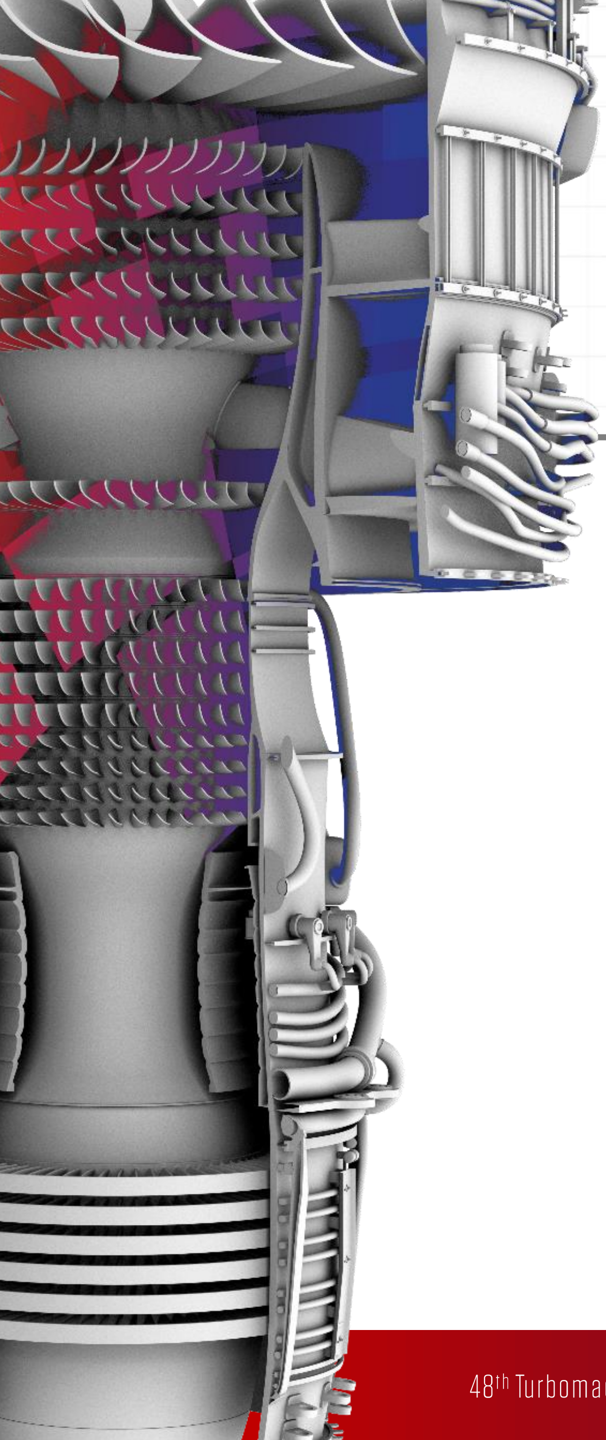


TURBOMACHINERY & PUMP SYMPOSIA

Poor Hydraulic Performance from Large Barrel Pumps

Johnny Pellin

Lead Engineer / Senior Machinery Reliability Engineer

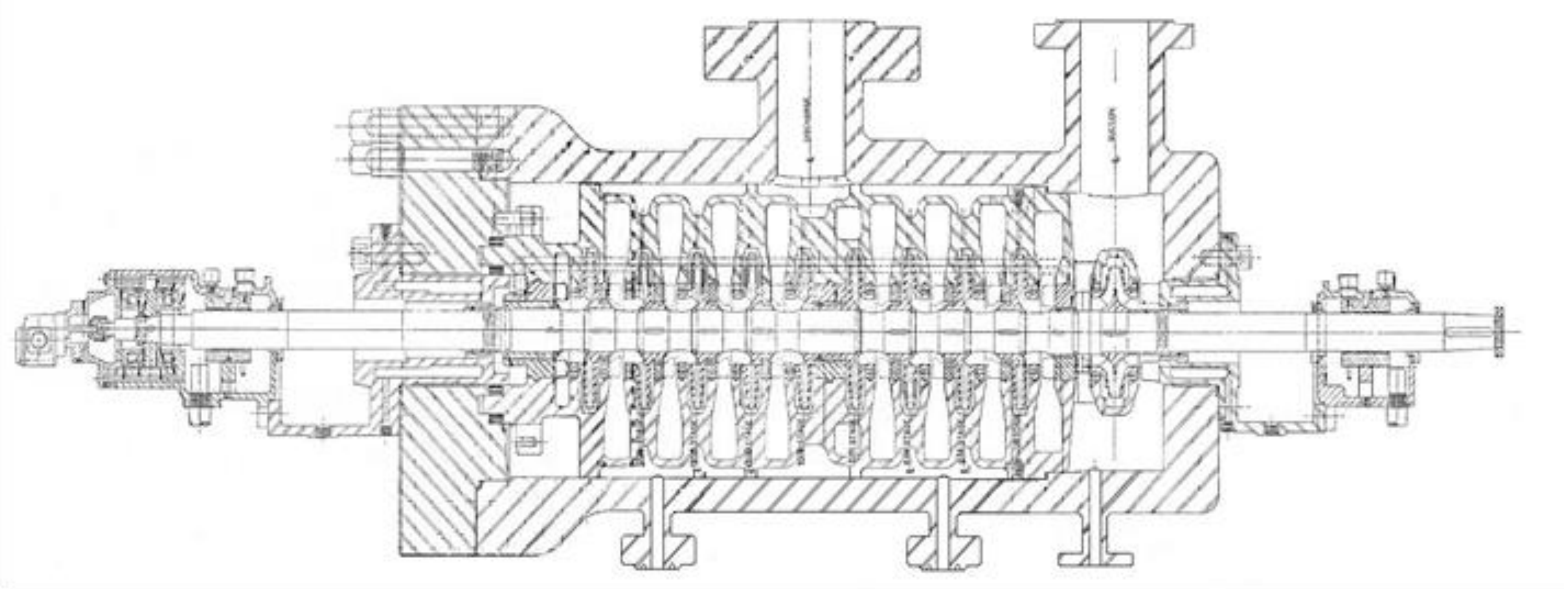
Flint Hills Resources, Pine Bend, MN Refinery

Poor Hydraulic Performance from Large Barrel Pumps

Johnny Pellin is currently serving as a lead engineer within the Machinery Reliability Group at the Flint Hills Resources refinery in Rosemount, Minnesota, where he has worked for 30 years. Mr. Pellin received a Bachelor of Science in Mechanical Engineering from The Wichita State University in Wichita, Kansas in 1988. He was granted a patent in 1995 for an "Oven for Baking Pizza." He coauthored a Lecture at the 12th International Pump Users Symposium in 1995 titled "Design and Implementation of a Mechanical Seal Program in an Oil Refinery."

Poor Hydraulic Performance from Large Barrel Pumps

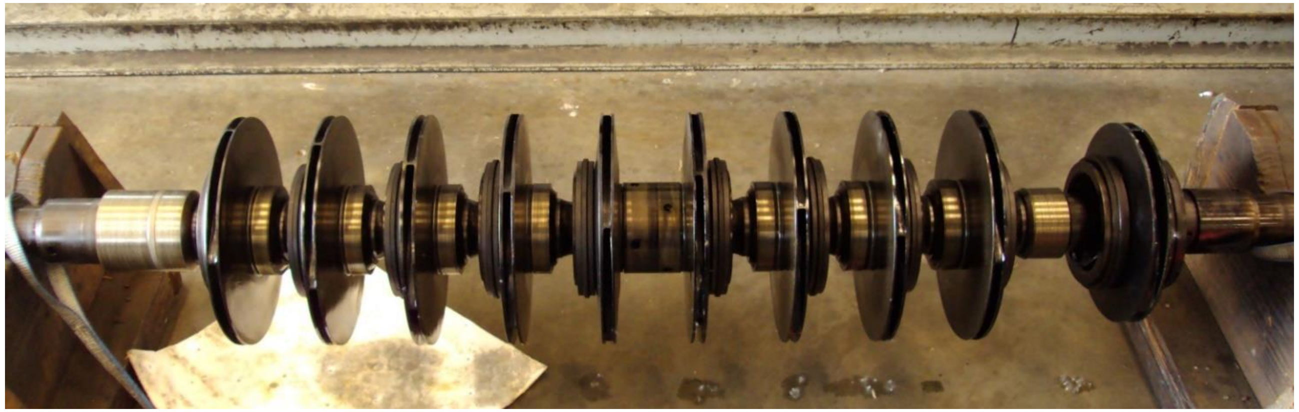
Problem: A pair of large barrel pumps have experienced poor reliability and poor hydraulic performance since their installation in 1993. Despite repeated overhauls and design changes, the problem persisted.



