

# Optimization of recycling strategy for solid industrial waste

**A V Rubinskaya, E I Pister, A A Ioffe, A Yu Vititnev and M V Karaseva**

Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russia

E-mail: pisterelizaveta@yandex.ru

**Abstract.** The rational and efficient use of natural resources is an important element for sustainable development. Waste is significant loss of material and energy resources. Recycling and disposal of the generating waste can cause the environmental pollution and human exposure to harmful substances and infectious organisms. The waste generation indicator is closely related to the level of economic activity in the country and reflects the structures of production and consumption formed in the society. The reduction in waste generation is an indicator of the progress of economic sectors towards less material-intensive structures of production and consumption. Plant origin waste is mainly generated in the lumber industry and it is a large-scale source of environmental pollution. The constant generation and accumulation of these wastes is a serious environmental problem. The main reason for the current state is the insufficient capacity for timber processing. It aggravates the problem of the integrated use of low-grade, small-scale wood and wood waste. As a result, the main competitive products in the forest complex of the Krasnoyarsk Region are currently lumber and round wood. The solution to the current problem concerning the optimal use of waste generated on the territory of the Krasnoyarsk Region must be solved with the help of mathematical modeling and optimization of the recycling process of lump plant waste. The rational use of lump plant waste is one of the most serious and unsolved problems.

## 1. Introduction

The use of the ecological potential of natural systems is traditionally not included in the category of the environmental management. But clean air, water, food are also natural resources. They are scarce in some territories and they are rich in others, but all these resources are exhaustible. Its carrier is nature's ability to heal itself. The greater the potential for sustainability of ecosystems, the cleaner air, water, food a person can manage.

It is necessary to maximize the convergence of indicators of financial and economic efficiency and environmental safety of any activities to reduce the unjustified destruction of the environment potential. The main possibility of such a combination is associated with a high correlation between the indicators of the economic productivity of land and the sustainability of natural ecosystems existing in such conditions. That makes it possible to use land and rental taxes for the environmental purposes. There exists a system of differentiation by the state, subjects of the Russian Federation and city municipalities of land tax rates, taking into account not only agro-industrial, infrastructural, but also environmental criteria. It is capable of compressing the areas occupied by producers mainly due to the rejection of the use of unproductive or undeveloped pieces of land without infrastructure. At the same time, the land with its natural ecosystems, acquire real significance from managers' point of view. A man-made human impact is unfavorable for the environment. The purpose of this investigation is to assess the ecological



potential of Russia and the impact of human activity on the environment. This problem is undoubtedly relevant, since at the present stage of the society development an issue about a healthy human existence raises. One of the main sources of pollution in urban areas is industrial waste resulting from the production process. Production waste has a negative impact on almost all components of the environment.

The development of recycling allows increase the volume of secondary raw materials used in the territory, reduce the costs of burning and disposal of production and consumption waste. It also allows reduce the energy intensity of the economy, increase investment attractiveness, reduce the threat to public health, create new employment, reduce pollution of regional ecosystems, improve the aesthetic condition of the territories that in modern conditions one can consider recycling as one of the important tools for solving environmental and economic problems. In the process of any industrial manufacturing, solid industrial waste (SIW) is inevitably generated. In some enterprises, SIW are partially used in the related industries. Thus, enterprises inevitably accumulate SIW of various types and state that must be recycled. More than 340 million tons of industrial waste of various types and hazard classes are generated annually on the territory of the Krasnoyarsk Region. Basically, the established volumes of waste are subject to disposal. It undoubtedly affects the ecological situation of the region. Most landfills for recycling do not meet current international standards and regulations.

On the basis of statistical data on the monitoring of production wastes and their consumption, the Directorate of the Federal Service for the Supervision of Natural Resources in the Krasnoyarsk Region for 2011 identified the types of solid industrial wastes that are generated in the territory of the region. A hazard class of industrial wastes was taken into account. It was determined according to the requirements of hygienic and radiation safety in identification wastes for the purpose of their use [1].

In order to estimate the recycling possibility of the selected SIW indicators characterizing their ability to be recycled were identified for each type of waste. These indicators are a coefficient of binding formation  $K_b$  and the criterion quality parameter  $K_c$ , depending on the method and conditions of waste preparation for further processing. A method of rank correlation was used to analyze the presence of closeness of the relationship between these indicators and to identify the most effective waste for recycling [2].

The ranking results of SIW of the Angara-Yenisei region according to the linking coefficients  $K_b$  and the criterion quality parameters  $K_c$  are presented in table 1.

