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Method Design for Distillers Solubles Recycling and Reusing into Fuel Pellets

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Abstract

The perspectives for processing distillers solubles from external accumulators into fuel pellets are given in the article. The distillers solubles from Ukrainian distilleries physicochemical properties were researched. It was found that distillers solubles from external accumulators are polydisperse, contain solid particles and dry organic substances - 50-60 g/L with a 85-90 wt.% moister contain. The distillers solubles dehydration efficiency in laboratory and industrial conditions was investigated. It was shown that high distillers solubles efficiency dehydration is possible in Ecomash SHS centrifugal units with a biconical rotor profile, which allow separating undissolved particles and ensuring suspended substances sedimentation at the level of 81.8% in a two-phase mode (sediment and fugate) and up to 86.6% in a three-product mode (sediment, thickened product, fugate). The regularity of moisture release during the distillers solubles drying process has been studied. The possibility carrying distillers solubles dehydrated in centrifuges up to 10–14 wt.% moister contain, which is sufficient for granulated fuel pellets formation, has been shown. The obtained pellets calorific value has been determined, which for samples from different distilleries is 4600–5550 kcal/kg. To improve boiler operation workability, distillers solubles samples from different plants and fuel pellets have been studied. To reduce the ash melting point, it is recommended to add mineral components, for example, hydrolyzed phosphogypsum. Based on the research, a resource-saving technology for distillers solubles processing into pellets and a scheme of mechanical dehydration units using modern centrifuges have been developed.

Keywords: *Distillers solubles; Fuel pellets; Centrifuge; Environmental; Ecological safety; Density; Thermal drying; Recycling of wastes; Solid phases separation.*

1. Introduction

Enterprises that process sugar beet molasses into alcohol, baker's and feed yeast consume about 8 million m^3 water per year. They also generate wastewater – near 8 million m^3 - with organic pollutants high concentration. For example, at a distillery with 60000 liters per day alcohol capacity, near 800 m^3 distillers solubles (DS) and near 800 m^3 slightly polluted wastewater are formed. The total factory wastewater flow has pollution indicators that exceed the standards for discharges into sewers or water bodies by tens and thousands of times. At most distilleries, distillers solubles are discharged into sludge-accumulating basin (draff-accumulating basin or DS-accumulating basin). In Ukraine such basins occupy approximately 1,500 hectares of arable land. This measure leads to soils, groundwater and atmosphere contamination with products wastewater pollutants incomplete decomposition products (Fig. 1).

A lot of DS processing methods are existed and well-known in world practice. But Ukrainian ethanol producers don't have modern processing technologies at their disposal, so the problem of creating an economical technology is relevant for them.

Reducing the negative environmental impact from alcohol production and DS-accumulating basins is possible if the DS is reused and processed into valuable products. This approach allows to deallocate old DS-accumulating basins and not to make new ones.

Currently, most distilleries in the world process the DS mainly into feed, using different methods. It is unprofitable to transport unprocessed DS: the large liquid volume and valuable substances low content make this waste transportation unprofitable. The proposed technologies for DS processing can be divided into four main technological schemes [1-3]: evaporation stations to produce dry feed or fertilizers; liquid phase aerobic microbiological processing to produce feed yeast; methane tanks with biogas production; combined schemes.

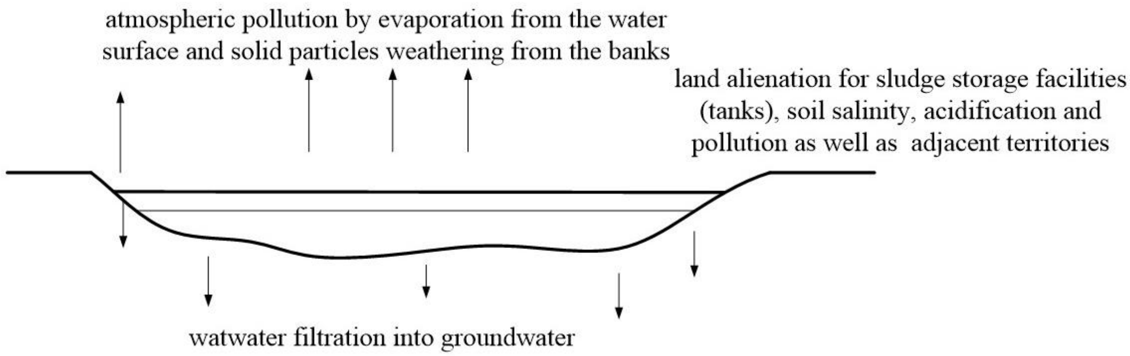


Fig 1. DS- accumulators basin negative environmental impact on ecosystem's components.

The combined technological schemes basis is well-known and technological techniques that have already successfully proven themselves - liquid and solid phases separation in centrifuges [4], feed yeast cultivation on a substrate [5-6], products drying and further using it as fertilizers [7-8] or feed additives for animals [9-10].

When DS separated in a gravitational field (sedimentation or centrifugation), a sediment and clarified DS are formed. By combined or separate sediment or clarified DS dehydration, four feed products can be obtained [11]: DDG – Distillers Dried Grains; DDS – Distillers Dried Solubles; DDGS – Distillers Dried Grains with Solubles; CDS – Condensed Distillers Solubles with 30-49 wt.% dry matter contain.

