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INVESTIGATIONS ON THE CLEANING BEHAVIOUR OF POLYMER WOVEN FILTER MEDIA IN SOLID LIQUID SEPARATION

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ABSTRACT

In the pharmaceutical and food industry the cleanability of filter media is a major problem. The cleaning is often not reliable or satisfying. Filter media are often replaced after usage. Therefore it is interesting to investigate the physical mechanism of filter media cleaning. Because detailed information about the cleaning process of filter media is necessary to evaluate the cleanability and to find the structure of filter media, which offers the best cleaning behaviour. This paper deals with the cleaning kinetic of a contaminated filter media and its fundamental understanding. It provides information about the influence of the surface finish and the texture of the filter media to the cleanability.

KEYWORDS:

Hygienic Design, cleanability of filter media, back flushing, mass transfer

1 Introduction

Many papers dealt with the cleanability of components of tubes, pipes or different surfaces. Graßhoff [3] for example investigated in 1983 the cleaning behaviour of cylindrical dead storages. He concluded that this problem could be solved only with constructive improvements. Lelieveld [6] discussed 1994 often appearing Critical Control Points and gave examples to solve them. Bénézech [2] investigated 2002 the cleanability of a progressive cavity pump often used in the food industry. His aim was establishing an exact test method. Beck [1] investigated 2005 the cleanability of different surfaces by changing parameters like surface roughness, surface energy and surface anisotropies. He inspected only real surfaces and its critical points. Hofmann [4] in contrast regarded the cleaning process as a mass transfer model and tried to realize it as a qualification method for estimating the cleanability.

In the area of technical surfaces, components of tubes and vessels many test methods and guidelines were established, but for the cleanability of filter media there are no instructions or test methods for their cleaning process. Cleaning of filter media represents a great challenge for the pharmaceutical, biotechnology and food industry and cannot always be reliably performed. Hence, expensive and non-environmentally friendly disposable filters are applied in many cases. The work is aimed at identifying the fundamental physics of filter media with backflushing. Thereby the influence of the surface finish and the texture of the filter media will be investigated.

2 Materials and Methods

In this work four different filter media were used. In table 1 these filter media are shown. In one set of experiments the cleanability of filter K and filter SK were investigated, which differ in their surface finish. For a second test series Filter TWL and Filter STN are used to examine the influence of the filter texture. Filter TWL has a twill weave texture and Filter STN has a satin weave texture.

	Finish	Thickness [µm]	Texture	Material
Filter K	calendared	205	Plain reverse dutch weave (PRD)	PET
Filter SK	Super calendared	200	Plain reverse dutch weave (PRD)	PET
Filter TWL	Calendared	320	twill weave (TWL)	PP
Filter STN	Calendared	350	satin weave (STN)	PP

TABLE 1: USED FILTER MEDIA AND THEIR PROPERTIES

To investigate the influence of the surface finish it is important to keep all other parameters like pore fluid velocity, filter thickness, material and texture of the filter media constant. However it is difficult to find filter media applying to this. So in this work the porosity of the used filter media was determined based on geometric parameters of the filter media [5].Then with the determined porosity the required volume flow rate to keep the pore velocity constant, can be calculated. The porosity of a filter media can be determined with formula 1.

$$\varepsilon = \frac{V_{complete} - V_{Fiber}}{V_{complete}} \qquad (1)$$

Because the filter media in this work are calendared or super calendared, the fibre is considered as an ellipsoidal cylinder. In figure 1 d $_{horizontal}$ is the horizontal diameter and d $_{vertical}$ the vertical diameter of the ellipsoid. The following chapters describe the determination of the porosity for the particular textures.

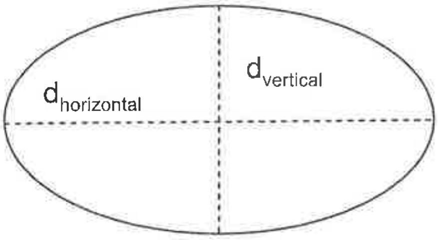

FIGURE 1 ELLIPSOIDAL CYLINDER

Calculation of the porosity of PRD texture

Figure 2 shows the PRD texture and its geometric dimensions.

