

PAPER • OPEN ACCESS

Effective Recovery of Pulp Waste in the Innovative Production of Environmentally Acceptable Wood Composites

To cite this article: Eva Ruzinska 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **221** 012162

View the [article online](#) for updates and enhancements.

Effective Recovery of Pulp Waste in the Innovative Production of Environmentally Acceptable Wood Composites

Eva Ruzinska¹

¹ Institute of Technology and Business in České Budějovice, Faculty of Corporate Strategy, Okružní 571/10, 370 01 České Budějovice, Czech Republic

eva.ruzinska11@gmail.com

Abstract. However, as a result of efforts to improve the environment, while maintaining the required qualitative characteristics, global developments in the field of wood materials (as raw materials of the 21st century) have led to the development of new or effective modifications of existing technologies, focusing on reducing the emission of formaldehyde and other toxic components in polycondensation adhesives applied to the preparation of composite wood materials. The suggested problem means reciprocal replacement of the toxic components of currently produced polycondensation adhesives (especially phenol-formaldehyde), e.g. kraft black liquors, which can be isolated as a secondary raw material from the pulp and paper industry in the production of sulphate pulp. Sulphate liquors are characterized by a relatively low reactivity to formaldehyde, thus are requiring their incorporation into the polymeric matrix of mixed lignin-phenol-formaldehyde polycondensate. For this reason, it is necessary to modify the reactivity of the original kraft black liquors by the modification reactions. New methods of processing sulphate liquors are focused only on the use of some components of black liquors or on the production of high-price products, which can be applied economically but especially "eco-friendly" in the preparation of wood composite materials as adhesives. The article deals with the problem of effective utilization waste of kraft black liquor from pulp and paper industry, which are possible apply in various modification treatment as reciprocal replacement of polycondensative adhesives for preparation of wood based composite materials. In our research, we focused on proposal of innovative adhesives mixtures which were applied for production of eco-progressive wood based composite materials with better hygienical properties and significantly reducing the content of toxic formaldehyde in adhesive mixtures.

1. Introduction

Nowadays research in the field of wood science is focused on the development of innovative value-added products derived from wood as well as on a maximized utilization rate, e.g. production of wood-based composites. On one hand constant increase in yield and efficiency of processing are most welcome, but on the other hand, decreasing quality of raw materials, customers' expectations of high quality products as well as pressing on complying with more severe hygienic standards make those requirements hardly possible to meet [1, 2, 10].

That is why adhesive bonding has become an efficient and economically viable way for better utilization of wood feedstock. Manufacturing of agglomerates or layered composites is an important branch of wood industry. Not only are these types of materials crucial semi-products or products for the development of furniture industry. Also increase in efficacy of wood processing – mainly aimed at utilization of low-value forest products and industrial wastes is crucial [2, 3].



Addressing the issue of waste generation and the ways of its safe, environmentally acceptable and economically advantageous disposal is currently an extremely topical economic but also a political issue in a global perspective. At the same time, the issue of the impact of the increasing amount of industrial waste on the environment and population health is at the forefront [9]. This issue is closely related to the introduction of an efficient way of handling industrial waste, giving preference to systematic measures already in place, in order to minimize, recycle and valorise the resulting waste.

In the sulphate pulp preparation process, as the most widely produced product of the pulp and paper industry, the production of waste products, e.g. kraft black sulphate liquors. The organic components of the sulphate liquors are utilized in the "regeneration" process, i.e. they are incinerated to provide heat energy and carbon, which serves to reduce sodium sulphate to sulphide as one of the components of the boiling solution. Such recovery of waste generated does not lead to the solution of environmentally acceptable means of recovery of waste products as the regeneration of the starting chemicals are released to gaseous pollutants (especially inorganic and organic sulphur compounds) [2, 3].

New kraft recovery of waste liquor is aimed only for the use of certain components to produce liquors of high prices, e. g. derivatives such as sulphate lignins or modification reactions modified kraft black liquor that can be applied in the preparation of composite wood materials (plywood panels, agglomerated materials) as adhesive hygienically acceptable and economically than currently used polycondensation (fenolformaldehyde - PF) resin. Recovery of toxic constituents (as phenol) in PF adhesives just natural polyphenols (of kraft waste liquor) obtained from chemical processing of biomass is more efficient to use in the preparation of materials with high added value [9, 10].

