ELECTRONIC SUPPLEMENTARY INFORMATION (ESI)

Mathematical modeling to size anaerobic stabilization ponds intended for slaughterhouse wastewater treatment – the role of temperature and hydraulic retention time

Summary

Table S1 – Temperature (ºC) ranges for anaerobic digestion

Reference	Psychrophilic	Mesophilic	Thermophilic
(MATHERI et al., 2016)	<20	30-42	43-55
(SINDALL, 2014)	< 20	30-40	50-60
(ZHANG et al., 2014)	10-30	30-50	50-60
(DENG et al., 2014)	15-25	35-37	55-60
(YENIGÜN; DEMIREL, 2013)	-	30-40	45-65
(DROSG, 2013)	-	36-43	50-65
(MANYI-LOH et al., 2013)	< 20	25-37	55-65
(TORTORA; FUNKE; CASE, 2012)	< 20	20-40	45-70
(VINDIS et al., 2009)	12-16	35-37	55-60
(AL SEADI et al., 2008)	< 25	25-45	45-70
(DEUBLEIN; STEINHAUSER, 2008)	< 25	25-45	> 65

(EL-MASHAD; ZHANG, 2010)	< 25	25-40	> 65
(ANGELIDAKI; SANDERS, 2004)	< 20	25-40	45-60
(BURKE, 2001)	< 20	20-40	43-71

SELORMEY, G. K. et al. A review of anaerobic digestion of slaughterhouse waste: effect of selected operational and environmental parameters on anaerobic biodegradability. **Reviews in Environmental Science and Biotechnology,** Springer Science and Business Media B.V.,1 dec. 2021.

Figure S1 - E_{COD} as a function of t_p (days) for all studied temperatures (^{0}C)

