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# OPEN-PIT MINING OF LIGNIN WASTE STORAGE

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The purpose of this paper is to develop performance criteria for fleet selection in surface mining of lignin as a raw material for factory-made fuel. The East Siberian Biotechnical Plant (ESBP) proposes to close the Lignin Waste Storage (LWS) at Tulun, Irkutsk Region of Russia. The LWS is a 9.6 ha facility used for the long-term storage of hydrolysis lignin and some fly ash. The project provided whole-year open-pit mining of lignin storage with one mining ledge within 3 years. Productivity – 1500 t/day or 447 000 t/year. Excavated lignin will be stockpile on the Pellet Plant territory for later processing. Part of this closure effort would involve constructing an artificial reservoir on the place of LWS. The objectives of this project were as follows: determine equipment needs and develop optimal procedures for the lignin excavation and transportation. Lignin moving may include site preparation, excavation, transportation and road surfacing. Lignin excavation is conduct by using techniques similar to those used for open-pit mining of peat. For this project, the excavator is the most important piece of equipment required for lignin removal and handling. The mining process consist of excavating the lignin (using Kraneks EK-270LC) and hauling it to pellet plant via six off-road tractors&semitrailers (John Deere 7730& ISON-8520).

***Key words*:** hydrolysis lignin, technogenic waste storage, excavation, handling, transportation

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**Introduction.** Lignin is an organic substance binding the cells, fibers and vessels, which constitute wood. After cellulose, it is the most abundant renewable carbon source on Earth. Industrial lignin is currently obtain as co-products of the manufacture of cellulose pulp for paper and some chemical derivatives. Although the amount of lignin extracted around the world is estimate to be over 70 million tons per year. Lignin is currently mainly use as an energy source in industrial processes.

Lignin does not biodegrade under the anaerobic conditions that dominate landfills, thus any lignin buried will remain sequestered [9]. Many researchers over the past few decades have tried to develop uses for lignin in an attempt to take advantage of its many positive attributes. The positive or promoting factors for lignin utilization, as listed by Lindberg et al. [5], are as follows:

• readily available in huge amounts;

• high energy content owing to the aromatic nuclei;

• a number of reactive points are present on the carbon skeleton which can be used for a wide range of substitution and addition reactions;

• good compatibility with several important basic chemicals;

• good adsorbent and ion exchange and adhesive properties.

However, despite the efforts of researchers, relatively few applications for lignin have been realized on an industrial scale. This is due largely to the inhomogeneity of lignin resulting from natural variability as well as from separation methods used by industry. Currently, the vast majority of lignin extracted by industrial processes is burn as fuel to recover energy. Only approximately 1 to 2 % of lignin produced commercially is use in other applications [6]. Several uses of non-sulfonated lignin have been proposed and demonstrated as feasible, although mostly they have not been able to gain a secure toehold in industrial practice. They have suffered in part due to a lack of a consistent and dependable industrial source.

Now in Russia is by different estimates from 100 to 200 million tons of a lignin in dumps. Lignin is perfectly granulated and briquetted therefore sometimes it is added to difficult pressed raw materials, for example – to birch waste, for improvement of quality of the made granules and briquettes. At the expense of the smaller specific content of oxygen warmth of combustion of a lignin is nearly 1.5 times higher, than at cellulose. In dumps, the lignin partially decays and warmth of its combustion decreases, but most often it is all the same higher, than at wood. Therefore, the granulated or briquetted lignin is good fuel. As lignin it is formed much, it pollutes environment and constantly lights up in dumps, – its utilization is extremely important. As its price, in fact, is negative, – production of fuel granules and briquettes from a lignin will be highly profitable business.

Landfill mining and reclamation (LFMR) is a process whereby solid wastes, which have previously been landfilled, are excavated and processed. The overall objective of this work was to use lignin as a raw material for making granulated fuel. This paper was divided in three major sections to address (1) evaluation of physical-mechanical properties of lignin in landfill; (2) develop of excavation and transportation technologies on lignin waste storage and; (3) to select the equipment for excavation and transportation technologies.

**Background.** The East Siberian Biotechnical Plant (ESBP) proposes to close the Lignin Waste Storage (LWS) at Tulun town in Irkutsk Region, Russia, located on the Iya River (Angara's basin), 390 kilometers northwest of Irkutsk.

The LWS is located between two rivers Azeyka and Iya at distance of 7 km to the South from ESBP (Figure 1). With the closing of the Tulun Hydrolysis Plant, continued operation of the LWS is no longer need. ESBP proposes to use hydrolysis lignin excavated from LWS for fuel pellets production in Tulun.

