51ST TURBOMACHINERY & 38TH PUMP SYMPOSIA

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PREDICTIVE MERIT OF COMPUTATIONAL FLUID DYNAMICS IN DETERMINING MARGINAL NPSH OF HYDROCARBON CENTRIFUGAL PUMP

CPC PUMPS INTERNATIONAL

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EST. S&B 1967

Presenter/Author Bios:

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- **Jim Li,** CPC Pumps International, is the Vice President of product development with extensive hydraulic machinery experience and academic works spanning different types and application of centrifugal pumps serving petroleum industry. Holds a Master’s degree in Mechanical Engineering from University of Missouri Colombia.
- **Mike Meraji,** S&B Engineers & Constructors, pumps and compressors engineer specialized in the machinery specification and selection, rotodynamic, machinery vibration, failure analysis and troubleshooting. Holds a Bachelor of Science in Mechanical Engineering and Marine Engineering from University of Houston and Texas A&M University, Master of Science in Mechanical Engineering and Master of Business Administration.

CASE STUDY SUMMARY:

- At inlet, sufficient pressure and NPSH margin is crucial for centrifugal pump operation. In cold and light hydrocarbon services; such as Liquefied Natural Gas, vapor pressure variations that is dependent on the temperature rise can significantly impact pump operation, in particular at lower specific speeds than 300.
- This study compares findings of Computational Fluid Dynamics (CFD) analysis and actual field data to draw conclusion and confirm higher NPSH margin required.
- CFD analysis as a tool, especially in early design phase, can benefit operational efficacy, improve design turnaround, and minimize rework or replacements.

PUMP APPLICATION:

Pump Design Parameters

Max Impeller Diameter: 18.75”

Nozzle Sizes: 3”x 4”

Design condition: 90 [GPM] at 1,320 [ft]

Design Efficiency: 16%

Running Speed: 3,560 [RPM]

Specific Speed: 155

Suction Specific Speed: 8,800

PUMP APPLICATION:

LIQUID CHARACTERISTICS				
	Units	Maximum	Minimum	**Note**
LIQUID TYPE OR NAME :	**Propylene**			Max & min values refer
VAPOR PRESSURE :	PSIA	**16.2**		only to the property
RELATIVE DENSITY :	S.G.	**0.61**		listed
SPECIFIC HEAT :	Btu/(lbm-°F)	**0.55**		
VISCOSITY :	cP	**0.16**		

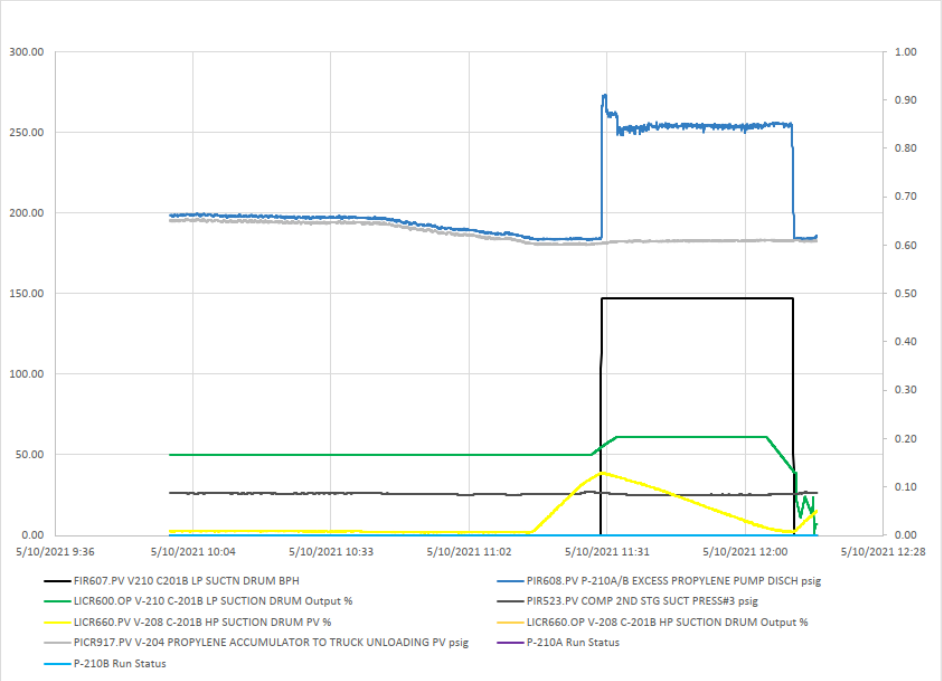
OPERATING CONDITIONS (6.1.2) **(Note 2 & 3)**						
	Units	Maximum	Rated	Normal		
NPSHa Datum:		C.L. Impeller				
PUMPING TEMPERATURE (**) :	°F		**-49**			
FLOW :	GPM		**75**	**75**		
DISCHARGE PRESSURE : (6.3.2)	PSIG		**267**			
SUCTION PRESSURE :	PSIG	**355**	**2**			**(Note 1)**
DIFFERENTIAL PRESSURE :	PSI		**264**			
DIFFERENTIAL HEAD :	FT		**1008**			
$NPSH_A$:	FT		**8.3**			
HYDRAULIC POWER :	HP		**12**			

FIELD OBSERVATIONS:

- Pumps did not Perform When Lined up with the Low-Pressure KO Vessels.
- Could not establish Flow.
- No sign of Vibration.
- No sign of Cavitation.
- Could not Develop the Required Head, and it Appeared Pumps are Vapor Locked on Startup.

FIELD OBSERVATIONS:

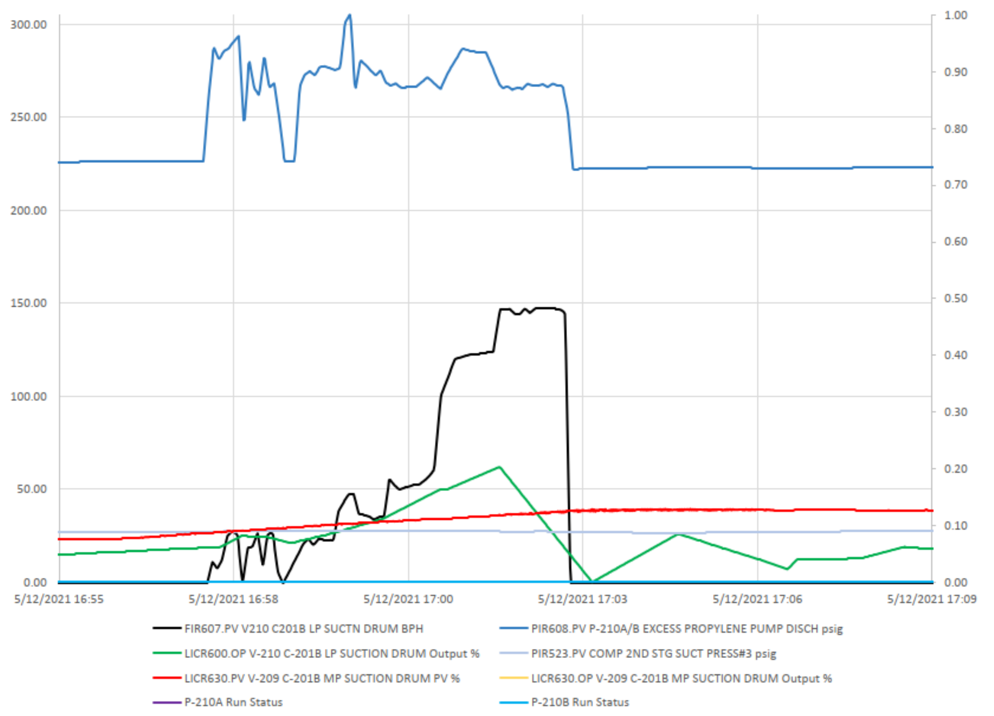
- Pumps Performed well when Lined up with HP KO Drum!
- When connected to HP KO Drum at 75 PSIG:
  - Yellow line is suction level in the drum.
  - **Black** line is discharge flow @ max 150 BBL/HR
  - Blue line is discharge pressure @ 250 PSIG



DCS Data Lined up to **High** Pressure KO Drum

FIELD OBSERVATIONS:

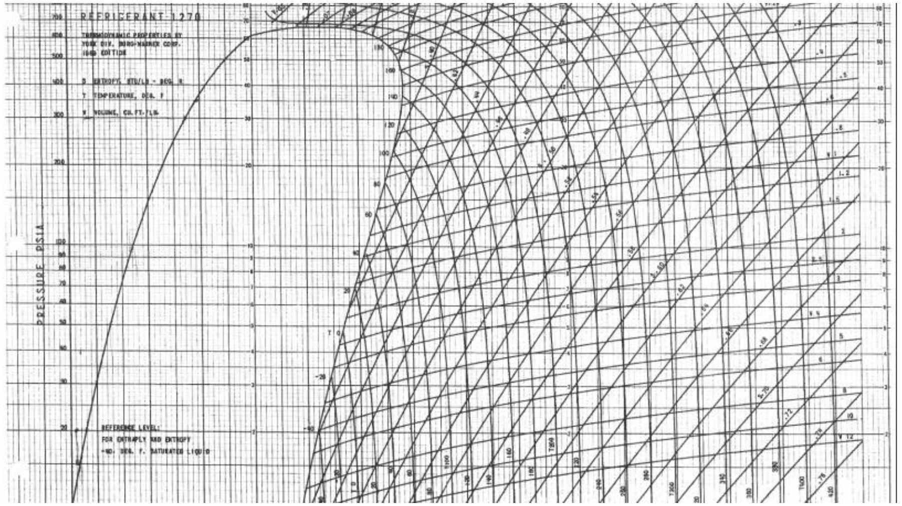
- Flow fluctuations signifies the pump struggles to establish flow at lower suction pressure.
- When connected to Medium KO Drum at 35 PSIG:
  - Red line is suction level in the drum.
  - Black line is discharge flow @ max 150 BBL/HR
  - Blue line is discharge pressure @ 275 PSIG.



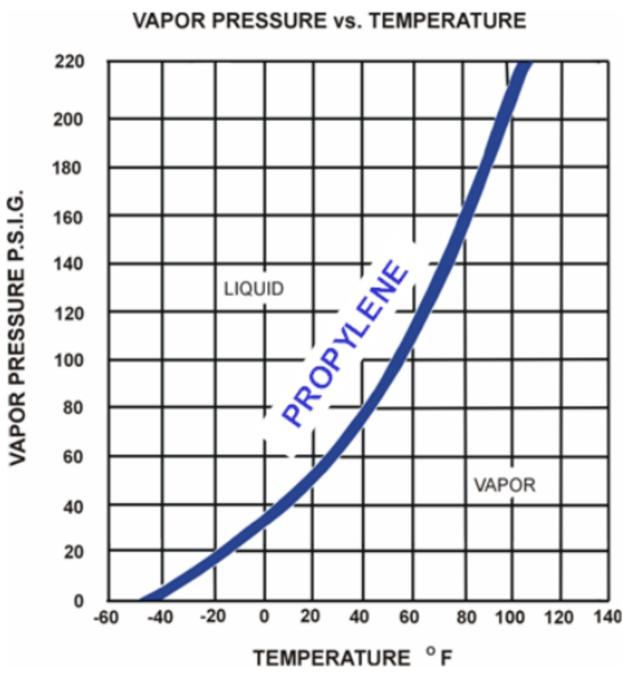
DCS Data Lined up to **Medium** Pressure KO Drum

INITIAL INVISTEGATIONS:

- Client Stated that pumps can operate properly when suction pressure is ≈ 20 PSIG!
- Reviewed Propylene Pressure Enthalpy Chart.
- Suction Drum assumed at Bubble Point; Static Head keeps in liquid state.
- Specific Heat = 0.55 $[BTU/(lb{-}°F)]$, Latent Heat = 190 $[BTU/lb]$
- Liquid @ 1.5 PSIG is -49° [F] Bubble Point



INITIAL INVISTEGATIONS:



- Static Pressure = (8.3 X .61)/2.31 = 2.19 [PSI]
- ΔP = 2.19 + 1.5 = 3.69 [PSI]
- New Bubble Point = 43.9° [F]
- ΔT = 49 – 43.9 = 5.0° [F]
- The System is in extremely tight Equilibrium.
- Introduction of > 10° [F] ΔT increase could set the equilibrium off balance and accelerate the vapor generation.
- Incipient Suction Recirculation could be generated with low ΔNPSH Margin?

HI 9.6.1 GUIDELINE FOR NPSH MARGINS:

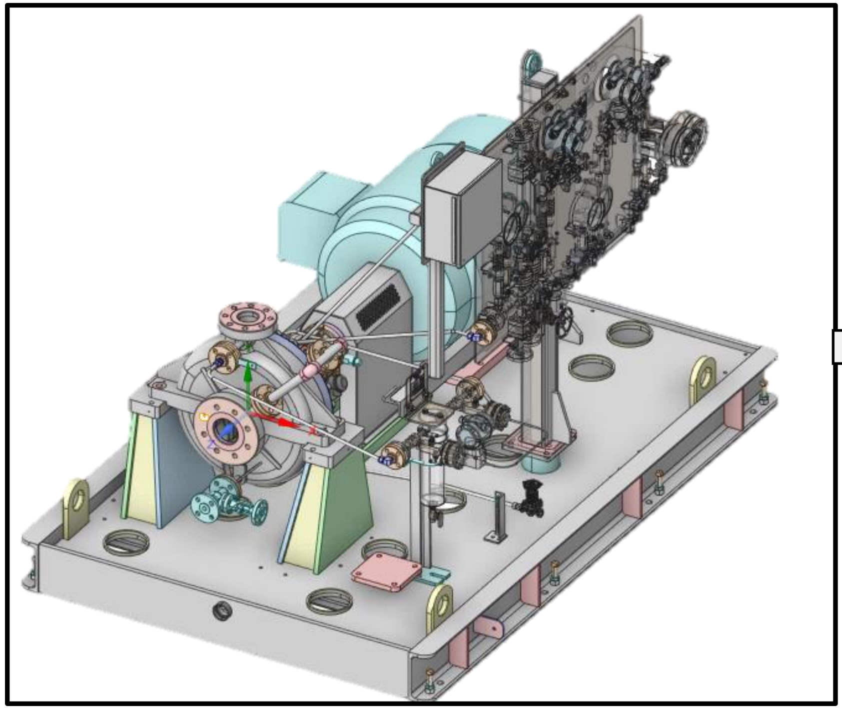
- Petroleum / Hydrocarbon Process Industry
  - HI recommends 3.3’ of NPSH Margin.
  - The selected pump 3.5’ of NPSH Margin.
  - The margin in compliance with the recommended HI values.
  - The Rated and EOC NPSH margins approved as acceptable for this service.

HI 9.6.1 GUIDELINE FOR NPSH MARGINS:

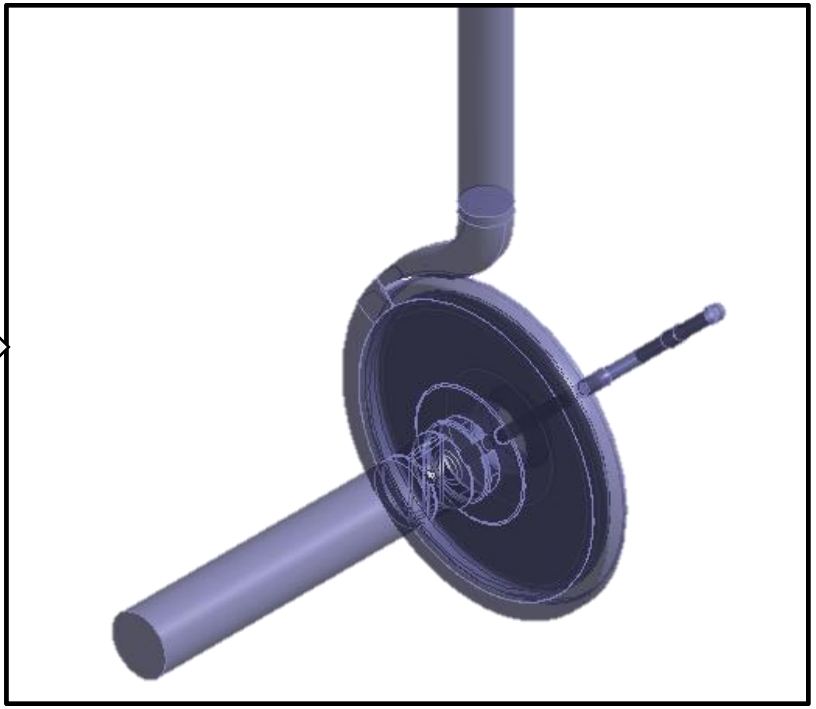
Industry	Application	NPSH Margin for the AOR; select the greater value
Petroleum / hydrocarbon process	Typical, except vertical canned pumps	1.1 ratio or 1.0 m (3.3 ft)
Chemical process	Typical	1.1 to 1.2 ratio or 0.6 m (2.0 ft) to 1.0 m (3.3 ft)
Electric power generation	Circulating / cooling water	1.0 m (3.3 ft)
Electric power generation	Boiler feed < 250 kW/stage	1.3 ratio
Water	Typical, stainless steel or aluminum-bronze impeller, < 75 kW/stage	1.1 ratio or 1.5 m (4.9 ft) minimum
Building services	Typical for pumps in open systems (not pressurized)	1.0 ratio up to a 1.1 ratio or 0.6 m (2.0 ft)
General	Often a standard catalog pump	1.1 ratio or 1.0 m (3.3 ft)

