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Pumping of Viscous Sucrose Solutions with Centrifugal Pumps

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Abstract

Applying centrifugal pumps for the pumping of viscous sucrose solutions has been difficult due to a lack of test data and an accurate viscosity correction method. In practice, many of these applications are suitable for centrifugal pumps when attention is paid to the appropriate pump design. Often viscous fluids have a high air content, so a gas removal pump ASP from Sulzer Pumps is a promising solution. Test results of pumping beet sugar molasses with normal and gas removing centrifugal pumps are presented. Experimental viscosity correction factors are compared to those of Hydraulic Institute.

1 Introduction

In the sugar industry, there has been growing interest to extend the use of centrifugal pumps to viscous sucrose solutions in the crystallization department. Traditionally, positive displacement pumps have been used for main process fluids throughout the crystallization process, starting from A sugar massecuite all the way to molasses. When looking at pumping efficiency only, the economical viscosity limit for centrifugal pumps is about 150 mm^2/s (150 cSt). [1] On the other hand, centrifugal pumps have some other benefits that increase the total cost efficiency: insensitiveness to hard impurities and foreign particles in the pumped media (e.g. in start-up), gentle transport of flocs or crystals, simple design, simple flow control, no need for a safety valve or recirculation line and relatively low purchase and maintenance cost.

Generally, 1000 mm^2/s (1000 cSt) is considered as some kind of maximum viscosity for centrifugal pumps. In practice, it is possible to use centrifugal pumps for even higher viscosities. Elevated viscosity decreases head and efficiency of the pump and increases power consumption (Fig. 1). One practical problem is how to make the required corrections to flow rate Q, head H and efficiency η, which are normally measured with water. The target is to get optimum pump selection with reliable operation but still without excessive oversizing. No actual test data or correction method for specific viscous fluids like sucrose solutions are publicly available. For this reason, general viscosity correction methods have been used or centrifugal pumps have been neglected totally.

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The correction factors published by Hydraulic Institute (HI) [2] are widely used to predict the performance of a centrifugal pump with viscous fluids. When the characteristic for pumping water is known, that for a viscous liquid can be determined by multiplying the water values by correction factors fQ, fH and fη. Thus

$$Q_v = fQ \cdot Q_w$$

$$H_v = fH \cdot H_w$$

$$\eta_v = f\eta \cdot \eta_w$$

where Q is flow rate, H is head, η is efficiency and subscript w refers to water and v to viscous fluid. Power input P for viscous fluid is then calculated from the following formula:

$$P_v = \frac{\rho_v \cdot g \cdot H_v \cdot Q_v}{\eta_v}$$

The correction factors of HI are a conclusion based on tests of conventional centrifugal pumps with petroleum oils, so they are not exact for other fluids or special hydraulic designs. In many cases, the correction method of HI gives a much too pessimistic prediction of pump performance and thus tremendous oversizing.

Another problem involved in practical viscous process fluids is entrained air. Air bubbles are mixed into the fluid typically in the inlet flows of the tanks, in outlet vortices when the liquid level is low and in other process equipment that whip the fluid surface. Since the rising velocity of the bubbles is relatively high in viscous fluids, they are not released in tanks but trapped and taken by the flow. In the centrifugal force field of the pump, air tends to separate from the fluid and form a bigger bubble that ”plugs” the flow channels from the liquid flow. The air bubble decreases the pumping capacity and pumping may eventually collapse totally. As presented in Table 1, measurements [3] in different beet sugar factories have shown that the air content of A sugar run-off, B sugar run-off and molasses can be well over 10 %. Together with a high viscosity, this amount of entrained air can cause serious problems for normal centrifugal pumps.

Sulzer Pumps has long experience of pumping “difficult” liquids in industrial processes. Viscous and often non-newtonian fiber suspensions and chemicals in the pulp and paper industry have forced the company to develop special pump designs. Many of these design features are applicable to the sugar industry, too.

2 Experimental Tests and Equipment

2.1 Test Fluids

In order to find a more accurate method of pump selection for crystallization applications, several pumps were tested in a laboratory with an actual process fluid. The test fluid was beet molasses (purity q = 63 %) which is assumed to give a good estimate of pumping also A sugar run-off and B sugar run-off. Its refractometric dry substance (RDS) content was modified between 76 - 85 % by diluting with water and again evaporating. The majority of the tests were made at 50°C. The reference tests were made at 40 and 70°C.

Some tests were carried out with air containing molasses by adding pressurized air into the flow pipe on the inlet side of the pump. The performance of a normal centrifugal pump was compared with a special gas removal pump, type ASP, from Sulzer Pumps.

2.1 Test Methods and Equipment

The refractometric dry substance content (RDS) was analyzed according to the factory standard of Sucros Ltd which uses a 1:1 diluted molasses sample. The viscosities of the molasses with different RDS values and temperatures were measured with a Haake VT500 rotational viscometer which can determine viscosity as a function of shear rate.

Four different pump sizes were selected for the tests, keeping in mind the capacity range required in crystallization. The tested pumps were single stage, end-suction type with semi-open impellers that were originally designed for handling non-newtonian fiber suspensions. The main characteristics of the test pumps are shown in Table 2. The tested gas removal pumps have the same hydraulic characteristics as normal pumps, added with a gas separating capability and integrated liquid ring vacuum pump for removing the separated gas. The cross section of the ASP gas removal pump is shown in Fig. 2.

