Wood fibreboard paraffin hydrophobization and the impact of this treatment on the board surface finishing quality

JOZEF KÚDELA
 Department of Wood Science, Faculty of Wood Sciences and Technology, Technical University in Zvolen, Slovak Republic

Abstract: *Wood fibreboard paraffin hydrophobization and the impact of this treatment on the board surface finishing quality.* The aim of this paper is to analyse the causes of surface treatment defects in commercially produced wood fibreboards (FB). The analysis of: the obtained (measured and calculated) thermodynamic characteristics and of the results of microscopic examinations demonstrated that the excessive FB hydrophobization with paraffin may cause the paraffin to release from the FB surface and to migrate into the first primer layer. For the sanded FBs, similar paraffin migration was also observed into the second primer layer. This entailed lowered drying rate for the coating materials applied on FB, lower adhesion of the coating materials to the substrate and also lower adhesion between the particular coating layers applied. At the same time, the occurring frequency of surface treatment defects increased.

Keywords: fibreboards, paraffin, surface treatment, coating materials, paint drying, thermodynamic characteristics

INTRODUCTION

Agglomerated materials, fibreboards (FB) included, exhibit considerable thickness swelling. This swelling enhances surface roughness, declines mechanical performance and increases element warping. Warping originated due to non-uniform swelling/shrinkage in agglomerated materials entail also negative consequences for construction elements manufactured from these materials (SUCHSLAND 2004). To improve water repellence and to reduce swelling in agglomerated materials, the producers admix paraffin as an additive substance.

The degree of wood material hydrophobization with paraffin and the related wood performance modifications depend on the paraffin amount, type and form as well as on the application mode into the wood substrate (ŠTEFKA 2002, ROFFAEL *et al*. 2005, GARAI *et al*. 2005, TORKAMAN 2008, CAI *et al*. 2016).

The surface finishing of agglomerated materials with coatings, however, may worsen their surface treatment quality, as the result of increasing defects occurrence and of failing certain performance aspects. LIPTÁKOVÁ and KÚDELA (1997) suggest that the above-listed problems arise due to the presence of hydrophobic admixtures (e.g. paraffin) in the related materials. Authors suggest that the water-repelling substances is a probable cause of surface properties modifications in wood materials. This may have negative impacts on the coating materials adhesion to the substrate. The application of solvent-based coating materials may also cause paraffin migration into the coating layer, compel paraffin to migrate towards the dry coating surface, and lower, in this way, the drying rate of the coating.

Similar problems to the above mentioned were observed during surface treatment of hard fibreboard doors. This coating substance application onto the fibreboard surface resulted in repetitive occurrence of defects such as: non-uniform coating spreading across the surface, origination of cracks and splits or the coating separation from the substrate.

The aim of this paper was to assess the surface treatment quality of these fibreboards. The assessment criteria were: occurrence of defects and performance modifications. At the same time analysis of underlying causes of observed manifestations. Thermos-dynamic characteristics was also assessed - for confirmation or rejection of paraffin presence on FB surface as well as for penetration through the coating layers.

MATERIALS AND METHODS
Surface treatment quality assessment in wood fibreboards

The surface treatment quality was assessed based on the defects generated and on the coating material drying. The surface treatment defects were assessed on the particular products manufactured of a commercially produced wood fibreboard. For the surface finishing a coating system was applied composing of three layers – two being a solvent-based primer and the third a two-component synthetic enamel.

The drying degrees 1 and 5 of the coating material applied on FB were determined following the standard STN 67 3052. The drying rate of the coating material was compared with the drying rate of the same material applied on glass substrate.

Determining surface free energy values for FBs and for coatings

The paraffin presence on FB surface and paraffin penetration through the coating layers were assessed based on comparing the surface free energy values before and after the application of the particular coating layers. These results were also compared with the surface free energy values obtained with dried coating substances applied on glass substrate.

The FB thermodynamic performance was investigated on five study sets, each representing ten specimens, with dimensions of $20 \times 50 \times h$ mm. Two testing sets were without coating, the first containing specimen with the original and the second with sanded surface. The third set represented specimen coated with one layer of the primer, the fourth specimen coated with two layers of the primer and the last, fifth set consisted of specimens covered with the complete coating system: two primer layers and the finishing enamel.

