MODELLING OF SAPROPEL FLOW USING SOLIDWORKS SIMULATION TOOLS

Roberts Vanags [1], Daina Kanaska[2]
Latvia University of Agriculture
r.vanags@inbox.lv, daina.kanaska@llu.lv

Abstract. In Latvia there are large sapropel resources, but per year only 0.03 % are extracted. The reason is high environmental requirements for extraction equipment as well as expensive costs; in addition small size extraction equipment for the needs of farmers is not available. There are analyzed different types of equipment for sapropel extraction in the paper and developed conceptual design of the new sapropel mining equipment intake node that thanks to the constructive solutions provides environmental requirements as well as is compact and suitable for farmer's needs. To clarify how the new device is able to perform its function as well to select the optimum parameters of design for one of the mechanical parts modeling in Solidwork Flow Simulation was used.

Keywords: sapropel extraction, modelling, flow simulation, design.

Introduction

Sapropel is organic sediments that accumulate deposition and transformation of dead aquatic organisms and debris along with mineral particles. Sapropel resources in Latvia depend on the physical and chemical properties. Pure humidity sapropel is characterized by [1]: relative humidity W = 75-95 % (dry matter 5-25 %); mass density, p = 1040-1080 kg·m^{-3}; content of organic matter (in dry matter), W_0 = 15-95 %, on average, 80 % of sapropel in Latvian lakes contain 60 % organic matter.

Resources of sapropel are very rich but actually obtainable quantity of sapropel per year is only 80 000 m3, that is average 0.03 % of the total identified resources of sapropel in Latvia. Sapropel extraction is restricted by strict rules of abstraction initiation of sapropel and expensive technological equipment costs. In order to legally be able to start sapropel extraction it is necessary to develop an opinion of the State Environmental Monitoring Bureau. The opinion confirms that sapropel extraction did not cause any damage to the environment, as well as all preventive measures to start up mining of sapropel are taken. In order to be allowed sapropel extraction it is very important to use environmentally friendly technology acquisition. Most mining equipment caused irreversible adverse effects on water reservoirs of biological balance. Such inadequate equipment is detrimental to plant, fish and bird ecosystem.

Recent years used sapropel mining technologies in Latvia and Europe are different from the so far most commonly used. Technologies are focused on environmentally friendly extraction process, which is most harmless to the environment. The most common of these technologies is the use of dredges. Such dredges are placed on pontoons, barges, rafts. This technology is used for deepening and cleaning water bodies. Dredger is based on a pump that from the water bodies of a watercourse together with the bottom layer also is pumping water. Further injected bottom is drained to storage basins, reservoirs. For sapropel extraction dredges by different companies and mining technologies are offered [2].

Point-vacuum method [2] is based on the vacuum pump operation principle. Sapropel extraction in the supply pipeline happens with vacuum propelled by an electric motor or internal combustion engine. Drive configuration depends on the specific areas of engineering possibilities; however, an electric motor is the most friendly version for a certain territory, which does not create exhaust gases. During the extraction of sapropel 2-2.5m radius around the mining site sapropel is pumped into the pipeline using vacuum. Further the storage tanks are brought ashore. Such an extraction method is environmentally friendly, but it consumes large energy resources. The unit is equipped with automatic, which controls sapropel density by sensors. Such automation is needed to get a clean and intact sapropel mud layer on top of the mining area, to exclusion of density changes in the installation. This extraction method is environmentally friendly, but it consumes large energy resources.

Currently available dredge pump by market leaders of sapropel extraction is considered a pneumatic suction dredge pump [2], such dredge suction is operated with compressed air in water pneumatic chambers being submerged. This pump high suction capability allows making bottom suction and feed on the surface with a very high concentration. As mechanical rippers in the equipment rotating cutters, auger and hydro rippers are used. With the pneumatic technology the highest environmental performance in water and on the shore are provided.