Poor Hydraulic Performance from Large Barrel Pumps

Pump Description:

- 10 stage, opposed configuration barrel pumps (API BB5)
- Split inner casing with internal balance lines
- Rated for 600 gpm (136 m^3/hour) at 5650 feet (1722 m) head
- Pumping heavy gas oil at 350 °F (177 °C) and 0.83 Specific Gravity
- 1250 HP (900 kW) induction motor drivers

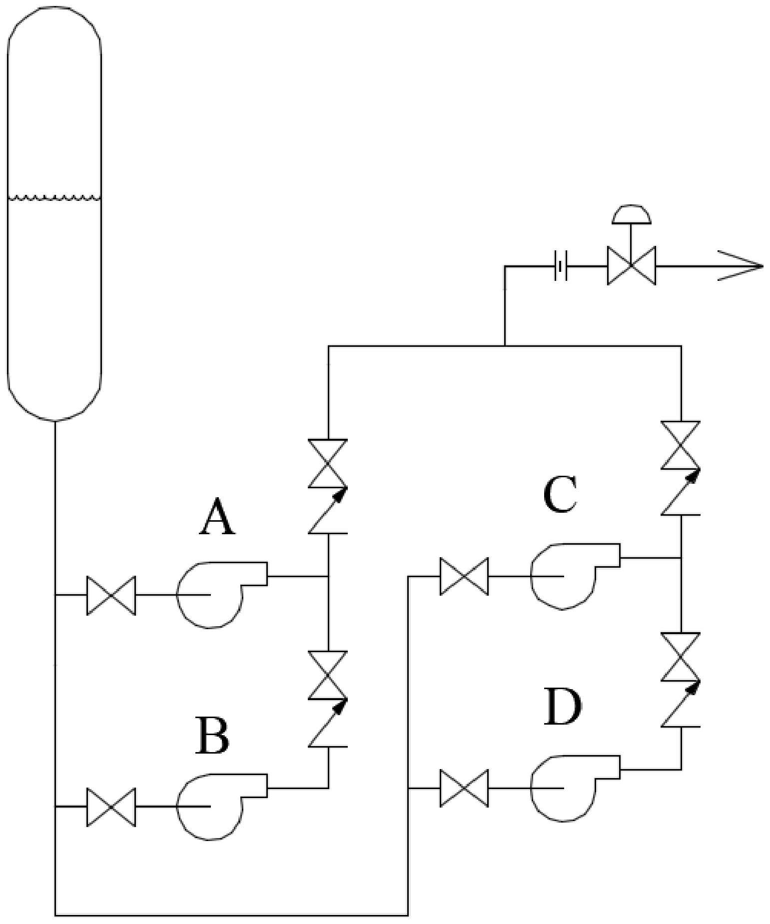


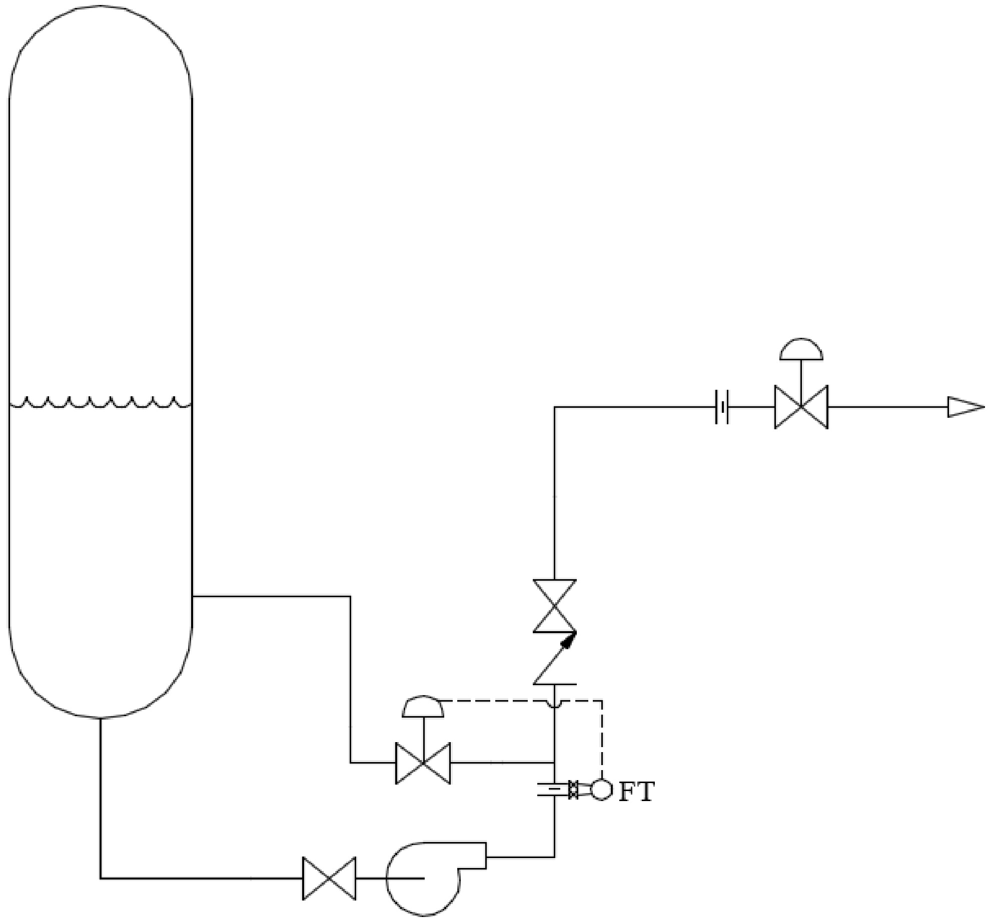
Poor Hydraulic Performance from Large Barrel Pumps

Unit Background

- Gas Oil Hydrotreater built in 1975 with two charge pumps running 1-out-of-2
- Original pumps rerated with maximum diameter impellers
- Unit rate increases required operating 2-out-of-2
- Added two identical pumps in 1993 running 3-out-of-4
- Recent rate increases would require running 4-out-of-4

Poor Hydraulic Performance from Large Barrel Pumps





Poor Hydraulic Performance from Large Barrel Pumps

Reliability

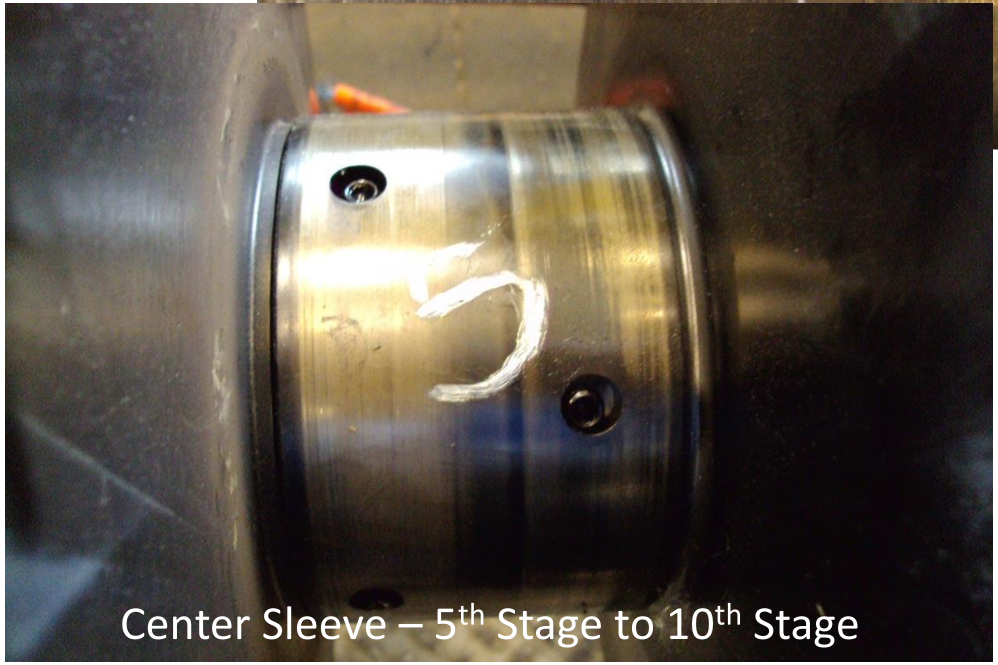
- A and B pumps running for 22 and 15 years since last overhaul
- C and D pumps require overhauls every 3 to 5 years
- Conditions found at overhauls:
  - Spec clearance in impeller eye rings
  - Extreme damage to hub rings
  - Extreme damage to separation bushing (1^{st} to 2^{nd} stage)
  - Spec clearance in center bushing
  - Extreme damage to throttle bushing

