ARISTOTLE UNIVERSITY OF THESSALONIKI
FACULTY OF RURAL & SURVEYING ENGINEERING
DEPARTMENT OF TRANSPORTATION & HYDRAULIC ENGINEERING

LAB. OF HYDRAULIC WORKS & ENVIRONMENTAL MANAGEMENT

DEWATERED BIOLOGICAL SLUDGE VALORIZATION BY VERMICOMPOSTING AND SOLAR DRYING IN OPEN GREENHOUSE

Athanasios Guitonas, Professor AUTh, Lab.Director

E.K. Oikonomou, Assistant Professor AUTh

UNESCO INWEB Aristotle University of Thessaloniki

UNESCO CHAIR & NETWORK
INTERNATIONAL NETWORK OF
WATER-ENVIRONMENT CENTRES FOR THE BALKANS
ARISTOTLE UNIVERSITY OF THESSALONIKI, GREECE

BIOLOGICAL SLUDGE DISPOSAL AND MANAGEMENT

GREAT IMPORTANCE:

- Great costs
  Apart from operational cost, 35 € / tn for biosolids since 2014 + 5 € / annually until 2020.
- Environmental restrictions.

SOLUTION:

- Implementation of vermicomposting transforming dewatered biological sludge to stabilized organic matter, suitable to be used as organic fertilizer.
- And solar biological sludge drying in open greenhouse.

BIOLOGICAL SLUDGE DISPOSAL AND MANAGEMENT

PREPARATION PHASE:

- Infrastructure needed for "V" is related to an impervious concrete surface on which biosolids are accumulated. A preliminary surface of 500 m^2 is used in the beginning of the process.

  Draining, runoff and evaporation of a great amount of sludge moisture takes place with the aid of mixing sludge together with carbon sources (e.g. straws, sawdust, branches, etc.) for ratio C/N = 25 – 35.
- Platform of impervious concrete surface, with little slope and protective outline for runoff collection.

BIOLOGICAL SLUDGE DISPOSAL AND MANAGEMENT

VERMICOMPOSTING PHASE:

- Use of Eisenia Foetida worms in initial concentration of around 1.0 – 2.5 kg / m^2, which, as time goes by, becomes more than 2.5 kg / m^2.
- Windrows of 0.5 m height because earthworms cannot tolerate temperature beyond 30^oC.
- Metabolic activities and bacterial competition leading to disappearance of pathogens after 90 days of vermicomposting.
- In international literature, reference to disappearance of pathogens and reduction of heavy metals Cr, Cd, Pb, Cu, Hg and Zn.
- Decrease in moisture from 80% to 65-70%.

BIOLOGICAL SLUDGE DISPOSAL AND MANAGEMENT

VERMICOMPOSTING PHASE:

- Vermicomposting surface: $S_{vermi} = 2/3 \times V_{year} \times 1.2\ (m^2)$ for three periods of 90 days process annually.
- Production of CO_2 and H_2O which is collected in a tank – 'compost-tea' is produced, a liquid of high agronomic value.
- The tank for the collection of H_2O has a volume of 50 m^3, bicameral, for better liquid mass balance management (precipitation, evaporation, irrigation, runoff, H_2O production), depending on the climatology regime of each area.

BIOLOGICAL SLUDGE DISPOSAL AND MANAGEMENT

SOLAR DRYING:

- Open platform of impervious concrete surface on which we spread biological sludge at height of 0.1 m.
- Biological sludge is mixed/blended by a rotary cultivator.
- The open platform is covered by an open type greenhouse for protection from sudden rain, with a chimney-like opening for acceleration of evaporation and reduction of moisture.

BIOLOGICAL SLUDGE DISPOSAL AND MANAGEMENT

SOLAR DRYING:

- Final humidity after solar drying: 40%.
- The quantity of water Q (kg H_2O / y) that evaporates

$$Q = [\ V \times (1 - DS_i / DS_f)\ ] \times 1000$$

  where V (m^3) the sludge volume on the greenhouse platform και DS_i και DS_f are the values of total sludge solids (%) before and after drying.
- In North Greece Mathioudakis, et al. (2013) have calculated the drying speed of dewatered biological sludge, from initial humidity of ~86%, U_{dr} = (8 – 11.4) kg H_2O / m^2 d, in an open aerated greenhouse, for a period between June to September.

EXPERIMENTAL PROCESS

INTRO:

- Experiments conducted for treatment of biological sludge by vermicomposting and solar drying by the Lab. of Hydraulic Works and Environmental Management, within the Research Project funded by the Municipal Enterprise for Water Distribution and Sewerage Systems of Drama.
- Experiments took place at the facilities of the company BIOORAMA, which breeds earthworms and has platforms suitable for vermicomposting.
- Dewatered biological sludge by belt filter presses, with final concentration solids (DS) ~20% and quantity produced 9 m^3/d.
- WWT by extended aeration with sludge age $\Theta d = 21$ d.