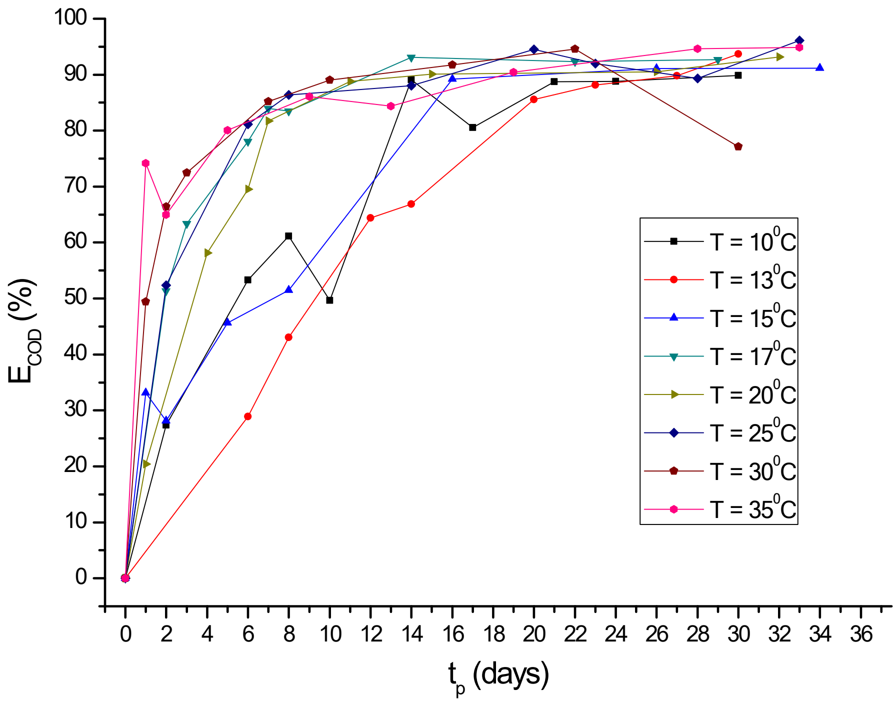
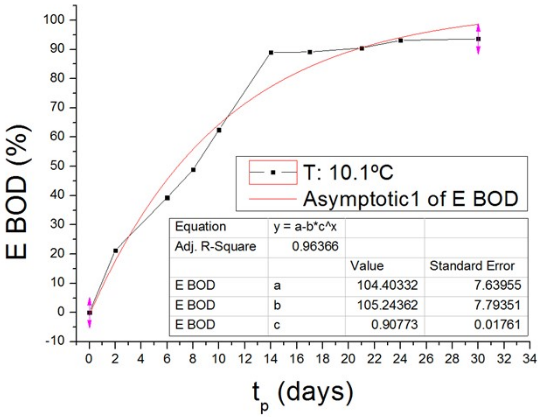
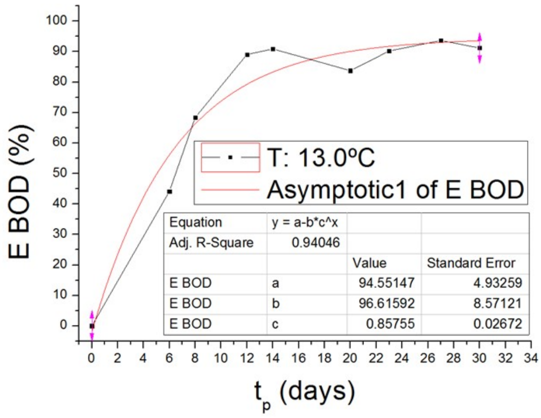
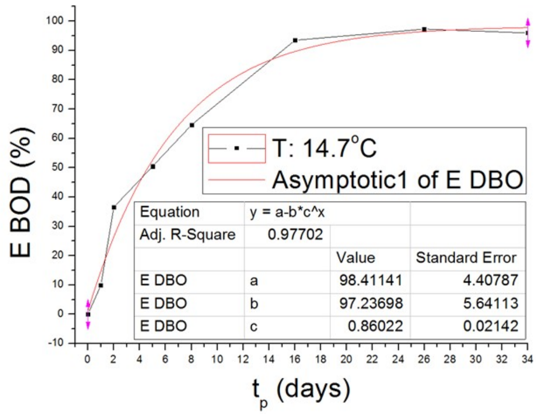
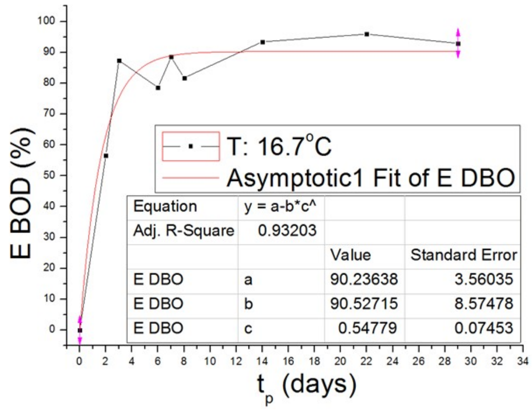


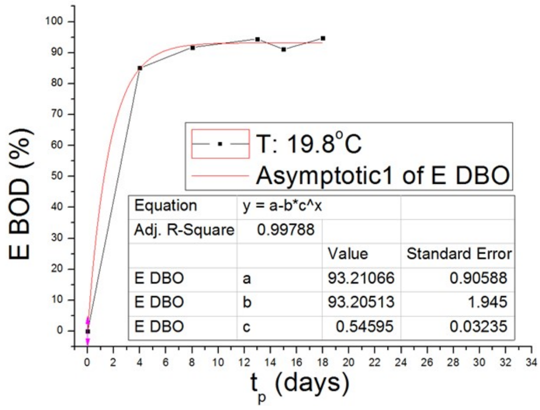
Figure S2 - Individual asymptotic regression model as a function of temperature (Figure S2)

