Determining the Minimum Safe Flow Line for a 5 Stage, 350 HP Variable Speed Centrifugal Pump

by
Robert Perez
Celanese Chemicals, Bishop, TX

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Abstract

An energy survey revealed that two, a main and spare, 5 stage, 3560 rpm, 350 hp, centrifugal pumps were well oversized for their application. The pumps are used to inject waste water into several disposal wells. Due to the excess capacity of these pumps, a spill back line and control valve had to be installed and used continuously to maintain a minimum safe operating flow rate.

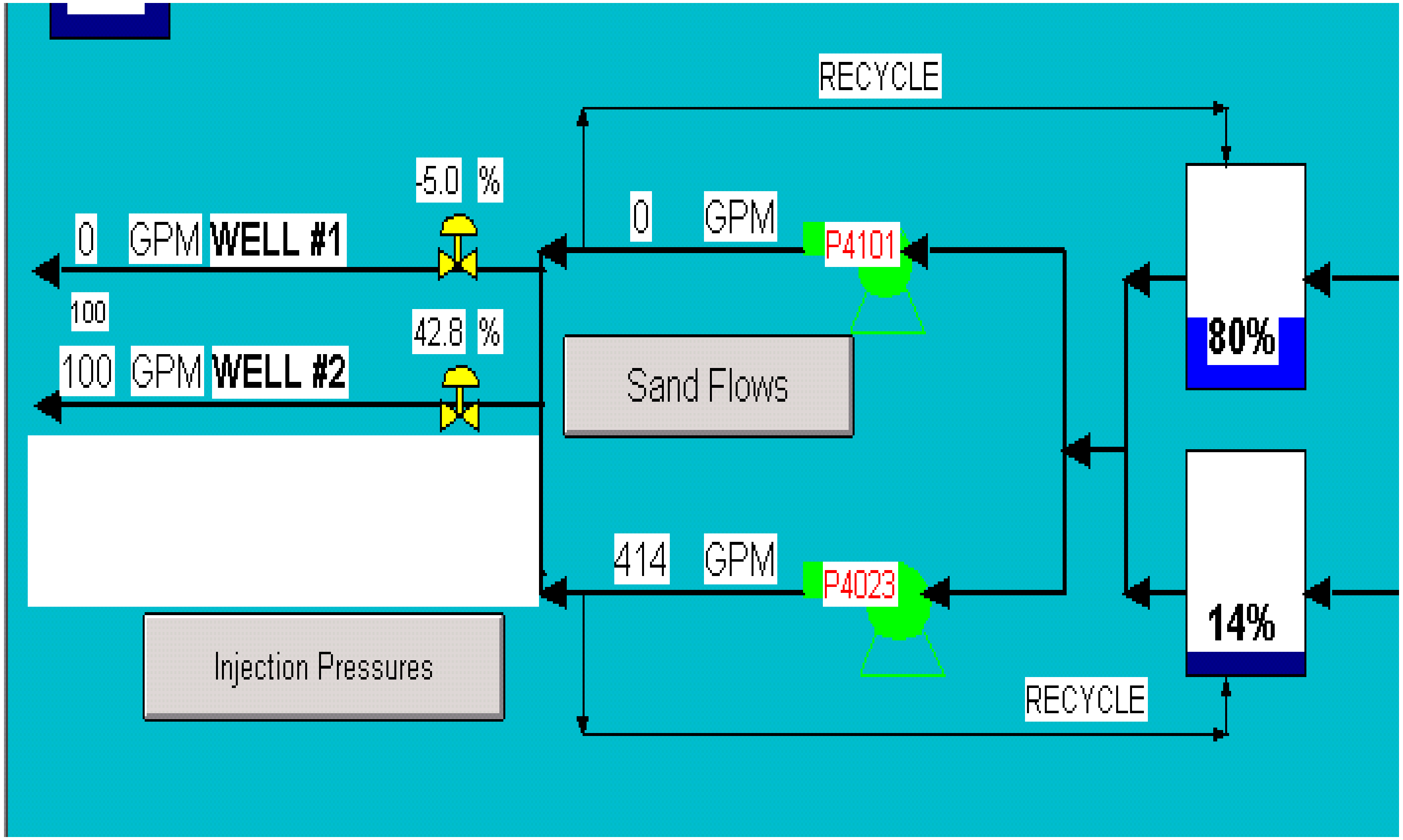
To reduce the energy consumption, a project was proposed to install a variable speed drive on one of the injection pumps and operate it at reduced speeds as required by demand. To complete the economic analysis we were asked to determine the minimum safe flow operating speed at the rated operating speed and use this information to set a minimum flow line for all potential pump speeds. This minimum flow line was used to determine if the spillback line would still be required at the reduced operating speeds.

