Oxygen Transfer Efficiency of the Aeration Process in Refinery Waste Water Treatment

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This paper presents the results of an experimental investigation of aeration of water with a corresponding mass concentration of waste motor oil depending on the height of the liquid column for varied flow of air introduced into the water. The aeration process for water column heights of 1 and 2 m were investigated. The purpose of investigations performed on an experimental installation was comparison of technical indicators of the aeration process depending on the height of the water column and air flow in order to achieve more efficient purification of waste water.

Keywords: refinery waste water, aeration, water column height, oxygen transfer efficiency

Process efficiency for depth and diffusion aeration mainly depends on the position of the air distributor, i.e. at what depth they are placed, how large is the space between distributors, and also bio-aeration tank geometry, number of installed distributors and also air flow. Certain criteria exist relating to the method and place distributors are installed in a bio-aeration tank. Distributors can be installed on the whole surface of the bottom of a bio-aeration tank, only on one side or at a certain height from the bottom. The distributor position must be such that the required amount of oxygen is supplied to all parts of the bio-aeration tank.

The realized efficiency of oxygen transport in different facilities for biological purifying of waste water depends a lot on the depth of the distributors in water, i.e. the height of the water column. The height of the water column represents the distance between the air distributor and the free surface of the liquid undergoing aeration.

This paper analyzes the influence of the height of the water column on indicators of the aeration process: coefficient of oxygen transport and also other technical indicators (oxygen introduction capacity, oxygen transport efficiency and energy efficiency of oxygen transport). In order to determine technical characteristics of an aeration system it is necessary to first determine the coefficient of oxygen transport in waste water, k_La. Investigation of the water aeration process with a corresponding mass concentration of waste oil depending on the height of the liquid column when varying the air flow introduced into water was performed on an experimental installation.

Experimental Installation

The coefficient of oxygen transport was determined on an experimental installation by enriching water with oxygen. Dissolved oxygen was first chemically extracted from water and then waste oil with a defined mass concentration was introduced in the water.

A polypropylene column with dimensions 700 × 700 × 2200 mm and accompanying connections and framework was used for experimental work in batch conditions. The cross-section surface of the column was defined according to recommendations for an air distributor.

Experimental work was performed for batch working conditions and varying air flow of 2 and 10 m^3/h. The water level in the column was 1 and 2 m high and the total volume was 490 and 980 L. Water aeration with waste oil content of 5 and 10 mg/L was performed. Dissolved oxygen was previously removed using a chemical method. Investigation of aeration of clean water not containing dissolved oxygen

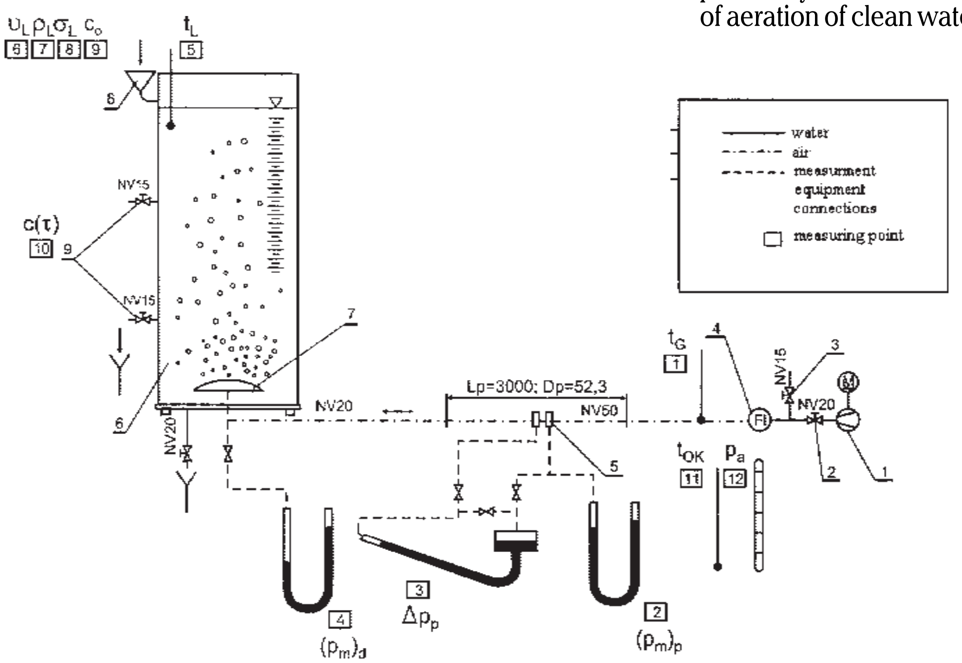

Fig. 1. Scheme of experimental installation
1 – low pressure compressor (blower); 2 – valve on the air inflow pipe; 3 – relieving valve; 4 – air flow regulator; 5 – air flow measuring orifice plate; 6 – column with corresponding connections and framework; 7 – disk-shaped membrane air distributor; 8 – water supply; 9 – sampling connection