Contact angles were measured with testing liquid, and then the corresponding thermodynamic characteristics were derived (surface free energy and its components). The contact angles were measured with a goniometer *Krüss DSA30 Standard.* The measuring liquid was redistilled water. The water drops, each with a volume of 0.0018 ml, were applied onto the substrate and then their profile development was scanned with a camera. The moment of turning the advancing contact angle to the receding one was determined with the method proposed in (LIPTÁKOVÁ and KÚDELA (1994). The contact angle value associated with this moment has been declared as an „equilibrium" contact angle. Measurements of the contact moment and the equilibrium contact angle values were used for obtaining the contact values for ideally smooth surface. This angle was subsequently used for calculating the values of surface free energy and its components. The FB surface free energy was calculated according to NEUMANN *et. al.* (1974), the disperse and polar component, γ_S^d and γ_S^p, according to KLOUBEK (1974). The surface free energy values for solid coatings applied on FBs and on glass were derived with using the related equilibrium contact angle values (LIPTÁKOVÁ and KÚDELA 2002). The calculation procedure was the same as in the former case.

Evaluation of the interactions at the interface FB –solid coating and solid coating – solid coating

The interactions between FB surface and solid coatings or between two solid coatings were investigated with focus on interactions between the unsaturated force fields across these phase boundaries.

The coating adhesion to the substrate and the compatibility of the particular layers in the coating system were evaluated based on the values of phase energy γ_{S1S2} and the values of adhesion work calculated from the experimentally obtained values of the disperse and polar components of surface free energy. The surface free energy at the interface between two solid materials was calculated according to the equation

$$\gamma_{S1S2} = \left(\sqrt{\gamma_{S1}^d} - \sqrt{\gamma_{S2}^d}\right)^2 + \left(\sqrt{\gamma_{S1}^p} - \sqrt{\gamma_{S2}^p}\right)^2 \qquad (1)$$

and the adhesion work W_a of the solid coating to the substrate according to the equation

$$W_a = 2\sqrt{\gamma_{S1}^d \gamma_{S2}^d} + 2\sqrt{\gamma_{S1}^p \gamma_{S2}^p} \qquad (2)$$

Calculations for surface free energy values were also done for the primer and for the synthetic two-component finishing enamel applied on glass substrate. The surface free energy was also specified for the free film reverse sides.

Subsequently, there was derived the coating´s cohesion work W_c as the twofold surface energy values determined for free films according to the equation

$$W_c = 2\gamma_S \qquad (3)$$

and coefficient S according to the equation

$$S = W_a - W_c \qquad (4)$$

RESULTS AND DISCUSSION
Surface treatment defects in wood fibreboards

The FB surface covered with the first layer of the primer exhibited local spots in which the coating material had not been dried to the appropriate degree.

a)

b)

c)

d)

Figure 1. Observed surface treatment defects in FBs. a) orange peel, b) bordered patch (crater), c) wrinkled surface, d) cracking and peeling of the solid coating

This had negative impacts during application of the subsequent coating layers – which is a typical phenomenon occurring during coating material application, primarily in automated processing. At these spots, the adhesion between the coating and substrate was impaired. Thus resulting in a variety of other defects, including those related to external look (orange peel, bordered patches, wrinkled surface, cracks generation in dried coating, and similar) – Fig. 1.

Experimental measurements results of the primer drying on the FB surface and on glass are summarised in Table 1.

Table 1. Primer drying on glass and on FBs.

Substrate	Drying time [min.]	
	1. degree	5. degree
Glass	10	13
FB original	12	23
FB sanded	14	26

The table demonstrates that more time was necessary to reach the drying degrees 1 and 5 on FBs than on glass. Comparing original and sanded FBs, the sanded ones exhibited worse results. The values for the 5-th drying degree were in accord with the common commercial standards set for the coating material quality; the observed facts, however, did not allow to ignore problems arising in operating conditions. Namely, it was natural to assume more paraffin migration due to higher temperatures during the coating application and drying. It is probable that the just applied coating layer has not been cured appropriately before applying second layer. This may be a potential cause of the discussed surface treatment defects.

