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Socio-ecologies of solid waste in Ijebu-Ode, Ogun State, Nigeria

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A B S T R A C T

The main purpose of this paper is to examine the socio-ecologies of solid waste in Ijebu-Ode, Ogun State, Nigeria. Descriptive survey design was adopted in which questionnaire and personal observation was used to elicit information from the respondents. A total of 115 respondents were selected and examined on the subject matter. Data gathered from the respondents were analysed using descriptive statistics. The finding showed that the characteristics of solid wastes in Ijebu-Ode include plastics, paper/glass, cartoon, sacks and food remnant as well as electronic waste which are generated from households, market places, religious centers and relaxation as well as event centers. The finding also revealed that there is indecent solid waste disposal in terms of waste separation, collection and recycling among the residents of Ijebu-Ode. Based on the finding of this study, it is recommended that government and non-governmental organizations should embark on public sensitization and distribution of garbage containers to residents of Ijebu-Ode in order to encourage sustainable waste disposal and waste management.

1. Introduction

For more than a decade now, many cities in Nigeria have been contending with the challenge of waste management due to increase in industrialization, urbanization and consumption patterns. In the process of finding solution to the problem of waste generation and management in Nigeria and many other developing countries, a lot of investigations/studies have been embarked upon by social scientists and environmentalists in recent times (Solaja et al., 2014; Uwadiegwu and Chukwu, 2013; Chukwuemeka et al., 2012; Fakere et al., 2012; Afangideh et al., 2012; Odufuwa et al., 2012; Douglas, 2004) in attempt to mitigate the challenge caused by it. The growing attention on the problem of waste generation and management among researchers is fundamentally based on the dire need to build healthy environment and improve socio-economic condition for human development. According to Chukwuemeka et al. (2012), achieving human development through effective waste management strategy is a monumental responsibility for social scientists and environmentalists in today's sustainable development era. This is essentially so because sustainable development is about inclusive improvement in the 3Ps (people, profit and planet) and as clearly established in the Agenda 21.

The word 'waste' depicts material or objects that lack direct value or worth to the producer (Science in Africa 2003 cited in Odufuwa, Odufuwa et al., 2012). It can also be described as anything which may not be directly useful or needed by the owner (EIONET, 2009; Edu, 2003 cited in Afangideh, Joseph and Attu, 2012). It can also be described as anything which may not be directly useful or needed by the owner (EIONET, 2009; Edu, 2003 cited in Afangideh, Joseph and Attu, 2012). According to OECD, waste can be defined as materials that are not prime products (i.e. products produced for the market) for which the generator has no further use for own purpose of production, transformation or consumption and which s/he discards or intends or is

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required to discard" (EIONET, 2009 cited in Abiti, 2013). In a similar definition, the UK Environmental Protection Act 1990 described waste as follows:

(a) Waste of all descriptions
(b) Any substance which constitutes a scrap material, an effluent or other unwanted surplus substance arising from the application of any process. Waste is usually classified according to (a) its source (b) its harmful effect on humans and the environment. (c) The control which are appropriate to deal with it.

However, waste can be considered as unwanted or unusable material disposed of by a person or group of people (Udechukwu, 2009 cited in Chukwuemeka et al., 2012) after utilizing the valuable part of it or due to excess of it which may also serve a purpose to another person or users. In most cases, waste appear to be unwanted materials produced as a result of man interaction with nature or his environment over a period of time (Douglas, 2004), unsustainable industrialization (Guti et al., 2012), urbanization (Odufuwa, Odufuwa et al., 2012) and consumption patterns (Nwokocha, 2012). Activities such as industrialization, urbanization, transportation, construction, increase extraction of natural resources and consumption pattern also create various forms of waste. Therefore, waste is an inevitable part of human existence, industrialization and consumption activities that becomes a social problem when the rate of collection and evacuation perpetually lag behind the rate of generation in any given society.

Nevertheless, waste can be classified using the three properties of matter into liquid, gaseous and solid waste. Solid waste can simply be described as unwanted physical or tangible materials like wood, plastics, paper, bottle, metal, polythene etc. that are thrown away or discarded by the owners (Afangideh et al., 2012; Uwadiegwu and Chukwu, 2013). This phenomenon has informed the conclusion of several studies to admit that greater proportion of waste generated from human activities come in form of solid waste (Edu, 2003 cited in Afangideh, Joseph and Attu, 2012; Solaja et al., 2014).

Though, solid-waste materials can as well serve as resource for manufacturing or recycling process. The rising level of solid waste production and ineffective management technique in Nigerian cities has been a source of concern to an increasing number of people in all strata of the society and government inclusive. Reports from empirical studies revealed that the condition of waste disposal and management in Ijebu-Ode continues to worsen despite efforts at managing or mitigating it. This has led to a situation where large parts of Ijebu-Ode, especially less developed areas, are becoming untidy due to improper domestic solid waste disposal and low participation in domestic waste recycling or management. It is very disturbing that waste phenomenon in Ijebu-Ode has become so aggravating to the extent that mountain heaps of waste now adorn roadsides forming part of city's landscape while in some instances roads are carve up by heaps of refuse (Odufuwa et al., 2012) . To this end, this paper examines the socio-ecologies of solid waste in Ijebu-Ode, Ogun State, Nigeria with particular emphasis on the sources and characteristics of waste produced in the area and also to reveal the perception of residents on waste disposal, collection and recycling. The concern in this study is solid waste which has been the dominant form of waste in Nigerian urban areas (Edu, 2003 cited in Afangideh, Joseph & Attu, 2012). Findings from this study will contribute to existing literature on household waste disposal and management. Also, it will be instrumental for policy makers, planners and other environmentalist in understanding the extent of environmental education approach to waste disposal and management to adopt from time to time.

2. Types of waste generated by household and organization

Waste comes in different forms; it could be solid-metal, gaseous-chemical or liquid. Studies which have been conducted to examine the nuances surrounding waste production in Nigeria. To corroborate this view, Akaninyere and Atser (2001) cited in Fakere, Fadairo and Oriye (2012) examined the typology, characteristics and future trends of solid waste in selected Nigerian urban cities (excluding Ijebu-Ode) and asserted that the major components of waste are degradable materials (food remnants, paper, and rags) and non-biodegradable (plastics, tins, metals, bottles, glass, and bones). Among which garbage was found contributing substantially more than other components (Akaninyere and Atser, 2001; Fakere et al., 2012). The finding was further buttressed by Fakere, Fadairo & Oriye 2012 who submitted that most activities which affect the environment stem from the need for food; its production, processing and preparation. As such, some of the wastes are likely to have socio-economic potentials if effective urban mining mechanisms are designed and applied.

3. Negative effect of waste on environment, plants and human beings

As observed by Vujic and Milovanovic (2012) waste is detrimental to the wellbeing of human beings, plants and animals. The negative impact of waste spread beyond it area of occurrence and it could be socially, physically or economically draining for human development and national growth has also noted by (Prokic et al., 2015; Thomson, 2011; Adesiyan, 2005; Fobil et al., 2005). One outstanding consequence of waste production is it contribution to climate change or global warming which posed serious challenge to both developed and developing countries with accompanied consequences like floods, damage of farm produces, death of aquatic species, displacement etc. which affects the quality of environmental resources (i.e. air, water, land and natural resources) and its capacity to provide supportive mechanism for lives (Odufuwa et al., 2012; Adewole, 2009). More explicitly, Adewole

(2009) classified the effect of waste into two broad categories which include:

(1) Environmental effects: The major environmental effects include climate change and air pollution, which includes odour, smoke, noise, dust, etc. Waste pollution – pollution from disposal site via flooding because of blocked drains and land degradation.
(2) Socio-Health effects: This includes: flies which carry germs on their bodies and legs and also excrete them; mosquitoes breed in stagnant water in blocked drains in favourable location in cans, tyres etc. that collects rain water; Rats: rat's spreads typlius, salmonella, leptospirosis and other diseases they cause injuries by biting and spoil millions of tons of food. The refuse workers also faces some hazards which includes: parasite infection and infected cuts resulting from skin contact with refuse, other includes hazards on disposal sites; are injuries from glass, razor blades, syringes, tissue damage or infection through respiration, ingestion or skin contact.

4. Commonly used methods of waste management in Nigeria

Three methods are in common used for dealing with waste in Nigeria namely:

(1) Recycling: This is a form of waste management strategy that involves reuse or transforming of waste materials into valuable resources for the sake of reducing volume of waste generation and it impact on social and environmental conditions (Chukwuemeka, et al., 2012; De Cuba et al., 2010). Recycling of waste materials can include conversion of waste into usable products or raw materials for further production of new products. According to Chukwuemeka et al., (2012), the process of recycling in some countries usually starts from the household, scavengers or waste collectors (who separate materials that can be recycled from the waste) to business or manufacturing organizations who recycle the waste before reaching the landfill.
(2) Composting: According to Uche, 2010 cited in Chukwuemeka et al., (2012), this method involves biological decomposing of waste material or organic matter such as food scraps and plant matter into a soil in order to serve as a natural fertilizer by supplying nutrients to the soil, increasing supportive solid organisms and defeating certain plant diseases thereby lessening the need for chemical fertilizers and pesticides in land scraping and agricultural activities (Chukwuemeka et al., 2012).
(3) Combustion: This form of waste management method includes burning of waste material in a designated facility to reduce its volume and in some cases, to produce energy (Chukwuemeka et al., 2012). According to Tim (2008), combustion is an I.S.W.M. option for managing waste material that cannot be recycled or composted (Chukwuemeka et al., 2012) and the method is also adopted by societies where landfill space is limited (Tim, 2008 as cited in Chukwuemeka et al., 2012). Although, it has been reported that combustion method of waste management can also produce toxic air emission if control equipment such as acid gas scrubbers and fabric filters are not fixed in combustors (Chukwuemeka et al., 2012).

5. Methodology

5.1. Research design

It is desirable to note that the quality of data generated as used for the study and overall understanding of waste generation and management is very important if any tangible and reliable containment result is to be achieved. This view is also emphasized in the study carried out by Stevanovic-Carapina et al., (2013) of which all possibility to the study of waste in Nigeria has taken good cognizance. This study adopted descriptive survey design in which both primary and secondary data sources were used. The primary data was gathered through a self-developed questionnaire and the secondary data were collected from literature, text, reports and other archival sources.

5.2. Study area: Ijebu-Ode

Ijebu-Ode is located at Longitude 3.180 E and Latitude 6.470 N is one of the 20 Local Government Areas (LGA) that make up Ogun State. Ijebu-Ode region covers an area of about 72 km^2 and the second largest urban centre in Ogun State in terms of population and infrastructural facilities, being next only to Abeokuta the state capital. Since the last two decades, the town has proved to be a rapidly growing and expanding urban centre. Its importance as an administrative headquarters and commercial centre predates the colonial period. Ijebu-Ode is a medium-sized city with a population of over 192,000. Topographically, Ijebu-Ode presents a generally gentle undulating plain which rises from about 20 meters above sea level. The topography is underlain by recent alluvial deposits. The town being of very low latitudes is liable to flood during the rainy season. This often results from over flow from drainage channels and blockages of drainage gutters by domestic garbage coupled with ill-maintenance of the drainages by the people and the government agency concerned. Areas usually affected are: Imepe, Degun, Oyingbo, Apebi, Folagbade Road, Balogun Kuku Road and old Ondo-Benin Road etc. Ijebu-Ode has the tropical wet and dry climate characterized by heavy annual rainfall, high temperature and relative humidity. Above all, the town is characterized by modern economics and administrative headquarters.

5.3. Population of the study

The population of the study comprised of residents of Ijebu-Ode, Ogun State, Nigeria. This consists of individuals who are knowledgeable about the subject matter and are willing to share their knowledge with the researchers. The estimated population of Ijebu-Ode is 185,355 (Adapted from Annual Abstract of Statistics, 2012).

5.4. Sample size and sampling technique

Due to the nature of the study, purposive sampling method was used to select 115 respondents who have been residing in Ijebu-Ode, Ogun State, Nigeria for more than five years and they are knowledgeable enough to provide useful information on the research problem at hand. The respondents were selected across political wards in Ijebu-Ode, Ogun State, Nigeria in order to accommodate the heterogeneous nature of the study area.

5.5. Method of data collection

A questionnaire was designed to elicit information from the respondents. The items contained in the questionnaire were generated from current literature. The items also passed through the evaluation and scrutiny of experts in test and measurement in order to ascertain the psychometric properties and content validity of the questionnaire. The reliability index of the data revealed Cronbach's alpha of 8.79 which indicates that the instrument is reliable for a social science research.

5.6. Method of data analysis

Data gathered from the respondents were analysed using descriptive statistics (i.e. frequency counts and percentage tables).

5.7. Data analysis and results

A total of 115 copies of questionnaire were administered out of which 15 were not completed as expected hence; 100 copies of questionnaire were used for analyzing the research objectives of the study.

5.8. Socio-demographic variables of the respondents

Results of the socio-demographic characteristics of the respondents were presented percentages in tables. The distribution of the respondents along gender revealed that 54.0 were females and 46.0 were males. Which implies that majority of the respondents are female. This is further shown in the table 1.

Also, analysis on the age distribution of the respondents shows that 2.0 % of the respondents are below 18 years old, 28.0 % are between the ages of 18 and 30 years old, 23.0 % of the respondents are between 30 and 40 years old while 47.0 % of the respondents are above 40 years old. Thus, majority of the respondents are adults with the age bracket 40 years and above. This result is further shown in table 2.