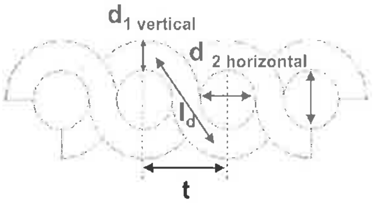

FIGURE 2: GEOMETRIC DIMENSIONS OF PRD TEXTURE

Figure 2 illustrates the side view, the top view and its geometrical dimensions of the filter media. There l_d is the fiber length, d_1 the diameter of the filling thread and d_2 the diameters of the warp thread. The indexes vertical or horizontal describe the vertical and horizontal dimensions of the ellipsoidal fibre form. (see figure 1) The division t is the distance between the central points of two neighbouring warp threads. For the calculations two filling threads and two warp threads were considered. So the volume of the fibre is composed of the volume of the filling thread and of the warp thread.

$$V_{\text{fibre}} = V_{\text{filling}} + V_{\text{warp}} \tag{2}$$

$$V_{\text{fibre}} = \frac{\pi}{4} \cdot d_{2\text{ vertical}} \cdot d_{2\text{ horizontal}} \cdot l_d + \frac{\pi}{4} \cdot d_{1\text{ vertical}} \cdot d_{1\text{ horizontal}} \cdot l_d \tag{3}$$

with

$$l_d = \sqrt{t^2 + (d_{1\text{ vertical}} + d_{2\text{ vertical}})^2} \tag{4}$$

The complete volume V_{complete} is composed on the following:

$$V_{\text{complete}} = t \cdot 2 \cdot d_{1\text{ horizontal}} \cdot d_{\text{filter}} \tag{5}$$

d_{filter} is the thickness of the filter media. With equations (1), (3) and (5) the porosity ε can be determined:

$$\varepsilon = \frac{t \cdot 2 \cdot d_{1\text{ horizontal}} \cdot d_{\text{filter}} - \frac{\pi}{4} \cdot (2 \cdot d_{2\text{ vertical}} \cdot d_{2\text{ horizontal}} \cdot d_{1\text{ horizontal}} + 2 \cdot d_{1\text{ vertical}} \cdot d_{1\text{ horizontal}} \cdot l_d)}{t \cdot 2 \cdot d_{1\text{ horizontal}} \cdot d_{\text{filter}}} \tag{6}$$

With this equation it is possible to approximate the porosity of both the filter media SK 22 and K 27. For either of them the area of one mesh can be determined and based on the calculated porosity the tube velocity can be determined, at which the pore velocity for both of the filter SK and K is constant.

Calculation of the porosity of TWL texture

In a twill weave, each filling thread floats across the warp threads in a progression of interlacing to the right or left, forming a distinct diagonal line. This diagonal line is also known as a wale. A float is the portion of a yarn that crosses over two or more yarns from the opposite direction. In figure 3 the TWL texture used for the investigation is shown. It is a 3/1 twill weave, that means the filling thread floats across three warp threads and then glides below one warp thread. In the next row this pattern is displaced one thread. For the calculation of the porosity four warp threads and two filling threads are considered.

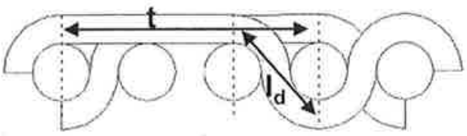

FIGURE 3: SCHEMA OF THE USED TWL TEXTURE

In figure 3 t describes the distance between the central points of four warp threads. The fiber length l_d can be determined by geometric considerations.

$$l_d = \sqrt{\left(\frac{t}{3}\right)^2 + (d_{1\,\mathrm{vertical}} + d_{2\,\mathrm{vertical}})^2} \tag{7}$$

The porosity for twilled weave can be determined analogue to the porosity of the PRD texture, unless that for the calculations four warp threads and two filling threads are considered.