We will present our methodology for determining the minimum safe operating flow using a simple field test method and API 610 Centrifugal Pump Standard vibration guidelines. This methodology can be readily applied to most types of centrifugal pumps.

Case Study Outline

- System Overview
- Problem
- Field testing
- Analysis of results
- Conclusions
- Lessons Learned

H_2O Injection System Schematic

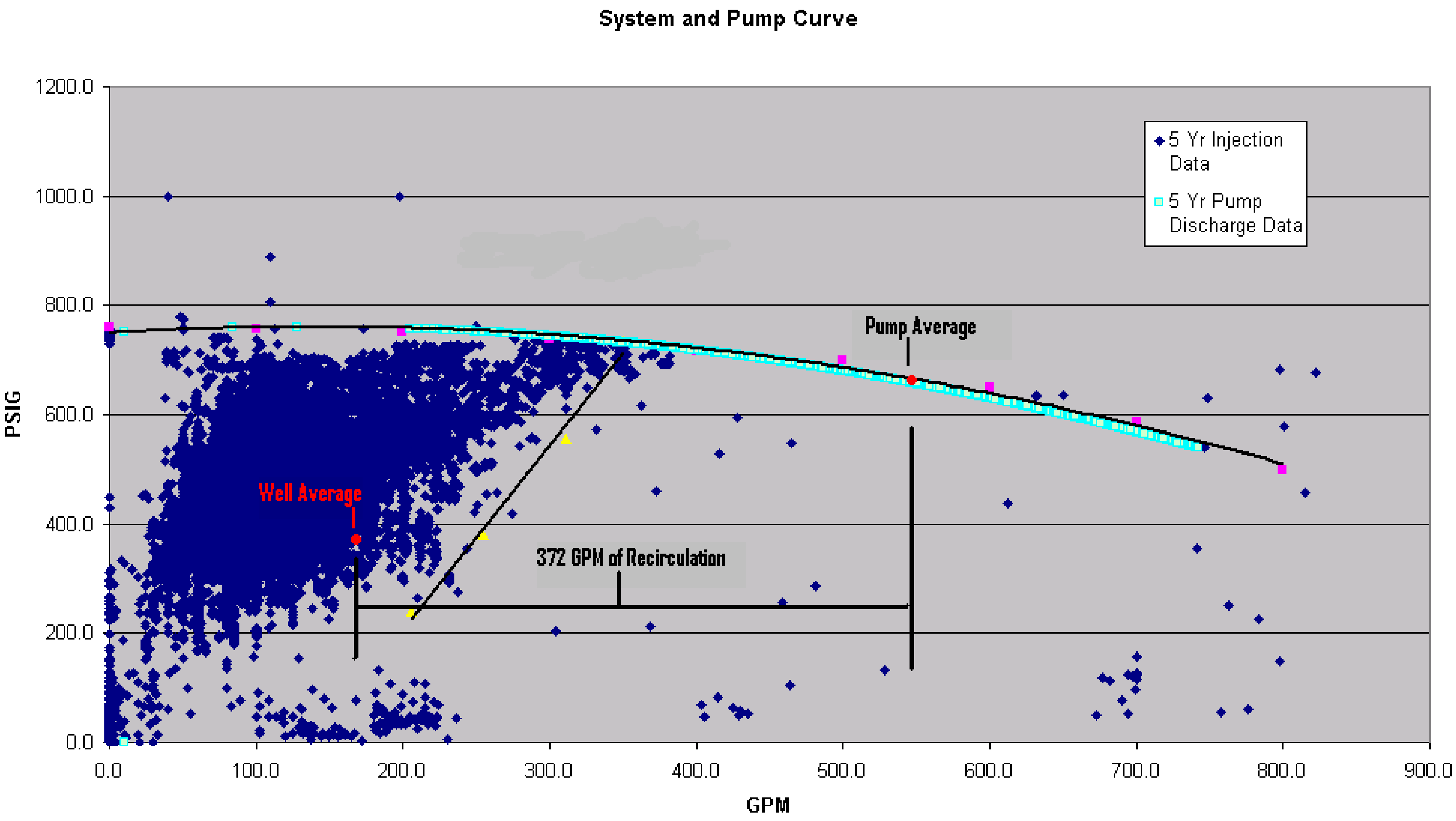


Injection Pump #1

Injection Pump #2

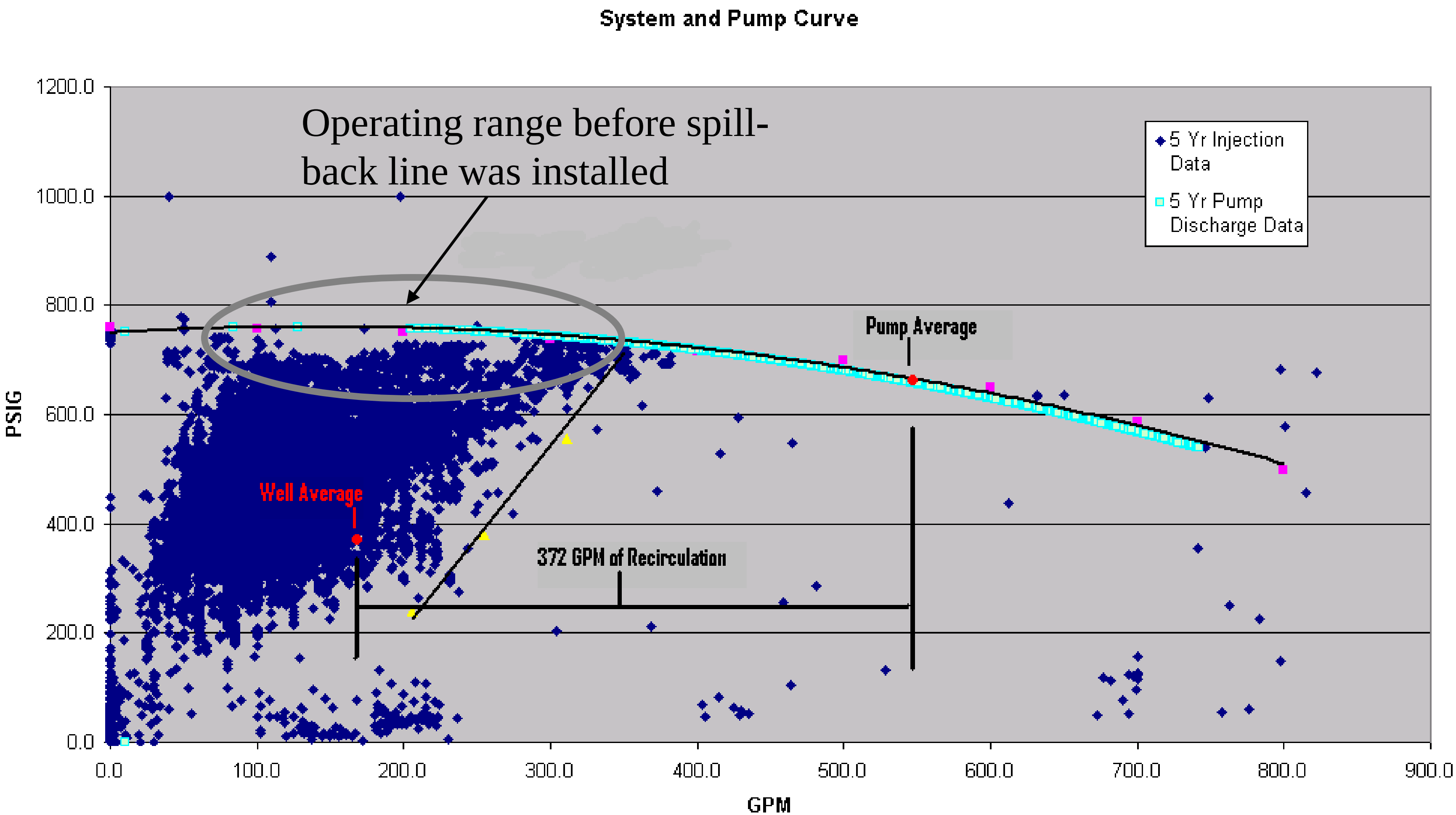
The Problem

- The injection well pumps were originally oversized. In 2004, 71% of the pump's discharge or 372 GPM was re-circulated because there was no automatic control, only a fixed flow orifice in re-cir line. This resulted in a loss of about 230



But..