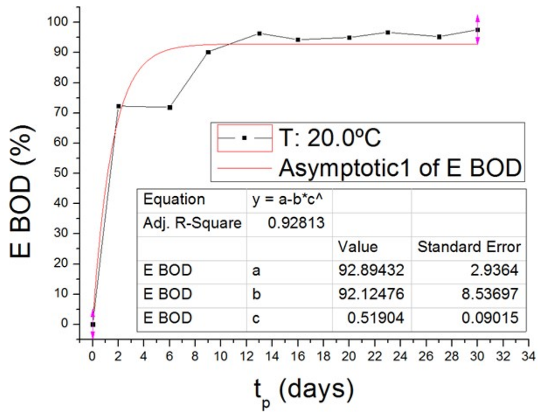

T: 10.1ºC
Asymptotic1 of E BOD
Equation | y = a-b*c^x
Adj. R-Square | 0.96366
Value | Standard Error
E BOD | a | 104.40332 | 7.63955
E BOD | b | 105.24362 | 7.79351
E BOD | c | 0.90773 | 0.01761
E BOD (%)
tp (days)

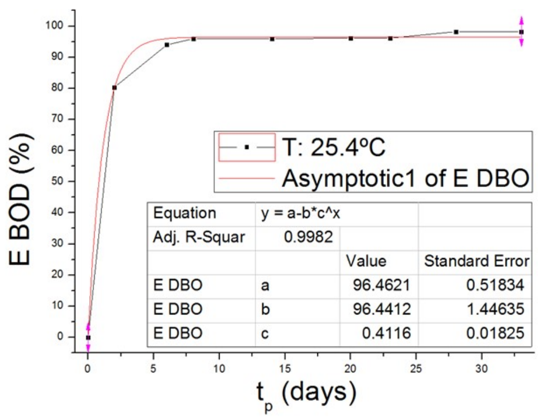

T: 13.0ºC
Asymptotic1 of E BOD
Equation | y = a-b*c^x
Adj. R-Square | 0.94046
Value | Standard Error
E BOD | a | 94.55147 | 4.93259
E BOD | b | 96.61592 | 8.57121
E BOD | c | 0.85755 | 0.02672
E BOD (%)
tp (days)


T: 14.7°C
Asymptotic1 of E DBO
Equation | y = a-b*c^x
Adj. R-Square | 0.97702
Value | Standard Error
E DBO | a | 98.41141 | 4.40787
E DBO | b | 97.23698 | 5.64113
E DBO | c | 0.86022 | 0.02142
E BOD (%)
tp (days)


T: 16.7°C
Asymptotic1 Fit of E DBO
Equation | y = a-b*c^
Adj. R-Square | 0.93203
Value | Standard Error
E DBO | a | 90.23638 | 3.56035
E DBO | b | 90.52715 | 8.57478
E DBO | c | 0.54779 | 0.07453
E BOD (%)
tp (days)


T: 19.8°C
Asymptotic1 of E DBO
Equation | y = a-b*c^x
Adj. R-Square | 0.99788
Value | Standard Error
E DBO | a | 93.21066 | 0.90588
E DBO | b | 93.20513 | 1.945
E DBO | c | 0.54595 | 0.03235
E BOD (%)
tp (days)


T: 20.0ºC
Asymptotic1 of E BOD
Equation | y = a-b*c^
Adj. R-Square | 0.92813
Value | Standard Error
E BOD | a | 92.89432 | 2.9364
E BOD | b | 92.12476 | 8.53697
E BOD | c | 0.51904 | 0.09015
E BOD (%)
tp (days)


T: 25.4ºC
Asymptotic1 of E DBO
Equation | y = a-b*c^x
Adj. R-Squar | 0.9982
Value | Standard Error
E DBO | a | 96.4621 | 0.51834
E DBO | b | 96.4412 | 1.44635
E DBO | c | 0.4116 | 0.01825
E BOD (%)
tp (days)