Furthermore, information collected on the marital status of the respondents revealed that 43.0 % of the respondents are single, 55.0 % of the respondents are married, and 2.0 % of the respondents are widowed, while none of the respondents are divorced. This distribution depicts that majority of the respondents are married with little or no family responsibilities. This information is further presented in table 3.

Moreover, the data collected on household size of the respondents showed that 24.0 % of the respondents has an household size between 1 to 3 persons; 47.0 % of the respondents has an household size between 4 to 6 persons, 20.0 % of the respondents has an household size between 6 to 8 persons, while 9.0 % of the respondents has an household size which is above 8 persons. This outcome illustrates that most of the respondents has a household size of 4-6 persons. This is also shown in table 4.

6. Major findings

The response of respondents in accordance to the stated research objectives are presented below.

6.1. Waste classification

On the classification of waste, respondents were asked to state the most frequent waste material they disposed of in their neighborhood. The result on waste classification shows that 7.0 % of solid waste generated in Ijebu-Ode comprised of electronic waste, 12.0 % include food remnants, garden waste and vegetables, 23.0 % contains paper, cartoon, glass, bottle and sacks, 15.0 % consists of wood, plastic, shoes and construction waste, 17.0 % entails metal, can and aluminum products while 26.0 % consists of garbage, animal waste and bones. Majority of the waste disposed of in the area comprised of garbage, animal waste and bones. This is also shown in table 5.

6.2. Sources of solid waste

The respondents were also asked to mention the source of waste neighborhood. The result shows that 42.0 % of the respondents picked household, 51.0 % picked market, while 5.0 % picked industries and just 2.0 % mentioned other sources such as religious places, recreation centers, and financial institution. This result is shown in table 6.

6.3. Residents' frequency of waste disposal

The respondents were asked to state how frequent they dispose their waste in the neighborhood. The result shows that 17.0 % of the respondents dispose their wastes every day, 22.0 % of the respondents dispose their wastes once-in-a-week and 41.0 % of the respondents dispose their wastes two times in a month,

Table 1
Gender Distribution of Respondents (Field Survey, 2016).

Gender Distribution of Respondents	Frequency (f)	Percentage (%)
Female	54	54.0
Male	46	46.0
Total	**100**	**100.0**

Table 2
Age Distribution of the Respondents (Field Survey, 2016).

Age Distribution of Respondents	Frequency	Percentage
Below 18 Years	2	2.0
18 - 30 Years	28	28.0
30 - 40 Years	23	23.0
Above 40 Years	47	47.0
Total	**100**	**100.0**

Table 3
Marital Status of Respondents (Field Survey, 2016).

Marital Status of Respondents	Frequency	Percentage
Single	43	43.0
Married	55	55.0
Widowed	2	2.0
Total	**100**	**100.0**

Table 4
Household Size of Respondents (Field Survey, 2016).

Household Size of Respondents	Frequency	Percentage
1-3	24	24.0
4-6	47	47.0
6-8	20	20.0
Above 8	9	9.0
Total	**100**	**100.0**

Table 5
Waste Classification (Field Survey, 2016).

Waste Classification	Frequency	Percentage %
Garbage/ animal waste/bones/	26	26.0
Food remnants/ garden waste/vegetables	12	12.0
Paper/ cartoon /glass/bottle/sack	23	23.0
Wood/plastic/shoes/ construction waste	15	15.0
Metal/can/aluminum products	17	17.0
Electronic products	7	7.0
Total	**100**	**100.0**

while 20.0% of the respondents usually dispose their waste on a monthly basis. This result is shown in table 7.

6.4. Solid waste collection

Furthermore, respondents were asked to mention the agent of solid waste collection in the neighborhood. Result shows that 71.0 % of the respondents affirmed that government agency in Ogun State is responsible for waste collection in Ijebu-ode, others 34.0 % of the respondents claimed that it is public vendors that help to collect waste in their neighborhood while 5.0 % of the respondents mentioned private institutions (i.e. schools and hospitals) that assist in waste collection in their area in Ijebu-Ode. This result is shown in table 8.

6.5. Availability of authorize dumpsite

To investigate the matter further, respondents were examined to know whether there is availability of authorize dump site in Ijebu-Ode, Ogun State, Nigeria. The result shows that 77.0 % of the respondents claimed that there is no authorized dumpsite in Ijebu-Ode while 23.0 % claimed that there is authorized dumpsite in Ijebu-Ode, Ogun State, Nigeria. This result revealed that majority of the respondents affirmed that there is no authorized dumpsite in Ijebu-Ode, Ogun Sate, Nigeria. The result is presented in table 9.

6.6. Respondents' perception on solid waste disposal, collection and recycling

The respondents' perception on solid waste disposal, collection and recycling in Ijebu-Ode were examined. This is to ascertain frequency of their participation in environmental sanitation, preference of waste separation before disposal and for recycling process. Level of Participation in Environmental Sanitation The level of participation in environmental sanitation among the respondents was examined. Result revealed that 11.0 % of the residents have never participated in environmental sanitation, 15.0 % of the residents rarely participate in the exercise while 74.0 % of the respondents often participate in the exercise. This shows that majority of the respondents use to observe environmental sanitation that is always done on the last Saturday of every month. This also implies that there will be increase waste generation on every last Saturday of the month in the neighborhood due to environmental sanitation. The result is shown in table 10.

6.7. Residents' preferred methods of waste disposal

Sequel to the result above, respondents were asked to express their preferred methods of waste disposal in their neighborhood. The result shows that 33.0 % of the respondents preferred to dispose their wastes by burning and burying, 48.0 % of the residents prefers composting and dum ping of wastes on open places, road side and drains for pick up by the agent of waste collection, while 19.0 % were of the view that indicates they don't have any preferred method of waste disposal. This result is also shown in table 11.

6.8. Waste sorting/separation

Respondents were examined to know whether they sort the waste before disposing it. The result shows that 9.0 % of the respondent always sort or separate their

Table 6
Sources of Wastes (Field Survey, 2016).

Sources of Wastes	Frequency	Percentage
Household	42	42.0
Market	51	51.0
Industries	5	5.0
Others	2	2.0
Total	**100**	**100.0**

Table 7
Residents' Frequency of Waste Disposal (Field Survey, 2016).

Frequency of Waste Disposal	Frequency	Percentage
Daily	17	17.0
Once-a-week	22	22.0
Twice in a Month	41	41.0
Monthly	20	20.0
Total	**100**	**100.0**

Table 8
Solid Waste Collection (Field Survey, 2016).

Solid Waste Collection	Frequency	Percentage
Government Agency	71	71.0
Private institution	5	5.0
Public vendors	34	34.0
Total	**100**	**100.0**

Table 9
Availability of Authorized Dumpsite (Field Survey, 2016).

Availability of Authorized Dump Site	Frequency	Percentage
Yes	23	23.0
No	77	77.0
Total	**100**	**100.0**

Table 10
Frequency of the Participation of Residents in Environmental Sanitation (Field Survey, 2016).

Residents Participation in Environmental Sanitation	Frequency	Percentage
Never	11	11.0
Rarely	15	15.0
Often	47	47.0
Very Often	27	27.0
Total	**100**	**100.0**

Table 11
Residents' Preferred Methods of Waste Disposal (Field Survey, 2016).

Methods of Waste Disposal	Frequency	Percentage
Burning and Burying	33	33.0
Open dumping and Composting	48	48.0
No preferred method	19	19.0
Total	**100**	**100.0**

Figure 1. Showing waste disposed on open space

waste before disposing them, and 23.0 % of the respondents sometimes do the sorting while 68.0 % of the respondents do not sort their waste before disposing them. The result is shown in table 12**.**

6.9. Reasons for not sorting their waste

The respondents further revealed the reasons for not sorting their waste. The result shows that majority (53.0 %) of the respondents are not aware of waste sorting, 6.0 % affirmed that they don't have garbage container to sort their waste, 38.0 % of the respondent said that they don't have time for sorting waste while 3.0 % of the respondents were of the believe that since waste is to be disposed of sorting of waste makes no difference. This result shows that majority of the respondents have never engage in waste sorting for recycling process. The result is shown in table 13.

Table 12
Waste Sorting /Separation (Field Survey, 2016).

Methods of Waste Disposal	Frequency	Percentage
Always	09	9.0
Sometimes	23	23.0
Not at all	68	68.0
Total	**100**	**100.0**

Table 13
Reasons for not sorting their waste (Field Survey, 2016).

Reasons	Frequency	Percentage
I am not aware of waste sorting	53	53.0
I don't have garbage container	06	6.0
I don't have time for sorting waste	38	38.0
I don't think it makes a difference to sort	03	3.0
Total	**100**	**100.0**

7. Summary and Recommendations

From the discussion so far, it is quite obvious that Ijebu-Ode is one of the urban areas in Nigeria where huge amount of solid waste is generated than what the current waste management facilities can efficiently cope with. As a result, this study examined the socio-ecologies of solid waste in Ijebu-Ode, Ogun State, Nigeria with particular emphasis on the characteristics of waste generated as well as disposal, collection and recycling processes. The finding of the study revealed that majority of the waste generated in the area comprised of biogradable and non-biogradable waste such as animal waste, bones, plastics, paper, glass, cartoon, sacks and food remnant as well as electronic waste. The source of solid waste in the study area includes household, markets, industries, religious places, recreation centers and corporate institutions.

The finding also showed that there is no authorized dumpsite in Ijebu-Ode, Ogun Sate, Nigeria and that waste collection in the area is done by government agency, public vendors and private institutions. Similarly, the finding of the study revealed that majority of the respondents participates in the monthly environmental sanitation. Furthermore, the finding showed that majority of the respondents disposed most of their waste on open places, road side and in public drains. Finding also shows that majority of the respondents were not aware of the importance of waste sorting before disposing it. Reasons for this state of affairs include not having time to sort their waste, insufficient distribution of garbage containers, as well as the believe that since waste is to be disposed of sorting it makes no difference.

Based on the findings of the study, it is therefore recommended that government (both at state and local levels) need to increase their efforts and involvements in waste collection and evacuation in urban areas and Ijebu-Ode metropolis. Also, there is need for adequate provision of waste containers as well as the distribution of these containers must cut across every segment of Ijebu-Ode, Ogun State, Nigeria. In the same way, there is utmost need for public sensitization and education on waste sorting and proper disposal of waste in Ijebu-Ode, Ogun State, Nigeria. This can be done by both government and non-governmental agencies through increase dissemination of information and sensitization on the waste management and benefits of waste sorting before disposal. More so, there should be at least two authorized dumpsites and waste collection centers where the residents can dispose their wastes after sorting them. This will assist in urban waste mining for recycling and manufacturing activities. Finally, there is need for environmental agencies to strengthen their capacity to prosecute any person, organization or group of people who discharge waste haphazardly in Ijebu-Ode metropolis, Nigeria.

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Socijalna ekologija i čvrst otpad u Ijebu-Ode, Ogun, Nigerija

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I Z V O D

Cilj ovog rada je sagledavanje upravljanja čvrstog otpada sa aspekta socijalne ekologije u Ijebu-Ode, Oguan, Nigerija. Za istraživanja korišćena je deskriptivna metoda, gde su upitnici i lična opservacija poslužili za dobijanje informacija od 115 ispitanika. Rezultati sprovedenog istraživanja pokazali su da se morfološki sastav u Ijebu-Ode sastoji od više vrsta otpada (plastika, papir, staklo, karton, organski otpad, elektronski otpad), a da su izvori generisanja otpada domaćinstva, marketi, verski i kulturni centri. Takođe, na osnovu istraživanja indetifikovano je i postojanje malih divljih deponija. Na osnovu sve obuhvatne analize, vladinim i nevladinim organizacijama, data je preporuka da pokrenu kampanju u cilju uspostavljanja održivog sistema upravljanja otpadom.

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Modelling landfill methane distribution into the ambient air: Case study of Novi Sad

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ABSTRACT

Waste disposal is a common practice in Serbia. Landfills are largely unregulated and most commonly, waste is disposed without pre-selection so it represents an uncontrolled methane source of emission. Methane is a greenhouse gas which is estimated to have 20 times higher potential for global warming than carbon dioxide. In this paper, based on the available data on the level of emissions from the landfill, the modeling of methane dispersion after emission was performed for the periods of the dominant meteorological conditions whereby the quantification and characterization of the methane behaviour and its dispersion into the ambient air was carried out. Analysis of the modelled methane concentrations showed that maximum concentration of 7478.9 μg/m^3 was reached at the distance of 466.6 m from the landfill itself, with no significant influence on the nearest settlements.

1. Introduction

Disposal of municipal solid waste which does not follow principles of environmental protection represents a serious risk to the environment and human health. Waste dumps can become dominant sources of deterioration of the air quality due to the emission of the methane, caused by anaerobic decomposition of the organic waste parts. Methane, which emission derives from anthropogenic sources, is one of the most important gases with a greenhouse effect. One of the first studies on the greenhouse gas (GHG) emissions shows that landfills contribute with 5-10 % to the global methane emissions (Global Warming Potential Values, 2014) and up to 10 % to an anthropogenic carbon dioxide fraction, which implies that waste dumps are significant pollution sources (Bingemer et al., 1987).

According to the national inventory of the greenhouse gases, for the period 2010-2013, methane emission takes a share of 13.9 % of the total GHG emissions. GHG emission from the waste sector is 5.1 %, and within the waste management sector it is estimated that 62 % of GHG emissions occur due to the waste disposal. According to the first biennial updated report of the Republic of Serbia under the United Nations Framework Convention on Climate Change, the further trend of the GHG emission within this sector depends solely on the improvement of the waste management. Based on this report, the most favorable scenario of the system improvement (increasing the amount of the municipal waste managed with biological treatment, using anaerobic digestion and a smaller degree of composting, thermal waste treatment using the heat in larger cities) would reduce the amount of the emissions by 15 % due to the reduction in the amount of the waste in the dumps (up to 50 %) and the existence of solely sanitary landfills and absolute utilization of methane found (Ministry of Agriculture and Environmental Protection, 2016).