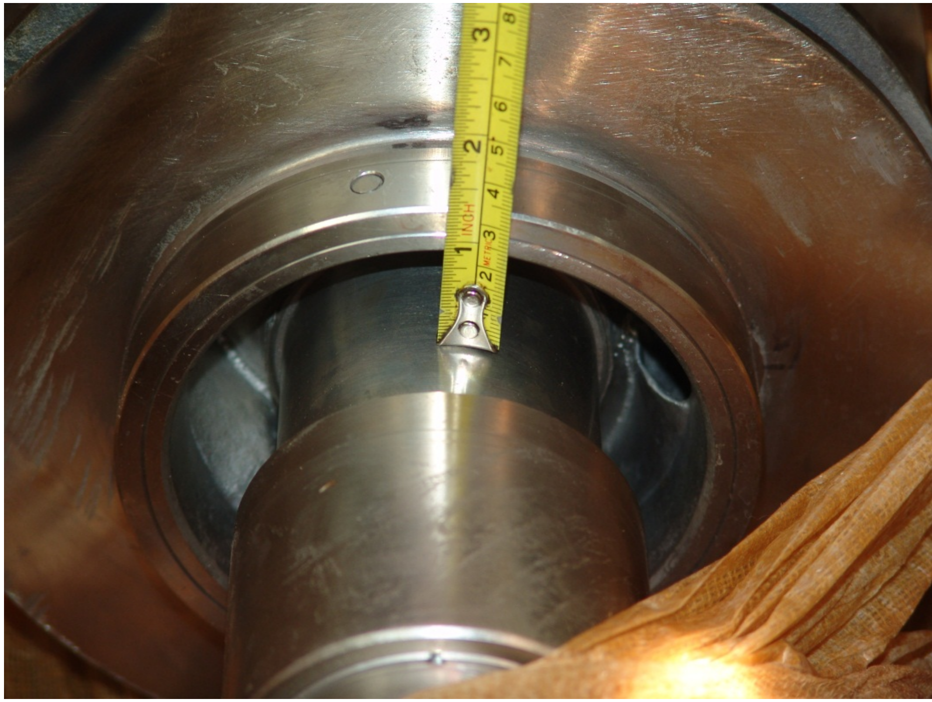
Spill back is needed to protect the pump. Prior to installing the re-circ line, the pump would run far to left on its curve causing poor reliability and high maintenance costs. To minimize energy consumption, a minimum flow control line had to be determined.



Spare Rotor (5 stages)

1st Stage Suction Eye (single suction impeller)

2nd Stage Suction Eye



Consequences of the Large 1st Stage Suction Eye

- Using maximum diameter impeller performance data at the best efficiency point (BEP), we determined the suction specific speed (N_{ss}) for the 1st stage impeller to be:

$$N_{ss} = \frac{RPM \times \sqrt{Q}}{NPSH^{0.75}} = \frac{3560 \times \sqrt{680}}{13^{0.75}} = 13{,}560$$

- This is well above the generally accepted limit of 11,000
- As the value of N_{ss} increases, you must increase the minimum continuous flow as a % of BEP to avoid hydraulic instabilities
- The minimum continuous stable flow (mcsf) can be anywhere from 30% to 90% BEP depending on the pump's N_{ss}