Figure 1. Lignin Waste Storage and Pellet Plant (Tulun)

The climate of the area is sharply continental with long winter and in the warm short summer. Average monthly temperature of January –22.3 °C, July +17.8 °C. The absolute minimum of temperature was noted in January –51 °C, an absolute maximum in July of +37 °C.

The mean annual duration of the frost-free period in Tulun makes 75 days. The period with negative average monthly air temperatures proceeds from October to April. The amount of precipitation for the period November-March – 60 mm. The amount of precipitation for the period April-October –344 mm.

The greatest depth of frost penetration in the soil of 2.96 m on the bared surface, 1.96 m under natural a cover, average 2.3 m, thickness of snow cover reaches 0.8 m. Average height of snow cover during the winter 0.3-0.4 m. Winds prevail valley the northwest and southeast directions. Speeds of a wind reach the greatest values during the spring period (April, May) to 3.2-3.4 m/s, up to 15 m/s rarer, the prevailing wind is the northeast.

**Project description.** The Tulun project is widely regarded as being key to demonstrating the viability of landfill mining in Russia. It is also a showcase for the concept of enhanced landfill mining, differs from ordinary landfill mining in that it tends to include the production of a refuse-derived fuel stream.

The LWS is a 9.6 ha facility used for the long-term storage of hydrolysis lignin and some fly ash. The facility was constructed in the 1991. Depth of lignin 7.5-22.0 m; volume – 1 223 000 $m^3$.

The project provided whole-year open-pit mining of lignin storage with one mining ledge within 3 years. Productivity –1500 t/day or 447 000 t/year. Excavated lignin will be stockpile on the Pellet Plant territory for later processing. Part of this closure effort would involve constructing an artificial reservoir on the place of LWS. In the plan, the dump of a lignin represents the oval of

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the wrong form extended from the northwest on the southeast on average on 460 m and from the southwest on the northeast on average on 250 m.

**Physical characteristics of the lignin in the dump.** The main purpose of the lignin investigation is to obtain and understand the geotechnical information on the subsoil conditions required for the excavation works.

The laboratory tests were performed on undisturbed samples based on the available of lignin sample. The tests related to physical and mechanical properties were performed in Mining university laboratory. The quantities of laboratory tests are summarized in table 1.

*Table 1*

**Lignin samples laboratory tests**

| Parameter | Mean value |
|---|---|
| Surface debris, % | 5 |
| Filtration coefficient deposit/stockpile, m/day | 0.2/26.9 |
| Friction Angle, degree | 41-45 |
| Average particle size, mm | 0.67 |
| Lignin density, kg/m$^3$ | 0.94 |
| Lignin (dry) density, kg/m$^3$ | 0.39 |
| Lignin particles density, kg/m$^3$ | 2.00 |
| Porosity factor | 4.19 |
| Moisture Content, % | 64.8 |

The particle size distribution of excavated lignin is an important parameter in the excavation process, design of landfill reclamation operations process, particularly for the sizing of mechanical separation and grinding equipment of pellet plant such as screens, magnetic separators, and hammer mills.

The distribution of different grain sizes affects the engineering properties of lignin (Table 2).

*Table 2*

**Lignin grain size distribution**

| Diameter, mm | Mass percentage passing |
|---|---|
| >5 | 1.49 |
| 2-5 | 3.83 |
| 1-2 | 7.34 |
| 0.5-1.0 | 22.60 |
| 0.25-0.5 | 25.90 |
| 0.10-0.25 | 29.50 |
| Pan | 9.82 |
| Total | 100 |

**Field assessment of lignin trafficability.** The bearing capacity or traction capacity of a lignin determines its ability to support traffic during lignin excavation and transportation. In the field, shear strength is usually measured using either a cone penetrometer or a shear vane [12].

One of the trafficability classifications is based on the number of passes possible in certain conditions. The technical limit go/no-go situation is 1 pass. In this case noticeable environmental damages are to be expected, as well as high operative costs due to excessive wear of machine components and high fuel consumption. Also generally, the driving velocity is low and the permitted load is minimal, hence the productivity becomes low. In addition, there is a high risk of total failure with expensive rescue costs. The operational efficiency improves as a function of the number of expected passes, and thus a 2 to 5- pass limit can be set as the lowest economic trafficability limit for transport. The conditions from an ecological point of view can be classified as good if 25 passes are possible, see Table 3 [13].

The impacts of the frequency of vehicle passes on lignin compaction [11]. These studies show that most compaction occurs during the first few passes of a vehicle (Figure 2). Subsequent passes have less effect [4], but may increase density levels and reduce non-capillary porosity [3].

