

## BIOMASS TRANSFER IN SOLID–LIQUID DRUG EXTRACTION

The biomass transfer of drug solid–liquid systems was investigated for nettle (*Urtica dioica* L.) and hawthorn (*Crataegus oxyachanta* L.). Extraction was provided by an ethanol–water solution. The experiments were carried out in Soxhlet columns on laboratory and pilot–plant scales at atmospheric pressure. The composition of the bioactive substances was determined by gas chromatography and mass spectrometry. The biomass transfer coefficients were determined from the bioactive substance composition. The experimental values of the mass transfer coefficients were in a good agreement with those calculated by the correlation model. The results of the investigation show that the biomass transfer efficiency depends on the drug nature, ethanol concentration, temperature, hydrodynamic conditions and time of extraction. The obtained results show better yields for both investigated drugs in a laboratory extraction column than in a pilot–plant, but the amount of bioactive extract is larger in a pilot–plant extraction column.

Mass transfer according to the two film theory has been investigated by many authors [1–7]. The extraction of drugs was studied as a mass transfer phenomenon of the bioactive substance between the solid and liquid phases [8–11]. Generally the extraction efficiency of the drugs depends on the drug nature, solvent, temperature and time of extraction [10–17].

The diffusion coefficients of the fatty oil extracted from *Oenothera* seed and *Klamath* weed (*Hypericum perforatum*) were determined in previous papers [18, 19]. The mass transfer coefficient of sage extraction (*Salvia officinalis* L.) was determined in paper [20].

In this paper biomass transfer during the extraction of nettle (*Urtica dioica* L.) and hawthorn (*Crataegus oxyacantha* L.) was investigated. The overall mass transfer coefficients were determined involving convection, inner and free transfer.

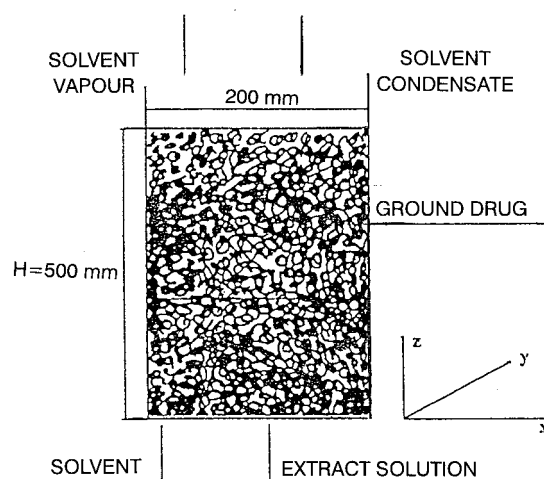


Figure 1. Streams flow in a drug packed bed

### THEORY OF BIOMASS TRANSFER

The mass transfer of the bioactive substance between the solid and liquid phase occurs in a drug packed bed shown in Figure 1.

In the initial extraction period, called fast extraction, the cell content of ground drug is rinsed out. In the slow extraction period diffusion of the bioactive substance occurs and can be expressed as:

$$\frac{\partial c}{\partial \tau} + v_x \frac{\partial c}{\partial x} + v_y \frac{\partial c}{\partial y} + v_z \frac{\partial c}{\partial z} = D \left( \frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} + \frac{\partial^2 c}{\partial z^2} \right) \quad (1)$$

where  $c$  is the bioactive substance concentration,  $\tau$  time,  $v$  is velocity of solvent flow,  $x$ ,  $y$ ,  $z$  the three dimensions of diffusion, and  $D$  is the diffusion coefficient according

to the Fick's second law. Taking into account only diffusion in the  $x$  direction eq. (1) can be formulated:

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \quad (2)$$

Eq. (2) can be solved for the given boundary conditions  $\Delta \tau$  and  $\Delta x$  and diffusion coefficient  $D$ . When the concentration is known, the diffusion coefficient for each bioactive substance can be determined.

The flux of biomass diffusion is:

$$j = -D \frac{dc}{dx} \quad (3)$$

Biomass transfer through the cell membrane can be expressed as:

$$\frac{dm_m}{dt} = K_m F_m \Delta c \quad (4)$$

where  $m_m$  is the amount of the membrane transferred substance,  $\Delta c$  is the average concentration gradient,  $F_m$

is the membrane surface and  $K_m$  is the biomass transfer coefficient through the membrane.

