Dryers for Sewage Sludge Dehydration

DANIJELA DOBERSEK, DARKO GORICANEC, JURIJ KROPE

Abstract— Alternative methods for decreasing amount of communal sludge are represented in this article. The sludge is formed as a side product in processing of waste water in sewage treatment plant. Selection of optimal dryer is essential. Because of its great influence on environment, and consequentially of public health, it is necessary to select the dryer which have previously been fully examined. Different types of rotational dryers, and fluidized bed dryers, are presented in this article.

Keywords— Waste water, sewage treatment plant, sludge, drying, rotational dryers, fluidized bed dryers

I. Introduction

ONE of the greatest goal and biggest challenge in the area of environmental protection is optimal treatment of wastes. That is why it is not surprising that this problem is actual for decades.

Increasing rate of wastes production and its negative influence to environment, together with increasing awareness of its influence on society, accelerated the changes in the field of waste treatment. Changes include legislation, and development of new technological processes for use of wastes for energy production [1- 5].

With increased growth of the population and industrial development the quantity of waste is increasing. The result is a rise in environmental awareness of people, who know that the improper management of waste can seriously jeopardize the future of life on earth.

Fast changing and upgrading of strategic documents, a regulatory framework, and providing new technologies, demand flexible and comprehensive systems for treatment of wastes.

Among all the other ways, waste materials are produced also in communal installations and devices whose aim is waste processing itself. One of such process is waste water processing in sewage treatments plants, and waste materials formed in such process are sludge, hard wastes, etc.

Processing of waste water is directed in secretion of unacceptable admixtures. That must be done in such a way, that after processing water becomes harmless for nature, and it can be used again. Procedures for water cleaning enable secretion of wastes in a form of sludge (mixture of hard materials and water). The percentage of water is usually higher than 99%.

Because of the huge amounts of sludge formed in this process, the variety of new technologies for sludge treatment is currently investigated. All technologies follow 3-R principle: Reduce, Reuse and Recycle [6].

Firstly, the amount of sludge production is decreased, using microbial communities, which have lower growth, and at the other hand better metabolic process. It is better in a sense of reusing of sludge in agriculture, and for energy recycle gained for sludge in the process of anaerobic digestion (methane production), or with incarnation of dry sludge [7].

There are several methods for sludge processing, and the method is usually chosen, by countries, due to the economical eligibility.

With appropriate treatment of community wastes, environment can be relived, because it is not necessary to store processed sludge. In the process of sludge treatment, it is necessary to provide dehydration of sludge, and further drying and preparation for effective energy use.

The wide range of technology for sludge processing is available, and wide range of dryers for this process is constructed. That is why the choice of technology and consequentially choice of dryers is very complex, and it demands great theoretical knowledge, and practice of drying.

Recent legislation for storage and processing of waste sludge, have led to investigation of new technologies. Because of that, the waste sludge is not considered as unusable waste anymore, but as a source of energy.

Sludge can be incinerated directly, or mixed with coal. With the incineration several problems can be solved:

- since the ash is formed, the amount of sludge that must be deposed at landfill is decreased,
- the amount of coal used is decreased, which has positive financial effect.

Furthermore, the mixture of biologically degradable wastes from waste water is by suitable thermal processing transformed to quality, biologically stabilized and hydrogenated sludge, which is suitable for reuse in agriculture or production [8].

II. Formation of Sludge in Sewage Treatments

The sludge is processed by biological, physic - chemical and thermal processes. The process is clearly represented on Fig. 1.

The amount of “fresh” sludge depends on the way of processing, and on characteristics of waste water. Average annual production of sludge is from 20 to 45 kg of dry material per person.

D. Dobersek, D. Goricanec and J. Krope are with the Faculty of Chemistry and Chemical Engineering, University of Maribor, Smetanova ul. 17, 2000 Maribor, SLOVENIA (corresponding author to provide phone: 00386 2 220 77 61; e-mail: danijela.dobersek@uni-mb.si, darko.goricanec@uni-mb.si, jurij.krope@uni-mb.si).