From the patents there are known vertical and horizontal screw pump methods. Vertical screw pump method is based on the screw transporter. This pump contains a pipeline where the central rotary shaft is based on bearings, which do not allow it to deviate from the pipeline centre. Loading device has two blades; the lower blade is made from a disk with screw-type surface and rigidly connected to the shaft. Upper screw is made in the form like strip with linear surface with straight line generatix laid in radial plane and comes through the screw rotation axis and circle equal to the screw pump cover diameter. The upper blade slope to the axis is variable. The strip is secured to the shaft using the plate laid in the plane perpendicular to the rotation axis and inclined floor being the extension of the screw pump wind [3].

In the horizontal screw pump method the unit is equipped with a horizontal fitting, which is placed in the screw conveyor, a rotary motion help sapropel pump to the pontoon, which is located above the water. Sapropel unit enters through the inlet port, which is immersed in sapropel layer, pumping around the layer. To achieve constant operation of the machine it has to move the suction channel opening direction [4].

To ensure environmental requirements for sapropel extraction, as well as reduce dimensions, making it suitable for the needs of farmers and for getting additional function of bottom cleaning the authors created a new sapropel mining equipment intake node, see Fig.1. To select the optimum parameters of design for this new unit we decided to use options of Solidwork Flow Simulation.

For stimulation it is necessary to clarify the incoming flow speed of sapropel v in the discharge of the fluid from an open vessel under the influence of gravity, it follows from Bernoulli equation that [5]:

$$v^2 / 2g = h \tag{1}$$

where v – incoming flow speed, m·s^{-1};
g – gravitational constant;
h – height, immersion depth from the incoming point of sapropel, m.

Speed of the fluid at the outlet aperture is the same as that of the
fluid particles falling freely from the height h. From Bernoulli's equation the speed of flow [5]:

$$v = \sqrt{2gh} \tag{2}$$

where v – incoming flow speed, m;
g – gravitational constant;
h – height, immersion depth from the incoming point of sapropel, m.

Materials and methods

Simulation object is the intake node that is possible to be added on different types of sapropel extraction facilities. The unit is immersed in the sapropel layer in a horizontal or vertical position depending on the mining equipment to which it is connected. Sapropel flows in the intake node from all four sides and the bottom of the node, by assistance of propellers sapropel is sucked in a large radius. Instead of the already pumped sapropel a new portion of sapropel enters from the upper layers, thereby longer sapropel extraction without moving of the mining equipment is provided. Intake node provides a steady supply of sapropel to the screw type feeding pump. Intake node ensures sapropel extraction by covering a large mining sector without moving the nozzle, thus causing better water turbidity during the extraction. The offered suction unit is shown in Fig.1. Node is equipped with four inlet channels 1, which are spaced into the inlet dome 8. Intake dome 8 is immersed in the sapropel layer 10; in the inlet channel 1, the propeller 2 is centered to acquire rotational movement from the drive shaft 3, which is based in bearings. Drive shafts 3 are connected together by a chain trans screw conveyor mission, which is recovered from the drive shaft of the screw conveyor 7, thereby synchronous operation of the propeller 2 is provided. Through the vertical pipe 6 the sapropel stream with assistance of the screw conveyor 4 flows along the vertical pipe 6 to the exhaust canal 5. By assistance of the inlet dome 8 and the closed system of the vertical pipe 6 conditions are provided that the sapropel layer 10 does not mix with water 9. Rotary motion of the conveyer is received from the drive shaft 7, which is recovered by assistance of the electric or hydro motor. Holes on the dome bottom part prevent the suction node from inflow in the equipment of large fractions of impurities.