Poor Hydraulic Performance from Large Barrel Pumps

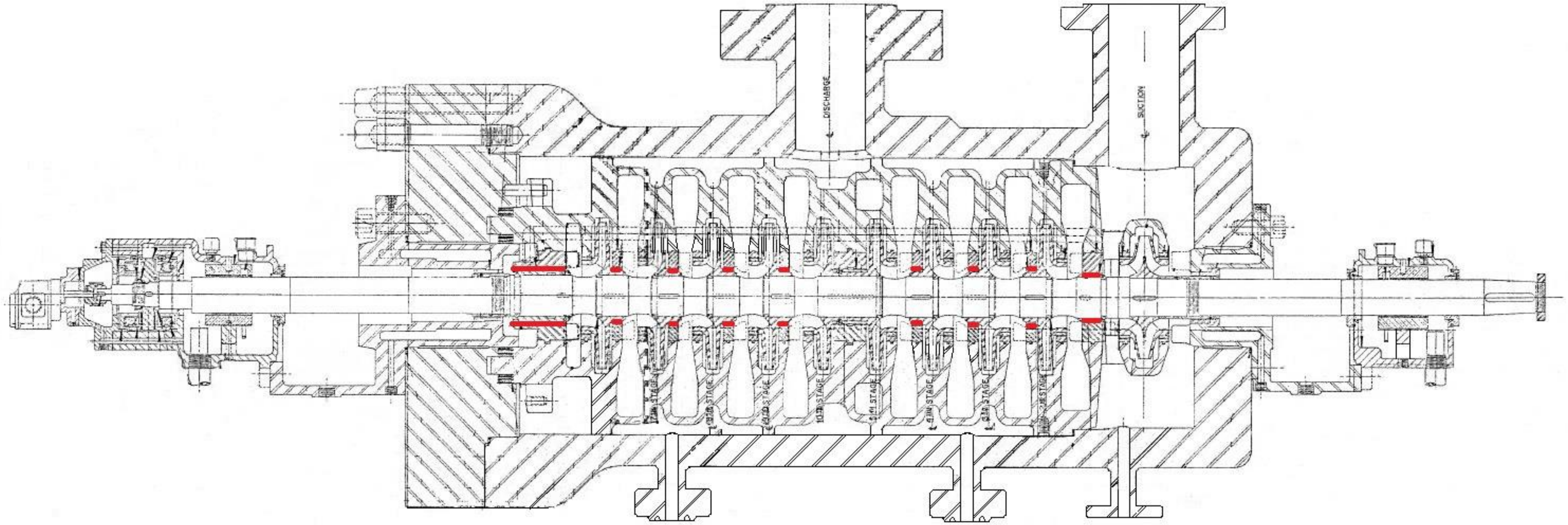

Second Stage Back Hub Ring


Throttle Sleeve – Outboard End


Separation Sleeve – 1st to 2nd Stage


Center Sleeve – 5th Stage to 10th Stage

Poor Hydraulic Performance from Large Barrel Pumps



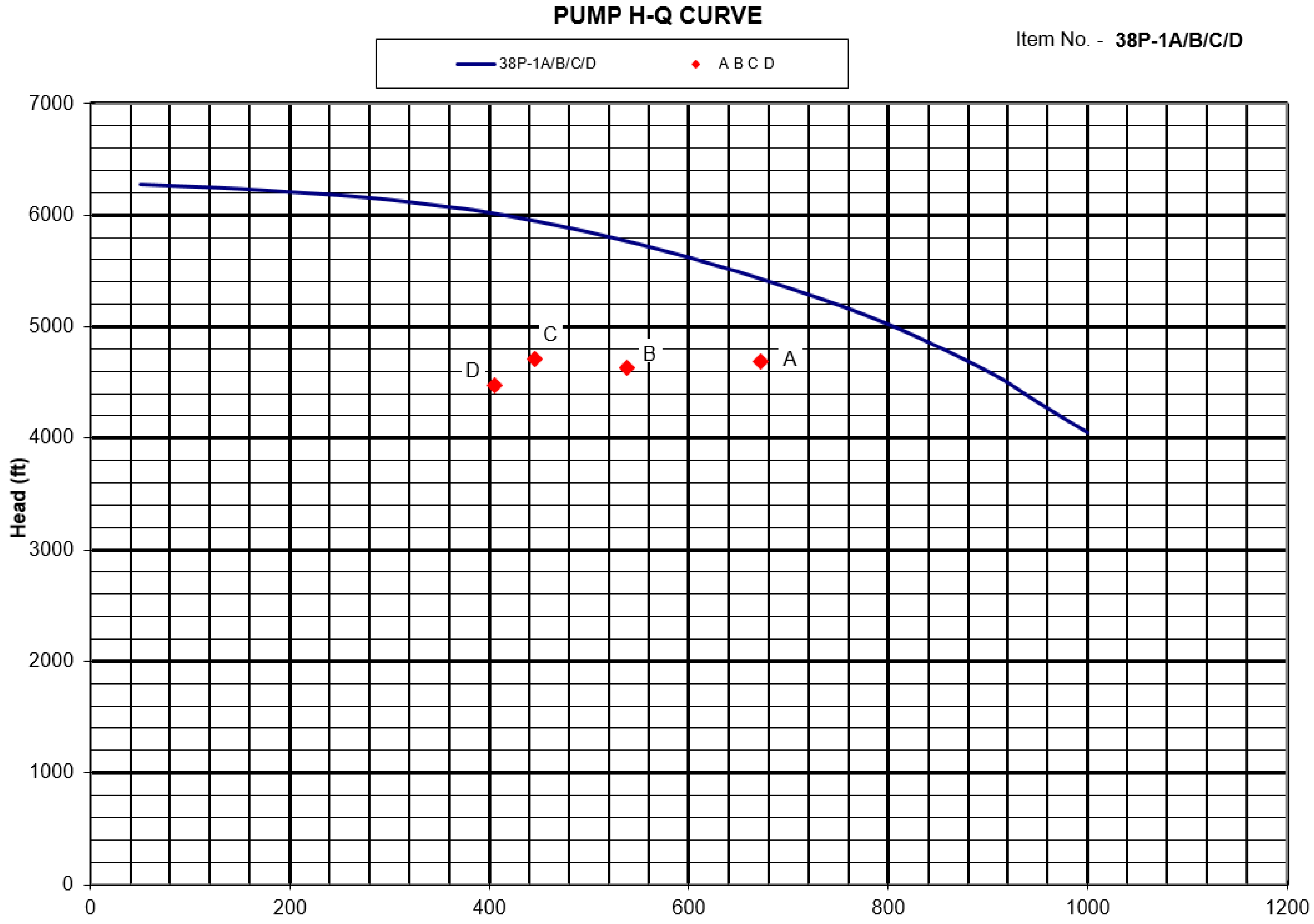
Wear rings and bushings shown in RED were badly damage. The others were in near perfect condition.

Poor Hydraulic Performance from Large Barrel Pumps

Hydraulic Performance

- No individual flow measurement for each pump prior to 2010
- After flow transmitters were added:
  - A pump at ~90 percent of curve after 22 years
  - B pump at ~85 percent of curve after 15 years
  - C pump at ~75 percent of curve after 2 years
  - D pump at ~80 percent of curve after 4 years

Poor Hydraulic Performance from Large Barrel Pumps



Poor Hydraulic Performance from Large Barrel Pumps

Questions:

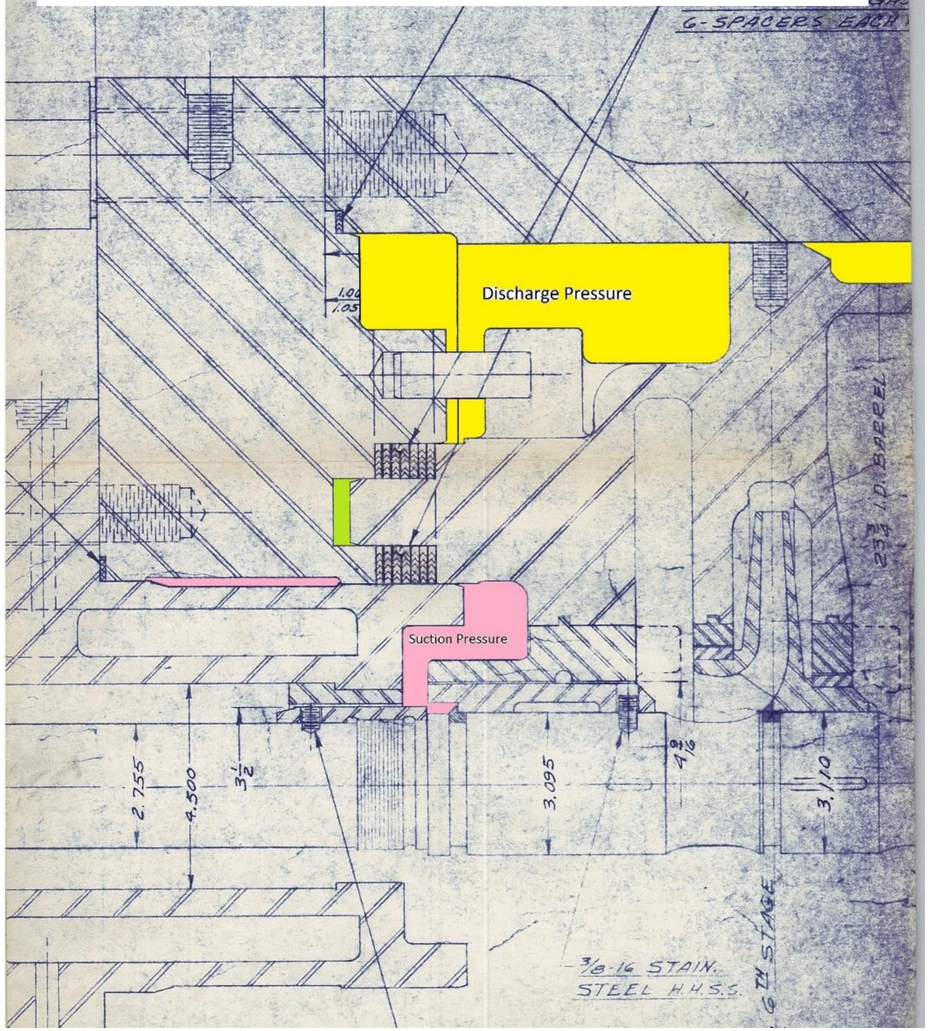
- Why are the back hub rings destroyed but the impeller eye rings in nearly perfect condition?
- Why are two of the bushings destroyed but the center bushing is unaffected?
- Why do the A and B pumps perform much better even though they have run much longer since the last overhaul?

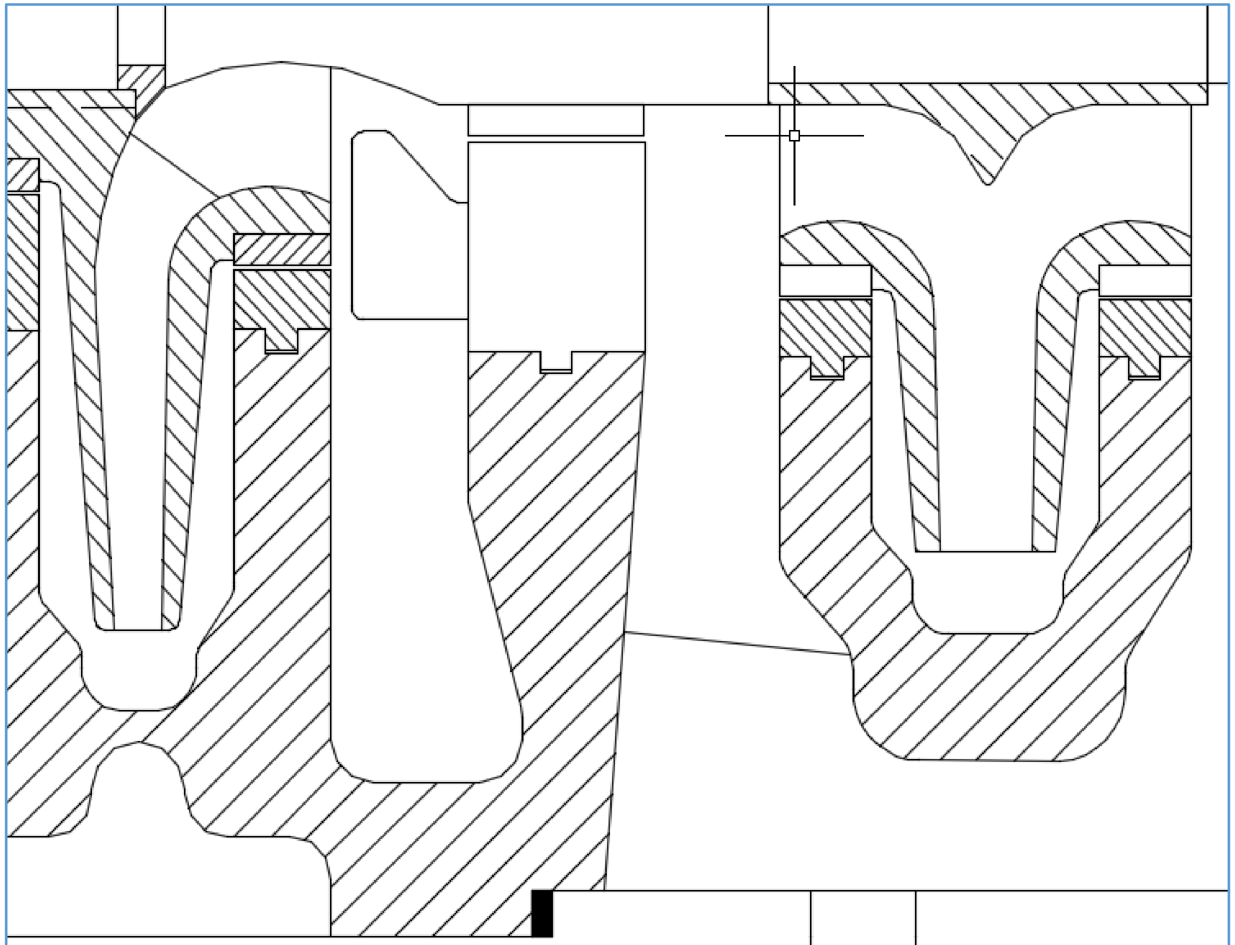
Poor Hydraulic Performance from Large Barrel Pumps

Possible Causes Considered:

- Internal recirculation past the gasket that seals the inner casing to the outer casing.
- Internal recirculation past the gaskets that seal the inner casing to the head
- Damage or defect in the inner casing (bad casting, volute erosion)
- Assembly error (clockwise and counter-clockwise impellers)
- Rapid erosion damage because of the piping arrangement (sand directed to C and D pumps and not to A and B pumps)

Stacks of compensator gaskets with spacers separate discharge pressure from suction at the outer head.





One internal gasket separates full discharge pressure from suction where the inner casing seals to the outer casing.

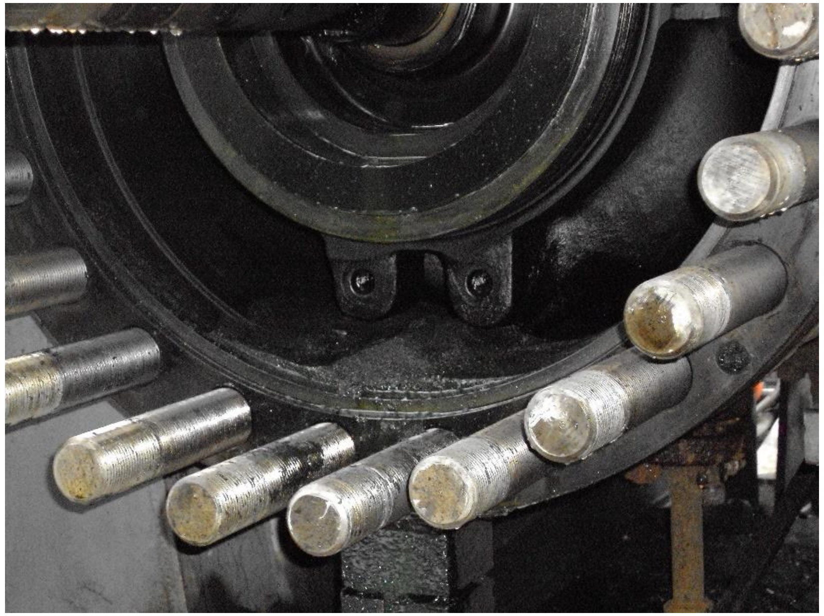
Poor Hydraulic Performance from Large Barrel Pumps