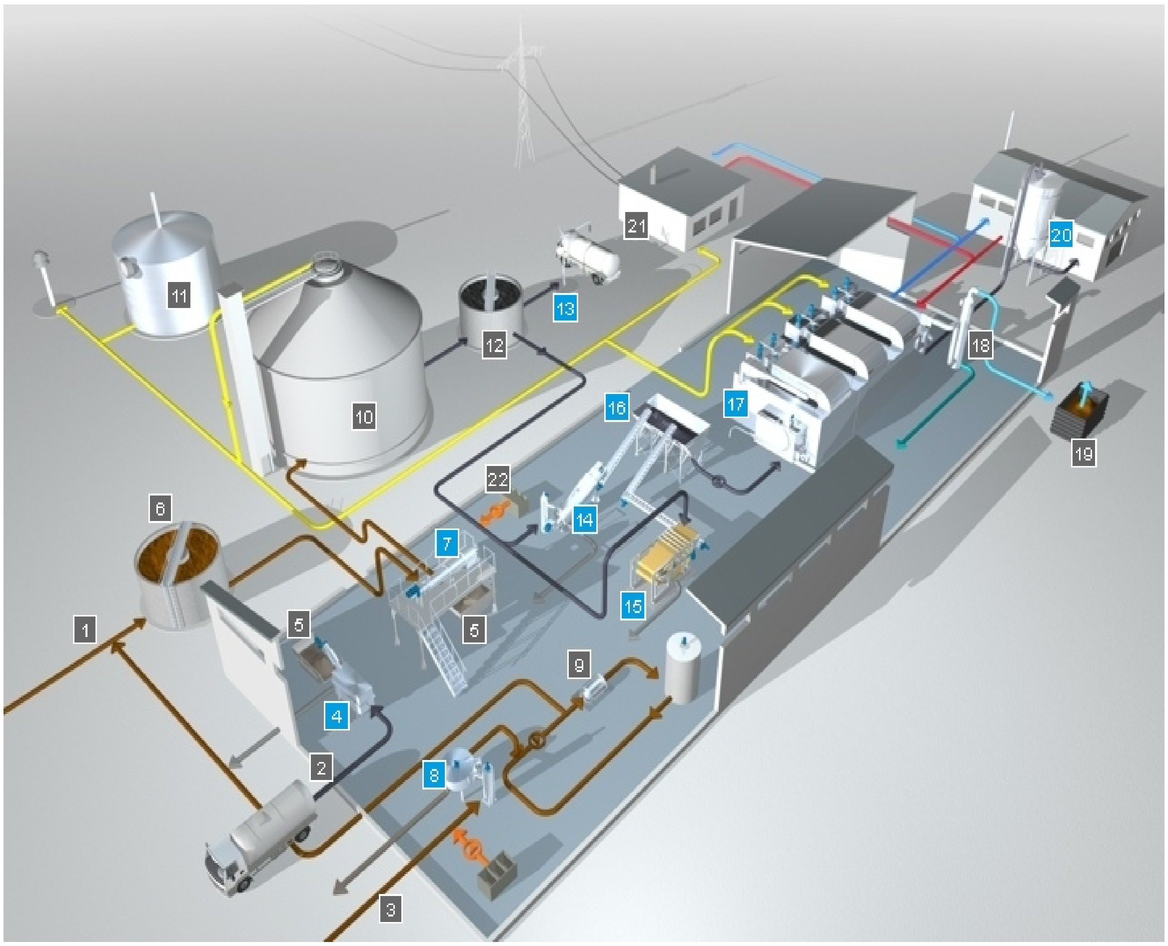
Primary sludge is generated from hard materials, stored in unprocessed waste water.

Secondary sludge contains biomass produced in the biological cleaning of waste water.

Important processes of sludge treatment are:

- tidy,
- removal of disruptive material,
- disinfection,
- removal of water with mechanical processes,
- drying with water evaporation, and
- increment with thermal oxidation of organic species.

The sludge processing includes several phases, represented at the Fig. 2:



1	primary sludge	12	post-thickener
2	septic sludge	13	HUBER Sludge Gallow
3	secondary sludge	14	sludge dewatering
4	septage receiving	15	sludge dewatering
5	screenings	16	Tank
6	pre-thickener	17	middle temperature sludge drying
7	sludge screening	18	Quenscher
8	sludge thickening	19	Biofilter
9	sludge desintegration / homogenisation	20	- thermal sludge utilisation
10	anaerobic digester	21	power/heat cogen.
11	gas holder	22	polymere station

Fig. 1: Schematic representation of sludge processing [9]

