

## DESIGN SHEET

CLIENT id:

DOCUMENT Nr:

Reference Nr:

// Rv.

// R2-1

PROJECT TITLE: WW Enterprises : BRFWF

STATUS:  
DRAFT \* FOR COMMENTEngineer: Date:  
25/07/2025

SUBJECT /Elem.t: PDST OFF-GAS IED Compliance :: Element

Checked by: Date:  
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Ref:

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## SECT.N: MAD-2 (D1 and D3) - FOOD WASTE REACTORS:

## P1-1 BIOGAS PRODUCTION RATES.

Std. Calc. Module. Rev.: 3.3

Specific Worksheet Ref.: -

Gravity Accel, G: [m/s<sup>2</sup>]

9.80665

Convert Press. [Bar.g] to [m.wg]

10.197162

Convert Press. [kN] to [kg.f]

101.97162

## P1-1.2 DATA:

IDEAL GAS: Eqn. of State:

Vm - Molar Volume at STP:

22.414 [Ltr]

STP: T.abs. =

273.150 [K]

{V=n.R.Ta/Pa}

R=R<sub>ij</sub>=

8314.46261820 [KJ/mol.K]

Pamb.= Pa =

101325.000 [Pa.] / [N/m<sup>2</sup>]

Compressibility, Z:

0.99 [-]

1013.250 [mbar.g]

Const.

39.166307 [-]

## P1-1.3 DESIGN CONDITIONS:

BIOGAS

T1:

Mean BIOGAS Temperature:

38.00 [°C]

T1<sub>abs</sub>:

311.15 [°C]

Operating

P1:

Mean Reactor Gas Space Operating Pressure:

27.95 [mBar.g]

P1<sub>a</sub>:

1041.20 [mBar.g]

Parameters:

n:

Conversion Factor to Normalised Conditions, STP:

0.9021 [-]

STD: T=0 °C, P=1.0 Bar.g

Sludge

Parameters:

sa:

Sediment allowance:

12.00% [%tge]

Typ. 0.5% ... 0.7% /annum:

Qty /Units:

N:

Number of digester reactors:

2 [-]

## P1-1.4 REACTOR: SLUDGE Side.

Physical  
Data.

di:

Reactor diameter (Internal):

18.288 [m]

From:

Available GA drgs.

h2:

Working cylinder Int.nl depth /effective Sludge height.

9.070 [m]

Ax:

Reactor cross-sectional area, (plan):

262.677 [m<sup>2</sup>]

H1:

Overall External exposed side wall height of Reactor.

8.92 [m]

SA<sub>shell</sub>:

Surface Area - SHELL:

512.568 [m<sup>2</sup>]

V1:

Reactor - Principal, cylinder sludge Volume.

2382.48 [m<sup>3</sup>]

V2:

Reactor - Truncated Base cone sludge Volume.

299.01 [m<sup>3</sup>]

VT:

Reactor - Total Theoretical Sludge Volume.

2681.488 [m<sup>3</sup>]

VE:

REACTOR - EFFECTIVE Working Sludge Volume.

2359.709 [m<sup>3</sup>]

per Reactor.

VT<sub>Loss</sub>:

Working volume loss.

321.78 [m<sup>3</sup>]h<sub>sed</sub>:

Estimated sediment depth, in cylinder, above cone.

0.09 [m]

## P1-1.5 REACTOR: GAS Side.

Physical  
Data.

R1:

Effective cone radius at cylinder top ring Level (Internal):

8.910 [m]

Virtual cone cap radius.

R2:

Effective cone radius at crown ring Level (Internal):

0.050 [m]

R1 - R2 :

Annular radius of truncated roof cone:

8.860 [m]

h3:

Truncated roof cone height:

h<sub>1</sub> :

1.908 [m]

Roof Inclination angle /pitch:

12.151 [°]

SA<sub>1</sub> :

Surface Area of Roof inclination: Lateral area.

255.084 [m<sup>2</sup>]SA<sub>2</sub> :

Surface Area of Cone Cap, flat (Top):

0.008 [m<sup>2</sup>]SA<sub>Rf</sub> :

TOTAL Surface Area - ROOF:

255.092 [m<sup>2</sup>]

Apothem of truncated roof cone:

9.063 [m]

V<sub>Rf</sub> :

GAS VOLUME contained in truncated roof cone:

V<sub>Rf</sub> :159.467 [m<sup>3</sup>]h<sub>Rf\_Cyl</sub> :

Effective cyl height above TSL (Top Sludge Level):

h<sub>Rf\_Cyl</sub> :

1.481 [m]

V<sub>Rf\_Cyl</sub> :

GAS VOLUME contained in cylinder above TSL:

V<sub>Rf\_Cyl</sub> :388.920 [m<sup>3</sup>]V<sub>Gas</sub>:

TOTAL GAS VOLUME in Reactor headspace:

548.387 [m<sup>3</sup>]

per Reactor.

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P1-1.6 REACTOR: FEEDSTOCK.

|            |                                                                                               |                                     |
|------------|-----------------------------------------------------------------------------------------------|-------------------------------------|
| DESIGN     | PRIMARY DIGESTION FEEDSTOCK TYPE:                                                             | FOOD WASTE                          |
| LIMITS:    | TSS-IN: DESIGN LIMIT FOR DIGESTION FACILITY (or Part thereof):                                | 21.500 [t.TSS/d]                    |
|            | TSS-IN: ACTUAL or PROPORTIONAL SHARE, Expressed as percent of Design Limit:                   | 100.00% [-]                         |
|            | DESIGN LIMIT: Proportionate DS Load Share:                                                    | Site Total: Per Reactor:            |
|            | TSS-IN: ACTUAL or PROPORTIONAL SHARE: TSS IN =                                                | 21.500 [t.DS/d] 10.75 [t.DS/d]      |
|            | TSS In: Dry Solids (DS) Range: Min -to- Max =                                                 | 9.98% [%tge DS] 9.50% ... 12.50%    |
|            | TEMPERATURE, Mixed Sludge T.feed =                                                            | 25.000 [°C]                         |
|            | MEAN VM Content Ratio: Range: 70% ...90% - VMr In =                                           | 89.50% [kg.VS /kg.DS]               |
| BATCH      | MAX TARGET REACTOR Feed Rate, per 24-hours Qf =                                               | 215.43 [m³/d] 107.72 [m³/d]         |
| /FEEDING   | PROCESS BATCHING FEED PERIOD, Bt =                                                            | 24.000 [hrs]                        |
|            |                                                                                               | Per Reactor: Per Reactor:           |
| SLUDGE     | Sludge Feed Rate: Pumped feed rate: Qp =                                                      | 4.99 [L/sec] *1 0.0050 [m³/s]       |
| PUMP -     | Feed Rate variance for solids rge: VSD range: Qp max =                                        | 6.00 [L/sec] Qp min = 3.00 [L/sec]  |
| FEED RATE: | Sludge Feed time per 24 hours: Volume feed time, VFt =                                        | 15.000 [mins /hr] 6.0000 [h /24hrs] |
|            | Mean Reactor Feed Volume Rate, per 24-hours, Qf =                                             | 107.78 [m³/d] 0.00125 [m³/s]        |
|            | *1 - Each Reactor is fed sequentially. Therefore pump rate = reactor feed rate per unit time. | 4.491 [m³/h]                        |

P1-1.7 REACTOR: HYDRAULIC RETENTION.

|           |      |                                              |               |              |
|-----------|------|----------------------------------------------|---------------|--------------|
| REACTOR   | HRT: | Actual, based on effective vol:              | 21.907 [Days] | 525.77 [hrs] |
| Hydraulic |      | Max. based on Theoretical reactor vol:       | 24.894 [Days] |              |
| Retention |      | Typical Min. Design Target [for Compliance]: | 19.00 [Days]  |              |
| Time:     |      |                                              |               |              |

P1-1.8 REACTOR: DIGESTION PROPERTIES - PER REACTOR.

|             |                                                                |                                   |                    |
|-------------|----------------------------------------------------------------|-----------------------------------|--------------------|
| SOLIDS      | Sludge mean dry solids (mass):                                 | 99.80 [kg /tonne wet sludge]      |                    |
| BALANCE:    | Total Susp.d Solids (TSS) in sludge feed:                      | Mean TSS In = 10750.00 [kg TSS/d] |                    |
|             |                                                                | TSS In = 9.98% [%tge]             |                    |
|             |                                                                | TSS Rem = 3697.62 [kg TSS/d]      |                    |
|             | Volatile Suspended Solids, (VSS) LOAD Input:                   | VSS In = 9621.25 [kg VSS/d]       |                    |
|             |                                                                | VSS In = 8.932% [%tge]            |                    |
|             |                                                                | VSS Rem = 2568.87 [kg VSS/d]      |                    |
|             | Inert Suspended Solids, (ISS) Input:                           | ISS In = 1128.75 [kg ISS/d]       |                    |
|             |                                                                | ISS In = 1.048% [%tge]            |                    |
|             |                                                                | ISS Rem = 1128.75 [kg ISS/d]      |                    |
| Primary     | PRIMARY MATTER Contribution: PM =                              | 100.000% [% Vol]                  |                    |
|             | Volatile solids destroyed: VSD Range: 70% ... 80% -            | 73.40% [VSD]                      |                    |
|             | Max Organic Loading Rate (OLR) for Primary Sludge:             | 5.00 [kg.VS /m³/d]                |                    |
| Secondary   | SECONDARY MATTER Contribution: VM =                            | 0.00% [% Vol]                     |                    |
|             | Volatile solids destroyed: VSD Range: 20% ... 50% -            | - - - [VSD]                       |                    |
|             | Max Organic Loading Rate for 50 /50 Primary /Secondary sludge: | 2.50 [kg.VS /m³/d]                |                    |
| SOLIDS      | COMBINED DESTRUCTION:                                          | 73.30% [VSD]                      | Tolerance... 0.10% |
| Destruction | VSS Destroyed                                                  | 7052.376 [kg /d]                  |                    |
|             | TSS Remaining in Digestate: Digestate TSS Out =                | 3.43% [%tge]                      |                    |
|             | VSS Remaining in Digestate: Digestate VSS Out =                | 2.38% [%tge]                      |                    |
| VS          | Actual VS Organic Loading Rate (OLR):                          | 4.077 [kg.VS /m³/d]               |                    |
| LOAD:       | MAX VS Loading:                                                | - - - [kg.VS /m³/d]               |                    |
| ALTERNATE   | DRY MASS OF DIGESTED SLUDGE: TSS Out =                         | 3697.624 [kg.DS/d]                |                    |
| METHOD      | DS CONTENT OF DIGESTED SLUDGE: TSS Out =                       | 3.43% [%tge]                      | Check Status:      |
| CHECK:      | MASS: VOLATILE SOLIDS DESTROYED: VSS Destroyed =               | 7052.376 [kg.VS/d]                | Ok - Good.         |