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Table 1
DESCRIPTION OF MEASURING EQUIPMENT (LIST OF MEASURED VALUES AND INSTRUMENTS)

Measuring point	Measured value	Denotation	Unit	Instrument
1.	Air temperature in front of the flowmeter	t_G	°C	Mercury thermometer
2.	Air over-pressure in front of the flowmeter	$(p_m)_p$	mm Hg	U-pipe with mercury
3.	Pressure loss through the orifice plate	Δp_p	mm Alc	Micromanometer with alcohol
4.	Air over-pressure in front of the air distributor	$(p_m)_d$	mm Hg	U-pipe with mercury
5.	Water temperature in the column	t_L	°C	Mercury thermometer
6.	Kinematical viscosity of water in the column	υ_L	m²/s	Modified Ostwald viscosimeter
7.	Water density in the column	ρ_L	kg/m³	Laboratory picnometer
8.	Surface tension of water	σ_L	N/m	Microbalance
9.	Starting mass concentration of dissolved oxygen in water	c_o	mg/L	"HANNA INSTRUMENTS 9142" device for measuring oxygen concentration
10.	Mass concentration of dissolved oxygen in water during the aeration process	$c(\tau)$	mg/L	"HANNA INSTRUMENTS 9142" device for measuring oxygen concentration
11.	Environment temperature	t_{ok}	°C	Mercury thermometer
12.	Atmospheric pressure	p_a	mbar	Barometer

was also performed to be able to compare process parameters for air distribution in standard investigation conditions with the ones obtained in real conditions for waste water with corresponding characteristics.

Figure 1 shows the experimental installation for investigating the influence of oil in water on the efficiency of the aeration process for different air flow values (1).

Table 1 contains a list of measured values and instruments on the described installation.

The column was filled first with previously prepared water from which oxygen was extracted using a chemical method. After that a defined amount of waste oil was dosed into the water.

Before investigations started the kinematical viscosity, density and surface tension of water had to be determined.

A complete investigation regime for defining process parameters of aeration of water with certain characteristics started by reading the temperature of the surrounding air and water in the column. Then the compressor was switched on and when the first bubbles appear, i.e. bubbles entered the air distributor the over-pressure value before the distributor $(p_m)_d$ and the orifice plate $(p_m)_p$ was measured, i.e. the pressure difference in front of and after the orifice plate (Δp_p). Air flow regulation is performed using a flow regulator and relieving valve until a set value for the adopted investigation regime is attained. When the flow is stabilized water sampling from the column in equal time intervals starts ($\Delta\tau$ = 60 s) and the dissolved oxygen content is measured until the same value is repeated three times. After one regime is investigated the compressor is switched off and the relieving valve completely opened. Water from the column is released into the drains through a draining valve. The column is then filled with a fresh amount of water. Thus, the installation is ready for a new investigation regime, i.e. the described procedure is repeated.

Result and Discussion

The coefficient of oxygen transport k_La is a parameter used to determine the transport intensity of oxygen in water, i.e. the rate the equilibrium state is reached.

The coefficient of oxygen transport is obtained as the product of the oxygen transport coefficient in water k_L and the specific surface of the contact between air and water in the aeration process (a).

Based on the oxygen flow through the batch reactor with complete mixing the general equation of material balance is:

$$Q \cdot c_o + \dot{V}_G \cdot c_{ul} - V_L \cdot R(\tau) = Q \cdot c + \dot{V}_G \cdot c_{iz} + V_L \cdot \frac{dc}{d\tau}, \qquad (1)$$

where:

V_G - air flow, m³/s;
Q - water flow (for batch process conditions Q=0), m³/s;
c_o - mass concentration of oxygen in the influent, kg/m³;
c - mass concentration of oxygen in the effluent, kg/m³;
c_{ul} - mass concentration of oxygen in air at the input, kg/m³ ;
c_{iz} - mass concentration of oxygen in air at the output, kg/m³;
$R(\tau)$ - specific oxygen consumption during biological treatment, kg/(m³·s);
V_L - water volume, m³.