Disposal to landfills is one of the most common ways of the municipal waste disposal in developing

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countries. In Serbia, there are 160 controlled and 3,500 uncontrolled waste dumps with undefined emission of landfill gas (Stanisavljević et al., 2014; Environmental Protection Agency, 2017). The estimation of methane emission from the landfills is extremely complex because landfills cover large areas. Besides, emission may depend on the topography, on the type of waste landfilled, on the type of materials used as a covering etc. Therefore, the methods for estimating the methane emissions from the waste dumps are different. Although the long-term methane emissions measurement is the most reliable and at the same time the most expensive, the application of the software packages for estimating the emissions are frequently used. One of the most commonly used software is "LandGem" of the US Environmental Protection Agency (USEPA). LandGem is often used to estimate the production of methane and carbon dioxide from cumulatively disposed municipal waste (USEPA, 2005). Methods defined by the Intergovernmental Panel on Climate Change - IPCC are also used to estimate the methane emissions from the solid waste dumps (IPCC, 2006). Different approaches for methane emission estimation are constantly developing (Karanjekar, 2015; Svensson, 2001).

The effects of landfills on air quality is not negligible. The reduction of the GHG emission from landfills is very important and may provide benefits to the environment, sustainable development and may decrease adverse impacts on human health.

This paper focuses on the quantification and characterization of the methane behavior and its distribution into the ambient air. For this purpose, based on the available data on the amount of methane emission from the municipal landfill in Novi Sad, simulation of the spatial distribution of methane, as well as the impact on the air quality using the ADMS Urban software has been performed.

2. Methods

Mathematical models are very useful tools for calculating the concentration of pollutants in atmosphere when the data on the specific measurements is not available. The spread of pollutants depends on several factors. For example, a set of parameters related to the source (emission sources and emission levels), dominant meteorological conditions (wind speed and direction, atmospheric stability, precipitation, cloudiness, etc.), then the parameters which refer to the environment itself in which the pollutant is released (the configuration of the area) are crucial for establishing a good basis for obtaining reliable results of the modelling of pollutant diffusion. According to the given statement, the simulation was carried out using The Atmospheric Dispersion Modelling System software (ADMS) which is developed by the consulting company "Cambridge Environmental Experts Consultants" (CERC). ADMS is one of the widely used dispersion models which simulate a wide range of pollution from various sources (CERC, 2017).

2.1 Input data

Source of emission

At the landfill in Novi Sad, municipal waste from the territory of the City and the surrounding (341,953 people are covered) is disposed of. A waste separation plant is located nearby the landfill. The landfill site covers an area of 56 ha, where the landfill itself covers 22 ha. The landfill height on various parts of the site varies in the range of 2.5 m to 14 m. The landfill contains c. 2,000,000 m^3 of the waste. The average quantity of the waste which is disposed of is 629.7 tons per day. The landfill has a passive degassing system which is aimed to prevent the accumulation of methane in the landfill body and cause explosion later (Regional waste management plan, 2011).

Since there are no data on the number nor the position of gas wells on the landfill, the source of methane emission is defined as the surface (Jeremy et al., 2014). The landfill surface as a source of the methane emission is graphically presented using ADMS Mapper program. The graphical segment of the landfill presents a real environment of the simulation (Figure 1).

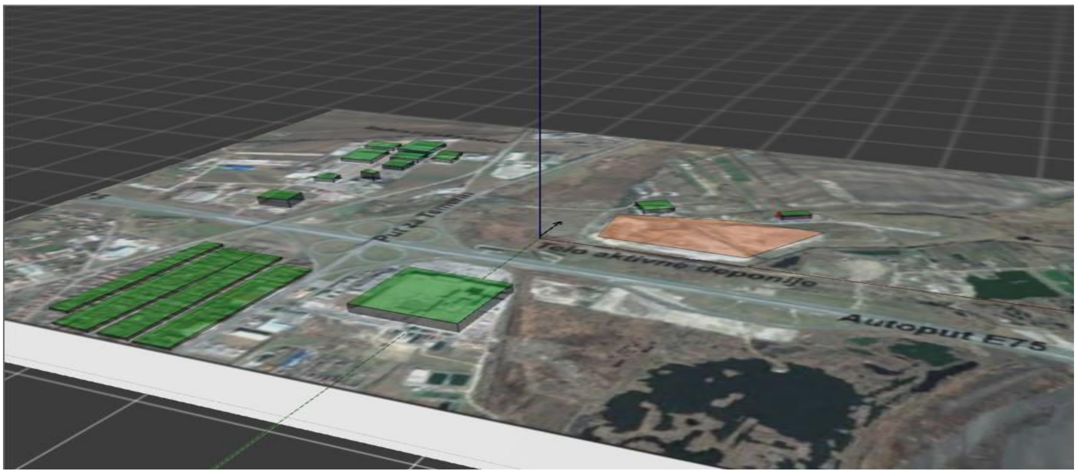

Figure 1. Defined area of the research - a landfill in Novi Sad as a surface source with the closest marked facilities

Emission

An IPCC methodology based on the First Order Decay (FOD) method is used to calculate methane emissions from the landfills (IPCC, 2006):

$$CH_4 emission = \left[\sum_{x}^{i} CH_4\ generated_{x,t} - R_t\right] \cdot (1 - OX_t)$$

Where:

CH_4 Emissions = CH_4 emitted in year T (Gg)
T = inventory year
x = waste category or type/material
R_T = recovered CH_4 in year T (Gg)
OX_T = oxidation factor in year T, (fraction)
CH_4 generated (x,t)

The amount of generated methane (CH_4) depends on the composition and age of waste but also on the conditions found on the landfill (temperature, moisture and oxygen content). The potential to generate methane from the waste that has been disposed in a certain year gradually decreases with time because the amount of degradable carbon is being reduced.

Therefore, in order to achieve a more precise calculation of the methane emission in a certain year, it is recommended to use the data on waste disposal for the period of 50 years at least (IPCC, 2006).

Additionally, due to the complex degradation process that occurs at the landfill, the amount of methane can vary in time and space within a certain waste dump. Research in this area confirm variability of the methane emissions, so Lando et al. (2017) reported that the average values of all values of estimated flux by point and scanning method were 38.3 and 71.2 g $CH_4/m^2/d$, respectively. Based on Scheutz (2009), the standard rate of methane emission ranged from 77 to 155 g $CH_4/m^2/d$, and by Boeckx et al. (2009), methane emission from a small covered landfill site showed, seasonally varying fluxes, ranging from 5.9 to 914.3 g $CH_4/m^2/d$. Field measurement of landfill methane in emissions indicated variability from 0.0004 to more than 4000 g $CH_4/m^2/d$ (Bogner et al., 1997).

Methane emission rate from landfills in Serbia are in the range of 0.3 g $CH_4/m^2/d$ (for shallow landfills) to 60 g $CH_4/m^2/d$ (for landfills with a waste volume of more than 100,000 m^3), which is relatively low and can be explained by the fact that these landfills are generally not managed and show less waste compaction and are therefore not fully anaerobic, which results in lower CH_4 generation (Stanisavljević et al., 2012).

Meteorological conditions

Data for air dispersion modelling include two sets of meteorological data:

1. Required parameters:
   - Wind speed (m/s) and wind direction (°)
   - Parameters related to the sensitive surface flux:
     - year/day/time/cloud cover (oktas) or surface flux (W/m^2)
2. Additional meteorological data:
   - Boundary layer height (m)
   - Surface temperature (°C)
   - Lateral spread (°)
   - Relative humidity (%)

The meteorological parameters used in this paper are: wind speed and direction, cloudiness and temperature in 2016.

These parameters were taken from the automatic air quality measuring station located in the surrounding that is not far from the landfill and are presented in this paper.

Terrain configuration

For the modeling of propagation of methane from landfills, surface roughness of 1 m which is typical for cities and woodlands is used in this paper.

3. Results and discussion

The simulations of the methane dispersion from the landfill is conducted within two scenarios: (I) the winter period (February-March) which is characterized by dominant winds with sometimes extreme windblasts and (II) the summer period (June-September) when temperatures are relatively high and wind speed is low.

The dominant weather conditions for the period January-March 2016 are characterized by a dominant northeast wind direction (NE), which is typical for this area. The NE wind reached a speed of 5.3 m/s in 2.4 % of cases (Figure 2). Wind calms were presented in 4 % of measurement cases. The average cloud cover during this period was 6 oktas, the temperature ranged from -9.7 to -16.7 °C (average temperature – 7 °C) while the average relative humidity was 80.4 % (Table 1).

During the period of the II scenario (June-September 2016.), north (N) wind directions (14 % of the measurement) and west (W) wind directions (15 %) were dominant. The northern direction of the wind has significantly higher speed. The maximal windblast of 5.4 m/s was recorded (Figure 3).

The northwest wind (NW) had a slightly lower frequency (11.7 %) but with significantly higher number of wind blasts within the range of wind class of 3.6-5.7 m/s in relation to the E and N direction. However, dominant winds during the summer period have lower frequency of higher wind speed compared to the winter winds. The wind calms were noted in 10 % of the measurements.

Table 1.
Meteorological data scenario I and scenario II

Period of the year	Temperature range (°C)	Average cloud cover (oktas)	RH (%)	Wind speed (m/s)
Scenario I January-March	-9.7 to 16.7	6	80.4	0.7-5.23
Scenario II June-September	15.5 to 27.5	4	81.4	0.19-5.45

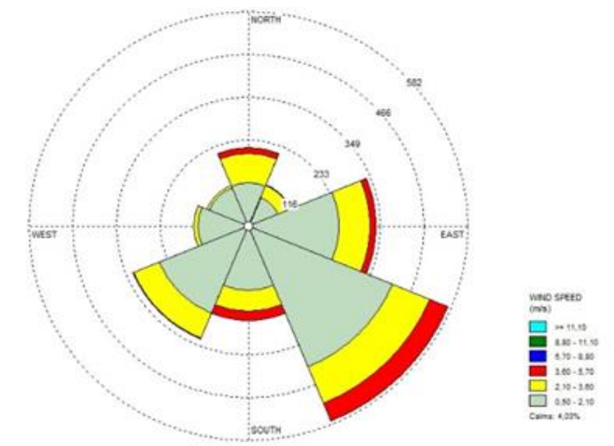

Figure 2. Wind rose (Scenario I)

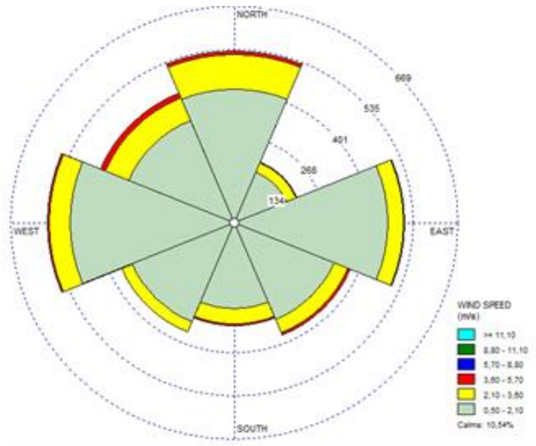

Figure 3. Wind rose (Scenario II)

After pre-processing of the meteorological data, a simulation of the methane dispersion was conducted for the both scenarios.

Software ADMS5 has the possibility to create short-term (daily and monthly) and long-term (annual) propagation scenarios, as well as pollutant concentration levels at different heights in relation to the surface of the soil and different distances from the pollution source.

Based on the contour maps of concentrations for the scenario I, modelled methane concentrations in the ambient air ranged from 1 μg/m^3 to 7478.9 μg/m^3. Numerical analysis of the data showed that the maximum modelled methane concentrations is reached 5 meters above the landfill and the distance of 466.6 m in the direction of the dominant wind (Figure 4).

In the case of Scenario II, the range of methane concentration in ambient air ranged from 3.07 μg/m^3 to 6371.26 μg/m^3, reaching its maximum to a height of 5m above the landfill lever and the distance of 380 m in the direction of the dominant wind blow.

In comparison to the summer period, the concentration levels of methane during the winter period are slightly higher and show a similar behavioral pattern (the distance and height of maximum concentrations).

The modelled methane concentration estimated within this paper are in the range of the modelled ambient concentration of the methane obtained in other studies (12-4259 ppm) (Lando, 2017).

Although methane is represented as one of the most important GHG, allowed concentrations of methane levels in ambient air are not standardized. However, studies suggest that 1,500 mg/m^3 of methane have an immediate toxic effect on people (Cotrău, 1991), while Dryahina (2010) discusses ambient methane levels of 30 ppm.

According to the Scenario I and II, the modeled concentrations of methane in ambient air are significantly below this level. Also, a methane dispersion during the dominant meteorological conditions is not spread in the right direction and does not reach settlements that are located c. 600 m from the landfill so it can be concluded that methane does not have a significant impact on the surrounding population.