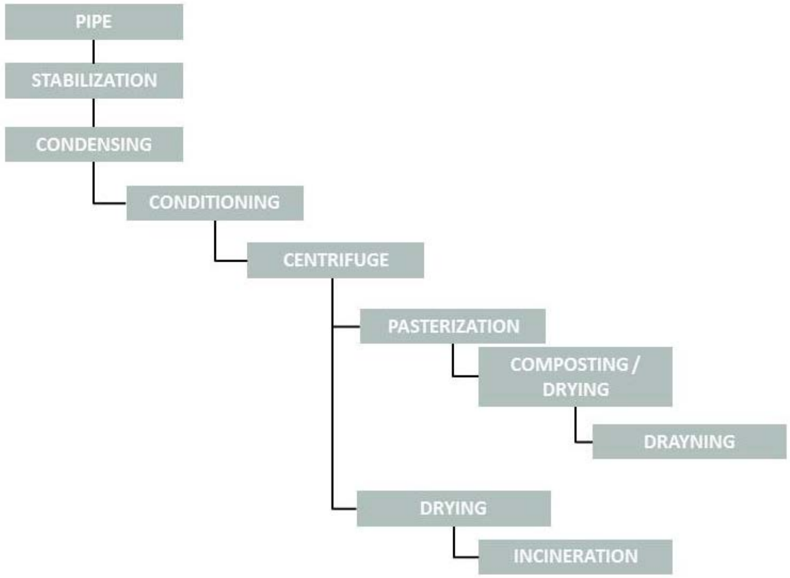


Fig. 2: Phases of the sludge [10].

A. *Chemical composition of sludge*

The quality of waste sludge is usually determined by pathogen organisms, and by concentration of hard metals. The concentration depends on activities of industrial and communal contaminants connected to the sewer system.

The chemical composition of primary and secondary sludge from biological sewage treatment is represented in table 1.

Concentration of hard metals (arsine, cadmium, copper, cobalt) changes due to the contribution of industry and economy to the sewage, and regarding to the effectiveness of the sludge processing unit.

Waste water from industry contains different composition of dissolved and suspended materials. On the other hand communal waste water differs only in concentration of pollutants.

In the modern communities approximately 400 L of waste water is produced per person. The ware contains less than 0,1% of suspended materials, from 100 to 350 mg/L of suspended materials and from 110 to 400 mg/L BPK_5.

Production of sludge:

- 54 g/PE×day primary sludge
- 25g/PE×day secondary sludge.

In Slovenia, the annual production of dry materials from sludge is 19.800 t, ant it is mostly stored at the landfill for non-hazardous wastes, some is incinerated, and a part of it is exported (Fig. 3). After 15.07.2009, unprocessed sludge from sewage treatments cannot be stored at landfills [12].

After the treatment is over, the sludge still contains more than 70 % of water. Because of the great humidity of sludge, the incineration is very difficult. Furthermore, in order to provide appropriate treatment of sludge, it is reasonable to analyse the variety of drying processes and to choose the one which is economically eligible.

Table 1: Average composition of waste sludge [11]

Parameter	Value
pH	7,70
Dry materials	30,50%
NH_4-N	1,60 g/kg dry materials
NO_3-N	0,17 g/kg dry materials
Organic N_2	14,18 g/kg dry materials
Total N_2	25,19 g/kg dry materials
Ca	70,98 g/kg dry materials
K	2,63 g/kg dry materials
Mg	9,17 g/kg dry materials
P	31,00 g/kg dry materials
As	6,05 mg/kg dry materials
Pb	53,82 mg/kg dry materials
Cd	1,19 mg/kg dry materials
Cr	43,40 mg/kg dry materials
Co	6,53 mg/kg dry materials
Cu	197,10 mg/kg dry materials
Mn	220,86 mg/kg dry materials
Mo	3,90 mg/kg dry materials
Ni	27,69 mg/kg dry materials
Hg	1,00 mg/kg dry materials
Zn	809,52 mg/kg dry materials

