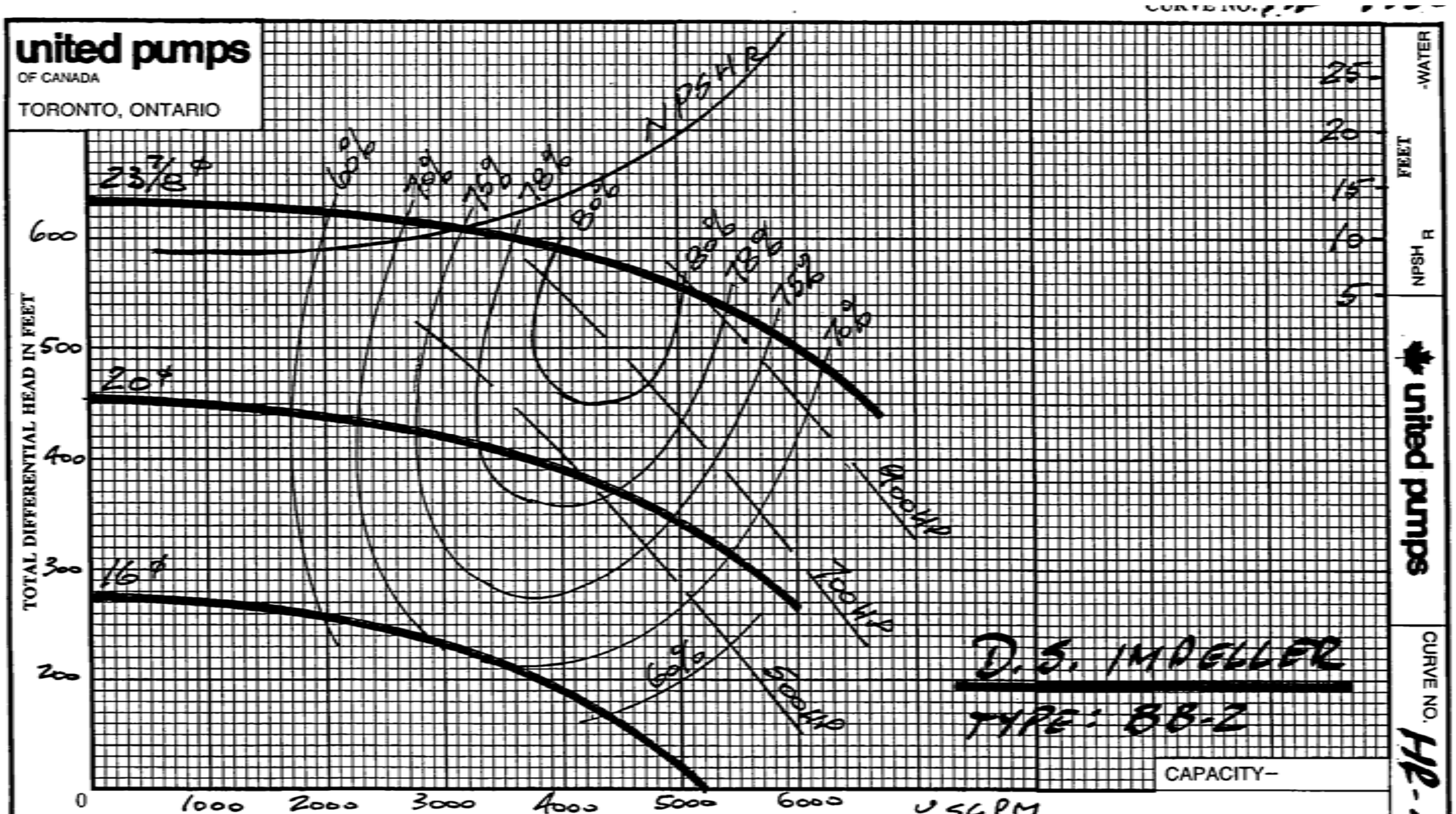
rpm	1160	1780	1780 / dbl
Ns (=RPM x gpm^0.5 / ft^3/4)	736	1,129	799
Nss (=RPM x gpm^0.5/NPSH^3/4)	< 9,000	12,622	< 9,000
efficiency, from curve	0.77	0.84	0.77
Head Coeff, from curve	1.09	1.04	1.09
Tip Spd, fps, = (H x 2g /HC)^0.5	171.5	175.8	171.7
Dia, in, = u x 12 / PI / (RPM/60)	33.9	22.6	22.1
HP = H x Q x SG / (3960 x n)	741	677	742
Min Nozzle (suc 20 fps, dis 40 fps)	8 x 10	8 x 10	8 x 10
Min Flow (non-HC, continuous op)	35%	49%	40%