**Table 1.** Results of the ranking of SIW

N	Types of waste <i>i</i>	$K_b$ $y_i$	$K_c$ $x_i$	Values ranks of variables		Ranks differences	
				$w_i$	$v_i$	$(v_i-w_i)$	$(v_i-w_i)^2$
1	Wood chips	0,99	85	1	4	3	9
2	Wood fillings	0,96	87	2	3	1	1
3	Crust	0,9	90	3	1,5	-1,5	2,25
4	Vermiculite	0,82	90	4	1,5	-2,5	6,25
5	Glass	0,8	80	5,5	6	0,5	0,25
6	Plastic	0,8	72	5,5	7	1,5	2,25
7	Polyethylene terephthalate	0,75	81	7	5	-2	4
8	Rubber-mechanical articles	0,7	65	8	9	1	1
9	Wood slag	0,67	58	9	10	1	1
10	Coal slag	0,6	67	10	8	-2	4
11	Incinerator	0,33	23	11	11	0	0
12	Haydite waste	0,31	18	12	15	3	9
13	Gypsum waste	0,3	20	13	13	0	0
14	Broken fireclay bricks	0,22	20	14	13	-1	1
15	Solid polystyrene waste	0,2	20	16	13	-3	9
16	Coke dust	0,2	15	16	16,5	0,5	0,25
17	Construction rubble that has lost its consumer properties	0,2	5	16	19,5	3,5	12,25

18	Textile	0,17	5	18	19,5	1,5	2,25
19	Waste in mining of ore minerals	0,16	15	19	16,5	-2,5	6,25
20	Mineral slurries	0,15	10	20	18	-2	4
Total		-	-	210	210	0	75

The Spearman rank correlation coefficient was calculated according to table 1.

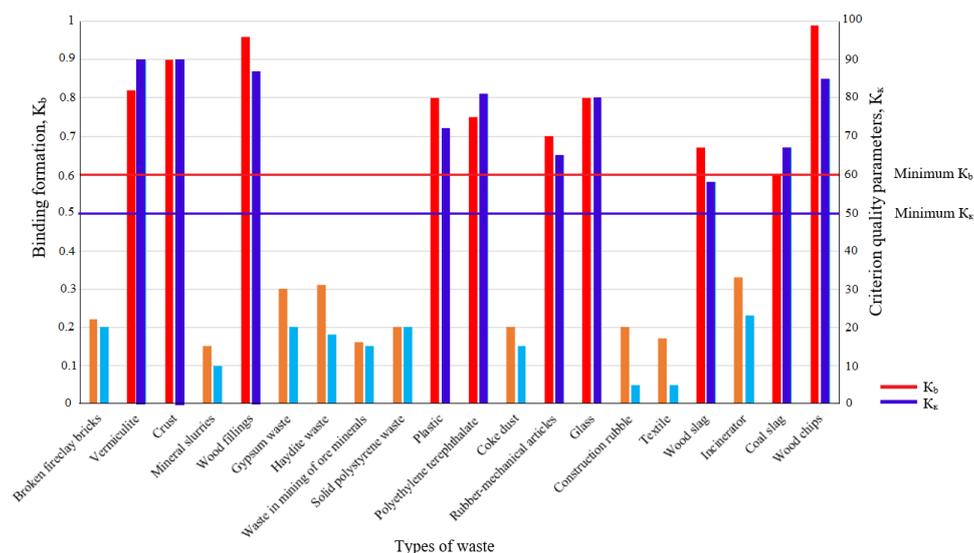
$$r_s = 1 - \frac{6 \cdot 75}{20^3 - 20} = 0,944$$

The obtained rank correlation coefficient is close to +1. It indicates a close positive relationship between the coupling coefficient and the criterion quality parameter. Therefore, the use of these indicators to estimate the possibility of recycling is appropriate.

It is necessary to determine which types of waste are appropriate, environmentally safe and technologically possible to use as secondary raw materials with the aim of recycling SIW in the Krasnoyarsk Region and in particular in the Angara-Yenisei territory. The different types of SIW were identified for this problem solving. They can be applied without harm to human health in obtaining finished products using the method of rank correlation using the Spearman coefficient [3].

For the purpose of possible SIW elimination (they are not subjects to further economically beneficial recycling) at the moment of the economy development a diagram was developed. It displayed coefficient of binding formation  $K_b$  and criterion quality parameters of  $K_c$  by waste types (Figure 1). The minimum level of parameters for the implementation of effective recycling of SIW for the coefficient of binding formation is 0.6, and for the criterion quality parameter is 50.

As one can see in the diagram, waste whose performance is higher or equal to the minimum levels includes the following types of SIW: coal slag, wood slag, wood ash, crust, wood chips and wood fillings, lump wood waste, polyethylene terephthalate, plastics, glass, rubber-mechanical articles, vermiculite. Thus, investigations have shown that solid industrial waste of plant origin is the most economically viable for recycling in the conditions of functioning of enterprises of the lumber industry complex.



**Figure 1.** Correlation assessment of the possibility of SIW effective recycling in the Angara-Yenisei region.

Identifying possible types of SIW for recycling in technological processes of lumber processing complexes will not be a sufficient incentive for enterprises to change the management system, since

there are big risks for the technologies introduction and finished product production due to weak market readiness and the legislative base to support such enterprises. Therefore, there exist urgent needs to estimate the risks of enterprises of the lumber industry complex operating under conditions of uncertainty.