Determining the Min-Flow Line

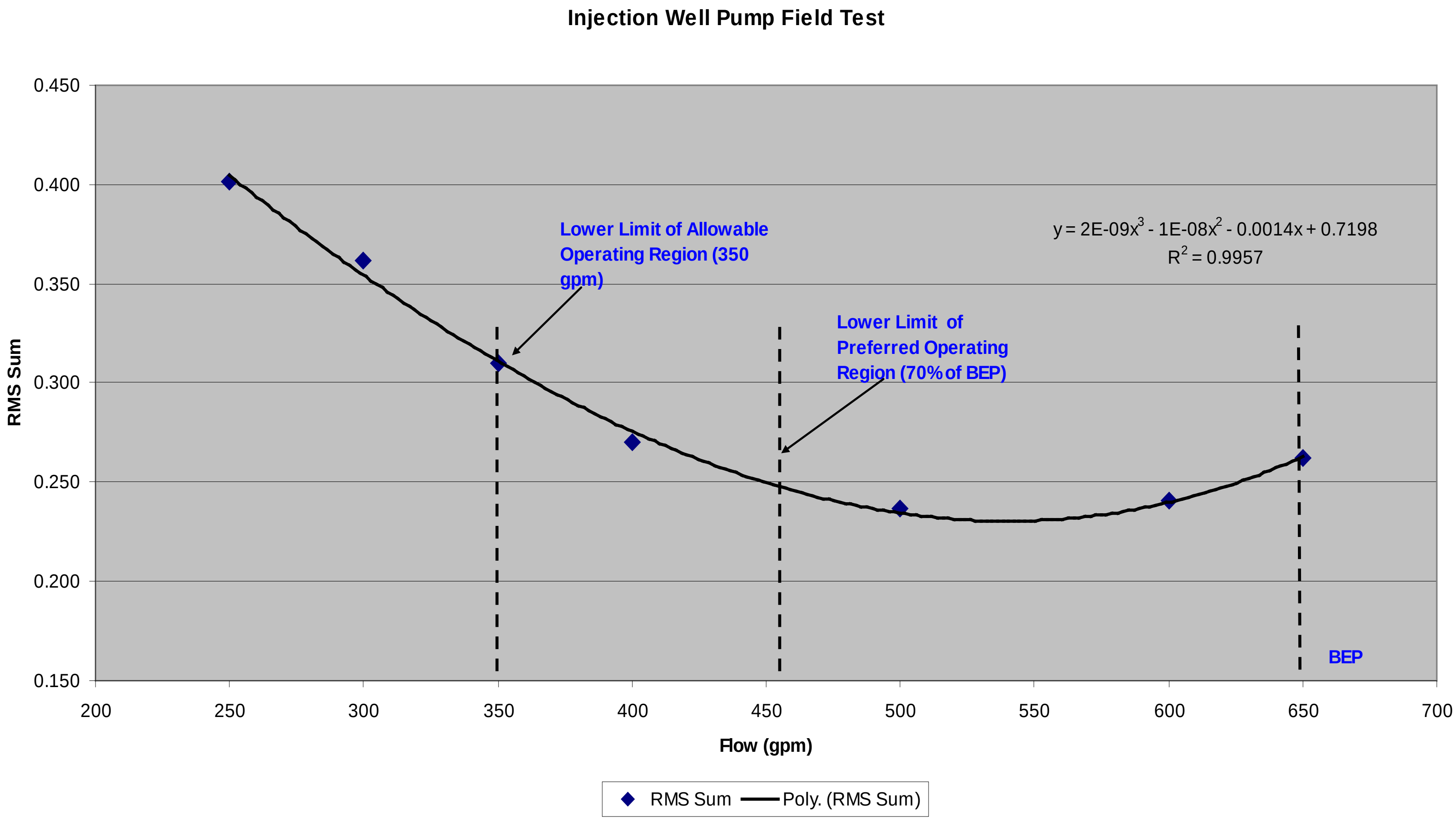
- We decided to measure and record pump vibration levels at
  - Six (6) pump positions (PIBA, PIBH, PIBV, POBA, POBH, POBV) and
  - Seven (7) flows from about 38% of BEP to BEP
- The test was done at a constant speed
- Flow was varied by manually varying the spill-back flow because the VFD had not been installed yet.
- We reduced each flow condition to one datum point by taking the RMS average of the six vibration measurement positions
- $V_{RMS}= ((PIBA)^2+(PIBH)^2+(PIBV)^2+(POBA)^2+(POBH)^2+POBV)^2)^{0.5}$

Determining the Min-Flow Line

	Pump In Board (in/sec) ips			Pump Out Board (in/sec) ips			Piping vibration (ips)		PSIG		
GPM	Horizontal	Vertical	Axial	Horizontal	Vertical	Axial	Inlet	Outlet	Inlet Pressure	Outlet Pressure	RMS Sum
650	0.136	0.145	0.070	0.117	0.094	0.042	0.346	0.123	0-10	610-660	0.262
600	0.126	0.127	0.054	0.121	0.079	0.045	0.300	0.110	1-9	650-690	0.240
500	0.131	0.114	0.060	0.123	0.075	0.043	0.278	0.096	1-10	710-740	0.237
400	0.140	0.134	0.063	0.143	0.094	0.046	0.352	0.112	0-10	760-800	0.270
350	0.155	0.190	0.084	0.127	0.103	0.045	0.359	0.103	0-11	770-800	0.310
300	0.158	0.230	0.114	0.143	0.128	0.057	0.419	0.122	0-11	775-820	0.362
250	0.160	0.275	0.107	0.155	0.143	0.064	0.403	0.143	-2 to11	780-825	0.401