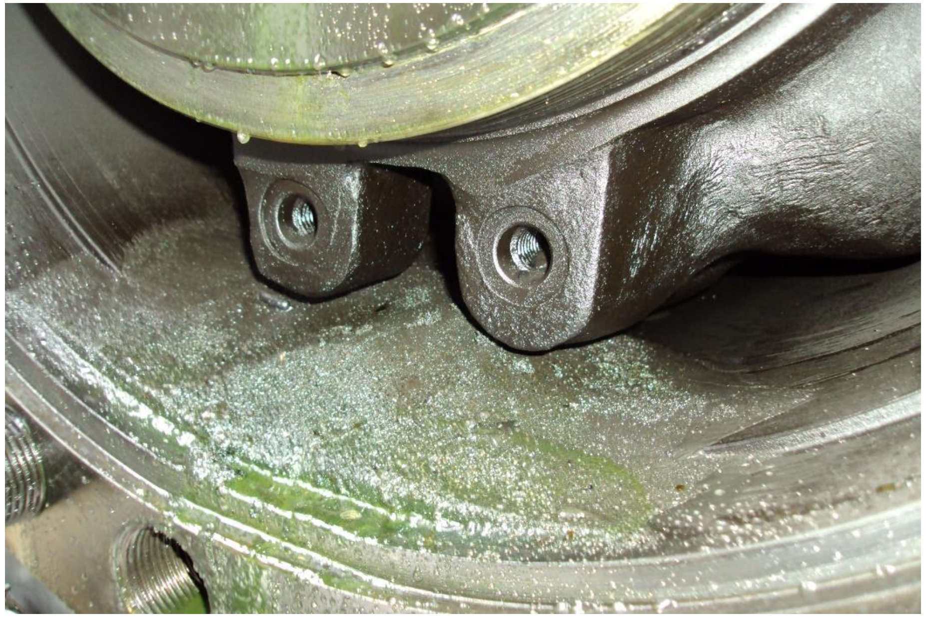
- A new inner casing was purchased to eliminate case condition as a possible cause.
- The pump manufacturer was asked to review our data and make recommendations. An OEM engineer was brought on-site to inspect the installation and advise during a full pump overhaul.
- All of the pressure and flow instruments were checked and calibrated.
- Nothing was found to explain the damage or the poor hydraulic performance.

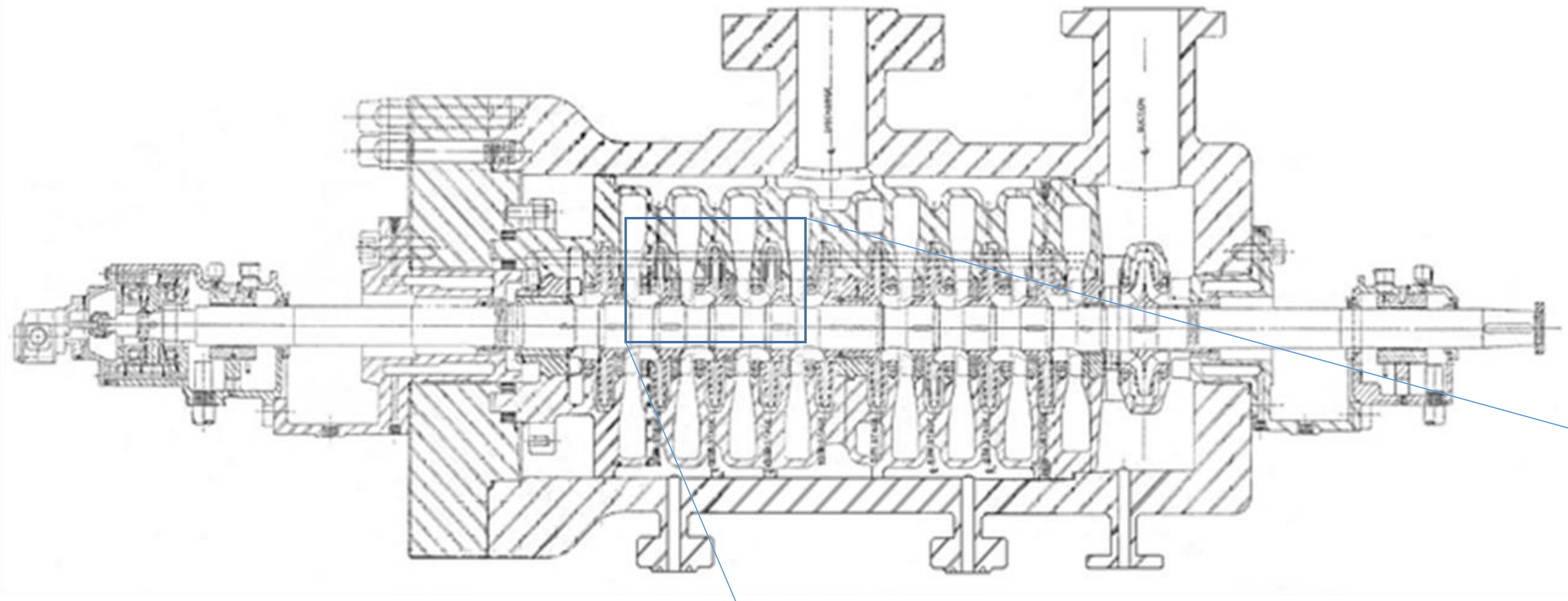
Poor Hydraulic Performance from Large Barrel Pumps

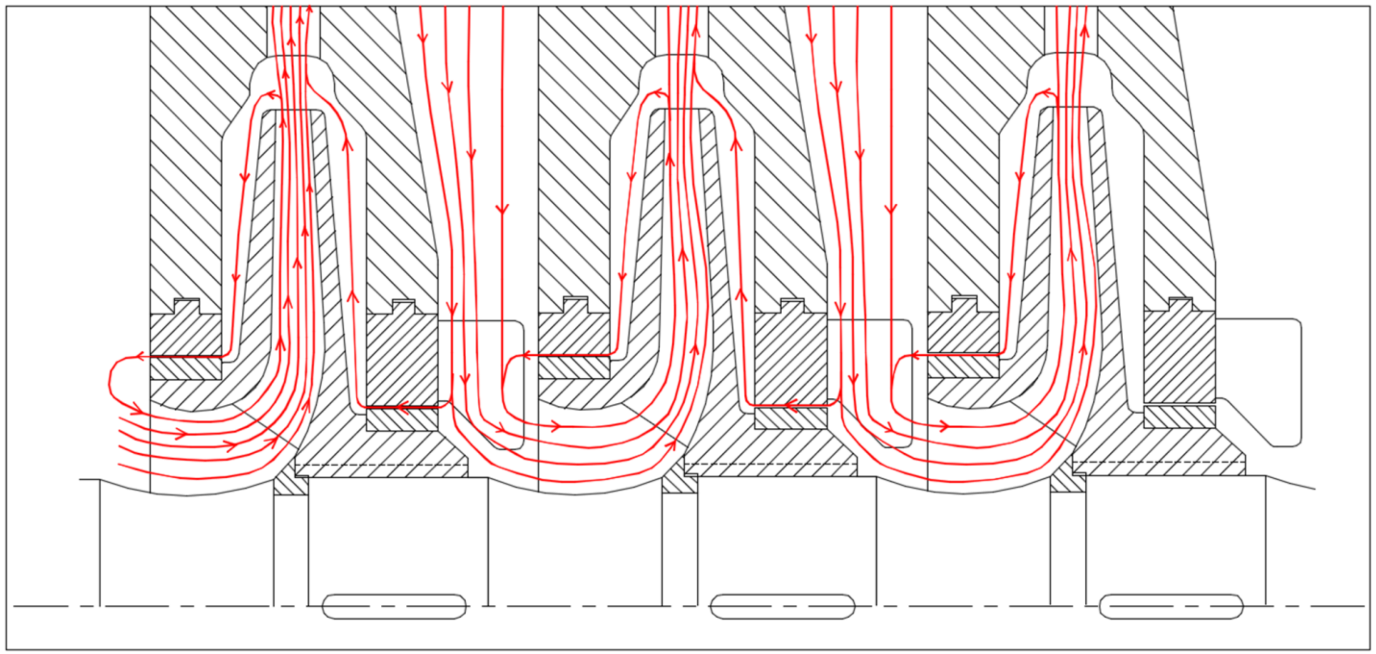
Conclusion:

The location and appearance of the damage is indicative of abrasive wear from passing hard solid particles. Pictures and notes from past overhauls confirmed the presence of abrasive solids.

