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Short communication

The fouling and cleaning of venous catheters: A possible optimization of the process using intermittent flushing

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ABSTRACT

The aim of this note is to report experimental results obtained for mass transport under controlled flow conditions in a system where convection and diffusion are coupled with chemical interactions associated to the protein adhesion. The context of the problem is of crucial practical importance in the framework of medical application and is concerned with the maintenance of central venous catheters. Then a phenomenological description is suggested giving a possible description of the process.

Keywords: Catheters; Adhesion; Fouling; Flushing; Cleaning; Convection; Mass transfer

1. Introduction

In many industrial activities, the fouling can become a very serious problem if cleaning processes are incorrectly designed or operated improperly. In recent years, considerable attention has been paid to understanding the processes involved in the formation and removal of deposits in order to extend the operating period between cleanings, and to improve the efficacy of cleaning methods. This is notably the case of studies on proteins and deposition of calcium phosphate in the milk industry (Changani et al., 1997; Gillham et al., 2000) and scale deposition in heat exchangers (Georgiadis and Papageorgiou, 2000; Georgiadis et al., 2000; Jamialahmadi and Muller-Steinhagen, 2007)

Fouling in the food and medical industry is more severe than in other industries because of the nature of deposits (such as protein or pathogenic bacteria) which require frequent or immediate cleanings for public health problems. For such industrial activities, specific protocols have been develop as for example the technique of flow pulsing which have showed recently an enhancement of the rate of cleaning proteins (Christian and Fryer, 2006; Augustin et al., 2010). Experiments on cleaning of whey protein show that an up to 50% shorter cleaning time is achievable when pulsed flow is applied (Gillham et al., 2000; Bode et al., 2007).

The administration of medicines or solutes by means of peripheral or central venous catheterization is a frequent practice that covers a wide variety of situations. Among the different acts of maintenance of the catheter the flushing holds a key position with a crucial objective: to avoid the occlusion of the device. Although it comes from the literature that the efficiency of the cleaning appears to be more dependent on the technical practice (standardized procedure, bolus, and positive pressure) than on the used solute (Garrelts et al., 1989; Goode et al., 1991; Smith et al., 1991; Thunder Project, 1993; Therapeutic position statement, 1994; McEvoy, 2001; Pierre, 2003; Repplinger et al., 2004), only a few papers give a description of the techniques (Booker and Ignattavicius, 1996; Coquin and Vigier, 2002) and no one gives a description of the way for administration.

In the framework of practical applications the Reynolds numbers of the flows in the catheters are in the range $2 < Re < 1500$, the lower values of Re being associated with flushing by perfusion and the higher to manual flushing with calibrated syringes of 10 ml.

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Nomenclature

a	radius of catheters, m
A, B	phenomenological coefficients
C	term of consummation, kg s^{-1}
N	exponent, dimensionless
P	term of contribution, kg s^{-1}
Q	quantity of matter, kg
Re	Reynolds number
t	time, s
α	phenomenological coefficients, kg s^{-1}
λ	inverse of time scale, s^{-1}
τ	time scale, s
ν	kinematic viscosity, m^2 s^{-1}
$\dot{\gamma}$	shear stress, s^{-1}
κ	exponent, dimensionless

Subscripts

c	convective flow
f	impulse
i	interruption
m	maximum
r	chemical reaction

Although the partial or total obstruction of the catheters occurs as a frequent complication, there exists no systematic study of the conditions of cleaning which remains (Hadaway, 2003, 2006) the best way for the prevention of the obstruction. Then the removal of proteins from the wall of the catheters are mainly governed by the hydrodynamic conditions of the flow namely wall shear stress in permanent or intermittent conditions.

The aim of the present work is to present experimental results for different ways of cleaning in controlled flow conditions using either a unique bolus or successive bolus leading to a possible optimization of intermittent cleaning together with a phenomenological description of the process of removal.