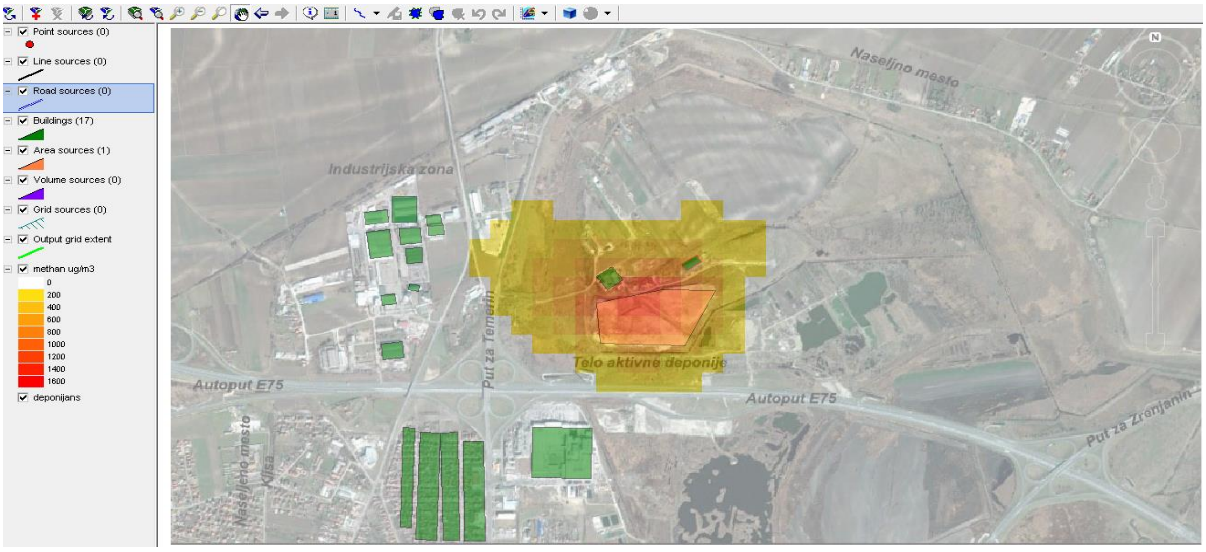

Figure 4. Example of contour maps of concentrations for scenario I

4. Conclusion

The paper shows the estimation of the distribution of methane from the landfill in Novi Sad during the winter and spring period using ADMS urban software tool.

The results demonstrated that the estimated quantities of the emitted methane during the dispersion simulation reach the values of the ambient concentration from 1µg/m^3 to 7478.9 µg/m^3 for the winter period and from 3.07 µg/m^3 to 6371.26 µg/m^3 for the summer period.

The estimated ambient concentrations of methane are relatively low which is a direct consequence of a low level of estimated emission i.e. poor waste management practice which often leads to the absence of entirely anaerobic conditions which are precondition for the methane generation.

By numerical analysis of the modeled concentrations, it was determined that the maximum methane concentrations were dispersed to a maximum half-diameter of 466 m from the landfill itself and did not arrived to the nearest settlements.

This paper also identifies the lack of adequate data on amount and type of landfilled waste during the previous period for a reliable estimation of the emission level from the landfill (data).

Further study requires a more precise methane emission estimation taking into account on site measurings at different temperature and precipitation regimes, while the modeled methane emissions need to be validated by monitoring ambient air at representative locations.

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Modelovanje distribucije metana u ambijentalnom vazduhu: studija slučaja deponija u Novom Sadu

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I Z V O D

Deponovanje otpada je uobičajena praksa u Srbiji. Deponije su mahom neuređene i najčešće se odlaže otpad bez prethodne selekcije tako da predstavljaju nekontrolisan izvor metana, gasa sa efektom staklene bašte za koji se procenjuje da ima 20 puta veći potencijal globalnog zagrevanja od ugljen dioksida. U ovom radu je na osnovu raspoloživih podataka o stepenu emisije sa deponije izvršeno modelovanje rasprostiranja metana nakon emisije sa deponije, za periode dominantnih meteoroloških uslova. Takođe je izvršena kvantifikacija i karakterizacija modela ponašanja metana kao i njegova distribucija u ambijentalnom vazduhu. Analizom modelovanih koncentracionih nivoa metana utvrđeno je da su se koncentracije dostizale maksimalne vrednosti od 7478,9 $\mu g/m^3$ na udaljenosti od 455 m u pravcu dominantnog vetra ne utičući značajno na okolno stanovništvo.

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Chassis loading investigation of two-shaft shredder for construction waste management

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A B S T R A C T

Recycling industry development need cracked materials with different composition and characteristics. New constructions shredders creation, their engineering design, development through adequate mechanical-mathematical models and practical realization determines the actuality of this paper. The materials crushing for recycling solves important environmental tasks related to environmental protection.
The two-shaft hydraulic shredder realized the first and the second stage from the crushing (disintegration) process. Disintegration as part of the recycling process can be successfully applied to the domestic and industrial waste processing, single- and multi-component materials crushing, and to secondary raw materials grinding. The paper is dedicated to the emerging loading of the two-shaft shredder chassis and the resulting calculations and verifications.
In the present work has been performed a modeling study of the chassis for such type of shredder for concrete, rubber, plastic and wood crushing. The studies of the mechanical load and behaviour of the chassis have been conducted. The equations characterizing the mechanical processes in the working conditions by the finite element method are solved. For this purpose has been generated a chassis three-dimensional geometrical model, which has been discretized to a planned network of finite elements in the ANSYS MECHANICAL APDL programming environment.

1. Introduction

Construction waste, besides an environmental problem, can also be a source of a number of valuable ingredients, in relation to which they have to be analyzed in two aspects: as a sustainable development problem and as alternative raw materials.
The solution of problems in construction waste processing is of particular importance due to the gradual natural mineral resources depletion and the need of the full use waste as useful products. Urban density is rapidly increasing in line with an expanding global population.

The importance of sustainable legacy creating is widely recognized throughout the world at every level of society. Waste management is an extremely important factor in achieving sustainable development and fundamental element of long-term sustainability strategies (Grigorova et al., 2017).

The continuous process of production and use of products from rubber, plastic, and the intensified construction lead to serious accumulation of waste, imbalance, and danger for the environment. In all industrial societies, a need appears for the waste reducing and their re-integration in the production process. The recycling of construction waste, as well as waste from rubber, plastic and wood, as a process, is extremely important both for the environment and the society (Vatskicheva and Grigorova, 2017). The waste management is a challenge, because of the high rate of

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the numerous manual operations, high transport costs and negative impact on the environment. Therefore particularly important is study and development of the various machines for crushing of the diverse waste streams.

The recycling industry development shows increasing need of crushed materials with different composition and characteristics. New crushing machines creation, their research by adequate mechanical and mathematical models, engineering design and practical implementation are current scientific problem (Lowrison, 1974; Vatskicheva, 2017).

Disintegration is a part of the recycling process can be successfully applied for domestic and industrial waste treatment, component and multi-component materials crushing. The process is used also for grinding of refuse utility with different mechanical characteristics – from the tough-elastic car tires and some types of plastics to the hard and brittle materials, such as glass, porcelain, chamotte, mica, concrete and others (Abadjiev and Tonkov, 2017; Vatskicheva and Grigorova, 2017a).

The crushing technological purpose is dependent on next processes and stages of processing or the product application. Such an attitude towards the secondary materials is a prerequisite for sustainable development, and the mandatory protection of people and environment (Vatskicheva and Grigorova, 2015). Crushers are the main machines applied for crushing in the industry and the majority of them are intended only for particular type processing. One alternative of the machines for secondary and waste materials crushing are the shredders. This is a group of relatively new machines which are classified mainly according to the number of the working shafts (Tonkov, 2007), and the technology of crushing: single-shaft, two-shaft, three-shaft, four-shaft, five-shaft shredders, with varying automation degrees and key parameters control, noise different level, rotation speed, pressurization level and others (Abadjiev and Tonkov, 2017).

Shredders are configured according to each of their unique applications, with a selection of different thicknesses and number of cutting cogs, shaft diameter, thickness of the distance bushings, drive power, productive capacity. The knives are made through a specific technology from special steels. This ensures extreme hardness, duration of operation, and maintenance low cost (Vatskicheva and Grigorova, 2017a).

The two-shaft hydraulic shredder consists of feeding conveyor, feed hopper, crushing chamber, output belt, unloading belt, and belt for metal particles separation. The shafts, which perform the main function of the machine, are arranged in the crushing chamber. A serious advantage of the shredders is the possibility to be integrated into systems for simultaneous processing of different types of multi-component waste, with separation and utilization of the components having different degree of hardness. The two-shaft shredders advantage is their high productive capacity. The disadvantages are associated with the high price and the maintenance high cost (Vatskicheva and Grigorova, 2017; Vatskicheva, 2017; Vatskicheva and Grigorova, 2017a).

The purpose of this paper is to discuss and present a constructive version of two-shaft shredder with a universal practical application for crushing different types of materials - concrete, rubber, plastic and wood. The two-shaft hydraulic shredder realized the first (initial) and the second (middle) stage from the crushing (disintegration) process. Due to the process specificity, these stages are less studied and there is the smallest number of implemented technological solutions of industrial importance.

The shredder separate assemblies are located on a common chassismultilift type. The feeding strip is a separate part of the shredder, and is transported independently. The shredder is moved from one platform to another through a towing vehicle multilift type with capacity up to16 tons. The focal point of this work is focused on the chassis model study of the shredder for waste concrete crushing. The structure of the chassis should be of durable material. This condition is very important for safely support of the vehicle components weight, and also for transmits loads, resulted from vertical, longitudinal and lateral accelerations.

When designing a chassis, should be considered material selection, strength, stiffness and weight and component packaging (Gauchia et al., 2010). The most significant issue in the truck manufacturing industries is to vehicles design with large load pay. When is possible the high strength steel use the load capacity can also increase.

Another important feature of the chassis, except strength is to have suitable torsional and bending stiffness. The two important criteria for chassis design are stiffness and strength (Tushar et al., 2012).

The studying, designing and chassis analysis should include and stress distribution, as well fatigue prediction process life.

In the studying the fatigue processes of materials and components life prediction the stress analysis is very important. Through this analysis can be determined the highest stress point (critical point) which gives information about a probable failure. The stress magnitude can be used to predict the chassis life span. For the components mounting (transmission, engine, suspension and ect.), the determination and optimization of the critical stress point location is important. (Ghazaly, 2014; Braess, 2007). This study discusses some aspects of the truck chassis stress analysis. For predicting and stress analyses investigating different finite element packages have been used.

2. Influence of the crushing machine selection criteria

The selection of the shredder type is made according to the properties of the crushed material and its strength characteristics. For brittle materials are used shredders, working with impact and pressure. Cutting single-,

Figure 1. Different types shredders
(Vatskicheva and Grigorova, 2017a)
a) Single-shaft shredder, working by scraping;
(b) Single-shaft shredder, working by cutting;
(c) Two-shaft and (d) Four-shaft shredders

two- and four-shaft shredders are used for tough-plastic materials. The material may be crushed by scraping or cutting. For scraping are suitable single-shaft shredders (Figure 1a), which are crushing machines with universal application. They are intended for materials with great thickness and resistance against destruction. Their advantages compared to the other types shredders are solid and stable structure, long service life. A disadvantage is the low productive capacity, determined by the slow working speed. In crushing by cutting, selection can be made between single-shaft, two-shaft or four-shaft shredder (Vatskicheva and Grigorova, 2015; Vatskicheva and Valkov, 2013).

The single-shaft shredders (Figure 1b) are rarely used for this type of materials crushing, because of their low productive capacity. Most often are used two-shaft shredders (Figure1c). An advantage of the two-shaft ones is their high productive capacity. The disadvantages are the high price and the machines maintenance activities (Vatskicheva and Grigorova, 2017a).

The two-shaft shredders realize the factual scissors effect, and the four-shaft ones provide larger zone of cutting (Tavakoli et al., 2008). The four-shaft shredders, shown on fig. 1d, are equipped with working shafts, on which there are installed cutting knives-disks. Both upper shafts are feeding, and the lower two – cutting. The existing two pairs of shafts (feeding and crushing) form a working chamber with conical shape (Vatskicheva and Grigorova, 2017a; Borshchev, 2004). The size of the crushed material determines the feed hopper dimensions and shape as well as crushing chamber dimensions.

The final product influence on the shredder selection is expressed in the following: as much as the size of the product is smaller than the size of the source material, the time and effort should be spent for crushing increase.

For particularly small fractions may be necessary second shredder, and sometimes whole production line, for example line for crushing to fine rubber powder. The output granulometry is depending on the crushing disks distance. (Abadjiev and Tonkov, 2017; Vatskicheva and Grigorova, 2017a; Borshchev, 2004).

The choice of crushing machine is determined by four main factors (Vatskicheva and Grigorova, 2017a; Vatskicheva and Grigorova, 2015; Vatskicheva and Valkov, 2013): material type for reduction, size of the material for shredding, the shredder productive capacity and the final product particle-size distribution. The specification of these four factors determines the best way for shredder design, manufacture and application.

3. Shredder machine specification

On the platform, the chassis is leveled on four hydraulic supports, driven and controlled by the shredder engine (Figure 2).

Figure 2. Two-shaft hydraulic shredder mounted on the chassis, subject of the study

For designing the basic unit of the machine – the crushing chamber and the shredding shafts, the following data are used (Vatskicheva and Grigorova, 2017a):

- Compressive strength of the destructed elements: maximum 55 MPa;
- Approximate dimensions of the chamber neat area: 900 x 700 mm;
- Feeding of the shredder: flow, discrete, controlled by an operator;
- Crushed material separation and loading: flow, continuous, automatic;
- Metal particles separation in the crushed material: flow, continuous, automatic, with magnetic boards;
- Approximate operated power: 210 kW.