The gas phase material balance gives:

$$\dot{V}_G \cdot (c_{ul} - c_{iz}) = A \cdot K_L \cdot [c^*(c_{iz}) - c], \quad (2)$$

where:

$c^* = c^*(c_{iz})$ - equilibrium mass concentration of oxygen depending on the mass concentration of oxygen in air at the output, kg/m^3;

$A = a \cdot V_L$ - total contact surface between air and water, m^2;

a - specific surface of contact between air and water, m^2/m^3.

The basic resistance to oxygen transport through the system occurs in a liquid so the total transport coefficient of oxygen by water (K_L) is approximately equal to the partial oxygen transport coefficient through water (k_L):

$$K_L \approx k_L, \quad (3)$$

Equations (2) and (3) give the expression for calculating the output mass concentration of oxygen in air:

$$c_{iz} = \frac{Ha \cdot (\dot{V}_G \cdot c_{ul} + V_L \cdot k_L a \cdot c)}{\dot{V}_G \cdot Ha + V_L \cdot k_L a \cdot (R_u \cdot T_G \cdot C_L)}, \text{ kg/m}^3, \quad (4)$$

where:

Ha - Pa . kmol (O_2+L)/kmol O_2, - Henry's constant,

R_u=8314, J/(kmol . K),- the universal gas constant,

T_G - absolute air temperature, K;

C_L, kmol/m^3,- molar concentration of oxygen in water,

$k_L a$, 1/s, - coefficient of oxygen transport.

The previous equations give the expression for determining the coefficient of oxygen in waste water for full working conditions as:

$$k_L a = \frac{Ha \cdot (m + R(\tau)) \cdot \dot{V}_G}{\dot{V}_G \cdot Ha - (m + R(\tau)) \cdot V_L \cdot R_u \cdot T_G \cdot C_L}, 1/\text{s}, \quad (5)$$

where:

m is the slope coefficient of the equilibrium curve.

The coefficient of oxygen transport for standard conditions is determined in the following way (2):

$$(k_L a)_s = \frac{(k_L a)_{t_L}}{\theta^{t_L - 20}} \quad (6)$$

where:

$(k_L a)_{t_L}$ - experimentally obtained coefficient of oxygen transport, 1/s

t_L - water temperature, °C;

θ=1.024 - temperature correction factor.

Based on the known value for the coefficient of oxygen transport $(k_L a)_s$ the following technical characteristics of aeration systems for aeration of waste water are calculated (3):

-real capacity of oxygen introduction *OC'*;

-real efficiency of oxygen transport *E'*;

-real energy efficiency of oxygen transport E_e'.

The real capacity of oxygen introduction is obtained as the product of the standard capacity of oxygen introduction and corresponding correction factors that convert standard investigation conditions to real ones:

$$OC' = \alpha \cdot OC \cdot \frac{\beta \cdot c_h^* - c_o}{c_s^*} \cdot \theta^{(t_L - 20)} \quad (7)$$

where:

OC is the standard capacity of oxygen introduction into waste water, kg/h;

α=0.8 ÷ 0.94 - relative transport degree of oxygen in waste water;

β=0.90 ÷0.97 - relative saturation degree of waste water with oxygen;

c_h^* - equilibrium mass concentration of dissolved oxygen in clean water in real conditions, corrected in relation to the height of the liquid column above the air distributor and molar participation of oxygen in air, mg/L.

$$c_h^* = c_s^* \cdot \left[1 + \frac{\rho_L \cdot g}{p_n} \cdot (H - h)\right], \text{ mg/L}$$

c_s^* - equilibrium mass concentration of dissolved oxygen in clean water, kg/m^3;

p_n - pressure corresponding to standard conditions, Pa,

H - total height of the water column, m;

h - height of the water column from the bottom of the tank to the distributor, m.

ρ_L - water density, kg/m^3.

The real capacity of oxygen introduction *OC'* into waste water should correspond to oxygen consumption during biological treatment.