Table A. Selected NPSH Margins from ANSI/HI 9.6.1-2012 Guideline for NPSH Margin

CFD ANALYSIS:



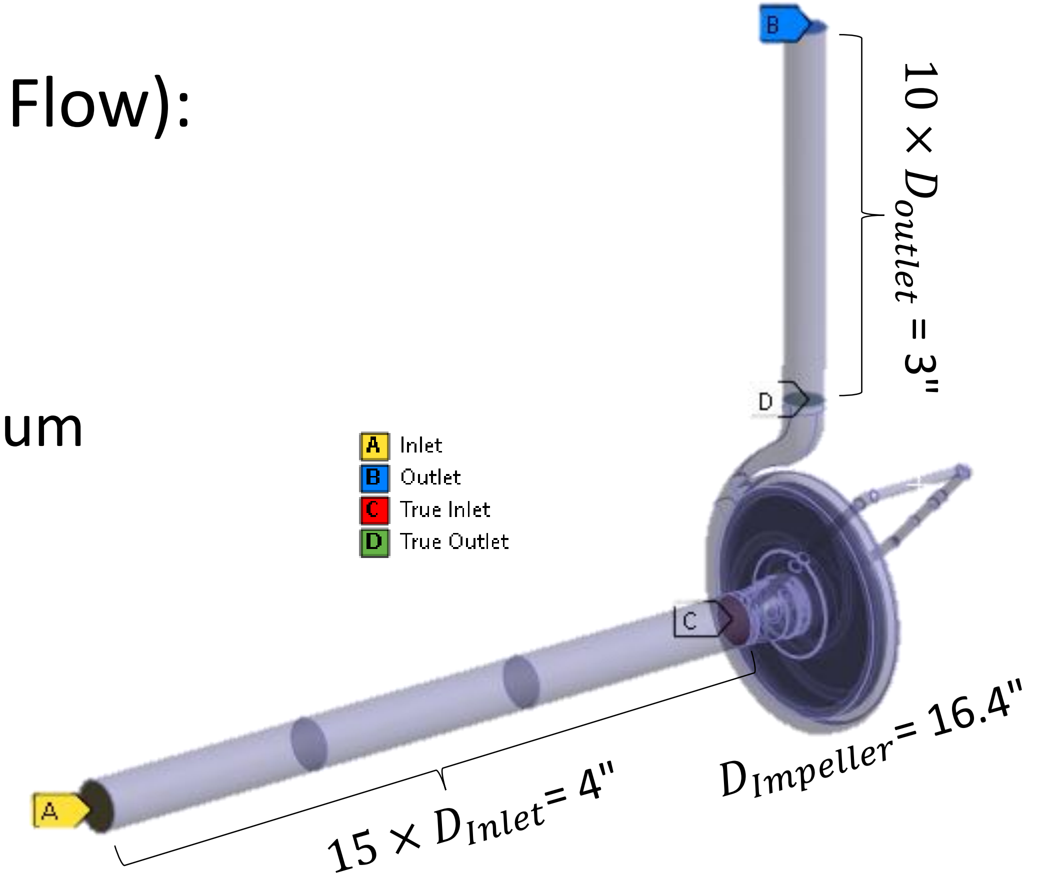
Physical Domain-OH2



Computational Fluid Dynamics Domain

MATHEMATICAL MODELING:

- Equations (Homogeneous Multi-Phase Flow):
  - Continuity - Rayleigh-Plesset Cavitation
  - Momentum – Turbulent, Buoyant, and No-Interfacial Momentum Transfer
  - Total Energy – Phases in Thermal Equilibrium
- Inlet (Flow to Enter and Exit):
  - Temperature : -45 [°C] / -49 [°F]
  - Total Pressure : 353 [KPa] / 51.2 [PSI]
- Outlet:
  - Bulk Mass Flow Rate : Density X 75 [GPM]



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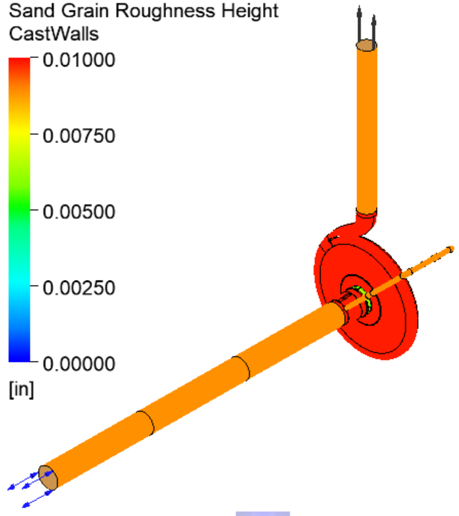
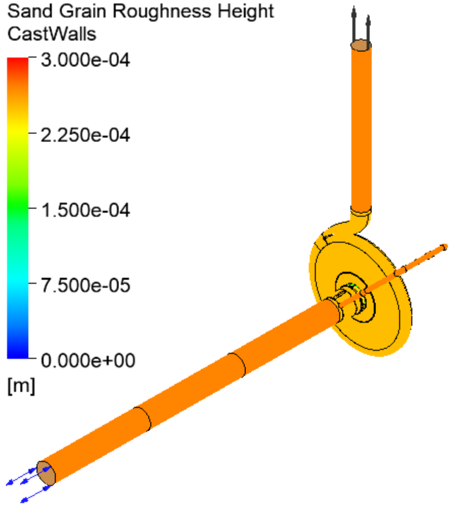
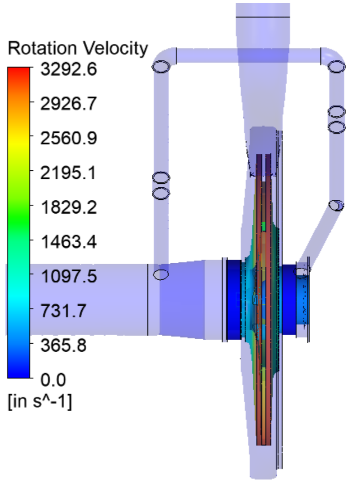
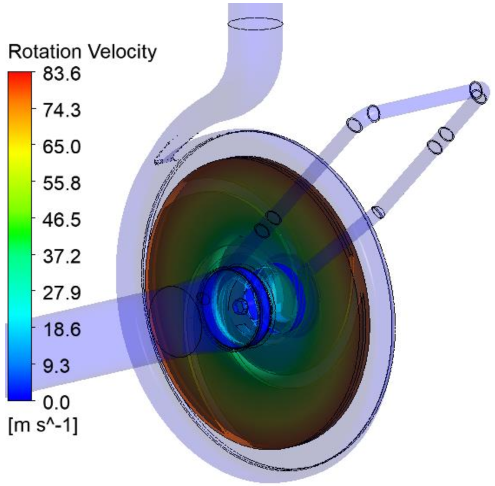
MATHEMATICAL MODELING:

- Wetted Surfaces:
  - Adiabatic
  - No-Slip
  - Roughness
    - Cast 250 E-6 [m] / 0.0098 [in]
    - Piping 45 E-6 [m] / 0.0018 [in]
    - Machined 3.2 E-6 [m] / 0.00013 [in]
- Rotating Surfaces:
  - Impeller – RRF (Rotating Reference Frame)
  - Wear Rings – Wall Velocity (Radii X N)
  - Shaft Rotating Speed, N = 3560 [RPM]



