Using coatings to reduce energy consumption in pumps and ventilators

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Abstract
This paper presents the results of research projects and information gathered in the field concerning energy consumption and the coatings applied to ventilators and pumps in Denmark. Project participants include pump and ventilator suppliers, suppliers of coating materials, the Danish Technological Institute as well a host of companies who have participated in field tests. Danish industrial companies use coating for maintenance reasons. In recent years companies have also recognized that coatings can improve the energy efficiency of pumps and ventilators. This reduction of energy consumption is a direct result of the coating process. The application of different types of coating material, affects efficiency to varying degrees. This paper shows that there is the potential for savings, especially with respect to electricity consumption and maintenance costs.

At the present time there exist no guidelines in Denmark with respect to coating material choice in relation to energy efficiency and application lifetime. This study is based on an analysis of the relevant literature, a series of laboratory tests with different types of coating and operation situations, and on site field tests which include measurements taken before and after coating.

This study has been able to document energy efficiency increases of up to 20 % for pump use, plus a significant extension of pump lifetime.

An increase in the energy efficiency of ventilators of up to 4 % has been documented. Ventilator lifetime can also be increased and maintenance costs reduced when the correct coatings are applied. The reduced risk for the building up of material on the wheel and inside the housing of the ventilator should also be factored in. This can be very important if the application is a transport ventilator.

Introduction
It is anticipated that the use of coatings will have a positive effect on the efficiency of centrifugal pumps and ventilators. Pumps and ventilators account for nearly 18 % of industrial electricity usage in Denmark, so any efficiencies achieved will be of significance. In light of the above, research projects and experiments have been carried out in Denmark in order to clarify to what extent coatings can improve energy efficiency – and have other positive effects.

Pump / ventilator efficiency

PUMPS
The power required to drive a pump is always greater than the output power of the fluid being pumped. Power loss is usually attributable to hydraulic, volumetric or mechanical factors. Efficiency is a comparison (ratio) between the power coming out of the system and that put into the system. Energy loss is minimized in an efficient system.

VENTILATORS
In theory a ventilator works in exactly the same way as a pump. The difference between the two lies in the level of fluid density in ventilators contra pumps.

Efficiency measured over lifetime

PUMPS

Centrifugal pump components are subject to degradation by erosion, abrasion, galling, corrosion and cavitation wear. These factors lead to a gradual reduction in pump efficiency, increased pump vibration and a reduction in operational life. It has been shown that larger clean water pumps can lose, on average, around 5% of their efficiency in the first five years of operation (Ref. 1).

VENTILATORS

The above mentioned reasons for decreased efficiency also affect ventilators, but to a lesser extent. Ventilators are, however, subject to at least one additional factor affecting efficiency which coating technology can have a positive impact on. During life-time material can build up on both the wheel and inside the housing. This material will, of course, have a negative impact on both ventilator-performance and efficiency, and coatings can affect the build up of this material.

Description of the present applied technology for coating

The coating currently in use on pumps and ventilators is a very strong epoxy reinforced with ceramics, a so-called composite material. A material, usually man-made, that is a three-dimensional combination of at least two chemically distinct materials with a distinct interface separating the components, is created to obtain properties that cannot be achieved by any of the components acting alone. This technology is only 10 years old, and was developed in the USA in connection with the development of space technology. That this technology entails better protection, longer operational life and energy savings is something that has only recently come to light.

Epoxy is a binding material, used in the industry because of its strength and adhesive properties. An ordinary epoxy has 2 – 4 bindings per molecule, but the epoxy applied to composite material has 12 – 14 bindings per molecule, which further improves its strength and adhesion properties. Where the material needs to withstand high levels of wear, it can be reinforced with ceramic particles. This can be necessary, for example, where additional wear is caused by sand. In such instances the ceramic particles added to the epoxy are bigger and are of a higher concentration. The outstanding adhesion properties of the epoxy bind the ceramic particles in such a way that a coating is only slowly degraded, even when pumping a very heavily wearing fluid. Tests show tensile strength exceeding 300 kg/cm^2, (Ref. 5).

Depending on the task the pump has to carry out, the composite material will be mixed differently and will be applied with different coating thicknesses. According to pump fluid and environment different coatings are used and applied in layers of 600 to 3000 µm.

Some coatings are applied to protect against chemical corrosion, others to protect against corrosion by hot water, others are especially appropriate for abrasive liquids.