Result of efforts to improve the environment, while maintaining the required qualitative characteristics, global developments in the field of wood materials have led to the development of new or effective modifications of existing technologies, focusing on reducing the emission of formaldehyde and other toxic components contain polycondensation adhesives applied to the preparation of composite wood materials (agglomerated). The suggested problem means reciprocal replacement of the toxic components (as phenol and formaldehyde) of currently produced polycondensation adhesives (especially PF), e.g. sulphate liquors, which can be isolated as a secondary raw material from the pulp and paper industry in the production of sulphate pulp [1, 2].

Sulphate liquors (kraft black) extracts are characterized by a relatively low reactivity to formaldehyde, thus not requiring their incorporation into the polymeric matrix of mixed lignin-phenol-formaldehyde polycondensate. For this reason, it is necessary to modify the reactivity of the original sulfate liquor by the modification reactions: methylation, acidification, hydroxymethylation, demethylation and the other modification reactions. The basic principle of the application of sulphate liquors to phenolformaldehyde adhesives is their ability in the alkaline environment to primarily form hydroxymethylated structures by the effect of formaldehyde [3, 8, 9].

The paper deals with the preparation of new versions of adhesives with the application of modified sulphate liquors, which after suitable chemical treatment can be applied to polycondensation adhesives in order to reciprocally replace part of the original phenol formaldehyde adhesive. The so-varied adhesives have been applied to the preparation of composite wood materials with environmentally acceptable hygienic characteristics by partial replacement of the toxic components.

2. Experimental part

In the experimental part of the attention modifier treatment kraft liquor, which were subsequently applied to the reciprocal laboratory prepared glue mixtures. The comparison was designed and prepared various variant adhesive mixtures which are used unmodified kraft black liquor. Prepared adhesive mixtures of glue (with reciprocal compensation commercial PF resin 10 – 60 % wt.) was used in the laboratory preparation of composite wood materials – three layers particle board (PB). They were subsequently evaluated selected physical, mechanical and hygienic properties of laboratory particle board which were compared with a standard manufactured wood composite (PB).

2.1. Modified treatment of waste sulphate liquor

Sulphate waste (kraft black) liquor is characterized by relatively low reactivity of formaldehyde which does not required to be incorporated into a polymeric matrix of mixed lignin-fenolformaldehyde polycondensate created initial reaction of kraft waste liquor and fenolformaldehyde resin. It is therefore necessary to modify the reactivity of the original kraft effluents modification reactions - methylation and following acidification kraft black liquors [2, 9, 10].

2.1.1. Methylation kraft black liquor. Methylation treatment of kraft black liquor has been carried out experimentally. The basis of methylated treatment was the reaction of formaldehyde with waste sulphate liquor at room temperature for 72 hours. The way was prepared methylated kraft liquor, which was further applied to the adhesive mixture with fenolformaldehyde adhesive (PF) with a gradual proportional refund PF adhesive from 10 to 60 % wt. [2, 8].

2.1.2. Acidification kraft black liquor. The second variant of the modification adjustment was in the previous post-treatment procedure prepared methylated kraft liquor acidification followed by a strong mineral acid with intensive stirring to value pH = 5. Physical changes observed during acidification occurred as follows: at pH = 12 the mixture appeared to be a homogeneous black solution; at pH = 10.5-11 the mixture became semi-soluble consistency of black color, very difficult to mix; pH = 10.0-10.5 precipitated low viscosity dispersion was chocolate brown; at pH = 8-9, volatile gaseous products of odorless odor (H_2S , CH_3SH , CH_3SCH_3) were intensively released. At pH = 6 - 8, CO_2 is released significantly, which results in a significant reduction in the acidified dispersion at a pH of 5-6 resulting in a thixotropic acidified dispersion having a yellowish-brown coloration [2, 8].