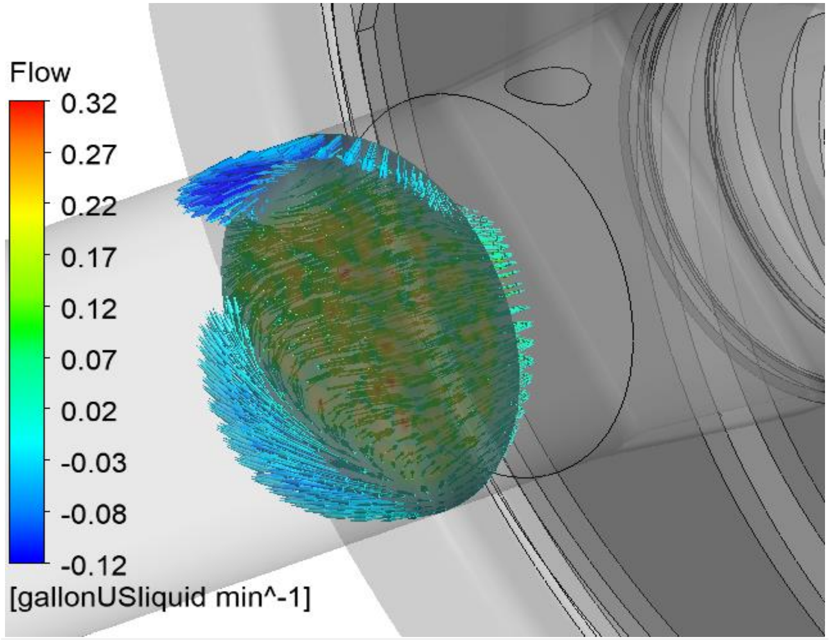




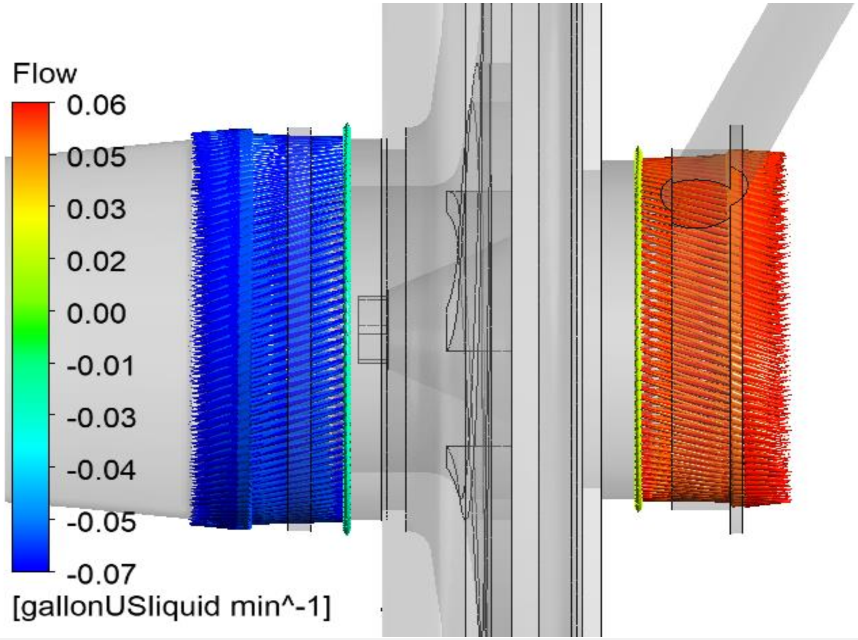


RECIRCULATION AND TEMPERATURE IMPACT:

- Liquid Flow Through Wear Ring Clearances



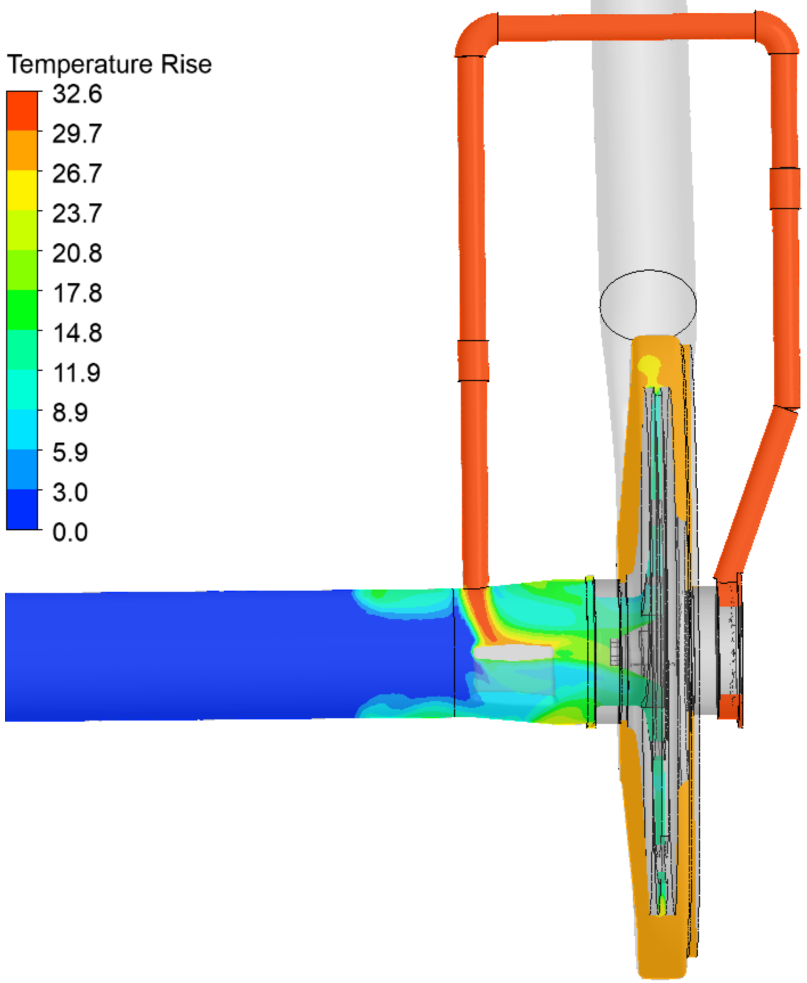
Intake 75 [GPM] @ -49 [°F]

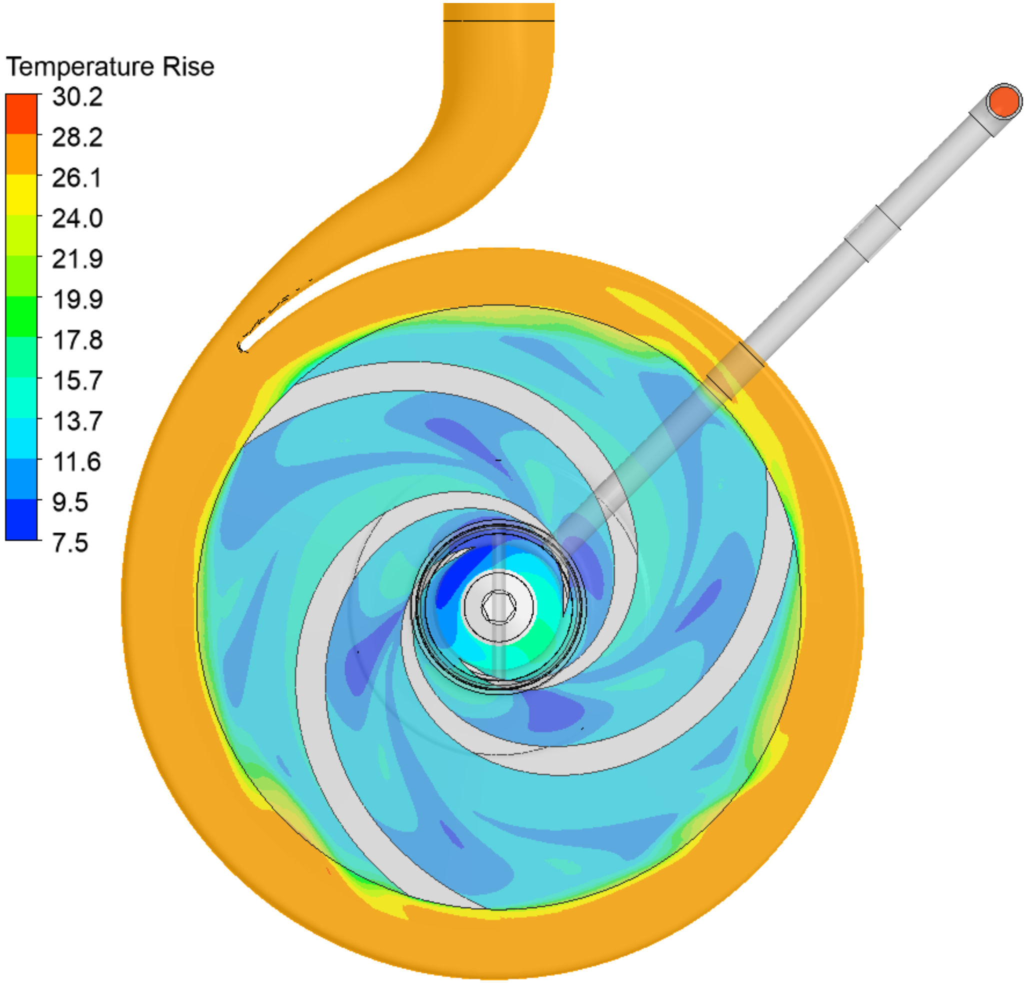


Front Wear Ring 35.4 [GPM] @ -19.7 [°F]
Back Wear Ring 27.7 [GPM] @ -19.8 [°F]

