Rotor-Tech®, Inc.

Results of NPHR Testing, Pump Model #'s

GS1100, GS2200, GS3300, GS4400

Rotor-Tech tested the following assemblies for NPSH (NPIP) during the period of April 1- April 11 2014.

GS1110-E15.0 @ 1500 RPM and 1800 RPM, Rated for 8.0 GPM @ 1500 RPM and 9.8 GPM @ 1800 RPM

GS2208-E15.0 @ 1500 RPM and 1800 RPM, Rated for 10.4 GPM @ 1500 RPM and 12.6 GPM @ 1800 RPM

GS3314-E25.0 @ 1500 RPM and 1800 RPM, Rated for 26.5 GPM @ 1500 RPM and 32.3 GPM @ 1800 RPM

GS4410-E25.0 @ 1500 RPM and 1800 RPM, Rated for 22.9 GPM @ 1500 RPM and 26.8 GPM @ 1800 RPM

For clarity the GS1110 and GS2208 were tested with a 15 hp motor and the GS3314 and GS4410 were tested with a 25 hp motor. These hp's allowed Rotor-Tech to test each pump at a differential pressure of 1000 psig.

The test stand consisted of the above mentioned pump/motor assemblies affixed to a scissor lift with a maximum lift height of 42 ft. The pumps, during testing, were monitored for fluid temperature, differential pressure and absolute suction pressure.

The differential pressure was monitored by an OMEGA calibrated digital flow gage for the GS1100 and GS2200 and a Headland flow meter for the GS3300 and GS4400. As our pumps are rated in GPM therefore all flow data was rounded to an accuracy of 0.5 gpm (the lowest accuracy for the headland flow meter in use).

As the scissor lift was elevated, the absolute suction pressure was measured by a calibrated digital Martel BETAGUAGE-PI-PRO-030A absolute pressure gage. This data was recorded to an accuracy of 0.00 bara.

2" suction rated (to 28"Hg) hoses with quick disconnect fittings were used for both the suction and discharge lines each 40' in length.

The testing fluid used was AZOLLA ZS (Hydran ISO) 68 hydraulic oil (Product code 15062) with a viscosity of 68 cSt @ 40 degrees C. Product code 15062.

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The motors were controlled by a Toshiba 60hp variable speed drive.

Each test (per pump @ RPM) were conducted over a time period of approximately one hour.

Following are Rotor-Tech's theoretical calculated NPSH values for each size pump at both 1500 and 1800 RPM. The test was conducted to test the validity of these theoretical calculations.

NOTE: These calculations were performed without vapor pressure factored into the final values as the fluid used has a vapor pressure of 1.0.

Also following are the test results broken down by pump size and RPM.

For the purposes of evaluation, Rotor-Tech has selected the cavitation definition used by the Hydraulic Institute in lieu of API 676 as API 676's basis for 'point of cavitation' defined as 3% below the 'non-cavitating flow' seems to be an arbitrary figure when discussing positive displacement pumps as this is the generally accepted criteria for centrifugal pumps and 'non-cavitation flow' is not defined in detail.

The Hydraulic institute uses several criteria for determining the 'point of cavitation'

- Cavitation noise is heard.
- A 5% reduction in capacity at constant differential pressure and speed
- A 5% reduction in power consumption at constant differential pressure and speed.

As these still do not adequately define 'point of cavitation' Rotor-Tech has selected to use the following method.

The point of cavitation is at the point of audible cavitation noises. In addition Rotor-Tech has imposed a criteria that unacceptable performance is at either the point of audible cavitation noise or a reduction in flow below the rated capacity of 5%. These points are denoted on the following tables in red.

At the completion of each stage of testing, the pumps were disassembled and inspected for visual signs of cavitation and none of the tested pumps showed any signs of internal damage due to cavitation.

In conclusion, Rotor-Tech believes that the calculated NPSHR (NPIP) values are mostly accurate from the testing performed and the data collected when all factors are considered. Although most pumps did not show audible sounds of cavitation at the approximate calculated levels (see calculations and tables) when factoring in the 'within 5% of rated flow" criteria alongside the audible cavitation criteria all pumps with the exception of the GS1100 and the GS2200 @ 1500 RPM demonstrated that they will output the required flow, without audible cavitation, at the theoretical calculations derived. The GS1100 series pumps are the smallest frame size and both the 1500 and 1800 RPM pumps along with the GS2200 series @ 1500 RPM did not have audible sounds of cavitation right up to the calculated NPSHR values but they fell below the 5% criteria before the calculated values were reached, therefore, for purposes of design on the GS1100 and GS2200 @ 1500 RPM series pumps we suggest the use of the NPSHR values shown that meet the 5% criteria. For purposes of design on all remaining pumps we suggest the use of the calculated values backed-up by the test data.

