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FLOWSERVE

Improvement of pump/plant performance by sound evaluation of both process fluid viscosity change and pump internal leakage

Giancarlo Cicatelli - Bruno Schiavello

Giancarlo Cicatelli is currently holding the position of Engineering and Technology manager for Flowserve in the Engineered Pump Division. He has started his industrial career serving as product design specialist, R&D team leader and manager of the Customer Service for the O&G business. He has his office in Italy.

Previously he was Research assistant at the von Karman Institute in Belgium and at the University of Cambridge (UK), focusing his interests in the field of Fluid Dynamics of Turbomachinery, in the area of gas turbine research.

He holds a PhD in Applied Sciences from the University of Brussels and has a master in Nuclear Plant Construction management from Polytechnic of Milan. He obtained his BS degree in aeronautical engineering from the University of Naples, Italy.

His principal technical fields of interest are focused on the Fluid Dynamic of Turbomachines, for the design, development and testing of centrifugal pumps and pumping systems. He is author of several scientific publications in the field of Fluid Dynamics applied to turbines and pumps.

He has been member of the Middle East Turbomachinery Symposium Advisory committee and Europump Technical committee member. He is also member of the Organizing committee of the ASME Pumping Machinery Symposium (2009-2015)

Bruno Schiavello is Director for Fluid Dynamics at Flowserve, Advanced Technology Pumps Department, in Bethlehem, Pennsylvania.
He started in 1975 with the R&D Department of Worthington Nord (Italy), joined in 1982 the Central R&D of Worthington, USA .

- Co-winner of the H. Worthington European Technical Award in 1979.
- Author of several papers and lecturer at various Seminars for pumps (suction recirculation, cavitation, two-phase flow) .
- Member of ASME (1984), and former Associate Editor for ASME JFE (1996-2002) .
- Recipient of the ASME 2006 Fluid Machinery Design Award, 2006
- Co-Lead Organizer of ASME Pumping Machinery Symposium (2005 – 2015)
- Member of Pump Advisory Committee for the International Pump Users Symposium 1984.

Mr. Schiavello received a B.S. degree (Mechanical Engineering, 1974) from the University of Rome, and a M.S. degree (Fluid Dynamics, 1975) from Von Karman Institute for Fluid Dynamics, Rhode St. Genese, Belgium.

Abstract

In the modern pump industry, processed fluids are characterized by a wide spectrum of viscosity values. An unpredicted variation of actual process fluid properties, including viscosity, may lead to unexpected pump performance alteration.

Also manufacturing deviations from expected internal pump geometry may cause pump performance deterioration

Both causes may determine undesired limitations of the pump operating range and plant production loss.

The present Case Study illustrates a real case story of incorrect evaluation of the process fluid viscosity and pump geometry deviations, both determining performance deteriorations, described through a detailed evaluation of the internal pump losses.

From the presentation of a real case, this case study highlights the importance of both the correct evaluation of viscous effects and the internal pump geometry through the application of existing loss correlations.

Summary

- Introduction
- Thoretical background
- Loss description
- Case story
    - Pump
    - Application and Condition of service
    - Data analysis
    - Solutions
    - Comments
- Conclusions and Lesson learned

Introduction

Pump industry is often faced with the problem of dealing with a variety of pump design issues. From performance to metallurgical challenges, pump technology is called to provide an answer to pump user demand.

Among the wide collection of technological issues, the viscous characteristics of the pumped liquid versus the pump design and selection, represents one of the most critical fluid dynamic parameters to be considered.

Also manufacturing deviation of pump geometry, namely internal clearances, can have high impact on performance with low capacity, high head multistage pumps

This real case aims to highlight the importance of a correct evaluation of both the liquid viscosity effects and internal clearances on pump performance. The application of existing correlations for loss analysis with ultimate impact on pump performance and plant production is outlined.

Theoretical background

Pump hydraulic design is the result of a compromise between a number of conflicting needs. Pump performances are ultimately influenced by internal losses that need to be evaluated and weighted against pump requirements in order to be minimized and made compatible with the overall design objective. One of the key factors in the determination of the internal losses is the liquid viscosity.

The dependence of the losses with the viscosity is in general evaluated through the Reynolds number; non-dimensional number which represents the relative importance of the convective or inertia forces against viscous forces.

$$\mathrm{Re} = \frac{V \cdot L}{\nu}$$

Loss dependence with Reynolds number

Mechanical losses		No dependence on Reynolds number
Volumetric Losses		Geometry, Reynolds number
Hydraulic Losses	Friction Losses	High dependence on Reynolds number
	Mixing Losses	Low dependence on Reynolds number
Disk Friction Losses		Dependence on Reynolds number

Methods to calculate disk friction losses, volumetric losses, hydraulic losses, are widely published in the literature. They are based on experimental correlations, which take into account specific geometrical characteristics of the pump under evaluation and process fluid parameters.