TEMPERATURE RISE:

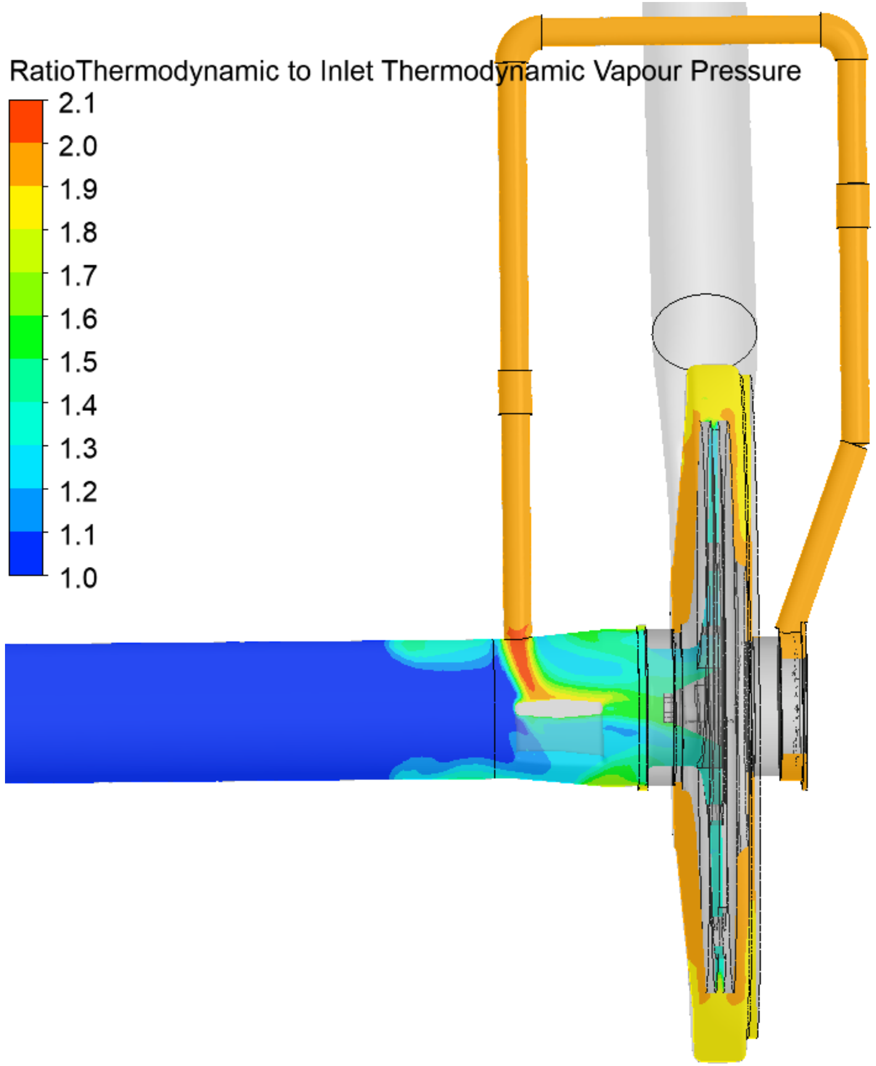
$(T - T_{Inlet})\ [°F]$





LOCAL TO INLET VAPOR PRESSURE RATIO:

$P_{Sat-Thermodynamic}/P_v(-49[°F])$



CAVITATION:

$$NPSH_A = \frac{P_{Inlet-Total-Absolut} - P_v}{\rho g}$$

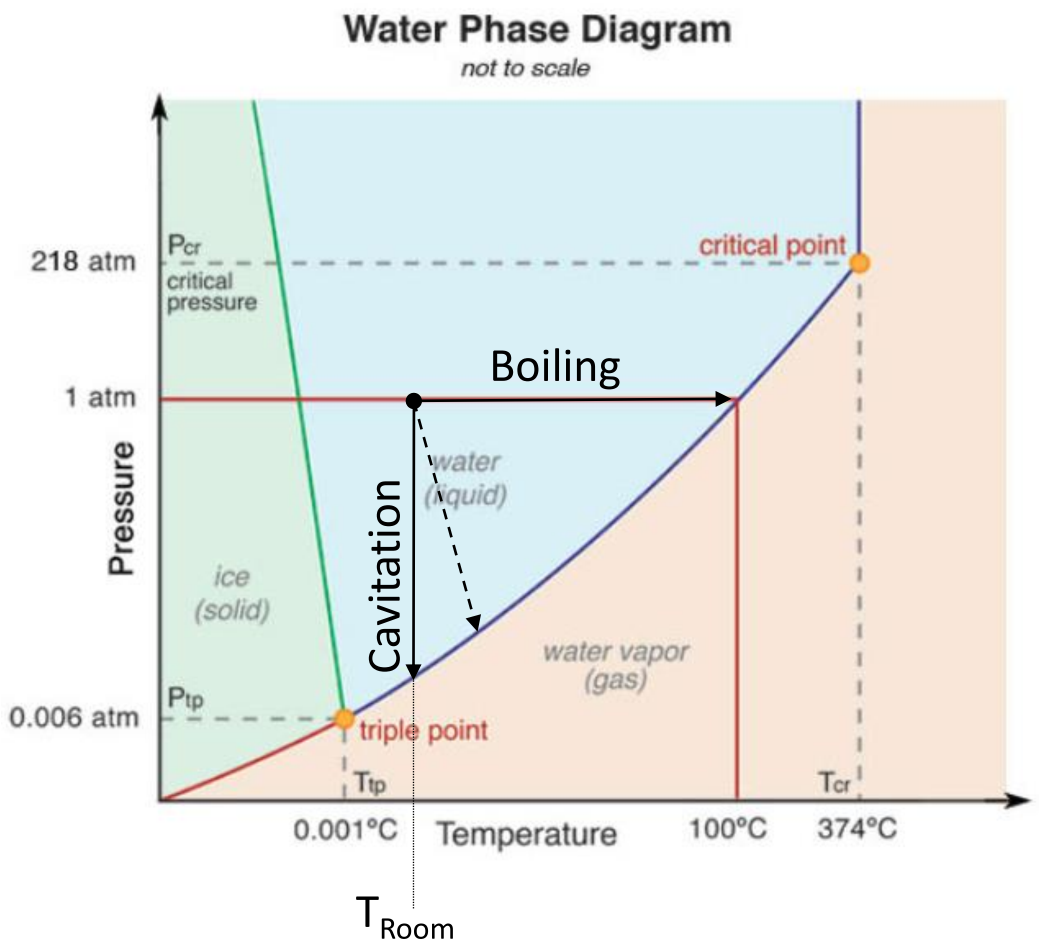
$$NPSH_3 = \boxed{\frac{P_{Inlet-Minimum-Absolut}}{\rho g} + \frac{V_{Inlet}^2}{2g}} - \frac{P_v}{\rho g}$$

$$H_{Inlet} = \frac{P_{Inlet-Minimum-Absolut}}{\rho g} + \frac{V_{Inlet}^2}{2g} + H_{Loss} + Margin$$

$$H_{Inlet} = \underbrace{\boxed{NPSH_3 + \frac{P_v}{\rho g}}}_{\text{Component Requirement}} + \underbrace{H_{Loss} + Margin}_{\text{System Requirement}}$$