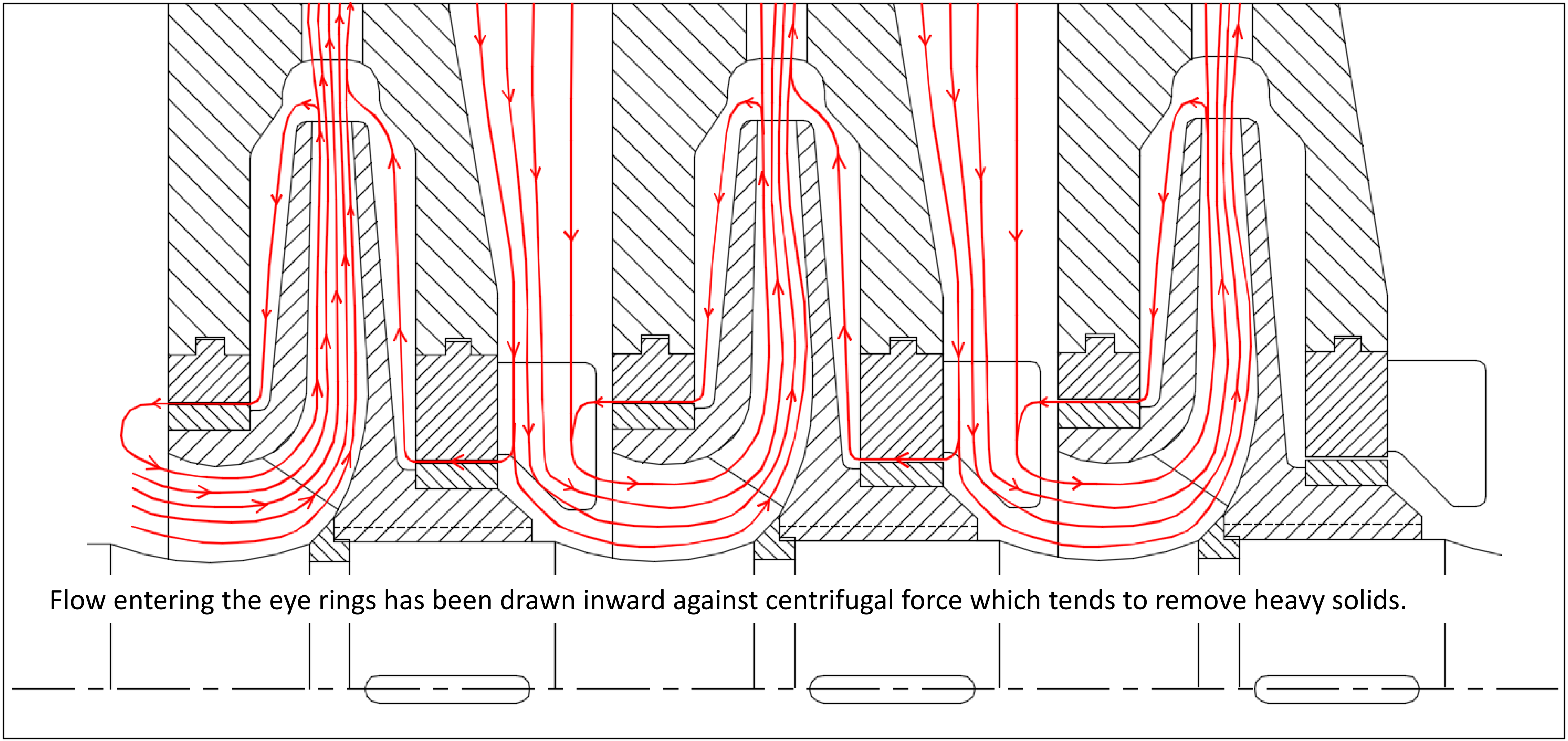








Because of the flow path, solids tend to be directed into the back hub rings and away from the eye rings.



Flow entering the eye rings has been drawn inward against centrifugal force which tends to remove heavy solids.

Poor Hydraulic Performance from Large Barrel Pumps

Solution:

- Harder materials on the affected wear rings and bushings
- The back wear rings, bushings and sleeves were upgraded to 420 and 440A stainless steel with Direct Laser Deposition surfacing. Hardness increased to 44 to 50 Rc
- Upstream changes to reduce the concentration of abrasives in the process stream

Poor Hydraulic Performance from Large Barrel Pumps

Outcome:

Failure!

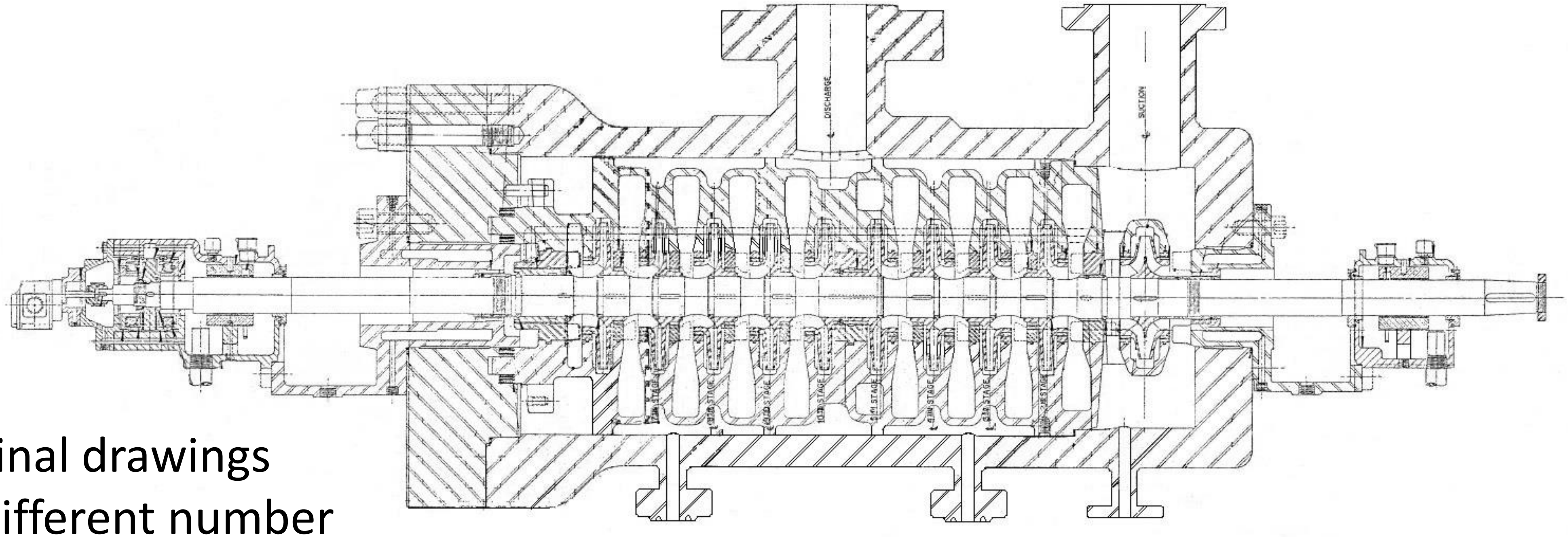
A spare rotor with harder bushings and wear rings was installed in C pump. The inner casing was replaced with new.

The performance was only improved from about 78 percent of curve to about 82 percent of curve. The performance rapidly degraded. Within a year all of the improvement was lost.

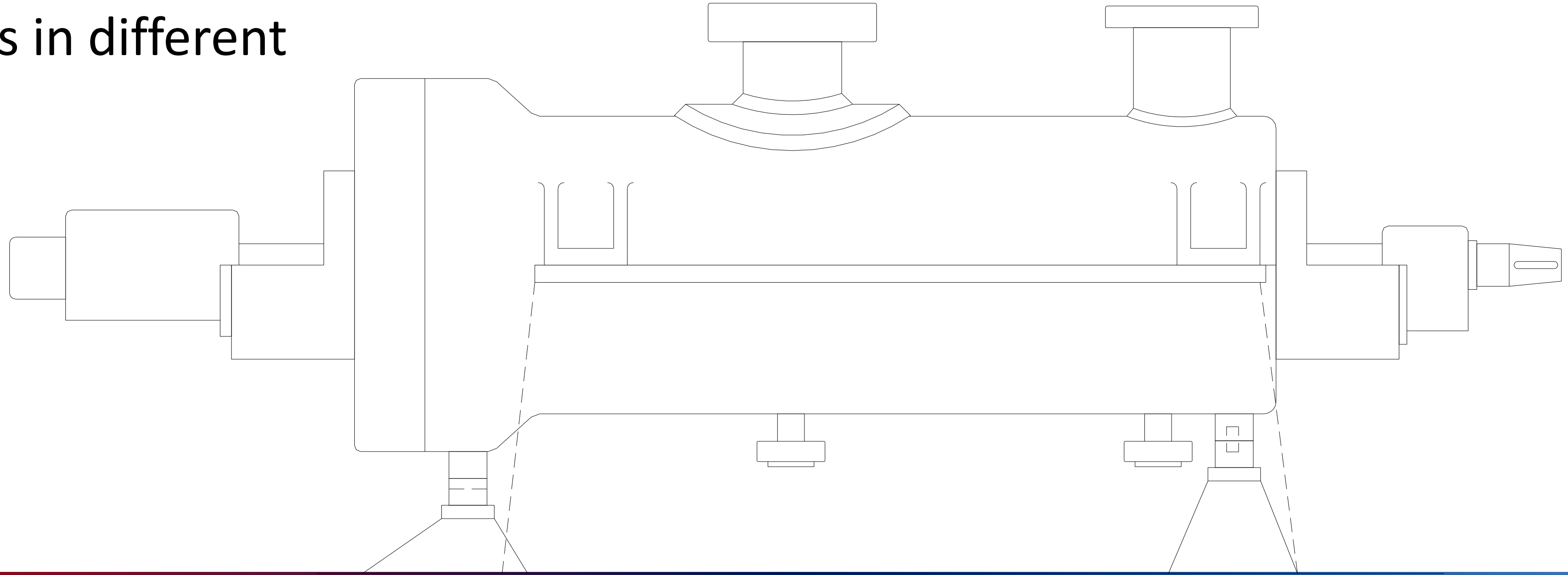
Poor Hydraulic Performance from Large Barrel Pumps