Standard coatings reinforced with small ceramic particles are smooth, whereas coatings which can resist a high level of abrasion are rougher. The roughness of a coating affects the energy efficiency of the product to which it is applied. However, most of the coating types applied are of the smooth type, and are in fact smoother than the metal surface of a new pump.

Additional Benefits

A pump or ventilator of high efficiency is of little value if the efficiency falls rapidly with time. Such fall offs in efficiency can be significantly reduced through the use of appropriate protective coatings. Instances have been recorded of pumps whose operational lifetime has been increased from 3 months to more than 3 years by the judicious application of coatings (Ref. 5). Coatings reduce maintenance costs. But will probably also prevent production down-time; for example in connection with a lack of cooling water as a result of a pump breakdown. A single instance of production down-time prevented can represent many times the value of the energy saving which can be achieved during the operational life of the pump.

Testing of coated pumps and ventilators

PUMPS

Several tests have been carried out during the past 2-3 years to investigate the impact of coatings on overall pump efficiency.

In this section the results of these tests will be discussed. Tests cover pumps which have been in use for several years and new pumps, (i.e. pumps which have not experienced wear). Evaluation criteria include: expected efficiency improvements, differences between different coating materials, expected impact on high pressure and low pressure pumps, and lifecycle cost analysis.

VENTILATORS

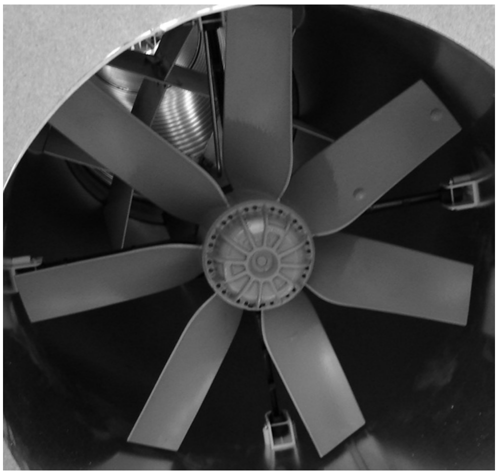
During the last year the program of testing has been expanded to also include ventilators. At the present time only a few new components have been tested. Tests have been carried out on ventilators of the type: axial construction, small size (power 0,5 kW) and centrifugal construction, medium size (power 15 kW).

In the picture below, the coated wheels are shown.

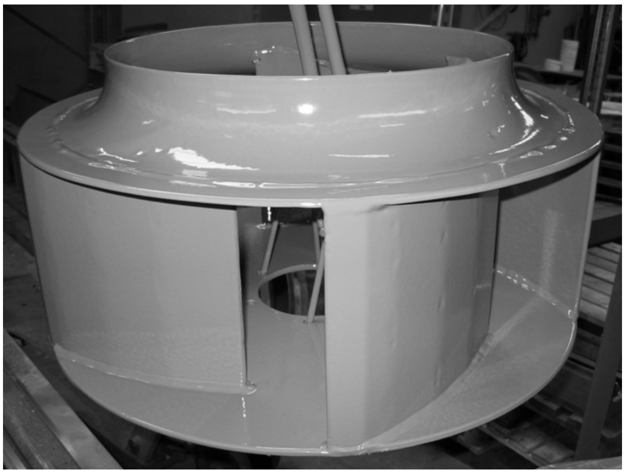
The diameter of the axial wheel is about 600 mm and the diameter of the centrifugal wheel is of approximately the same size. The big difference in power need – 30 times - is primarily caused by the sizeable difference in delivered pressure. At the present time tests have only been carried out to determine the impact of coating material on performance and efficiency. If these results are positive, then all a full program of tests analogous to those carried out for pumps will be carried out on ventilators. The results of ventilator tests are represented later in this paper.

Used pumps in Paper mills and Waste water plants

A 55 kW centrifugal pump, with a traditional closed wheel, was tested in a test rig for off-shore pumps before and after coating. Both the wheel and the pump casing were coated with Chesterton Arc 855.



Coated – axial wheel



Coated – centrifugal wheel

Although the pump, which has been running for years, doesn't seem damaged, a huge increase in performance was achieved by coating the pump, as is shown in *Fig. 1*. The coated pump when working at a rate of 2 000 litres per minute is capable of delivering approximately 770 000 Pa (7,7 bars) of pressure instead of 720 000 Pa (7,2 bars) – a 7 percent improvement in hydraulic delivery.