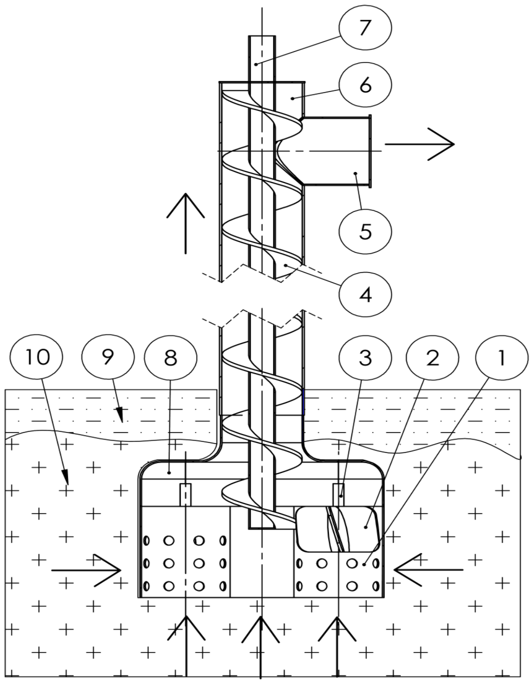

Fig. 1. **Intake node of sapropel mining equipment:** 1 – inlet channel; 2 – propeller; 3 – drive shaft; 4 – screw conveyor; 5 – exhaust channel; 6 – vertical pipe; 7 – drive shaft of screw conveyor; 8 – inlet dome; 9 – water; 10 – sapropel layer

To create the prototype of this new intake node for further experiments it is necessary to decide the values of the structural elements and operating modes; it was decided to use Solidwork Flow Simulation facilities to select the optimum parameters of the unit structural elements and operating modes for further prototyping. There are known different types of modeling in the process of design of equipment; one of the possible solutions is to use methods of Truth trees and Boolean algebra for appreciation of the working quality of the designed equipment in the phase of testing and commissioning [6]. Solidworks Flow Simulation offers a wide range of physical models and fluid flow capabilities, so you can obtain better insight into the product behavior that is critical to your design success covering a broad range of applications: external and internal fluid flows; laminar, turbulent, and transitional fluid flows. With the help of Solidwork Flow Simulation it is easy to make modeling of the flow of sapropel, read the raw data. The following options enable to carry out experiments with the help of the virtual model; it is easy to change the number of blades, angle and dimensions or other parameters. In order to perform simulation with the input parameters it is needed to collect summary tables of the variable parameters. Table 1 displays the parameters of structural elements and operating modes of the intake unit for optimization.

Table 1

Parameters for optimization of sizes and dimensions of intake node

Parameter groups	Parameters for optimization
Structural elements	Number of propeller blades, n
	Start angle of propeller, α
	Pitch of propeller
	Distance from propellers
	Inlet dome diameter
	Dimensions of incoming channels
	Locations of propellers
	Distance from incoming point to screw conveyor

Table 1 (continued)

Parameter groups	Parameters for optimization
Operating modes	Incoming flow speed, v
	Rotation speed of propeller
	Direction of rotation of propeller

In the paper we will make optimization for the values of two parameters: n – number of blades of the propeller and α – start angle of the propeller. The criteria for optimization are the max value of V – outgoing speed (after that passes through a turbine) and the character of the flow inside the node (laminar/turbulent).

Results and discussion

Output parameters are selected depending on the whole most frequent parameters in Latvian lakes. Propeller variable parameters are chosen optimally by the other equipment parameters.

From Bernoulli's equation the results of different depth of the sapropel incoming point are summarized:

Table 2

Incoming flow speed in dependence on depth of incoming point

Depth of incoming point h, m	Incoming flow speed v, $m \cdot s^{-1}$
1	4.4
2	6.3
3	7.7
10	14
15	17.1

In Solidworks Flow Simulator simulation with different turbine parameters was carried out. More prevalent sapropel resources in Latvia start from 2-3m depth [8], so the simulation is selected for sapropel extraction in 3 m depth. According to Table 2 for h = 3m, the incoming flow speed is v = 7.7 $m \cdot s^{-1}$. Constant parameters were supposed: diameter of the turbine D – 150 mm, width of the turbine H – 100 mm; pitch – 150 mm (turbine blades convolution step), revolutions – 0.55, rotation speed of the turbine – 100 rad^{-1}.

After carrying out the simulation the turbine version with the highest output speed was selected. For the unit full functioning, the productivity of the supply hub is most important. In accordance with the data from Table 3 it can be concluded that the ultimate parameter is at 175° start angle and 5 blades. Such characteristics ensure higher turbine output speed 27.8 $m \cdot s^{-1}$, and pronounced laminar flow. Fig. 2. demonstrates the most optimal simulation results for outgoing speed in dependence on the start angle (α) and the number of blades (n).