The pumping tests were done in a full scale test loop in a laboratory. The volume of the pump tank was about 4 m^3 and it was equipped with a cooling/heating jacket to maintain the required temperature. A schematic diagram of the test arrangement and measurements is shown in Fig. 3. The measurements were arranged in accordance with relevant testing standards, e.g. ISO 2548.

3 Results and Discussion

3.1 Viscosity Measurements

The viscosity measurements showed that beet molasses has newtonian behavior, i.e. its viscosity remains constant at changing shear rates. The measured dynamic viscosities at 40, 50 and 70°C for different RDS values are shown in Fig. 4. The measured viscosities follow reasonably well the values presented in Sugar Technologists Manual [4]. For hydrodynamic purposes, the mostly used kinematic viscosity ν is obtained from dynamic viscosity η by dividing it with density ρ:

$$\nu = \frac{\eta}{\rho}$$

3.2 Pumping Tests with Normal Centrifugal Pumps

A comparison of pump head curves when pumping water and molasses at 50°C with different RDS values is shown in Fig. 5. This pump shows the typical behavior at elevated viscosity: At low flow rates, the pump gives even a higher head with molasses than with water. When the flow rate increases, the head with molasses decreases below the water curve. The explanation is that at a low flow rate, leakage through gaps between the impeller and casing is smaller when the viscosity is higher. At higher flow rates, friction losses in flow channels increase and start to rule the behavior, thus decreasing the head. Generally, head curves for viscous fluids are quite nice-looking and pump operation is very stable under all tested conditions. The curves show that this pump can handle molasses of RDS 85.2 % at 50°C. The dynamic viscosity of this molasses is about 4700 mPas (4700 cP) and its kinematic viscosity is 3260 mm^2/s (3260 cSt). At a higher temperature, the RDS value could be even higher, since viscosity decreases when temperature rises. Practically all A sugar run-off, B sugar run-off and molasses pumping applications in sugar processes fall below this limit. In storage tanks, the temperature is often lower, so the viscosity needs to be checked when selecting the pump.

An efficiency comparison for the same pump is shown in Fig. 6. The efficiency decreases clearly when viscosity increases. According to a theoretical analysis, most of the efficiency loss is caused by increased disc friction losses.

It is possible to calculate experimental correction factors fQ, fH and fη for flow, head and efficiency when pumping molasses. According to the tests, flow correction factor fQ was

close to 1 in many cases, so in this presentation we concentrate on head and efficiency correction factors, fH and fη. In Fig. 7 and 8 are shown experimental fH and fη correction factors at the best efficiency point for all tested pumps. In Fig. 9 and 10, correction factors fH and fη obtained by the HI method are compared to corresponding experimental correction factors. Correction factor fH and especially fη for different pumps deviate very much from each other. The deviation is caused by different impeller shape (indicated by specific speed n_q), impeller diameter and rotational speed. The HI method gives clearly too pessimistic correction factors in all cases. E.g. for pump number 2 and the molasses of RDS 85.2 %, the theoretical fη is 0.0 (extrapolated value), which would mean that the power input is infinite. In practice, it is far from that.

The correction method of HI does not make any difference between different pump designs or rotational speeds. Therefore, it seems to be too simplified and in practice, it prevents the selection of a centrifugal pump even though one would work properly. As a consequence of these test runs, Sulzer Pumps has developed a pump selection method which is tailored for viscous fluids in the crystallization department of sugar factories. This method takes into account specific design features of the pumps and differences between pump sizes.

3.3 Pumping Tests with Air Containing Molasses

The influence of air content on the head curve of a normal centrifugal pump is shown in Fig. 11. The test fluid is molasses of RDS 77 % at 50°C, and air is fed into the suction pipe of the pump. Air feed is controlled to maintain a constant volume percentage of 5 % at each volume flow. This amount of air has a drastic influence on the characteristics of the pump, and in a practical application, the flow would collapse totally. When the same test is done with the ASP gas removal pump, the curves look very different (Fig. 12). The head curve of air containing molasses follows very closely the curve of air-free molasses. Only when the flow exceeds the best efficiency point, there is a clear distinction between the curves. The duty point for a viscous fluid is normally selected from the left side of the best efficiency point, since elevated viscosity makes head curves steeper. Thus the air content does not require any extra correction when a gas removal pump is used.

4 Conclusion

The pumping tests show that a centrifugal pump with the appropriate hydraulic design can deliver all other sucrose solutions in sugar factory crystallization except massecuites. This has also been proven in actual factory conditions with numerous references. The practical limit for the refractometric dry substance content (RDS) is somewhere close to 85 %, but it is strongly dependent on pumping temperature and pump size. When the viscosity correction is done with a specific calculation method for sugar factory fluids and the given pump design, pump sizing and especially motor sizing can be optimized. If a general viscosity correction method (e.g. by Hydraulic Institute) is applied, pump selection is safe but usually the pump and motor are generously oversized and uneconomic. Sometimes too conservative viscosity correction makes pump selection impossible.

According to air content measurements in several sugar factories, viscous fluids often have a high air content. Some pumping problems that have been addressed to high viscosity may actually be caused by a high air content. For this reason, the ASP gas removal pump has been applied in sugar factories. Both real applications and laboratory tests have proven that ASP is able to pump air containing viscous sucrose solutions.