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P1-1.9 REACTOR: SUMMARY MASS BALANCE.

|                    |                  |         |                     |
|--------------------|------------------|---------|---------------------|
| FLOW <sub>IN</sub> |                  | 107.715 | [m <sup>3</sup> /d] |
| TSS <sub>IN</sub>  |                  | 9.980   | [%tge]              |
| TSS <sub>IN</sub>  |                  | 10750   | [Kg/d]              |
| VM                 |                  | 89.500  | [%tge]              |
| VSS <sub>IN</sub>  | S <sub>0</sub> = | 8.932   | [%tge]              |
| VSS <sub>IN</sub>  | S <sub>0</sub> = | 89321   | [mg/l]              |
| VSS <sub>IN</sub>  | S <sub>0</sub> = | 9621    | [Kg/d]              |
| ISS <sub>IN</sub>  |                  | 1.048   | [%tge]              |
| ISS <sub>IN</sub>  |                  | 1129    | [Kg/d]              |
| CHECK              |                  | Good    | [Kg/d] TSS          |

|                     |     |         |                     |
|---------------------|-----|---------|---------------------|
| FLOW <sub>OUT</sub> |     | 107.715 | [m <sup>3</sup> /d] |
| TSS <sub>OUT</sub>  |     | 3.433   | [%tge]              |
| TSS <sub>OUT</sub>  |     | 3698    | [Kg/d]              |
| VM                  |     | 69.474  | [%tge]              |
| VSS <sub>OUT</sub>  | S = | 2.385   | [%tge]              |
| VSS <sub>OUT</sub>  | S = | 23849   | [mg/l]              |
| VSS <sub>OUT</sub>  | S = | 2569    | [Kg/d]              |
| ISS <sub>OUT</sub>  |     | 1.048   | [%tge]              |
| ISS <sub>OUT</sub>  |     | 1129    | [Kg/d]              |
| CHECK               |     | Good    | [Kg/d] TSS          |

KEY:

TSS - Total Suspended Solids  
VSS - Volatile Suspended Solids  
ISS - Inert Suspended Solids  
VM - Volatile Matter  
VSD - Volatile Solids Destruction

P1-1.10 FATE OF INERTS (Mixed OR Accumulating)

VSD Calc. from MASS BALANCE:

Van Kleeck Formula: (Expected to be marginally higher)

Calculated under specific reactor gas yield determinations:  
MEAN VSD

MIXED

|  |        |        |
|--|--------|--------|
|  | 73.300 | [%tge] |
|  | 75.091 | [%tge] |
|  | 73.300 | [%tge] |
|  | 73.897 | [%tge] |

CHECK

2569 [Kg/d] VSS<sub>OUT</sub>

P1-1.11 REACTOR: BIOGAS PRODUCTION YIELDS:

SPECIFIC BioGas Unit Volume / TSS mass  
GAS PROD.n BioGas Unit Volume / VSS mass feed  
Yields. [SGP] BioGas Unit Volume / VSS mass destroyed

0.970 [Nm<sup>3</sup> CH<sub>4</sub> /Kg TSS]  
1.083 [Nm<sup>3</sup> CH<sub>4</sub> /Kg VSS]  
>> 1.478 [Nm<sup>3</sup> CH<sub>4</sub> /Kg VSD]

Calc. Check: :: ok.  
Calc. Check: :: ok.  
Calc. Check: :: ok.

P1-1.12 REACTOR: Unit gas production per kg VSS destroyed:  
GAS PROD.n Max Gas Production (Digested)  
FLOW Gas Production Yield for retention period:  
RATES:

96.768 [m<sup>3</sup>]  
5.113E-05 [m<sup>3</sup>/s per m<sup>3</sup>/sludge volume]  
0.121 [m<sup>3</sup>/s] per reactor  
10423.412 [m<sup>3</sup>/d] per reactor

ACTUAL:  
Uncorrected  
for Temp &  
Press.

Per Mass TSS Feed = 10423.412 [m<sup>3</sup>/d] per reactor  
Per Mass VSS Feed = 10423.412 [m<sup>3</sup>/d] per reactor  
Per Mass VSS destroyed = 10423.412 [m<sup>3</sup>/d] per reactor

MEAN, BIOGAS PRODUCTION

[Per Reactor] :: Estimate: 10423.412 [m<sup>3</sup>/d] 0.1206 [m<sup>3</sup>/s]  
[Combined] :: Estimate: 20846.82 [m<sup>3</sup>/d] 0.2413 [m<sup>3</sup>/s]

[Combined - Peak] :: Estimate: 23452.68 [m<sup>3</sup>/d] 0.2714 [m<sup>3</sup>/s]

P1-1.13 MAD-2 (D1 and D3) - FOOD WASTE REACTORS: BIOGAS PRODUCTION RATES.

**MEAN BIOGAS PRODUCTION [Normalised]:**

Normalising MEAN, BIOGAS PRODUCTION  
to STP: based on: 9.98 % TSS In.

[Per Reactor] :: Estimate:  
[Combined] :: Estimate:

[Nm<sup>3</sup>/d] [Nm<sup>3</sup>/h] [Nm<sup>3</sup>/s]  
**9402.84** 391.7848 0.1088  
18805.67 783.5697 0.2177

**PEAK BIOGAS PRODUCTION [Per Reactor, some 20mins post feed]. To be used in Sizing all Gas Take-off Branch pipework.**

Apply PEAK Due to sequential reactor feed, gas yield will fluctuate. Gas off-take piping and PRV needs to accommodate max  
FACTORS for instantaneous yield:

PIPE SIZING: Gas Yield Peak Factor for active Reactor, post feed:

Pkf =  $\frac{[-]}{[Nm^3/d]}$  Typical value: 1.1 ... 1.5  
**1.25** [Nm<sup>3</sup>/d] [Nm<sup>3</sup>/h] [Nm<sup>3</sup>/s]  
**11753.54** 489.7310 0.1360  
21156.38 881.5159 0.2449

PEAK, BIOGAS PRODUCTION

[Per Reactor] :: Estimate:  
[Combined] :: Estimate:

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STATUS:  
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25/07/2025

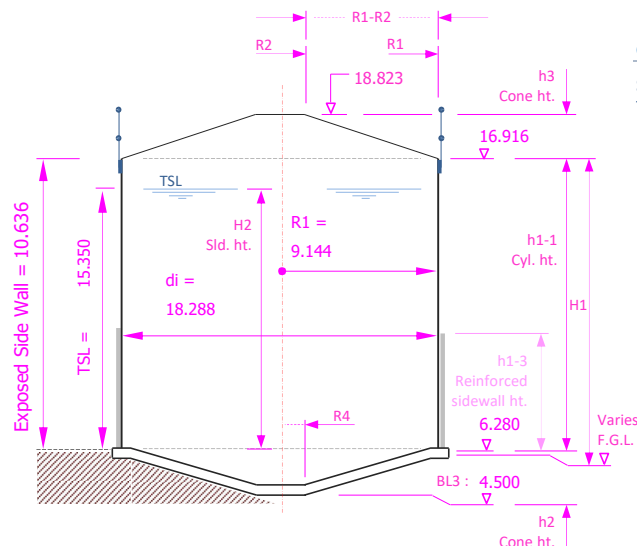
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- - - - -

Ref:

&gt;&gt;&gt; References / Results

P1-1.14 FIG: 1.0 SUMMARY REACTOR ARRANGEMENT



## CORE DETERMINATIONS:

## SIDE WALL CONSTRUCTION

|       |            |                                                             |
|-------|------------|-------------------------------------------------------------|
| TYPE: |            | - CONCRETE                                                  |
| h1-1: | 10.636 [m] | - Section height: Reactor Cylinder Side Wall.               |
| H1:   | 8.916 [m]  | - Overall External Exposed Side Wall Height of Reactor.     |
| h1-2: | 1.720 [m]  | - Section height: Reactor buried side wall height.          |
| h1-3: | - - - [m]  | - Section height: Reactor cylinder side wall reinforcement. |
| H2:   | 9.070 [m]  | - Internal working sludge height of Reactor.                |
| ::    | 3.473 [m]  | - Int.nl max. gas headspace between TSL and gas take-off.   |
| ::    | 11.450 [m] | - PVRV discharge height above adj. ground level (Approx).   |

## REACTOR ROOF -INTERNAL:

|                                                 |                    |                           |                                |
|-------------------------------------------------|--------------------|---------------------------|--------------------------------|
| Base cone radius (Extern.l) at top ring Lvl:    | R <sub>1</sub> :   | 9.144 [m]                 |                                |
| Truncated roof height:                          | h <sub>1</sub> :   | 1.908 [m]                 |                                |
| Annular radius of truncated roof cone:          | R1 - r :           | 9.094 [m]                 |                                |
| Roof Inclination angle /pitch:                  |                    | 11.847 [deg.]             | Inclined Length: 9.292 [m]     |
| Virtual cone cap base radius:                   | r <sub>2</sub> :   | 0.050 [m]                 |                                |
| Virtual cone cap height:                        | h <sub>2</sub> :   | 0.010 [m]                 | Inclined Length: 0.051 [m]     |
| Surface Area of Roof inclination: Lateral area. | SA <sub>1</sub> :  | 268.386 [m <sup>2</sup> ] | Check: Lateral SA: 268.385 [m] |
| Surface Area of Cone Cap, flat (Top):           | SA <sub>2</sub> :  | 0.008 [m <sup>2</sup> ]   | Apothem of                     |
| TOTAL Surface Area - ROOF:                      | SA <sub>Rf</sub> : | 268.394 [m <sup>2</sup> ] | truncated cone roof: 9.292 [m] |
| Volume of truncated roof cone:                  | V <sub>Rf</sub> :  | 167.947 [m <sup>3</sup> ] |                                |