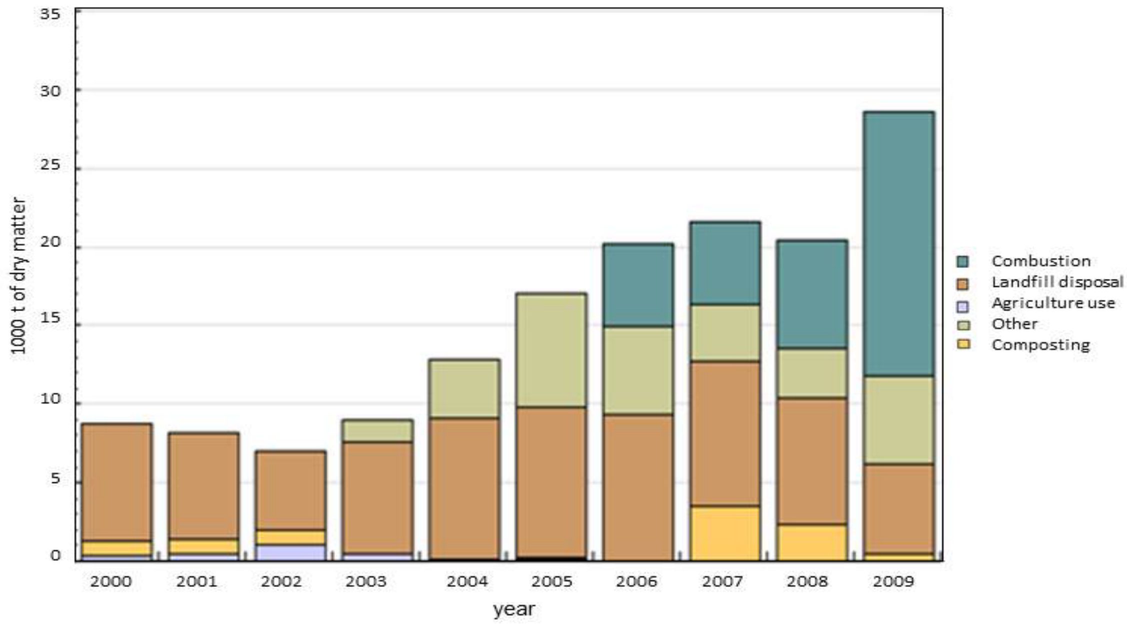


Figure 3: Treatment of sludge produced, in Slovenia [13]

B. Humidity in sludge

Generator of humid material is water, which appear as:

- Liquid, which drains, and it must be removed before drying, with filtration of centrifugation.
- Liquid, which is restrained at the surface of material in huge capillary (d > 10 - 7 m). In this case the forces are weak, so the vapour pressure is not reduced. That type of humidity if called unbounded vapour.
- Liquid, restrained by small capillary (d < 10 - 7 m) - Surface forces (tension) starts to decrease the vapour pressure at the certain value of humidity. It can be dried only to the equilibrium humidity, which depends on temperature and humidity of ai [14].

In the process of drying with air only unbounded vapour can be removed (x - x*), which corresponds to air conditions [15].

Water is usually as unbounded liquid in sludge (Fig. 5) and it fulfils intermediate spaces. It can be removed by gravity densification.

Other part of water is capillary water, and it can be removed only by draining with increased pressure.

Third, and the smallest part of water is adsorbed water, and it can be removed only by providing heat.

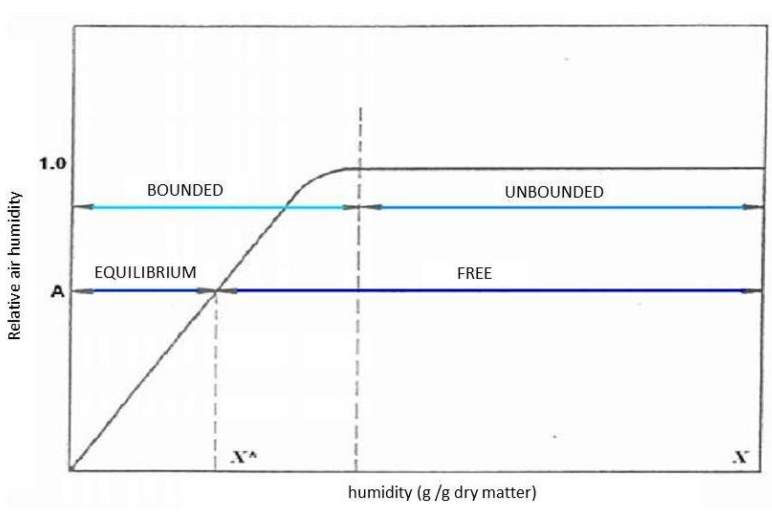


Figure 4: Humidity in hard material [15]