The coating also improved overall efficiency. Efficiency improved from about 0,48 to 0,61 (48 % to 61 %) when the pump was operating at 2 000 litres per minute. In the instance that the control system can handle the coated pump efficiently – i.e. control its speed – it is possible to decrease electricity consumption by 25-30 %.

The cost of coating this type of pump, including the cost of materials, is about 5 000 euros. Achieved efficiency improvements when operating at 2 000 litres per minute and 7,5 bars represent a reduction in power consumption of 11 kW. Assuming 6 000 running hours and an electricity price of 4 eurocents per kWh the yearly savings in electricity achieved exceed 2 640 euros.

A further test was carried out on a pump which operated under very difficult conditions (waste water). The pump was damaged in such a way, that the decision was taken to renovate (by using ARC material) before coating the pump.

The performance curve shown in *Figure 3* has a peculiar shape. This is because the pump is a "hydro-steel" pump. It isn't constructed to produce pressure, but to move large volumes of water with solid material in solution.

Figure 4 shows that the coating has a positive impact on efficiency under high pressures, but of course the pump is not designed for use under these conditions.

At the optimal rate of operation (450 m^3/h) overall efficiency improved from 50 % to 52 % (a 4 % efficiency improvement). It should be bourn in mind that the statistics garnered in this instance are for a renovated pump.

New pumps, small & low pressure

The following data set was obtained in experiments conducted using a test rig established at The Danish Technological Institute. In these experiments a new pump was subject to analysis and because of this it has been possible to compare the

