NPSH: Accounting for Dissolved Gases

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Case of Water Injection Pump

Water Injection Pump	
Pump Flowrate, m3/hr	300
Pump differential head, m	2600
Water temperature, deg C	45
Suction Vessel Pressure, barg	-0.6
Estimated NPSHR3, m	
NSS - 9000	8.5
Yedidiah Method	6.2
Henshaw Method	4.6
Estimating NPSHA	
Water vapour pressure, bara	0.096
Static head from liquid level to pump C/L, m	7.1
Frictional loss, bar	0.08
Pump suction pressure, bara	1.02951
NPSHA, m	9.5
NPSH Margin, m	1.0

Looks perfect, isn't it?

3 Mistakes in Pump's life!

NPSHR definition may not be proper for dissolved gas situation

Does not account for dissolved gases – Oxygen without minerals

NPSH Margin issue

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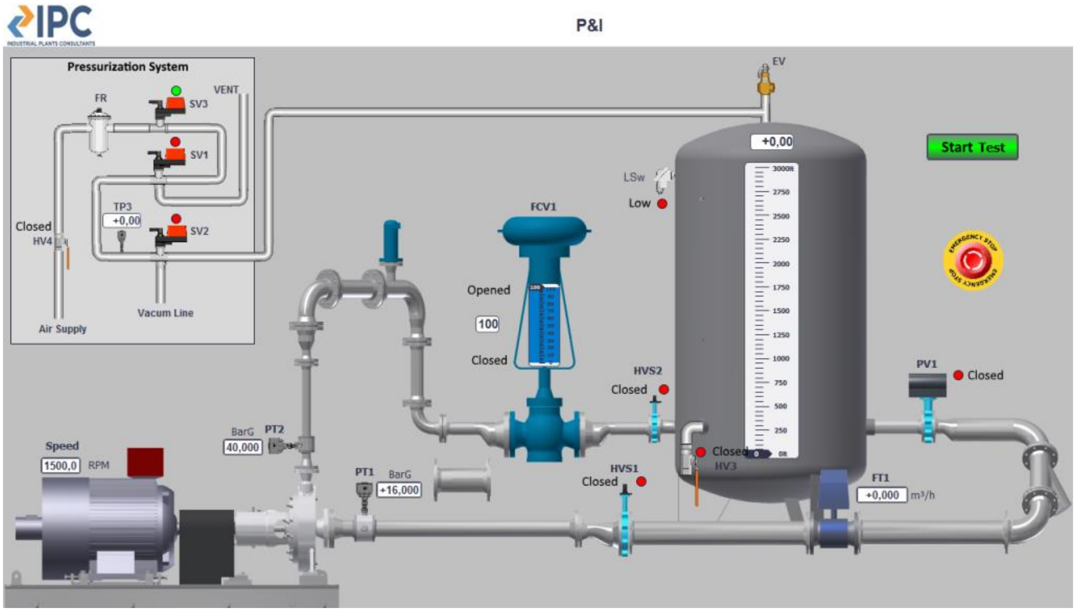
NPSHR Test and Definitions

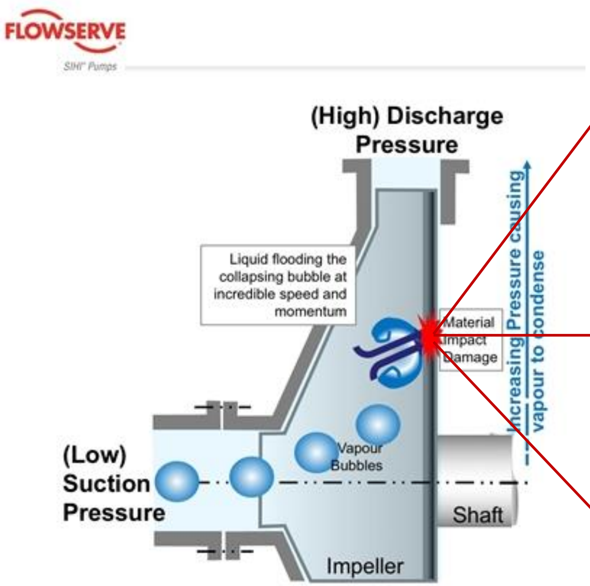


Used from http://www.ipc-eng.com/centrifugal-pump-test-bench/
For reference purpose

- Cold, deaerated water is used
- Set pump speed and flowrate
- Change pressure in test vessel so that pump cavitates
- Note pressure in pump suction pressure transmitter to estimate NPSHA <u>at which pump cavitates</u> → NPSHR

How Do You Identify Cavitation?