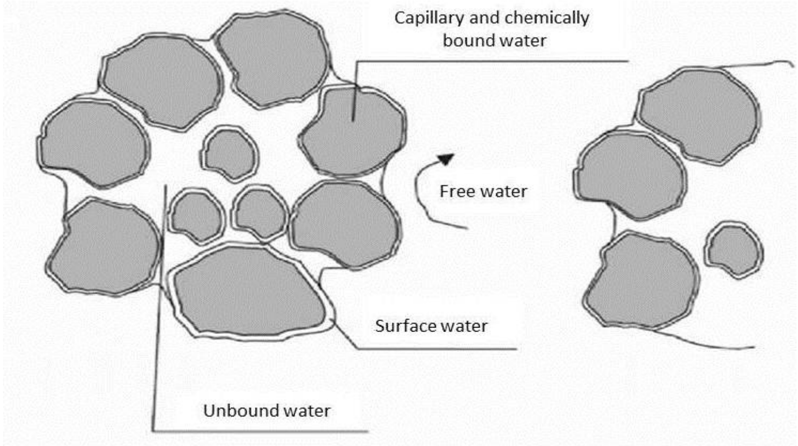


Figure 5: Distribution of water in sludge [14]

II. Sludge Drying

There are several types of dryers available at the market. They differ in the principle of operating:

- Convection
- Contact
- Vacuum
- Freezing
- Radiation, and
- High frequency

For drying the waste sludge from sewage treatments the convectional dryers are most frequently used, or more precise: rotational dryer and fluidized bed dryer are used [16, 17].

One - step continuous adiabatic dryer is analysed. A flow of wet material is dried from starting humidity to final humidity x_{s2}. Humidity removed from material:

$$q_{mv} = q_{ms1} - q_{ms2} = q_{ms} \cdot (x_{s1} - x_{s2}) \quad (1)$$

where:
q_{ms1} - mass flow of humid material, kg/s,
q_{ms} - mass flow of material, kg/s, and
x_s - humidity, kg/kg.

Mass flow of dry gas stays unchanged regardless the vapour, and only overall flow and humidity of gas are changed.

$$q_{mv} = q_{mvz2} - q_{mvz1} = q_{mz} \cdot (x_{z2} - x_{z1}) \quad (2)$$

Amount of dry gas needed for drying:

$$q_{mz} = \frac{q_{mv}}{x_{z2} - x_{z1}} = \frac{q_{ms1} - q_{ms2}}{x_{z2} - x_{z1}} \quad (3)$$

Specific amount of dry gas needed:

$$I = \frac{q_{mz}}{q_{mv}} = \frac{1}{x_{z2} - x_{z1}} \quad (4)$$

The heat balance for dryer, with previous heating of gas, is simplified by equation:

$$q_{mz} \cdot h_{z1} + q_{ms1} \cdot h_{s1} + \dot{Q} = q_{mz} \cdot h_{z2} + q_{ms2} \cdot h_{s2} + \dot{Q}_v \quad (5)$$

where:
Q_V - heat loses in dryer,
h - specific enthalpy.

C. Rotational Dryer

Rotational drying is frequently used process in chemical engineering.

The drying is held in rotational dryers, composed from slightly inclined sinkhole. The wet material enters the upper part of dryer, and it is dried due to the rotational forces. The slope of sinkhole is necessary because the removal of dry material is easier. The simplified scheme directly heated rotational dryer is represented at the Fig. 6.

The direction of gas flow is dictated by characteristics of wet material, which is to be dried. Concurrent flow is used for drying temperature unresisting materials, and counter - current flow is suitable for all other drying, since the greater efficiency is achieved by second method.

In the first case the flow of gas increase the flow of material, and in the second case it has opposite influence [15, 18].