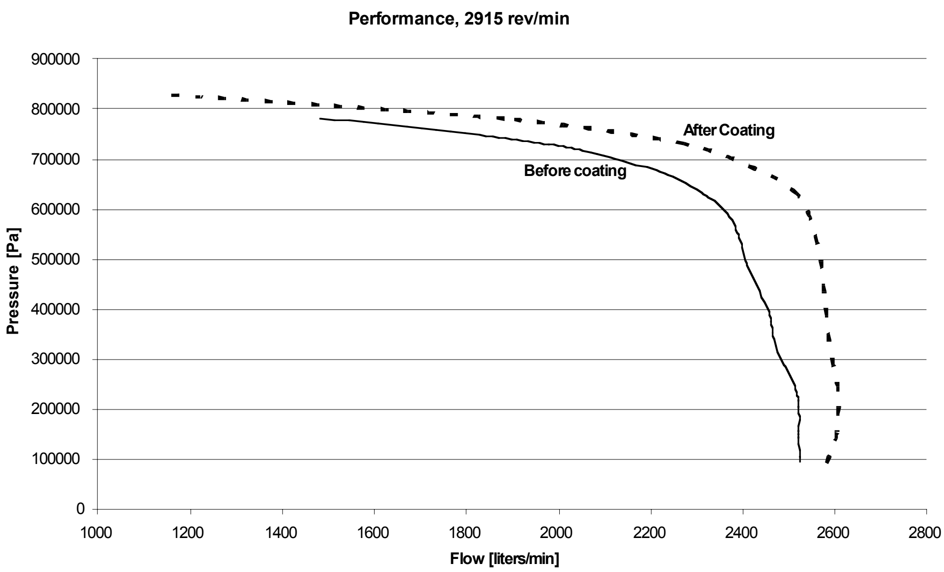


Figure 1. Pump performance, high pressure used pump / paper mill

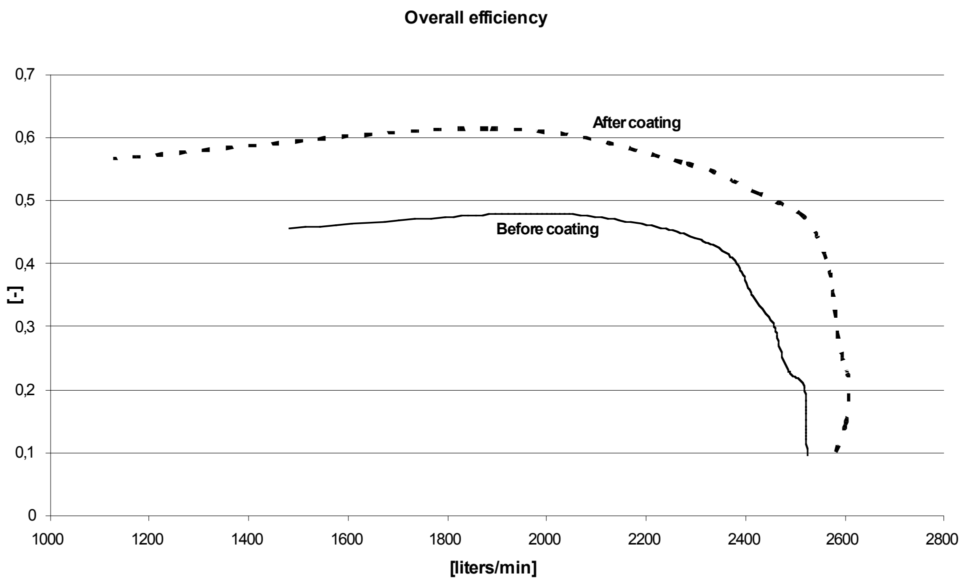


Figure 2. Overall efficiency, high pressure used pump / paper mill

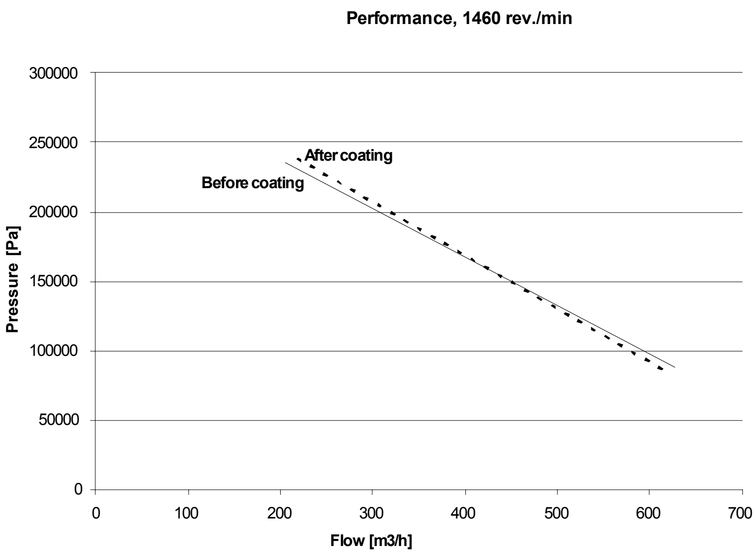


Figure 3. Pump performance, low pressure used pump / waste water

performance and efficiency specifications as published by the manufacturer with measured performance and efficiency before and after coating.

A 4kW centrifugal pump was employed in testing. This type of pump is widely used – both for industrial purposes and for heat supply.

Many manufacturers are sceptical of the benefits of coating technology. A major area of concern is the impact on performance that may occur when the internal volume of the pump is reduced by coating both the casing and the wheel – this in spite of the fact that only very thin layers of coating are applied – 0,6 mm. This issue is of course of greater significance for small pumps. Notwithstanding this there is no significant difference in performance between the three sets of data shown in figure 5. The performance recorded for this new pump is almost the same as the performance claimed by the manufacturer, and there is no significant difference between performance before coating and after coating. In fact, the only slight difference between the different set ups is visible under high pressure. The pump was coated with the very smooth Arc S2 coating. No particular working environment was envisaged for the pump, the only goal being to detect maximum efficiency improvement. Arc S2 at the moment is the best product when the fluid is pure water and the temperature is below 50°C.

Figure 6 shows measured overall efficiency for the pump before and after coating –measured data for test rig. Data from the manufacturer only shows pump efficiency and it is, therefore, not possible to compare it directly with the measured data. Therefore manufacturer-data are not shown in figure 6.