Surface free energy

The experimental results related to surface free energy were evaluated focusing on finding out whether the surface free energy values exhibited significant differences between the coatings applied on FBs and on glass. If yes, the slower drying rate and subsequently originated defects might be expected due to the presence of hydrophobic substances (paraffin in our case) admixed into wood. These substances dissolve in the coating and then penetrate through the coating layers. In the opposite case, the paraffin should not be considered as the causal agent of the observable defects. The values of surface free energy and its polar and disperse components for FBs without mechanical pretreat-ment and for FBs with applied coatings are in Tables 2 and 3.

Tables 2 and 3 summarise the additive character of the FB surface free energy. The energy values were low, the disperse component was dominant. The high variability reflects the inhomogeneous FB surface. The differences between the original and sanded FBs were not confirmed statistically significant.

These values are lower by about 50 % compared with the corresponding values obtained for beech wood, using the same method (KÚDELA and LIPTÁKOVÁ 2006, KÚDELA *et al* 2016).

Table 2. Surface free energy of FBs without mechanical pre-treatment (sanding): uncoated boards and boards coated with particular coating layers (n = 60).

Specimen number	Surface treatment	Surface free energy and its components [mJ·m^{-2}]		
		γ_{Sl}	$\gamma_{Sl}{}^{d}$	$\gamma_{Sl}{}^{p}$
1	Original FB	35.30 (4.16)	29.04 (1.62)	6.26 (2.67)
2	Primer 1×	37.61 (2.75)	30.15 (0.77)	7.46 (1.99)
3	Primer 2×	46.31 (5.19)	31.13 (0.50)	15.18 (5.31)
4	Primer 2× + finishing enamel 1×	40.57 (2.37)	31.04 (0.55)	9.52 (1.3)

The figures in bold are for the arithmetic mean values, the figures in parentheses represent standard deviations. This holds also for the following tables.

118

Table 3. Surface free energy of sanded PBs: uncoated boards and boards coated with particular coating layers (n = 60).

Specimen number	Surface treatment	Surface free energy and its components [mJ·m^{-2}]]		
		γ_{S2}	γ_{S2}^{d}	γ_{S3}^{p}
1	Original FB	36.33 (5.56)	29.18 (1.97)	7.15 (3.73)
2	Primer 1×	36.75 (3.42)	29.74 (1.04)	7.01 (7.01)
3	Primer 2×	39.16 (3.90)	30.46 (0.81)	8.70 (3.17)
4	Primer 2× + finishing enamel 1×	40.74 (4.04)	30.82 (0.73)	9.92 (3.38)

In the case of original fibreboards, not subject to sanding, the application of one layer of the primer on the FB surface resulted only in small changes in the surface free energy values. In the case of the sanded boards, no surface free energy changes were detectable. After the application of the first coating layer, the FB surface free energy maintains its prevailing non-polar characteristics. The results obtained for fibreboards differed significantly from the results obtained with films applied on glass and even bigger differences were obtained by comparison with free films in which the energy was assessed on their reverse side (Table 4). These differences are summarised in Table 4. The table presents that these differences are generated due to chemical composition of these coatings, varying through their thickness during the drying, in relation to orientation of the molecules at the phase boundary between the coating and the substrate.

The obtained results concerning the phase-boundary-related energy show that the first application of the primer initiated considerable migration of paraffin from the substrate surface into the coating - up to the coating surface. Paraffin accumulated on the applied coating layer could cause difficulties with application and drying of the subsequent layers – also in the case when the first layer had been already cured.

Table 4. Surface free energy values for free films and coatings applied on glass (n = 60).

Substrate	Coating	Surface free energy and its components [mJ·m^{-2}]		
		γ_{N}	γ_{N}^{d}	γ_{N}^{p}
Free film	Primer	54.8	30.1	24.7
	Finishing enamel	57.1	29.5	27.3
Glass	Primer	48.73 (5.3)	30.99 (0.75)	17.14 (5.98)
	Finishing enamel	44.65 (6.85)	30.73 (0.65)	13.92 (6.92)
	Primer + finishing enamel	40.57 (2.37)	31.04 (0.55)	9.58 (1.89)

The application of the second primer layer increased the surface free energy values. This growth was more evident in the case of the non-sanded FBs exhibiting surface free energy values close to the values obtained with a standard coating on glass (Table 4). Simultaneously the surface polarity also significantly increased. In the case of the sanded board, both the surface free energy and the surface polarity exhibited only a slight increase compared to the values obtained with the coating applied at one layer. These results confirm that the application of the second coating layer caused paraffin migration into the wet coating on the surface of the sanded fibreboards.