Volumetric losses

Volumetric losses account for power losses originated by internal liquid leakage through the pump internal clearances, mainly wear rings and balancing drum clearances. They are strongly affected by the geometry of the clearances and depend on Reynolds number, which is usually in the laminar regime. In general terms volumetric losses decrease with the increase of viscosity since the friction factor in the clearance grows with decreasing Reynolds number. Volumetric losses are highly dependent on internal clearances

Volumetric loss thru balancing straight drum is dominant with multistage pumps, particularly with low Ns-stage and high number of stage.

Hydraulic losses

Hydraulic losses can be described as head (or total pressure) losses and can be represented as the result of two different contributions: *Friction losses* and *Mixing losses*.

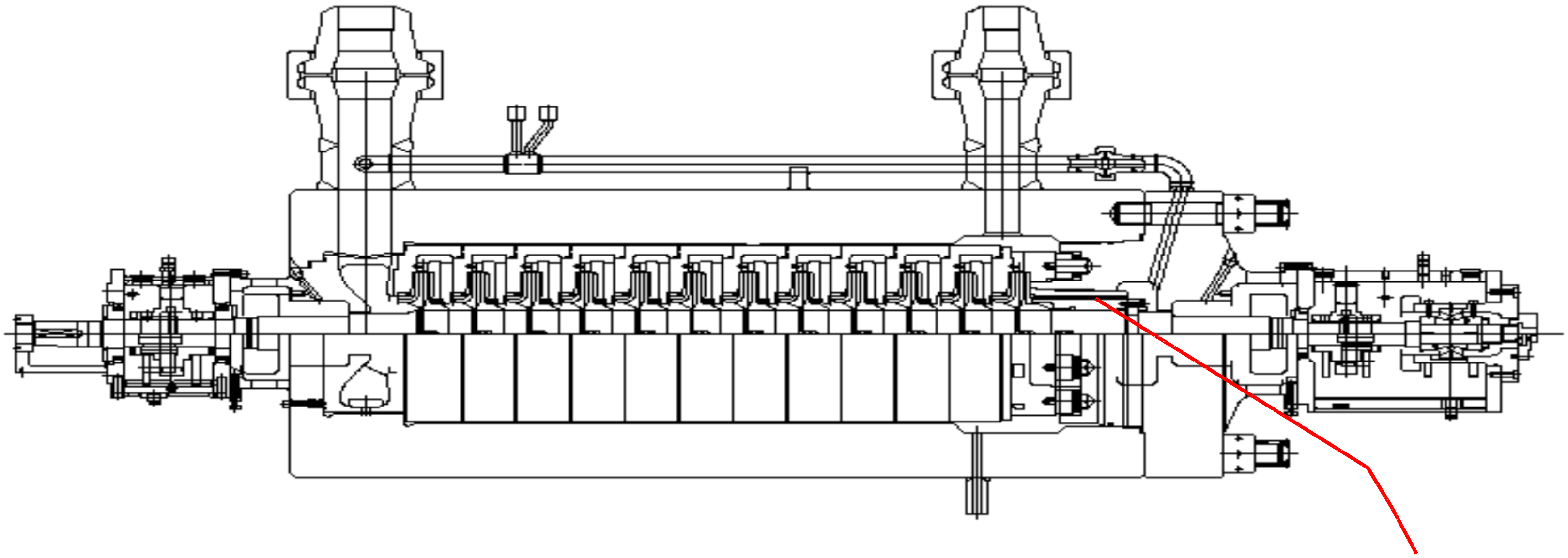
Friction losses, caused by the shear effect of the liquid against walls of all hydraulic passages, are strongly Reynolds dependent. On the other side, with the term of *mixing losses* it is generally indicated the losses caused by non uniformity of the liquid, as it appears when there is a local velocity non uniformity: i.e. wakes, separated flows, secondary flows in the form of intense vortical activity. In all those phenomena, convective terms are strongly predominant on viscous terms and bringing the pertinent Reynolds number on the high range, corresponding to fully turbulent flows.

Disk friction losses

Disk friction losses normally identify the power losses generated on the external surfaces of impeller shrouds which are spinning the liquid entrapped in the side cavities formed between each impeller shroud and the facing side wall of the stationary casing. These losses vary significantly with viscosity and then result to be Reynolds number dependent.