- Cavitation is bubble collapse and subsequent damage to impeller



Visual confirmation of bubble collapse → $NPSH_i$

Presence of small amount of bubbles can be tolerated

Impeller life affected → $NPSH_{40000hrs}$

Noticeable pump Q-H curve performance degradation → $NPSH_{3\%}$

For reference purpose from: https://insights.globalspec.com/article/12400/minimizing-pump-cavitation-what-is-the-ideal-nsph-margin

Pump NPSHR Curve

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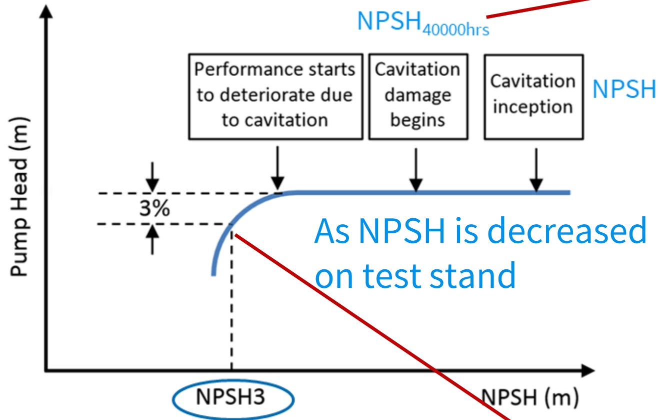
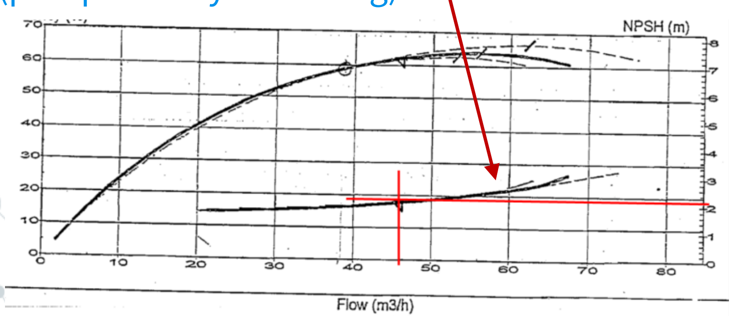


Used for special applications like:

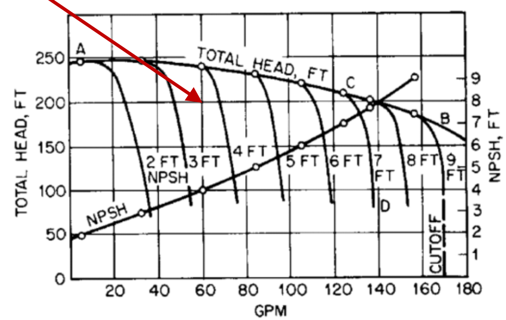
- BFW pump
- Water injection pumps
- High speed pumps
- High suction energy pumps

Needs to be specified in datasheet

Default NPSHR on vendor pump curve is NPSH3 (pump already cavitating)



Retest for various flowrates to construct Q-H-NPSHR curve



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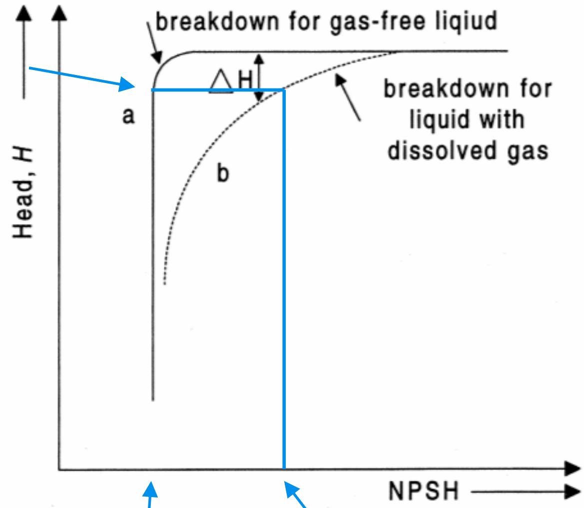
Dissolved Gases NPSHR Effect