The overall biomass transfer can be expressed as:

$$\frac{dm}{dt} = K F \Delta c \quad (5)$$

where  $m$  is the amount of extractable substance,  $\Delta c$  is the average concentration gradient and  $K$  is the overall mass transfer coefficient.

The solvent for both phases is the same and the biomass balance is:

$$-Sdy = L dx \quad (6)$$

and,

$$m = S \left( \frac{y_1}{2} - \frac{y_2}{2} \right) = L \left( \frac{x_1}{2} - \frac{x_2}{2} \right) \quad (7)$$

where  $S$  is the solid phase,  $L$  the liquid phase,  $y_1$  and  $y_2$  are the initial and final concentrations in phase  $S$ ,  $x_1$  and  $x_2$  are the initial and final concentrations in phase  $L$ .

#### BIOMASS TRANSFER COEFFICIENT DETERMINATION

The overall mass transfer coefficient can be expressed:

$$K = \frac{1}{(1/k_i) + (l_p/D_{in}) + (\delta/D)} \quad (8)$$

where  $k_i$  is the convention transfer coefficient from the solvent side,  $D_{in}$  the diffusion coefficient inside the drug particle, inner diffusion,  $l_p$  the particle size (particle diameter),  $D$  the diffusion coefficient in the bounded layer, free diffusion, and  $\delta$  the thickness of the bounded layer.

The diffusion coefficient in the bounded layer was determined according to the following equation:

$$D = 7.4 \cdot 10^{-8} \frac{(a_s \cdot M)^{0.5} T}{\mu \cdot V_m^{0.6}} \quad (9)$$

where  $a_s$  is the parameter of molecule solvent association,  $M$  the molar mass of the solvent,  $T$  temperature,  $\mu$  the solvent viscosity and  $V_m$  molar volume of the bioactive substance.

The inner diffusion coefficient in the drug particle is defined as:

$$D_{in} = \frac{d^2 [lg a - lg(m/m_0)]}{0.43 \cdot b \cdot \tau} \quad (10)$$

where  $d$  is the average diameter of the drug particle,  $m_0$  the initial content of bioactive substance in the drug,  $m$  the content of bioactive substance in the exhausted drug after extraction,  $a$  the constant for a cylinder  $a=0.6945$ ,  $b$  the rinse coefficient of the drug and  $\tau$  extraction time.

The average drug particle diameter  $d$  was determined according to the following equation:

$$d = \frac{100}{\sum_i \frac{g_i}{d_i}} \quad (11)$$

where  $d$  is the average particle diameter and  $g$  the mass fraction of the particle size.

The overall mass transfer coefficients were correlated by the following equation:

$$Sh = A_0 R_e^{A_1} S_c^{A_2} \quad (12)$$

where

$R_e$  is the Reynolds number defined as:

$$R_e = 2/3 \frac{\phi}{1-\epsilon} \frac{w \cdot d_{eq} \cdot \rho}{\mu} \quad (13)$$

where  $\phi$  is the shape parameter of the particle,  $\epsilon$  the porosity of the ground drug,  $w$  the liquid phase velocity,  $d_{eq}$  the equivalent diameter of the particle (diameter of a sphere which has the same volume as particle),  $\rho$  the density of the liquid phase and  $\mu$  the liquid phase viscosity.

$S_c$  is the Schmidt number defined as:

$$S_c = \frac{\mu}{\rho \cdot D} \quad (14)$$

$Sh$  is the Sherwood number defined as:

$$Sh = \frac{K \cdot \delta}{D} \quad (15)$$

and  $A_0$ ,  $A_1$  and  $A_2$  are correlation constants.

#### EXPERIMENTAL

Experimental investigations were performed in laboratory and pilot-plant scale Soxhlet columns. The nettle (*Urtica dioica L.*) and hawthorn (*Crataegus oxychantha L.*) were used as drugs for extraction. The solid-liquid extraction experiments were carried out by ethanol-water solution at atmospheric pressure. The granulation composition of the ground drugs is given in Table 1.