2.2. Preparation of the adhesive mixtures

Glue mixture to be applied in the preparation of composite wood materials (PB) were prepared with the gradual replacement of the original proportional fenolformaldehyde adhesive (PF) native and modified liquors gradually from 10 to 60 % by weight. Similarly, the reference test was used units - only with PF adhesive glue mixture consisting only of origin kraft black liquor [1, 2].

2.3. Laboratory preparation and evaluation properties of particle boards

Experimental prepared three variants of three-ply particle boards (PB) mixed with the application of mixtures adhesives [1, 2]:

- I. variant ("uprava p"): PB with the application of the original untreated kraft liquor (from 10 to 60 % wt. reciprocal replacement of PF adhesive with original kraft black liquor),
- II. variant ("uprava metyl"): application of modified PB - methylated liquor (from 10 to 60 % wt. reciprocal replacement of PF adhesive with methylated liquor),
- III. variant ("uprava acid"): application of the modified PB - acidified liquor (from 10 to 60 % wt. reciprocal replacement of PF adhesive with acidified liquor).

Conditions for the preparation of particle boards:

- moisture content of particles: surface 4,95 %, middle 3,47 %,
- a mixture of glue deposits at the surface 10 %, in the middle 7 %,
- prepared particleboards - dimensions: 280 x 360 x 16 mm (three-layers beech),
- ratio of weight of surface to centre particles= 3: 5
- conditions pressing: 195 °C, specific pressure of 4,8 MPa, the total pressing time 480 seconds,
- PB prepared air-conditioned 14 days after preparation, temperature: (20 ± 2 °C), moisture content (65 ± 5 %).

Evaluation of selected physical and mechanical properties of laboratory prepared particle boards:

- tensile strength perpendicular to board plain plane according to EN 319,
- the swelling diameter in water (20 ± 2 °C) for 2 hours and 24 hours according to EN 317.

2.4. Evaluation of hygienic properties of prepared adhesive mixtures and PB

Phenol (monohydroxybenzene) belongs to the group of aromatics in which the hydroxyl group is attached directly to the aromatic nucleus. Monomolecular phenols are high-toxicity compounds that cause protein degradation and tissue wear. Phenol entry into the body is possible in three ways: oral, percutaneous and inhalation. Phenol penetrated into the body undergoes partial cumulative biodegradation, partially oxidized to hydroquinone and pyro-catechin. The products of these changes are metabolised in the form of common compounds (conjugation with sulfuric acid, glucuronic). It has been found that some intermediates of this biotransformation may have mutagenic and leukemic effects [3].

In the manufacture and use of PF adhesives, there is a potential health risk due to the toxicity of free formaldehyde monomers. To assess the risk associated with PF adhesives (during production, mixing of glue mixtures, pressing), it is necessary to distinguish accurately between raw material, resin oligomers and cured PF adhesives. Novo-lacs do not contain free formaldehyde and have a low content of free phenol; on the other hand, the resins of the cured PF adhesives are almost harmless and, f. e.. The US Food and Drug Administration (FDA) allows PF adhesives to come into contact with food [2, 3]. Phenolformaldehyde adhesives with a free phenol content of 1-5% are considered to be harmful to health. Adhesive blends based on PF adhesives are considered non-toxic when the free phenol content is less than 0.2%.

Formaldehyde belongs to toxicologically relevant substances and its effects on the human organism. The effects of formaldehyde on the human organism are divided into acute and chronic. Acute effects include eye irritation with tearing, irritation of the nose and throat with cough and shortness of breath, headaches, nausea, dry mouth. Chronic effects include dermatitis, chronic cough, chronic airway disorders, asthma, bronchitis, laryngitis, menstrual and reproductive disorders, loss of appetite, weight loss, kidney, liver, central nervous system disorders. Other possible effects on the organism are: toxic, mutagenic and carcinogenic. However, according to literary sources, data on the concentrations at which the individual expressions occur are different [4, 5, 6, 7, 9].

2.4.1. Determination of free phenol in liquid PF adhesive. The free phenol content in liquid phenolformaldehyde adhesives is determined by bromometric determination. The free phenol must be isolated from the adhesive by displacing the phenol with water vapor (according to analytical selective method – for the glue and adhesive mixtures) [2].