However, it should be noted that processing into dry feed additives is only appropriate for fresh DS and requires significant energy resources for the drying process.

An important problem is finding ways to use spent DS-accumulating basins, in which this alcohol industry waste has accumulated for years and now it is unusable.

The energy resources lack for heating, process steam production and other energy needs, as well as numerous traditional energy environmental problems has led to the increasing solid organic biofuels spread. Scientific resource analysis shows that today biofuels are actively produced from various organic waste, such as [12-14]: crop waste (straw, corn cobs, sunflower seed husk, rice husk); waste from wood and wood processing industry; waste from livestock complexes, cattle, poultry farms, etc.; organic sewage sediments and other organic sludges.

Despite the variety DS processing methods stills existing in world practice, the problem of creating an economical technology remains relevant, especially for Ukrainian ethanol producers who don't have modern technologies for processing organic waste [15]. World experience shows that perspective direction for DS utilization is its use as animal feed. One way to utilize DS is to produce feed yeast, but post-yeast DS is formed, which is also highly concentrated wastewater. DS processing into fertilizers or biogas also leads to wastewater formation. Land irrigation is another way for DS utilization, but itis used only by some plants as a temporary measure and has a number of disadvantages [16].

The above disadvantages indicate the need to find alternative ways to dispose large-tonnage DS waste, that was accumulated in external alcohol plants DS basins. Fuel pellets production from DS is perspective. The main such method advantage is the possibility to recycle waste that does not have economically viable prospects for use and is unsuitable for disposal by other methods, for example, waste from old SD- accumulator, fermented and contaminated with mechanical impurities and dust. Dry pelletized DS is an environmentally friendly biofuel with a high calorific value comparable to dense wood species and charcoal [17]. Dry pelletized DS is also easy to dose for supplying into solid fuel boiler units.

However, for DS use as fuel pellets, there are a lot of unresolved problems, that are not described in modern scientific sources, namely: determining the method for condensed DS transporting from DS- accumulator to the processing sites; determining the possibilities for DS purification from impurities, dehydrating and reducing the moisture content by mechanical methods; determining the DS drying kinetics depending on its moisture content; determining the final product calorific value and its suitability for use in modern solid fuel stoves.

The above scientific problems are this article’s subject. Ways to solve them depend on DS composition from a specific industrial production, and therefore require experimental research with real industrial wastes

The aim of this research is to design a method for DS processing from old accumulator into fuel pellets with all stage’s technological parameters determination. This is necessary for DS environmentally friendly and safe use and for setting the equipment operating parameters for such recycling.

To achieve this goal, the following tasks had to be solved: to research the DS physicochemical properties from external DS-accumulators basins from different distilleries; to research DS pre-dehydration efficiency in industrial centrifuges; determine the moisture loss patterns in DS drying process; to determine fuel pellets from DS calorific and operational characteristics.

2. Material and methods

2.1. Object and materials of study

For the effective DS use, it was necessary to research the condensed SD transporting features from DS accumulator in pulp form to processing sites, methods dehydration and drying methods, as well as granulation for further transportation to disposal sites.

DS samples for analysis were taken from an external DS-accumulation basin. (Fig. 2). Without mechanical dehydration facilities at the distillery, DS with 95 wt.% moister content is going into external DS-accumulation basin (Fig. 2a).

Figure 2a. DS-accumulation basin photo during settling.

The DS-accumulation basin dimensions vary: 15–30 m wide, 30–60 m long, and 4–7 m deep. The external DS-accumulation basin is filled with ~80%–85% condensed SD sediment and up to 5% clarified liquid with an uneven depth up to 1 m. During settling, the DS is separated into condensed and clarified products. As the external DS-accumulation basin fills, the clarified DS part is overflowed through an emergency overflow into a separate tank, while the external DS-accumulation basin contains a viscous condensed DS product with 85 wt.% moister content (Fig. 2b). During storage, the condensed DS product becomes clogged with different particles from environment (mechanical impurities, etc.). Depending on moister content and environment temperature, anaerobic fermentation processes occur in the condensed DS with biogas emission.

Fig 2b. Old DS-accumulation basin with condensed DS.

For the study, DS samples were selected from the Karavan and Artemivsk distilleries, located in Ukraine.

The DS physicochemical composition (suspended and dissolved substances), the suspended substances sedimentation kinetics in DS at different concentrations, and sediment compaction degree under Earth's gravity and a centrifugal field at ambient temperature were studied. The DS settling properties in the gravitational field were investigated using 500 mL graduated cylinders and in the centrifugal forces field using a laboratory centrifuge.

To organize DS transportation and condensed DS mechanical dehydration from external accumulation basin, changes in the DS bulk density and fluidity depending on moister content were studied using standard methods. The DS fluidity was determined using a cylindrical funnel with an opening diameter equal 8 mm. During the study, the DS with different moister content outflow rate through the funnel was determined. The DS moister was changed by diluting a condensed DS portion with water. At the next stage, the DS drying process in laboratory conditions was studied, as well as the DS ash melting properties at different ash contents. To determine condensed DS drying time and mechanism a sediment sample from external basin weighing 100 g was selected and placed in a laboratory oven for contact thermal drying at t = +108 – 120°C. During the study, changes in the weight and sample appearance, drying time and temperature in the laboratory oven were recorded.