## REACTOR BASE - INTERNAL:

|                                              |                    |                           |                                |
|----------------------------------------------|--------------------|---------------------------|--------------------------------|
| Cone radius (Intern.l) at base of side wall: | R <sub>1</sub> :   | 8.900 [m]                 | Cone diameter: 17.800 [m]      |
| Truncated base cone depth:                   | d <sub>1</sub> :   | 1.780 [m]                 |                                |
| Annular radius of truncated base cone:       | R1 - r :           | 3.300 [m]                 |                                |
| Base slope /inclination angle:               |                    | 28.342 [deg.]             | Inclined Length: 3.749 [m]     |
| Virtual cone cap base radius:                | r <sub>2</sub> :   | 5.600 [m]                 |                                |
| Virtual cone cap depth:                      | d <sub>2</sub> :   | 3.021 [m]                 | Inclined Length: 6.363 [m]     |
| Surface Area of Base slope: Lateral area.    | SA <sub>1</sub> :  | 170.799 [m <sup>2</sup> ] | Check: Lateral SA: 170.800 [m] |
| Surface Area of Cone Cap, flat (Bottom):     | SA <sub>2</sub> :  | 98.520 [m <sup>2</sup> ]  | Apothem of                     |
| TOTAL Surface Area - BASE:                   | SA <sub>Rf</sub> : | 269.320 [m <sup>2</sup> ] | truncated cone roof: 3.749 [m] |
| Volume of truncated base cone:               | V <sub>Rf</sub> :  | 299.006 [m <sup>3</sup> ] |                                |

P1-1.15 PDST POST DIGESTION STORAGE TANK:

|                                                |                                      |                                      |
|------------------------------------------------|--------------------------------------|--------------------------------------|
| NUMBER OF TANKS:                               | 1 [-]                                |                                      |
| INTERNAL DIAMETER:                             | 10.230 [m]                           |                                      |
| INTERNAL SECTIONAL WORKING HEIGHT:             | 10.670 [m]                           |                                      |
| INTERNAL PLAN AREA:                            | 82.194 [m <sup>2</sup> ]             |                                      |
| OVERALL INTERNAL WORKING VOLUME:               | 877.004 [m <sup>3</sup> ]            | ≈ Per Tk. 877.004 [m <sup>3</sup> ]  |
| PDST VOLUME THROUGHPUT:                        | ≈ Total. 215.431 [m <sup>3</sup> /d] | ≈ Per Tk. 215.43 [m <sup>3</sup> /d] |
| PDST /SECONDARY STORAGE APPRX. RETENTION TIME: | * 4.071 [days]                       | ≈ Per Tk. 4.071 [days]               |

\* Excludes any minor mass and solids loss through pre-screening.

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- - - - -

Ref:

&gt;&gt;&gt; References / Results

SECT.N: **MAD-2 (D1 and D3) - FOOD WASTE REACTORS:****P1-2** BIOGAS CESSATION.

Std. Calc. Module. Rev.: 3.4

Gravity Accel, G: [m/s<sup>2</sup>] 9.80665

Convert Press. [Bar.g] to [m.wg] 10.19716213

Specific Worksheet Rev.: -

Convert Press. [kN] to [kg.f] 101.9716213

## P1-2.1 REACTOR: SUMMARY MASS BALANCE.

|                                    |         |                     |
|------------------------------------|---------|---------------------|
| FLOW <sub>IN</sub>                 | 107.715 | [m <sup>3</sup> /d] |
| TSS <sub>IN</sub>                  | 9.980   | [%tge]              |
| TSS <sub>IN</sub>                  | 10750   | [Kg/d]              |
| VM                                 | 89.500  | [%tge]              |
| VSS <sub>IN</sub> S <sub>o</sub> = | 8.932   | [%tge]              |
| VSS <sub>IN</sub> S <sub>o</sub> = | 89321   | [mg/l]              |
| VSS <sub>IN</sub> S <sub>o</sub> = | 9621    | [Kg/d]              |
| ISS <sub>IN</sub>                  | 1.048   | [%tge]              |
| ISS <sub>IN</sub>                  | 1129    | [Kg/d]              |
| CHECK                              | Good    | [Kg/d] TSS          |

|                        |         |                     |
|------------------------|---------|---------------------|
| FLOW <sub>OUT</sub>    | 107.715 | [m <sup>3</sup> /d] |
| TSS <sub>OUT</sub>     | 3.433   | [%tge]              |
| TSS <sub>OUT</sub>     | 3698    | [Kg/d]              |
| VM                     | 69.474  | [%tge]              |
| VSS <sub>OUT</sub> S = | 2.385   | [%tge]              |
| VSS <sub>OUT</sub> S = | 23849   | [mg/l]              |
| VSS <sub>OUT</sub> S = | 2569    | [Kg/d]              |
| ISS <sub>OUT</sub>     | 1.048   | [%tge]              |
| ISS <sub>OUT</sub>     | 1129    | [Kg/d]              |
| CHECK                  | Good    | [Kg/d] TSS          |

**KEY:**

TSS - Total Suspended Solids  
VSS - Volatile Suspended Solids  
ISS - Inert Suspended Solids  
VM - Volatile Matter  
VSD - Volatile Solids Destruction

Where:

S = concentration, whereas both % and kg are not concentrations.

Y = yield. Y is a product of the degradation. i.e., the degradation follows first-order kinetics, and CH<sub>4</sub> is produced as VSS is degraded/destroyed.

## P1-2.2 FATE OF INERTS (Mixed OR Accumulating)

## MIXED

VSD Calc. from MASS BALANCE:

Van Kleeck Formula: (Expected to be marginally higher)

Calculated under specific reactor gas yield determinations:

MEAN VSD

|        |        |
|--------|--------|
| 73.300 | [%tge] |
| 75.091 | [%tge] |
| 73.300 | [%tge] |
| 73.897 | [%tge] |

CHECK

|      |                           |
|------|---------------------------|
| 2569 | [Kg/d] VSS <sub>OUT</sub> |
|------|---------------------------|

## P1-2.3 SUMMARY OF RESPECTIVE OPERATING VOLUMES for Determination of HRT:

*REACTOR: Liquid Volumes*

No.

Value

Mesophilic Anaerobic Digestion, MAD-2, volume. 1 2681.488 [m<sup>3</sup> Each.]*Comments:*

Assumes 100% effective volume, hence theoretical.

Combined Effective Digester Volume

|         |                   |
|---------|-------------------|
| 2681.49 | [m <sup>3</sup> ] |
|---------|-------------------|

Digester HRT (Hydraulic Retention Time)

|        |        |
|--------|--------|
| 24.894 | [days] |
|--------|--------|

cf. 24.894 Chk: Good

Post Digestion Storage:

|       |        |
|-------|--------|
| 4.071 | [days] |
|-------|--------|

## P1-2.4 METHANE PRODUCTION YIELD, For Part of Facility Under Consideration:

VSS [kg/d] destroyed

|         |        |
|---------|--------|
| 7052.38 | [Kg/d] |
|---------|--------|

VSS [mg/l] destroyed

|          |        |
|----------|--------|
| 65472.29 | [mg/l] |
|----------|--------|

Mean Biogas Production, from Municipal sludge only

Y<sub>td, Biogas</sub>

|         |                      |
|---------|----------------------|
| 9402.84 | [Nm <sup>3</sup> /d] |
|---------|----------------------|

Biogas Production Rate

|       |                                           |
|-------|-------------------------------------------|
| 1.478 | [Nm <sup>3</sup> biogas/kg VSS destroyed] |
|-------|-------------------------------------------|

Methane Content

|        |        |
|--------|--------|
| 61.00% | [%vol] |
|--------|--------|

Methane GAS Production

Y<sub>m</sub> = Y<sub>td, CH<sub>4</sub></sub>

|          |                      |
|----------|----------------------|
| 5735.730 | [Nm <sup>3</sup> /d] |
|----------|----------------------|

Y<sub>R</sub> = Y<sub>td, CH<sub>4</sub></sub> Rate

|       |                                                     |
|-------|-----------------------------------------------------|
| 0.813 | [Nm <sup>3</sup> CH <sub>4</sub> /kg VSS destroyed] |
|-------|-----------------------------------------------------|

ACTUAL - Y<sub>R</sub> = Y<sub>td, CH<sub>4</sub></sub> Rate

|       |                                                    |
|-------|----------------------------------------------------|
| 0.902 | [m <sup>3</sup> CH <sub>4</sub> /kg VSS destroyed] |
|-------|----------------------------------------------------|

## P1-2.5 DURATION PROCESS UNIT(s) Have Been Removed from Service:

Date Digestion Reactor was removed from service:

|            |         |
|------------|---------|
| 05/07/2023 | Cmt.: - |
|------------|---------|

Date Calculations under taken to establish residual gas yield:

|            |  |
|------------|--|
| 21/01/2025 |  |
|------------|--|

Elapsed number of days:

|        |        |
|--------|--------|
| 565.00 | [days] |
|--------|--------|

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DOCUMENT Nr:

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// R2-1

PROJECT TITLE: WW Enterprises : BRWF

STATUS:  
DRAFT \* FOR COMMENTEngineer: Date:  
25/07/2025

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SECT.N: **MAD-2 (D1 and D3) - FOOD WASTE REACTORS:**

Source: Introduction to Biosystems Engineering.

**P1-3 FIRST ORDER KINETICS FOR GAS REMAINING AFTER DEGEDATION OF SLUDGE SOLIDS.**

Std. Calc. Module. Rev.: 3.4

Specific Worksheet Rev.: -

## P1-3.1 NARRATIVE:

Conc. of solids remaining at time, t,  
is given by:

$$S = (S_0 \cdot \exp(-k \cdot t)) \text{ at time, } t.$$

Conc. of solids degraded at time, t,  
is determined by:

$$S = S_0 - (S_0 \cdot \exp(-k \cdot t)) \text{ at time, } t.$$

Methane Yield, CH<sub>4</sub>:I.e. Vol of CH<sub>4</sub> produced at time, t  
= Y<sub>m</sub> \* YRWhere:S = concentration of the biodegradable organic matter (expressed as VS, COD or BOD) in the digester [Kg.m<sup>-3</sup>].k = First-order degradation kinetic rate constant. [Day<sup>-1</sup>]Note:k can be determined from known time t=HRT. Thus, calculate exponent constant k from known data at, t=t<sub>0</sub> and t=HRT, Thus:

## P1-3.2 DETERMINE KINETIC RATE CONSTANT -k:

| Param          | VSS Remaining [%] | [Kg/d]   | [mg/l]   |
|----------------|-------------------|----------|----------|
| S <sub>0</sub> | 100.00            | 9621.25  | 89321.00 |
| S              | 26.70             | 2568.87  | 23848.71 |
| k              | 0.053045          | 0.053045 | 0.053045 |

| Param          | VSS Degraded [Kg/d] |
|----------------|---------------------|
| S <sub>0</sub> | 0.00                |
| S <sub>0</sub> | 7052.38             |
| k              | 0.053045            |

| Param          | Metahne Prod.n [Nm <sup>3</sup> /d] |
|----------------|-------------------------------------|
| S <sub>0</sub> | 0.00                                |
| S <sub>0</sub> | 1.48                                |