CASE STORY: The pump

12 stages radially split diffuser type pump.
All the impellers are assembled with "in-line" orientation.



Straight drum on the right is used for balancing axial thrust with return of balancing line to the pump suction nozzle

CASE STORY: Application and C.O.S.

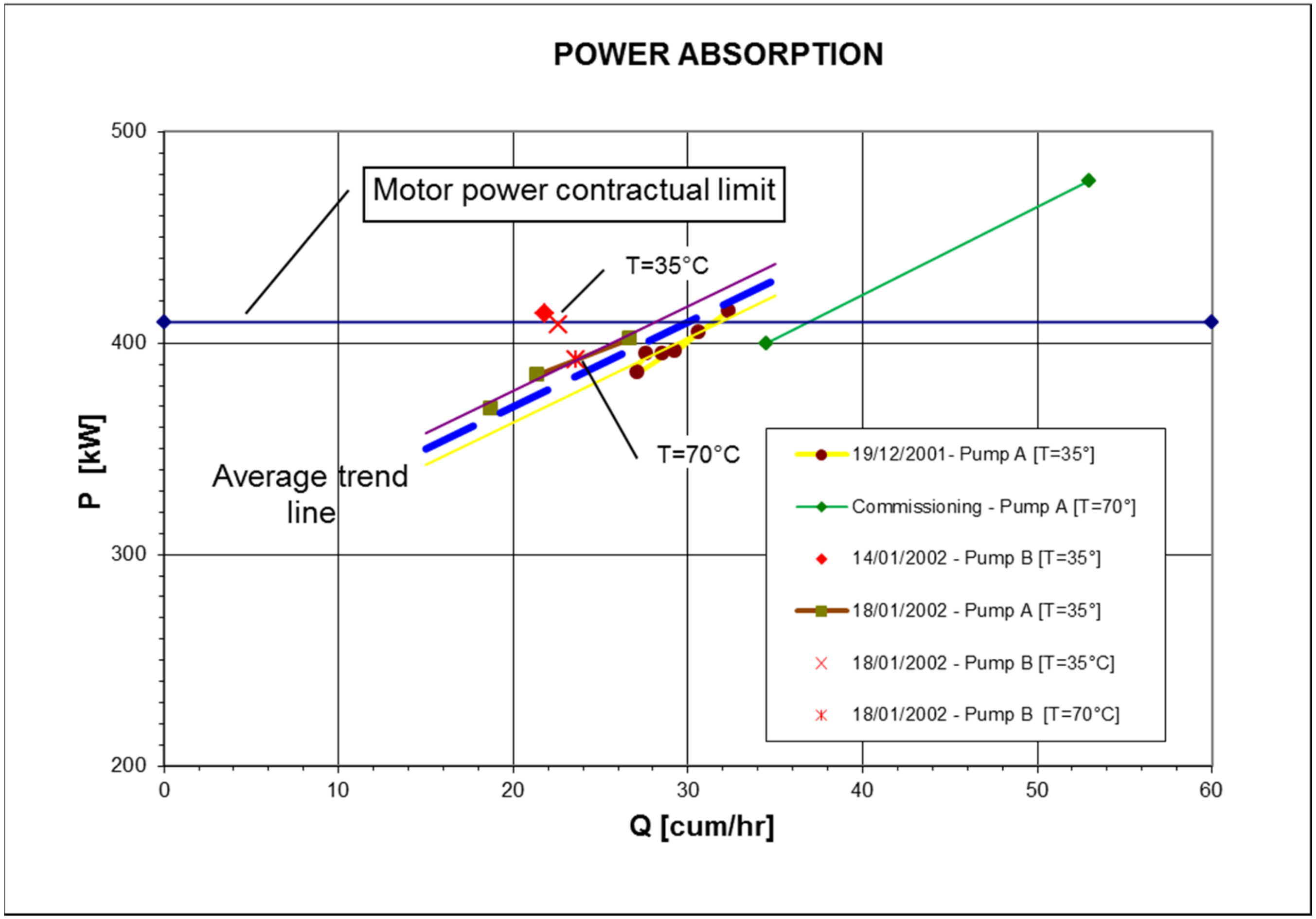
Two identical pumps were installed in a petrochemical plant on a hydrogenation service. The pump service was a reactor feed with nearly constant discharge pressure and minimal system friction losses i.e. constant head operation.

One pump was operating (100% capacity) and the other was on stand-by.