2.2. Research methods

2.2.1. Research methodology for DS mechanical dehydration at industrial centrifuges

DS mechanical dehydration at the Artemovsk distillery was carried out using a HAUS DDI 4042 centrifuge, at the Karavansk distillery it was carried out using an Ecomash SHS 521A-113 centrifuge. The centrifuge appearance and main technical characteristics are presented in Table 1.

Table 1. Comparative centrifuges characteristics during the research.

No	Characteristic	HAUS DDI 4042	Ecomash SHS 521A-113
1	Appearance		
2	Rotor inner diameter, D_r, mm	400	Cylindrical-biconic, 520
3	Rotor revolution, n_r, rev/min	4000	2600
4	Maximum separation factor, Fr	3555	1800
5	Relative screw revolution , Δn_{sc}, rev/min	7–22	16–23
6	Centrifuge weight, kg	2200	3900

In the Ecomash SHS 521A-113 centrifuge, the DS dehydration was carried out in 2 modes: two-phase separation mode (decanter): dehydrated sediment (cake) and clarified DS (fugate) and in the three-product separation mode: dehydrated sediment (cake), condensed product and clarified DS (fugate). When the centrifuge in the Ecomash SHS 521 operates in the two-product separation mode, the condensed product exit is blocked by plugs.

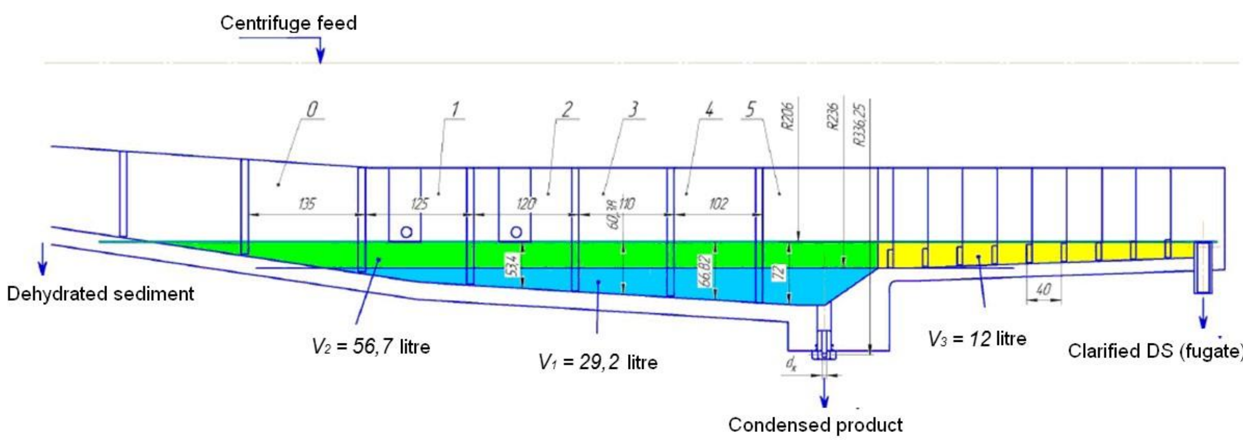


Figure 3. Longitudinal section of the Ecomash SHS 521 centrifuge rotor.

2.2.2. Methodology for studying DS ash melt and DS calorific properties

For comparison, the ash content in various products was determined: DS in the centrifuge feed and fugate at Artemivsk plant; DS after drying at the Artemivsk plant; sunflower husk pellets; DS at the Karavansk plant and DS from the DS-accumulation basin at Karavansk plant.

The DS ash content was determined after 1 hour of DS exposure at a temperature +600°C, while light gray ash formation was observed in all samples (except DS sample from the Artemivsk plant after thermal drying). This is probably due to the fuel pellets enrichment from sunflower husks with ash, which enter the DS during the thermal drying. The ash content of all DS samples was within 3-9 wt.%. To study the DS melting onset, ash samples were heated to a temperature +650°C with subsequent holding for an hour, then the samples were inspected, then heated to a temperature +750°C with holding for an hour and the samples were inspected. The samples melting points were determined on special equipment in accordance with the regulatory documentation requirements (ISO 540-2008).

3. Research results

3.1. DS analysis research results

The suspended solids content (crushed grain residues), dissolved substances (enzymatic hydrolysis and microorganisms metabolism products) in DS with 50–60 g/L dry matter concentration from various production sources is presented in Table 2.

Table 2. DS content and properties analysis.