Typical Casing Sizes

	Pump Speed		
Q (GPM)	**1160**	**1780**	**3550**
0	3 x 4	2 x 3	1.5 x 2
100	3 x 4	2 x 3	1.5 x 2
200	4 x 6	3 x 4	2 x 3
300	4 x 6	3 x 4	3 x 4
500	4 x 6	4 x 6	4 x 6
700	6 x 6	6 x 6	4 x 6
1000	6 x 8	6 x 6	6 x 6
1500	8 x 8	6 x 8	6 x 6
2000	8 x 8	8 x 10	6 x 8
2500	8 x 10	8 x 10	8 x 10
3500	10 x 12	10 x 12	
4500	12 x 14	10 x 12	
5500	14 x 16	12 x 14	
7000	16 x 20	12 x 14	
10000	16 x 20	14 x 16	

Overhung Pumps – Typical Coverage

Pump Size (Dis x Suc)	Impeller Diameter (inches) 7	9	11	13	15	17	20	23	27	30 *
1-1/2x3	2									
2x3	2	2,4	2,4	2,4						
3x4	2	2,4	2,4	2,4	2,4					
4x6	2	2,4	2,4	2,4	2,4	4,6	4,6			
6x8		2,4	2,4	2,4	2,4	4,6	4,6	4,6	4,6	
8x10					4	4,6	4,6	4,6	4,6	
10x12						4,6	4,6	4,6	4,6	
12x16	3600 rpm (2-pole)						4,6	4,6	4,6	6
16x20 *	1800 rpm (4-pole)								4,6	6
20x24 *	1200 rpm (6-pole)									6
	* OH2 only									