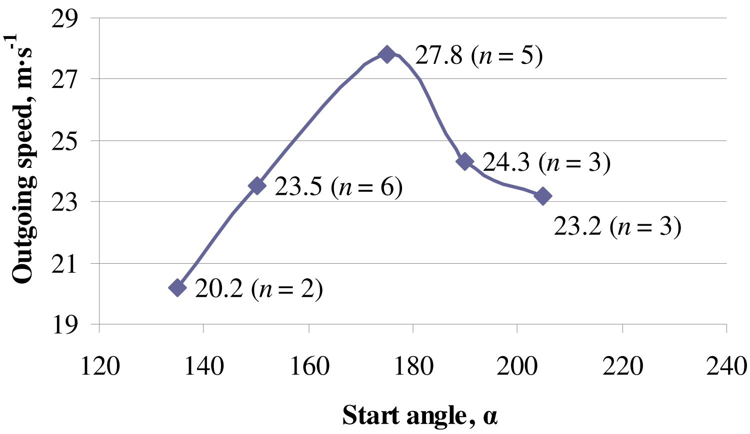

Fig. 2. **Most optimal simulation results for outgoing speed in dependence on start angle (α) and number of blades (n)**

Simulation of sapropel flow from the suction point after it passes through a turbine. Turbine blades have different characteristics and differences in their number. After turbines it can be seen that the outgoing flow is laminar or turbulent. In order to improve the suction unit equipment parameters the turbine flow rate increase is needed. In order for this unit to work with the very greatest productivity it requires maximum laminar flow and high maximum output flow rate. Fig. 3 demonstrates two examples from the simulation; with these images we appreciate the character of the flow, so that it is compact enough as well without significant turbulence.

Table 3

Simulation results with different turbine parameters

No.	Start angle, α	Number of blades, n	Outgoing speed, $m \cdot s^{-1}$, V
1	135°	2	18.039
2		3	20.2139
3		4	18.6382
4		5	18.5154
5		6	18.9147
6	150°	2	18.8042
7		3	23.1377
8		4	16.0951
9		5	19.6525
10		6	23.4607
11	175°	2	20.8625
12		3	19.772
13		4	20.5812
14		5	27.7717
15		6	17.3599
16	190°	2	21.2078
17		3	20.1636
18		4	21.7141
19		5	22.166
20		6	24.3389
21	205°	2	17.8485
22		3	23.2477
23		4	20.5956
24		5	22.3598
25		6	21.8595

Fig. 3a shows sapropel flow with some turbulence (you can see a little flow forming a spiral shape), but here is one of the highest output speeds to ensure the most complete sapropel movement for future assembly. Flow after the assembly is concentrated in order to move forward. This result is obtained at the turbine parameters: n – 5, α – 175°, v – 7.7 $m \cdot s^{-1}$. With these parameters the turbine output flow rate develops V – 27.8 $m \cdot s^{-1}$.

Fig. 3b shows sapropel flow, which is more laminar flow, but concentration of the flow after the assembly is worse than in the previous example. This result is obtained at the turbine parameters: n – 4 (blades), α – 150° (start angle), v – 7.7 $m \cdot s^{-1}$ (incoming flow speed). With these parameters the turbine output flow rate develops V – 16.1 $m \cdot s^{-1}$ – just two times less than in the previous case.

Both cases according to the flow visual characteristics are acceptable for further development, but the turbine parameters: n – 5, α – 175° were selected because of better results of the output flow rate as well as higher flow concentration.