No	Name	DS from Artemivsk distillery	Karavansky distillery (DS from external accumulation basin)
1	Solid phase initial content in DS (dry matter), g/L	55.5	58.0
2	The separation phase volume ratio into clarified and condensed products after settling for 20 hours	45 % 55 %	50 % 50 %
3	The separation phase volume ratio into clarified and condensed products after centrifugation in a laboratory centrifuge with Fr = 530–745 for 50 s	60 % 40 %	62.5 % 37.5 %
4	DS suspended particles Granulometric composition by size fractions, mm:	Fraction output	
	>3.0	5.5%	1–3%
	1.0 – 3.0	16.2%	5–20%
	0.1 – 1.0	22.5%	15–25%
	0.04 – 0.1	5%	5–10%
	<0.04	50.8%	74–42%

The DS separation proportions from different sources into clarified and condensed products during settling are approximately the same 50±5%/50±5%. The v matter concentration in the condensed DS product after 20 hours of settling in a gravitational field is ≈ 100 g/L (W = 90%). Over time, further condensed sediment settling and compaction does not occur in the gravitational field. The DS kinetics from different sources and concentrations are shown at Fig. 4.

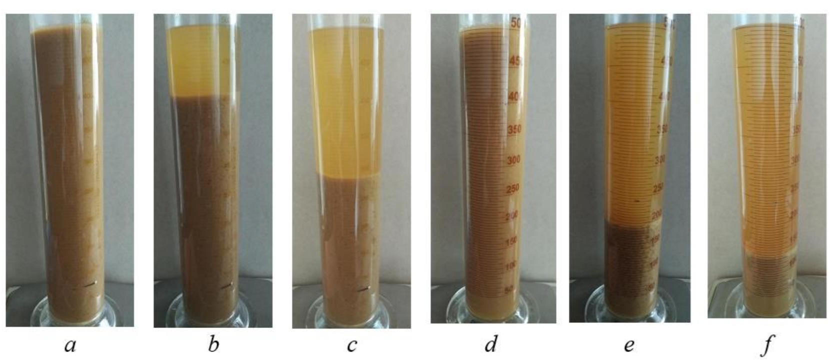


Fig 4. DS settling kinetics from centrifuge fed (dry matter concentration is about 49.25 g/L) and the fugate (dry matter concentration is about 27.25 g/L): a – initial DS; b – DS settling for 2 hours; c – DS settling for 20 hours; d – centrifuge fugate; d – fugate settling for 2 hours; e – fugate settling for 20 hours.

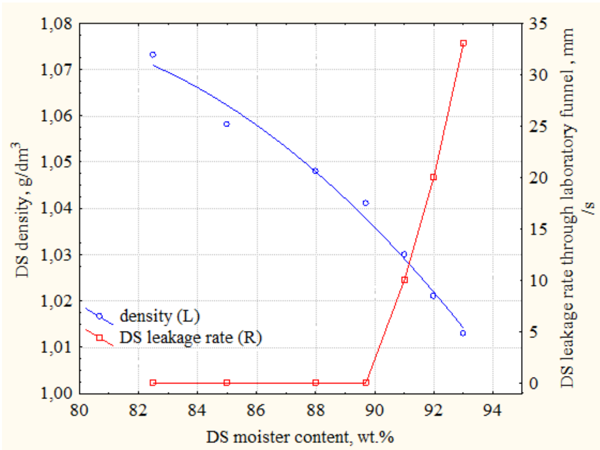


Fig. 5. DS dependence of change in density ρ and fluidity Q on moister content W.

The dry matter concentration (DMC) in the condensed product after grouting in a centrifugal field (Table 1) Fr 530 – 745 for 50–60 s is approximately 140 g/L (W ~ 86%), which is approximately equal to the DS condensed product in a gravitational field from an external DS-accumulation basin after compaction for several years. Thus, for effective DS separation into condensed and clarified products, it is advisable to use centrifugation

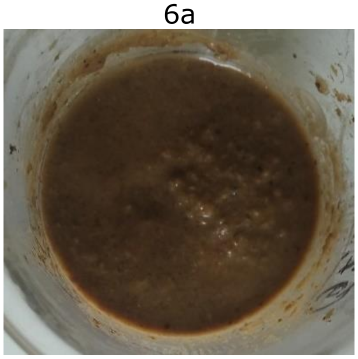
Changes studies in the DS density and DS fluidity from the DS-accumulation basin depending on its moister content are shown at Fig. 5 and Fig. 6. The research results showed that at a 91–93 wt.% moister content, the DS is sufficiently liquid for transportation by a DS pump from the DS accumulator to the processing site.

Thus, for the DS extraction from basin up to 7 m deep and up to 30 m wide with a narrow road along the perimeter, it is advisable to use a dredger with a centrifugal DS pump, which starts DS pumping with: ~ 85 – 90 wt.% moister content; mechanical impurities content up to 30 mm in size from a depth of ~ 1 m, while the pumped slurry pressure is low. For further DS transportation through the DS pipeline, it is necessary to carry out a rough DS purification from mechanical impurities and, if necessary, slightly dilute the DS with water and pump it with a volumetric screw pump with pressure control in the DS pipeline. The DS transporting process through the pipeline and diluting it with water must be equipped with an automatic control system.


6a


6b


6c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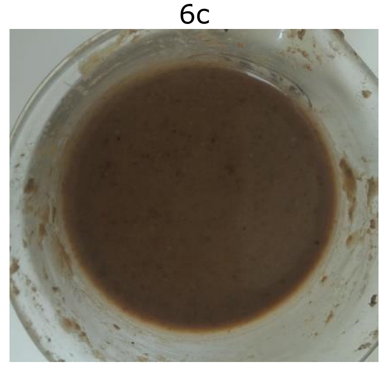
6f

Figure 6. DS from external basin with different moister content: a – 82,5 wt.%; b – 85 wt.%; c –88 wt.%; d – 91 wt.%; e – 92 wt.%; f – 93 wt.%.