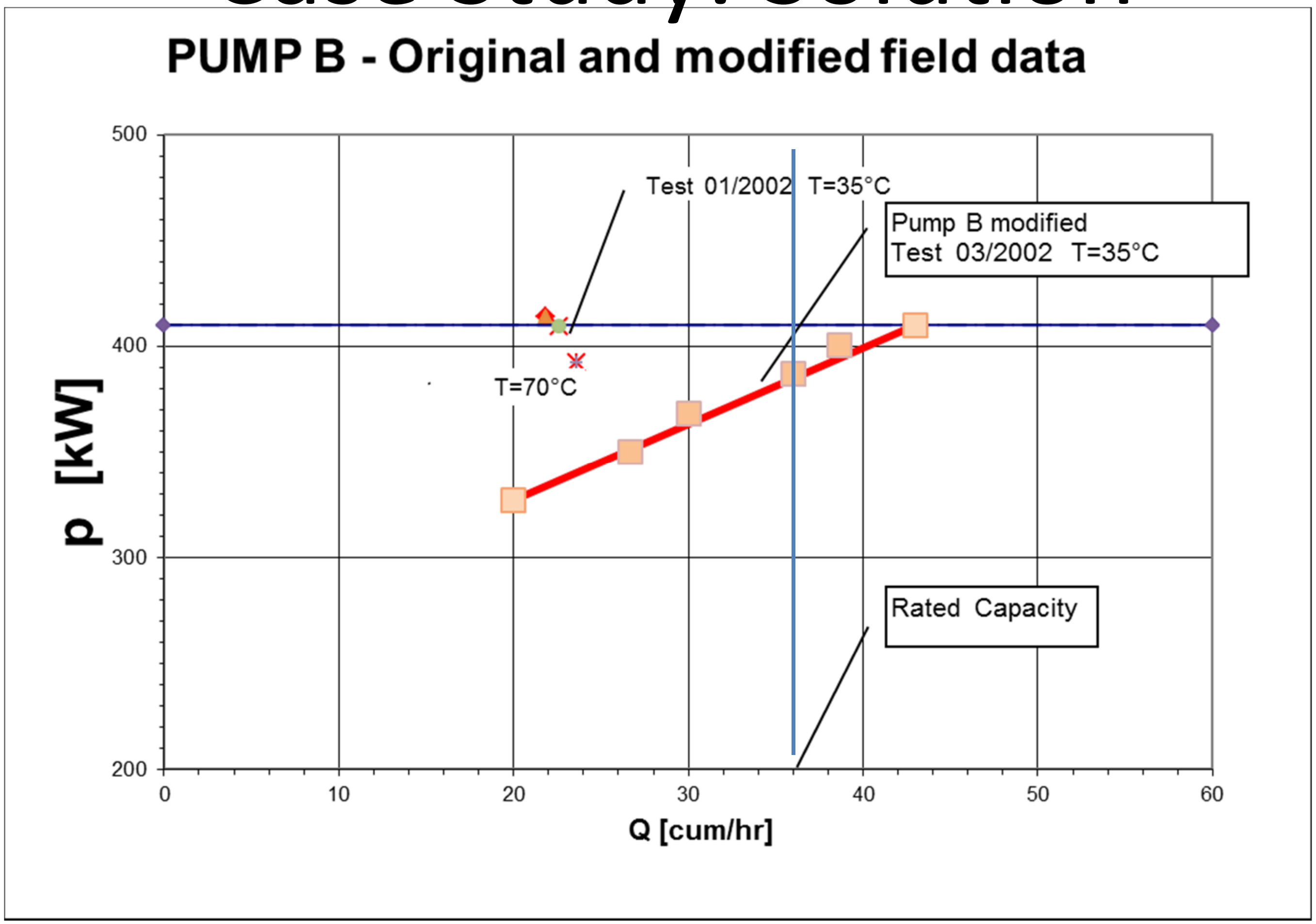
Speed	2980 rpm	
Q_{RATED}	36 m^3/hr	158.6 gpm
H_{TOT}	1655 m	5435 ft
N_S(stage-rated)	74.0	383 US
T_{FLUID}	80°C	176 °F
Power limit	410 kW	595hp