$$\varepsilon = \frac{t \cdot 2 \cdot d_{1\,\mathrm{horizontal}} \cdot d_{\mathrm{filter}} - \frac{\pi}{4} \cdot (3 \cdot 2 \cdot d_{2\,\mathrm{vertical}} \cdot d_{2\,\mathrm{horizontal}} \cdot d_{1\,\mathrm{horizontal}} + 2 \cdot d_{1\,\mathrm{vertical}} \cdot d_{1\,\mathrm{horizontal}} \cdot (l_d + \frac{2}{3} \cdot t))}{t \cdot 2 \cdot d_{1\,\mathrm{horizontal}} \cdot d_{\mathrm{filter}}} \tag{8}$$

Calculation of the porosity of STN texture

The used STN-Texture has the following interlace (figure 4). The filling thread floats across four warp threads and then glides below four warp threads. In the next row this pattern is displaced one thread. For the calculations eight warp threads and two filling threads are considered.

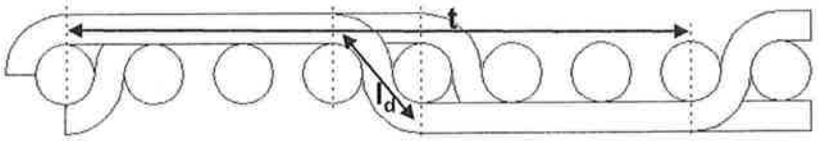

FIGURE 4: SCHEMA OF THE STN TEXTURE

The porosity is generated with the following formula:

$$\varepsilon = \frac{t \cdot 2 \cdot d_{1\,\mathrm{horizontal}} \cdot d_{\mathrm{filter}} - \frac{\pi}{4} \cdot (7 \cdot 2 \cdot d_{2\,\mathrm{vertical}} \cdot d_{2\,\mathrm{horizontal}} \cdot d_{1\,\mathrm{horizontal}} + d_{1\,\mathrm{vertical}} \cdot d_{1\,\mathrm{horizontal}} \cdot 2 \cdot (l_d + \frac{3}{7} \cdot t)}{t \cdot 2 \cdot d_{1\,\mathrm{horizontal}} \cdot d_{\mathrm{filter}}} \tag{9}$$

with

$$l_d = \sqrt{\left(\frac{t}{7}\right)^2 + (d_{1\,\mathrm{vertical}} + d_{2\,\mathrm{vertical}})^2} \tag{10}$$

Experimental procedure

Before starting with the cleaning experiments the filter media must be contaminated reproducibly. This is realized with a contamination unit, where the filter media is clamped closely. The operating mode of the contamination unit relates to the one of a pressure nutsche. With the aid of it a thin filter cake is formed on the filter media. The contamination in this work is Riboflavin, also called Vitamin B2. The advantage of this vitamin is its fluorescent properties. Because of this the detection limit is very low. The determination of the concentration of Riboflavin was carried out with a fluorescent spectrometer. For all experiments the mass of Riboflavin on the filter media before the streaming experiment was the same.
After the contamination the filter media is fixed in a developed aseptic geometry and cleaned by back flushing in a through streaming plant, which is developed at the Institute for Mechanical Process Engineering (MVM). With this plant it is possible to vary streaming velocity, temperature, and pH of the cleaning fluid and to realise different cleaning procedures.
In this work the different filter media and their cleanability were investigated for two different streaming velocities. The sampling takes place at the outlet of the through streaming plant. The plant consists of a pressure vessel and a filter holder, in which the filter media is fixed. The pressure of the vessel determinates the streaming velocity. The mass flow rate is detected by a balance.

3 Results and Discussion

3.1 Kinetic of the filter cleaning process

At the beginning it was necessary to know the cleaning kinetic of the K filter contaminated with Riboflavin. To find out this the K filter (see table 1) was adopted. The experiment time was set on 240 s and the sample drawing took place at 2, 6, 10,18, 26, 36, 42, 90,150 and 240 s. The experiment was repeated at least 3 times. The kinetic is shown in figure 5. Plotted is the mass rate of Riboflavin against the cleaning time of the filter media.