Testing was supervised and data compiled by J. Guerrero and D. Echols.

Dave Echols

President

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NPSH at Pump Inlet
(Net Positive Suction Pressure (Head) for GS 1100 Pump at 1500 RPM)

1. Shaft Speed in radians per second
   Speed = 1500 RPM , Gear Diameter (Do)= 1.755 In.
   C1 = 2 Π Radians / Rev
   C2 = 1 / 60 min/ sec
   Speed Radians = C1 X C2 = $2\Pi \times \frac{1500}{60}$ = 157.08

   Speed Radians = 157.08 Shaft Speed (rad./sec.)

2. Gear tip velocity in feet per second
   $Vo = \frac{Do}{12/2} \times (\text{Speed Rad})$ Vo = 0.07 X 157.08 = 10.996 ft/ sec

   C3 = 1.125 ft water / ft Glycol
   C4 = 0.432781 psi / ft water g = 32.2 ft / $sec.^2$

   $\text{Fill} = \frac{(Vo)^2}{2g} = \frac{10.996^2}{64.4} = \frac{120.897}{64.4} = 1.877$ ft glycol

3. Pressure to fill gears
   Fill psi = Fill X C3 X C4 = 1.877 X 1.125 X 0.432781 = 0.914 psia

4. Net Positive Suction Pressure required (NPSHr) = 0.914 psia = 1.86" Hg = 0.06 BARa

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NPSH at Pump Inlet
(Net Positive Suction Pressure (Head) for GS 1100 Pump @ 1800 RPM)

1. Shaft Speed in radians per second
   Speed = 1800 RPM , Gear Diameter (Do)= 1.755 In.
   C1 = 2 Π Radians / Rev
   C2 = 1 / 60 min/ sec
   Speed Radians = C1 X C2 $= 2\Pi \text{ X } \frac{1800}{60} = 188.496$

   Speed Radians = 188.496 Shaft Speed (rad./sec.)

2. Gear tip velocity in feet per second
   $Vo = \frac{Do}{12/2}$ X (Speed Rad) Vo = 0.07 X 188.496 = 13.19 ft/ sec

   C3 = 1.125 ft water / ft Glycol
   C4 = 0.432781 psi / ft water g = 32.2 ft / sec.^{2}

   $\text{Fill} = \frac{(Vo)^2}{2g} = \frac{13.19^2}{64.4} = \frac{173.98}{64.4} = 2.70$ ft glycol

3. Pressure to fill gears
   Fill psi = Fill X C3 X C4 = 2.7 X 1.125 X 0.432781 = 1.315 psia

4. Net Positive Suction Pressure required (NPSHr) = 1.315 psia = 2.68" HG = .09 BARa

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NPSH at Pump Inlet
(Net Positive Suction Pressure (Head) for GS 2200 Pump @ 1500 RPM)

1. Shaft Speed in radians per second
   Speed = 1500 RPM , Gear Diameter (Do)= 2.105 In.
   C1 = 2 Π Radians / Rev
   C2 = 1 / 60 min/ sec
   Speed Radians = C1 X C2 $= 2\Pi \times \frac{1500}{60} = 157.08$

   Speed Radians = 157.08 Shaft Speed (rad./sec.)

2. Gear tip velocity in feet per second
   $Vo = \frac{Do}{12/2} \times (\text{Speed Rad})$ Vo = 0.088 X 157.08 = 13.82 ft/ sec

   C3 = 1.125 ft water / ft Glycol
   C4 = 0.432781 psi / ft water g = 32.2 ft / $sec.^2$

   $Fill = \frac{(Vo)^2}{2g} = \frac{13.82^2}{64.4} = \frac{190.99}{64.4} = 2.96$ ft glycol

3. Pressure to fill gears
   Fill psi = Fill X C3 X C4 = 2.96 X 1.125 X 0.432781 = 1.44 psia

4. Net Positive Suction Pressure required (NPSHr) = 1.44 psia = 2.93" Hg = 0.098 Bara

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NPSH at Pump Inlet
(Net Positive Suction Pressure (Head) for GS 2200 Pump @ 1800 RPM)

1. Shaft Speed in radians per second
   Speed = 1800 RPM , Gear Diameter (Do)= 2.105 In.
   C1 = 2 Π Radians / Rev
   C2 = 1 / 60 min/ sec
   Speed Radians = C1 X C2 $= 2\Pi \times \dfrac{1800}{60} = 188.496$

   Speed Radians = 188.496 Shaft Speed (rad./sec.)