The experiments on a laboratory scale were carried out in an ordinary Soxhlet glass column of 6 mm

Table 1. Granulation of ground drugs

Drug particle size	Hawthorn ( <i>Crataegus oxychantha L.</i> ) %	Nettle ( <i>Urtica dioica L.</i> ) %
Particle > 2000 $\mu$	3.00	2.00
Particle > 1000 $\mu$	8.10	3.50
Particle > 630 $\mu$	2.20	9.90
Particle > 500 $\mu$	15.30	10.50
Particle > 315 $\mu$	33.50	10.80
Particle > 125 $\mu$	21.00	39.00

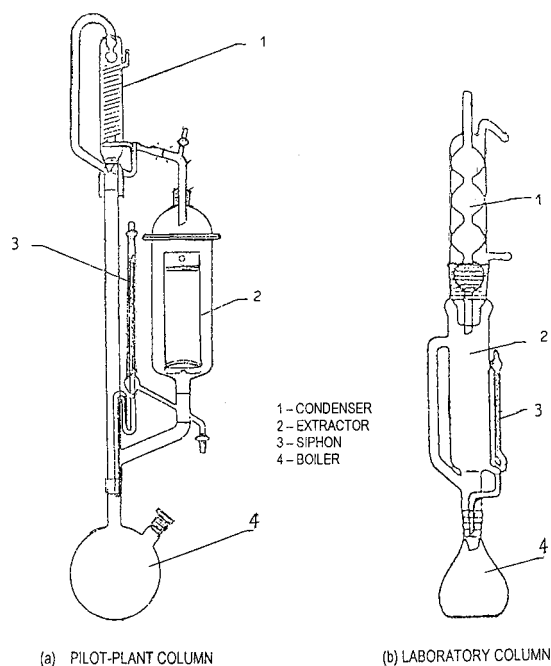


Figure 2. Pilot-plant (a) and laboratory (b) Soxhlet column

Table 2. Reynolds number in a laboratory column

Drug	Volume mass of ground drug kg/m <sup>3</sup>	Particle porosity	Re
Hawthorn (1988) (charge 1)	456	0.703	0.91
Hawthorn (1988) (charge 2)	456	0.703	0.99
Hawthorn (1988) (charge 3)	456	0.703	0.85
Nettle (1991) (charge 1)	178	0.884	2.09
Nettle (1991) (charge 2)	178	0.884	1.77
Nettle (1991) (charge 3)	178	0.884	1.91

diameter and a packed bed height of 500 mm with of 1.5 dm<sup>3</sup> reboiler (Figure 2 (b)).

A pilot-plant glass column of 1050 mm height and 65 mm diameter with hilsn was used for the performed experiments (Figure 2(a)). The height of the glass hilsn

Table 3. Hyperazide extracted in a pilot-plant Soxhlet column

Number of charge	Mass of charge kg	Solvent ethanol: water, dm <sup>3</sup>	Temper. of extraction, °C	Time of extraction	Yield %	Hyperazide %
1	1.24	4.20:1.80	85	15 h 30'	15.70	-
2	2.90	8.40:3.60	85	16 h 35'	12.97	3.85
3	3.00	9.10:3.90	85	16 h 30'	11.70	3.85
4	3.00	8.00:3.00	85	15 h 50'	12.25	3.18
5	3.00	9.70:3.30	85	15 h 55'	11.20	3.36
6	3.00	9.20:3.30	85	12 h 0'	9.92	2.78
7	3.07	7.70:3.30	85	21 h 0'	9.12	2.91
8	2.80	7.00:3.00	85	19 h 0'	9.42	2.97

is 500 mm the and diameter 200 mm. The reboiler has a volume of 10 dm<sup>3</sup>.

The values of the Re number for laboratory conditions are given in Table 2.

The compositions of bioactive substances: chlorophyl "a" and "b" (Table 3) in the nettle and hyperozide (Table 4.) in the hawthorn were determined by gas chromatography and mass spectrometry. Chlorophyl "a" and "b" when determined by a spectrometer at the wave lengths  $\lambda = 663$  nm and  $\lambda = 645$  nm. Hyperozide was determined by spectrophotometrically according to DABB.

## RESULTS AND DISCUSSION

The obtained experimental results of drug extraction yields are given in Table 3.

Table 3 shows the hyperazide yield dependence on the solvent ratio and temperature, as well as time of extraction with laboratory conditions. Table 4 shows the chlorophyl yield dependence on the solvent ratio and temperature, as well as extraction time.

The experimental values of the overall biomass transfer coefficients were determined from eq. (5).