It is clear that any *in vivo* study is not possible because of technical and ethical reasons nevertheless the whole results are considered to be relevant of the clinical practice by virtue of the general protocol used for this study. The first challenge was to develop a protocol for obtaining a quantitative and reproducible pollution of the catheters as close as possible as *in vivo* deposit. It is well known that the fibronectin and the albumin play important roles in many processes of adhesion and desadhesion and are present in great quantities in blood (Potts and Campbell, 1994). The fibronectin is an adhesive protein which can adhere to cells, other proteins or biomaterials such as vascular prosthesis walls (Horbett, 1994). After being fixed, it can promote the adhesions of other proteins such as albumin (Potts and Campbell, 1994; Chevallier et al., 2003; Drumheller, 1999).

Then it appeared reasonable to use these proteins as representative of *in vivo* deposit in real situations. The present results are thus obtained in experimental conditions as close as possible to real hospitable conditions thus leading to conclusions which could be of interest in practice.

The aim of this work is to investigate the fouling and cleaning of central venous catheters under controlled flow conditions. The proteins adhesion leads to possible important fooling of the wall of the catheters. The cleaning is then more or less efficient due to the interaction with the wall shear stress. To the end a phenomenological approach is suggested for the understanding of the observed possible optimization of the flushing.

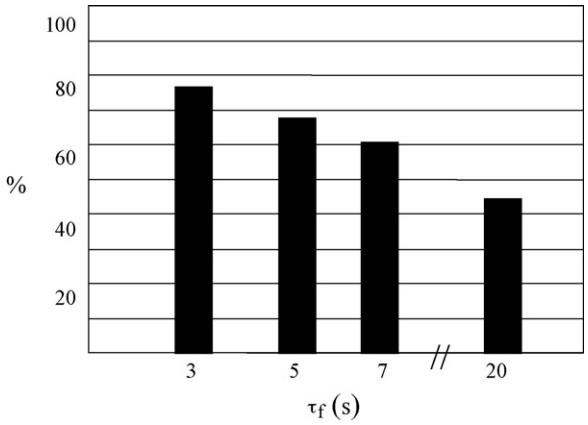

Fig. 1 – Percentage (%) of removed proteins with respect to the total quantity.

2. Materials and methods

A specific method was developed to obtain a reproducible deposit of proteins in the catheter lumens. The protocol is largely described elsewhere (Vigier et al., 2005; Merckx et al., 2009) and can be summarized in the following way. After being uniformly cleanse with a 0.1% solution of sodium dodecyl sulfate (SDS) (in a sweating-room at 37 °C for 24 h) the catheters were filled with a 5 μg/ml solution of fibronectin (24 h at 37 °C) to facilitate the adhesion of the bovine albumin (10 mg/ml). At the end of this process, a known and reproducible amount of fibronectin and albumin is fixed on the wall of the catheter.

A calibrated syringe (10 ml) containing the flushing solution (aqueous solution of NaCl 0.9%) is then inserted in a mechanical device permitting to impose controlled permanent or intermittent flow conditions. The catheters (6,5F, BD Careflow^{TM}, Becton Dickinson) used were 16 cm long with a inner radius of $a = 0.1$ cm.

The efficiency of the cleaning was measured by the amount of albumin found in the recuperated cleaning solution and was titrated by a UV spectrophotometer (Gilsonll2 UV/VIS detector) at 280 nm. Twelve catheters were used for each test condition. Statistics were performed using the U test of Mann and Whitney. The time intervals for the intermittent flushing were chosen in reference (Repplinger et al., 2004; Coquin and Vigier, 2002) with the practises pertaining to hospital.

3. Experimental results and discussion

The first part was to investigate the efficiency of the continuous cleaning (with a calibrated cleaning volume of 10 ml) flow. Fig. 1 shows some results for the percentage (%) of removed proteins with respect to the total quantity of fixed proteins for four cleaning durations τ_f. The two extreme durations $\tau_f = 2.5$ s and $\tau_f = 10$ s although slightly exterior to the values observed in practical situations were retained in the experimental study to give limiting values in the data. The mechanism for the desadhesion of the proteins is clearly related to the wall shear stress in the catheter. We observe from Fig. 1 that the efficiency of the continuous cleaning is decreasing when increasing the duration of cleaning due to the fact that increasing the duration of cleaning leads to a decrease of the wall shear stress. The