The chassis of the machine is a frame structure, typical for the devices of type multilift. It consists of two main longitudinal beams and two vertical beams for gripping from the transport vehicle, as it is shown on Figure 3.

The part of the chassis, in which the hydraulic station is located, is closed with tin lids, and the part under the crushing chamber and the output strip are open. In the four corners of the chassis are installed four lifting and leveling cylinders, each with separate command for precise leveling on uneven terrains. The type of cylinders is CBX4 2 1 A1 D100 S600 with 600 mm step (move). In the ends of each cylinder is mounted a round seating for distribution of the weight over the terrain (Figure 4).

The chassis of the machine is a structure of rectangular and square welded pipes ISO 4019, 100x100x5, 100x50x5 and 100x50x4. It is analyzed for deformations during its lifting from the vehicle multilift type by the hook in its front part. The three points in which the chassis is supported at this position are the hook and the rear two levelling roller supports. The chassis frame has been verified, as on the weights of all elements – chamber, hoppers, tanks, engine have been applied. The chassis structure has been verified for total strength. There have been applied the loads from the shafts weight, the chamber elements, the input hopper, as well as the support reactions (resistances) in the shafts bearings (Ghazaly, 2014; Gauchia et al., 2010). The investigations have been conducted through the mathematical models and numerical procedures described below.

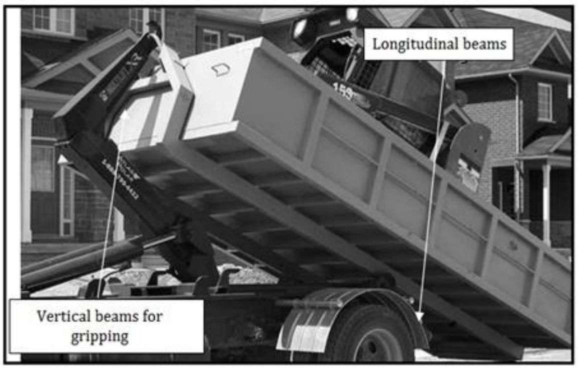

Figure 3. Chassis construction type

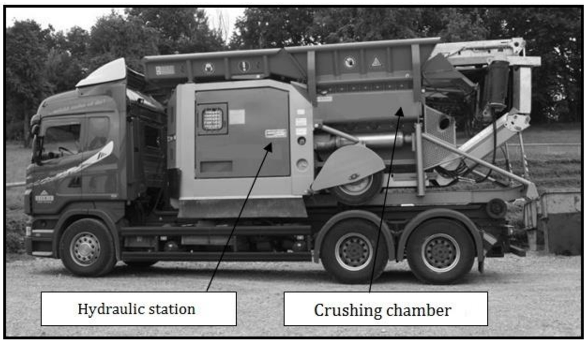

Figure 4. Crushing chamber and hydraulic station placed on the chassis

4. Model study conception

One of the many design tools, which has increasingly popular is The Finite Element Analysis (FEA). It has been used for the solution of many types of problems. FEA is used in civil construction design, aviation and for many others goods industries. The market competition puts tremendous pressure on the corporations to launch reasonably priced products in short time, making them to rely more on virtual tools (CAD/CAE) accelerating the design and development of products (Sathish and Balakrishnan, 2013; Prakash and Srikanth, 2016).

FEA is used to predict multiple types of static and dynamic structural responses. Due to FEA optimizations can be performed before the parts are constructed and implemented. The widely used and most common commercial finite element packages are ANSYS, ABAQUS, COMSOL, ALGOR, HYPERVIEW, LSDYNA, NASTRAN, etc. The powerful computers and FEA software creation gives opportunity for realization of complex models. This resulting in the better decisions to the problems, both of design engineers, as well as the customer (Siraj and Sheikh, 2014).

The mechanical load and behavior of the chassis are investigated through solving equations. These equations characterize the mechanical processes under operating conditions by the method of the finite element (FEM). For this purpose has been generated a chassis three-dimensional geometrical model, which has been discretized to a planned network of finite elements in the ANSYS MECHANICAL APDL programming environment.

In Table 1 are shown summarized results of the verification of the chassis strength with the accepted steel mechanical properties.

The chassis maximum and minimum deformations are presented on the Table 2 and the Figure 5.

The study results show that the maximum stresses for the examined structure do not exceed the permissible values for the material of the chassis multilift type.

Table 1
Data for the accepted in the verification material of the beams of the frame

Name	Steel	
General	Mass Density Yield Strength Ultimate Tensile Strength	7.85 g/cm^3 207 MPa 345 MPa
Stress	Young's Modulus Poisson's Ratio Shear Modulus	210 GPa 0.3 ul 80.7692 GPa
Stress Thermal	Expansion Coefficient Thermal Conductivity Specific Heat	0.000012 ul/c 56 W/(m K) 460 (kg c)

Table 2
Maximum and minimum frame deformations

Name	Minimum	Maximum
Volume Mass	303,791,000 mm^3 2,386.94 kg	
Von Mises Stress Displacement	0 MPa 0 mm	614.396 MPa 2.57114 mm

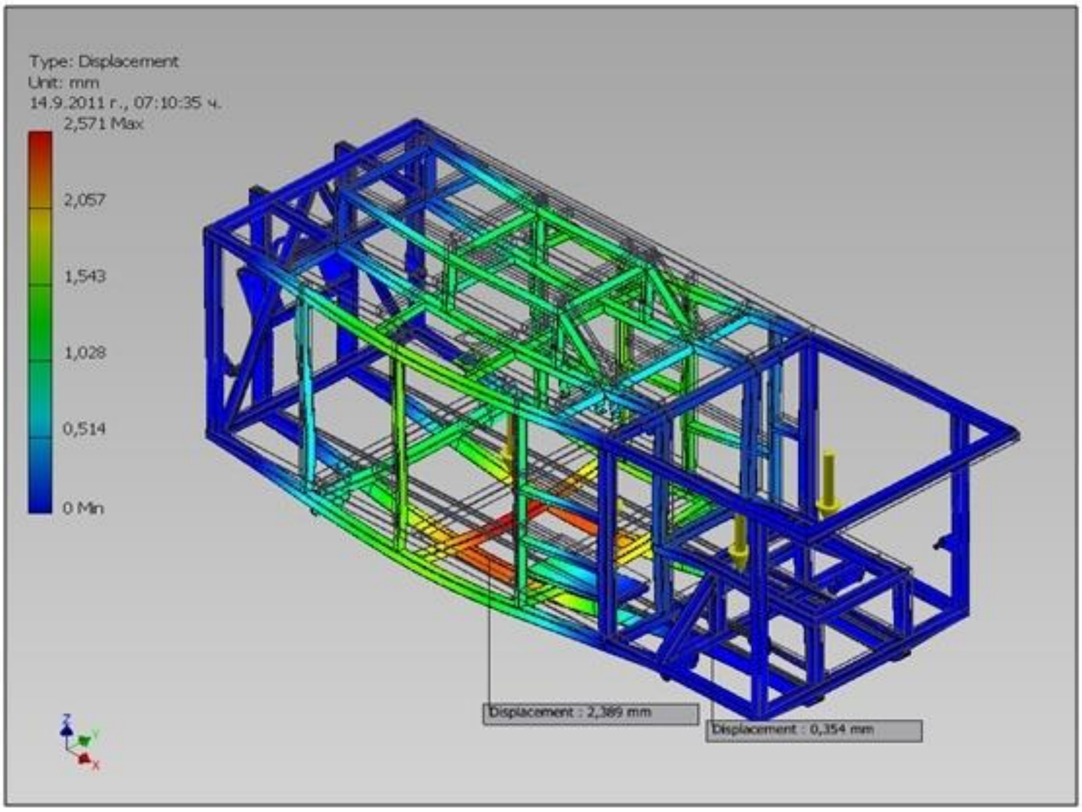

Figure 5. Data for frame maximum and minimum deformations

5. Conclusions

The crushing processes have a complex character. Solids resist crushing, so achieving the required size consumes a significant amount of energy. Therefore, the technological shredding mechanisms design with the highest energy efficiency is important.

Disintegration is an important process related to the processed raw materials destruction. The crushed materials growing need, with different composition and characteristics, has consistently led to create new shredder designs with universal application to process different materials. The recycling machines development which realizing the first and second stages of the disintegration cycle is an innovation factor for large economic potential use of many waste products, as well as secondary raw materials.

The refinement of the basis factors for choosing a crushing machine, namely: material type for reduction, size of the material for shredding, productive capacity and final product particle-size distribution, determines the best way to design and shredder apply.

Need to create universal shredding mechanisms with high technically efficient is based on number of facts. The most important are:

- Huge quantities of waste accumulation that are currently not processed;
- Inadequate and cost-effective technique for carrying out the environmentally friendly processing of these products;
- High energy consumption of existing recycling facilities.

The studies, related to the shredder constructions theoretical investigations and practical implementation present a number of challenges. Two-shaft shredder is the optimal combination of structural and economic parameters. The result of the studies carried out indicates that the examined chassisstructure, type multilift, can be used for two-shaft shredder crushing machines.

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Ispitivanje konstrukcije šasije sekača sa dva vratila za upravljanje građevinskim otpadom

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I Z V O D

U reciklažnoj industriji kao ulazna sirovina koriste se usitnjeni materijali različitog sastava i karakteristika. Shodno tome, u ovom radu, akcenat je stavljen na sagledavanju uticaja konstrukcijskog rešenja i inženjerskog dizajna sekača, kroz razvoj adekvatnih mehaničko matematičkih modela i same praktične realizacije, na mogućnost usitnjavanja. Usitnjavanje materijala rešava veoma bitne probleme po pitanju zaštite životne sredine. Hidraulični sekač sa dva vratila može se efikasno koristiti za primarno usitnjavanje (komunalnog i industrijskog otpada, jedno ili više komponentnog otpada) i sekundarno usitnjavanje (mineralnih sirovina). U radu su predstavljena istraživanja modeliranja šasije pomenutog sekača za usitnjavanje betona, gume, plastike i drveta, kao i uticaj konstruktivnog rešenja šasije na mehaničko opterećenje vratila. Kreiranje trodimenzionalnog geometrijskog modela šasije i formiranje mreže metode konačnih elemenata izvršeno je programskim paketom ANSYS MECHANICAL APDL.

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Positive examples of wastewater treatment effectiveness in "Natron-Hayat" Maglaj factory

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ABSTRACT

In the paper are described the basic characteristics of wastewaters in the cellulose and paper factory "Natron-Hayat" Maglaj. Particular emphasis is placed on the description of the technological process of wastewater treatment at the "Natron-Hayat" Maglaj factory which is represented in the paper by a technological scheme and represents one of the more complex systems for wastewater treatment. In the experimental part, the results of the efficiency of the wastewater treatment system at the "Natron-Hayat" Maglaj factory were given. It can be said that the basic raw materials for paper production are cellulose fibers and water. The role that water has in the cellulose and paper industry as the solvent, agent for cooking and washing of the produced pulp, indicates the presence of water in almost all stages of cellulose fiber production (Žarković et al., 2004). In accordance with the principles of sustainable development, cellulose and paper industry must face strict regulations on the protection of the environment which includes rationalization of raw material consumption, water, energy and chemicals, with minimal negative environmental impact. Wastewaters generated in the factory "Natron-Hayat" Maglaj are subjected to the purification before discharging into surface water recipient. The wastewaters from "Natron-Hayat" Maglaj factory are discharged into river Bosna.

1. Introduction

The term wastewater in the broad sense refers to any water which has changed its physical, chemical and biological characteristics to a greater or lesser extent while using, or it can be said one used water is wastewater (Popović, 2001). The role of water in the cellulose and paper industry is so important that it is often considered to be another source of raw material in addition to plant species. It was interesting, but also useful to examine the quality of the wastewater as well as the efficiency of the purification system, since the wastewater from the cellulose and paper industry is highly polluted and it is discharged into the river Bosna, which goes further directly through the town of Maglaj affecting the plants and living beings in the mentioned river, and thus influences the life quality of citizens.

The largest volume of water in the cellulose and paper industry is used on defibring of cellulose raw materials and the production of suspension, whereby the cellulose and paper industry is one of the largest consumers and natural resource polluters (Žarković et al., 2004). Large amounts of water are used during the process of washing pulp which is very important both from an economic and from an environmental point of view, because the quality of the pulp washing is directly related to the efficiency of chemicals regeneration and the quality of generated wastewaters. The purpose of the cellulose fiber washing process is to economically remove the maximum of soluble organic and inorganic materials with a minimum of fresh and recycled water (Halilović, 2016).

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In the domestic and foreign literature (Žarković et al., 2004; Popović, 2001; Gačeša and Klašnja, 1994), numerous examples can be found as solutions to the problem of water and wastewater quality in the cellulose and paper industry. The end objective which is rational water consumption and minimal impact on natural water courses, according to previously made researches can be achieved by increasing the degree of closed circular flow of water and the application of modern methods for wastewater treatment. Rational use of water with optimum recirculation level provides less load of central wastewater treatment plant (Žarković et al., 2004).

Direct discharge of wastewater, without prior treatment, to a nearby river, lake or sea, is the cheapest and easiest way, but for the environment it is the most unfavorable solution. One of the measures that the company establishes in addition to obligatory wastewater treatment is the imposition of increasingly stringent requirements for the more quality effluent, so that it can be reused, even for technical purposes (Popović, 2001).