Dissolved gas comes out of solution as pressure drops

- Dissolved gas bubbles provide nuclei for vapor bubble generation
- Gas occupies more space, liquid velocity increases, pressure further decreases

3% head loss



NPSH3 for gas-free liquids

NPSH3 for liquids with dissolved gases

NPSHR in test stand is determined with Deaerated water

Need to account for presence of Dissolved Gases

For reference from:
Wood, D., et al, “Application Guidelines for Pumping Liquids That Have a Large Dissolved Gas Content”, 15th Texas A&M Pump Symposium, 1998

Dissolved Gas Situations

- Dissolved and Entrained Gases are treated at par (BWROG-TP-12-019 REV 0, NRC report)
- Entrainment is avoided by adequate submergence in suction vessel

For submergence above bottom outlet

$$h = 0.892\left(\frac{Q_L^2}{g \times d}\right)^{0.25}$$

Where Q_L is liquid flow in m^3/s
d is pipe outlet diameter in m
h is submergence in m

Fluid systems with dissolved gas:

- Amine / Other acid gas removal solvents
- Glycol
- Boiler Feed Water
- Chilled Water
- Water Injection Pumps
- Lube Oil System
- Naphtha / Kerosene Tank Pumps
- Gas blanketed systems (fuel gas more difficult)

Fluid systems with entrained gas:

- Cooling Water
- Pumps with Suction in Vacuum
- Lube Oil System
- Refinery main fractionator bottom / draw-off pumps

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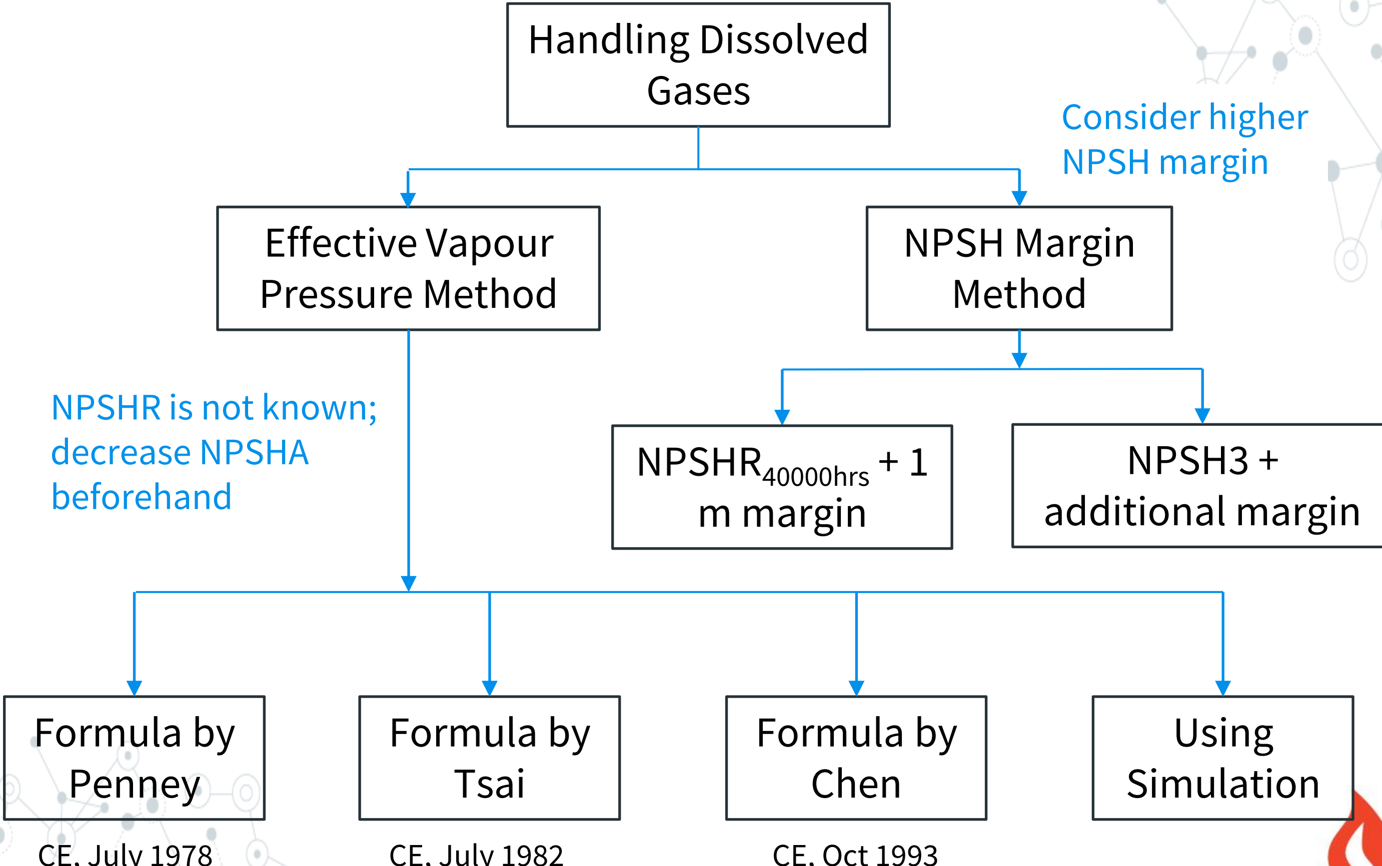
Handling Dissolved Gases to Avoid Cavitation