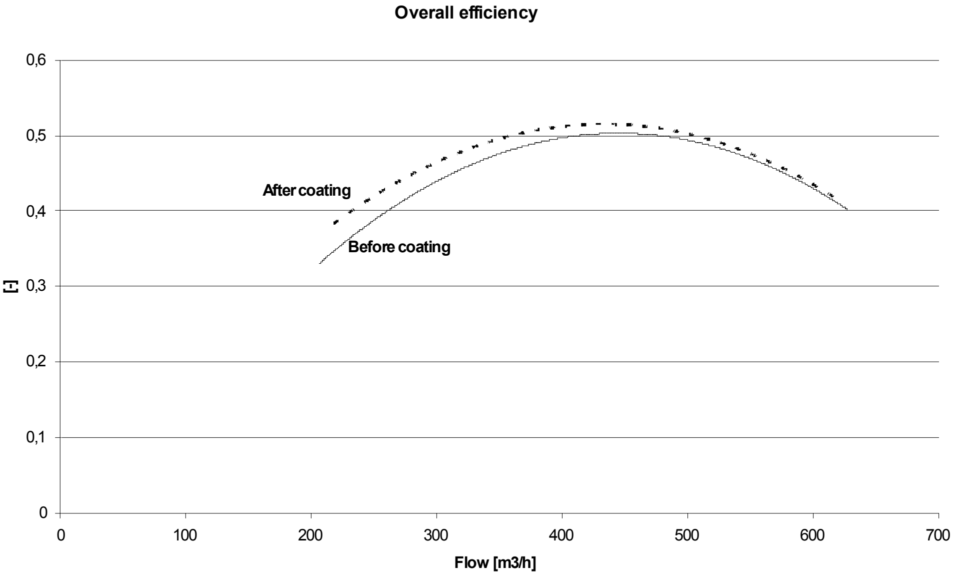


Figure 4. Overall efficiency, low pressure used pump (renovated) / waste water

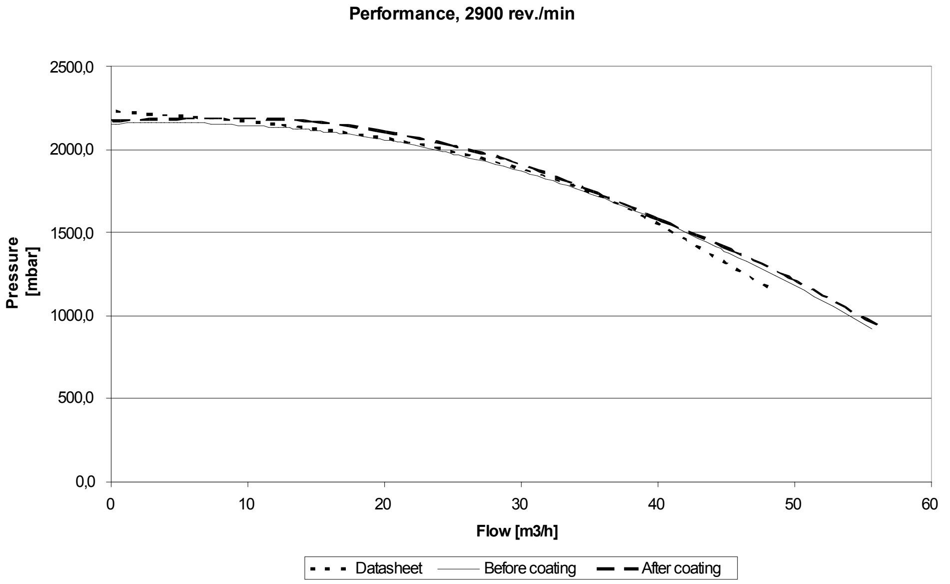


Figure 5. Pump performance, small low pressure new pump

Figure 6 demonstrates that the coating has a positive impact on the overall efficiency of a small new pump. The improvement under optimal working conditions (35 m^3/h and 1 750 mbar) is about 10 %. The overall efficiency of the pump increases from 50 % before coating to 55 % after coating.

The cost of coating this kind of pump post manufacture is at present approximately 1 000 euros. This cost would of course fall if the manufacturer coated the pump as part of the manufacturing process. A new uncoated pump costs in the region of 500 euros – including the motor.

Under optimal working conditions (35 m^3/h), the pump has a power consumption of 3,4 kW in uncoated form and 3,1 kW in coated form. Assuming 6 000 running hours per year and an electricity price of 4 eurocents per kWh the difference in annual electricity costs between the uncoated and coated pumps exceed 72 euros. Given this there have to be other benefits to coating the pump, such as increasing pump lifetime, to make doing so a realistic option. Coating the pump could also become an attractive option if the cost of coating the pump were to fall.