*Table 3*

**Environmental classification based on number of passes**

| Number of passes | Technical limit | Environmental acceptance |
|---|---|---|
| 1-3 | No-go | Not acceptable |
| 3-5 | | Not acceptable |
| 6-10 | Economical | Tolerable |
| 11-25 | | Good |
| 25- | Environmental | Excellent |

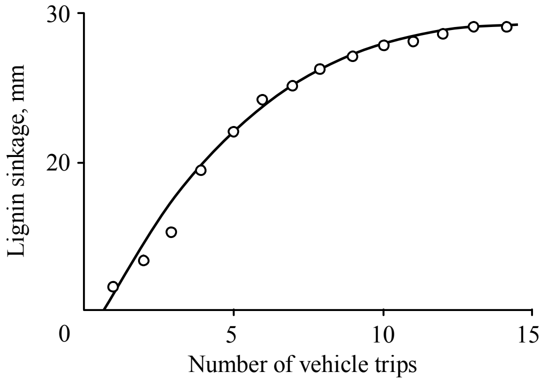


Figure 2. Lignin sinkage values under the wheel as related to number of vehicle trips

The second research approach involves in situ testing methods – the vane shear and cone penetrometer tests, the commonly used methods for predicting trafficability of soils and off-road mobility of vehicles [10, 13, 15].

Shear strength and cone index depend on various factors, including soil texture, organic matter content, bulk density and, most importantly, soil moisture content [14]. Cone index (CI), shear strength ($\tau$) and deformation modulus (E value) are the parameters used in the soil strength classification (Table 4) developed under the Eco Wood Operations Protocol for eco-efficient wood harvesting on sensitive sites [11]. Each of these parameters can be measured quite readily in the field using portable equipment. Soil strength determines the bearing capacity' and traction capacity' of soil, and thereby soil trafficability.

Figure 3. Field testing of lignin excavation and stockpiling

*Table 4*

**Eco Wood soil strength classification and lignin strength**

| Soil strength | | Soil strength parameters | | | Allowed soil bearing capacity |
|---|---|---|---|---|---|
| Classes | Soil strength description | Cone index | Module E | Shear strength | |
| | | *CI*, kPa | *E*, MPa | $\tau$, kPa | *NGP*, kPa |
| 1 | Strong soil | >500 | 60 | >60 | >80 |
| 2 | Average soil | 300-500 | 20-60 | 20-60 | 60-80 |
| 3 | Soft soil | <300 | <20 | <20 | 40-60 |
| Lignin | Soft soil | 252 | 0.79 | 32 | 40-60 |

Field testing of lignin excavation and stockpiling presented as Figure 3.

The soil bearing capacity is usually consider as the maximum allowable wheel contact pressure. The actual wheel pressure, however, is difficult to assess, because the true contact area depends on the tyre and soil properties [13]. In the EcoWood soil strength classification, the estimation of allowed bearing capacities (contact pressure of vehicles) is based on nominal ground pressure equations.

The elastic module depends on the consistency and density of the lignin as an elastic technogenetic packed soft soil.

**Process.** This technology has several different components, which can be modified to adapt to site-specific conditions. The site needs to be accessible by the heavy equipment needed to conduct the excavation activities. There should be a readily available source of suitable fill material for backfilling the excavation. For disposal at an off-site facility, there must be a way to remove the soil from the site and transport it to the facility. Excavation and transport can be conducted in any climate; however, actual fieldwork is generally seasonally dependent. The hydrogeology at the site should be considered, and excavation may not be appropriate if the groundwater is shallow.

Excavation and transport technologies have the following advantages:

- permanent;
- immediate result for the removal of exposure pathways;
- easily implemented;
- limited long-term monitoring and institutional controls;
- flexible.

Excavation and transport offers many advantages as a treatment alternative. The main advantage is that it is a permanent remedy and the source of the contamination is eliminated, thus addressing both acute and chronic risks to human and ecological receptors.

When soil is excavated, there is an immediate removal of the exposure pathway since there is not a period of time required for the technology to treat or break down the contamination [8].

**Mass Excavation.** This method of excavation uses for removing large quantities of lignin at varying depths over a wide area. Landfill excavation and land remediation are potential methods for treatment of waste from old landfills. The resource recovery is one of the beneficial areas of generating revenue for the success of excavation projects. The mining process consisted of excavating the contaminated ground and hauling it to an on-site lined unit via six tractors+semitrailers.

Development mining of a dump is made selective in the locations of bulk contaminated ground. Stockpiles of contaminated material will be constructed around the lignin storage foe the future using for reclamation plan. Dust was not an issue as the material was reportedly wet and solid. No odor issues were encountered during mining. Visibly, lignin particles are being spread by vehicles, that leave the storage area. The aim is to stop it by installing wheel washers for cars and tractors.

Lignin is excavating in quarry face 4 m deep aligned in the north-south direction. The quarry face is starting from one end (either the north or the south end) of the mining area and the excavation is continue until the limit of the material in the layer of horizon.