The task of wastewater purification is to remove wastewater pollution to the extent that treated wastewater can be discharged into the recipient without any harmful consequences (Gačeša and Klašnja, 1994). Thus, the primary purpose of wastewater treatment is to provide a more complete release from various pollutants and toxics, whose dimensions are within very wide ranges, from simple junctions to large, floating pieces of material. The degree to which wastewater should be purified depends on its composition, mass, class and recipient size and legal regulations. Most countries in the world, in their legislation, require such water quality that will be discharged in the recipient that is necessary previously subject it to treatment (Đuković et al., 2000).

Wastewaters generated in the factory "Natron-Hayat" Maglaj are subjected to the purification before discharging into surface water recipient. The aim of this work is to examine the efficiency of devices for wastewater treatment in the factory "Natron-Hayat" Maglaj and to examine the quality of purified wastewater. Results are expressed through the reduction degree of the following parameters: chemical oxygen demand (COD), suspended matter content (SM) and biological oxygen demand (BOD_5) of treated wastewater being discharged into a watercourse.

2. Characteristics of wastewaters in the cellulose and paper industry

Wastewaters from cellulose and paper industry are loaded with organic pollution and contain chemicals that are used in the paper production process, small pieces of wood, cellulose fiber, which if not removed can cling to the gills of fish, dissolved lignin from wood, sulfur compounds. They contain a large amount of solid substances, which if they are not purified and discharged into the rivers quickly cover the bottom of the river destroying the fish and aquatic world which depends on the food from the bottom of the river (Bobar and Bajramović, 2011). There are black and white wastewaters and their characteristics are given in table 1. Black wastewaters originate from the cellulose production process, and the largest quantities are formed after washing the cellulose and they are dark brown in color. Their coloration comes from the presence of lignin, and this color affects photosynthesis ability of the aquatic plant (Bobar and Bajramović, 2011). Wastewater from the paper sector is called white water.

These wastewaters can have a variable character, both in quantity and quality. The amount of wastewater can vary widely, both during a day and for a longer period of time. Especially it is emphasized impact discharge of wastewater, that indicates the discharge of a larger amount of wastewater in a relatively short time.

Biological oxygen demand and chemical oxygen demand are the most common criteria for wastewater pollution. The pollutant criteria serve to estimate the damage caused by untreated wastewater to the recipient and to select the treatment method. For the sizing and evaluation of the purification plant performance, it is not only necessary to know the concentration but also the amount of pollution (load) that is being introduced. Load is expressed through the volume of wastewater that reaches the plant in the unit of time (Gačeša and Klašnja, 1994).

3. Wastewater treatment in "Natron-Hayat" Maglaj factory

Methods of wastewater treatment can be classified in various ways. Wastewater treatment is usually divided into (Gačeša and Klašnja, 1994):

- previous processing,
- primary,
- secondary,
- tertiary purification (in some industries), and
- processing and disposal of sludge generated during wastewater treatment.

Previous treatment of wastewaters involves removal of rough suspended and floating material and removal of inert material. Primary purification removes suspended and emulsified matter from wastewater by precipitation. Secondary purification removes the colloidal and part of the dissolved organic matter by chemical or biological means. Tertiary purification is used to remove residual pollution and for disinfection of purified water (Gačeša and Klašnja, 1994).

Figure 1 shows the technological process of wastewater purification in the "Natron-Hayat" factory.

In the equalization tank pH value of wastewater is measured, pH correction is done and coagulant dosage of $Al_2(SO_4)_3$ is added. The role of the coagulant is to neutralize the negatively charged particles and then to adsorbe them to itself thus creating conditions for their faster precipitation (Bušatlić et al., 2013). Then the wastewater through the pump is transferred from the egalitization tank to the primary clarifier tank. In the primary clarifier that is radial, it is added as flocculant

Table 1
Cellulose and paper industry wastewater characteristics (Mečević, 2009)

Characteristics	Black wastewaters	White wastewaters	All wastewaters
Amount	18,000 m^3/day	22,000 m^3/day	40,000 m^3/day
BOD_5	7,000-12,000 kg/day	3,000-6,000 kg/day	10,000-18,000 kg/day
COD	14,000-35,000 kg/day	6,000-13,000 kg/day	20,000-48,000 kg/day
SM	3,500-7,000 kg/day	6,000-13,000 kg/day	9,500-20,000 kg/day
Max BOD_5	700 mg/dm^3	350 mg/dm^3	
Max COD	2,000 mg/dm^3	750 mg/dm^3	
Max SM	400 mg/dm^3	750 mg/dm^3	

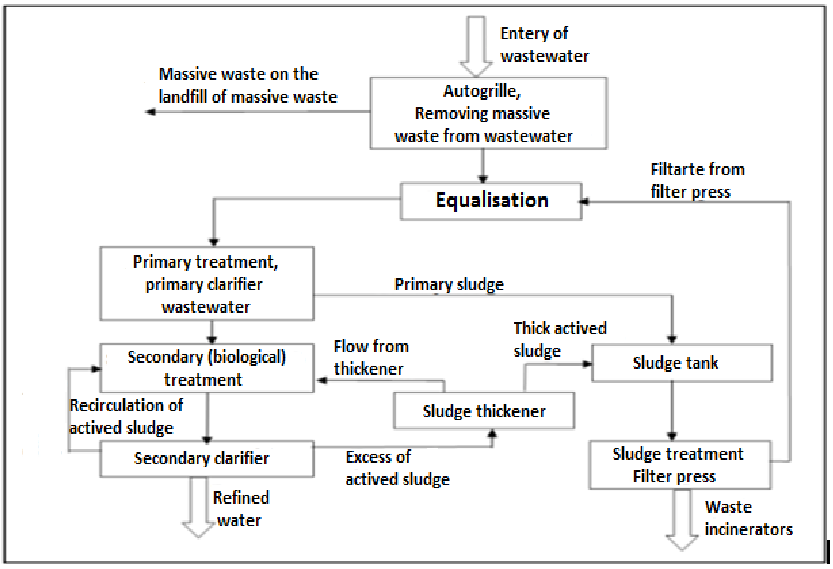

Figure 1. Schematic view of wastewater purification in "Natron-Hayat" Maglaj factory (Mečević, 2009)

an anionic polyelectrolyte. Precipitated particles from the primary clarifier are removed as a thickened slurry called "Primary Sludge". Primary sludge is drained by means of two submersible pumps which are placed on the scraper sludge and they work periodically. In the channel between the primary clarifier tank and the first aeration pool nutrients, iron sulfate ($FeSO_4$) and sodium hypochlorite ($NaClO_4$) are added. There are three aeration tanks for (secondary) biological treatment and one secondary clarifier divided into three sections. In aeration tanks is used activated sludge that contains microorganisms that will degrade organic pollution. The air is constantly introduced with a diffuser.

The primary sludge is taken directly to the sludge reservoir, while the sludge generated in the secondary purification (the active sludge) partly returns to the first aeration pool and partly goes to the sludge thickener and then into the sludge reservoir. The mixed primary sludge and the excess of the active sludge are sent to the trap filter press where dehydration of sludge is performed. In order to achieve better dehydration effects before the filter press the mixed sludge is treated with a cationic polyelectrolyte. The cake obtained on the filter press is then sent to the burning boiler and the filter through the sewerage network is sent to an equalization pool. Wastewaters from all parts of the plant are collected through the collecting channel and then treated at wastewater treatment plant (Halilović, 2016).

4. Experimental part

Experimental studies have been conducted in the period from 05.10.2015. until 29.04.2016., with the exception of 03.03.2016. until 04.04.2016. when factory remounting was done, in cellulose and paper factory "Natron-Hayat" Maglaj.

To determine the efficiency of the system for wastewater treatment during a period of a six months, every work day the following samples were taken:

- water samples after primary processing, ie. primary sedimentation and
- water samples at the entrance and the exit of the purification system, and the following parameters are analyzed:

  - the chemical oxygen demand (COD),
  - the biological oxygen demand (BOD_5), and
  - the content of suspended matter (solids) (SM).

The regulation on conditions for discharging industrial wastewater into the environment Federation

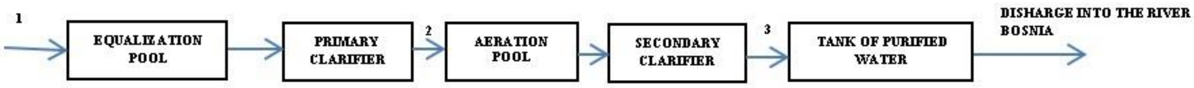

Figure 2. Schematic view of water sampling places: 1-sample taking and analysis of unpurified water: COD, BOD_5 and SM; 2-sampling after primary clarifier and COD and SM analysis; 3-purified water sampling and determination of COD, BOD_5 and SM (Halilović, 2016)

a) b) c) d)

Figure 3. The sampling places of wastewater: a) at the entrance to the treatment plant, b) after the primary clarifier, c) the overflow from the secondary clarifier-purified water, d) the output of treated wastewater into the river Bosna (Halilović, 2016)

of BiH determines and prescribes emission limit values for wastewater discharging into the environment and minimal percentage of load reduction compared to the parameters COD, BOD5 and suspended solids content after the secondary purification. The effectiveness of the devices for wastewater treatment was analyzed after:

- the primary purification (primary treatment or precipitation) and
- the secondary (biological) purification (after which purified water is discharged into the river Bosna).

4.1. Sampling

Figure 2 shows a schematic view of the places where the sampling of wastewater was done.

Figure 3 shows the sampling places in the wastewater treatment section.

4.2. Analyzed parameters and examination methods

Water sampling is done so that the water from water sampling place is first stired, and then from the various parts and depths a certain volume of water is poured in the bottle.

COD is chemical oxygen quantity demanded for organic compounds oxidation and part of inorganic salts, and it is expressed as mg/dm^3 O_2. COD was examined according to the internal method of "Natron-Hayat" Maglaj, and is based on heating a sample at boiling temperature with a strongly acidic solution of dichromate in the presence of a catalyst Ag_2SO_4 (Halilović, 2016). The dichromate is added to the excess and the unused portion is determined by titration with a standard solution of ferro ammonium sulfate ($Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$). The amount of dichromate consumed is calculated as the equivalent of the oxygen intake. Dichromate is reduced to equation (Rajaković-Ognjanović, 2016):

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O \quad (1)$$

$HgSO_4$ is added, which prevents oxidation of chloride ion into chloride.

BOD is the amount of oxygen necessary to the water sample microorganisms under aerobic conditions at a temperature of 20 °C for a certain time period of incubation, to oxidize the organic matter in water (Gačeša and Klašnja, 1994).

Biological oxidation of organic matter is a very slow process and theoretically it would take an infinite amount of time to complete it. However, for a period of 20 days, 95 to 99 % of the original organic matter is oxidized. Since, from a practical point of view, that is a very long period of time, it was adopted that the incubation period for standard BOD determination is 5 days, at which time, at a temperature of 20 °C, it is oxidised 60-70 % of originally present organic matter (BOD_5) (Gačeša and Klašnja, 1994). The first stage in which it happens carbon oxidation to CO_2 and hydrogen oxidation to H_2O lasts relatively short, 7 to 10 days. The second stage in which nitrogen is oxidized to nitrite and then to nitrate, nitrification, lasts considerably longer. As water temperature rises, oxygen consumption and oxygen oxidation increase. The BOD is also the basic indicator that serves as an indicator of the impacts of wastewater on the receiver water where the oxygen content is reduced. As a rule applies, that during the determination of the degree of purification of polluted water at the plants it is necessary to achieve in the effluent such a BOD value that will not reduce the dissolved oxygen content downstream in the watercourse. For determination of BOD_5 manometer method and device BOD SYSTEM Oxidirect, Lovibond, shown in Figure 4 is used

Figure 4. Device for BOD_5 determination, BOD OXIDIRECT, LOVIBOND (BOD Measurement System, 2016).

Figure 5. Procedure of suspended matter examination – internal method "Natron-Hayat" Maglaj (Halilović, 2016)

according to manual that comes with the instrument (Halilović, 2016).

Suspended substances in water are 70 % organic and 30 % inorganic. They pollute the water esthetically and ecologically. If they are mainly of organic origin, their subsequent chemical degradation changes the composition of water. They precipitate in calm waters and endanger the living beings at the bottom of the water, and also reduce the transparency of the water.

Suspended solids were determined according to the internal method "Natron-Hayat" Maglaj (figure 5) (Halilović, 2016):

$$M_1 = \frac{(m_1 - m_0) \cdot 1000}{V} \quad (2)$$

M_1– content of suspended matter (SM), (mg/dm^3),
m_0 – filter paper mass, (mg),
m_1 – filter paper mass after filtration and drying, (mg), and
V – sample volume, (cm^3).

According to the regulation on conditions for discharging wastewater into the environment and the public sewage system of Federation of BiH the limit value of parameter COD of the wastewater that are discharged into surface water recipients is 125 mg/dm^3 O_2, of parameter BOD_5 is 25 mg/dm^3 O_2 and total suspended solids is 35 mg/dm^3 (Law on Water, 2006).

5. Results and discussion of the results

Given the large number of obtained data in the tables average values for individual months of the examined parameters are shown. Table 2 shows the COD values for unpurified and purified wastewater (after secondary treatment) and the wastewater after the primary sedimentation (p.s.). Also, in the table COD parameter reduction degree after the primary treatment (p.t.) and after secondary purification (s.p.) is given.

COD parameter reduction degree or purification efficiency (P.E.) compared to the COD parameter after the primary treatment is determined as follows:

$$\text{P.E. (COD)}_1 = \frac{913{,}343 - 417{,}234}{913{,}343} = 0.543 = 54.3\ \%$$

The average degree of reduction after primary precipitation is 54.3 %. After the water enters the equalization tank, it is dosed, among other chemicals, $Al_2(SO_4)_3$, that serves as a coagulant, which will reduce the organic and inorganic loads. Then, during the primary precipitation, a certain amount of flocculant is added in the wastewater, which will allow faster and more efficient precipitation of the impurities contained in the water. Based on a given reduction degree, it can be concluded that a large part of organic water pollution is lost in primary clarifier.