3.2. DS mechanical dehydration in industrial centrifuges study results

The results of the centrifuges HAUS DDI 4042 (DS from the Artemivsk distillery) and Ecomash SHS 521A-113 (DS from the Karavansk distillery accumulation basin) comparative analysis are summarized in Table 3.

Table 3. DS mechanical dehydration in industrial centrifuges.

Name	HAUS DDI 4042		Ecomash SHS 521A-113			
Experiment number	1	2	3	4	5	6
Centrifuge operating mode	Two-phase separation (decanter)			Three-phase mode		
Rotor revolution, rev/min	3594	3594	2100	2100	2100	2400
Relative screw revolution, rev/min	11,3	11,3	12	12	12	16
Separation factor	2870	2870	1274	1274	1274	1664
Centrifuge feed characteristics						
Fed consumption, m^3/hour	16	6	12	11	8	3,5
DMC, g/L	58	58	60,5	55,5	55,5	90
Suspended matter, g/L	35,5	35,5	57,5	49	49	–
Dissolved substances, g/L	22,5	22,5	3	6,6	6,6	–
Fugate centrifuges characteristics						
DMC, g/L	30,68	27	22,5	18	17,5	24,5
Suspended matter, g/L	8	5	15	10	10	–
Dissolved substances, g/L	22,68	22	7,5	8	7,5	–
Condensed product						
DMC, g/L	–	–	–	45	49	63,5
Suspended matter, g/L	–	–	–	43	47,2	–
Dissolved substances, g/L	–	–	–	2	1,8	–
Sediment centrifuges characteristics						
Overall efficiency of substance transfer into sediment, %	47	53	74,1	78,7	83,4	88,3
Efficiency of suspended solids transition into sediment, %	77,5	86	81,8	86,6	89,3	92
Moister content in sediment, %	62	67	75,35	73–75		

Data analyses from Table 3 indicates a dependence between the DS dehydration efficiency and dehydration mechanical on the centrifuge feed rate. Reducing the DS flow rate leads to an increase in the solid phase retention degree due to an increase in its residence time in the centrifuge. At DS flow rate of about 16 m^3/hour in HAUS DDI 4042 centrifuge feed, large DS particles are observed to enter the fugate. Reducing the DS flow rate in HAUS DDI 4042 centrifuge feed to 6 m^3/hour increases suspended solids transfer into the sediment from 77.5% to 86%, although the sediment moisture content increases from 62 wt.% to 67 wt. %. At the Artemovsk Distillery, the DS is processed to obtain DDG. At the same time, as studies have shown (Table 3), a lot of soluble substances, including protein and other valuable substances useful for feed, remain in the centrifuge residue. The mechanically dehydrated centrifuge sediment contains matters that have a high calorific value and can be used as raw material for fuel pellets.

Three-product mode using in the Ecomash SHS centrifuge with a biconical rotor profile at a feed flow rate of more than 10 m^3/hour allows the product in the fugate to be returned to the centrifuge feed without combustible mass loss and soluble substances accumulation in the circulation (i.e. without increasing the viscosity in the feed). This allows to increase insoluble substances outcomes in the centrifuge sediment without changing its moister content. At the same time, the suspended substances output in the sediment will increase from 81.8% in the two-phase mode to 86.6% in the three-phase mode.

3.3. DS dry kinetic study results

During the thermal drying process, the DS lumps formation is observed, with moisture remaining inside the lumps (Fig. 7). Therefore, it is recommended to pre-examine the DS by mechanical dehydration to obtain a loose product using industrial centrifuges, which will release moisture more intensively during thermal drying. For DS direct drying, it was recommended to use a drum dryer, which would mix the material during the rotation process and prevent clumping.

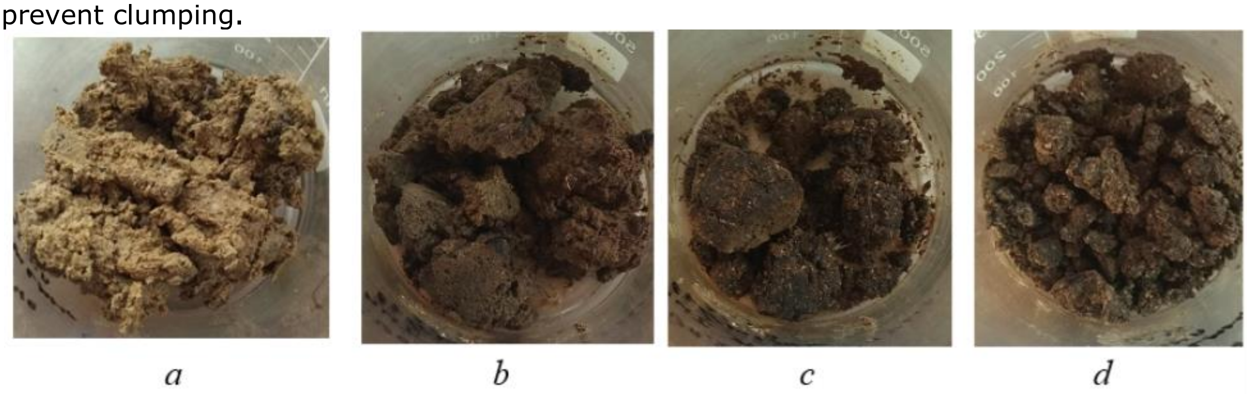

Fig. 7. DS during the drying process with changes in moister content: a – 86,5 wt.%; b – 78,8 wt.%; c – 65,8 wt.%; d – 55,7 wt.%.

