Contents lists available at ScienceDirect

Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

Inclusion and removal of pharmaceutical residues from aqueous solution using water-insoluble cyclodextrin polymers

L. Moulahcene[a,c], **M. Skiba**[a,b,*], **O. Senhadji**[c], **N. Milon**[a], **M. Benamor**[c], **M. Lahiani-Skiba**[a,b]

[a] *Pharmaceutical Technology and Biopharmaceutics Laboratory, Faculty of Medicine and Pharmacy, Rouen University, 22 Bd Gambetta, 76183 Rouen, France*
[b] *In-Cyclo, 75 Route de Lyons, 76183 Rouen, France*
[c] *Laboratoire des procédés membranaires et des techniques de séparation et de purification, Faculté de technologie, Université de Bejaia, Algeria*

ABSTRACT

A novel insoluble cyclodextrin polymers (PolyCyC®) (monopolymer, bipolymer, tripolymer and tetrapolymer) containing different cyclodextrins (α, β, γ-cyclodextrin) crosslinked with citric acid were used for removing progesterone as an endocrine disruptor from aqueous solutions. The adsorption experiments were carried out by using recycling column procedure; results show that these polymers exhibited high adsorption capacities and cycle number more than activated carbon. The effects of initial pH, initial concentration, adsorbent amount, ionic strength, flow rate and temperature were studied but only with β-cyclodextrin polymer, kinetic study was also investigated using different models for all polymers which shows that kinetic extraction can be modeled by pseudo second order model.

The different cyclodextrin polymers were characterized by Fourier transform infrared spectroscopy, X-ray analysis, scanning electronic microscopy and surface area analysis.

Keywords: Progesterone; Endocrine disruptor; Cyclodextrin polymer (PolyCyC®); Adsorption

1. Introduction

The US Environmental Protection Agency (US-EPA) has defined endocrine disruptors as "exogenous agents that interfere with the production, release, transport, metabolism, binding, action, or elimination of the natural hormones in the body responsible for the maintenance of homeostasis and the regulation of developmental processes" (Eertmans et al., 2003). An increasing number of chemical compounds in the environment have been identified as endocrine disruptors using in vitro and in vivo bioassays. These include pesticides, industrial chemicals, pharmaceuticals and natural hormones acting as ligands for the estrogen, androgen or arylhydrocarbon receptor or exerting a combined action (e.g. estrogenic and anti-androgenic activity) (Eertmans et al., 2003), via the food chain, the air and the water as well as during fetal development, man and wildlife are exposed to this kind of substances. In humans, adverse health trends affecting the reproductive organs of both males and females had been reported. For males, lowered sperm counts, increased incidences of other reproductive disorders related to infertility (hypospadias and cryptorchidism) and testicular cancer were associated with exposure of children to endocrine disruptors prior to or after birth (Sharpe and Skakkebaek, 1993). A feminisation of male is also reported in wildlife due to their exposure to endocrine disruptor this effect is observed in a wide range of wildlife species, including (Fry, 1995), panthers (Facemire et al., 1995), turtles, frogs (Palmer and Palmer, 1995) and fish (Purdom et al., 1994).

Among endocrine disruptors, progesterone which is a natural hormone utilized as a drug to control the reproductive function and for postmenopausal therapy, this substance has been detected in wastewater, drinking water and agricultural watershed (Osman et al., 2008) and it was identified as an endocrine disruptor for several body at trace

* *Corresponding author at*: Laboratoire de Pharmacie Galénique, Faculté de Médecine & Pharmacie, 22, Boulevard Gambetta, 76183 Rouen Cedex, France. Tel.: +33 2 35 14 85 96.
E-mail addresses: mohamed.skiba@univ-rouen.fr, mohamed.skiba@in-cyclo.fr (M. Skiba).

Available online 6 September 2014
http://dx.doi.org/10.1016/j.cherd.2014.08.023
0263-8762/

Nomenclature

α-CD	alpha-cyclodextrin
β-CD	Beta-cyclodextrin
γ-CD	gamma-cyclodextrin
ΔH	enthalpy
ΔS	entropy
ΔG	free energy change
μm	micrometer
λ	wavelength
θ	diffraction angle of X-ray
Da	Dalton
Eq	equation
F	flow rate
FTIR	Fourier Transform Infrared
HCl	chloridric acid
ID	diameter
K_d	the inclusion constant
k_i	the intraparticle diffusion rate constant
k_{fd}	the film diffusion rate coefficient
mm	millimetre
NaCl	sodium chloride
NaOH	sodium hydroxide
ng	nanogram
nm	nanometer
P-β-CD	beta-cyclodextrin polymer
P-γ-CD	gamma-cyclodextrin polymer
P-α-CD	alpha-cyclodextrin polymer
PA	polymer amount
ppm	parts per million
Q	the adsorbent amount
T	temperature
TA	total acidic groups
US-EPA	United States Environmental Protection Agency
w	weight
XRD	X-ray diffractometry
XRPD	X-ray powder diffractometry

concentration [ng/l] for human and wildlife such as nematodes (Hoss and Weltje, 2007). There are several direct and indirect pathways through which progesterone can be introduced into the aqueous environment, from urine excretion of women or by effluents coming from sewage treatment plants.