2.4.2. Determination release formaldehyde by chamber method from laboratory prepared PB. In Europe, according to EN 717-1, valid class with the lowest acceptable level of free formaldehyde emissions from wood based materials is the class E1, with a value of less than 0.124 mg/m³ (by chamber method). According to the EN 717-2 gas analysis test method, the requirements for the released formaldehyde content of finished wood products (wood based composites) are within the range ≤ 3.5 mg/m²h or ≤ 5 mg/m²h within 3 days after production.

3. Results and discussion

In the experimental part of our research, we focused on the study of modification reactions of sulphate liquor to increase its reactivity and better incorporation into the mixed polymeric lignin-phenolformaldehyde matrix in the process of crosslinking of the proposed and prepared glue mixtures. Due to the low reactivity of sulphate lignin (from black liquors) towards formaldehyde and subsequent insufficient incorporation into polymeric matrix [2] upon polycondensation, the following modifications may be performed: methylation – introduction of hydroxymethyl groups [8] to the structure in the reaction with formaldehyde and subsequent treatment of the methylated liquor by the acidification reaction.

Modification adjustments of waste sulphate liquors (industrial pulp and pulp waste) were carried out in accordance with the Dolenko and Clarke methods [8]. The actual process of modification of the sulphate liquors of methylation and the acidification of already prepared methylated black liquor

was chosen on the basis of our previous research work [1, 2, 3]. The input raw material - unmodified sulfate liquors as well as methylated and acidified liquors were analysed to obtain the necessary information on the physical and chemical properties of the prepared sulfate extracts for the subsequent preparation of the adhesive mixtures applied in the experimental laboratory preparation of the particleboard.

From physical properties, dry matter, pH value, dynamic viscosity and density were evaluated by analytical procedures in accordance with standard methodologies. The measured and evaluated data are shown in table 1. From the chemical properties, the content of reducing substances was evaluated by the BERTRAND analytical procedure. The content of reducing substances has been calculated on D-glucose due to the low concentration of carbohydrates present after the delignification process during the sulphate brew of pulp preparation, where black sulfate extracts are also produced as one of the waste degradation products.

It is clear from the evaluated physical properties of modified sulphate liquors that the acidification modifiers have significantly changed the alkaline pH value of the original and methylated liquors to pH acid, which conditioned the increase of the reactivity of the acidified liquors compared to the original and methylated liquors. This increase was reflected in the assessment of selected physical-mechanical characteristics of experimentally prepared particleboards. Also, the value of reducing substances, which is relatively low, has been shown to be the highest in the acidified liquors is the higher reactivity of the treated sulphate liquors - 3.54 times higher than in the original untreated kraft black liquors and 1.51 times higher than that of the methylated liquor.

We have analysed the physical and chemical (hygienical-toxicological) properties of the commercial polycondensation phenolformaldehyde adhesive for the proposal and preparation of adhesive mixtures with reciprocal replacement of PF adhesives. Table 2 lists the results as a comparison of the producer's characteristics and the real values we have set. Physical characteristics were determined: dry matter content, pH value, dynamic viscosity, density and consistency (important technological characteristics in the preparation and application of adhesives). From the chemical (hygienical-toxicological) characteristics, the content of NaOH, free phenol and formaldehyde in the liquid resin was evaluated by standard analytical procedures for adhesives.

The most significant reduction in free phenol content was observed in acidified liquor, with a lower decrease of variant I - with the original and methylated liquors (Table 3) It is clear that reciprocal substitution of a toxic component such as phenol in adhesive compositions leads to the preparation of more environmentally acceptable adhesives compared to commercially produced PF resins that are at the limit of the content of this pollutant and cannot be considered non-toxic.