Bibliography

[1] Sulzer Centrifugal Pump Handbook. Elsevier Science, Oxford 1998.
[2] American National Standard for Centrifugal Pumps. Hydraulic Institute, Parsippany 1994.
[3] Air Content Measurements of the Process Fluids in Different Beet Sugar Factories. Sulzer Pumps, 1997 - 2000. Unpublished.
[4] Bubnik, Z.; Kadlec, P.; Urban, D.; Bruhns, M.: Sugar Technologists Manual. Verlag Dr. Albert Bartens, Berlin 1995.

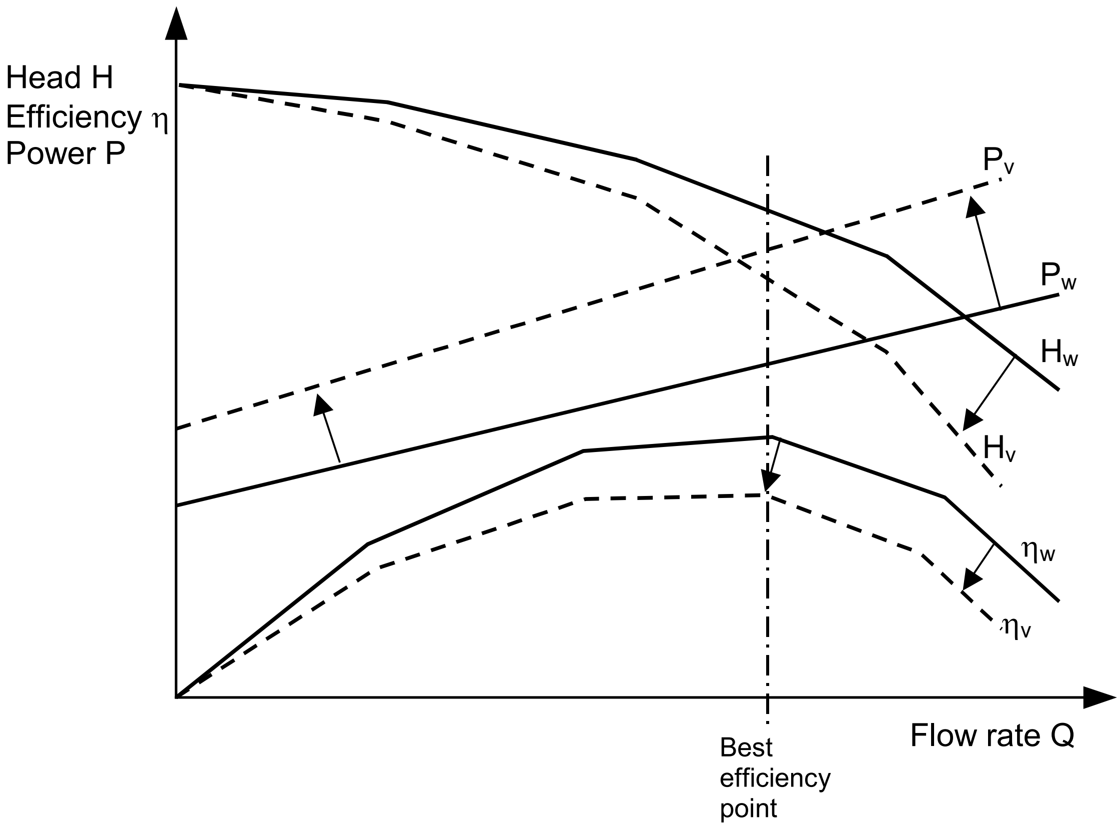

Fig. 1 Change in the characteristics of a centrifugal pump when pumping viscous fluids. Subscript w refers to water and v to viscous fluid.

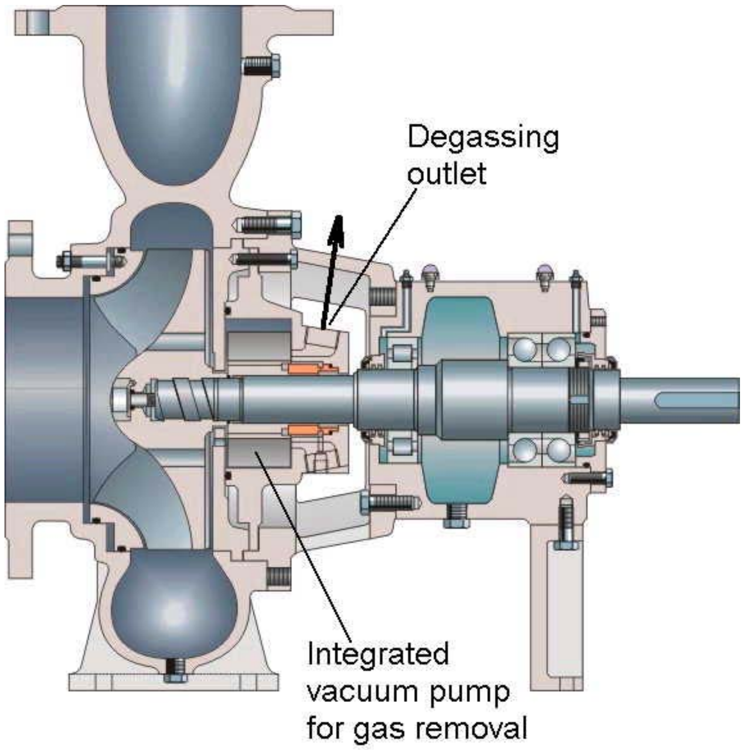

Fig. 2 Cross section of the ASP gas removal pump from Sulzer Pumps.