Removal and elimination of progesterone from aqueous solutions has been studied in literature by using different methods such as ozone oxidation (Broséus et al., 2009), nanofiltration and ultrafiltration (Yoon et al., 2007; Koyuncu et al., 2008), electrodialysis membrane (Laura and Schäfer, 2010) and adsorption on activated carbon (Shane et al., 2007).

Adsorption is one of the most widely used purification methods finding an enormous number of applications in numerous industrial processes. Adsorption has gained wide acceptance and popularity for removal of pollutants because it is an efficient and economically feasible process for purification. Study of adsorption equilibrium and kinetics are very important because their data are the basis for the selection of suitable adsorbent, design of separation process, analysis of economical and so on. Recently a new material (adsorbent) is synthesized to remedy to limited regeneration cycle of activated carbon and selectivity which is cyclodextrin polymer, several works in literature reveal that the regeneration of cyclodextrin polymer is much better than that of typical anion-exchange polymers and of activated carbon (Chen et al., 2012).

Cyclodextrins (CDs) are cyclic oligosaccharides consisting of six or more glucopyranose units. Due to their structural features, they have an external hydrophilic surface and a hydrophobic cavity inside which a wide variety of guest molecules are included to form inclusion complexes (Ghuzlaan et al., 2009).

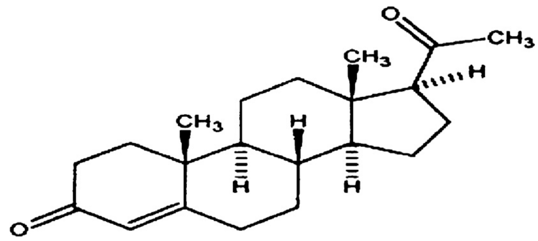

Fig. 1 – Molecular structure of progesterone.

Insoluble cyclodextrin polymers (P-CD) can be obtained using cyclodextrin (CD) as complex molecule and bi or polyfunctional substance as cross-linking agent such as, polyamidoamine units (Li et al., 2011), diiosyanate (Mohamed et al., 2010), epichlorohydrin (Crini et al., 1998; Chen et al., 2012), hexamethylene diisocyanate (HMDI) (Bhaskar et al., 2004), succinic anhydride (Girek and Ciesielski, 2011) and citric acid (Zhao et al., 2009; Skiba and Lahiani-Skiba, 2013).

These cyclodextrin polymers have been successfully applied to the removal of diverse organic pollutants from water: dyes (Crini et al., 2003; Yilmaz Ozmen and Yilmaz, 2007), aromatic amines (Bhaskar et al., 2004), phenol (Romo et al., 2008), pesticides (Liu et al., 2011) and chlorophenol. Insoluble cyclodextrin polymers have been also used in other domain, in the pharmaceutical sector essentially in drug release (Gazpio et al., 2008), in food sector, cyclodextrin polymer was used for determination of brilliant blue in food (Li et al., 2009) and in catalysis (Yang et al., 2012).

In this paper, a novel insoluble cyclodextrin polymers crosslinked with citric acid were used to remove progesterone from aqueous solution. The effects of several operating variables, such as contact time, pH, ionic strength, flow rate and temperature was studied, these polymers were also characterized by using X-ray analysis, scanning electronic microscopy and IR analysis after and before extraction. This study provides a valuable example for the removal of trace progesterone from water.

2. Materials and method

2.1. *Chemicals*

Insoluble cyclodextrins polymers (PolyCyC®) granules with a molecular weight of 10,000 Da ((Poly-β-cyclodextrin (P-β-CD), Poly-α-cyclodextrin (P-α-CD), Poly-α-γ-cyclodextrin (P-α-γ-CD) and Poly-α-γ-β-cyclodextrin (P-α-γ-β-CD), were acquired from start-up In-Cyclo®, Rouen-France, the progesterone powder (purity ≥99.0%) (its chemical structure is shown in Fig. 1) was purchased from UP John Company (USA) and was used without further purification, chloridric acid, sodium chloride and sodium hydroxide were obtained respectively from Cheminova, Labosi and Merck KGaA.

2.2. *Materials*

2.2.1. *UV/VIS spectra and pH measurement*

UV/VIS spectra were obtained with JASCO spectrophotometer, which was used for progesterone quantification in aqueous solutions at $\lambda_{max} = 250\,nm$. pH values of the solutions were measured using a digital pH meter model Inolab.

2.2.2. *FT-IR spectra*

IRAffinity-1 SHIMADZU spectrometer was used to record the FTIR spectrums of progesterone, cyclodextrin polymer before and after adsorption. The pellets were obtained using small amounts of the samples mixed and ground with KBr in an