Table 1. Evaluated characteristics of sulphate liquors

Evaluated characteristics	Kraft black liquor I. (p.):	Methylated liquor II. (metyl.)	Acidified liquor III. (acid.)
Solid content (% wt.) ^a	55.03	52.14	53.36
pH	13.45	13.12	5.02
Viscosity dynamics (mPa.s) ^b	1189	612	236
Density (g.cm ⁻³) ^c	1315	1280	1210
Reducing compounds (mg.l ⁻¹) ^d	0.0433	0.6541	0.1537

^a - solid content was determined gravimetrically according to STN EN 10082

^b - dynamic viscosity was determined on a rotational viscometers Rheotest 2 (according to EN 2555)

^c - density was determined pycnometrically at 20 °C

^d - reducing compounds was determined by method of BERTRAND (the amount of reducing agents is most often converted to D-glucose)

Table 2. Evaluated characteristics of commercial PF adhesive

Evaluated characteristics	PF adhesive I.*	PF adhesive II.**
Solid content (% wt.) ^a	44.0 – 45.0	52.14
pH	10.5 – 12.0	11.24
Viscosity dynamics (mPa.s) ^b	500 - 900	780
Density (g.cm ⁻³) ^c	1180 - 1220	1207
Consistency Ford F4 (s) ^d	56	60
Content of NaOH (% wt.)	max. 7,54	6,87
Free phenol (% wt.) ^e	< 0.20	0.19
Free formaldehyde (% wt.) ^f	< 0,20	0.21

* I. producer's values, II.** - our measurement values

^a - solid content was determined gravimetrically according to STN EN 10082

^b - dynamic viscosity was determined on a rotational viscometers Rheotest 2

^c - density was determined pycnometrically at 20 °C

^d - consistency was determined by method of Ford cup (apparent consistency - 20 °C)

^e - content of free phenol was determined by bromometric method

^f - content of free formaldehyde determined by potentiometric method

In the case of finished experimentally prepared particleboards, the free formaldehyde content by the chamber method was evaluated by the standard EN 717-1 method. The measured and evaluated emission results of pollutant - free formaldehyde are given in table 4 for the individual variant of the prepared particleboard. As a reference, a version of a commercially produced PB glued only using PF adhesive without the addition of additives or any modifier additives was prepared and evaluated. From the evaluated results, it is clear that all the variants of the prepared adhesive compositions used in the laboratory preparation of the particleboards showed a reduction in free formaldehyde emission from the finished PB. The most significant reduction in formaldehyde emissions was observed for variant III. with reciprocal substitution of PF adhesive. Another in turn was variant I, which also showed a slight decrease in released formaldehyde emissions and the latter was variant II. - with application of methylated liquors. This moderate reduction is probably due to the addition of an additional amount of formaldehyde in the methylation modifying reaction during chemical activation which is insufficiently incorporated into the mixed lignin-polycondensation matrix in the crosslinking and curing process of the glue mixes for particleboard pressing.

After the design and evaluation of the physical and chemical characteristics of the modified sulphate liquors and the original black liquor, glue mixtures were prepared with a reciprocal replacement of PF adhesive from 10 to 60 % by weight. These adhesive compositions were applied in the experimental laboratory preparation of chip boards as variants:

- I. variant ("uprava p"): PB with the application of the original untreated kraft liquor (from 10 to 60 % wt. reciprocal replacement of PF adhesive with original kraft black liquor),
- II. variant ("uprava metyl"): application of modified PB - methylated liquor (from 10 to 60 % wt. reciprocal replacement of PF adhesive with methylated liquor),
- III. variant ("uprava acid"): application of the modified PB - acidified liquor (from 10 to 60 % wt. reciprocal replacement of PF adhesive with acidified liquor).

Table 3. Determination of free phenol in liquid PF adhesive mixtures

PB with reciprocal replacement of PF with sulphate liquors (% wt.)	Kraft black liquor I. (p.) (% wt.)	Methylated liquor II. (metyl.) (% wt.)	Acidified liquor III. (acid.) (% wt.)
10	0.18	0.18	0.17
20	0.17	0.16	0.14
30	0.16	0.15	0.12
40	0.16	0.14	0.10
50	0.14	0.12	0.08
60	0.13	0.12	0.08

* reference sample – commercial PF adhesive (without the addition of sulphate liquors) < 0.20 % wt.