From Table 2 it can be seen that the COD average value before purification was 913,343 mg/dm^3 O_2 and after the secondary purification 111,014 mg/dm^3 O_2. On the basis of these two values can be determined COD parameter reduction degree or percentage of load reduction compared to the parameter COD after secondary purification:

$$\text{P.E. (COD)}_2 = \frac{913{,}343 - 111{,}014}{913{,}343} = 0.878 = 87.8\ \%$$

Table 2
The average efficiency of COD values decrease after primary treatment and secondary purification for each month in the examination period (Halilović, 2016)

Month	$COD_{before\ treatment}$ (mg/dm^3 O_2)	$COD_{after\ p.s.}$ (mg/dm^3 O_2)	$COD_{after\ treatment}$ (mg/dm^3 O_2)	Reduction degree of $COD_{after\ p.t.}$ (%)	Reduction degree of $COD_{after\ s.p.}$ (%)
October	867,513	374,421	108,205	56.8	87.5
November	949,306	401,667	129,667	57.7	86.3
December	927,200	448,975	128,300	51.6	86.2
January	971,265	447,382	116,088	53.9	88.0
February	881,222	399,556	91,111	54.7	89.7
April	883,550	431,405	92,715	51.2	89.5
average	913,343	417,234	111,014	54.3	87.8
Permitted value of COD reduction degree after the secondary water treatment by Regulation of Federation of BiH					**75 %**

Table 3
The average efficiency of SM values decrease after primary treatment and secondary purification for each month in the examination period (Halilović, 2016)

Month	$SM_{before\ treatment}$ (mg/dm^3)	$SM_{after\ p.s.}$ (mg/dm^3)	$SM_{after\ treatment}$ (mg/dm^3)	Reduction degree of $SM_{after\ p.t.}$ (%)	Reduction degree of $SM_{after\ s.p.}$ (%)
October	498,250	53,600	10,600	89.2	97.9
November	767,444	64,444	15,000	91.6	98.0
December	643,600	50,200	17,200	92.2	97.3
January	577,176	54,412	12,471	90.6	97.8
February	638,944	48,222	11,889	92.5	98.1
April	569,500	54,400	13,100	90.4	97.7
average	615,819	54,213	13,377	91.2	97.8
Permitted value of SM reduction degree after the secondary water treatment by Regulation of Federation of BiH					**90%**

Regulation on the conditions for discharge of wastewater into the environment of Federation of BiH defines the minimum percentage of the load reduction in relation to the COD parameter, mg/dm^3 O_2, which must reach the plant for wastewater treatment (after the secondary water treatment, and according to the mentioned regulation secondary treatment means second level of purification which generally includes biological treatment with a secondary settlement), and amounts 75 %. Based on the analyzed data can be concluded that the COD percentage reduction, mg/dm^3 O_2 of the plant for wastewater treatment in a factory "Natron-Hayat" Maglaj is very good.

Table 3 shows the suspended matter content values for unpurified and purified wastewater (after secondary treatment) and the wastewater after the primary sedimentation. Also, in the table SM parameter reduction degree after the primary treatment and after secondary purification is given.

SM parameter reduction degree in the wastewater or purification efficiency (P.E.) compared to the SM parameter after the primary treatment is determined as follows:

$$\text{P.E. (SM)}_1 = \frac{615{,}819-54{,}213}{615{,}819} = 0.912 = 91.2\ \%$$

Based on the data from Table 3 it can be concluded that the efficiency of the primary clarifier is very good and most of the suspended particles are precipitated in the primary sedimentation tanks.

From Table 3 it can be seen that the SM average value before purification was 615,819 mg/dm^3, and after the secondary purification 13,377 mg/dm^3. SM parameter reduction degree or percentage of load reduction compared to the SM parameter after secondary purification:

$$\text{P.E.(SM)}_2 = \frac{615{,}819-13{,}377}{615{,}819} = 0.978 = 97.8\ \%$$

The degree of suspended matter reduction of unpurified water, after its purification in wastewater treatment plant is 97.8 %. Regulation on the conditions for discharge of wastewater into the environment of Federation of BiH defines the minimum percentage of the load reduction in relation to the SM parameter, mg/dm^3, which must reach the plant for wastewater treatment after the secondary water treatment and amounts 90 %.

In table 4 is shown the average efficiency of BOD_5 values decrease after secondary purification.

The efficiency of purification devices for the wastewater treatment in relation to BOD_5 parameter is:

$$\text{P.E. (BOD}_5) = \frac{180{,}124-12{,}642}{180{,}124} = 0.93 = 93.0\ \%.$$

Table 4
The average efficiency of BOD_5 values decrease after secondary purification for each month in the examination period (Halilović, 2016)

Month	$BOD_{5\ before\ treatment}$ (mg/dm^3 O_2)	$BOD_{5\ after\ treatment}$ (mg/dm^3 O_2)	Reduction degree of $BOD_{5\ after\ s.p.}$ (%)
October	145,000	15,000	89.7
November	173,143	19,750	88.6
December	184,500	9,600	94.8
January	189,625	10,250	94.6
February	196,143	10,500	94.6
April	192,333	10,750	94.4
average	180,124	12,642	93.00
Permitted value of BOD_5 reduction degree after the secondary water treatment by Regulation of Federation of BiH			**70-90%**

6. Conclusion

The effectiveness of devices for wastewater treatment in the factory "Natron-Hayat" Maglaj fully meets the legal regulation on conditions for discharging wastewater into the environment. Results are expressed through the reduction degree of the following parameters: COD, suspended matter and BOD_5 of the purified wastewater being discharged into a watercourse. The obtained values of the reduction degree of examined parameters are significantly higher than the legally prescribed minimum values of Federation of BiH. The average value of COD parameter for purified wastewater discharged into the surface water recipient is 111,014 mg/dm^3 O_2, the average value of suspended substances amounts to 13,377 mg/dm^3 and the average value of BOD_5 is 12,642 mg/dm^3 O_2. All the values are lower than those prescribed by the Regulation. This paper confirms that the quality of wastewater treatment in the cellulose and paper factory "Natron-Hayat" Maglaj is very good, and thus the quality of purified wastewater that will be discharged in river Bosna is convenient.

Concerning the influence of the input parameters or the quality of the unpurified wastewater on the value of the output parameters or the quality of the purified wastewater it can be concluded that to some extent the input parameters can affect the efficiency of the purification and the quality of the purified water. However, purification of wastewater in the cellulose and paper factory "Natron-Hayat" Maglaj does not always happen under the same conditions. If there is loaded wastewater at the entrance to the system, in order to maintain the efficiency of the purification system in the prescribed values, larger amounts of chemicals are added into the system. For this reason, it would also be necessary to monitor the amount of spent chemicals to be purified and to do the analysis.

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Pozitivni primeri efikasnosti prečišćavanja otpadnih voda u fabrici „Natron-Hayat“ Maglaj

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I Z V O D

U radu su opisane osnovne karakteristike otpadnih voda u fabrici celuloze i papira „Natron-Hayat“ Maglaj. Poseban naglasak je stavljen na opis tehnološkog procesa prečišćavanja otpadnih voda u fabrici „Natron-Hayat“ Maglaj, koji je predstavljen u radu tehnološkom šemom, a koji predstavlja jedan od složenijih sistema za prečišćavanje otpadnih voda. U eksperimentalnom delu dati su rezultati efikasnosti sistema za prečišćavanje otpadnih voda u fabrici "Natron-Hayat" Maglaj. Može se reći da su osnovne sirovine za proizvodnju papira celulozna vlakna i voda. Uloga koju voda ima u industriji celuloze i papira kao rastvarač, sredstvo za kuvanje i sredstvo za pranje dobijene celuloze, ukazuje na prisustvo vode u skoro svim fazama procesa proizvodnje celuloznih vlakana [1]. U skladu sa principima održivog razvoja, industrija celuloze i papira mora da se suoči sa strogom zakonskom regulativom o zaštiti životne sredine koja podrazumeva racionalizaciju potrošnje sirovina, vode, energije i hemikalija, uz minimalne negativne uticaje na životnu sredinu. Otpadne vode koje nastaju u fabrici „Natron-Hayat“ Maglaj podvrgavaju se prečišćavanju pre ispuštanja u površinski vodorecipijent. Otpadne vode iz fabrike „Natron-Hayat“ Maglaj se ispuštaju u reku Bosnu.

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Modeling and prediction of flotation performance using support vector regression

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A B S T R A C T

Continuous efforts have been made in recent year to improve the process of paper recycling, as it is of critical importance for saving the wood, water and energy resources. Flotation deinking is considered to be one of the key methods for separation of ink particles from the cellulose fibres. Attempts to model the flotation deinking process have often resulted in complex models that are difficult to implement and use. In this paper a model for prediction of flotation performance based on Support Vector Regression (SVR), is presented. Representative data samples were created in laboratory, under a variety of practical control variables for the flotation deinking process, including different reagents, pH values and flotation residence time. Predictive model was created that was trained on these data samples, and the flotation performance was assessed showing that Support Vector Regression is a promising method even when dataset used for training the model is limited.

1. Introduction

Paper production, due to its constantly increased consumption in recent years, has a huge environmental impact. The most obvious one is the overconsumption of wood resources, but it is also associated with pollution, water and energy consumption. Hence, recycling of waste paper is extremely important, as the production of recycled paper uses up to 50 % less energy compared to paper produced from trees, decreases air pollution significantly and saves 17-24 trees per each tone of produced paper (Costa et al, 2005).

One of the most important tasks in the process of paper recycling is removing the ink from wastepaper without damaging the cellulose fibres, meaning that a fibre could be reused up to seven times before being permanently disposed. As opposed to some other materials, paper can be recycled only limited numbers of times, as the fibres tend to become shorter and lose its quality with each subsequent recycling (Bajpai, 2014; Trumic et al., 2016).

There are many available techniques for wastepaper recycling, and the choice of the technology depends heavily on the type and quality of the raw material and the required quality of the final product (Carre et al, 2007). One of the most frequently used techniques for removing ink particles and other contaminants from cellulose fibers is deinking flotation. In the flotation process, air is bubbled through a low consistency paper suspension, where bubble interacts with hydrophobic ink particles, forming bubble-particles agglomerate that lifts away into the foam layer. The foam, that should ideally contain only the ink particles and other contaminants, is scraped away as a reject stream, while the accept stream should contain cellulose fibers, fillers and water (Trumic et al., 2007). However, the ideal separation is not possible, because deinking flotation is a very comlpex process which depends on different physical and chemical parameters. Although each of these parameters influences the deinking flotation independently, their mutual interdependence is also very important. The aim of this paper is prediction and modeling of separation of ink particles and cellulose

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fibres during the deinking flotation process of printed paper using Support Vector Regression (SVR). The concentration of oleic acid as the surfactant, pH value and residence time in flotation, are used as the input model parameters, where as the toner recovery in reject stream and celulose fiber recovery in accept stream are used as the output model parameters.

Predictive modeling is based on the analysis of relationships between the input variables in order to make predictions about the continuous output variables. In supervised machine learning these relationships are learned from the data, during the process that is referred to as training. The trained model can be further applied to input data parameters that were not used during the training process, enabling in this way the extraction of implicit and previously unrevealed properties about the modeled process from the data.

Only a limited number of studies reports the application of machine learning to deinking processes. Artificial Neural Networks (ANN) are used for modelling and prediction of the flotation deinking behaviour of industrial paper recycling processes (Pauck et al., 2014), while Labidi et al. (2007) propose a model for prediction of flotation efficiency of ink removal based on ANN. Verikas et al. (2000) developed a method for monitoring of ink removal based on neural network color image analysis. Laperrière and Wasik (2001) applied ANNs for modeling and simulation of pulp and paper quality characteristics. Multivariate Nonlinear Regression (MNLR), Radial Basis Function Neural Networks (RBFNN) and Recurrent Neural Networks (RNN) were employed to predict the flotation performance (Nakhaei & Irannajad, 2015). Chehreh Chelgania et al. (2018) used SVR for modeling of coal flotation. However, to the best of our knowledge, Support Vector Regression was not previously used for prediction and modeling of deinking flotation performance.

The remaining of this paper is organized as follows. In Section 2. SVR method is explained. In Section 3. obtained experimental results are presented and discussed. Concluding remarks are given in Section 4.

2. Support vector regression

Support Vector Machines (SVM) is a supervised machine learning method originally developed for solving binary classification problems. Suppose the data points are given as *N*-dimensional vectors. SVM searches for a linear classifier that separates the data into two classes such that the margin (separation) between two classes is maximal. In case the data points are two-dimensional, the separator is simply the line; for three-dimensional data points, the separator is the plane and for *N*-dimensional data vectors the separator is the (*N*-1)-dimensional hyperplane. Data points that lie closest to the margin are called support vectors.