The real efficiency of the transport system is expressed in percentages and represents the ratio between the real capacity of oxygen introduction and the total oxygen flow brought by the aeration system (4):

$$E' = \frac{OC'}{\dot{G}_{O_2}} = \frac{OC'}{(\dot{V}_G)_n \cdot \rho_G \cdot y_{O_2}} \cdot 100, \quad \%, \quad (8)$$

Table 2

TECHNICAL CHARACTERISTICS OF THE AERATION SYSTEM FOR CORRESPONDING INVESTIGATION REGIMES

Regime number	Water level in column m	Waste oil concentration mg/L	$(V_G)_n$ m^3/h	$(k_L a)_s$ 1/h	OC` g/h	E' %	E_e` g/kWh
1	1	5	2.285	3.167	6.163	0.844	18.397
2	1	5	5.678	4.082	8.082	0.439	9.773
3	1	5	10.406	5.250	10.393	0.288	7.056
4	1	10	2.285	2.589	5.038	0.699	15.039
5	1	10	5.671	3.446	6.693	0.364	8.093
6	1	10	10.406	4.371	8.505	0.236	5.774
7	2	5	2.379	2.248	9.528	1.118	28.442
8	2	5	5.862	2.378	9.519	0.463	11.510
9	2	5	10.735	4.527	18.999	0.625	12.898
10	2	10	2.379	1.993	8.204	1.002	24.489
11	2	10	5.899	2.160	8.837	0.426	10.686
12	2	10	10.724	2.5776	10.730	0.271	7.284