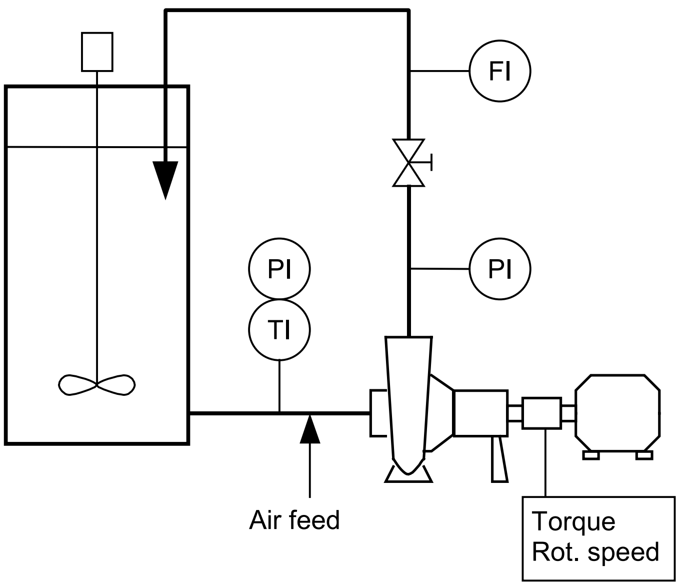

Fig. 3 Schematic drawing of the test arrangement.

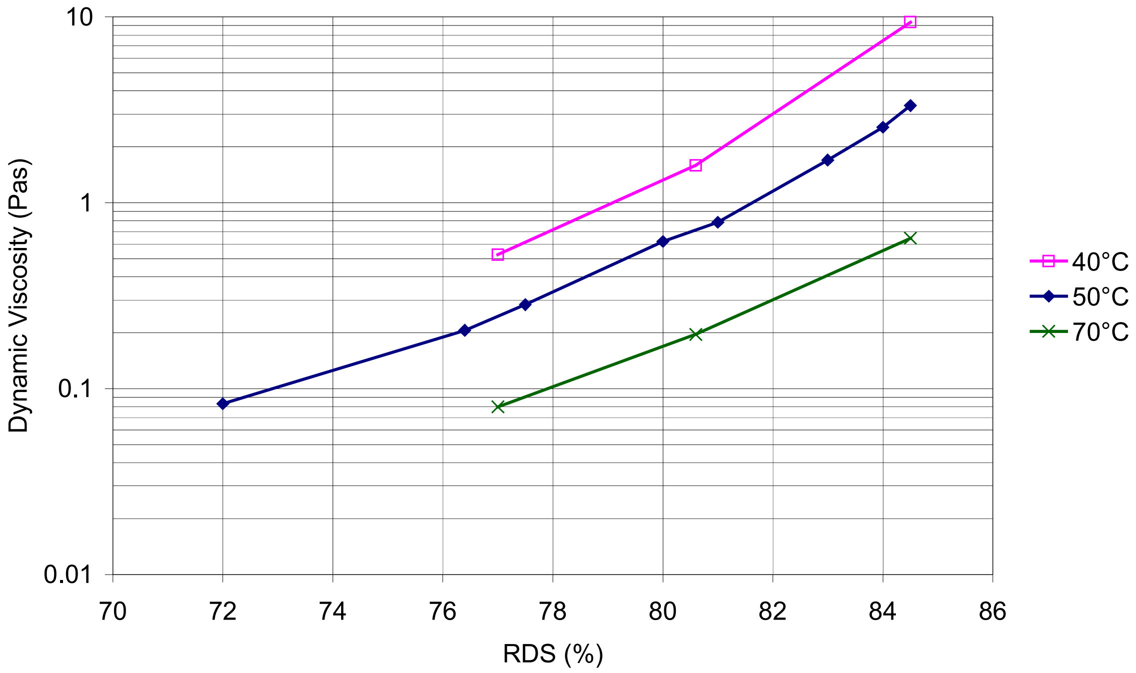

Fig. 4 Measured dynamic viscosity for beet molasses at 40, 50 and 70°C.