-	T= 80°C	T=35°C
Specific gravity	0.80	0.82
Viscosity μ	0.79 cP	2.5-2.7 cP

CASE STORY: Field performance data



Case Study: Solution



Case Study: Analysis & Solution

RELATIVE LOSS ANALYSIS: Original design (A,B) and B modified											
									Loss difference vs reference [%]		
Pump	Field Test Date	Scope	Fluid Temp (°C)	Qmax @ Pmax (410kW)	Qmax/Qrated (%)	Pump geometry	Fluid viscosity [Cp]	Re/Re(ref)	Head	Disc friction	Overall leakage
A	-	Commissioning	70	37	103	Design (Ref)	0,79	1	=	=	=
A	Dec01-Jan02	Field test	35	30	83	Design (Ref)	2,6	0,3	+5	+3	=
B	Jan- 02	Field test	70	29	80	Design deviation(*)	0,79	1	=	=	+14
B	Jan-02	Field test	35	23	64	Design deviation (*)	2,6	0,3	+5	+3	+14
B mod	**Mar-02**	**Field test**	**35**	**43**	**119**	**Des. improv.(**)**	**2,6**	**0,3**	**+5**	**+3**	**-10**

(*) Balancing drum: i) large clearance ii) eccentricity

(**) Reduced clearance of balancing drum and wear rings + orifice plate in the balancing line

1) Balancing drum: marked reduction of clearance and centered
2) Wear rings: slight reduction of clearance
3) Orifice plate in the balancing line (higher resistance)

Case Study Pump Geometry:
Field Inspection and Modification

Field Inspection

Pump A : Internal geometry was found as designed, particularly internal clearances (wear rings and balancing drum) complying with API values and within manufacturing tolerances.

Pump B : Significant geometrical deviation from design:

a) wear rings – clearance slightly higher

b) balancing drum – clearancesignificantly higher plus radial offset (eccentricity)

Modification

Pump A : No change

Pump B :

- New balancing drum with reduced clearances (< API) and centered
- Special long orifice in the balancing line (high L/D) with higher hydraulic resistance.
- New wear rings with slightly reduced clearances (API minimum)

COMMENTS - ANALYSIS

Pump A (T=70°C) was in line with the shop test within the approximation of the measurements and process fluctuations over the period under field commissioning.

Pump A (T=35°C) gave an increase of the liquid viscosity by a factor 3x. The consequent difference in viscosity had an impact on the absorbed power which could be quantified in ~20-25kW (Pump A). This was confirmed by loss analysis as excess of: a) hydraulic head loss (Re)   b) disc friction power loss (Re)

Pump B (T=70°C) did experience an excess of leakage through the balancing drum which resulted in some excess of absorbed power compared to the actual performance of pump A. The actual clearances (pump B) were found higher then the design clearance. The volumetric loss analysis partially under-predicted the field leakage pointing to additional source of leakage. This was identified with a radial offset of the drum (eccentricity) after a more accurate inspection.

Pump B (T=35°C) experienced additional losses due to viscosity increase, which is comparable to similar effects seen in pump A

COMMENTS - SOLUTION

Calculations of volumetric (power) loss indicated that a reduction of the balancing drum clearance from the original design (API) to 0.33 mm (dia), would translate in a reduction of power absorption of 19-20 kW. In addition, the reduction of clearance in the wear ring resulted in a further reduction of power loss related to leakage. Furthermore, an increase of hydraulic resistance in the balancing line with an orifice plate, lead to an even more reduction of leakage through the balancing line with consequence of further reduction of power loss. Overall, pump B modified as above, showed that the max capacity at the specified limit power was above the rated capacity.

The approach of reducing the clearance of balancing drum is based on past experience with similar pump applications (size, speed, power, material, liquid) ensuring reliable operations and essentially complying with API specs (balancing drum clearance not compulsory).

CONCLUSIONS

The presentation of a real case story shows the consequences of: a) large variation of the process liquid viscosity with the process temperature range, leading to large pump performance variations, b) deviation of pump geometry (balancing drum clearance) causing additional deterioration of field performance, all leading to a reduction of operational pump capacity and plant output.

Based on correct field data and pump loss models analysis, it was possible to identify the causes of the apparent pump deterioration and the means for enhancing the plant production.

The dominant parameters could be clearly segregated and independently linked respectively, to the system design/operation factors, and to the pump design or manufacturing aspects.

The relative degree of positive impact of each parameter, on plant financial results, could be anticipated. This led to a clear action plan, with high potential for getting or even exceeding the plant production target in a short and costly effective field implementation.

LESSON LEARNED

The responsibility of each actor (process designer/operator, pump designer) could be made easier and facilitated by a shared understanding of the technical aspects, as a basis for a clear separation of system related issues (process parameters optimization) from pump aspects.

The prediction of the key loss components, given by individual loss analysis methodology, was fully consistent with field performance data, and so providing even more confidence to the pump designer/analyst.

The solution steps, with highest potential benefit and compatible with the process optimization, have been implemented with full satisfaction of the customer, both for the high pump reliability and plant production maximization.

Thank you for the attention!