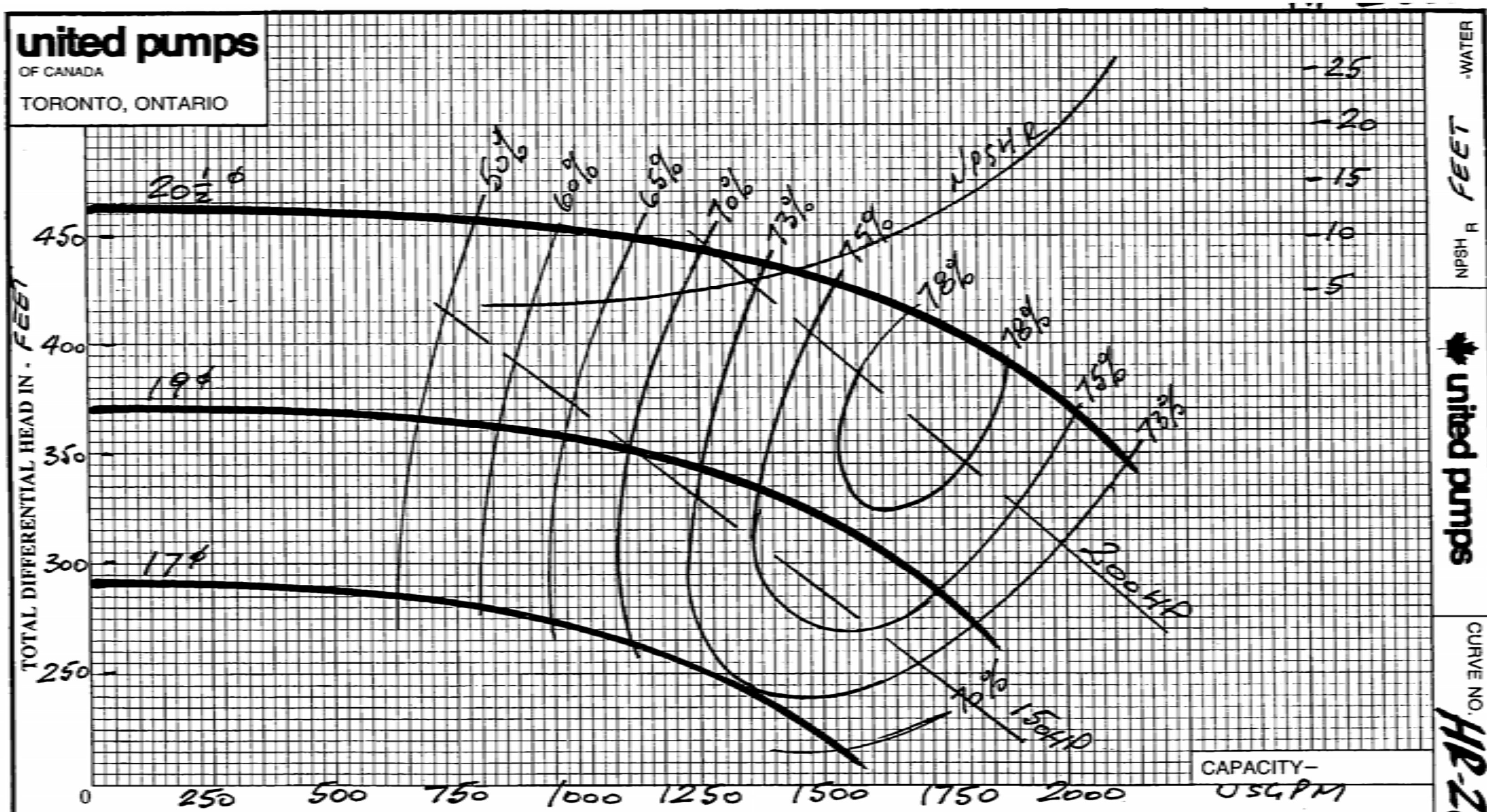
RING CLEARANCE .023 ON 11.7 DIA	NS: 725	ISSUE DATE: 6.20.94 5.30.97	IMPELLER 40501	VOLUTE 40518	CASE PATT. 40518	PUMP SIZE & TYPE A 10×14×23 HDR
MAX. PART SIZE 7/8	S.S.: 10500					
WET WR² LBS IN² 10.100	EYE AREA: 107			5DV-16.8		R.P.M.- 1780

Worked Example: H= 380 ft, Q= 1750 gpm, NPSHa= 8 ft, hydrocarbon

rpm	1160	1780	1780 / dbl
Ns (=RPM x gpm^0.5 / ft^3/4)	564	865	612
Nss (=RPM x gpm^0.5/NPSH^3/4)	< 10,168	15,602	< 11,032
efficiency, from curve	0.70		0.70
Head Coeff, from curve	1.0		1.02
Tip Spd, fps, = (H x 2g /HC)^0.5	156.4		155.0
Dia, in, = u x 12 / PI / (RPM/60)	30.9		20
HP = H x Q x SG / (3960 x n)	240		217
Min Nozzle (suc 20 fps, dis 40 fps)	6 x 6		6 x 6
Min Flow (non-HC, continuous op)	39%		49%