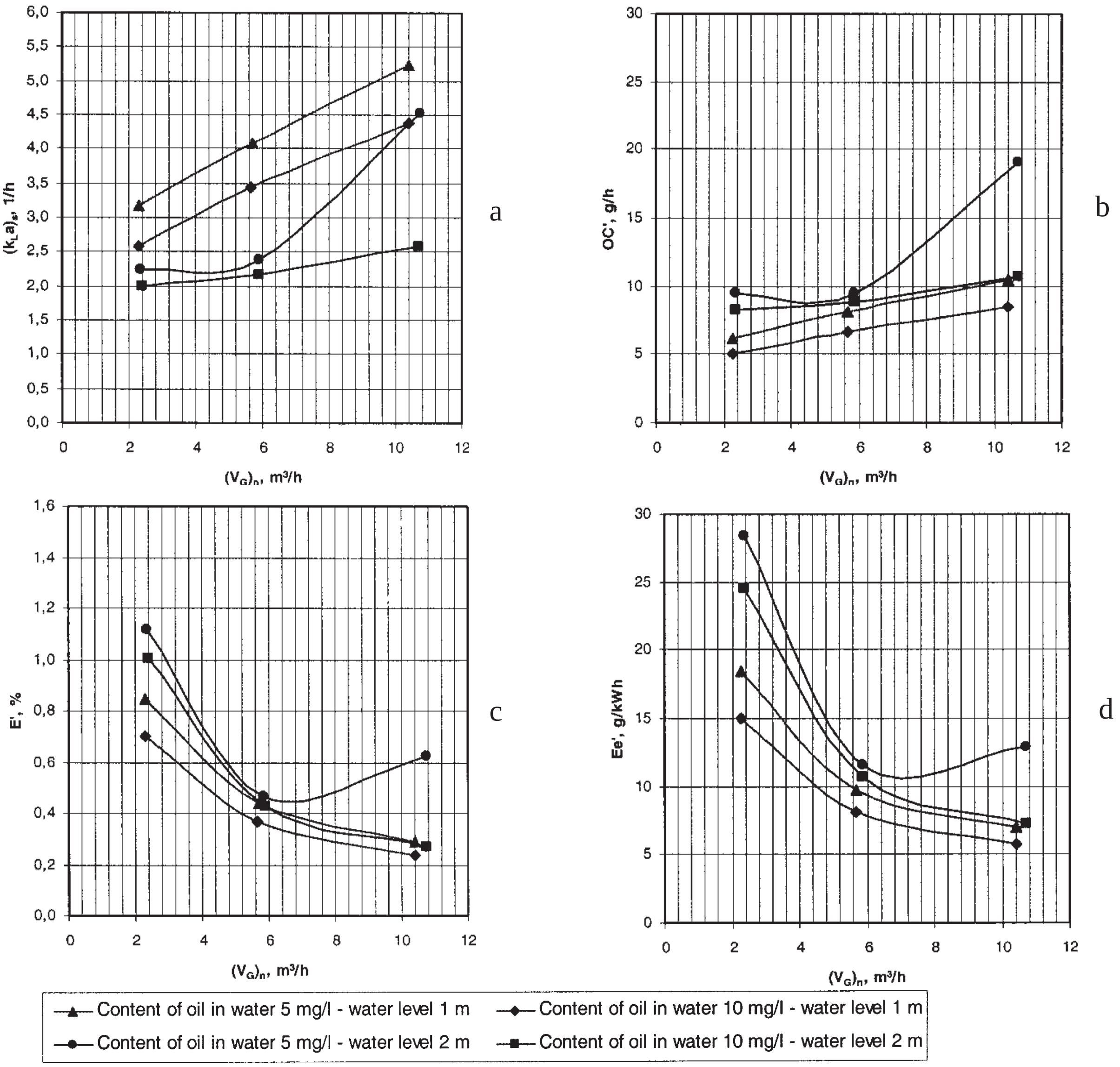

Fig. 2. Dependence of some technical characteristics of a disc-shaped membrane air distributor on air flow for different water level in column and oil presence in waste water a) coefficient of oxygen transport for standard conditions $(k_La)_s$; b) real capacity of oxygen introduction OC'; c) real oxygen transport efficiency E'; d) real energy efficiency of oxygen transport E_e'

where:

G_{O2} - mass flow of oxygen introduced into the water by the aeration system, kg/h;

$(V_G)_n$ - volume air flow for p_n=101,3 kPa, t_L = 20°C, m³/h;

y_{O2} = 0.232 - mass concentration of oxygen in air.

The real energy efficiency of oxygen transport represents the ratio between the real capacity of oxygen introduction and the engaged power needed to drive the aeration device:

$$E_e^{'} = \frac{OC^{'}}{\sum_i P_i}, \text{kg/kWh}, \qquad (9)$$

where:

$\sum_i P_i$ - sum of engaged power of all electromotors (for aerator, pump, blower etc. drive), kW.

Based on all experimental work performed on the described installation with water level in the column heights of 1 and 2 m and air flow varying between 2 and 10 m³/h and waste motor oil content from 5 to 10 mg/L the $(k_La)_s$ values given in table 2 were obtained using the investigated model. The values obtained for $(k_La)_s$ were used to determine the values of real capacity of oxygen introduction (*OC'*), real oxygen transport efficiency (*E'*) and real energy efficiency of oxygen transport (E_e') given in table 2.

Technical characteristics of the aeration system in dependence on air flow for different water level in column and oil presence in waste water are given as diagrams in figure 2.

Conclusion

Each of the analyzed parameters of the aeration process (air flow, water column height and mass concentration of oil in water) has an influence on the efficiency and thus on the final result of the aeration process.

The contact time between the liquid and gaseous state, i.e. how good oxygen transport efficiency will be realized depends on the height of the water column above the air distributor and the air flow rate.

The experimental results obtained point out that the technical indicators of the aeration process for a liquid height of 2 m in the presence of 5 mg/L of oil in water and air flow of 10 m³/h are significantly improved compared to the ones obtained for flows of 2 and 6 m³/h, while for the same liquid height and oil presence of 10 mg/L the air flow value does not have a significant influence on technical indicators of the aeration process. For the same concentration of oil in water and the same air flow and water height of 1 m the time period of water saturation with oxygen is from 25 to 40% shorter than for aeration with a water height of 2 m. Based on this, the air flow needs to be defined for each water height in column that would enable the same aeration process conditions.

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ASPECTE METODOLOGICE ÎN CERCETAREA ŞTIINŢIFICĂ
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Editura Academiei Române ne oferă, prin această nouă apariţie, o carte foarte utilă unui cercetător, indiferent că este la început de carieră sau este un cercetător cu experienţă.

Trăsătura distinctivă a învăţământului superior faţă de restul sistemului educativ este existenţa activităţii efective de cercetare ştiinţifică, a producerii de cunoaştere. Una din funcţiile principale ale universităţii este de a introduce studenţii în cunoaşterea ştiinţifică, iniţiindu-i în mecanismele de producere a ştiinţei şi determinându-i să participe efectiv la cercetare, iar cartea este un indrumar valoros pentru a realiza acest scop.

Lucrarea cu 313 pagini structurate în 11 capitole şi 6 anexe prezintă elementele de bază privind cunoaşterea şi demersurile de urmat în domeniul cercetării ştiinţifice, cu o aplecare mai specială spre domeniul biomedical.