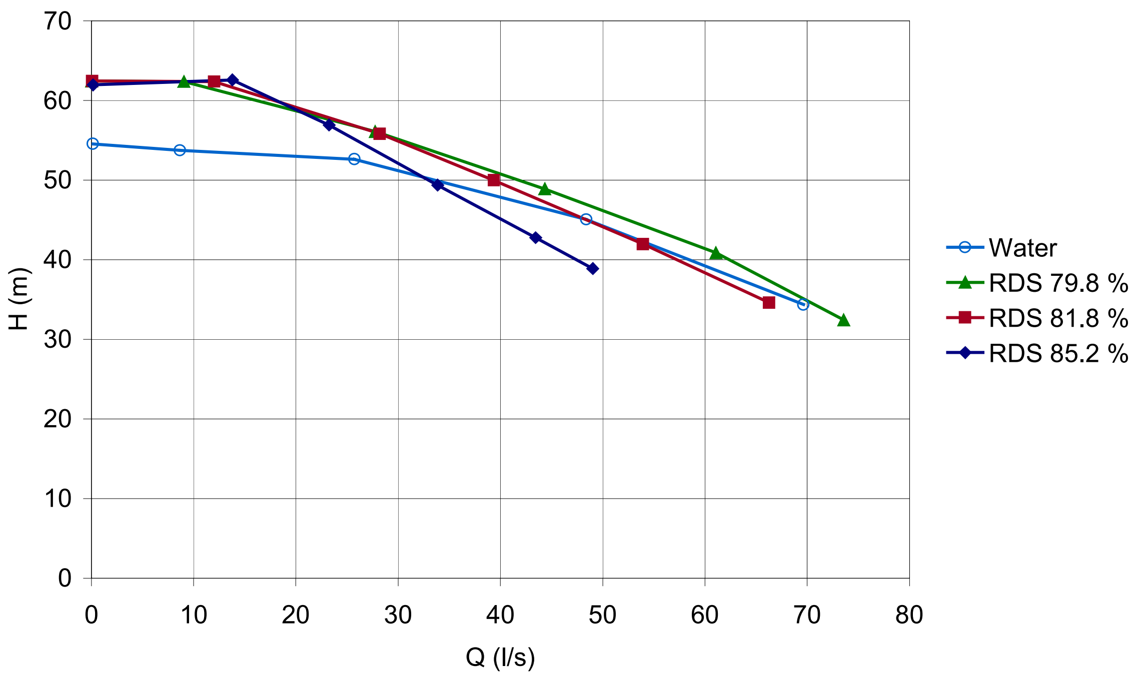

Fig. 5 Head curves of pump 2 for water and molasses with different RDS values at 50°C.

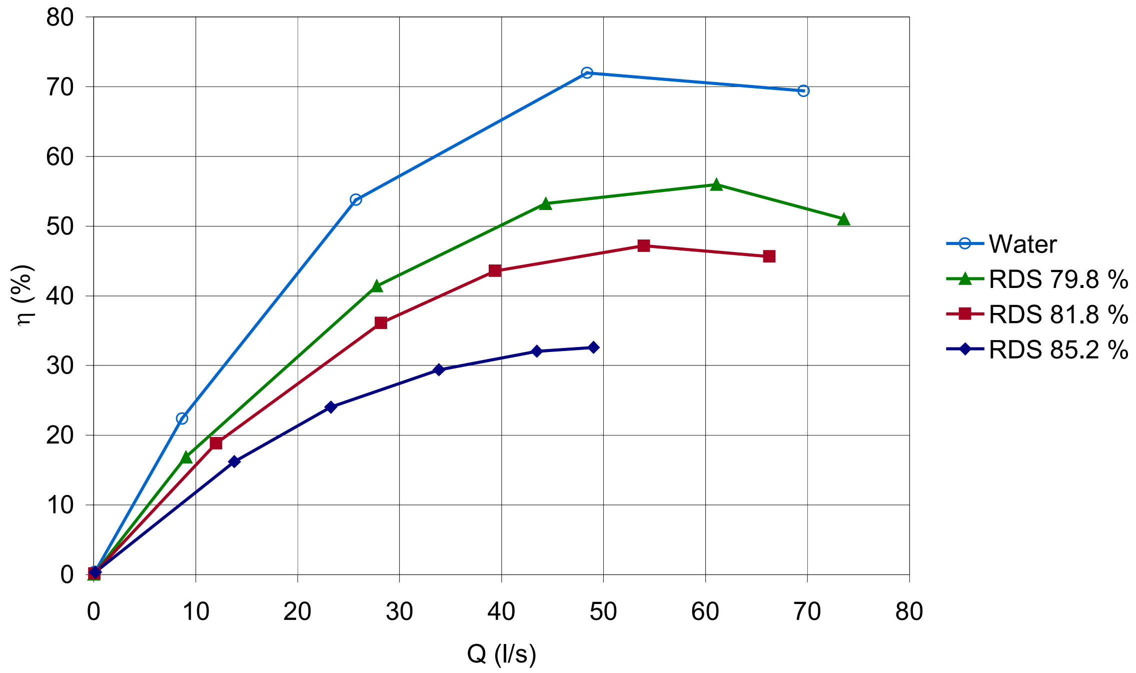

Fig. 6 Efficiency curves of pump 2 for water and molasses with different RDS values at 50°C.