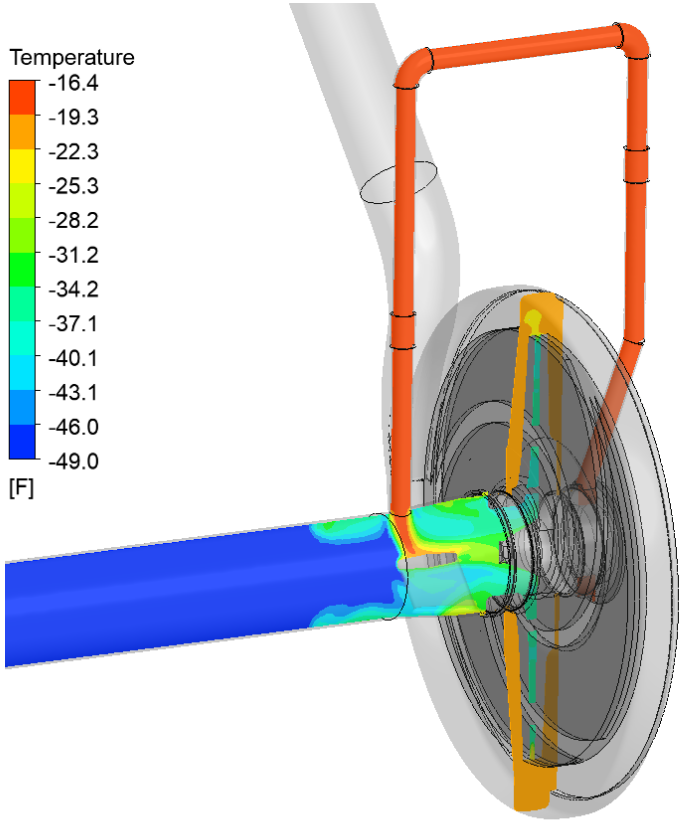
Component Requirement
e.g. Pump Selection and Pumping Liquid

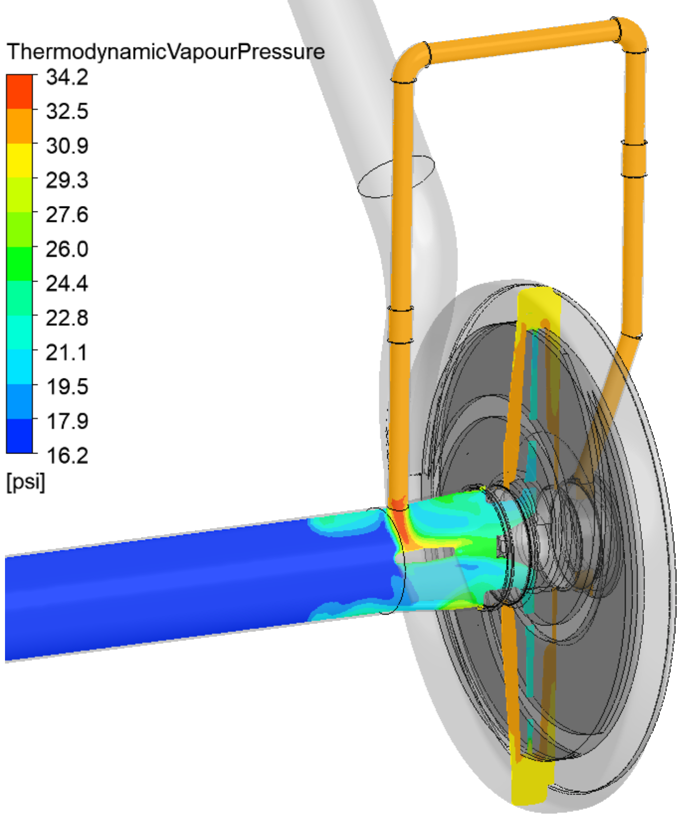
System Requirement
e.g. Rust, Pressure Fluctuations, Change in Pump Upstream

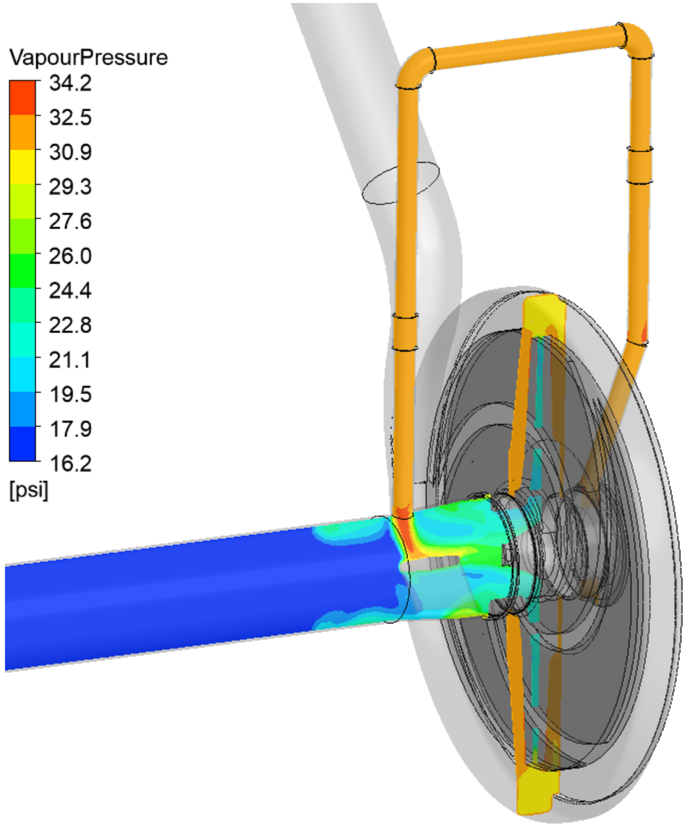


LOCAL LIQUID TURBULENT VAPOR PRESSURE:

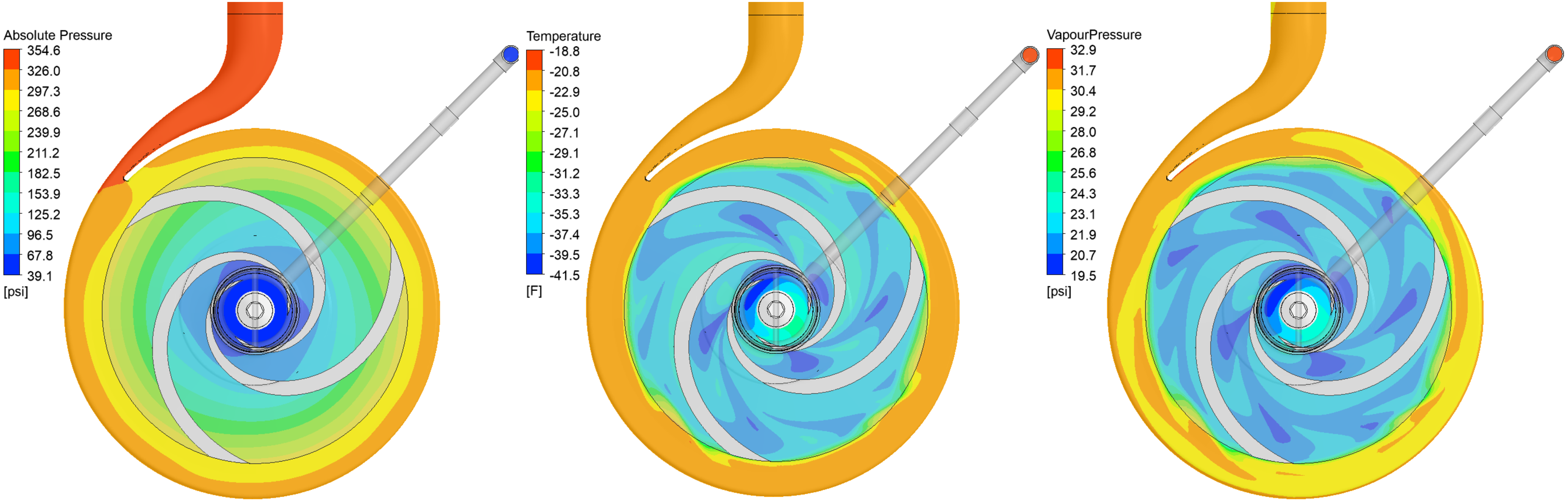
$$P = P_{Sat-Thermodynamic} + P_{Turbulance} = P_v(T) + \frac{2}{3}\rho k$$







VAPOR PRESSURE AT TEMPERATURE:



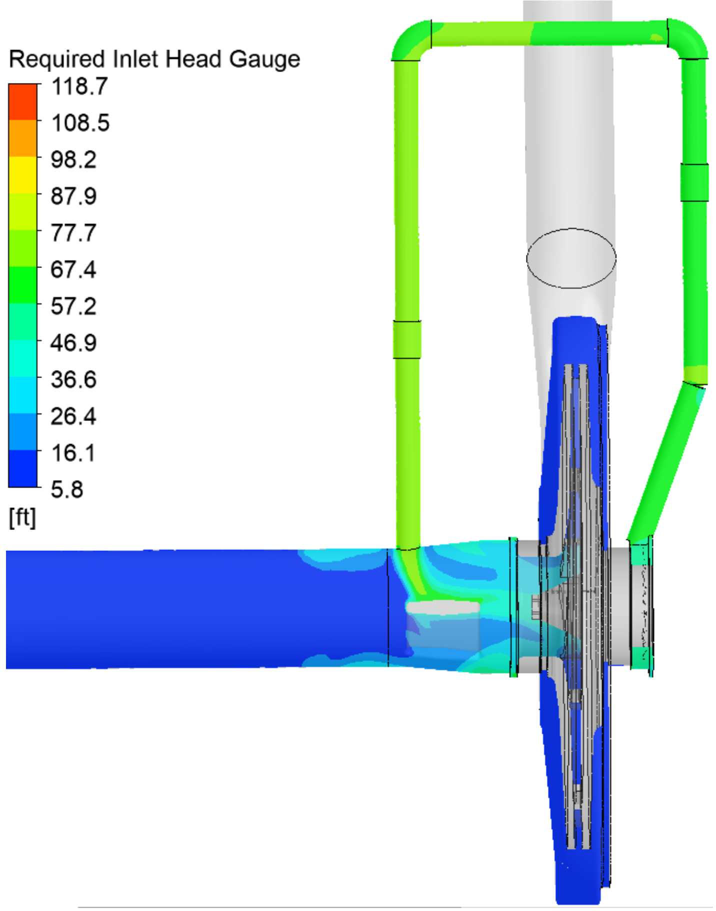
PREDICTING MARGINAL INLET PRESSURE:

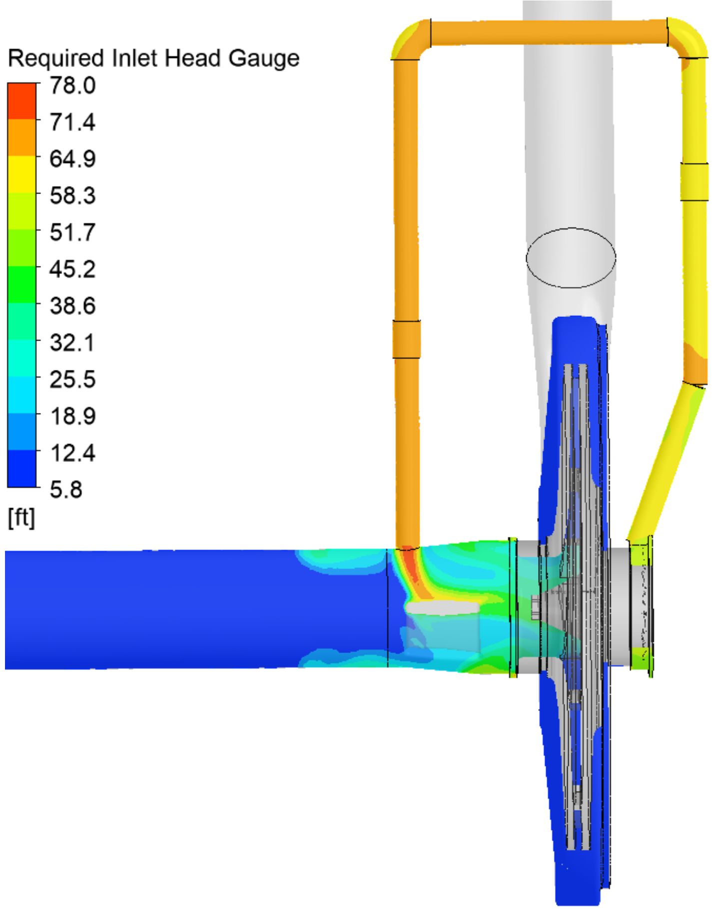
$Predicted\ Marginal\ Inlet\ Pressure =$

$[Pressure - Vapor\ Pressure] \geq 0 \quad \rightarrow \quad Maximum\ \{P_v(T_{inlet}) \quad and \quad P_{Total-Inlet} - (Local\ Pressure - Vapor\ Pressure)\}$

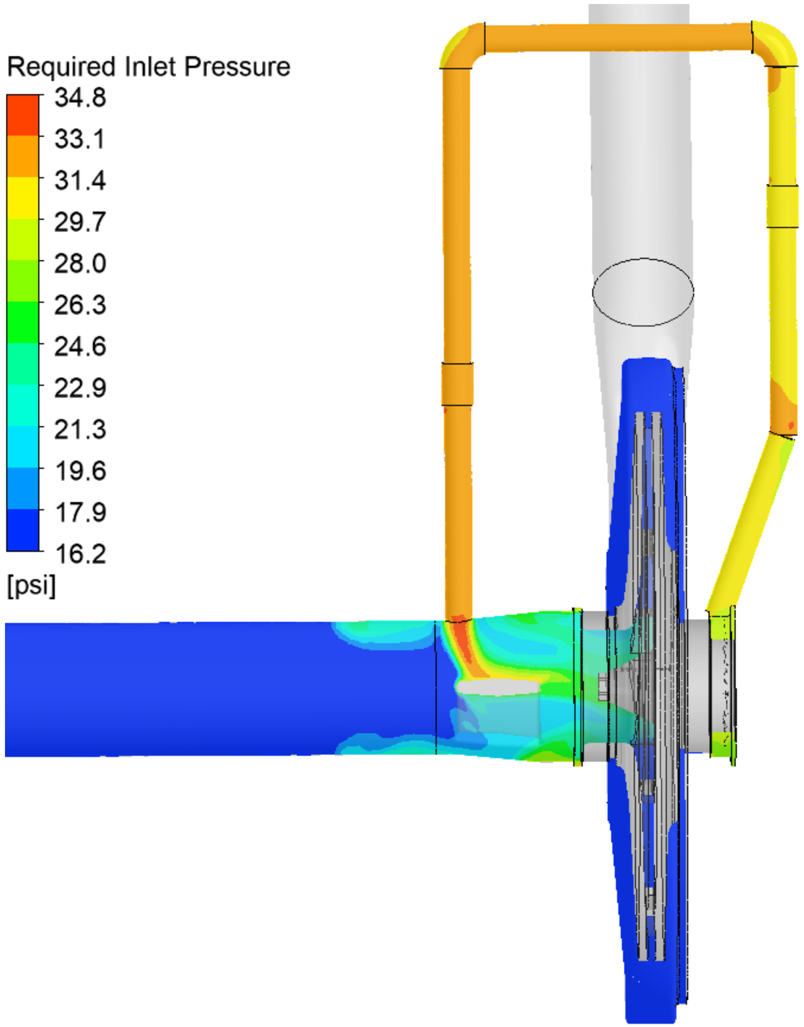
$[Pressure - Vapor\ Pressure] < 0 \quad \rightarrow \quad P_v(T_{inlet})$

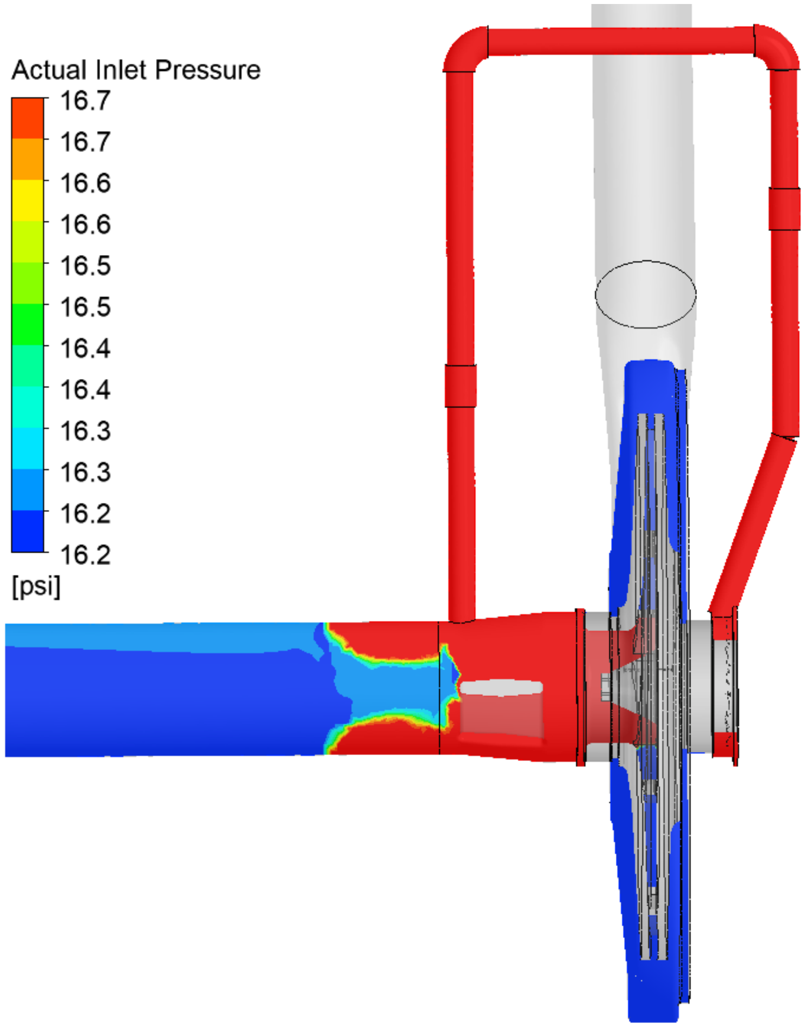
By This Analysis The Engineer Would Be Able To Establish Safe Inlet Pressure Margin