If the data points $x_i \in R^n$ are not linearly separable in the given input space, they can be mapped into a higher-dimensional space using a transform $\varphi(x_i)$, where the separation might be possible. We introduce the kernel function related to the transform $\varphi(x_i)$ using the relation $k(x_i, x_j) = \varphi(x_i) \cdot \varphi(x_j)$ (Cortes & Vapnik, 1995). Hence, the decision boundary may be nonlinear in the original input space, but be a hyperplane in the transformed high-dimensional feature space. Some common kernel functions are linear, polynomial, radial basis function, sigmoid etc. SVM can also be used to solve regression problem. In that case it is denoted as Support Vector Regression (SVR). Regression is a predictive technique that models the relationship between a dependent variable (output) and a set of independent variables (inputs). As oposed to classification where the output variable is discrete (class label), in regression the output variable takes continuous values. Since the output is a real number, it is not possible to give an exact prediction as in classification case; hence an error ε is introduced and the loss function is defined that ignores all the errors that are situated within the error ε of the true value (Vapnik, 1995). An example of one-dimensional linear SVR is given in Figure 1.

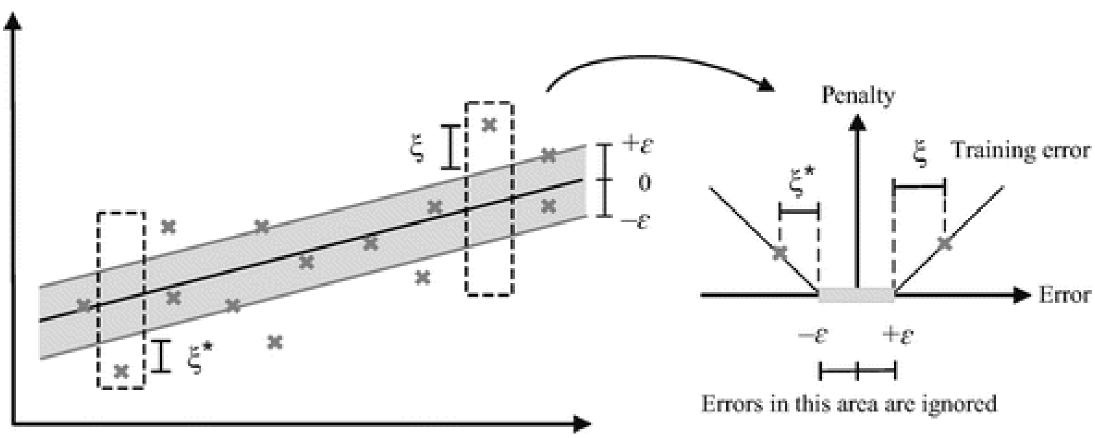

Figure 1. One-dimensional linear SVR

Let us define *N* data points used for training an SVR model $x_i \in R^n, i = 1,2,...,N$ and the target variable that needs to be predicted $y_i, i = 1,2,...,N$. The goal of SVR is to determine a function $f(x)$ that deviates from y_i by a value not greater than ε for each training data point x_i.

$$f(x) = \langle \omega, x \rangle + b; \quad \omega \in R^n, b \in R \tag{1}$$

where ω is the weight, *b* is the bias and $\langle \cdot,\cdot \rangle$ denotes the dot product. Values ω and *b* are determined from the training data by maximizing the margin $2/\|\omega\|$, or equivalently by minimizing $\frac{1}{2}\|\omega\|^2$, where the factor $\frac{1}{2}$ is used for mathematical convenience only (Vapnik et al., 1997):

$$\arg\min \frac{1}{2}\|\omega\|^2; \text{ subject to } \begin{cases} y_i - f(x_i) \le \varepsilon \\ f(x_i) - y_i \le \varepsilon \end{cases} \tag{2}$$

It is assumed that y_i exists such that for each pair $(x_i, f(x_i))$ the optimization problem is solvable with the error ε from the true value. In case there is no model that satisfies given constraints, the error tolerances ξ_i, ξ_i^* are introduced (see Figure 1) and the optimization problem becomes:

$$\arg\min \frac{1}{2}\|\omega\|^2 + C\sum_{i=1}^{N}\left(\xi_i + \xi_i^*\right); \text{ subject to } \begin{cases} y_i - f(x_i) \le \varepsilon + \xi_i \\ f(x_i) - y_i \le \varepsilon + \xi_i^* \\ \xi_i, \xi_i^* \ge 0 \end{cases} \tag{3}$$

where constant *C*>0 defines the amount of error larger than ε that is tolerated. This optimization problem can be solved using Lagrange multipliers. To obtain the dual formula, a Lagrange function is constructed from the primal function by introducing nonnegative Lagrange multipliers α_i, α_i^*, η_i, η_i^* for each training data point x_i.

$$\begin{aligned} J\left(\omega, \xi_i, \xi_i^*, \alpha_i, \alpha_i^* \eta_i, \eta_i^*\right) &= \frac{1}{2}\|\omega\|^2 + C\sum_{i=1}^{N}\left(\xi_i + \xi_i^*\right) - \sum_{i=1}^{N}\left(\eta_i \xi_i + \eta_i^* \xi_i^*\right) \\ &- \sum_{i=1}^{N}\alpha_i\left(\varepsilon + \xi_i - y_i + f(x_i)\right) - \sum_{i=1}^{N}\alpha_i^*\left(\varepsilon + \xi_i^* + y_i - f(x_i)\right) \end{aligned} \tag{4}$$

The solution is found by differentiating *J* with respect to $\omega, b, \xi_i, \xi_i^*$ and equating with zero, which leads to solution:

$$\begin{aligned} \omega &= \sum_{i=1}^{N}\left(\alpha_i - \alpha_i^*\right) \cdot x_i \\ b &= y_i - \langle \omega, x_i \rangle - \varepsilon, \; 0 < \alpha_i < C \\ b &= y_i - \langle \omega, x_i \rangle + \varepsilon, \; 0 < \alpha_i^* < C \end{aligned} \tag{5}$$

The function used to predict new values then becomes:

$$f(x) = \sum_{i=1}^{N}\left(\alpha_i - \alpha_i^*\right) \cdot \langle x_i, x \rangle + b \tag{6}$$

where bias b is defined in (5).

If the mapping is nonlinear the kernel functions are introduced. Suppose that each data point x_i is mapped to a higher-dimensional space $\Phi : x_i \rightarrow \varphi(x_i)$ where $k(x_i, x_j) = \varphi(x_i) \cdot \varphi(x_j)$ is the kernel function. The solution to an optimization problem for the nonlinear case becomes:

$$\begin{aligned} \omega &= \sum_{i=1}^{N}\left(\alpha_i - \alpha_i^*\right) \cdot \varphi(x_i) \\ f(x) &= \sum_{i=1}^{N}\left(\alpha_i - \alpha_i^*\right) \cdot k(x_i, x) + b \end{aligned} \tag{7}$$

3. Experimental results and discussion

Experimental specimens were obtained using white paper MAESTRO A4, 80 g/m^2 that was mechanicaly striped in paper shredder, soaked in destiled water and blended to obtain specimens of cellulose fibers, and HP LaserJet CB435A toner that was heated for 60 minutes at 100 ^{o}C and then mechanically grained to obtain toner specimens. Specimens of cellulose fibers and toner were further withdrawn, transferred to the Denver 2,2 litre flotation cell and floated at the condition specified below in Table 1 and Table 2.

The parameters which may have a significant effect on the deinking process, but are not used as the practical control variables and must be optimized, are summarised in Table 2.

The variables surfactant concentration (oleic acid with or without $CaCl_2$), pH (in the range 3 – 12) and flotation time (in the range 1-10 min) were used as input model parameters, where as the toner recovery in foam product (E_t) and celulose fiber recovery in sink product (E_m) were used as the output model parameters to assess flotation performance. In order to calculate Em, the float and sink products were filtered through the Buchner funnel, dried at the room temperature and weighed, while the dried froth filter pads were then heated at 550 °C in a muffle furnace to determine the ash content by x-ray fluorescence (XRF), for Et calculation.

For each experiment 75 measurings were performed, i.e. 75 pairs of input/output model parameters were created. 90 % of all data were randomly selected for training the model and the remaining 10 % were used for testing the prediction ability of the created model. The data that were used for testing were not included in the training dataset.

As a measure of performanse Mean Squared Error (MSE) was used, which defines mean squared deviation between observed and predicted value of the output parameter:

$$MSE(y, f(x)) = \frac{1}{N}\sum_{i=1}^{N}\left(y_i - f(x_i)\right)^2 \qquad (8)$$

where y_i represents the observed value of the output parameter and $f(x_i)$ is the predicted value obtained using the trained model. MSE is always nonnegative with values closer to zero defining better model.

Beside MSE, the coefficient of determination R^2 was also used as a measure of performance, defined as:

$$R^2(y, f(x)) = 1 - \frac{\sum_{i=1}^{N}\left(y_i - f(x_i)\right)^2}{\sum_{i=1}^{N}\left(y_i - \bar{y}\right)^2} \qquad (9)$$

where $\bar{y}$ denotes the mean of y. Values of R^2 closer to one define better model. While MSE is an absolute measure of fit, R^2 represents a relative measure of fit.

Table 1
Ranges of deinking parameters used as the input model variables

Process control variables	Range of process control variables
Flotation pH	3 – 12
Surfactant in flotation cell:	
Oleic acid	0.1 – 6 kg/t
Oleic acid + $CaCl_2$	0.1 – 6 kg/t + 30 kg/t
Oleic acid + $CaCl_2$	0.1 – 6 kg/t + 60 kg/t
Flotation time	1 - 10 min

Table 2
Optimization variables for flotation deinking

Optimization variables	Range of optimization variables	Adopted value
Pulping pH	7 - 10 (Dorris et al., 1994; Azevedo et al., 1999; Dorris et al., 2011; Gong, 2013.)	8
Pulping time	4 - 240 min (Behin et al., 2007; Jiang et al., 2000; Pauck et al., 2012)	120 min
Pulping temperature	35 - 60 °C (Ali et al., 1994; Dorris et al., 1994; Behin et al., 2007; Pauck et al., 2014)	45 °C
Pulping consistency	5 - 18 wt % (Liphard et al., 1993; Behin et al., 2007; Jiang et al., 2000)	5 wt %
Flotation temperature	20 - 45 °C (Dorris et al., 1994; Luo et al., 2003; Pathak et al., 2011; Pauck et al., 2014)	20 °C
Flotation consistency	0,7 - 1,5 % (Azevedo et al., 1999; Labidi et al., 2007; Pathak et al., 2011; Dorris et al., 2011; Pauck et al., 2012)	1 wt %
Agitation speed	1000 - 1400 rpm (Dorris et al., 1994; Pelach Serra, 1997; Azevedo et al., 1999; Labidi et al., 2007; Pathak et al., 2011)	1100 rpm
Airflow rate	225 - 775 l/h (Pelach Serra, 1997; Labidi et al., 2007)	260 l/h

SVR was implemented using LIBSVM library (Chang et al., 2011) with radial kernel function:

$$k\langle x_i, x\rangle = \exp\left(-\gamma\|x_i - x\|^2\right),\ \gamma > 0 \tag{10}$$

where the optimal coefficients γ and C are determined using grid search.

Tables 3-5 present results of SVR prediction of the toner recovery in foam product (E_t) and celulose fiber recovery in sink product (E_m) when oleic acid, oleic acid with addition of $CaCl_2$, respectively, were used as surfactants. High values of coefficient of determination for E_m confirm the predictive capability of SVR in all three cases, with $R^2 = 0.96$, $R^2 = 0.94$ and $R^2 = 0.97$ for differents surfactants, as listed in Tables 3-5. On the other hand, prediction of E_t leads to lower $R^2<0.9$, indicating that additional training data is necessary for creating models with higher predictive performance.

Table 3
MSE and R^2 when oleic acid was used as surfactant

Surfactant	**Oleic acid**	
	Em	Et
MSE	2.27	207.63
R^2	0.96	0.85

Table 4
MSE and R^2 when oleic acid + 30 kg/t $CaCl_2$ was used as surfactant

Surfactant	**Oleic acid + $CaCl_2$**	
	Em	Et
MSE	5.38	52.59
R^2	0.94	0.87

Table 5
MSE and R^2 when oleic acid + 60 kg/t $CaCl_2$ was used as surfactant

Surfactant	**Oleic acid + $CaCl_2$**	
	Em	Et
MSE	1.42	106.03
R^2	0.97	0.72

4. Conclusion

The paper presents a machine learning based approach for modeling and prediction of separation of toner particles and cellulose fibers in printed paper recycling using flotation deinking. Support Vector Regression was chosen as a method for prediction. Although dataset used for this task was limited (only 75 samples for both training and testing), the obtained result indicate that SVR is able to discover nonlinear relationship between input flotation parameters and output flotation performance measures. SVR is a promising method and suggests that even a smaller dataset can be used for training the model, which is able to generalize for unseen test data.

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Modelovanje i predikcija performansi flotacije korišćenjem metode potpornih vektora za regresiju

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I Z V O D

Poslednjih godina vrše se značajna ulaganja u poboljšanje procesa reciklaže papira kako bi se uticalo na očuvanje šumskih, vodnih i energetskih resursa. Flotacija predstavlja najznačajniji postupak za separaciju čestica tonera od vlakana celuloze iz suspenzije papira. Modelovanje procesa flotacije je vrlo složeno, a dobijeni modeli su često komplikovani za implementaciju i upotrebu. U ovom radu predstavljen je model za predikciju performansi procesa flotacije koji je zasnovan na upotrebi metode potpornih vektora za regresiju (SVR). Reprezentativni uzorci za učenje modela dobijeni su u laboratorijskim uslovima, ispitivanjem uticaja različitih promenljivih kojima se kontroliše proces flotacije, poput tipa i koncentracije surfakanta, pH vrednosti i vremena flotiranja. Dobijeni rezultati potvrđuju da se metod potpornih vektora za regresiju može uspešno koristiti za predikciju performansi procesa flotacije čak i kada je skup podataka za učenje modela ograničen.

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