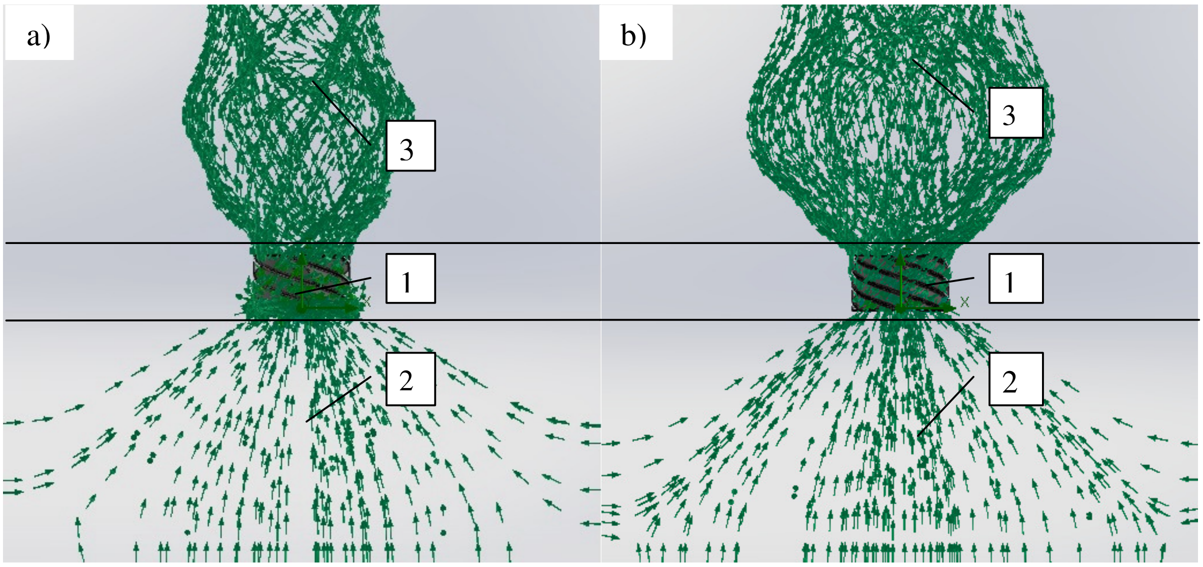

Fig. 3. **Sapropel flow visualisation:** a) turbine parameters; *n* – 5 (blades); *α* – 175º (start angle); b) *n* – 4 (blades); *α* – 150º (start angle); 1 – turbine; 2 – incoming flow; 3 – outgoing flow

Conclusions

1. The new construction of the intake node compatible with various types of sapropel mining equipment provides environmental requirements as well as is compact and suitable for the needs of farmers.
2. To select the optimum parameters of the design for this new unit in Solidworks Flow Simulator simulation was carried out and the turbine parameters were selected: diameter 150 mm, width 100 mm, number of blades 5, start angle of the propeller 175º that provide the outgoing speed of flow 27.8 $m \cdot s^{-1}$. The obtained results will become the basis to select the sizes and dimension parameters of the intake node prototype.

References

1. Segliņš V., Brangulis A. Valsts ģeoloģijas dienests, Latvijas zemes dzīļu resursi (State Geological Survey, Latvian subsoil resources), Latvija, 1996, 28 p. (In Latvian)
2. Vanags R. Investigation of sapropel extraction technical tolls, 14th International Scientific Conference “Engineering for rural development” Proceedings, vol. 14, LLU, Jelgava, 2015. pp. 151-154.
3. RU2061867C1. Yuzov V., Avkhach V. M., Facility for sapropel extraction. Registred: 27.06.1992. Effective from: 10.06.1996. (In Russian)
4. RU2230856C1. Skvortsov S. A., Device for vleaning water basin and ectraction of sapropel. Registred: 20.10.2002. Effective from: 20.12.2002. (In Russian). [online] [13.01.2016]. Available at: http://worldwide.espacenet.com/publicationDetails/originalDocument?CC=RU&NR=2230856C1&KC=C1&FT=D&ND=4&date=20040620&DB=EPODOC&locale=en_EP
5. Kaķītis A. Rhelogical properties of sapropel/Proceeding of the Latvia University of Agricuture- No. 6 (283), Jelgava, 1996, pp. 102-108. (In Latvian)
6. Kanaska D., Verdins G., Vanags R. Modeling of performance of packing equipment units test/13th International Scientific Conference “Engineering for rural development”, Jelgava, LUA, May 29-30, 2014, publ LUA, pp. 348-343. [online] [20.03.2016]. Available at: http://www.tf.llu.lv/conference/proceedings2014/Papers/59_Kanaska_D.pdf
7. Stankeviča K., Kļaviņš M., (2013) Sapropelis un tā izmantošanas iespējas. (Sapropel and the possibilities for use.) Material Science and Applied Chemistry, No. 14, 2013. pp. 1-18. (In Latvian).