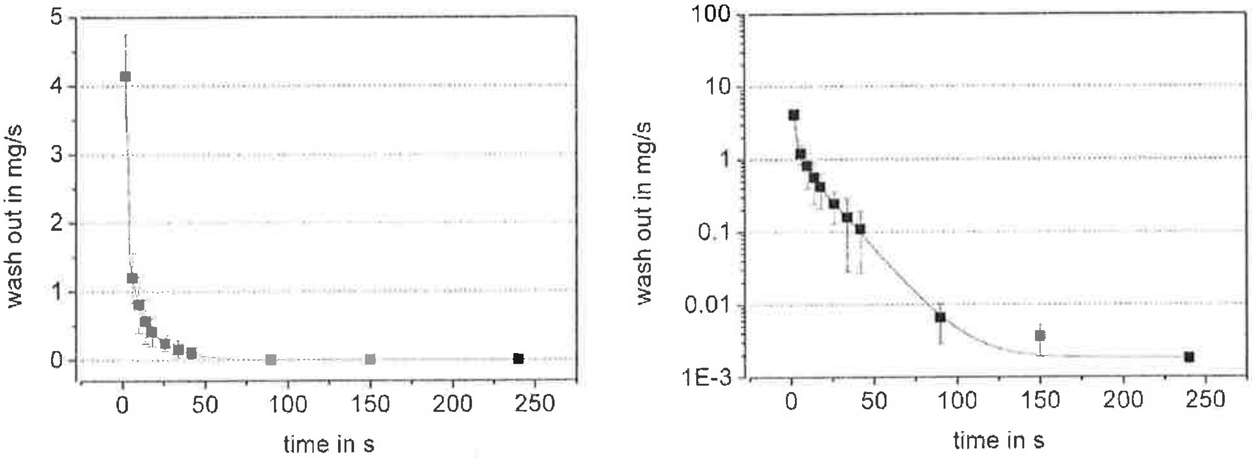

FIGURE 5: KINETIK OF THE CLEANING PROCESS WITH RIBOFLAVIN: LEFT: LINEAR PLOT, RIGHT: LOG PLOT

It was considered that in the first 2 seconds of the experiment the filter cake was carried away with the flow. After this the mass rate of Riboflavin declines to the amount of 0.04 mg/s at 42 s of the cleaning process. It is evident that the kinetic shows an exponential decay. The logarithmic plot in figure 5 divides the kinetic in two phases. In the first phase (till 90 s) the hydrodynamic effects are apparantly. The wash out declines very strongly. At the second phase (after 90 s) the kinetic and the slope is gentler. The influence of the hydrodynamic effects are much smaller. In this phase only diffusive processes are dominating.

3.2 Influence of the streaming velocity on the cleaning process

As a second point it was necessary to investigate the influence of the streaming velocity on the cleaning kinetic. The experiments were done with the same filter media as before and the investigations were repeated at least three times.

The mass rate of Riboflavin, which was washed out, is significantly increased for the higher velocity within the first 6 s. Then after 10 s of the cleaning time the mass rate of the higher velocity tends to be much lower than for lower velocity. That means in the first seconds the most mass of Riboflavin is brought out and then the limit value is achieved earlier for the higher streaming velocity. This can be seen in figure 6. For the higher velocity the wash out is at 0.00395 mg/s after 42 s. This amount is achieved for the lower velocity only after 150 s.
To accelerate the cleaning process in the diffusive phase other methods than backflushing has to be investigated. Ideas for this are high frequency backpulsing and handling with ultrasonic sound.