Let's imagine a particular type of product obtained using SIW as a function of the species characteristics of the components of the finished product  $B_{pr}$  from the types of waste used in the production of this product. This functional dependence in the normalized designations of the factor:

$$y = f(x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17}, x_{18}, x_{19}, x_{110},)$$

in natural designations of the factor:

$$B_{pr} = f(C, W_c, W_f, G, P_t, P, S_c, S_w, R, V)$$

Table 2 presents the investigated factors, the types of waste and their total volumes by enterprises.

**Table 2.** Initial matrix for statistical and mathematical analysis of SIW.

Types of waste			Volume of waste		
Natural values		Normalized values	Natural values		Normalized values
C	Crust	$x_{11}$	89929,24	$V_1$	$x_{21}$
$W_c$	Wood chips	$x_{12}$	1286889,07	$V_2$	$x_{22}$
$W_f$	Wood fillings	$x_{13}$	589138,58	$V_3$	$x_{23}$
G	Glass	$x_{14}$	423,64	$V_4$	$x_{24}$
$P_t$	Polyethylene terephthalate	$x_{15}$	1452,13	$V_5$	$x_{25}$
P	Plastic	$x_{16}$	622,77	$V_6$	$x_{26}$
$S_c$	Coal slag	$x_{17}$	650117,83	$V_7$	$x_{27}$
$S_w$	Wood slag	$x_{18}$	3217,17	$V_8$	$x_{28}$
R	Rubber-mechanical articles	$x_{19}$	615,76	$V_9$	$x_{29}$
V	Vermiculite	$x_{110}$	290018,88	$V_{10}$	$x_{210}$

On the basis of the performed correlation analysis using the Spearman rank correlation coefficient, as well as on the basis of a sample of solid industrial wastes with the assessment of their significance for recycling, new activities were proposed. They consider industries where it is possible to use certain types of SIW. It is possible to obtain various plate materials with high strength characteristics when grinding polyethylene terephthalate to a certain particle size distribution and adding it to the composition of plate products from 10% to 40%. So, upon receipt of fiberboard with a thickness of 2.5 mm with the addition of 10-20% polyethylene terephthalate, the strength of the plate will be 75-90 mPa. Thus, it is possible to adjust the production of plate and block materials with increased strength indicators using polyethylene terephthalate waste without great investments.

It has been established that it is possible to obtain a certain adhesive substance processing together in a certain percentage of bast and crust by a dry grinding method to a certain particle size distribution, heating the resulting mass to a certain temperature. It is possible to produce plates with GOST-established strength properties using the composition obtained in the production of fiberboard, as well as to reduce the consumption of wood raw materials, to reduce the cost and toxicity of plates while maintaining the physical and mechanical characteristics of the finished product. At the same time, the form of the plates is not changed. The problem of utilizing significant reserves of crust is also solved.

## Conclusion

Thus, without disrupting the technological process, enterprises can produce plate products, building, construction and surfacing materials for special purposes with some additional properties that will increase the production capacity of enterprises. They also reduce raw material consumption, and decrease the production costs of finished products, expand the markets for finished products, including Western European consumers, improve the quality of products, reduce material and energy costs of production. These activities will improve the ecology of the region significantly through waste disposal.

## References

- [1] Office of Rosprirodnadzor in the Krasnoyarsk Region Available from <http://24.rpn.gov.ru/node/854>
- [2] Bezrukikh Yu A, Rubinskaya A V and Mezentseva N V 2015 Ways of rational use of wood resources in the framework of the integrated use of wood biomass *Int. Scie. Research* **3(24)** 55-8
- [3] Chistova N G, Rubinskaya A V, Kazakov E A, Shinkevich I V and Matygulina V N 2016 Analysis of the formation of solid industrial waste and the possibility of recycling *Conf. Proc. NITS Sociosphere* **10** 145-50
- [4] Rubinsky A V, Chistova N G and Zyryanov M A 2015 Environmental assessment of obtaining a modified wood-based building material *Conf. Proc. of SWorld* **1(38)** 22-7
- [5] Zyryanov M A, Rubinsky A V and Chistova N G 2015 Recycling of solid industrial wastes in the production of slab products *Conf. Proc. of SWorld* **1(38)** 27-31
- [6] Mokhirev A P, Bezrukikh Yu A and Medvedev S O 2015 Processing of wood waste of enterprises of the lumber industry complex as a factor of sustainable environmental management *Inzhenerny Vestnik Dona* **36(2-2)** 81
- [7] Bezrukikh Yu A, Bogunov L A, Galitskih V N, Elshin L A, Kataykina N N *et al* 2015 *Problems of economics and management of enterprises, industries, complexes* (Novosibirsk)
- [8] Kozhevnikov A K, Aksenov N V, Chistova N G and Rubinskaya A V 2015 Formation of solid industrial wastes and their recycling in the forest complex *In the world of scientific discoveries* **8(68)** 75-85