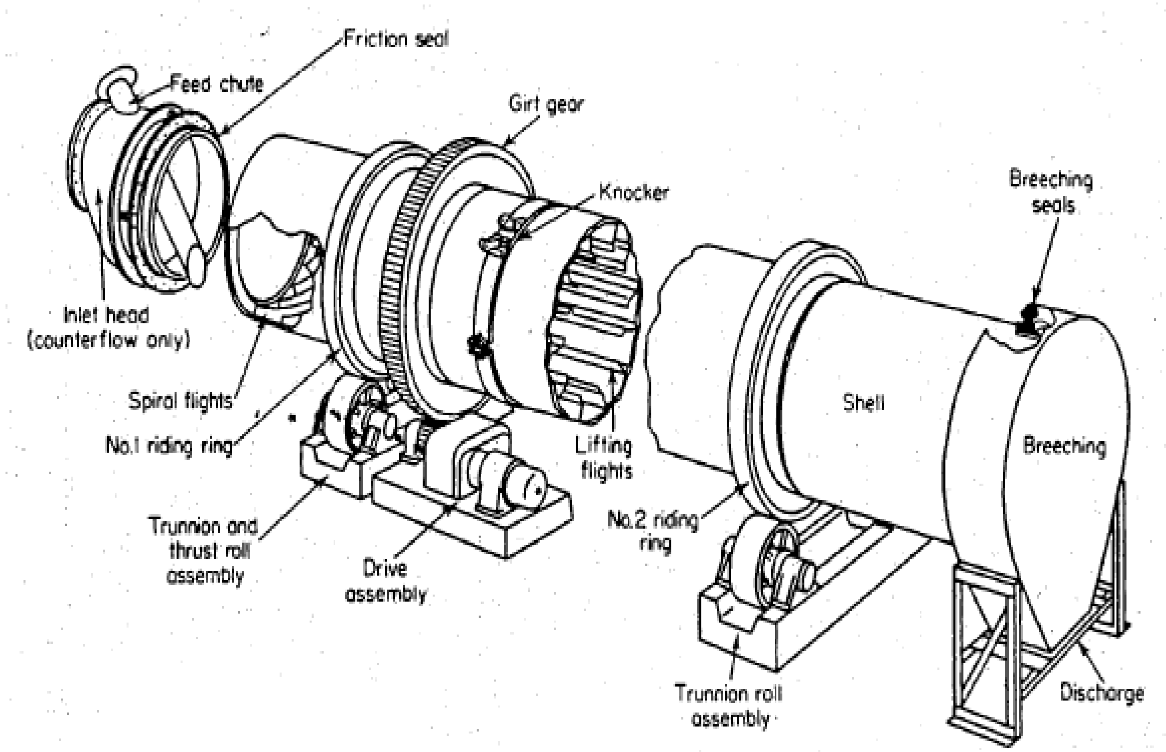


Fig. 6: The simplified scheme of rotational dryer [15]

Rotational dryers are divided in several categories:

- direct,
- indirect-direct,
- indirect, and
- special.

The division is due to the way of heat transfer, which can be direct (heat is added or removed by direct exchange between gas and wet material), or indirect (heating gas is separated from material by steel walls). Also the combination of direct and indirect types of dryers is possible, which is why there are variety of dryer's type available on the market.

A. *Fluidized bed dryers*

Fluidized bed dryers are frequently used for drying granular materials, sludge, suspensions, etc. They are commonly used in production of variety of goods such as: chemicals, carbohydrates, food, biomaterials, ceramics, etc. Furthermore they are also used in waste treatment, and for environmental protection. Important advantages of this process are:

- appropriate mixing of material,
- good heat transfer and
- simple mass transfer.

In the process of dust drying (particle size from 50 to 2000 μm) other dryers can be substituted by rotational dryers. A common dryer is constructed in such a way that gas flows from the bottom layer of particular material upwards. When the rate of flow is low, the layer of material, which is uniformly distributed, is static. The decrease in pressure depends on the rate of fluidized gas, and it increases with the speed of gas increases. At certain speed, the layer is fluidized, when the gas flow supports whole weight of layer. In that case, the minimal fluidization is obtained, and the speed of gas is called the minimal fluidized velocity.

The minimal velocity is determined experimentally, using different correlations that depend on the particle's size, dimension of column and operating parameters. Particles with high content of water demand higher minimal velocity in comparison with relatively dry particles. The fluidized layer is only the top layer of material, and all the others are stationary during the drying [18].

Typical system is made from blower, heater, column, systems for gas cleaning (cyclones, filters, etc.). In order to save some energy exhaust gas is partially recycled. Fluidized layer with bubbles is vertically separated into two regions, named dense phase and dispersed phase. The first one is places at the bottom, and above it, the dispersed phase is placed. The density is decreasing upwards (Fig. 7).