Table 4. Formaldehyde release from experimental prepared particleboards determined by chamber method

PB with reciprocal replacement of PF with sulphate liquors (%wt.)	Kraft black liquor I. (p.) (mg.m⁻³)	Methylated liquor II. (metyl.) (mg.m⁻³)	Acidified liquor III. (acid.) (mg.m⁻³)
10	0.119	0.120	0.116
20	0.117	0.119	0.111
30	0.114	0.118	0.104
40	0.109	0.116	0.096
50	0.108	0.115	0.095
60	0.108	0.115	0.094

* reference sample – commercial PB prepared using PF adhesive (without the addition of sulphate liquors) - 0.122 mg.m⁻³)

Specification of the technological conditions of preparation of the proposed and experimental particleboards is given in chapter 2.3. Table 3 shows measured and evaluated values of free phenol content in prepared adhesive mixtures with reciprocal replacement of commercial PF adhesive with unmodified and modified (methylated and acidified) sulphate extracts. The reference sample was a PF adhesive without the addition of additives or modifiers, which had a free phenol content of 0.19 % by weight, almost 0.2 % wt of ecological acceptability, where PF glue can be considered non-toxic. For all prepared adhesive mixtures with reciprocal substitution of PF adhesives with both original and modified sulphate liquors, the free phenol content (as determined by the bromometric method) was confirmed.

On prepared chipboard plates of variants I, II. and III. the following physical and mechanical properties were evaluated:

- tensile strength perpendicular to the plane of the plate according to EN 319,
- the swelling diameter in water (20 ± 2 ° C) for 2 hours and 24 hours according to EN 317.

Thickness swelling is an important physical parameter for determining the suitability of the use of particleboards in a wet environment, for contact with water when used. It is recommended that the thickness swelling after 2 and 24 hours be less than 10 % wt. From the mathematical and statistical evaluation of all prepared PB variants, none of the variants prepared exceeded this recommended value for hardwood particle boards (according to EN 317). Figure 1 illustrates graphically 95 % confidence intervals for the thickening of laboratory-prepared particleboards throughout the range of reciprocal replacement of PF adhesive (from 10 to 60 % by weight) of unmodified and modified sulphate liquors - variant I.- with the application of the original kraft black liquors, variant II. - with application of methylated liquors and variant III. - with the application of acidified liquors.

Evaluating of the thickness swelling after 2 and even after 24 hours of exposure to water was shown to be the best variant III, which recorded the lowest values of this evaluated characteristic. Similar

characteristics of thickness swelling were achieved by variant II. as the second one in the order and the last is variant I. - with the application of the original untreated black liquor. Statistically significant differences were observed after 24 hours of exposure to the test samples. The effect of modified sulphate liquors on reducing the thickness swelling after exposure 2 and 24 hours in the reciprocal replacement of PF adhesive from 10 to 30% by weight is of importance, which is extremely important for the use of PB prepared in this way in a humid environment, for PB resistance to water.

From the mechanical properties, tensile strength perpendicular to the board plain for laboratory prepared particle boards with varying reciprocal replacement of PF adhesive with sulphate liquors (from 10 to 60% wt.) Was evaluated according to EN 319. In Figure 2 are shown 95 % confidence intervals for the average values of these mechanical characteristics. From the graphically interpreted results it is clear that the individual variants of the PB prepared are statistically significant and that the proportional substitution of the PF adhesive by the original untreated liquors results in a decrease of the observed property statistically significantly from 20 % reciprocal substitution for variant I.

When applying modified sulphate liquors, the tensile strength perpendicular to the plain board decreases from 30 % by weight for variant II. and variant III. compared to the reference sample PB glued only with non-additive PF adhesive - shown in Figure 2 as a variant with 0 % wt. However, after the mathematical and statistical evaluation of the mentioned characteristic, the order for the individual variant is obvious: the best results were achieved by variant III, then variant II. with reciprocal compensation up to 30% by weight and the last one is variant I. when refunding up to 20 % of PF commercial PF adhesive.

When comparing the economic indicators associated with the modifications, it became clear that the price of waste sulfate liquors alone is 50 times lower than the price of the commercially produced PF adhesive. Taking into account the costs associated with the modification, the price of the most suitable variant is 64 % lower than the price of the PF adhesive alone used to make the particleboards.