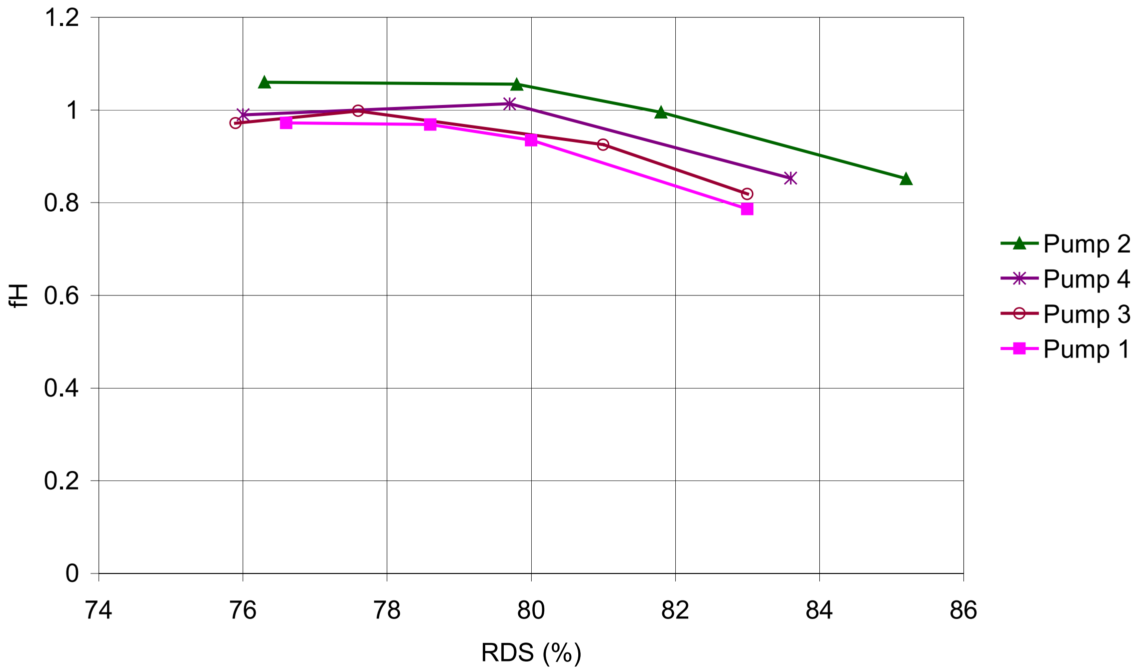

Fig. 7 Experimental head correction factor fH for tested pumps at best efficiency point. Molasses at 50°C. Head with water is 1.

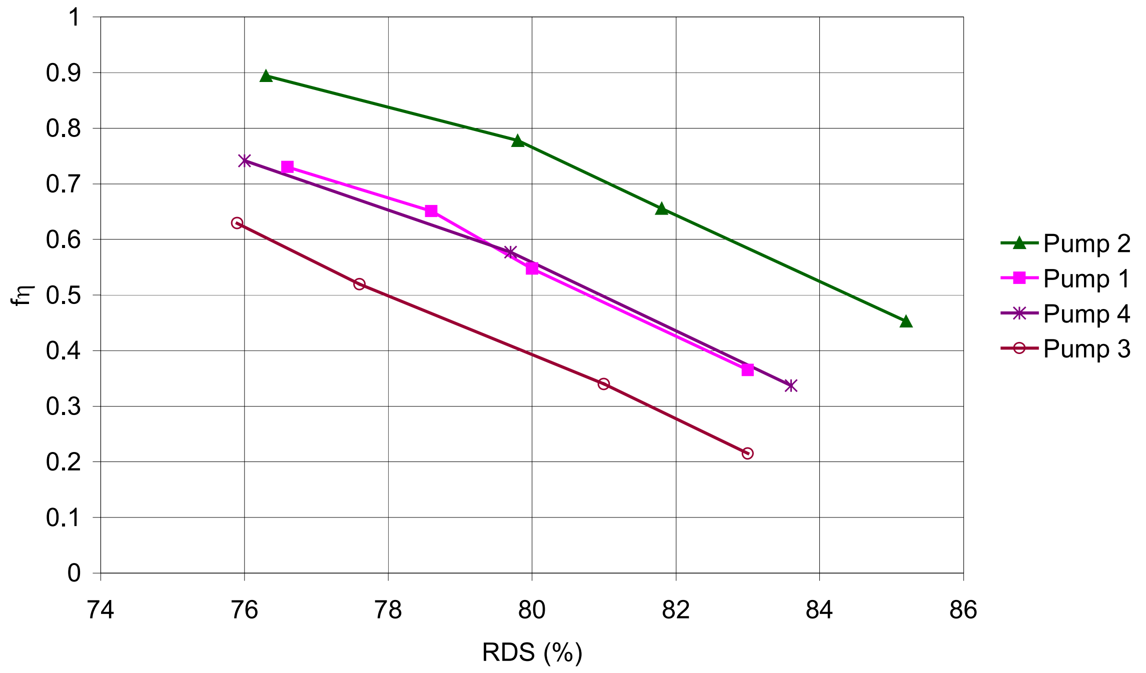

Fig. 8 Experimental efficiency correction factor fη for tested pumps at best efficiency point. Molasses at 50°C. Efficiency with water is 1.