A team was formed and another analysis was started to try and determine the root cause. This time, a discrepancy was noted almost immediately. There was a critical difference between the depiction of the case drains in the pump cross-sectional drawing and the general arrangement drawing. The Cross-Section showed three case drains. The General-Arrangement only showed two case drains.

We needed to determine which drawing was correct.



Two original drawings show a different number of case drains in different locations.



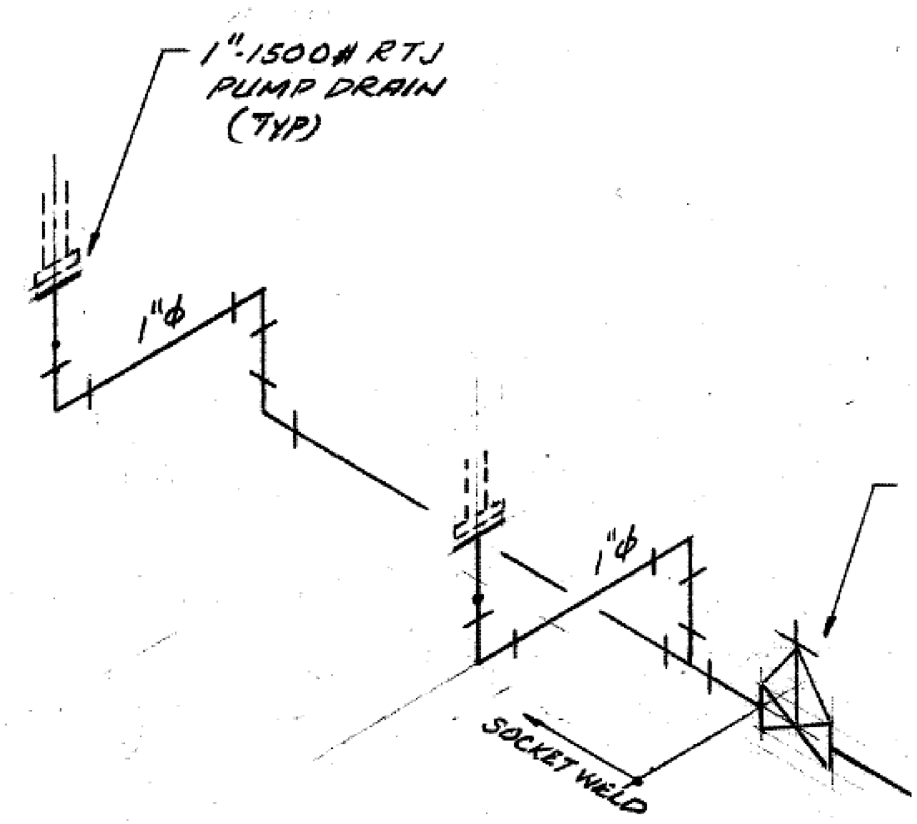
Poor Hydraulic Performance from Large Barrel Pumps

Pictures from previous repairs clearly showed two case drains inside the outer casing. One was located in the suction portion of the casing. The other one was in the discharge portion of the casing.

Poor Hydraulic Performance from Large Barrel Pumps

Piping drawings were reviewed. The isometric drawing of the drain piping showed two drain lines manifolded together into a single line with one block valve.

A field walkdown was performed to verify the configuration of the piping. The piping matched the isometric drawing. The two drain lines were manifolded together with a single block valve on the common line.



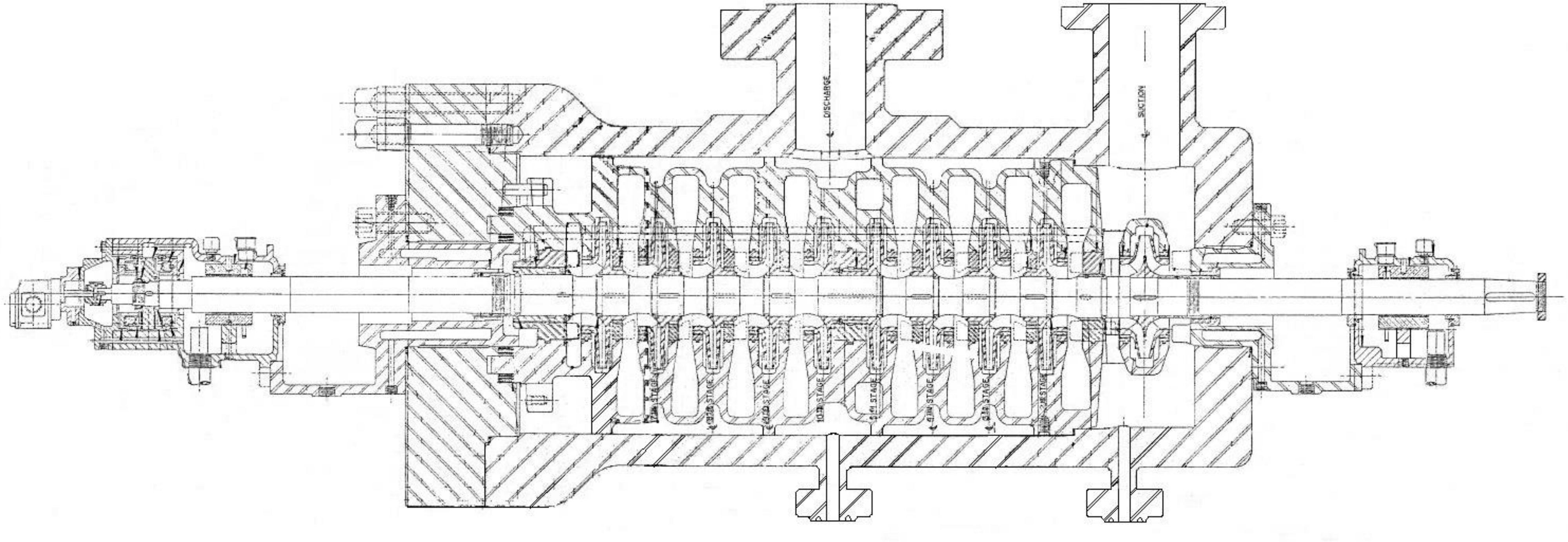
Poor Hydraulic Performance from Large Barrel Pumps

Root Cause

The two case drains were piped together making a direct bypass of discharge pressure back to suction.

- The piping was modeled. With a differential pressure of 1800 psi (124 bar), the drain piping was bypassing about 200 gpm (45 m^3/hour) or one third of the rated flow of the pump.
- The location of the discharge drain was at the largest diameter inside the casing and at the low point of the case. This was serving to concentrate the solids like a centrifuge and direct them back into the pump suction, accelerating the abrasive wear.

Poor Hydraulic Performance from Large Barrel Pumps



The original cross-sectional drawing was modified to shot the actual location and configuration of the case drains

Poor Hydraulic Performance from Large Barrel Pumps

Solution:

Replace the case drain piping. Run two independent lines with separate drain valves.

Note: This problem was unique to the two newer pumps (C and D). The older, original pumps (A and B) did not have the drain lines tied together this way.