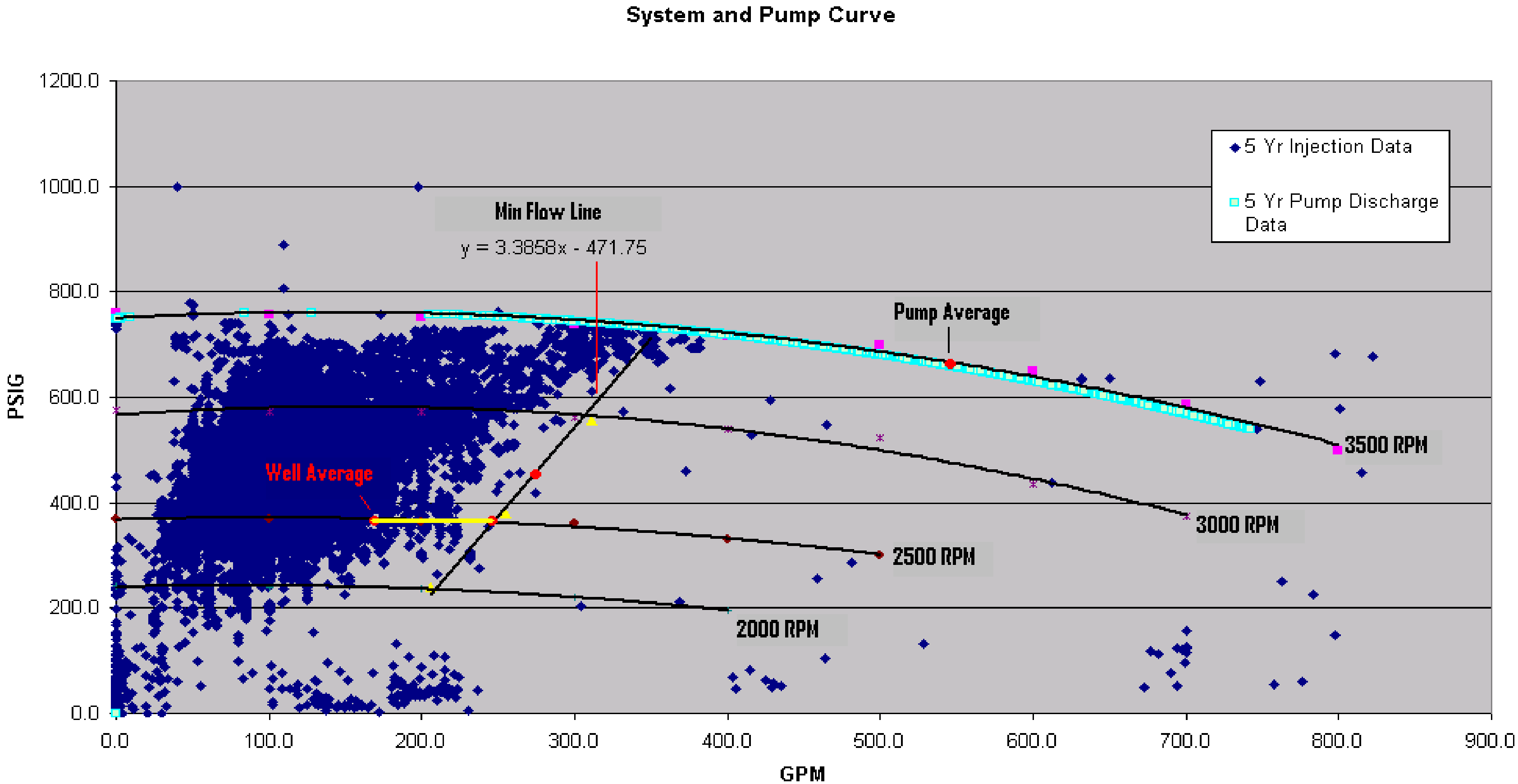
Determining the Min-Flow Line

API 610 states that the lower limit flow-rate, within the allowable region, occurs at the point where vibration levels increase 30% above vibration level at the 70% BEP flow-rate. Here are our field vibration data taken at seven (7) flow-rates:



Determining the Min-Flow Line

Through field testing, it was determined that the minimum safe flow is 53% of BEP at the various speeds. The pump should not operate to the left of the minimum flow line shown below.



Determining the Min-Flow Line

- The minimum safe operating flow line was determined by plotting the 53% of BEP points for various operating speeds and then finding the best fit line for these points.

- Suction energy (S.E.) is defined as:

  - S.E.= D_e x N x N_{ss} x S.G., where D_e, is the suction eye diameter, N is rpm, and N_{ss} is the suction specific speed. Nss=13,600 for the 1st stg impeller

  - S.E. = 6” x 3570 x 13,600 x 1.0 = 291 x 10^6=>Very high suction energy!!! (High S.E. is 120 x 10^6 for horizontal split case pumps)