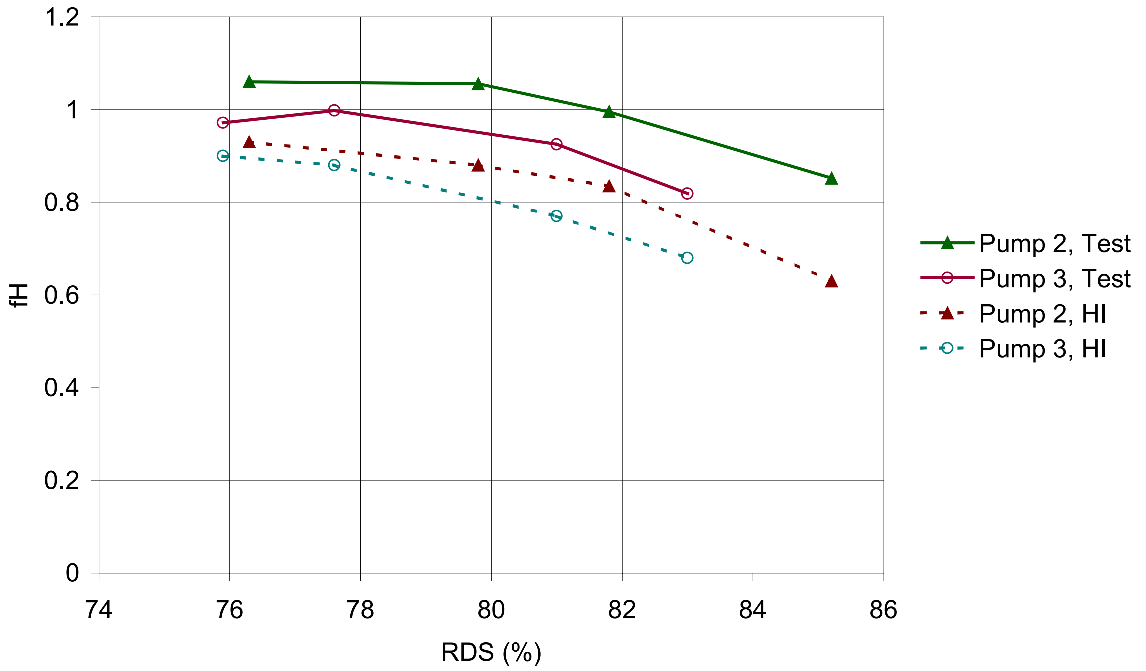

Fig. 9 Head correction factor fH obtained by HI method as compared to measured correction factor at best efficiency point. Molasses at 50°C.

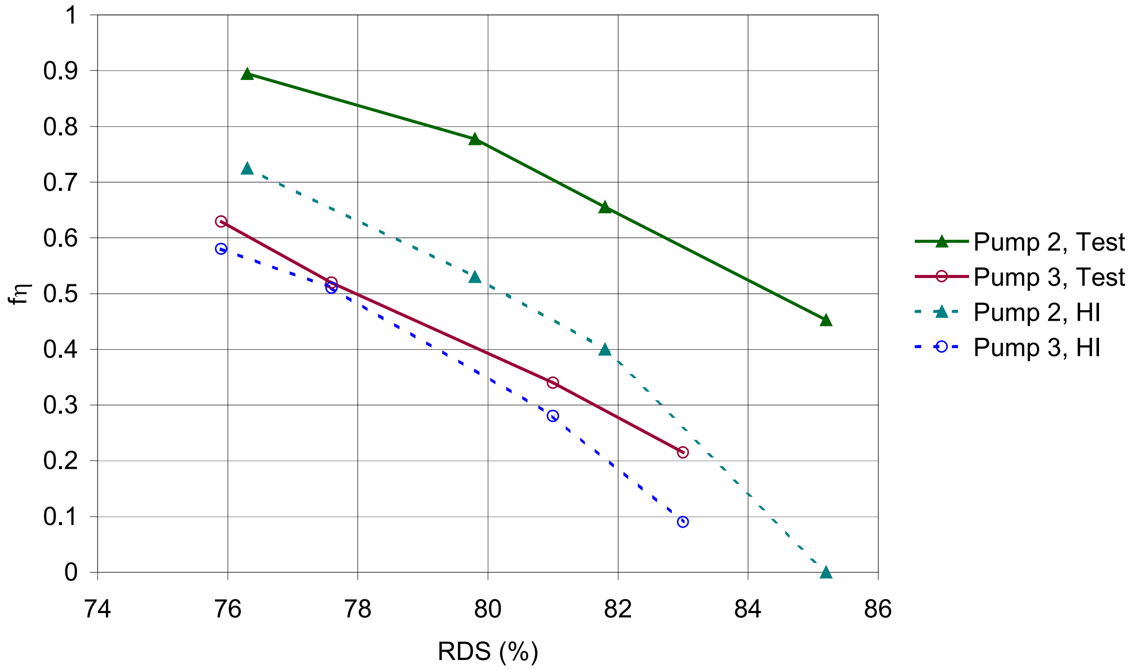

Fig. 10 Efficiency correction factor fη obtained by HI method as compared to measured correction factor at best efficiency point. Molasses at 50°C.