2. Gear tip velocity in feet per second
   $Vo = \dfrac{Do}{12/2} \times (\text{Speed Rad})$ $\quad Vo = 0.088 \times 188.496 = 16.59$ ft/ sec

   C3 = 1.125 ft water / ft Glycol
   C4 = 0.432781 psi / ft water $\quad g = 32.2$ ft / sec.^{2}

   $\text{Fill} = \dfrac{(Vo)^2}{2g} = \dfrac{16.59^2}{64.4} = \dfrac{275.23}{64.4} = 4.27$ ft glycol

3. Pressure to fill gears
   Fill psi = Fill X C3 X C4 = 4.27 X 1.125 X 0.432781 = 2.08 psia

4. Net Positive Suction Pressure required (NPSHr) = 2.08 psia = 4.235 "Hg = 0.14 Bara

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NPSH at Pump Inlet
(Net Positive Suction Pressure (Head) for GS 3300 Pump @ 1500 RPM)

1. Shaft Speed in radians per second
   Speed = 1500 RPM , Gear Diameter (Do)= 2.41 In.
   C1 = 2 Π Radians / Rev
   C2 = 1 / 60 min/ sec
   Speed Radians = C1 X C2 $= 2\Pi \times \frac{1500}{60} = 157.08$

   Speed Radians = 157.08 Shaft Speed (rad./sec.)

2. Gear tip velocity in feet per second
   $Vo = \frac{Do}{12/2} \times (\text{Speed Rad})$ Vo = 0.1004 X 157.08 = 15.773 ft/ sec

   C3 = 1.125 ft water / ft Glycol
   C4 = 0.432781 psi / ft water g = 32.2 ft / sec.^{2}

   $\text{Fill} = \frac{(Vo)^2}{2g} = \frac{15.773^2}{64.4} = \frac{248.78}{64.4} = 3.86$ ft glycol

3. Pressure to fill gears
   Fill psi = Fill X C3 X C4 = 3.86 X 1.125 X 0.432781 = 1.88 psi

4. Net Positive Suction Pressure required (NPSHr) = 1.88 psi = 3.823"HG = 0.128 Bara

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NPSH at Pump Inlet
(Net Positive Suction Pressure (Head) for GS 3300 Pump @ 1800 RPM)

1. Shaft Speed in radians per second
   Speed = 1500 RPM , Gear Diameter (Do)= 2.41 In.
   C1 = 2 Π Radians / Rev
   C2 = 1 / 60 min/ sec
   Speed Radians = C1 X C2 = $2\Pi \times \frac{1800}{60}$ = 188.496

   Speed Radians = 188.496 Shaft Speed (rad./sec.)

2. Gear tip velocity in feet per second
   $Vo = \frac{Do}{12/2} \times (\text{Speed Rad})$ Vo = 0.1004 X 188.496 = 18.92 ft/ sec

   C3 = 1.125 ft water / ft Glycol
   C4 = 0.432781 psi / ft water   g = 32.2 ft / sec.^{2}

   $\text{Fill} = \frac{(Vo)^2}{2g} = \frac{18.92^2}{64.4} = \frac{357.97}{64.4} =$ 5.56 ft glycol

3. Pressure to fill gears
   Fill psi = Fill X C3 X C4 = 5.56 X 1.125 X 0.432781 = 2,71 psia

4. Net Positive Suction Pressure required (NPSHr) = 2.71 psia   = 5.518" HG = 0.187 BARA

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NPSH at Pump Inlet
(Net Positive Suction Pressure (Head) for GS 4400 Pump @ 1500 RPM)

1. Shaft Speed in radians per second
   Speed = 1500 RPM, Gear Diameter (Do)= 2.73 In.
   C1 = 2 Π Radians / Rev
   C2 = 1 / 60 min/ sec
   Speed Radians = C1 X C2 = $2\Pi \times \frac{1500}{60} = 157.08$

   Speed Radians = 157.08 Shaft Speed (rad./sec.)