For DS thermal drying time comparative assessment (energy consumption) d from different sources, DS samples were taken and sequentially dried in a contact dryer under the same drying conditions. DS samples differed in different initial moisture content (Fig. 8):

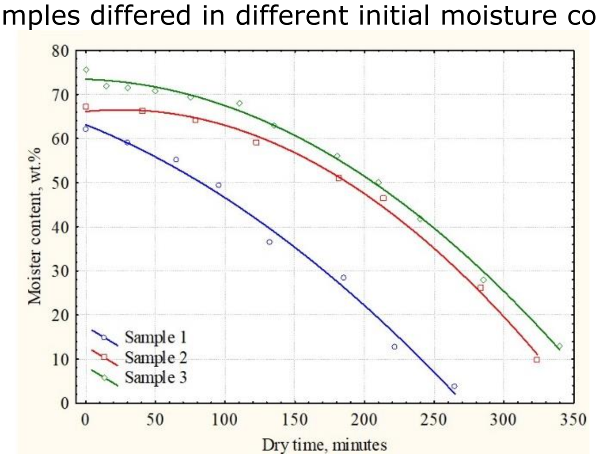

Fig. 8. Change in relative DS moister content during thermal drying at a temperature = 150°C.

– sample No. 1 – centrifuge sediment of the Artemivsk plant with moister content W = 62 wt.%, obtained at DS flow rate centrifuge feed at ~16 m^3/hour (sample weight 14 kg, moisture content 8.68 kg);
– sample No. 2 – centrifuge sediment of the Artemivsk plant with moister content W = 67 wt.%, obtained at DS flow rate centrifuge feed at ~6 m^3/hour (sample weight 17.4 kg, moisture content 11.658 kg);
– sample No 3 – Ecomash SHS 521 centrifuge sediment with moister content W = 76 wt.%, obtained at DS flow rate centrifuge feed at ~8 m^3/hour from an external accumulation basin (sample weight 15.4 kg, moisture content 11.4 kg).

Thus, the energy consumption (time) for DS thermal drying is a multiple to the moisture amount removed from DS, which corresponds to the theoretical understanding of the drying process. The obtained dependences for different DS samples both in terms of chemical composition and initial moister content have the same dehydration dependence type - a second-order polynomial:

$W_1 = 63,1606 - 0,127 \cdot \tau - 0,0004 \cdot \tau^2$ (1)

$W_2 = 66,1256 + 0,0306 \cdot \tau - 0,0006 \cdot \tau^2$ (2)

$W_3 = 73,4361 - 0,0095 \cdot \tau - 0,0005 \cdot \tau^2$ (3)

where $W_{1\text{-}3}$ – DS moister content, wt. %; τ – DS drying time under the conditions specified in the experiment.

3.4. DS ash melt and calorific properties study results

After heating the DS ash to temperature of +750°C, a thin crust of local surface melt is found on the ash samples in some zones and the ash becomes partially non-flowing and sticks together. In this case, the ash sticks to the ceramic dishes in individual particles and is removed from it only by mechanical abrasion (Fig. 9).

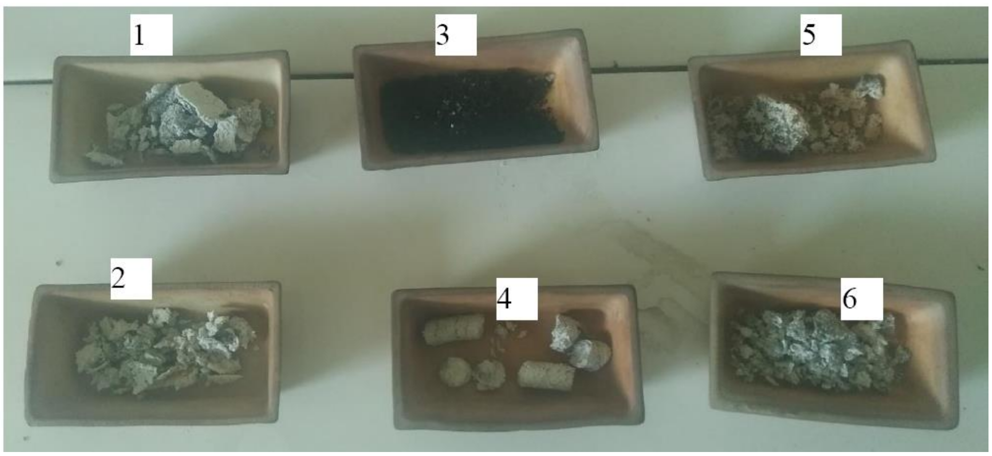

Fig. 9. DS ash: 1 – centrifuge feed (Artemivsk distillery); 2 – centrifuge fugate (Artemivsk distillery); 3 – DS after thermal drying (Artemivsk distillery); 4 – sunflower husk pellets; 5 – dregs from external DS-accumulation basin (Karavansk distillery); 6 – centrifuge feed (Karavansk distillery).