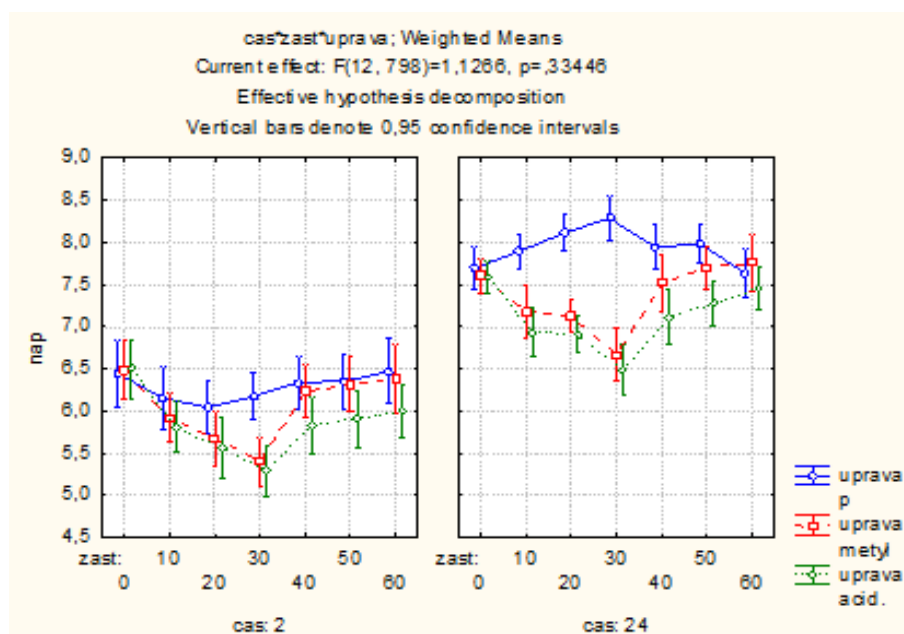


Figure 1. Confidence intervals the average of thickness swelling (%) for laboratory prepared PB for exposure 2h and 24 hours with varying reciprocal replacement of PF adhesive with sulphate liquors (from 10 to 60 % wt.)

notes: cas 2, cas 24 – time after 2 and after 24 hours exposure, „nap“ – thicknes swelling, „uprava p – I. variant, „uprava metyl“ – II. variant, „uprava acid“ – III. variant, zast. – reciprocal replacement of PF adhesive with sulphate liquors

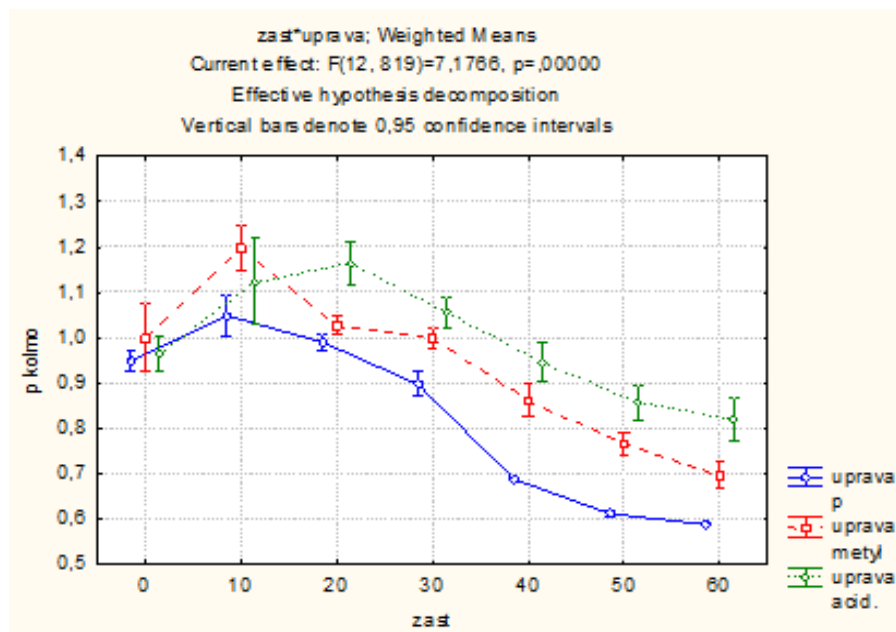


Figure 2. Confidence intervals for means of tensile strength perpendicular to board plain (N.mm^{-2}) for laboratory prepared particle boards with varying reciprocal replacement of PF adhesive with sulphate liquors (from 10 to 60 % wt.)