EXPERIMENTAL PROCESS

INTRO:

- Sludge control, in relation to the concentration limits of heavy metals for agricultural use (Directive 86/278 EC, Appendix 1B and Joint Ministerial Decision 80568/4225/ 1991), with analyses conducted by the Technological Educational Institute of Kavala.

Samples of dewatered biological sludge at different periods of time	Concentration of heavy metals in dewatered biological sludge of the WWTP of Drama (mg/kg)	Limits of heavy metals in sludge for agricultural use (Directive 86/278 EC) (mg/kg)
Cu	143 – 191	1.000 – 1.750
Cr Total	42 – 239	Total: 510 CrIII: 500
Cr(VI)	0.28 – 3.8	10
Ni	33 – 64	300 - 400
Pb	41 – 70	750 – 1200
Cd	1.2 – 7.3	20 – 40
Zn	1135 – 1327	2500 – 4000
Hg	0.2 – 0.9	16 – 25

EXPERIMENTAL PROCESS

VERMICOMPOSTING PREPARATION PHASE:

- Transportation of sludge 20 m^3, with initial moisture ~80%, to a preparation surface, adjustment of the ratio C/N, with straws, which is mixed to reach C/N = 32.
- Runoff and evaporation of a small percentage of the initial moisture of the biological sludge.
- Use of earthworms «Eisenia Foetida», moisture reduction to ~70% and beginning of vermicomposting.

EXPERIMENTAL PROCESS

MAIN VERMICOMPOSTING PHASE:

- After solar drying and in case of pelletization, further hygienization is achieved, with more pathogens' reduction, absence of Salmonella Spp and values of E.Coli < 3 cfu/g

	E. Coli	Salmonella Spp.
Before vermicomposting	49000 cfu/g	presence
After vermicomposting	< 3/g	absence/25g

- At the end of vermicomposting, reduction of sludge volume by 50% (10 m^3) and concentration reduction of seven heavy metals.

EXPERIMENTAL PROCESS

Concentration of heavy metals in dewatered biological sludge of the WWTP of Drama after 90 days of vermicomposting

Samples of dewatered biological sludge at different periods of time	Concentration of heavy metals in dewatered biological sludge before vermicomposting (mg/kg)	Concentration of heavy metals in dewatered biological sludge after vermicomposting (mg/kg)
Cu	143 – 191	22.1
Cr(VI)	0.28 – 3,8	< 0,1
Ni	33 – 64	1.44
Pb	41 – 70	6.65
Cd	1.2 – 7.3	< 0.4
Zn	1135 – 1327	271
Hg	0.2 – 0.9	Non-traceable

EXPERIMENTAL PROCESS

MAIN VERMICOMPOSTING PHASE:

- Production of humic and fulvic acids, which diminish pH from 6.7 to 5.8 and solubilize a part of divalent heavy metals in sludge (all except for Cr^{+6}), which leave with runoff ('compost-tea').
- Collection of runoff in a tank, adding flocculants for divalent heavy metals sedimentation.
- The runoff collected in the tank may be recycled at the entrance of the WWTP for treatment, when vermicomposting takes place within the area of the WWTP.

EXPERIMENTAL PROCESS

MAIN VERMICOMPOSTING PHASE:

- The sediment of heavy metals may be disposed to a sanitary landfill site.
- As a result of the two processes, the final heavy metals' concentration in vermicomposted sludge is very low, which covers the demands of European Directive 86/278 EC.
- Extended aeration in WWTP of Drama leads to biological sludge with very high value of stabilization, meaning that sludge is no more waste, but stabilized humus-like material, with excellent soil conditioning properties.

EXPERIMENTAL PROCESS

MAIN VERMICOMPOSTING PHASE :

- Dewatered sludge preparation for vermicomposting and vermicomposting

PREPARATION

VERMICOMPOSTING

VERMICOMPOSTING

EXPERIMENTAL PROCESS

SOLAR DRYING:

- After vermicomposting, experimental measurement of partial solar drying rate of vermicomposted sludge, in days of total sunshine, with continuous mixing by a rotary cultivator.
- The vermicomposted sludge V = 10 m^3 is placed on a platform, with 0,1 m height, for solar drying, loses weight and volume, and moisture decreases from 65% (DS_i = 35%) to 40% (DS_f = 60%).

EXPERIMENTAL PROCESS

SOLAR DRYING:

- Solar drying of vermicomposted sludge at the facilities of BIOORAMA.