Worked Example: H= 380 ft, Q= 1750 gpm, NPSHa= 13 ft, hydrocarbon

rpm	1160	1780	1780 / dbl
Ns (=RPM x gpm^0.5 / ft^3/4)	564	865	612
Nss (=RPM x gpm^0.5/NPSH^3/4)	< 9,000	10,905	< 9,000
efficiency, from curve	0.70	0.77	0.70
Head Coeff, from curve	1.0	1.05	1.02
Tip Spd, fps, = (H x 2g /HC)^0.5	156.4	152.4	155.0
Dia, in, = u x 12 / PI / (RPM/60)	30.9	19.6	20
HP = H x Q x SG / (3960 x n)	240	217	217
Min Nozzle (suc 20 fps, dis 40 fps)	6 x 6	6 x 6	6 x 6
Min Flow (non-HC, continuous op)	39%	42%	49%



RING CLEARANCE .020 ON 8 3/4 DIA	NS : 820	ISSUE DATE: 6.5.94	IMPELLER 1956XT 24244	VOLUTE 6820A	CASE PATT. 6820	PUMP SIZE & TYPE A6x8x20 HR
MAX. PART SIZE 3/4	S.S. : 10.900					R. P. M.- 1770
WET WR² LBS IN² 3100	EYE AREA : 43					

Sizing Spreadsheet

- Arrange the calculations in a spreadsheet
  - enter: Q, H, NPSHa, SG, viscosity
  - calculate all parameters for typical speeds (1150, 1750, 3550 rpm), and for single or double suction impellers
    - Ns, Nss, expected efficiency, diameter, expected nozzle sizes, power
  - if ambitious, could also calculate: minimum flow, suction energy, viscosity corrections, motor sizes, etc

Buying Pumps -
Marrying the Hydraulic Selections with the Pump Standards

Pump Standards (North American)

- API 610 – for heavy duty pumps
- ASME/ANSI B73.1 and B73.2 standards, essentially dimensional interchangeability standards for chemical process pumps
- Hydraulic Institute (HI) standards – for general service pumps

Pump Standards - Applicability

	VIL	Hor O/H	Btwn Brg
API 610	Y	Y	Y
ANSI B73.1		Y	
ANSI B73.2	Y		
Hydr Inst (HI)	Y	Y	Y

General Info - API 610-10th

- Per (5.3.5) minimum casing pressure design conditions are 600 psig at 100 F (4000 kPag at 38 C), or at least a Class 300 flange rating per B16.5
- Per (5.3.9), radially split casings are required for:
  - T > 200C
  - flammable or hazardous fluid with SG < 0.7 at pumping temp
  - flammable or hazardous fluid at rated P-dis > 100 bar
- Per (5.3.11), centre-line mounting required, except that per (8.2.1.2) between-bearing pumps with T < 150C may be foot mounted
- Per (8.1.2.7), the bearing housing temp for grease lubricated OH3 pumps shall be <= 82C at T-amb of 43C

General Info – ANSI/ASME B73 pumps

- Casing pressure-temperature rating per B16.5 Class 150 flange rating
- Typical application limits (per API 610 – 8th ed)
  - service is non-flammable and non-toxic
  - P-dis <= 19 barg, P-suc <= 5 barg
  - T-max <= 150 C
  - Head <= 120 m
  - N <= 3600 rpm
  - diameter <= 330 mm (13 in) for overhung pumps
- Typical Company limits
  - Low process-fluid temperature limit
  - Driver size limit for Vertical inline pumps

ANSI B73.1 – Typical Coverage

ANSI Pump Size (Dis x Suc)	Impeller Diameter (inches): 6	8	10	13	15	17
1x1-1/2	2,4	2,4				
1-1/2x3	2,4	2,4	2,4	2,4		
2x3	2,4	2,4	2,4	2,4		
3x4		2,4	2,4	2,4		
4x6			2,4	4	4	4
6x8				4	4	4
8x10				4	4	4

VIL Pump Coverage

2 = 3600 rpm (2-pole)

4 = 1800 rpm (4-pole)

ref: B73.1, Table 4 "Approximate Performance Standards for Pumps (60 hz)"

What type of plant?

- Class of Plant
  - Class 1 : low first cost, lower on-stream factor
  - Class 2: a Class 1 plant with selective upgrades
  - Class 3: higher first cost, higher on-stream factor
- Construction (wrt pumps)
  - Modularized or not modularized

Questions?