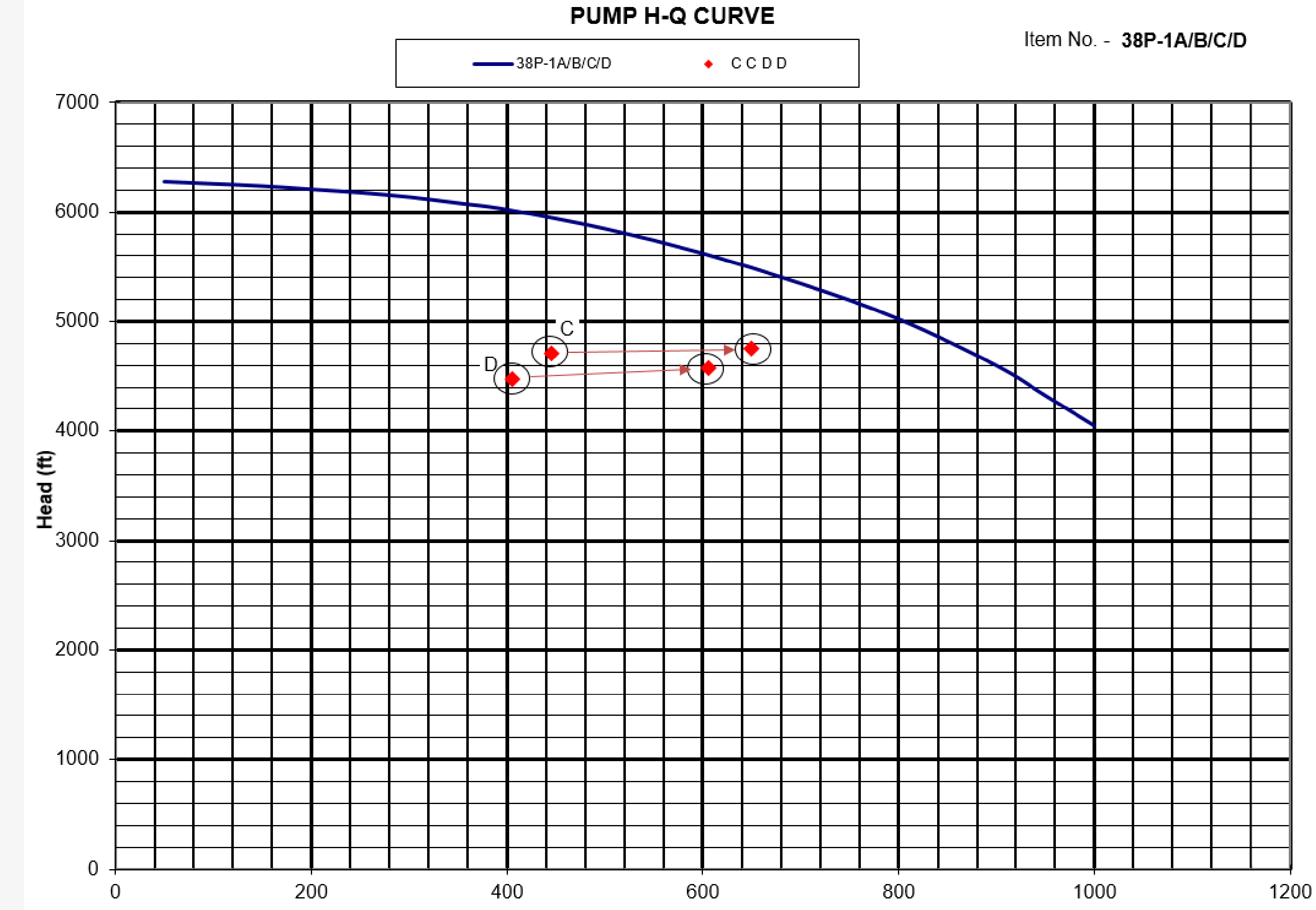
Poor Hydraulic Performance from Large Barrel Pumps

Outcomes:

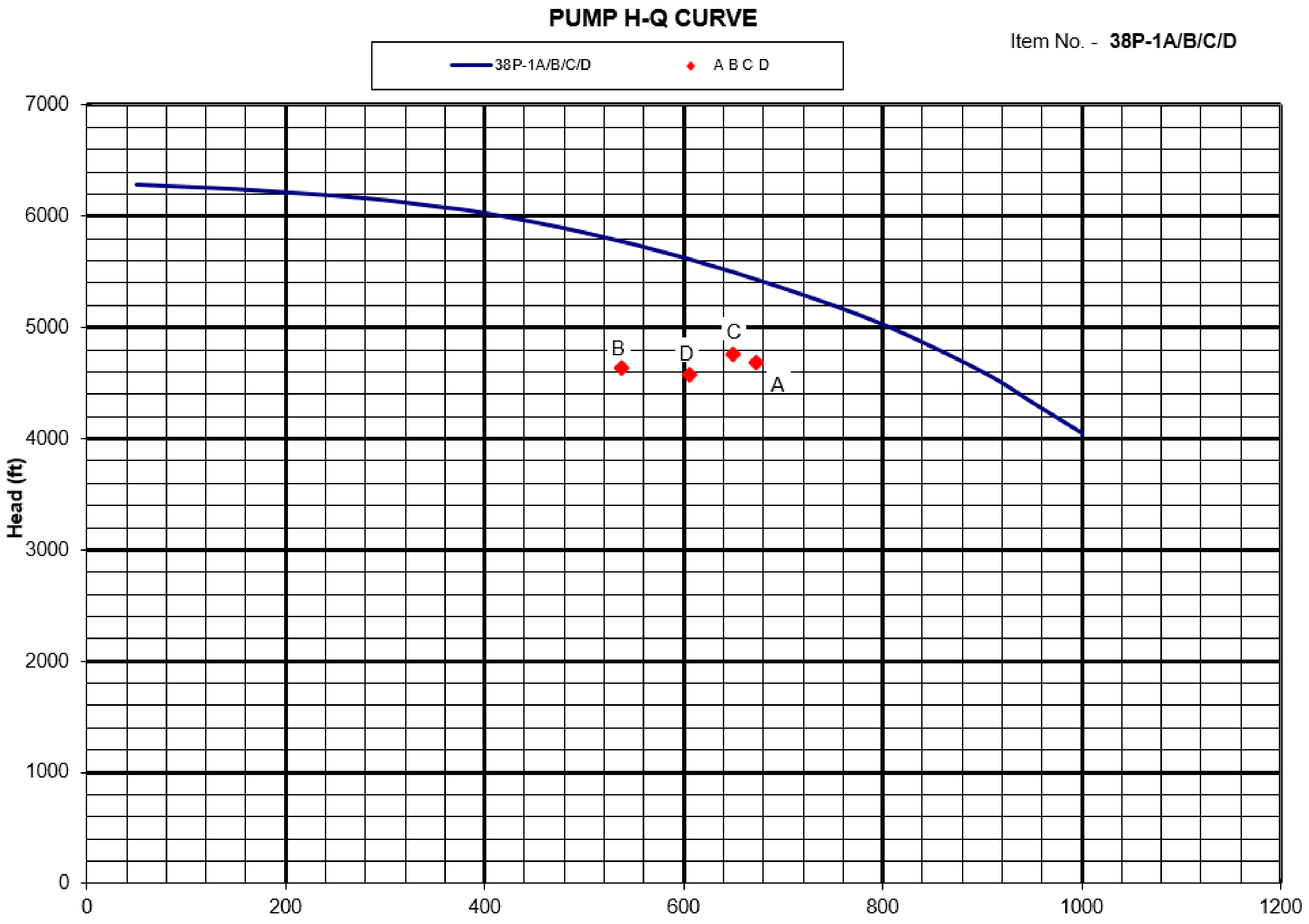
The drain lines on the D pump were modified to eliminate the bypass. The flow from that pump increased by about 7000 bbl/day. Performance improved from 76% of curve to 86% of curve. Operators were able to drop back to running three pumps out of four and increase the capacity of the unit by about 2000 bbl/day.

Because of leaking block valves, we have not been able to complete the modifications to the C pump. This is planned for the unit turnaround currently in process. The following plots are based on the expectation that we will see the same improvement with C pump as we did with D pump.

Poor Hydraulic Performance from Large Barrel Pumps



Poor Hydraulic Performance from Large Barrel Pumps



Full performance was not restored because the pumps had been running for years with abrasive solids present. It is believed that the case drain error was also accelerating the abrasive damage by directing the solids back to the suction, over and over again.

Poor Hydraulic Performance from Large Barrel Pumps

Economics:

- The piping modifications cost about $20,000 (US).
- Shutting down the fourth pump saved 1200 HP.
- Increasing unit capacity was able to generate substantial revenue.
- Utilization risk was reduced by restoring a full spare pump to the service.

Poor Hydraulic Performance from Large Barrel Pumps

Lessons Learned

- Details mater – A small error on one drawing resulted in a piping mistake. That piping mistake has cost many millions of dollars over the past 25 years.
- Don't assume anything – When we found the difference between the two drawings, we almost brushed it aside as unimportant.
- Abrasive damage to wear rings and bushings can occur at very specific locations based on flow paths.