In all the three tested variants, the application of the synthetic two-component enamel resulted in the same surface properties of the complete coating system. The differences between the arithmetical means were not significant. We may state that the application of the finishing

synthetic enamel inhibited the paraffin penetration onto the coated surface. The thermoset performance of the coating material had also an important role. This fact, however, does not mean that problems will not occur, primarily in the case of sanded FBs.

Interactions at the interface FB– solid coating and solid coating – solid coating

The interactions at the phase boundary FB – primer were evaluated based on the interface energy and adhesion work (Tables 5 and 6). The interface energy values results were of the unsaturated polar component of the surface free energy of the coating. The adhesion primarily resulted from the interaction between non-polar forces associated with the relatively low polarity of the substrate surface. In non-sanded FBs, the cohesion between the layers did not increase significantly until applying the second primer layer and the finishing enamel. In the sanded FBs, however, even this complete coating system did not significantly improve even the adhesion between the second primer layer and the surface enamel.

Table 5. Interface energy in the system FB – solid coating

Original FB			
Interface (Phase boundary)	γ_{S1S2}	γ_{S1S2}^{d}	γ_{S1S2}^{p}
	$[\text{mJ}\cdot\text{m}^{-2}]$		
FB – primer	6.09	0.00	6.09
(FB + 1× primer) – primer	5.01	0.00	5.01
(FB + 2× primer) – finishing enamel	1.78	0.02	1.76
Sanded FB			
FB – primer	5.28	0.01	5.27
(FB + 1× primer) – primer	5.39	0.00	5.39
(FB + 2× primer) – finishing enamel	5.18	0.01	5.17

Table 6. Adhesion work W_a and parameter *S* in the system FB – coating

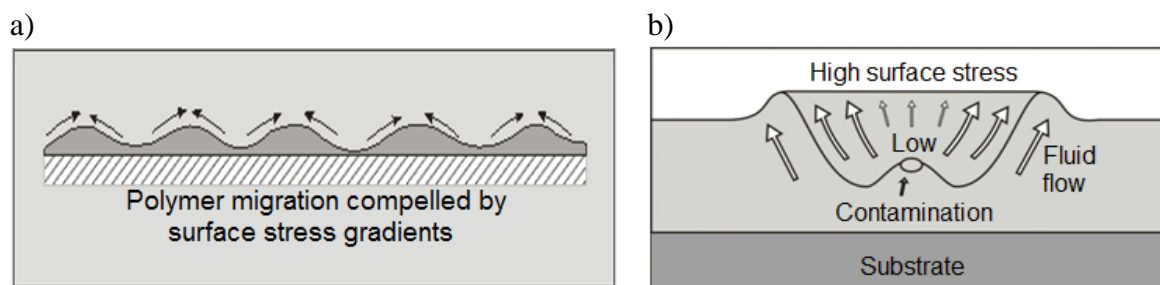| Original FB				
Interface (Phase boundary)	W_a	W_a^{d}	W_a^{p}	S
	$[\text{mJ}\cdot\text{m}^{-2}]$			
FB – primer	84.63	59.75	24.88	− 25.01
(FB + 1× primer) – primer	87.42	60.27	27.15	− 22.22
(FB + 2× primer) – finishing enamel	101.30	60.59	40.75	− 12.85
Sanded FB				
FB – primer	88.64	59.29	29.35	− 21.00
(FB + 1× primer) – primer	86.18	50.86	26.32	− 23.46
(FB + 2× primer) – finishing enamel	90.77	59.94	30.83	− 23.39

a) b)

Figure 2. Schematic representation of solid particles migrating through the coating (a) crater formation (b) movement compelled by surface stress gradient (Witte 1999)

In all measurements, the *S* parameter values were negative. This means that the dry coating had higher cohesion that the adhesion to the substrate. When the coating system is loaded, the different coating layers are contracting at different rates, and the coating peeling

from the substrate is probable (see Fig.1d). Defects, however, may also occur between the first and the second primer layer in non-sanded FBs and in all coating layers in the sanded FBs.

The primary cause of orange peel, bordered spots and craters (Figs 1a, b) may result from the coating material contamination with paraffin during the coating application and drying. Paraffin diffusion into the coating material reduced the surface tension of this material (see Tables 2 and 3). In such a case, surface stress gradient originated, causing the coating polymer flow from the sites with a lower to the ones with the higher gradient. The results were uneven surface, orange peel and craters (Fig. 2).