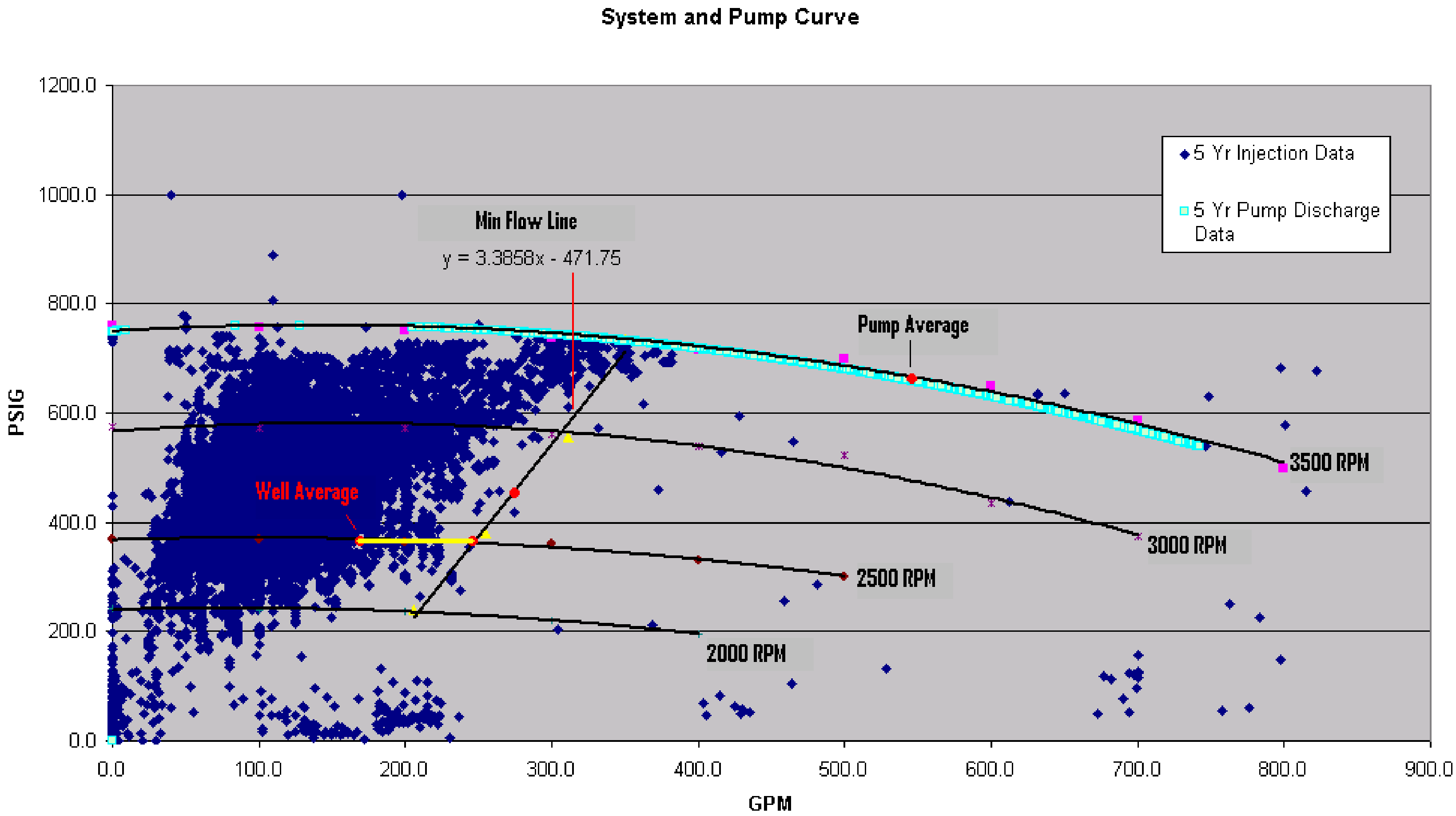
  - S.E. is proportional to speed (N), so it makes sense that the min flow “curve” should be linear.

- Based on testing and SE concept, we arrived at this final equation for min-flow control line:

$$MCSF = 0.0941 \times RPM + 2.22$$

Solution

Install a VFC and spill-back valve to allow the pump to operate at lower speeds and lower flow rates up to the min-flow line using the min-flow line equation obtained from the field test data. This optimizes energy savings, while maintaining reliability