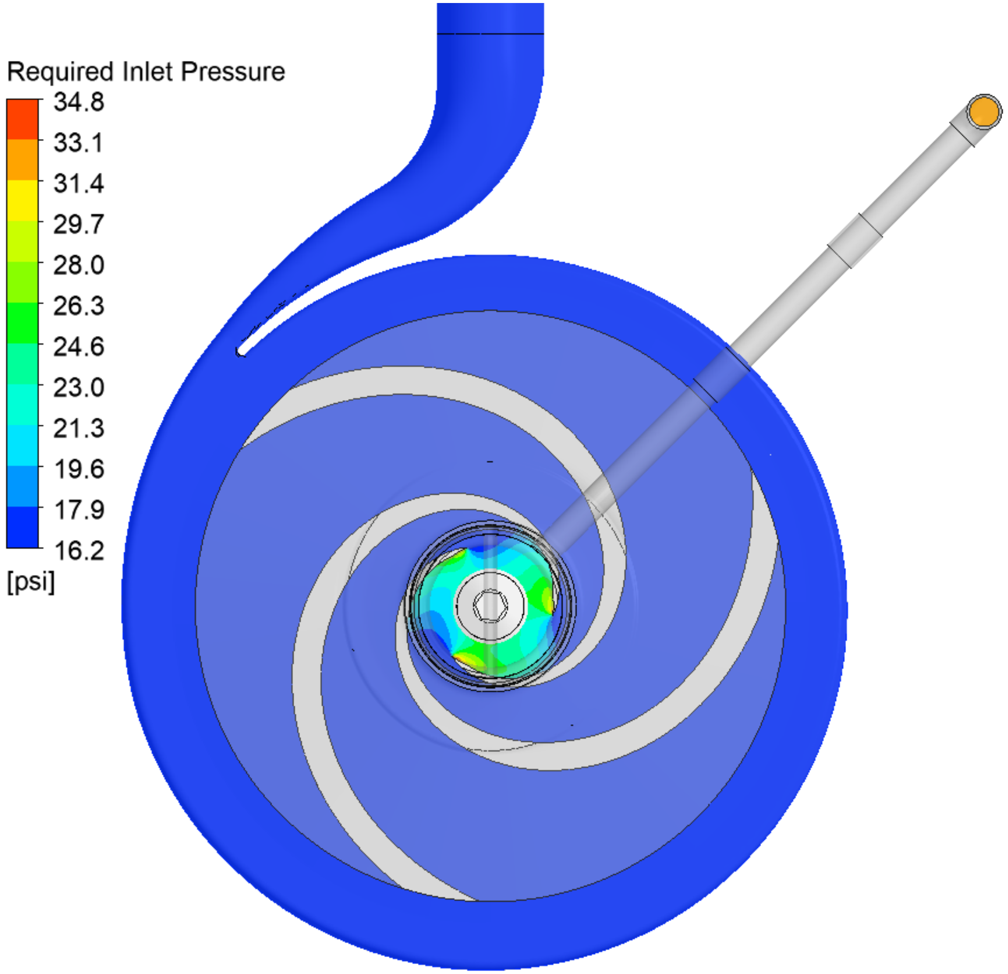


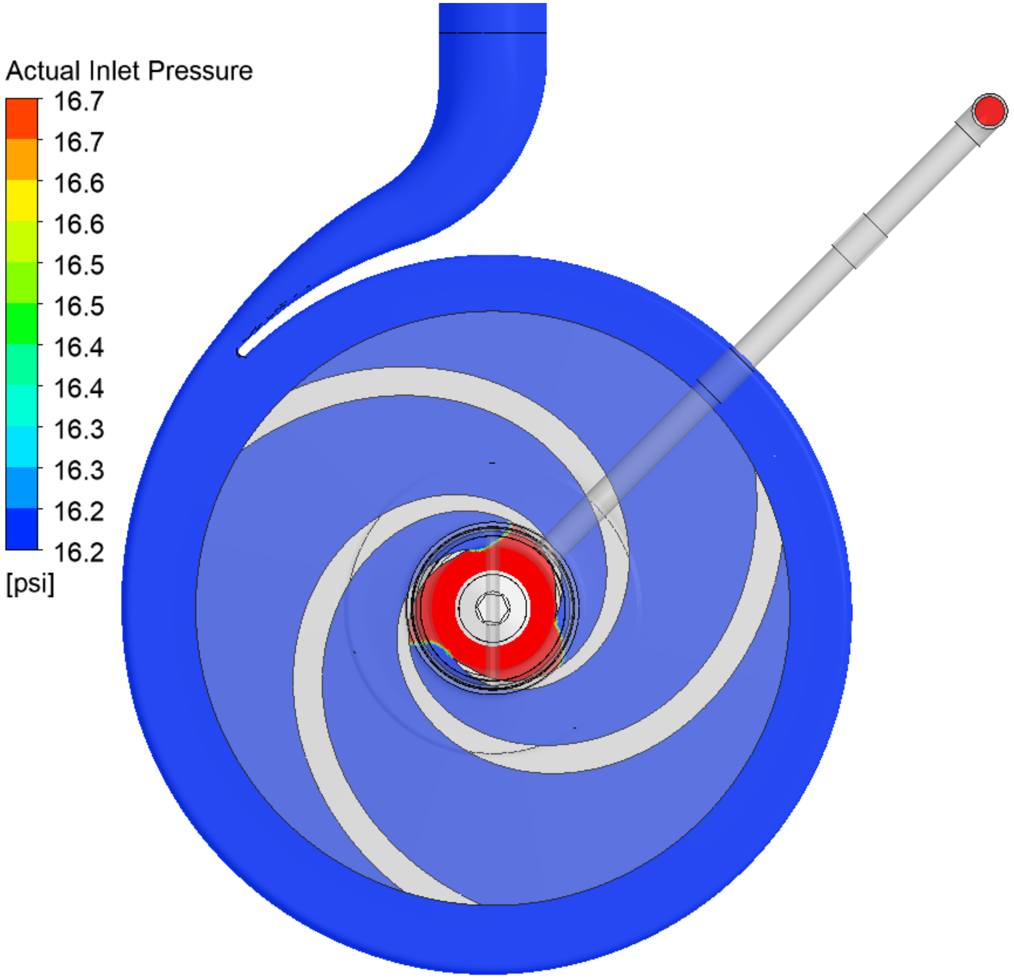
INLET PRESSURE SIMULATION:





IMPELLER EYE PRESSURE SIMULATION:





ANALYSIS SUMMARY:

- CFD study shows that the temperature inside the pump varies from inlet to outlet. The recirculated liquid through the wear ring clearances can increase the temperature in the suction area, and the liquid vapor pressure significantly reduces NPSH margin.
- The pump had sufficient NPSH margin per Hydraulic Institute NPSH margin criteria to operate satisfactorily at 16.7 [PSIA] suction pressure. However, field information revealed the pump could operate without cavitation only when suction pressure was increased to ≈34.7 [PSIA]. CFD simulation projected 34.8 [PSIA] is required to operate cavitation free. CFD results supports the actual field operation data.
- Temperature variations throughout the pump for hydrocarbon liquids can play an important role in a pump's normal operation. To Rely solely on pumps hydrodynamics analysis for light hydrocarbon liquids may underpredict NPSH requirements.

CONCLUDING REMARKS:

- The temperature rise in centrifugal pumps shall be considered for low specific speed and light hydrocarbon services.
- Hydraulic Institute established NPSH margins based on pumped liquid may require to be amended for the API 610 pumps.
- Further study of temperature rise impact on pump performance under similar or various conditions would be beneficial.
- It is highly recommended for the pump manufacturers to plot temperature rise curve mapped on the performance curves for low specific speed pumps.
- Pump thermohydraulics CFD analysis to be perform along hydrodynamics CFD analysis for low efficiency pumps.

THANK YOU FOR YOUR CONSIDERATION:

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