Examining the FBs with Scanning Electron Microscope (SEM) revealed that the surface treatment defects at the cover, such as cracking spots and peeling (Fig. 1d), were associated with fibre surface covered with an amorphous substance (Figs. 3 b, c, d) identified potentially as paraffin – based on the surface free energy values.
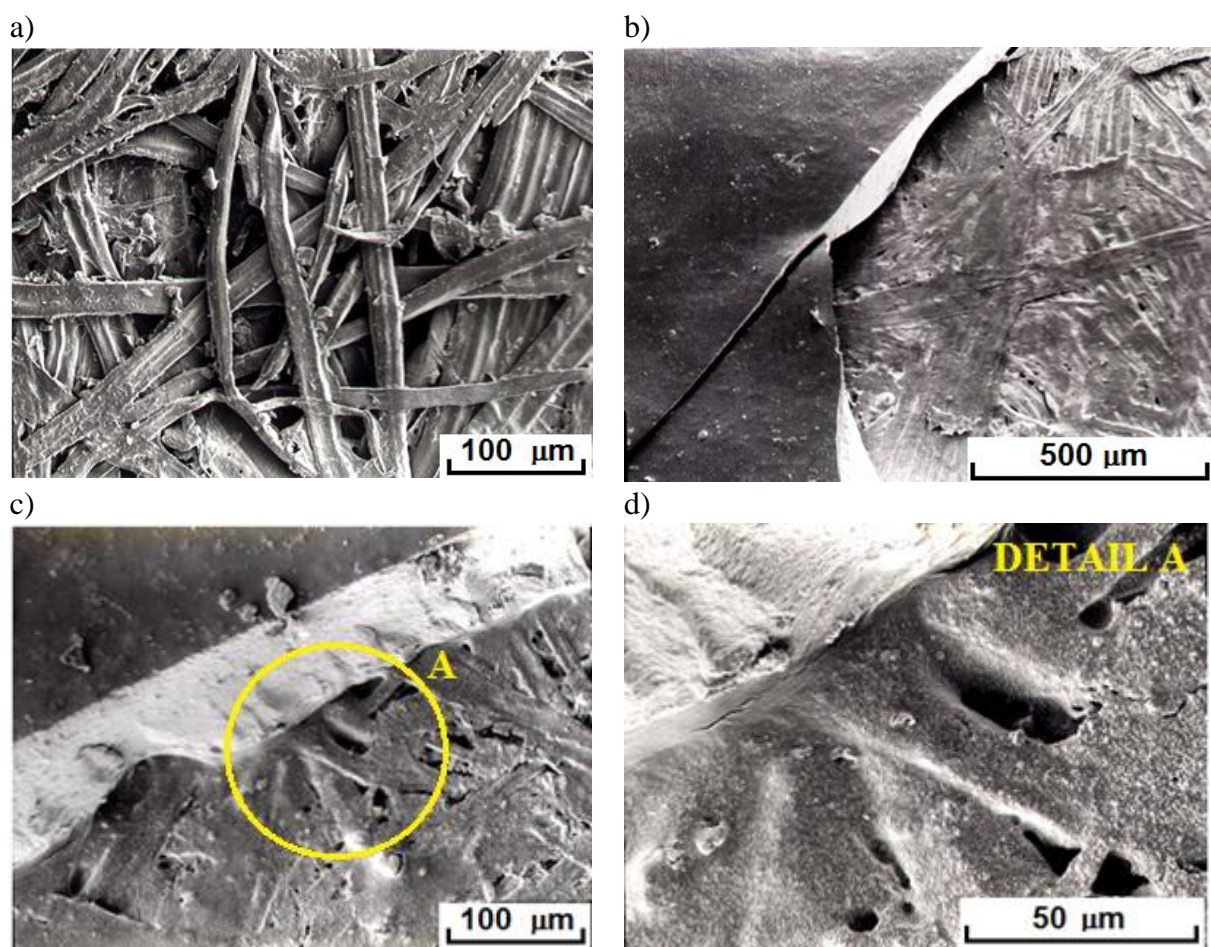
a)

b)

c)

d)

Figure 3. Fibreboard surface at a spot with impaired coating. a) FB surface before surface treatment, b), c), d) FB surface at disturbed spots exhibiting more paraffin concentration

CONCLUSION

Based on the analysis of the results related to thermodynamic characteristics and based on the performed microscopic observations, it can be confirmed that the excessive FB hydrophobization with paraffin has negative impact: lower drying rate of coating materials applied on FBs, worse adhesion of these materials to the substrate equally as the adhesion between the individual layers of the coating system applied, together with increasing the occurrence frequency of the surface treatment defects.