The reasons for the different biomass ash fusibility may be the weight of fusible substances weight in the ash, for example, sodium, potassium ratio to the other inorganic components weight [18-19]. In this regard, the DS chemical composition and DS properties, fuel pellets from sunflower husks and DS from an external DS-accumulation basin with phosphogypsum addition (for additional mineralization and lowering the ash temperature), as well as the calorific value and melting points were determined (Table 4).

Table 4. DS and sunflower seed husk fuel pellets comparative characteristics.

Characteristics	DS from Karavansk distillery external DS-accumullation basin	DS from Karavansk distillery external DS-accumullation basin with phosphogypsum addition	Sunflower seed husk fuel pellets
Deformation temperature – ash flow temperature, °C	1080–1240	1199–1261	1356–1478
Moister content, wt. %	2.0	6.5	7.6
Ash content wt., %	2.9	3.5	1.6
Calorific value MJ/kg	19.25–21.37	21.7–23.2	20.34–21.05
Calorific value, kcal/kg	4600–5104	5170–5550	4870–5028

Due to their organic components, the test samples have similar calorific values to wood pellets, higher than brown coal, but slightly lower than coal [20-25].

Research results analysis (Table 5) shows that mineral component (hydrolyzed phosphogypsum, solution) addition before DS mechanical dehydration at centrifuge led to an increase in the total ash content and an increase in the ash deformation temperature from 1080 to 1199°C. Such a solution will reduce ash sticking and allow boilers use, that operating on sunflower husk pellets for pellet burning (currently used at the distillery for DS drying).

Table 5. Ash from organic waste chemical composition.

Element (atomic number)	DS ash from Karavansk distillery external DS-accumulation basin	DS ash from Karavansk distillery external DS-accumulation basin with phosphogypsum addition	Ash from sunflower seed husk fuel pellets
O (8)	42.383	40.334	30.308
Na (11)	0.406	0.461	0.640
Mg (12)	3.226	2.912	11.757
Al (13)	3.318	3.592	–
Si (14)	17.231	14.491	3.240
P (15)	3.355	2.867	1.282
S (16)	2.702	2.513	1.687
Cl (17)	0.626	0.712	0.986
K (19)	7.966	8.702	27.379
Ca (20)	10.987	8.830	21.513
Ti (22)	0.397	0.511	$441x10^{-6}$
Cr (24)	0.270	0.594	$123x10^{-6}$
Mn (25)	0.108	0.231	$301x10^{-6}$
Fe (26)	6.216	11.059	0.997
Ni (28)	0.116	0.396	$59x10^{-6}$
Cu (29)	0.115	0.217	$354x10^{-6}$
Zn (30)	0.171	0.400	$146x10^{-6}$
As (33)	$197x10^{-6}$	0.095	–
Rb (37)	–	$104x10^{-6}$	$201x10^{-6}$
Sr (35)	–	$221x10^{-6}$	$443x10^{-6}$
Zr (40)	–	$164x10^{-6}$	–
Mo (42)	$34x10^{-6}$	$46x10^{-6}$	–
Sn (50)	$66x10^{-6}$	$96x10^{-6}$	–
Ir (77)	$74x10^{-6}$	$317x10^{-6}$	–
Pb (82)	0.368	0.988	$34x10^{-6}$

3.5. Research results discussion and method for DS from external accumulation basins recycling design

The DS condensed product. stored in external distilleries basins. contains less dissolved substances than fresh DS and has a high calorific value and requires processing. That is why it is advisable to use the DS condensed product from external storage basin (Fig. 2b) as a raw material for fuel pellets or mineral fertilizers production.

The analytical and laboratory studies conducted allowed us to develop and recommend the following scheme for DS processing (Fig. 10). which has been tested in industrial conditions.

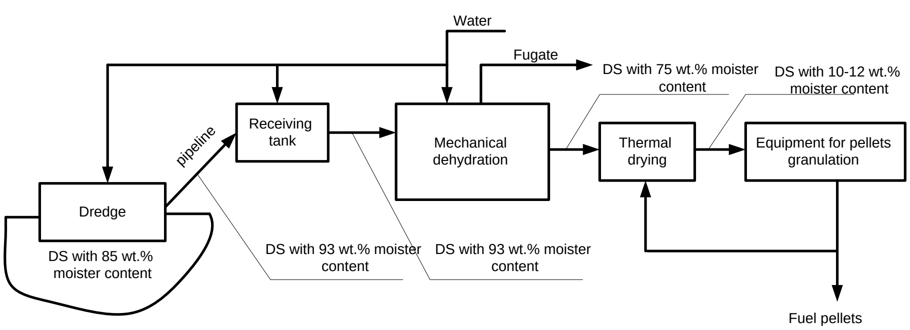

Fig. 10. Technological scheme for condensed DS processing into fuel pellets.