notes: „p.kolmo“ – tensile strength perpendicular to board plain, „zast“ – reciprocal replacement of PF adhesive with sulphate liquors, „uprava p – I. variant, „uprava metyl“ – II. variant, „uprava acid“ – III. variant

4. Conclusions

The aim of our research was to design and prepare innovative environmentally acceptable products with a significantly reduced content of pollutants (phenol, formaldehyde) reciprocal replacing these toxic ingredients and utilizing the potential treatment of industrial waste from pulp and paper industry. From the results mentioned in the experimental part of the paper, it is clear that substitution of PF commercial adhesive by natural waste sulphate liquors even after their industrial processing is a suitable variant to reduce the emissions of a toxic pollutant such as formaldehyde.

For evaluation of physical and chemical properties of the modified black liquor it is clear that the acidification of the modification treatment have changed markedly alkaline pH and the original methylated liquors pH acidic, which justified an increase in reactivity acidified black liquor compared to the original and methylated liquors. This increase was reflected in the assessment of selected physical-mechanical characteristics of experimentally prepared particleboards - in the evaluation of thickness swelling and tensile strength perpendicular to the plane of the board. The best variant of particleboards as well as prepared adhesive mixtures with reciprocal substitution of commercial PF adhesive have been proved variant III - with the application of acidified liquors, where the evaluation of all evaluated characteristics - physical, mechanical and chemical.

The results of our research have shown that it is necessary to re-focus on the management of industrial sector, which were previously considered to be promising as a replacement for toxic, expensive and non-organic component in adhesives, but did not pay them enough attention. At present, efforts to develop innovative technologies in production processes need to focus on the preparation of environmentally acceptable materials with regard to human health, workers in production and also for the preservation of the environment.

Acknowledgment

The article was created for financial support and as a result of the solution of the internal grant project No. 8110IGS201818 "Creating professional studies as a tool for innovation and development

of pedagogical activities" at the The Institute of Technology and Business in České Budějovice, Czech Republic.

References

- [1] E. Ružinská et al., "Product and technological innovation - new fibrous wood biocomposites". *31st IBIMA Conference, ISI Proceedings*, Milan, Italy, 5 p. ISBN 978-0-9998551-0-2, 2018.
- [2] P. Boruszewski, M. Maminski and E. Ružinská (eds), "*Raw materials and particleboards – a current status and perspectives*". SGGW Press, 111 p., ISBN 978-83-7583-389-8, 2012.
- [3] E. Ružinská et al., "*Risk substances in woodworking industry*". Monograph. Warsaw University of Life Sciences Press. 114 p. ISBN 978-83-7583-591-5, 2014.
- [4] E. Roffael et al., "On the formaldehyde release of wood particles". *European Journal of Wood and Wood Products*, Vol. 70, No. 6, pp. 911-912, 2012.
- [5] A. Duong, "Reproductive and Developmental Toxicity of Formaldehyde". *Mutat. Res*, Vol. 728, No.3, pp. 118-138, 2011.
- [6] Z. Que, T. Furuno, "Formaldehyde emission from wood products. *Wood Sci Technol.*, Vol.41, pp. 267-279, 2007.
- [7] EPA. *Toxicological Review of Formaldehyde Inhalation Toxicity*. 2010. EPA/635/R-10/002C.
- [8] A. J. Dolenko, M. R. Clarke, "Resin binders from kraft lignin". *Forest Prod. Journ.*, 38, 8, pp. 41-46, 1978.
- [9] H. Y. Kordheili et al., "Reduction of Formaldehyde Emission from PB by Phenolated kraft Lignins". *Journal of Adhesion*, Vol. 92, Issue 6., 2016
- [10] P. Figueiredo et al., "Properties and chemical modification of lignin". *Progress in Materials Science*, 93, 233, 2018.