EXPERIMENTAL PROCESS

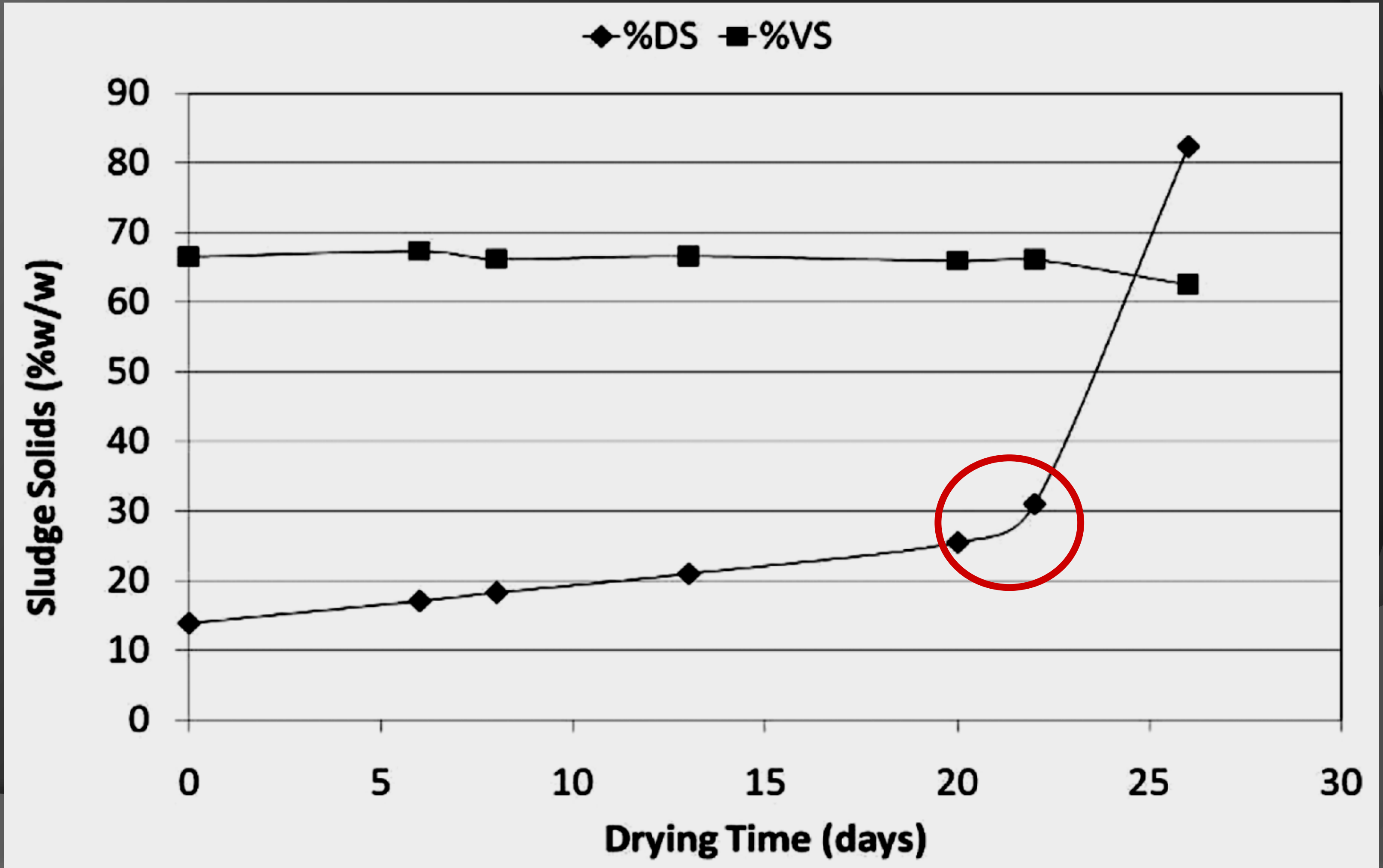
SOLAR DRYING :

- ~ 4-5 days (4.5 days) necessary for moisture reduction.
- Solar drying rate U_{dr} = 9.3 kg H_2O / m^2 d.
- The partial solar drying rate calculated is also estimated by Mathioudakis et al. (2013) for the part of the curve of the drying time (vs) solids percentage (% w/w) > 30% to 75%.

Experi-ment	Month	Solar drying rate (kg H_2O / m^2 d)	Experi-ment	Month	Solar drying rate (kg H_2O / m^2 d)
1	May	2.5	5	September	8.4
2	June	11.4	6	October	7.5
3	June	9.8	7	April	4.0
4	July	8.0	8	May	9.2

EXPERIMENTAL PROCESS

SOLAR DRYING: Typical sludge behavior during solar drying process and volatile solids reduction.