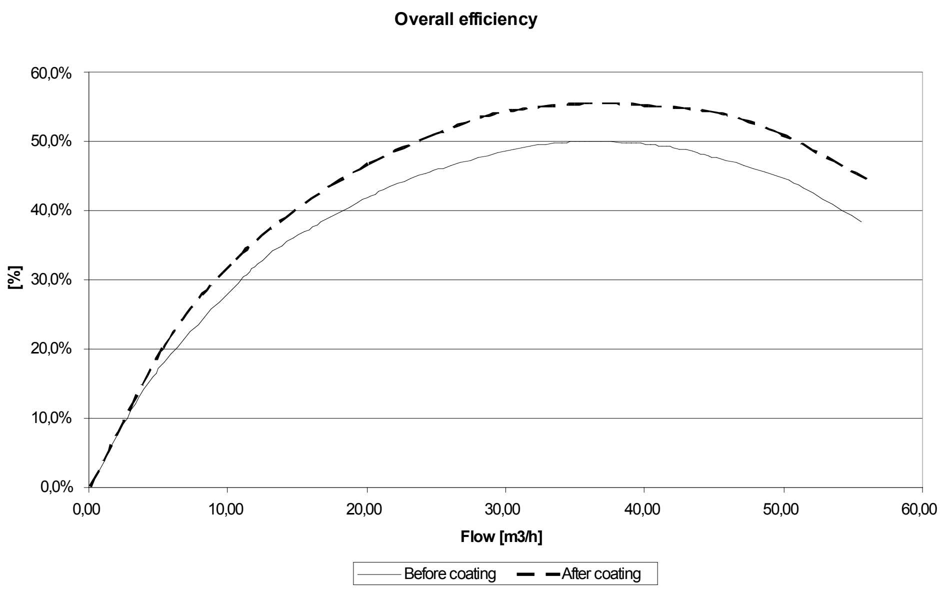


Figure 6: Overall efficiency, small low pressure new pump

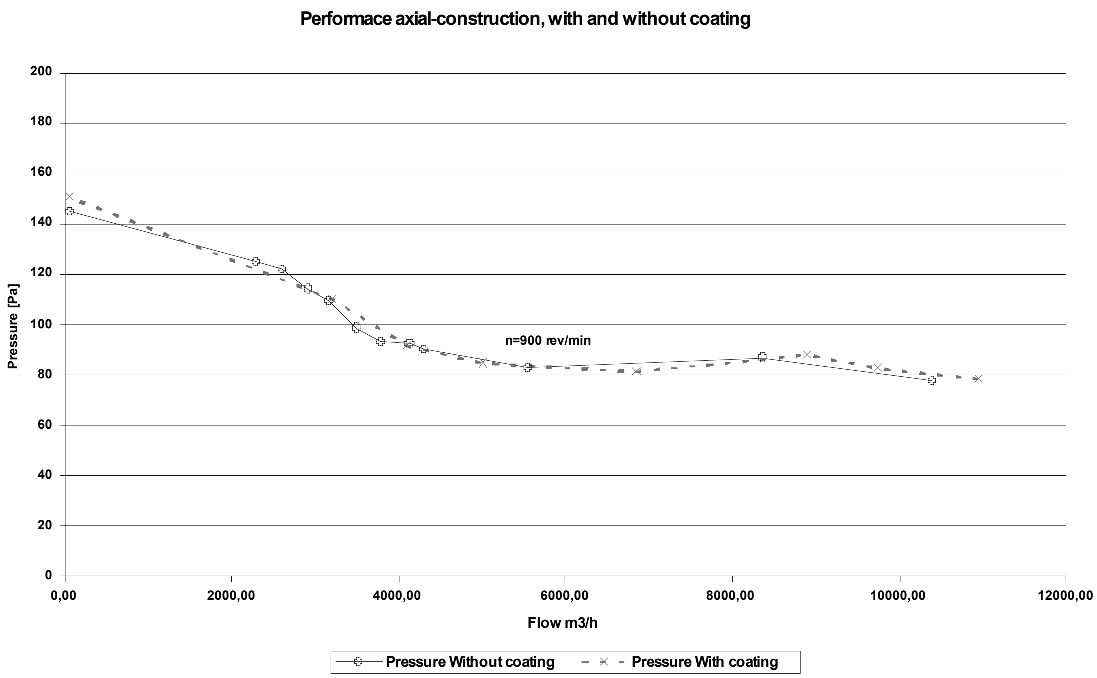


Figure 7: Performance, small ventilator

Ventilator – axial construction, small size

In cooperation with the ventilator manufacturer, a product was selected for testing. The ventilator has the following specifications:

- input power about 0,5 kW, velocity 900 rev./min;
- maximum delivered flow about 10 000 m^3/h;
- maximum delivered pressure about 150 Pa.

The ventilator is normally used in the agricultural sector. Rearing pigs in barns, for example, requires climate control to secure the physical development of the pig. Furthermore, the environment in such barns is a very demanding one with high humidity, and aggressive chemicals in the exhaust-air controlled by the ventilator.