P1-3.3 DETERMINATION OF VSS and CH<sub>4</sub> PRODUCTION CHANGE AFTER SERVICE TIME LAPSE:

Digester: Out-of-Service, Elapsed number of days:

VSS Remaining after elapsed time with no feed:

VSS Degraded over elapsed time period:

Methane GAS Production on day: 565

|                                                  |                                |   |                                                    |
|--------------------------------------------------|--------------------------------|---|----------------------------------------------------|
|                                                  | 565.00 [days]                  | - | Reactor D5 was removed from service on: 05/07/2023 |
| S, [Kg/d]                                        | 0.0000000 [Kg/d]               |   |                                                    |
| S, [Kg/d]                                        | 9621.2500 [Kg/d]               |   |                                                    |
| Y <sub>m</sub> = Y <sub>td, CH<sub>4</sub></sub> | 7825.0066 [Nm <sup>3</sup> /d] |   |                                                    |

Digester: Out-of-Service, Elapsed number of days -1:

VSS Remaining after elapsed time with no feed:

VSS Degraded over elapsed time period:

Methane GAS Production on day: 564

|                                                  |                                |  |  |
|--------------------------------------------------|--------------------------------|--|--|
|                                                  | 564.00 [days]                  |  |  |
| S, [Kg/d]                                        | 0.0000000 [Kg/d]               |  |  |
| S, [Kg/d]                                        | 9621.2500 [Kg/d]               |  |  |
| Y <sub>m</sub> = Y <sub>td, CH<sub>4</sub></sub> | 7825.0066 [Nm <sup>3</sup> /d] |  |  |

%cnt CHANGE IN VSS DEGRADATION:

0.000000000 [%] - BIO-ACTIVITY CESSATION JUDGED

%cnt CHANGE IN CH<sub>4</sub> (METHANE) PRODUCTION:

0.000000000 [%] - BIO-ACTIVITY CESSATION JUDGED

P1-3.4 VSS DEGRADATION, DETERMINE BACTERIOLOGICAL HALF-LIFE DECAY and REDUCTION IN CH<sub>4</sub> YIELD:

|                                     | 3rd Half-Life | 5th Half-Life | 7th Half-Life | 9th Half-Life | 11th Half-Life | 13th Half-Life |
|-------------------------------------|---------------|---------------|---------------|---------------|----------------|----------------|
| S, [Kg/d]                           | 1202.66       | 300.66        | 75.17         | 18.79         | 4.70           | 1.17           |
| at (Apprx.):                        |               |               |               |               |                |                |
| t <sub>0.5</sub> = ln(2) / k [days] | 39.21         | 65.34         | 91.48         | 117.61        | 143.74         | 169.88         |
| 13.07 [days]                        | 39.20         | 65.34         | 91.47         | 117.60        | 143.74         | 169.87         |
| VSS Degrade Chg: [%]                | 0.652724      | 0.164349      | 0.041381      | 0.010419      | 0.002623       | 0.000661       |
| CH <sub>4</sub> Yield Chg: [%]      | 0.741578      | 0.169461      | 0.041698      | 0.010439      | 0.002625       | 0.000661       |

## MIN. ELAPSED DAYS

|                         |           |           |           |            |            |            |
|-------------------------|-----------|-----------|-----------|------------|------------|------------|
| POST PROCESS CESSATION: | 40 [Days] | 66 [Days] | 92 [Days] | 118 [Days] | 144 [Days] | 170 [Days] |
|-------------------------|-----------|-----------|-----------|------------|------------|------------|

|                          |            |                      |                           |                           |                               |                               |
|--------------------------|------------|----------------------|---------------------------|---------------------------|-------------------------------|-------------------------------|
| CONCLUSION(s) /Comments: | BIO-ACTIVE | LIMITED BIO-ACTIVITY | NO PRACTICAL BIO-ACTIVITY | NO PRACTICAL BIO-ACTIVITY | BIO-ACTIVITY CESSATION JUDGED | BIO-ACTIVITY CESSATION JUDGED |
|--------------------------|------------|----------------------|---------------------------|---------------------------|-------------------------------|-------------------------------|

Activity Limits: &gt;20% &gt;5%, &lt;=20% &gt;1%, &lt;=5% &gt;1%, &lt;=5% &lt;= 1% &lt;= 1%

ACTUAL ELAPSED PROCESS CESSATION TIME: [Days] 565.0 | Eqv. Apprx. to 43th half life.

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Reference Nr:

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PROJECT TITLE: WW Enterprises : BRFWF

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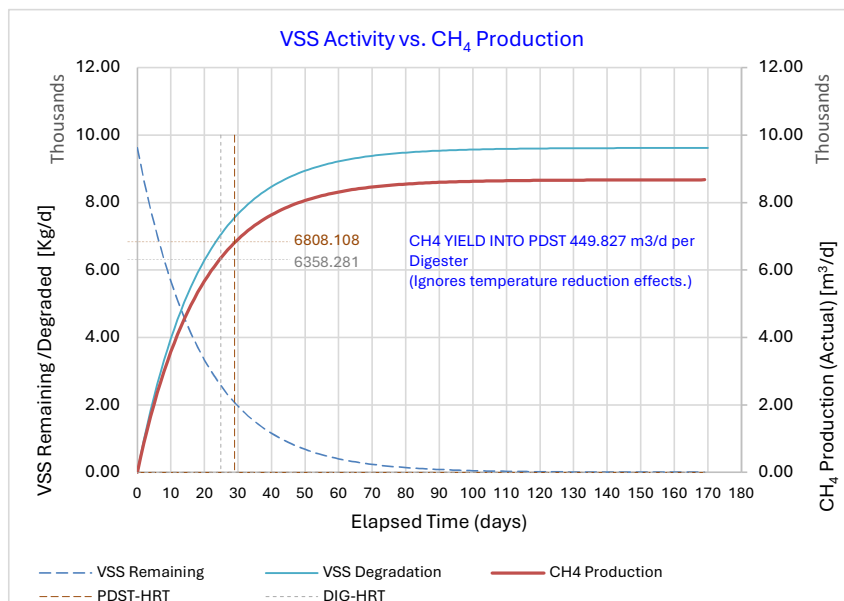
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## P1-3.5 DATA GRAPHS:



## COMMENT:

Clearly, the graph shows the decline in methane production being asymptotic, tending to infinity.

The typical minimum accepted elapsed time cut-off for values, deemed as a practical limit of the asymptote is the 5th half-life.

However, from a process safety perspective, it would be better to consider the 7th half-life as the minimum cut-off limit and, ideally the 11th half-life for prudence.

FOR POST DIGESTION:

Establish the overall combined CH<sub>4</sub> gas produced in the intervening period:

[DIG-HRT] expiry, through to:  
[DIG-HRT] + [PDST-HRT] expiry.

## P1-3.5.1 ESTABLISH PDST RETENTION PERIOD BOUNDARY LIMITS:

START, DIG-HRT

[Day-Ref]: 24.8942

FINISH, PDST-HRT

[Day-Ref]: 28.9652

Limit Tolerance:

0.000100

## VSS DEGRADED AT RETENTION PERIOD BOUNDARY LIMITS:

VSS DEGRADED AT:

[DIG-HRT] Start: [kg/d] 7052.376

[DIG-HRT] + [PDST-HRT] End: [kg/d] 7551.308

CH<sub>4</sub> PROD.N AT RETENTION BOUNDARY LIMITS:CH<sub>4</sub> PRODUCTION AT:[DIG-HRT] Start: [m<sup>3</sup>/d] 6358.281[DIG-HRT] + [PDST-HRT] End: [m<sup>3</sup>/d] 6808.108MAX CH<sub>4</sub> GAS YIELD Per DIGESTER, Into PDST: [m<sup>3</sup>/d] 449.827MAX CH<sub>4</sub> GAS YIELD COMBINED, Into PDST: [m<sup>3</sup>/d] 899.653

(Assumes PDST Tank at or near capacity and most favourable conditions for maximum gas production with no degrade as a result of the digestate cooling.)

AVERAGE CH<sub>4</sub> GAS Prod.n over PDST HRT Period: [m<sup>3</sup>/d] 6563.4234

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PROJECT TITLE: WW Enterprises : BRWF

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P1-3.6 TABULATE DATA FOR GRAPHICS:

| Time, t<br>[days] | VSS Remaining |           |           | VSS degrad.<br>S, [Kg/d] | CH4 Prod.n<br>[Nm³/d] | CH4 Prod.n<br>[m³/d] | CH4 PROD.N<br>Chge.[%] |
|-------------------|---------------|-----------|-----------|--------------------------|-----------------------|----------------------|------------------------|
|                   | S, [%]        | S, [Kg/d] | S, [mg/l] |                          |                       |                      |                        |
| 1E-08             | 100.00        | 9621.25   | 89321.00  | 0.000                    | 0.00                  | 0.00                 | 100.0000               |
| 1                 | 94.83         | 9124.19   | 84706.46  | 497.057                  | 404.26                | 448.14               | 48.6742                |
| 2                 | 89.93         | 8652.81   | 80330.31  | 968.436                  | 787.63                | 873.12               | 31.5816                |
| 3                 | 85.29         | 8205.79   | 76180.25  | 1415.461                 | 1151.20               | 1276.15              | 23.0473                |
| 4                 | 80.88         | 7781.86   | 72244.59  | 1839.392                 | 1495.99               | 1658.36              | 17.9364                |
| 5                 | 76.70         | 7379.83   | 68512.26  | 2241.422                 | 1822.96               | 2020.82              | 14.5370                |
| 6                 | 72.74         | 6998.57   | 64972.75  | 2622.682                 | 2133.04               | 2364.56              | 12.1157                |
| 7                 | 68.98         | 6637.00   | 61616.10  | 2984.246                 | 2427.10               | 2690.54              | 10.3057                |
| 8                 | 65.42         | 6294.12   | 58432.86  | 3327.129                 | 2705.97               | 2999.67              | 8.9032                 |
| 9                 | 62.04         | 5968.95   | 55414.07  | 3652.299                 | 2970.43               | 3292.84              | 7.7858                 |
| 10                | 58.83         | 5660.58   | 52551.25  | 3960.670                 | 3221.23               | 3570.86              | 6.8759                 |
| 11                | 55.79         | 5368.14   | 49836.32  | 4253.109                 | 3459.07               | 3834.52              | 6.1215                 |
| 12                | 52.91         | 5090.81   | 47261.65  | 4530.441                 | 3684.63               | 4084.55              | 5.4867                 |
| 13                | 50.18         | 4827.81   | 44820.00  | 4793.444                 | 3898.53               | 4321.67              | 4.9459                 |
| 14                | 47.59         | 4578.39   | 42504.49  | 5042.861                 | 4101.38               | 4546.54              | 4.4803                 |
| 15                | 45.13         | 4341.86   | 40308.60  | 5279.392                 | 4293.75               | 4759.79              | 4.0756                 |
| 16                | 42.80         | 4117.55   | 38226.16  | 5503.703                 | 4476.19               | 4962.03              | 3.7213                 |
| 17                | 40.59         | 3904.82   | 36251.30  | 5716.425                 | 4649.19               | 5153.81              | 3.4087                 |
| 18                | 38.49         | 3703.09   | 34378.47  | 5918.158                 | 4813.27               | 5335.69              | 3.1314                 |
| 19                | 36.50         | 3511.78   | 32602.40  | 6109.469                 | 4968.86               | 5508.17              | 2.8840                 |
| 20                | 34.61         | 3330.35   | 30918.08  | 6290.896                 | 5116.41               | 5671.75              | 2.6622                 |
| 21                | 32.83         | 3158.30   | 29320.77  | 6462.950                 | 5256.35               | 5826.87              | 2.4625                 |
| 22                | 31.13         | 2995.13   | 27805.99  | 6626.116                 | 5389.05               | 5973.97              | 2.2820                 |
| 23                | 29.52         | 2840.40   | 26369.46  | 6780.852                 | 5514.90               | 6113.48              | 2.1182                 |
| 24                | 28.00         | 2693.66   | 25007.15  | 6927.594                 | 5634.24               | 6245.78              | 1.7694                 |
| 24.8942           | 26.70         | 2568.87   | 23848.71  | 7052.376                 | 5735.73               | 6358.28              | 0.0002                 |
| 24.8943           | 26.70         | 2568.86   | 23848.58  | 7052.390                 | 5735.74               | 6358.29              | 0.2033                 |
| 25                | 26.55         | 2554.50   | 23715.22  | 7066.755                 | 5747.42               | 6371.24              | 1.8333                 |
| 26                | 25.18         | 2422.52   | 22490.03  | 7198.726                 | 5854.76               | 6490.23              | 1.7088                 |
| 27                | 23.88         | 2297.37   | 21328.14  | 7323.880                 | 5956.54               | 6603.06              | 1.5947                 |
| 28                | 22.64         | 2178.68   | 20226.28  | 7442.568                 | 6053.07               | 6710.07              | 1.4399                 |
| 28.9651           | 21.51         | 2069.95   | 19216.87  | 7551.297                 | 6141.50               | 6808.10              | 0.0001                 |
| 28.9652           | 21.51         | 2069.94   | 19216.77  | 7551.308                 | 6141.51               | 6808.11              | 0.0505                 |
| 29                | 21.47         | 2066.13   | 19181.34  | 7555.124                 | 6144.62               | 6811.55              | 1.3931                 |
| 30                | 20.37         | 1959.39   | 18190.39  | 7661.865                 | 6231.43               | 6907.78              | 1.3039                 |
| 31                | 19.31         | 1858.16   | 17250.63  | 7763.091                 | 6313.76               | 6999.05              | 1.2215                 |
| 32                | 18.32         | 1762.16   | 16359.42  | 7859.088                 | 6391.83               | 7085.60              | 1.1451                 |
| 33                | 17.37         | 1671.12   | 15514.25  | 7950.126                 | 6465.87               | 7167.67              | 1.0743                 |
| 34                | 16.47         | 1584.79   | 14712.74  | 8036.460                 | 6536.09               | 7245.51              | 1.0085                 |
| 35                | 15.62         | 1502.92   | 13952.65  | 8118.335                 | 6602.68               | 7319.33              | 0.9473                 |
| 36                | 14.81         | 1425.27   | 13231.82  | 8195.979                 | 6665.83               | 7389.33              | 0.8904                 |
| 37                | 14.05         | 1351.64   | 12548.23  | 8269.612                 | 6725.71               | 7455.72              | 0.8373                 |
| 38                | 13.32         | 1281.81   | 11899.96  | 8339.441                 | 6782.51               | 7518.67              | 0.7878                 |
| 39                | 12.63         | 1215.59   | 11285.18  | 8405.662                 | 6836.36               | 7578.38              | 0.7416                 |
| 40                | 11.98         | 1152.79   | 10702.16  | 8468.462                 | 6887.44               | 7635.00              | 0.6984                 |
| 41                | 11.36         | 1093.23   | 10149.26  | 8528.018                 | 6935.88               | 7688.69              | 0.6579                 |
| 42                | 10.78         | 1036.75   | 9624.92   | 8584.497                 | 6981.81               | 7739.61              | 0.6201                 |
| 43                | 10.22         | 983.19    | 9127.68   | 8638.059                 | 7025.37               | 7787.90              | 0.5846                 |
| 44                | 9.69          | 932.40    | 8656.12   | 8688.853                 | 7066.68               | 7833.70              | 0.5513                 |
| 45                | 9.19          | 884.23    | 8208.92   | 8737.023                 | 7105.86               | 7877.12              | 0.5201                 |
| 46                | 8.72          | 838.55    | 7784.83   | 8782.704                 | 7143.01               | 7918.31              | 0.4908                 |
| 47                | 8.27          | 795.22    | 7382.64   | 8826.025                 | 7178.25               | 7957.37              | 0.4633                 |
| 48                | 7.84          | 754.14    | 7001.24   | 8867.109                 | 7211.66               | 7994.41              | 0.4375                 |
| 49                | 7.43          | 715.18    | 6639.54   | 8906.069                 | 7243.35               | 8029.53              | 0.4131                 |
| 50                | 7.05          | 678.23    | 6296.52   | 8943.017                 | 7273.40               | 8062.85              | 0.3903                 |
| 51                | 6.69          | 643.19    | 5971.23   | 8978.056                 | 7301.89               | 8094.44              | 0.3687                 |
| 52                | 6.34          | 609.96    | 5662.74   | 9011.285                 | 7328.92               | 8124.39              | 0.3485                 |
| 53                | 6.01          | 578.45    | 5370.19   | 9042.798                 | 7354.55               | 8152.81              | 0.3294                 |
| 54                | 5.70          | 548.57    | 5092.75   | 9072.682                 | 7378.85               | 8179.75              | 0.3114                 |

DIG-HRT

PDST-HRT

3rd Half-Life

3rd Half-Life

## DESIGN SHEET

CLIENT id:

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PROJECT TITLE: WW Enterprises : BRWF