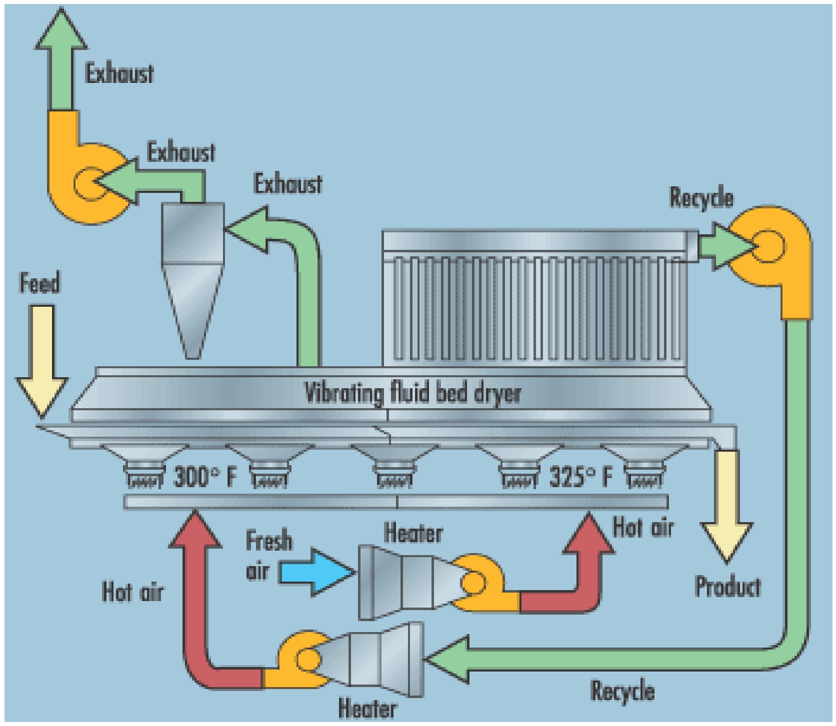


Fig. 7: Fluidized bed dryer [18]

Fluidized gas brings tiny particles with it, during its travel through layers of material. The amount of material accumulated in dispersed phase is decreasing, and the dispersion height is increasing until the height where the matter stays unchanged is reached. That point is called transfer free height (TDH). TDH is evaluated using different empiric correlations. Because there is no widely accepted correlation TDH is usually determined experimentally.

B. *Heat Transfer*

Heat transfer in gas - fluidized layer can be performed by conduction, convection and radiation. The contribution of different factors, from rate of heat transfer, to heat transfer coefficient, depends on:

- classifications of particles,
- conditions of flow,
- fluidized regimes,
- type of regulators,
- operating temperature and
- pressure.

Heat transfer can be determined using equation:

$$Q_{pt} = U \cdot A_d \cdot (T_d - T_z) \qquad (6)$$

where:
Q_{pt} - rate of heat transfer, W
U - heat transfer coefficient, (W/m^{2}K)
A_d - area od particles, m^2
T_d - temperature of particles, K
T_z - temperature of gas, K.

The value of the heat transfer coefficient is ordinary low (from 1 to 700 W/(m^{2}K)).

Heat transfer coefficient is a function of operating parameters, particle's characteristic, and geometry of dryers. It can be determined using correlation depended on the Reynolds number for particles:

$$U = \frac{\lambda_g}{d_d} \cdot Nu \qquad (7)$$

where:
λ_g - thermal conductivity of particles, (W/mK)
d_d - particle diameter,
Nu - Nusselt's number

C. *Comparison of Dryers*

The analysis of individual process modes is provided for both dryers. Advantages and disadvantages of both dryers are summarized in Table2.

Table 2: Advantages and disadvantages of rotational and fluidized bed dryers

Demand	**Rotational dryer**	Fluidized bed dryer
1. Sludge processing		
- Different types of sludge and its characteristics (primary sludge, biologically processed sludge, active sludge, ash content, particle size, etc.) - Variation of hard material quality during drying	- Huge flexibility during variation of sludge quality - Advantages are better grain quality and greater density - Ash is very hardly found	- Simple flexibility - Demeand equal distribution of grain size - Suitable ,in small region, for low organic and high fiber content of sludge - Sensitive to big particles
2. Usage of different energy sources		
Lost of heat (gas turbines and engines)	Yes, if the temperature od exhausted gases >400°C. Below this value it us suitable for additional source of energy .	Yes, it demands unit for vapor production.
Hot water from process	Yes, as additional source for heating.	No, because of low temperatures .
Biogas	Yes.	Yes in combination with vapor boiler.
2. Usage of different energy sources		
Vapor (< 6 bar)	Yes, as additional source for heating.	Yes, as additional source for heating.
Vpor (> 6 bar)	Yes, as additional source for heating.	Yes .
Primary energy (oil, natural gas)	Yes.	Yes in combination with vapor boiler.
Heating oil	Yes, as additional source for heating.	Yes.
3. Operating conditions		
Typical efficiency during sludge drying	1,0 - 15 t/h of evaporated water	1,0 - 20 t/h of evaporated water
Load	40 - 100 %	30 - 100 %
Aggregate drying > 90 % s.s.	Yes, app. 92 - 96 % s. s.	Yes, app. 94 - 98 % s. s.
Partial drying	No	No
Possibility of direct heating	Yes	No
Possibility of indirect heating	Yes	Yes
Automatic operation	Yes	Yes
Automatic flexibility for variation of sludge quality	Yes	Yes
Simple use	Process control during automatic operation	Process control during automatic operation
Space needed	Compact shape, more space needed	Compact shape, less space needed.
4. Quality of product		
Hygienization of sludge guaranteed, and drying is perfect	Yes, Hygienization of sludge guaranteed because of long residual time and control of the temperature.	Yes, same as for RD. Problems occurs when mixing is not provided .
Stable, uniquely shaped grains	Yes, spherical grains, very stable under pressure, with small deviations is size, and great density.	Good quality when mixing is provided
Dust content	Very low	More that with RD, and the ratio decreases if mixing is provided .
5. Exhaustion		
- smell - dust - exhaustion gases (NO_X, CO, SOx, H_2S, NH_3)	- Standard equipment during drying involves removal of exhaustion gases with bio filters, thermal oxidation, etc. - Depresion obtained with closed air lop	- Same as for RD
6. Safety Demands		
- Explosion protection - Fire control - Common safety demand for employers (ladders, closed areas, etc)	- In compliance with safety analysis (EN 1050) - Inert drying space is guaranteed with vapor atmosphere	- Same as for RD