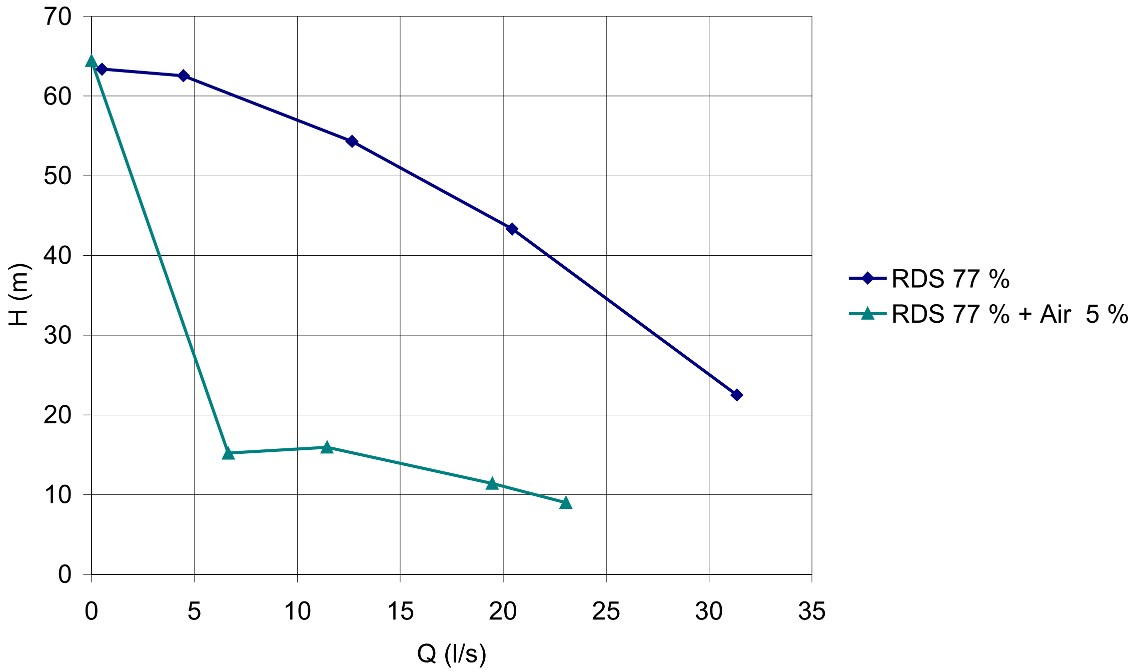

Fig. 11 Effect of air content on the head curve of a normal centrifugal pump. Molasses at 50°C.

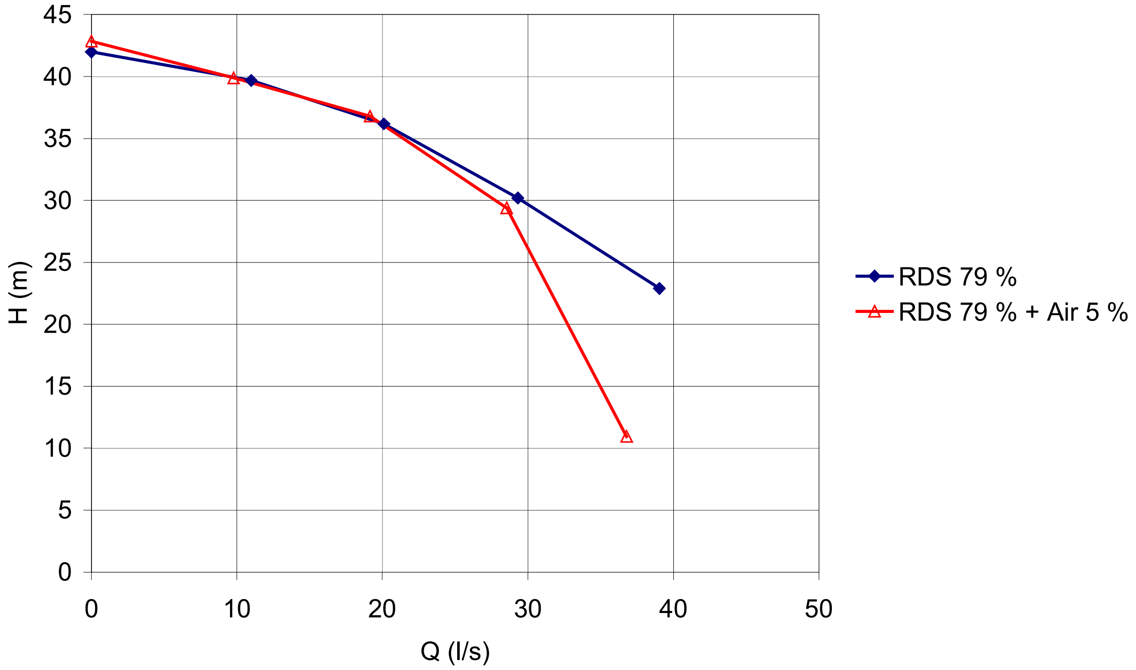

Fig. 12 Effect of air content on the head curve of ASP gas removal pump, best efficiency point 29 l/s. Molasses at 50°C.

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Table 1 Measured air contents of process fluids in different beet sugar factories. [3]

Fluid	**Air content**				
	Factory A 1997	**Factory A 2000**	**Factory B 1997**	**Factory C 1998**	**Factory D 1999**
A sugar run-off	15.9 - 18.1 %	4.6 - 5.2 %			
B sugar run-off	8.2 - 13.5 %	2.6 %	5.2 - 7.5 %		10-15 %
Molasses	5.3 %	6.0 %		9 - 11.5 %	

Table 2 Main characteristics of the tested pumps. D is impeller diameter, n is typical synchronous rotational speed, Q and H are flow rate and head of the pump at best efficiency point, and n_q is specific speed defined by equation $n_q = n\sqrt{Q} / H^{0.75}$ (where Q is in m^3/s).

Pump	**1**	**2**	**3**	**4**
D (mm)	210	210	330	330
n (1/min)	2910	2950	1440	1460
Q (l/s)	20.5	52	13.4	29
H (m)	44	45	29.3	30
n_q	24.4	38.7	13.2	19.4

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