Ventilator maintenance is, therefore, a significant issue. In the majority of instances, such ventilators are installed with frequency converters. This is of importance because of the decrease in ventilator performance entailed. The converter can compensate for this fact by increasing the frequency to the ventilator-motor. Of course this also increases energy consumption, but this is necessary to ensure the welfare of the pigs.

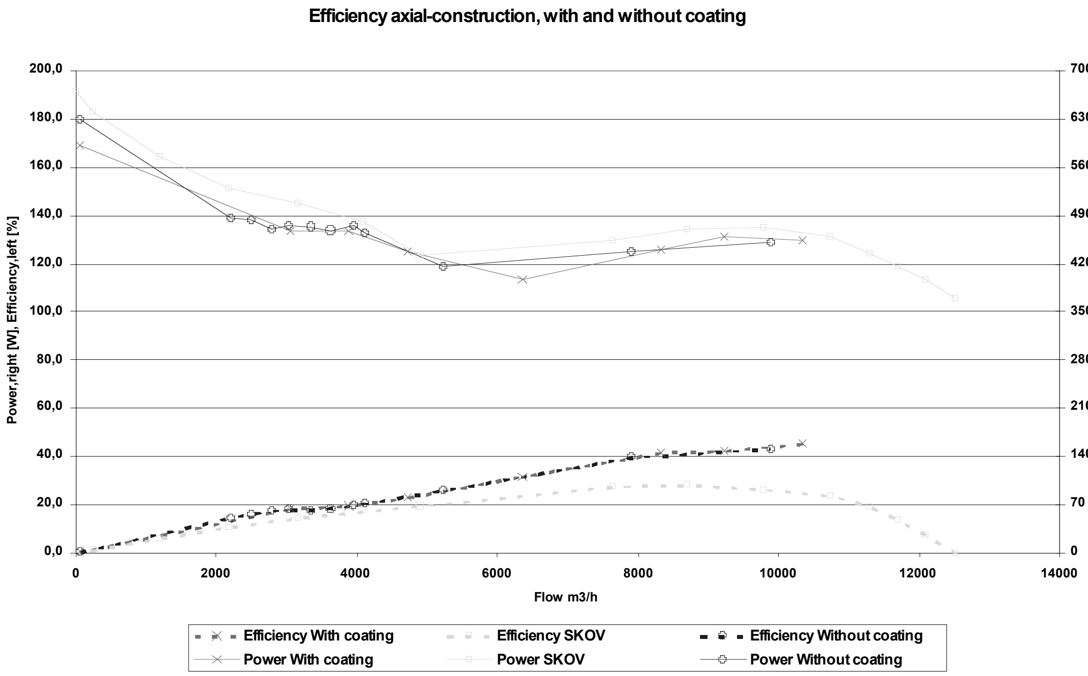


Figure 8: Efficiency, small ventilator

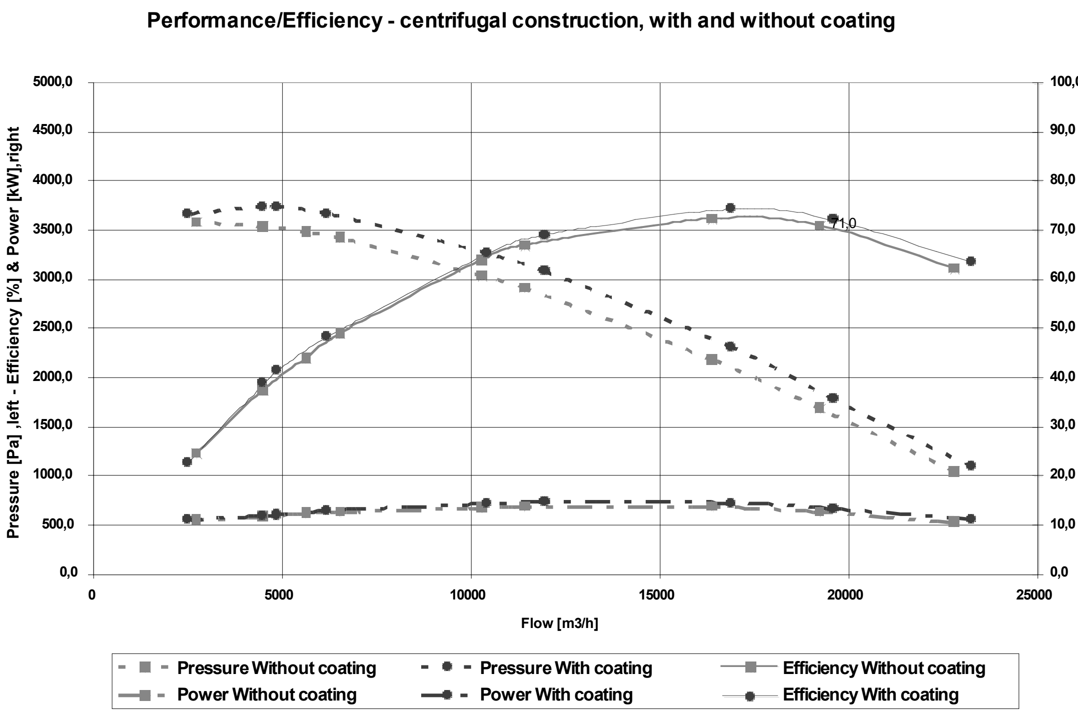


Figure 9: Performance & Efficiency, medium sized ventilator

As for pumps, results show that it is possible to coat even small ventilators without significantly affecting their hydraulic performance. Manufactures often site the effect on hydraulic performance as their main reason for not coating components. In figure 8 we do not see an improvement of the overall (motor fan) efficiency by coating a new ventilator; this is again similar to results achieved for pumps. The justification for coating a ventilator of this size and type lies in the reduction in maintenance costs achieved given constant overall efficiency. Cleaning these ventilators 2-3 times a year over the course of their life-time is one of the most significant costs associated with the ventilator.

In *Figure 8* we have both shown manufacturer's claimed performance figures (ventilator without coating) and test data from the laboratory (ISO 5801) for both ventilators with or without coating. Where coating has taken place, only the wheel has been coated.

Ventilator – centrifugal construction, medium size

In cooperation with the ventilator manufacturer, a product was selected for testing. The ventilator has the following specifications:

- input power circa 15 kW, velocity 2 950 rev./min;
- maximum delivered flow circa 20 000 m^3/h;
- maximum delivered pressure circa 3 500 Pa.

Figure 9 shows improvements in both performance and efficiency can be achieved by coating new ventilators of this type with ARCS2, which gives a very smooth surface. Coating and testing were carried out in a series of steps. Initially the ventilator was tested without coating, after this the wheel was coated and the product tested again, finally both wheel and wheelhouse were coated. The test data shows no significant variations in the results achieved between the scenario in which only the wheel was coated and that in which both wheel and wheel housing were coated. For this reason, only data from the test with both wheel and wheelhouse coated and data from the test carried out without coating are shown here for purposes of comparison.