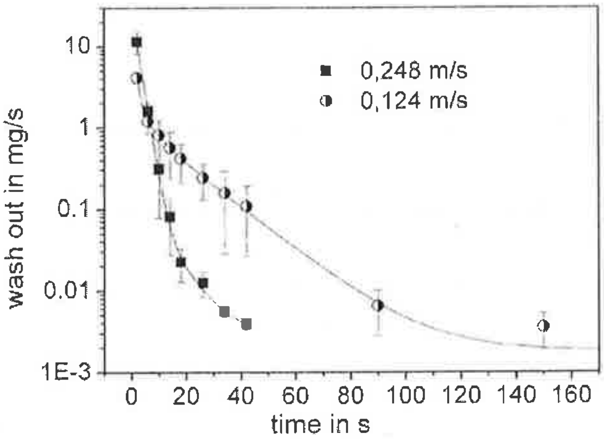

FIGURE 6: COMPARISON OF THE STREAMING VELOCITY

3.3 Influence of the surface finish on the cleaning process

In this work also the influence of the surface finish of filter media are investigated. For these experiments the filter media SK and K (see table 1) are used. In figure 9 the results are shown. The difference between calendared and super calendared filter media are the process conditions at the fabrication. In the calendaring process the filter media were pressed through two rolls. The process of super calendaring and calendaring differ in the temperature and the pressure. For the super calendared filter media the temperature and pressure are much higher and consequently the surface is much clogged than for calendared or uncalendared filter media.

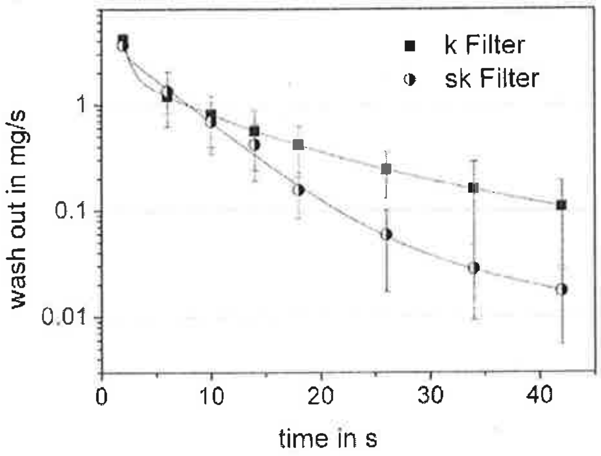

FIGURE 7: COMPARISON OF THE SURFACE FINISH ON THE CLEANING PROCESS

As shown in figure 7 the influence of calendaring filter media on the cleaning process is low. The tendency however shows that the slope of the SK filter in the first phase of the cleaning process is much higher than that of the K filter. So it seems, that the SK filter has a better cleaning behaviour than the K filter. But to verify these assumptions, it is necessary to investigate an uncalendared filter media.

3.4 Influence of the texture on the cleaning process

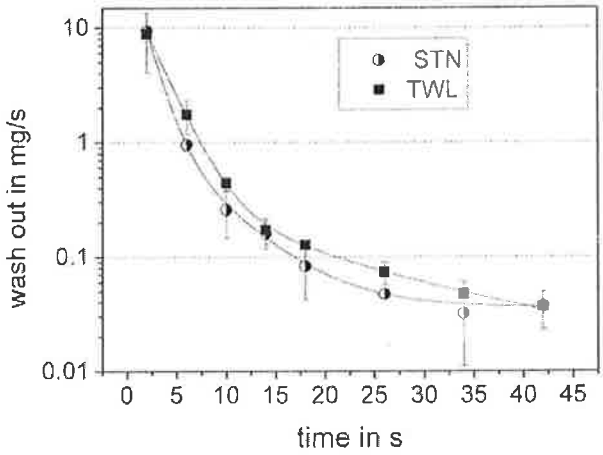

FIGURE 8: COMPARISON OF FILTER STN AND TWL

To investigate the influence some cleaning experiments of different filter textures were operated. The results are shown in figure 7. It seems that the filter media with the TWL texture have a better cleaning behaviour than the STN texture, but the differences are not so significant. The reason for this behaviour can be found in their texture. The warp thread glides below four warp threads at the STN texture whereas at the TWL texture the filling thread floats only across three warp threads.

Consequently at the TWL texture there are more godges, where the duty can deposit and which are difficult to clean.

Conclusion

The work has discussed the kinetic of the cleanability of filter media. It was shown that the kinetic decreases exponentially. Also the influence of the streaming velocity was considered. The results show that with a higher streaming velocity the cleaning effect gets much higher . The influence of the calendering of the filter media has also an effect. Filter media, which are super calendered show a better cleaning behaviour than filter media which are calendered, because the roughness of calendered filter media is higher than of super calendered filter media. The results of the comparison of the filter texture show that TWL filter have a better cleaning behaviour than STN filter.

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