The DS from the external basin with 85 wt.% moister content is removed by a dredger. diluted with water to 93 wt.% moister content according to the study results (Fig. 5) and fed into the pipeline. which transports it to a receiving tank with a mixer. Next. the DS is dehydrated in centrifuges on a mechanical dehydration module up to 75 wt.% moister content. Increasing the suspended solids sedimentation process driving force in the DS due to the centrifugal field leads to DS effective and rapid separation into a clarified product and a compacted sediment. DS mechanical dehydration optimization in a centrifuge based on rotor revolution. flow rate and dry DS matter concentration in the centrifuge feed is recommended taking into account the energy and economic costs for mechanical dehydration and subsequent thermal DS drying. The mechanical dehydration unit. which involves hydrolyzed phosphogypsum introduction into the DS. is shown at Figure 11.

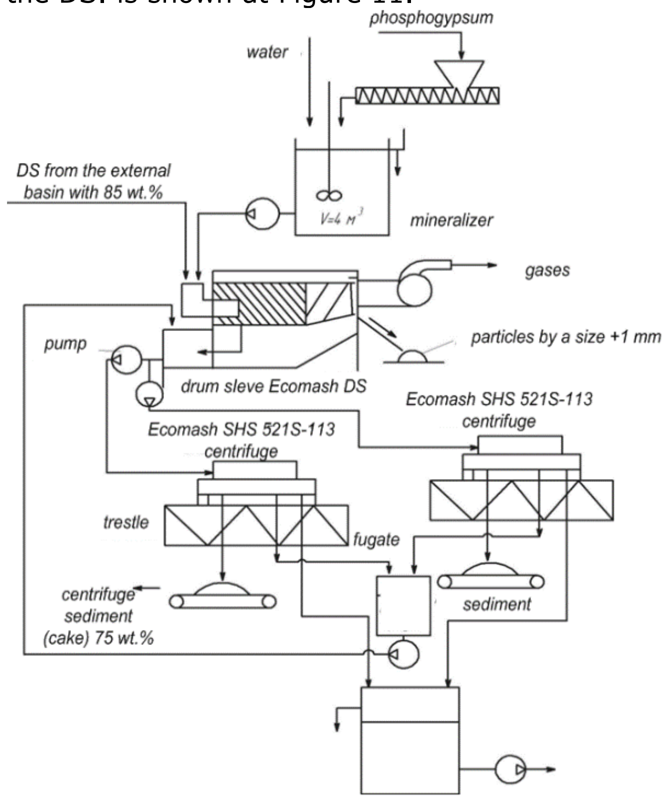

Fig. 11. Ecomash SHS 521S-113 centrifuges mechanical dewatering module (three-product mode) for DS.

The centrifuge sediment (cake) is fed into a drum dryer. where the distillate is dried from 75 wt.% to 10-12 wt.% moister content. In this form. the distillate is granulated. According to the research results. the DS pellets calorific value is perspective substitute for wood pellets or a substitute for sunflower husks. which are used at operating distilleries for drying distillate. Also. on the existing equipment. which is mass-produced. for pelleting food feed. a matrix was selected and dried DS pelleting was carried out. During the pelleting process. the pellets temperature rose to 90°C. after cooling the pellets in air. the moister content in DS pellets was 5 wt. %. Our investigations align with similar studies in chemical technology [26-30].

4. Conclusions

The DS samples from external distillery DS-accumulation basins physicochemical properties were investigated. It was found that the DS from the DS collectors is polydisperse. contains a dry matter of 50–60 g/l with moister content near 85–90 wt.%. For DS effective transportation from external collector to further processing places. it is advisable to dilute it to a fluid state at 91–93 wt.% moister content and a density of 1.01–1.02 g/dm^3. For DS condensing. centrifugation high efficiency has been proven in laboratory conditions; at a separation factor Fr 530–745 for 50–60 s. the DMC is approximately 140 g/L.

Preliminary DS dewatering in industrial conditions have shown Ecomash SHS centrifugal units high efficiency with a biconical rotor profile. which allow separating undissolved particles and ensuring the suspended solids sedimentation at the level 81.8% in a two-phase mode (sediment and fugate) and up to 86.6% in a three-product mode (sediment. condensed product. fugate).

Moisture release pattern studies during the DS drying process showed a similar polynomial dependence for drying time on the initial moister content for different DS samples. At an initial 62–76.5 wt.% moister content. the drying time to 10–14 wt.% moister content will be 240–340 minutes. At an initial 62–76.5 wt.% moister content. the drying time to 10–14 wt.% moister content will be 240–340 minutes.

The pellets calorific value was determined. Pellets were obtained after dehydrated DS granulation. Calorific value for samples from different distilleries was 4600 - 5550 Kcal/kg. To increase the boiler operation convenience and decrease ash melting point. it is recommended to add mineral components. for example. hydrolyzed phosphogypsum. Based on the research. a technology for DS processing into pellets and mechanical dehydration units scheme were developed.

Symbols

W – moisture contents. %;
v – matter concentration. g/L;
τ – drying time. minutes.

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