Cele 11 capitole ale cărţii sunt:

- Noţiuni sumare de epistemologie;
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- Programe internaţionale de cercetare ştiinţifică;
- Tipologia cercetării ştiinţifice şi metodele de colectare a datelor în cercetarea ştiinţifică;
- Etapele cercetării ştiinţifice;
- Proiectul de cercetare;
- Prezentarea rezultatelor cercetării ştiinţifice;
- Evaluarea cercetării ştiinţifice;
- Etica cercetării ştiinţifice;
- Proprietatea intelectuală.

Fiecare capitol prezintă sumar cadrul general şi, acolo unde este cazul, principiile de aplicare, fiind însoţit de o bogată bibliografie.

Ordonarea capitolelor este făcută într-un flux al cunoaşterii, care porneşte de la noţiuni sumare despre ştiinţă şi de la definiţiile acceptate pe plan mondial (prin manualele Frascati, Oslo şi Canberra sau ale O.C.D.E.) ajungând la sistemul naţional de cercetare ştiinţifică cu Planul naţional şi programele sale. Se prezintă oportunităţile de finanţare, inclusiv prin programele de cercetare internaţionale.

Capitolul privind tipologia cercetării şi metodele de colectare a datelor reprezintă o contribuţie deosebită, prin informaţiile sistematizate puse la dispoziţie, în special despre metodele mixte.

Capitolul referitor la etapele cercetării ştiinţifice dezvoltă *paşii* de urmat de către un cercetător, pornind de la alegerea temei, până la interpretarea şi valorificarea rezultatelor. Un subcapitol se ocupă de motivarea cercetătorului. Mentorii trebuie să recunoască şi să folosească motivarea ca pe un factor de creştere a performanţelor.

Proiectul de cercetare este prezentat într-un capitol separat, ţinând cont de importanţa acestuia în activitatea de cercetare, deoarece nu poate exista cercetare ştiinţifică fără un proiect (finanţat sau nu). Sunt menţionate aspecte legate de scrierea unei propuneri, cât şi de managementul proiectului.

Un capitol extrem de util pentru debutanţi este cel referitor la prezentarea rezultatelor cercetării ştiinţifice, ca un mijloc de transmitere a cunoştinţelor, dar şi de control, verificare şi analiză. Se descrie modul de prezentare oral şi prin poster, dar şi modul de redactare şi de prezentare a unei teze, a unui articol ştiinţific şi a unui raport de cercetare. O atenţie specială este acordată modului de prezentare a unei bibliografii. Puţină lume cunoaşte că, încă din anul 1986, teza (disertaţia) face obiectul standardului internaţional ISO 7144/1986.

Capitolul referitor la evaluare se referă atât la evaluarea instituţiilor, dar şi la evaluarea indivizilor, cu descrierea celor două instrumente de evaluare: peer-review şi bibliometria.

În structura cărţii, în capitolul 10, se tratează aspectele etice ale cercetării ştiinţifice, de la problemele generale, la cercetarea pe subiecţi umani şi/sau animale. Introducerea dimensiunii etice în ştiinţă trebuie să devină o preocupare constantă a instituţiilor de cercetare şi a cercetătorilor, cartea punând la dispoziţie elementele necesare, inclusiv cadrul european de referinţă.

Ultimul capitol prezintă elemente de bază referitoare la proprietatea intelectuală, tratându-se cele două mari componente: drepturile de autor şi drepturile conexe şi proprietatea industrială.

În final, se prezintă 6 anexe pe care autorii au considerat necesar să le pună la dispoziţia cititorilor.

Cartea, care este o adevărată monografie cu caracter pluridisciplinar şi interdisciplinar a domeniilor de cercetare ştiinţifică şi conexe, se adresează masteranzilor, doctoranzilor, mentorilor, tuturor celor interesaţi.

Mentorii, pe baza bibliografiei, pot dezvolta, pentru studenţi şi debutanţi, oricare din capitole, punând diferite accente în funcţie de scopurile urmărite.

Textul cărţii este bogat ilustrat cu grafice şi desene reprezentative, care susţin afirmaţiile ca şi logica în care s-au scris capitolele.

Aşa cum a arătat academician Ionel Haiduc în prefaţă, "*volumul este o carte deosebit de utilă, care răspunde unei nevoi reale, şi sunt convins că va fi mult folosit dacă va ajunge pe masa cercetătorilor. Autorii merită felicitări şi mulţumiri pentru efortul de a aduna într-un singur volum atâta informaţie relevantă pentru organizarea, desfăşurarea şi finalizarea cercetării ştiinţifice*".

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