EXPERIMENTAL PROCESS

SOLAR DRYING:

- In order to deal with sudden rainfall, and morning humidity, coverage of the platform by open greenhouse, with a chimney-like opening, so as to avoid using mechanical aerators.
- Solar drying rates in open greenhouse are similar to those of air-drying because we always refer to the part of the curve of drying time (vs) solids percentage (% w/w) > 30% and up to 75%.
- Thus, no odor appears.
- Further pathogens' reduction takes place due to UV-light.

EXPERIMENTAL PROCESS

SOLAR DRYING:

- Solar drying takes place in an open greenhouse

RESULTS AND DISCUSSION

ANALYSES BY THE GREEK ORGANIZATION OF AGRICULTURE - DEMETRA:

- Dewatered sludge with high values of organic matter (68%), relatively low values of total nitrogen (N_{tot} = 1.15%) and high ratio of C/N (29.56).
- After vermicomposting, reduction of organic matter to 54% and increase of total nitrogen (N_{tot}) to 4.7%, from which 2.07% is $(NO_3)^-N$, which increases sludge agronomic value, because such nitrogen is directly disposed to the plants.

RESULTS AND DISCUSSION

ANALYSES BY THE GREEK ORGANIZATION OF AGRICULTURE - DEMETRA:

- Increase of other elements, e.g. phosphorus (P) from 1.5% to 1.86% and potassium (K) from 0.40% to 5.86%.
- Final ratio C/N = 6 so high stabilized sludge.
- Almost zero pathogens (absence Salmonella Spp. and E.Coli <3 cfu/g) after vermicomposting, solar drying and pelletization.
- Great reduction of heavy metals.

RESULTS AND DISCUSSION

ANALYSES BY THE GREEK ORGANIZATION OF AGRICULTURE - DEMETRA :

- Before and after vermicomposting.

Elements - nutrients	Percentage % dry matter
N total	1.14%
P total	1.5%
K total	0.40%
Organic matter	67%
After solar drying 14,94% sludge moisture.	54%

$N\text{-}NH_4$ % dry matter	N Kjeldahl % dry matter	$N\text{-}NO_3$ % dry matter	P mg/kg (dry matter)	K mg/kg (dry matter)	Ca mg/kg (dry matter)	Mg mg/kg (dry matter)	Fe mg/kg (dry matter)
0.29	4.7	2.07	1.86	5.86	5.252	961	99.1

RESULTS AND DISCUSSION

SOLAR DRYING:

- Partial solar drying rate calculated to V_{dr} = 9.3kg H_2O / m^2 d.
- Moisture reduction of vermicomposted sludge from 65% to 40% after of 4.5 days of total sunshine.
- Dependence of solar drying rate from the value of radiation in each area and based on this, the necessary surface for solar drying is calculated.
- In the experiment, implementation of solar drying at the part of the curve of solids percentage (%w/w) > 30% to 70%, where very fast drying takes place even in areas with low solar radiation.

RESULTS AND DISCUSION

SLUDGE DISPOSAL:

- For the commercial sludge disposal, there is a further possibility for further humidity reduction up to 25% ant then pelletization.
- Pelletization leads to better results of hygienization.
- Easy use of pellet in agriculture.
- 20% is the best humidity for sludge conservation as pellet and best agricultural use – with lower values of humidity powder is produced making it less easy to manage.

CONCLUSIONS

PROPOSED METHODOLOGY FOR BEST BIOLOGICAL SLUDGE MANAGEMENT:

- Zero or very low pathogens values, so vermicomposted sludge may be used as a fertilizer at vast cultivations.
- It meets legislation requirements Directive 86/278 EC and 80568/4025/1991 Joint Ministerial Decision.

CONCLUSIONS

PROPOSED METHODOLOGY FOR BEST BIOLOGICAL SLUDGE MANAGEMENT:

- For valorization of dewatered biological sludge with volume of V = 2.800 m^3 / y, with humidity 80%, from the WWTP of Drama, with the combined method of vermicomposting and solar drying, only a total surface of $S_{tot} \approx 3.500\ m^2$ of platforms is needed.
- The methodology may easily be implemented in areas with Mediterranean climate, and for medium sized WWTPs (~ 20m^3/d dewatered sludge)
- Low investment method with low operational costs.

RESEARCH OF LABORATORY OF HYDRAULIC WORKS & ENVIRONMENTAL MANAGEMENT AUTh

Thank you for your attention!

Athanasios Guitonas, Professor AUTh

Laboratory Director

guitonas@topo.auth.gr

++30 69774405186 ++30 2310996104

UNESCO CHAIR & NETWORK
INTERNATIONAL NETWORK OF
WATER-ENVIRONMENT CENTRES FOR THE BALKANS
ARISTOTLE UNIVERSITY OF THESSALONIKI, GREECE

INWEB

Aristotle University of Thessaloniki