The obtained overall mass transfer coefficients are given in Figures 3. The diffusion parameters are given in Table 5. Figure 3 shows the biomass transfer coefficient vs. the average logarithmic difference of the hyperazide concentration. Figure 4 shows the biomass transfer coefficient vs average logarithmic difference of the chlorophyl concentration.

The obtained overall mass transfer coefficients were modeled by equation (12) for laminar flow and the following correlation model was derived:

$$Sh = 0.33 Re_e^{0.5} \cdot Sc_e^{0.3} \quad (16)$$

The obtained correlation produced an agreement between the experimental and calculated values with a mean deviation of 9.6 % for hawthorn and 13.8% for nettle.

## CONCLUSIONS

The obtained results in this paper show that the yields of bioactive substance for both examined drugs

Table 4. Chlorophyll extracted in a laboratory Soxhlet column

Number of charge	Mass of charge kg	Solvent ethanol: water, dm <sup>3</sup>	Temper. of extraction, °C	Extraction time	Yield %	Chlorophyll %
1	20	410	78-80	6 h 10'	9.00	2.67
2	100	600	78-82	22 h	8.00	4.64
3	50	400	78-82	6 h	9.50	3.27
4	45	560:240	85	10 h	10.88	1.23
5	50	240:560	96-98	16 h	20.00	0.30
6	11	280:120	85	2 h	14.55	1.38
7	45	560:240	85	3 h	18.66	1.86
8	50	240:560	96-98	9 h	25.40	1.36
9	136	1200	78-82	16 h 30'	9.11	2.97

Table 5. Diffusion parameters for laboratory conditions

Drug	Inner diffusion coefficient $D_{in}$ , m <sup>2</sup> /s	Free diffusion coefficient $D$ , m <sup>2</sup> /s	Conventional coefficient $k_e$ , m <sup>2</sup> /s
Hawthorn (1988) (charge 1)	$0.105 \cdot 10^{-12}$	$0.6703 \cdot 10^{-9}$	$2.2593 \cdot 10^{-10}$
Hawthorn (1988) (charge 2)	$0.114 \cdot 10^{-12}$	$0.6802 \cdot 10^{-9}$	$1.4677 \cdot 10^{-10}$
Hawthorn (1988) (charge 3)	$0.146 \cdot 10^{-12}$	$0.5705 \cdot 10^{-9}$	$0.7760 \cdot 10^{-10}$
Nettle (1991) (charge 1)	$0.253 \cdot 10^{-12}$	$0.2510 \cdot 10^{-9}$	$0.4034 \cdot 10^{-10}$
Nettle (1991) (charge 2)	$0.252 \cdot 10^{-12}$	$0.2985 \cdot 10^{-9}$	$1.2115 \cdot 10^{-10}$
Nettle (1991) (charge 3)	$0.202 \cdot 10^{-12}$	$0.2997 \cdot 10^{-9}$	$2.2015 \cdot 10^{-10}$

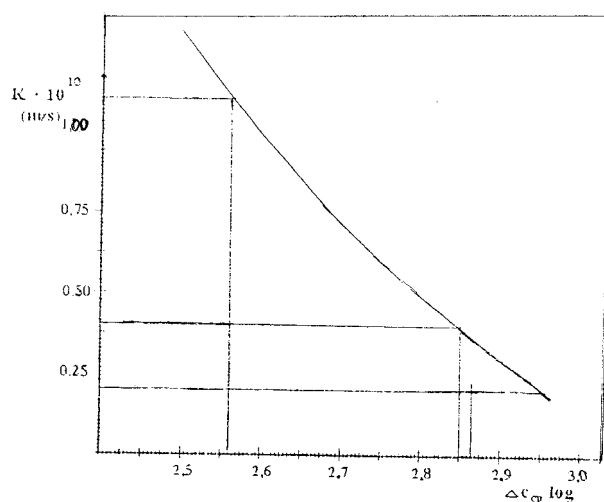


Figure 3. The biomass transfer coefficient vs. average logarithmic difference of the chlorophyll concentration

are higher in the laboratory than in the pilot-plant Soxhlet column. The results of the investigation of biomass transfer coefficients show that the inner diffusion coefficients are the lowest. The results of modeling biomass transfer coefficients demonstrate that the experimental values are in good agreement with the calculated ones for a ground drug bed.