Effective Vapour Pressure Methods

- Penney to Tsai to Chen is algorithmizing of similar approach when Simulation tools were not available
- Methodology
  - From Pump studies, it is well known that effect of Entrained + dissolved gas can be tolerated upto 2-3 vol%
  - For a dissolved gas saturated liquid, flash calculation is performed till flash gas is 2-3 vol%
  - Pressure at which flash gas is 2-3 vol% is designated as effective vapour pressure
  - NPSHA is estimated at this effective vapour pressure
  - Pump is selected to provide NPSHR to NPSHA margin as per Purchaser specification i.e. 1 m

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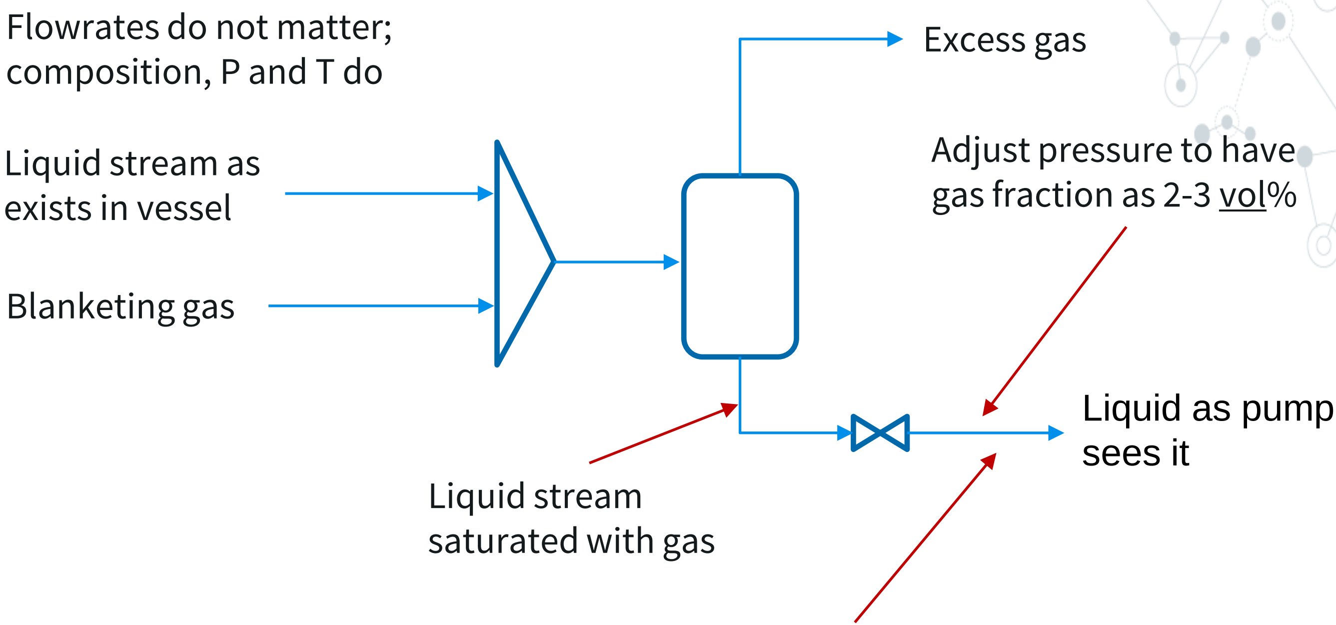
Effective Vapour Pressure – Simulation