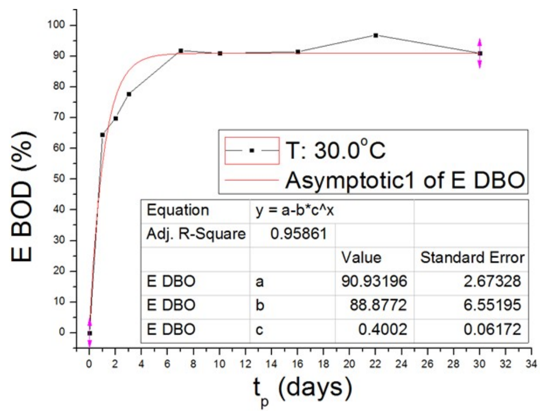

T: 30.0°C
Asymptotic1 of E DBO
Equation | y = a-b*c^x
Adj. R-Square | 0.95861
Value | Standard Error
E DBO | a | 90.93196 | 2.67328
E DBO | b | 88.8772 | 6.55195
E DBO | c | 0.4002 | 0.06172
E BOD (%)
tp (days)

Figure S2 - Individual asymptotic regression model as a function of temperature (Figure S2) - continuation

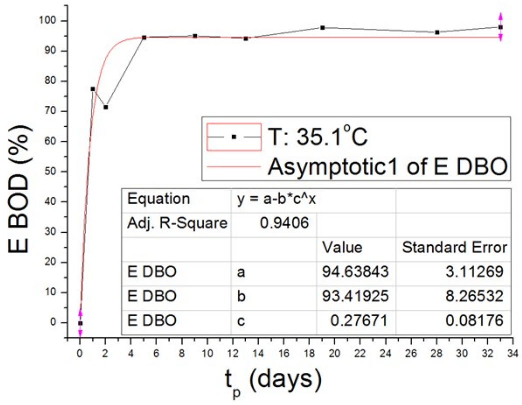
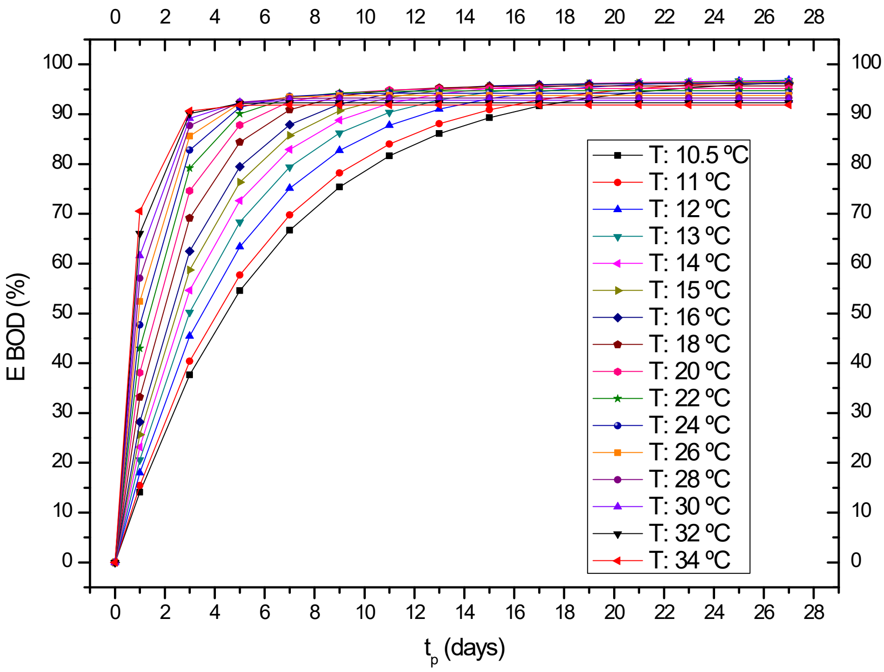


Figure S3 - Simulation of E_{BOD} vs t_p for theoretical temperatures within the studied range using the Equation 11



EXAMPLE OF APPLICATION: USE OF PROPOSED MODEL FOR SWTTP DIMENSIONING.