In the case where several types of sludge are presented, rotational dryer is more suitable. This is because of the lower mechanical stress during the crystallization (forming of grains), and also due to the possibility of processing particles with different characteristics, and greater capacity.

The direct rotational dryer is the most economical one. That is because beside oil and natural gas, also smoke gases can be used as fuel. The dryers are suitable mostly for processing of sludge from sewage treatments. In the case of fluidized bed dryers (FDB), middle pressure steam and oil are used as fuel. Provision of water boiler or oil furnace demands higher investments.

Evaporation of water from sludge is greater with FBD and it can reach the value of 20t per hour, In comparison with RD, FBD demand smaller operating space.

On the other hand, RD offers better distribution of particle sizes (evenly distributed) and, final product is almost without dust. In comparison with RD; FBD gives smaller particles with greater ratio of dust. Regardless of the high entering temperatures in RD, appropriate cooling particles are not overheated.

During the drying of sludge some inconvenient smell are produces, and that is why working environment must be air-conditioned. Intensity of smell depends on the sludge type, and on temperature of drying.

Both RD and FDB have similar smell characteristics. In the case of indirect drying, the amount of exhausted gas is low. Nonetheless, more gas is exhausted in the processes using RD that FDB, and that affects the operation costs.

Legislation for safety determines that every single sewage treatment must fulfill condition stated in EN 1050. Because processes including both, RD and FDB, are associated with low emission of dust, they are relatively safe.

It can be concluded that:

- RD is better choice because of the middle range evaporation, and no additional units (boiler) are needed.
- Furthermore RD is suitable for changing properties of sludge, and quality of graining is very good
- Even though more water is evaporated in FBD, other disadvantages make FDB inferior choice.

III. Conclusion

The Drying of waste sludge is not always necessary, but in most cases is the most suitable option.

With the drying the amount of sludge is decreased, and consequentially lowest costs of transport are obtained.

Thermal drying increases the heat value of sludge, and decreases the content of pathogen organisms. Furthermore, the composition of sludge is improved.

There are a lot of types of dryers, but convection and contact are the best ones. The type of dryer used depends on the process of drying, and the process is chosen due to the type of sludge. The water content of dry sludge is between 10 and 15 %, and it can be used in agriculture if the water content is less than 40 %.

Same percentage of humidity is necessary for sludge incineration. It can be partially dry (35 to 45 % of dry matter) or with 90% of dry matter. In the second case, it is mixed with partially dry sludge and then burned.

In the case of thermal drying, the consumption of energy is high, and the process is very expensive. Comparison of drying expenses lead to conclusion that drying the sludge is the most economical. When decision is made, besides economical also other parameters are considered: simple service, reliability of choice, simple storing and transport.

Energy consumption is highly influenced by the content of water in the sludge. In the case of thermal drying huge amounts of energy are consumed (biogas and energy needed for burning). When crystallization contact area is increased drying is more effective.

Sludge drying, where the content of dry matter is from 48 to 80 %, is not suitable for sticky mixture of sludge. In that case partially drying (from 30 to 48% d. m.) or total drying (from 80 to 97% d. m.) is more appropriate. Humid air, which leaves the dryer is filtrated, before it is emitted to the atmosphere.

Selection of optimal dryer is essential. Because of its great influence on environment, and consequentially of public health, it is necessary to select the dryer which have previously been fully examined.

At the very end, based on serious of analysis, it can be concluded that rotational dryer is better choice for sludge drying than fluidized bed dryer.

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