The excavated lignin is loading on semitrailer with the excavator and transporting to the pellet plant. The hauling distance is 7 km. The planned gross quantity of lignin by mining years is given in table 5.

*Table 5*

**Planned gross quantity of lignin by mining years**

| Winter time, m3 | | | | Summer time, $m^3$ | | | | Total During mining, thousand $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 1st year | 2nd year | 3rd year | Total | 1st year | 2nd year | 3rd year | Total | |
| 117.5 | 223.25 | 223.25 | 564.0 | 132.5 | 251.75 | 251.75 | 636.0 | 1200.0 |
| Daily capacity, $m^3$ | | | | | | | | |
| 1762,5 | | | | 1766,6 | | | | |

The project accepted transport, one-onboard longitudinally cross system of lignin mining. Having fulfilled the first phase, on the second phase there will be a drying of lignin surface by this time, and during the winter period of time – frost penetration in a lignin on depth to 0.5 m. Excavator is installed on a surface of the second horizon. Further operations repeat.

Equipment involved may be a front-end loader, a hydraulic excavator, or a combination of these. The Load & Haul fleets at the time of the project consisted of following (Table 6). The types

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of equipment used and the environmental conditions will affect the man- and machine-hours required to complete a given amount of work. Each piece of equipment is specifically designed to perform certain mechanical tasks. Therefore, base the equipment selection on efficient operation and availability. Lignin excavation is conducted using techniques similar to those used for open-pit mining of peat. For this project, the excavator is the most important piece of equipment required for lignin removal and handling. It is efficient, relatively low cost, can move high tonnages of materials quickly, and can operate over many terrain types. The mining method selection problem is an approach to equipment selection that reasons that the environmental conditions will imply a particular mining method, and that the selection of loader and truck types will follow intuitively from there. This problem then focuses on choosing the correct excavation method for the given conditions.

*Table 6*

**Resources used for the lignin mining**

| Equipment | Equipment Make and Model | Number of equipment | Operation Description |
|---|---|---|---|
| Excavator | Kraneks EK-270 LC | 1 | Lignin excavation and loading on to the semitrailers |
| Tractors + semitrailers | John Deere 7730 + ISON-8520 | 6<br>6 | Hauling excavated lignin to the pellet plant and for transporting the contaminated ground to the lined-cell for disposal |
| Dozer | T10MB | 1 | Moving and stockpiling reclaimed soil. Road construction |
| Front-end loader | Amkodor 342P-01 | 1 | Contaminated ground excavation and loading on to the semitrailers |

Equipment selection is one of the most important aspects of open pit design. The number and capacity of equipment mainly affect mining costs. Equipment selection for open-pit mines is definitely a major decision, which will affect greatly the economic viability of an operation [1]. For selecting of hydraulic excavators and tractor-semitrailer combination, equipment selection criteria must be determined. These criteria are collected in 3 different categories, which are:

• production criteria;
• lignin deposit parameters;
• equipment criteria.

Various authors have used nominal ground pressure (NGP) as an indicator of ground pressure by machinery [6].

Research results have shown that approach to describing vehicle trafficability of cohesive lignin describe the soil strength of lignin and provide a good basis for developing a trafficability evaluation system of lignin open-pit mining.

**Conclusions.** Landfill mining and reclamation is a developing technology and method of waste management. The concept of landfill mining and reclamation and related technology merits serious consideration.

In this study, representative samples of lignin were collected from Lignin Waste Storage at the Tulun Hydrolysis Plant Resource Recovery Complex in Tulun, Irkutsk Region, Russia, which was operated from 1991 until 2007. Based on these samples, the selected characteristics were determined and statistically analyzed. Such a statistical analysis could not be found in the literature. The fines fraction, representing about 80 % of the mass, was the largest fraction of excavated material. Research results have shown that approach to describing vehicle trafficability of cohesive lignin describe the soil strength of lignin and provide a good basis for developing a trafficability evaluation system of lignin open-pit mining. The soil cone index and shear strength values calculated in this research do not concur with the classes of EcoWood soil strength classification and indicate that the lignin is an elastic technogenetic packed soft soil.

These technological developments can be a basis for scientific discussions with the purpose of examination and development of new technologies for lignin open-pit mining. This method of lignin excavation with modern equipment was testing in lignin storage. Lignin excavation is conducted using techniques similar to those used for open-pit mining of peat. As a result of this technology,

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economy of scale will continue to be an extremely important factor in the competitiveness of the lignin as a raw material for making granulated fuel.

The methodology to determine the reclaimed lignin used in this study can be recommended for studies at other Lignin Waste Storages. Eventually, the site will be remediated as a sustainable nature park.

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