A certain slaughterhouse has the capacity of 750 slaughters per day (preliminary project estimation), generating a contribution of 2,000 L of effluent *per capta*. Admitting a safety factor of 25%, wastewater production is estimated in 1,875 m^3 day^{-1}. BOD concentration of raw wastewater is 1,200 mg O_2 L^{-1}. Average temperature for the coldest month is 16 °C. The environmental legislation preconizes a minimum BOD organic load removal of 95% before discharge into natural waterbodies. How could the constructive project of a SWWTP be for meeting this demand?

ANSWER:

INPUT DATA:

T (average air temperature): 16 °C;
Q (input flow): 1,875 m^3 day^{-1};
S_0 (input BOD): 1,200 mg O_2 L^{-1}, or simply mg L^{-1};
E_{BOD} : 95% BOD removal;
$HRT_{total} \cong t_p$ (days);

a) Estimating the total hydraulic retention time (HRT_{total}) using the proposed model (Equation 13):

$$HRT_{total}(days) = \frac{\left\{log\left[-\frac{E_{BOD} - (100 - 0.24T)}{(102 - 0.34T)}\right]\right\}}{log(1.12 - 0.026T)}$$

$$HRT_{total}(days) = \frac{\left\{log\left[-\frac{95 - (100 - 0.24 * 16)}{(102 - 0.34 * 16)}\right]\right\}}{log(1.12 - 0.026 * 16)}$$

$$HRT_{total}(days) = \frac{\left\{log\left[-\frac{95 - (96 * 16)}{(97)}\right]\right\}}{log(0.704)}$$

$$HRT_{total}(days) = \frac{log(0.012)}{log(0.704)} = 12.7 days$$

b) Calculating the total SWWTP volume (Equation 14):

$$V_{total} = HRT_{Total} \times Q$$

$$V_{total} = 12.6 * 1{,}875 = 23.6\ m^3$$

c) Determining how many ponds (n) will be constructed:

Considering field characteristics, 4 equivalent ponds (opted by the user).

d) Determining individual volume of each pond

Admitting 4 equivalent ponds, $V_n = \frac{23.6}{4}$ = **5,900 m³**

e) Estimating the accumulated HRT (HRT_n) for each pond in the system (for equivalent ponds):

$$HRT_n = \frac{HRT_{total}}{n_{total}} \times n$$

In which *n* = position of the pond in the sequential system

Obs: for ponds with different dimensions, HRT_n is calculated by summing the HDT of the individual predecessor ponds.

After the 1st pond (n = 1), HRT_1 = 3.2 days. For n = 2, HRT_2 = 6.4 days and so on, totaling HRT_4 = 12.7 after the 4th pond, disregarding little rounding calculations.

f) Estimating the accumulated BOD removal efficiency ($E_{BOD,\ n}$) for each pond in the system, considering the proper HRT_n (Equation 11):

$$E_{BOD,\,n} = (100 - 0.24T) - [(102 - 0{,}34T) \times (1.12 - 0{,}026T)^{HRT_n}]$$

Admitting T = 16 °C, for the first anaerobic pond (n = 1) the value of HRT_1 = 3.2 days and $E_{BOD,\ 1}$ = 64.3%. After the 2nd pond, the accumulated BOD removal is 85.5% and so on.

g) Calculating the output BOD ($S_{out,\ n}$) for each pond:

$$S_n = S_0 - \left(S_0 * \frac{E_{BOD,\,n}}{100}\right)$$

For the first pond, $S_{out,\ 1}$ = 428 mg L^{-1}; after the 2nd pond, the residual BOD is $S_{out,\ 2}$ = 174 mg L^{-1} and so on.

In summary, the performance of the anaerobic pond system is:

	HRT_{acc} (days)	$E_{BOD,\ acc}$ (%)	S_{out} (mg L^{-1})
Anaerobic pond 1	3.2	64.3	428
Anaerobic pond 2	6.4	85.5	174
Anaerobic pond 3	9.6	92.7	88
Anaerobic pond 4	12.7	95.0	60