2. Gear tip velocity in feet per second
   $Vo = \frac{Do}{12/2} \times (\text{Speed Rad})$ Vo = 0.11375 X 157.08 = 17.87 ft/ sec

   C3 = 1.125 ft water / ft Glycol
   C4 = 0.432781 psi / ft water   g = 32.2 ft / sec.^{2}

   $\text{Fill} = \frac{(Vo)^2}{2g} = \frac{17.87^2}{64.4} = \frac{319.33}{64.4} = 4.96$ ft glycol

3. Pressure to fill gears
   Fill psi = Fill X C3 X C4 = 4.96 X 1.125 X 0.432781 = 2.415 psia

4. Net Positive Suction Pressure required (NPSHr) = 2.415 psia = 4.988 "HG = 0.166 BARA

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NPSH at Pump Inlet
(Net Positive Suction Pressure (Head) for GS 4400 Pump @ 1800 RPM)

1. Shaft Speed in radians per second
   Speed = 1500 RPM , Gear Diameter (Do)= 2.73 In.
   C1 = 2 Π Radians / Rev
   C2 = 1 / 60 min/ sec
   Speed Radians = C1 X C2 $= 2\Pi \times \frac{1800}{60} = 188.496$

   Speed Radians = 188.496 Shaft Speed (rad./sec.)

2. Gear tip velocity in feet per second
   $Vo = \frac{Do}{12/2} \times (\text{Speed Rad})$ Vo = 0.11375 X 188.496 = 21.44 ft/ sec

   C3 = 1.125 ft water / ft Glycol
   C4 = 0.432781 psi / ft water   g = 32.2 ft / sec.^{2}

   $\text{Fill} = \frac{(Vo)^2}{2g} = \frac{21.44^2}{64.4} = \frac{459.67}{64.4} =$ 7.14 ft glycol

3. Pressure to fill gears
   Fill psi = Fill X C3 X C4 = 7.14 X 1.125 X 0.432781 = 3.475 psia

4. Net Positive Suction Pressure required (NPSHr) = 3.475 psia = 7.075 " HG = 0.239 BARA

GS-1110 E. 15HP (1500)AC-3

DATA

DISCHARGE PRESSURE (PSIG)	FLOW (USGPM)	SUCTION PRESSURE (BARA)	TEMP. (F)	SPEED (Hz)
1000 psig	10 GPM	0.85 bara	95 F	50 Hz
1000 psig	10 GPM	0.75 bara	95 F	50 Hz
1000 psig	10 GPM	0.65 bara	95 F	50 Hz
1000 psig	10 GPM	0.55 bara	95 F	50 Hz
1000 psig	10 GPM	0.45 bara	95 F	50 Hz
1000 psig	10 GPM	0.35 bara	95 F	50 Hz
1000 psig	10 GPM	0.25 bara	95 F	50 Hz
1000 psig	10 GPM	0.15 bara	95 F	50 Hz
1000 psig	8 GPM	0.09 bara	95 F	50 Hz
1000 psig	7 GPM	0.07 bara*	95 F	50 Hz

*Cavitation Heard

** Below rated flow by more than 5%

GS-1110 E. 15HP (1800)AC-3

DATA

DISCHARGE PRESSURE (PSIG)	FLOW (USGPM)	SUCTION PRESSURE (BARA)	TEMP. (F)	SPEED (Hz)
1000 psig	12 GPM	0.85 bara	100 F	60 Hz
1000 psig	12 GPM	0.80 bara	100 F	60 Hz
1000 psig	12 GPM	0.69 bara	105 F	60 Hz
1000 psig	12 GPM	0.59 bara	105 F	60 Hz
1000 psig	12 GPM	0.50 bara	105 F	60 Hz
1000 psig	12 GPM	0.40 bara	110 F	60 Hz
1000 psig	12 GPM	0.30 bara	110 F	60 Hz
1000 psig	12 GPM	0.21 bara	110 F	60 Hz
1000 psig	10 GPM	0.13 bara	110 F	60 Hz
1000 psig	8 GPM	0.09 bara **	110 F	60 Hz
1000 psig	8 GPM	0.08 bara*	110 F	60 Hz

* Cavitation Heard

** Below rated flow by more than 5%

GS-2208 E. 15HP (1500)AC-3

DATA

DISCHARGE PRESSURE (PSIG)	FLOW (USGPM)	SUCTION PRESSURE (BARA)	TEMP. (F)	SPEED (Hz)
1000 psig	12 GPM	0.82 bara	95 F	50 Hz
1000 psig	12 GPM	0.72 bara	95 F	50 Hz
1000 psig	12 GPM	0.62 bara	100 F	50 Hz
1000 psig	12 GPM	0.52 bara	100 F	50 Hz
1000 psig	12 GPM	0.42 bara	100 F	50 Hz
1000 psig	12 GPM	0.32 bara	100 F	50 Hz
1000 psig	12 GPM	0.22 bara	100 F	50 Hz
1000 psig	11.5 GPM	0.20 bara	100 F	50 Hz
1000 psig	10 GPM	0.16 bara	100 F	50 Hz
1000 psig	8 GPM	0.10 bara **	100 F	50 Hz
1000 psig	8 GPM	0.08 bara*	100 F	50 Hz