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|     |      |        |         |          |         |         |               |        |
|-----|------|--------|---------|----------|---------|---------|---------------|--------|
| 55  | 5.41 | 520.23 | 4829.65 | 9101.022 | 7401.90 | 8205.30 | -             | 0.2944 |
| 56  | 5.13 | 493.35 | 4580.14 | 9127.899 | 7423.76 | 8229.53 | -             | 0.2785 |
| 57  | 4.86 | 467.86 | 4343.52 | 9153.386 | 7444.49 | 8252.51 | -             | 0.2634 |
| 58  | 4.61 | 443.69 | 4119.12 | 9177.557 | 7464.15 | 8274.30 | -             | 0.2491 |
| 59  | 4.37 | 420.77 | 3906.32 | 9200.480 | 7482.79 | 8294.97 | -             | 0.2357 |
| 60  | 4.15 | 399.03 | 3704.51 | 9222.218 | 7500.47 | 8314.57 | -             | 0.2230 |
| 61  | 3.93 | 378.42 | 3513.12 | 9242.833 | 7517.24 | 8333.15 | -             | 0.2111 |
| 62  | 3.73 | 358.87 | 3331.63 | 9262.383 | 7533.14 | 8350.78 | -             | 0.1998 |
| 63  | 3.54 | 340.33 | 3159.51 | 9280.923 | 7548.22 | 8367.49 | -             | 0.1891 |
| 64  | 3.35 | 322.75 | 2996.28 | 9298.505 | 7562.52 | 8383.35 | -             | 0.1790 |
| 65  | 3.18 | 306.07 | 2841.48 | 9315.179 | 7576.08 | 8398.38 | 5th Half-Life | 0.1695 |
| 66  | 3.02 | 290.26 | 2694.68 | 9330.991 | 7588.94 | 8412.63 | 5th Half-Life | 0.1604 |
| 67  | 2.86 | 275.26 | 2555.47 | 9345.986 | 7601.13 | 8426.15 | -             | 0.1519 |
| 68  | 2.71 | 261.04 | 2423.45 | 9360.207 | 7612.70 | 8438.98 | -             | 0.1439 |
| 69  | 2.57 | 247.56 | 2298.25 | 9373.693 | 7623.67 | 8451.13 | -             | 0.1363 |
| 70  | 2.44 | 234.77 | 2179.51 | 9386.483 | 7634.07 | 8462.67 | -             | 0.1290 |
| 71  | 2.31 | 222.64 | 2066.92 | 9398.611 | 7643.93 | 8473.60 | -             | 0.1222 |
| 72  | 2.19 | 211.14 | 1960.13 | 9410.113 | 7653.29 | 8483.97 | -             | 0.1158 |
| 73  | 2.08 | 200.23 | 1858.87 | 9421.021 | 7662.16 | 8493.80 | -             | 0.1097 |
| 74  | 1.97 | 189.88 | 1762.83 | 9431.366 | 7670.57 | 8503.13 | -             | 0.1039 |
| 75  | 1.87 | 180.07 | 1671.76 | 9441.175 | 7678.55 | 8511.97 | -             | 0.0984 |
| 76  | 1.77 | 170.77 | 1585.39 | 9450.479 | 7686.12 | 8520.36 | -             | 0.0933 |
| 77  | 1.68 | 161.95 | 1503.49 | 9459.301 | 7693.29 | 8528.32 | -             | 0.0884 |
| 78  | 1.60 | 153.58 | 1425.82 | 9467.668 | 7700.10 | 8535.86 | -             | 0.0837 |
| 79  | 1.51 | 145.65 | 1352.15 | 9475.602 | 7706.55 | 8543.01 | -             | 0.0793 |
| 80  | 1.44 | 138.12 | 1282.30 | 9483.127 | 7712.67 | 8549.80 | -             | 0.0752 |
| 81  | 1.36 | 130.99 | 1216.05 | 9490.262 | 7718.47 | 8556.23 | -             | 0.0713 |
| 82  | 1.29 | 124.22 | 1153.23 | 9497.030 | 7723.98 | 8562.33 | -             | 0.0675 |
| 83  | 1.22 | 117.80 | 1093.65 | 9503.447 | 7729.20 | 8568.12 | -             | 0.0640 |
| 84  | 1.16 | 111.72 | 1037.15 | 9509.533 | 7734.15 | 8573.60 | -             | 0.0607 |
| 85  | 1.10 | 105.95 | 983.57  | 9515.305 | 7738.84 | 8578.81 | -             | 0.0575 |
| 86  | 1.04 | 100.47 | 932.75  | 9520.778 | 7743.29 | 8583.74 | -             | 0.0545 |
| 87  | 0.99 | 95.28  | 884.56  | 9525.969 | 7747.51 | 8588.42 | -             | 0.0516 |
| 88  | 0.94 | 90.36  | 838.87  | 9530.891 | 7751.52 | 8592.86 | -             | 0.0490 |
| 89  | 0.89 | 85.69  | 795.53  | 9535.559 | 7755.31 | 8597.07 | -             | 0.0464 |
| 90  | 0.84 | 81.26  | 754.43  | 9539.986 | 7758.91 | 8601.06 | -             | 0.0440 |
| 91  | 0.80 | 77.07  | 715.45  | 9544.185 | 7762.33 | 8604.85 | 7th Half-Life | 0.0417 |
| 92  | 0.76 | 73.08  | 678.49  | 9548.166 | 7765.57 | 8608.44 | 7th Half-Life | 0.0395 |
| 93  | 0.72 | 69.31  | 643.44  | 9551.942 | 7768.64 | 8611.84 | -             | 0.0375 |
| 94  | 0.68 | 65.73  | 610.20  | 9555.522 | 7771.55 | 8615.07 | -             | 0.0355 |
| 95  | 0.65 | 62.33  | 578.67  | 9558.918 | 7774.31 | 8618.13 | -             | 0.0337 |
| 96  | 0.61 | 59.11  | 548.78  | 9562.138 | 7776.93 | 8621.03 | -             | 0.0319 |
| 97  | 0.58 | 56.06  | 520.43  | 9565.192 | 7779.41 | 8623.79 | -             | 0.0303 |
| 98  | 0.55 | 53.16  | 493.54  | 9568.088 | 7781.77 | 8626.40 | -             | 0.0287 |
| 99  | 0.52 | 50.42  | 468.04  | 9570.835 | 7784.00 | 8628.87 | -             | 0.0272 |
| 100 | 0.50 | 47.81  | 443.86  | 9573.439 | 7786.12 | 8631.22 | -             | 0.0258 |
| 101 | 0.47 | 45.34  | 420.93  | 9575.909 | 7788.13 | 8633.45 | -             | 0.0245 |
| 102 | 0.45 | 43.00  | 399.18  | 9578.252 | 7790.04 | 8635.56 | -             | 0.0232 |
| 103 | 0.42 | 40.78  | 378.56  | 9580.473 | 7791.84 | 8637.56 | -             | 0.0220 |
| 104 | 0.40 | 38.67  | 359.00  | 9582.580 | 7793.56 | 8639.46 | -             | 0.0208 |
| 105 | 0.38 | 36.67  | 340.46  | 9584.577 | 7795.18 | 8641.26 | -             | 0.0198 |
| 106 | 0.36 | 34.78  | 322.87  | 9586.472 | 7796.72 | 8642.97 | -             | 0.0187 |
| 107 | 0.34 | 32.98  | 306.19  | 9588.269 | 7798.18 | 8644.59 | -             | 0.0178 |
| 108 | 0.33 | 31.28  | 290.37  | 9589.973 | 7799.57 | 8646.13 | -             | 0.0168 |
| 109 | 0.31 | 29.66  | 275.37  | 9591.589 | 7800.88 | 8647.58 | -             | 0.0160 |
| 110 | 0.29 | 28.13  | 261.14  | 9593.121 | 7802.13 | 8648.97 | -             | 0.0151 |
| 111 | 0.28 | 26.68  | 247.65  | 9594.574 | 7803.31 | 8650.28 | -             | 0.0144 |
| 112 | 0.26 | 25.30  | 234.86  | 9595.952 | 7804.43 | 8651.52 | -             | 0.0136 |
| 113 | 0.25 | 23.99  | 222.72  | 9597.259 | 7805.49 | 8652.70 | -             | 0.0129 |
| 114 | 0.24 | 22.75  | 211.22  | 9598.499 | 7806.50 | 8653.81 | -             | 0.0122 |
| 115 | 0.22 | 21.58  | 200.31  | 9599.674 | 7807.46 | 8654.87 | -             | 0.0116 |
| 116 | 0.21 | 20.46  | 189.96  | 9600.789 | 7808.37 | 8655.88 | -             | 0.0110 |
| 117 | 0.20 | 19.40  | 180.14  | 9601.846 | 7809.23 | 8656.83 | 9th Half-Life | 0.0104 |

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CLIENT id:

DOCUMENT Nr: 1

Reference Nr:

// Rv.

// R2-1

PROJECT TITLE: WW Enterprises : BRWF

STATUS:  
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25/07/2025

SUBJECT /Elem.t: PDST OFF-GAS IED Compliance :: Element

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- - - - -

Ref:

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|     |      |       |        |          |         |         |                |        |
|-----|------|-------|--------|----------|---------|---------|----------------|--------|
| 118 | 0.19 | 18.40 | 170.84 | 9602.848 | 7810.04 | 8657.74 | 9th Half-Life  | 0.0099 |
| 119 | 0.18 | 17.45 | 162.01 | 9603.799 | 7810.81 | 8658.59 | -              | 0.0094 |
| 120 | 0.17 | 16.55 | 153.64 | 9604.701 | 7811.55 | 8659.41 | -              | 0.0089 |
| 121 | 0.16 | 15.69 | 145.70 | 9605.555 | 7812.24 | 8660.18 | -              | 0.0084 |
| 122 | 0.15 | 14.88 | 138.18 | 9606.366 | 7812.90 | 8660.91 | -              | 0.0080 |
| 123 | 0.15 | 14.11 | 131.04 | 9607.135 | 7813.53 | 8661.60 | -              | 0.0076 |
| 124 | 0.14 | 13.39 | 124.27 | 9607.864 | 7814.12 | 8662.26 | -              | 0.0072 |
| 125 | 0.13 | 12.69 | 117.85 | 9608.556 | 7814.68 | 8662.88 | -              | 0.0068 |
| 126 | 0.13 | 12.04 | 111.76 | 9609.212 | 7815.22 | 8663.47 | -              | 0.0065 |
| 127 | 0.12 | 11.42 | 105.99 | 9609.834 | 7815.72 | 8664.03 | -              | 0.0061 |
| 128 | 0.11 | 10.83 | 100.51 | 9610.423 | 7816.20 | 8664.57 | -              | 0.0058 |
| 129 | 0.11 | 10.27 | 95.32  | 9610.983 | 7816.66 | 8665.07 | -              | 0.0055 |
| 130 | 0.10 | 9.74  | 90.39  | 9611.513 | 7817.09 | 8665.55 | -              | 0.0052 |
| 131 | 0.10 | 9.23  | 85.72  | 9612.016 | 7817.50 | 8666.00 | -              | 0.0050 |
| 132 | 0.09 | 8.76  | 81.29  | 9612.493 | 7817.88 | 8666.43 | -              | 0.0047 |
| 133 | 0.09 | 8.30  | 77.09  | 9612.946 | 7818.25 | 8666.84 | -              | 0.0045 |
| 134 | 0.08 | 7.88  | 73.11  | 9613.375 | 7818.60 | 8667.23 | -              | 0.0042 |
| 135 | 0.08 | 7.47  | 69.33  | 9613.782 | 7818.93 | 8667.59 | -              | 0.0040 |
| 136 | 0.07 | 7.08  | 65.75  | 9614.167 | 7819.25 | 8667.94 | -              | 0.0038 |
| 137 | 0.07 | 6.72  | 62.36  | 9614.533 | 7819.54 | 8668.27 | -              | 0.0036 |
| 138 | 0.07 | 6.37  | 59.13  | 9614.880 | 7819.83 | 8668.58 | -              | 0.0034 |
| 139 | 0.06 | 6.04  | 56.08  | 9615.209 | 7820.09 | 8668.88 | -              | 0.0032 |
| 140 | 0.06 | 5.73  | 53.18  | 9615.521 | 7820.35 | 8669.16 | -              | 0.0031 |
| 141 | 0.06 | 5.43  | 50.43  | 9615.817 | 7820.59 | 8669.43 | -              | 0.0029 |
| 142 | 0.05 | 5.15  | 47.83  | 9616.098 | 7820.82 | 8669.68 | -              | 0.0028 |
| 143 | 0.05 | 4.89  | 45.36  | 9616.364 | 7821.03 | 8669.92 | 11th Half-Life | 0.0026 |
| 144 | 0.05 | 4.63  | 43.01  | 9616.617 | 7821.24 | 8670.15 | 11th Half-Life | 0.0025 |
| 145 | 0.05 | 4.39  | 40.79  | 9616.856 | 7821.43 | 8670.37 | -              | 0.0024 |
| 146 | 0.04 | 4.17  | 38.69  | 9617.083 | 7821.62 | 8670.57 | -              | 0.0022 |
| 147 | 0.04 | 3.95  | 36.69  | 9617.298 | 7821.79 | 8670.76 | -              | 0.0021 |
| 148 | 0.04 | 3.75  | 34.79  | 9617.502 | 7821.96 | 8670.95 | -              | 0.0020 |
| 149 | 0.04 | 3.55  | 32.99  | 9617.696 | 7822.12 | 8671.12 | -              | 0.0019 |
| 150 | 0.04 | 3.37  | 31.29  | 9617.880 | 7822.27 | 8671.29 | -              | 0.0018 |
| 151 | 0.03 | 3.20  | 29.67  | 9618.054 | 7822.41 | 8671.44 | -              | 0.0017 |
| 152 | 0.03 | 3.03  | 28.14  | 9618.219 | 7822.54 | 8671.59 | -              | 0.0016 |
| 153 | 0.03 | 2.87  | 26.69  | 9618.376 | 7822.67 | 8671.73 | -              | 0.0015 |
| 154 | 0.03 | 2.73  | 25.31  | 9618.524 | 7822.79 | 8671.87 | -              | 0.0015 |
| 155 | 0.03 | 2.59  | 24.00  | 9618.665 | 7822.90 | 8672.00 | -              | 0.0014 |
| 156 | 0.03 | 2.45  | 22.76  | 9618.798 | 7823.01 | 8672.12 | -              | 0.0013 |
| 157 | 0.02 | 2.32  | 21.58  | 9618.925 | 7823.12 | 8672.23 | -              | 0.0012 |
| 158 | 0.02 | 2.20  | 20.47  | 9619.045 | 7823.21 | 8672.34 | -              | 0.0012 |
| 159 | 0.02 | 2.09  | 19.41  | 9619.159 | 7823.31 | 8672.44 | -              | 0.0011 |
| 160 | 0.02 | 1.98  | 18.41  | 9619.267 | 7823.39 | 8672.54 | -              | 0.0011 |
| 161 | 0.02 | 1.88  | 17.46  | 9619.370 | 7823.48 | 8672.63 | -              | 0.0010 |
| 162 | 0.02 | 1.78  | 16.56  | 9619.467 | 7823.56 | 8672.72 | -              | 0.0010 |
| 163 | 0.02 | 1.69  | 15.70  | 9619.559 | 7823.63 | 8672.80 | -              | 0.0009 |
| 164 | 0.02 | 1.60  | 14.89  | 9619.646 | 7823.70 | 8672.88 | -              | 0.0009 |
| 165 | 0.02 | 1.52  | 14.12  | 9619.729 | 7823.77 | 8672.96 | -              | 0.0008 |
| 166 | 0.01 | 1.44  | 13.39  | 9619.808 | 7823.83 | 8673.03 | -              | 0.0008 |
| 167 | 0.01 | 1.37  | 12.70  | 9619.882 | 7823.89 | 8673.09 | -              | 0.0007 |
| 168 | 0.01 | 1.30  | 12.04  | 9619.953 | 7823.95 | 8673.16 | -              | 0.0007 |
| 169 | 0.01 | 1.23  | 11.42  | 9620.020 | 7824.01 | 8673.22 | 13th Half-Life | 0.0007 |
| 170 | 0.01 | 1.17  | 10.83  | 9620.083 | 7824.06 | 8673.27 | 13th Half-Life | - - -  |