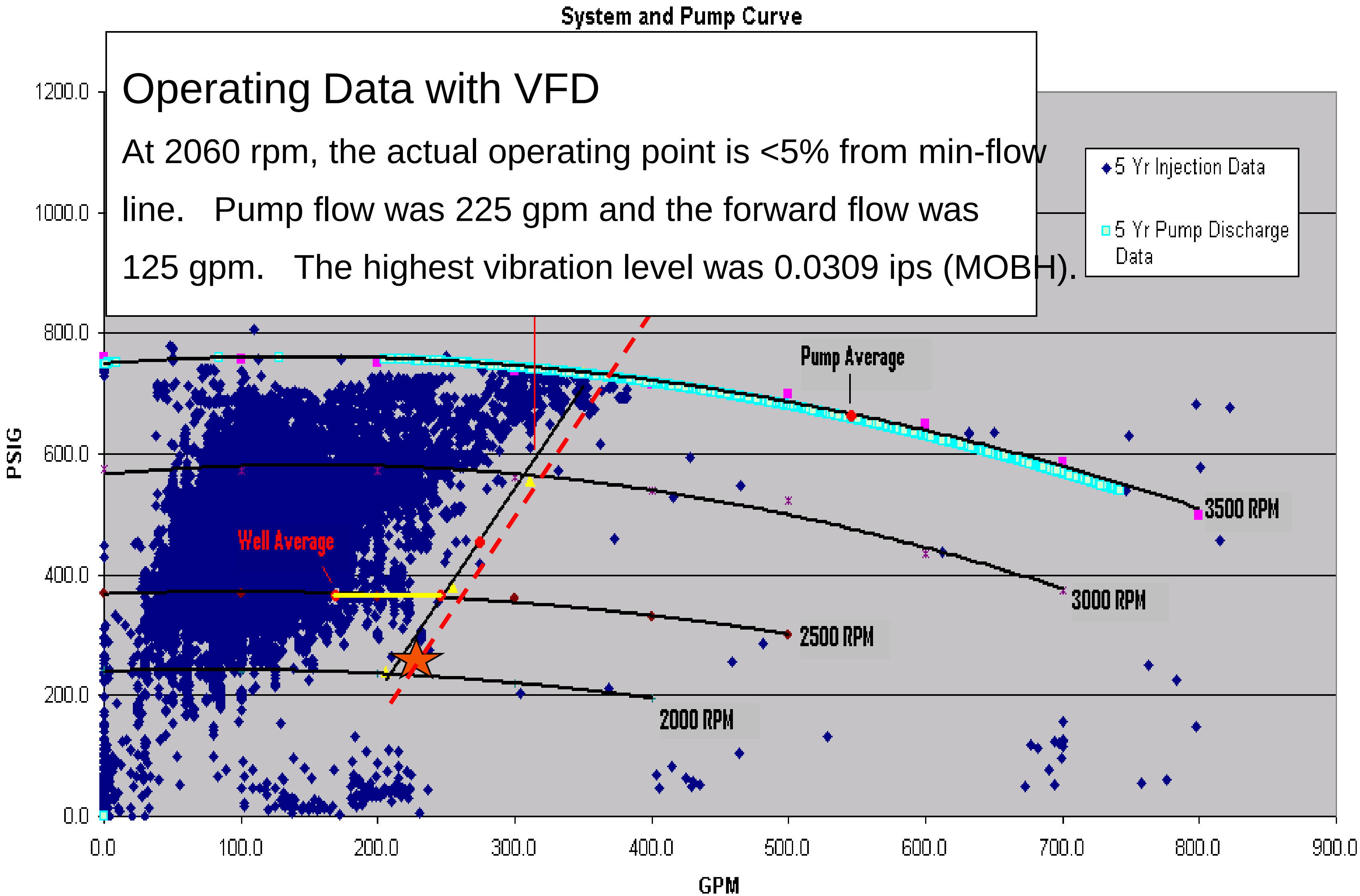


Conclusions

- Field testing enable us to determine the safe minimum flow for these pumps at 3560 rpm operation.
- The 3560 rpm minimum flow was used to create a min-flow line for varying pump speeds.
- With a VFC and an automatic control valve on the re-circ line the controls were programmed so the minimum flow line is never violated.
- The control valves on each well head will not be needed and can be left wide open.
- **Note: The pump has been operating under VFD control for over 6 months without any failures or problems. Under current conditions, we are saving over 250 hp.**

Operating Data with VFD

At 2060 rpm, the actual operating point is <5% from min-flow line. Pump flow was 225 gpm and the forward flow was 125 gpm. The highest vibration level was 0.0309 ips (MOBH).



Lessons Learned

- API 610 provides useful guidelines for determining minimum pump flow
- These guidelines can be applied under actual field conditions
- Applying a “field-verified” minimum flow line to VFD logic can save energy cost while improving reliability

References:

- API 610, Pump Standard, “Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Services.”
- Perez, R., Operating Centrifugal Pumps Off-Design, Pumps & Systems Magazine, April 2005, pp 20-27
- 2004 Goulds Pump Manual, Tech-A-6 NPSH Suction Specific Speed and Suction Energy, page 714