*Cavitation Heard

** Below rated flow by more than 5%

GS-2208 E. 15HP (1800)AC-3

DATA

DISCHARGE PRESSURE (PSIG)	FLOW (USGPM)	SUCTION PRESSURE (BARA)	TEMP. (F)	SPEED (Hz)
1000 psig	15.5 GPM	0.81 bara	95 F	60 Hz
1000 psig	15.5 GPM	0.71 bara	95 F	60 Hz
1000 psig	15.5 GPM	0.61 bara	95 F	60 Hz
1000 psig	15.5 GPM	0.51 bara	95 F	60 Hz
1000 psig	15.5 GPM	0.41 bara	95 F	60 Hz
1000 psig	15.5 GPM	0.31 bara	95 F	60 Hz
1000 psig	14.75 GPM	0.21 bara	95 F	60 Hz
1000 psig	12.4 GPM	0.14 bara	97 F	60 Hz
1000 psig	9 GPM	0.08 bara	97 F	60 Hz
1000 psig	8 GPM	0.07 bara*	97 F	60 Hz

* Cavitation Heard

** Below rated flow by more than 5%

GS-3314 E. 25HP (1500)AC-3

DATA

DISCHARGE PRESSURE (PSIG)	FLOW (USGPM)	SUCTION PRESSURE (BARA)	TEMP. (F)	SPEED (Hz)
1000 psig	29 GPM	0.58 bara	90 F	50 Hz
1000 psig	29 GPM	0.48 bara	90 F	50 Hz
1000 psig	29 GPM	0.38 bara	90 F	50 Hz
1000 psig	27 GPM	0.28 bara	90 F	50 Hz
1000 psig	26 GPM	0.18 bara	90 F	50 Hz
1000 psig	16 GPM	0.08 bara **	90 F	50 Hz
1000 psig	13 GPM	0.05 bara*	90 F	50 Hz

*Cavitation Heard
** Below rated flow by more than 5%

GS-3314 E. 25HP (1800)AC-3

DATA

DISCHARGE PRESSURE (PSIG)	FLOW (USGPM)	SUCTION PRESSURE (BARA)	TEMP. (F)	SPEED (Hz)
1000 psig	34 GPM	0.72 bara	130 F	60 Hz
1000 psig	34 GPM	0.61 bara	130 F	60 Hz
1000 psig	34 GPM	0.51 bara	130 F	60 Hz
1000 psig	34 GPM	0.41 bara	130 F	60 Hz
1000 psig	33 GPM	0.31 bara	130 F	60 Hz
1000 psig	31 GPM	0.21 bara	130 F	60 Hz
1000 psig	29 GPM	0.18 bara **	130 F	60 Hz
1000 psig	28 GPM	0.15 bara*	130 F	60 Hz

* Cavitation Heard
** Below rated flow by more than 5

GS-4410 E. 25HP (1500)AC-3

DATA

DISCHARGE PRESSURE (PSIG)	FLOW (USGPM)	SUCTION PRESSURE (BARA)	TEMP. (F)	SPEED (Hz)
1000 psig	29 GPM	0.72 bara	95 F	50 Hz
1000 psig	29 GPM	0.62 bara	100 F	50 Hz
1000 psig	29 GPM	0.52 bara	100 F	50 Hz
1000 psig	28 GPM	0.42 bara	100 F	50 Hz
1000 psig	28 GPM	0.32 bara	100 F	50 Hz
1000 psig	26 GPM	0.22 bara	100 F	50 Hz
1000 psig	25 GPM	0.15 bara*	100 F	50 Hz
1000 psig	22 GPM	0.12 bara*	100 F	50 Hz

*Cavitation Heard

** Below rated flow by more than 5%

GS-4410 E. 25HP (1800)AC-3

DATA

DISCHARGE PRESSURE (PSIG)	FLOW (USGPM)	SUCTION PRESSURE (BARA)	TEMP. (F)	SPEED (Hz)
1000 psig	34 GPM	0.72 bara	130 F	60 Hz
1000 psig	34 GPM	0.61 bara	130 F	60 Hz
1000 psig	34 GPM	0.51 bara	130 F	60 Hz
1000 psig	34 GPM	0.39 bara	130 F	60 Hz
1000 psig	33 GPM	0.30 bara	130 F	60 Hz
1000 psig	33 GPM	0.20 bara	130 F	60 Hz
1000 psig	30 GPM	0.15 bara*	130 F	60 Hz
1000 psig	28 GPM	0.12 bara*	130 F	60 Hz

* Cavitation Heard

** Below rated flow by more than 5%