CLIENT id:

DOCUMENT Nr:

Reference Nr:

// Rv.

// R2-1

PROJECT TITLE: WW Enterprises : BRWF

STATUS:  
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25/07/2025

SUBJECT /Elem.t: PDST OFF-GAS IED Compliance :: Element

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- - - - -

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SECT.N: **MAD-2 (D1 and D3) - FOOD WASTE REACTORS:****P1-4** DETERMINATION OF TVOC (METHANE COMPONENT), OF CHANNELLED EMISSION FROM PDST (POST DIGESTION STORAGE TANK)

Std. Calc. Module. Rev.: 1.0

Specific Worksheet Rev.: -

## P1-4.1 DATA:

## NUMERICAL MATH CONSTANTS:

|                                                                         |                              |              |
|-------------------------------------------------------------------------|------------------------------|--------------|
| ACCELERATION DUE TO GRAVITY:                                            | G: [m/s <sup>2</sup> ]       | 9.80665      |
| SPECIFIC GAS CONSTANT OF DRY AIR:                                       | Rd: [J/Kg.K]                 | 287.05800    |
| SPECIFIC GAS CONSTANT OF WATER VAPOUR:                                  | Rv: [J/Kg.K]                 | 461.49500    |
| TEMPERATURE > ABSOLUTE ZERO                                             | Ta: [°C]                     | -273.15000   |
|                                                                         | [K]                          | 0.00000      |
| NATURAL LOGARITHM:                                                      | e: [-]                       | 2.71828      |
| ADIABATIC GAS CONSTANT - AIR:                                           | gamma: [-]                   | 1.40000      |
| Universal GAS CONSTANT:                                                 | Ru: [J/kg.mol]               | 8.31446      |
| Molar Volume for: 0 deg.C, 1 Atm. Pressure (I.e. STP), for any gas, is: | [Ltrs] or [dm <sup>3</sup> ] | 22.41396     |
| ISA, NTP and STP Standard Atmospheric Pressure:                         | [Pa]                         | 101325.00000 |

## P1-4.2 NARRATIVE:

To establish a theoretical means of assessing the potential limit for TVOC (Total Volatile Organic Carbon) within the channelled emissions derived from secondary storage (and/or post-digestion or degassing tanks) located immediately downstream of the mesophilic digestors within a bio digestion facility.

The need is born out of the following:

- Establishing real-world samples that are representative across the board and not specific to either: (i) their time and date, (ii) The specific upstream processes employed, (iii) quality of feedstock on a particular day and/or (iv) the digestion technology employed.
- Establish pragmatic engineering values to assess abatement technologies, where no sampling is possible due to the digestion plant having not yet been constructed or has been off-line for a significant intervening period etc.

Clearly, in practice, samples will ultimately need to be taken to provide some correlation and verification of approach.

The TVOC of the Post Digestion off-gas is assumed to comprise:

CH4 Component: >= 98.50% Other Components: < 1.50%

Hence, Methane is the dominant volatile organic component and the Other gas components will, in essence be accounted for in overall safety factors, for post-digestion application.

## P1-4.3 DATA:

## MOLAR MASSES:

| GAS:              | SYMBOL: |            | Atomic Mass: | Nr Mols: | Element Mass: | Molar Mass:     |
|-------------------|---------|------------|--------------|----------|---------------|-----------------|
| AMMONIA           | NH3     | H: [g/mol] | 1.007940     | 3        | 3.023820      |                 |
|                   |         | N: [g/mol] | 14.006855    | 1        | 14.006855     | [g/mol] 17.0307 |
| HYDROGEN SULPHIDE | H2S     | H: [g/mol] | 1.007940     | 2        | 2.015880      |                 |
|                   |         | S: [g/mol] | 32.067500    | 1        | 32.067500     | [g/mol] 34.0834 |
| METHANE           | CH4     | H: [g/mol] | 1.007940     | 4        | 4.031760      |                 |
|                   |         | C: [g/mol] | 12.010600    | 1        | 12.010600     | [g/mol] 16.0424 |

## P1-4.3.1 ESTABLISH OFF-GAS COMPONENT FACTORS FOR: Parts Per Volume : Mass conc.

GAS TEMPERATURE: T1: [°C] 28.00 T1\_abs: [K] 301.15  
GAS PRESSURE: P1: [Bar.a] 1.00 P1: [Pa.a] 101325.00

Molar Volume for: Methane (as an ideal gas) based on T1 and P1: [Ltrs] or [dm<sup>3</sup>] 24.71132

Volume : Mass Concentration Factor for Actual Gas Temp, and Pressure:

For: METHANE, CH4 Gas: 0.64918  
For: HYDROGEN SULPHIDE, H2S Gas: 1.37925  
For: AMMONIA, NH3 Gas: 0.68918

## DESIGN SHEET

CLIENT id:

DOCUMENT Nr:

Reference Nr:

// Rv.

// R2-1

PROJECT TITLE: WW Enterprises : BRWF

STATUS:

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25/07/2025

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## P1-4.4 DETERMINE PDST GAS HEADSPACE VOLUME:

POST DIGESTION STORAGE TANK DETAILS: Carried From: SECTION: P1-1.15

|                                                |                               |         |                                |         |
|------------------------------------------------|-------------------------------|---------|--------------------------------|---------|
| NUMBER OF TANKS:                               | n: [-]                        | 1       |                                |         |
| INTERNAL DIAMETER:                             | D1: [m]                       | 10.230  |                                |         |
| INTERNAL RADIUS:                               | R1: [m]                       | 5.115   |                                |         |
| TANK SHELL HEIGHT:                             | H1: [m]                       | 11.145  |                                |         |
| INTERNAL SECTIONAL WORKING HEIGHT:             | [m]                           | 10.670  |                                |         |
| INTERNAL PLAN AREA:                            | [m <sup>2</sup> ]             | 82.194  |                                |         |
| OVERALL INTERNAL WORKING VOLUME:               | [m <sup>3</sup> ]             | 877.000 | ≈ Per Tk. [m <sup>3</sup> ]:   | 877.004 |
| PDST VOLUME THROUGHPUT:                        | ≈ Total. [m <sup>3</sup> /d]: | 215.431 | ≈ Per Tk. [m <sup>3</sup> /d]: | 215.43  |
| PDST /SECONDARY STORAGE APPRX. RETENTION TIME: | [days]                        | 4.071   | ≈ Per Tk. [days]:              | 4.071   |

\* Excludes any minor mass and solids loss through pre-screening.

## PDST SCADA CONTROL LEVELS:

|                            |                |        |              |             |
|----------------------------|----------------|--------|--------------|-------------|
| PDST FILL ENABLE LEVEL     | [m]            | 9.700  |              |             |
| PDST FILL DISABLE LEVEL:   | [m]            | 9.800  |              |             |
| PDST MIXING ENABLE LEVEL:  | [m]            | 0.900  |              |             |
| PDST MIXING DISABLE LEVEL: | [m]            | 0.800  |              |             |
| MIXING RUN TIME:           | [min per hour] | 60.000 | - EFFECTIVE: | CONTINUOUS. |
| MIXING DWELL TIME:         | [min]          | 0.000  |              |             |

## P1-4.4.1 PROCESS OPERATIONAL CONDITIONS - GAS SIDE:

Calc. MAX. PROCESS LIQUID VOLUME: [m<sup>3</sup>] 805.503 - REPRESENTS: 91.848%  
Based on: Fill Disable Level. of Tank Design Net vol.