The biomass transfer efficiency depends on the drug nature, ethanol concentration, temperature, dynamic flow and extraction time. The biomass transfer efficiency is better for laboratory than pilot-plant

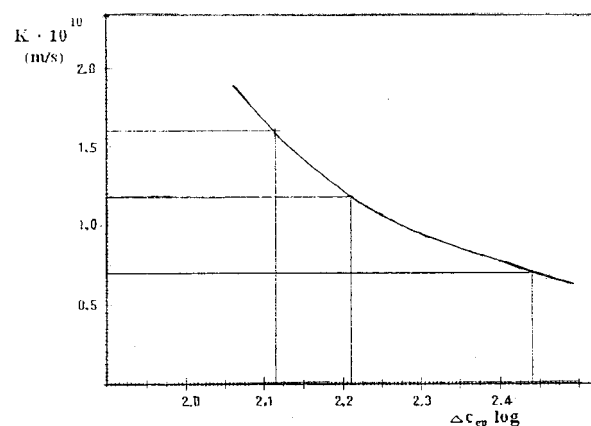


Figure 4. The biomass transfer coefficient vs. average logarithmic difference of the hyperazide concentration

dimension. However, the amount of bioactive extract is larger in the pilot plant column.

#### NOTATION

- a – particle parameter
- $a_s$  – solvent association constant
- b – rinse coefficient
- c – biomass concentration, kg/m<sup>3</sup>
- d – average particle diameter,  $\mu\text{m}$
- D – diffusion coefficient, m<sup>2</sup>/s
- $d_{eq}$  – equivalent diameter of the particle,  $\mu\text{m}$
- F – specific contact surfaces, m<sup>2</sup>
- g – mass fraction, kg/kg
- L – liquid phase
- $l_p$  – particle dimension,  $\mu\text{m}$
- K – overall biomass transfer coefficient, m/s
- $k_e$  – biomass conventional coefficient, m/s

M – molar mass of the solvent, kg/mol  
 m – bioactive mass, kg  
 Sc – Schmidt number  
 Sh – Sherwood number  
 Re – Reynolds number  
 T – temperature, K  
 w – velocity  
 Vm – molar volume of bioactive substance in the extract solution at the boiling temperature, m<sup>3</sup>/mol  
 x – bioactive substance composition in the liquid phase, mol/mol  
 y – bioactive substance composition in the solid phase, mol/mol

#### Subscript

in – inner drug cell  
 l – liquid phase  
 m – membrane  
 p – particle  
 1,2 – initial and final period

#### Greek symbols

δ – bed thickness  
 ρ – density, kg/m<sup>3</sup>  
 ε – bed void fraction  
 μ – viscosity, N/s  
 φ – particle parameter (for grass and leaves = 0.25)

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#### IZVOD

#### PRENOS BIOMASE PRI EKSTRAKCIJI ČVRSTO-TEČNO SUVIH BILJAKA

(Naučni rad)

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Ekstrakcija suvih biljaka proučavana je kao prenos mase gde se difuzija bioaktivne supstance odvija kontaktom čvrste i tečne faze. Prenos biomase u sistemima čvrsto-tečno suvih biljaka ispitivan je za koprivu (*Urtica dioica l.*) i glog (*Crataegus oxychantha l.*). Ekstrakcija je obavljena sa rastvorom etanol-voda. Eksperimenti su izvođeni u laboratorijskoj i poluindustrijskoj Soksletovoj koloni na atmosferskom pritisku. Sastav bioaktivne supstance je određivan gasnom hromatografijom i masenom spektrometrijom. Iz ovih vrednosti su određivani koeficijenti prenosa biomase. Eksperimentalne vrednosti koeficijenata prenosa biomase se dobro slažu sa izračunatim primenom korelacionih modela. Rezultati ispitivanja pokazuju da efikasnost prenosa biomase zavisi od koncentracije etanola u vodi, temperature i vremena trajanja ekstrakcije. Dobijeni rezultati pokazuju da je bolji prinos bioaktivne supstance za obe ispitivane biljke u laboratorijskoj ekstrakcionoj nego u poluindustrijskoj koloni.

Ključne reči: prenos mase bioaktivne supstance • kopriva • glog • koeficijenti prenosa mase čvrsto-tečno •

Key words: Drug extraction • Nettle • Hawthorn • Biomass transfer coefficient • Solid-liquid systems •