$$NPSHA = P_{suction} + P_{static\text{-}head} - P_{friction} - P_{effective\text{-}vap\text{-}pr}$$

Ensure adequate submergence in suction to avoid entrainment

Gas solubility in liquid may need identification of component as Henry’s law component in few simulation softwares

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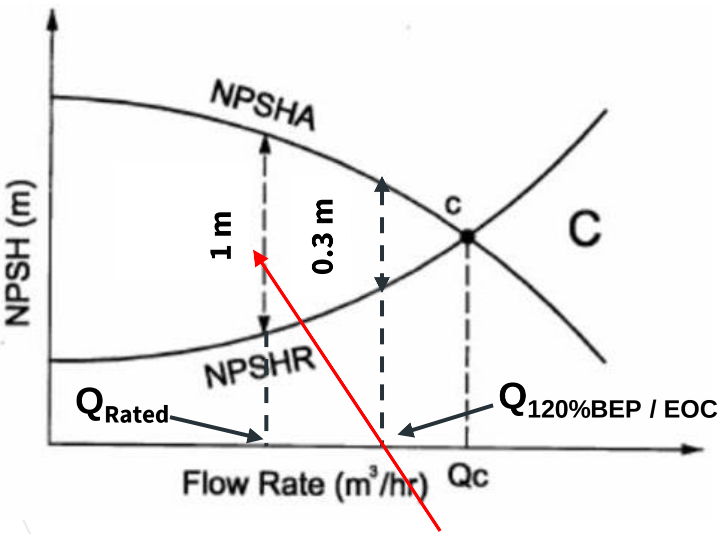
NPSH Margin and Standards

- API 610 → no specific guideline; left to Purchaser
- Typical guidelines in Purchaser's specs



This is not always adequate; depends on industry, dissolved gases, pump suction energy etc

Hydraulic Institute, ANSI/HI 9.6.1-2012 suggests NPSH margin

Industry	NPSH Margin
Petroleum	NPSHA / NPSH3 > 1.1 OR NPSHA - NPSH3 > 1 m whichever is higher
Chemical	For Nss < 11000 US units NPSHA / NPSH3 > 1.1 OR NPSHA - NPSH3 > 0.6 m whichever is higher
Electric Power Plant - Cooling Water	NPSHA / NPSH3 > 1.1
Electric Power Plant - BFW Pumps	NPSHA / NPSH3 > 1.1 - 1.2
Wastewater System	NPSHA / NPSH3 > 1.05 - 1.2

Engineering Practice for dissolved gases:

NPSHA = NPSH3 + 5 m OR

$NPSHA = NPSH_{40000hrs} + 1$ m

Examples Make Things Clear

Parameter	Hot oil circulation pump - Nitrogen Blanket	Hot oil circulation pump - Fuel Gas Blanket	Flare (Diesel) KOD Pump - Nitrogen purge	Flare KOD (Diesel) Pump - Fuel Gas purge	Flare KOD (Naphtha) Pump - Nitrogen purge	Flare KOD (Naphtha) Pump - Fuel Gas purge	Rich Amine Pump	Sour Water Feed Pump	Amine pump - Nitrogen Blanketed	Amine pump - Fuel Gas Blanketed	BFW Pump
1. Process Parameters											
Pump Flowrate, m3/hr	770	770	110	110	110	110	180	25	40	40	750
Pump differential head, m	143.2	143.2	78	78	78	78	70	150	1150	1150	650
Fluid temperature, deg C	120	120	80	80	40	40	50	74	40	40	130
Liquid density, kg/m3	900	900	750	750	650	650	1037	975	1027	1027	930
Suction Vessel Pressure, bara	3.120	3.120	1.20	1.20	1.20	1.20	1.45	2.17	2.18	2.18	2.70
Static head from liquid level to pump C/L, m	10	10	5	5	5	5	5	5	5	5	10
Frictional loss - suction, bar	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pump suction pressure, bara	3.90	3.90	1.47	1.47	1.42	1.42	1.86	2.55	2.58	2.58	3.51
2. NPSHR3, m											
Vendor data, m	6.3	6.3	1.9	1.9	1.9	1.9	6.9	4.1			
3. Estimating NPSHA - Conventional Method (Least Conservative Method)											
Liquid vapour pressure, bara	0.008	0.008	8.83E-06	8.83E-06	0.37	0.37	0.20	0.15	0.07	0.07	2.70
NPSHA, m	44.1	44.1	20.0	20.0	16.5	16.5	16.4	25.1	25.0	25.0	8.9
NPSH Margin, m	37.8	37.8	18.1	18.1	14.6	14.6	9.5	21.0			
4. Estimating NPSHA - Assuming Saturated Liquid (Most Conservative Method)											
Liquid vapour pressure, bara	3.120	3.120	1.200	1.200	1.200	1.200	1.450	2.170	2.180	2.180	2.70
NPSHA, m	8.9	8.9	3.6	3.6	3.4	3.4	4.0	4.0	4.0	4.0	8.9
NPSH Margin, m	2.6	2.6	1.7	1.7	1.5	1.5	-2.9	-0.1			
5. Estimating NPSHA - Effective Vapour Pressure Method											
Effective Vapour pressure, bara	2.7	2.95	1.05	1.13	1.14	1.18	0.20	2.09	0.78	1.23	2.70
NPSHA, m	13.6	10.8	5.7	4.7	4.4	3.7	16.3	4.8	17.9	13.4	8.9
NPSH Margin, m	7.3	4.5	3.8	2.8	2.5	1.8	9.4	0.7			

- Neglecting dissolved gas is incorrect; considering liquid as saturated is overly conservative
- NSPHA estimation considering effective vapour pressure is the way to go
- Nitrogen blanketing gives lower effective vapour pressure than fuel gas

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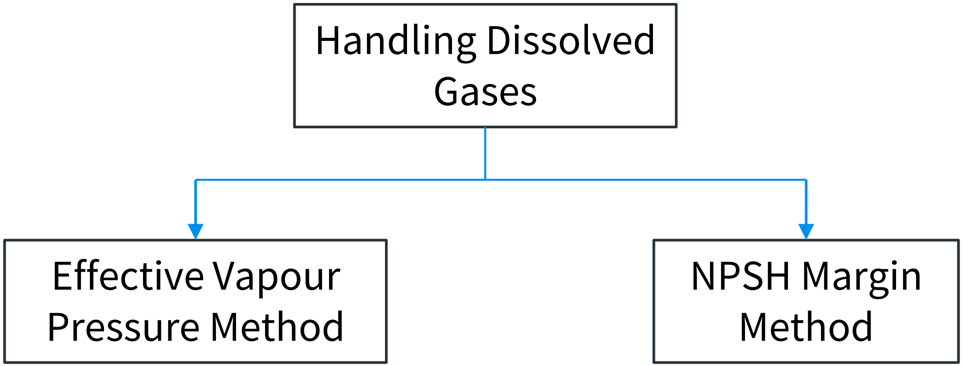
Handling Dissolved Gases: Evaluation



- Penney used for Cooling Water Pump
- Supported by Wood for Nitrogen blanketed liquid refrigerant Pump
- Budris (US NRC report) feels this method is overly conservative
- Suggestion is to use this method for situations like blanketed vessels, amine systems, Naphtha / Kerosene tank pumps
- 1 m margin between effective vapour pressure based NPSHA and NPSH3

- BFW / Water injection pumps are deaerated to very low dissolved gas level; still damage is known to occur
- Oxygen without minerals is aggressive; use this method for such applications
- Estimate NPSHA based on liquid vapour pressure
- Use 5 m margin between NPSHA/ NPSH3 or 1 m margin between NPSHA / $NPSH_{40000hrs}$