The coated ventilator's highest achieved efficiency was 75,0 %. The highest figure the un-coated ventilator returned was 72,5 %. This represents an improvement in overall efficiency of 3-4 %. Again this improvement is achieved from year 0, as the ventilator in question is new. We expect a coated ventilator to be able to maintain this level of efficiency – this will not be true of a ventilator without coating.

Optimum efficiency is achieved in both instances at a flow rate of approximately 17 000 m^3/h. The coated ventilator is able to achieve slightly higher pressures at the same flow rate. If coating is to deliver reduced electricity bills in this instance, the velocity achieved by the coated ventilator must be reduced in relation to the velocity of the ventilator without coating – otherwise improved efficiency will result increased delivered hydraulic power not reduced power consumption.

Conclusion

The paper documents some of the activities carried out in recent years, in Denmark, aimed at promoting coating technology. It has been demonstrated that coating a variety of different types of pump application can have a positive impact on energy efficiency. If the application runs at a sufficient volume or/and annual running hours reach a certain level the energy savings alone can finance the coating.

Small pumps will be an important future area of research. Project activities are currently being carried out to investigate whether it is possible to achieve a significant amount of potential improvements by only coating part of the pump. Results so far achieved with partially covered pumps indicate that coating technology may be cost effective in all pump sizes and at the very least for centrifugal- and axial ventilators.

It seems that efficiency improvements mostly occur as a result of coating the wheel. Coating the housing has not so far been shown to achieve an efficiency improvement. The housing in many cases already has a relatively smooth surface, and this could explain the lack of improvements achieved when the housing is coated.

It's well known that ventilators in aggressive environments loose some performance over time, but the efficiency loss levels this entails have not been documented. In such cases, coating the wheel may well be a very cost-effective form of maintenance.

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