The application of the first layer of the solvent-based primer on the FB surface caused paraffin to release from the substrate surface and to migrate into the coating. In the sanded FB, the paraffin penetration was also observable in the second layer of the primer. No paraffin, however, was identified on the dried coating system surface after the application of the final, third coating layer consisting of a two-component synthetic enamel.

The phase boundary between the FB and the primer demonstrated mostly the interactions between non-polar forces. The correlation found between the adhesion work values and parameter *S* values confirm that the defects may occur also in the particular coating layers and at interfaces between these layers.

REFERENCES

1. CAI, L., FU, Q., NIU, M. *et al*. 2016: Effect of chlorinated paraffin nanoemulsion on the microstructure and water repellency of ultra-low density fiberboard. BioResources, 11(2): 4579–4592.
2. GARAI, R. M., SÁNCHEZ, I. C., GARCIA, R. T. *et al*. 2005: Study on the Effect of Raw Material Composition on Water-Repellent Capacity of Paraffin Wax Emulsions on Wood. J. Disper. Sci. Technol., 26(1):9–18
3. KLOUBEK, J. 1974: Calculation of surface free energy components of ice according to its wettability by water, chlorobenzene and carbon disulphide. J. Colloid Interface Sci., 46: 185–190.
4. KÚDELA, J, JAVOREK, Ľ., MRENICA, L. 2016. Influence of milling and sanding on beech wood surface properties. Part II. Wetting and thermo-dynamical characteristics of wood surface. Ann. WULS-SGGW, For and Wood Technol., No. 95: 154–158
5. KÚDELA, J., LIPTÁKOVÁ, E. 2006: Adhesion of coating materials to wood. J. Adhesion Sci. Technol., *20*(8): 875–895.
6. LIPTÁKOVÁ, E., KÚDELA, J. 1994: Analysis of wood-wetting process. Holzforschung, 48(2): 139–144.
7. LIPTÁKOVÁ, E., KÚDELA, J. 2002: Study of the system wood – coating material. Part 2. Wood – solid coating material. Holzforschung 56(5): 547–557.
8. NEUMANN, A. W., GOOD, R. J., HOPPE, C. J., SEJPAL, M.1974. An equation of state approach to determine surface tensions of low–energy solids from contact angles. Colloid Interface Sci., 49(2): 291–303.
9. ROFFAEL, E., SCHNEIDER, T., DIX, B., BUCHHOLZ, T. 2005: On paraffin sizing of medium density fiberboards (MDF). Part 1: Influence of the chemical composition of paraffin and type of emulsifier on the hydrophobic properties of MDF. Holz als Roh- und Werkstoff, 63(3):192–203.
10. STN 67 3052, 1980: Stanovenie zasychania náterových látok.
11. SUCHSLAND, O. 2004: The swelling and Shrinking of wood. A practical technology primer. Madison: Forest Products Society, 189 p.
12. ŠTEFKA, V. 2002: Kompozitné drevné materiály. Časť II. Zvolen: Technická univerzita vo Zvolene, 205 p.
13. TORKAMAN, J. 2008: Reduction of Water Absorption and Swelling of Fiberboard. In.: International Conference on Durability of Building Materials and Components. Istanbul, Turkey 11-14 May 2008, pp. 1–5.

14. WITTE, J. 1999: Flourované povrchové aktívní látky pro barvy a nátěry. In.: Nové poznatky v oboru nátěrových hmot a jejích aplikací. Pardubice: Univerzita Pardubice, pp. 198–205.

Correspondin author:

Prof. Dr. Jozef Kúdela
Department of Wood Science
Faculty of Wood Sciences and Technology
Technical University in Zvolen
T. G. Masaryka 24
960 53 Zvolen
Slovak Republic
e-mail: kudela@tuzvo.sk