ROOF GEOMETRY: Conical Roof Slope: [° to Horiz] 20.000 - MATH: Deg.:Rad 57.296  
(Proposed) Datum level relative to Tk top ring: [m] 0.100  
Diameter of Roof Crown Ring (Flat Area): d<sub>1</sub>: [m] 1.000

|                                                                      |       |                                                  |       |
|----------------------------------------------------------------------|-------|--------------------------------------------------|-------|
| Truncated Roof Cone:                                                 |       | Roof Virtual Cone-Cap:                           |       |
| Annular radius of truncated roof cone: R1 - r <sub>1</sub> : [m]     | 4.615 | Base Radius r <sub>1</sub> =r <sub>2</sub> : [m] | 0.500 |
| Truncated Roof Height: h <sub>1</sub> : [m]                          | 1.680 | Virtual Cone Ht. h <sub>2</sub> : [m]            | 0.182 |
| Inclined surface radius of Truncated Roof Cone: L <sub>1</sub> : [m] | 4.911 | Inclin.d surface rad: L <sub>2</sub> : [m]       | 0.532 |

Roof Radius, R1 = (R1-r<sub>1</sub>)+r<sub>2</sub> (Chk): [m] 5.115  
Inclin.d surface radius for complete cone: L<sub>1</sub>+L<sub>2</sub>: [m] 5.443

ROOF SURFACE AREAS: Surface Area of Inclined Roof Cone: SA1: [m<sup>2</sup>] 86.633  
Surface Area of Roof Cone Cap, (Top flat section): SA2: [m<sup>2</sup>] 0.785  
Surface Area of Roof Vertical sidewall element: SA3: [m<sup>2</sup>] 3.214  
Surface Area of Roof TOTAL: [m<sup>2</sup>] 90.633

## ROOF GAS VOLUMES:

PDST, Tank Operating level, if different from FILL DISABLE LVL: [m] 9.800  
CYLINDRICAL VOID Above T.S.L (Top Sld Lvl.): [m<sup>3</sup>] 110.551  
CYLINDRICAL VOID Above Superstructure Top-Ring to Datum Level: [m<sup>3</sup>] 8.219  
VOLUME of truncated Roof Cone: [m<sup>3</sup>] 50.960  
ROOF TOTAL GAS SPACE VOLUME, at Operating Level: [m<sup>3</sup>] 169.730

## P1-4.5 DISPLACEMENT EFFECTS OF PROCESS AIR MIXING SYSTEM :

AIR MIXING SYSTEM: Air Injection Rate: MIN: [m<sup>3</sup>/h] \*1 173.000  
Air Injection Rate: MAX: [m<sup>3</sup>/h] \*2 300.000

Nb.s \*1 -Min. Required for effective Mixing. \*2 -Assume PD, therefore tank liquid depth not relevant to application.

REF: Manufacturer: BUSCH  
Model: MM1322AP  
Rating: 15kW  
Duty Cap. 300 m<sup>3</sup>/h at 1.7 Bar.g

Calc. AERATION Variance Factor, as a rate of tank headspace gas chges per unit time: Typ. Range: 1.0 to 2.8: [h<sup>-1</sup>] 1.768

## DESIGN SHEET

CLIENT id:

DOCUMENT Nr:

Reference Nr:

// Rv.

// R2-1

PROJECT TITLE: WW Enterprises : BRWF

STATUS:  
DRAFT \* FOR COMMENTEngineer: Date:  
25/07/2025

SUBJECT /Elem.t: PDST OFF-GAS IED Compliance :: Element

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&gt;&gt;&gt; References / Results

## P1-4.6 ESTABLISH OFF-GAS TVOC (Methane) EMISSION OVER DURATION OF PDST RETENTION:

|         |                                   |           |         |                   |        |
|---------|-----------------------------------|-----------|---------|-------------------|--------|
| START:  | EFFECTIVE [DIG-HRT].              | [day-Ref] | 24.8942 |                   |        |
| FINISH: | EFFECTIVE [DIG-HRT] + [PDST-HRT]. | [day-Ref] | 28.9651 |                   |        |
|         | PDST-HRT DURATION Check:          | [days]    | 4.0709  | cf. Actual [days] | 4.0709 |

|                                                                         |                                                     |          |
|-------------------------------------------------------------------------|-----------------------------------------------------|----------|
| Notional MAXIMUM CH <sub>4</sub> Prod.n over PDST-HRT retention period: | Vol. Produced: [m <sup>3</sup> ]                    | 899.6533 |
| (When tank is at, or nearing its full capacity)                         | Mean CH <sub>4</sub> Vol. Rate: [m <sup>3</sup> /d] | 220.9946 |
|                                                                         | Mean CH <sub>4</sub> Vol. Rate: [m <sup>3</sup> /h] | 9.2081   |

|                                                                            |                                                    |          |
|----------------------------------------------------------------------------|----------------------------------------------------|----------|
| Notional MAX CH <sub>4</sub> Prod.n over PDST-HRT retention period (Chk.): | CH <sub>4</sub> Vol. Produced: [m <sup>3</sup> /d] | 899.6533 |
| Combined aggregate of D1 and D3.                                           | Data value count for period:                       | 8.0      |

|                                                   |                                                     |              |
|---------------------------------------------------|-----------------------------------------------------|--------------|
| METHANE GAS DENSITY:                              | Typical for mean gas temp. T1: [kg/m <sup>3</sup> ] | 0.6408       |
| MEAN CH <sub>4</sub> Prod.n over PDST-HRT period: | Mass rate: [kg/d]                                   | 141.6134     |
|                                                   | Mass rate: [kg/h]                                   | 5.9006       |
|                                                   | Mass: [mg/d]                                        | 141613441.50 |
|                                                   | Mass: [mg/h]                                        | 5900560.06   |

|                                                      |                                        |          |
|------------------------------------------------------|----------------------------------------|----------|
| Based on the maximum Air Injection Mixing Rate Only. | Mass : Vol Conc.: [mg/m <sup>3</sup> ] | 19668.53 |
|                                                      | Est.d Headspace vol conc.: [ppm v/v]   | 30297.31 |

|        |                                         |         |                                                                                       |               |
|--------|-----------------------------------------|---------|---------------------------------------------------------------------------------------|---------------|
| CHECK: | T <sub>1-abs</sub> [K]:                 | 301.150 | CH <sub>4</sub> Molar Vol. based on T1 and P1: 1 k.mol methane gas: [m <sup>3</sup> ] | 24.711        |
|        | P <sub>1-abs</sub> [bar.a]:             | 1.000   | No. methane gas mols per day: [k.mols/d]                                              | 8.943         |
|        |                                         |         | Mol Mass of methane gas: [kg/k.mol]                                                   | 16.042        |
|        | Mass of METHANE (CH <sub>4</sub> ) gas: |         | Mass of CH <sub>4</sub> : [kg/d]                                                      | 143.468       |
|        |                                         |         | Mass of CH <sub>4</sub> : [kg/h]                                                      | 5.978         |
|        |                                         |         | Mass of CH <sub>4</sub> : [mg/h]                                                      | 5977817.769   |
|        |                                         |         | Mass of CH <sub>4</sub> gas: [mg/d]                                                   | 143467626.446 |

## P1-4.7 ESTIMATE STEADY-STATE OFF-GAS TVOC (Methane) EMISSION CONCENTRATION:

## CONSTRAINTS:

The PDST is operated as variable volume. Thus, it is not practical to express emissions directly as a mass per volume throughput of digestate. Since this would require a full tank to be held for a fixed period. As such will not be representative of real-world conditions. Hence, the approach taken is to express emissions as mass rate per unit of emission free surface area.

|                                                                             |                                            |           |
|-----------------------------------------------------------------------------|--------------------------------------------|-----------|
| UNCONFINED EMISSION ACROSS SURFACE AREA OF TANK SURFACE:                    | Emission Area: [m <sup>2</sup> ]           | 82.194    |
| (Presumes Tank Full and excludes and beneficial effect of Aeration Mixing.) | MEAN Emission Rate: [kg/m <sup>2</sup> /d] | 1.723     |
|                                                                             | MEAN Emission Rate: [mg/m <sup>2</sup> /h] | 71788.038 |
|                                                                             | MEAN Emission Rate: [mg/m <sup>2</sup> /s] | 19.941    |

|                   |                                                   |        |
|-------------------|---------------------------------------------------|--------|
| PDST CONCLUSIONS: | MEAN STATIC Emission Rate: [mg/m <sup>2</sup> /s] | 19.941 |
|-------------------|---------------------------------------------------|--------|

## P1-4.8 ESTIMATE CHANNELLED EMISSIONS FOR TANK PROCESS CYCLE PHASES:

|                                                                          |                           |                                                                                        |        |
|--------------------------------------------------------------------------|---------------------------|----------------------------------------------------------------------------------------|--------|
| TANK PROCESS PHASE:                                                      | STATIC (Steady-State)     | CONTINUOUS QUIESCENT /STATIC EMISSION RATE: [mg/m <sup>2</sup> /s]                     | 19.941 |
| (TVOC /Methane)                                                          |                           |                                                                                        |        |
| Emission Rates.                                                          | AERATION PHASE:           | AERATION Variance Factor, from Static: Range: 1.0 to 2.8: [-]                          | 1.768  |
|                                                                          |                           | MEAN AERATING EMISSION RATE: [mg/m <sup>2</sup> /s]                                    | 35.246 |
| Governs potential abatement process media life or thermal energy demand. | FILLING PHASE:            | MEAN PUMP INFLOW RATE: (24 hrs) Effective Forced Displacement: [m <sup>3</sup> /h]     | 8.98   |
|                                                                          |                           | MAX INSTANTANEOUS PUMP INFLOW RATE: Effective Forced Displacement: [m <sup>3</sup> /h] | 14.40  |
|                                                                          |                           | Discharge Turbulance Variance Factor: [-]                                              | 1.25   |
|                                                                          |                           | OVERALL FILLING Variance Factor, applied to Static Rate: Range: 1.0 to 15.0. Calc: [-] | 1.604  |
|                                                                          |                           | MEAN FILLING EMISSION RATE: [mg/m <sup>2</sup> /s]                                     | 31.990 |
|                                                                          | FILLING + AERATION PHASE: | AERATION Variance Factor, from Static: Range: 1.0 to 2.0: [-]                          | 1.56   |
|                                                                          |                           | MEAN FILL + AERATION EMISSION RATE: [mg/m <sup>2</sup> /s]                             | 31.053 |

## ESTABLISH A MEAN:MAX RATIO FOR CHANNELLED EMISSIONS:

|                           |               |                                                                        |         |
|---------------------------|---------------|------------------------------------------------------------------------|---------|
| Governs abatement process |               | Channelled Emission MEAN:MAX Ratio. Range: 1.0 to 3.0: [-]             | 1.35    |
| Load flux.                | FILLING PHASE | SHORT-TERM DURATION: MAX or PEAK Emission Rate: [mg/m <sup>2</sup> /s] | 43.187  |
|                           | PEAK CONC.    | AGGREGATE: SHORT-TERM FILL CYCLE DURATION: [mins per day]              | 58.6211 |
|                           | LOAD.         | No. OF PDST FILL CYCLES PER DIGESTER: [-]                              | 4.00    |
|                           |               | No. of Digesters Displacing to PDST: [-]                               | 2.00    |
|                           |               | Based on assumed Fill-Cycles per Digester Discharge:                   |         |
|                           |               | SHORT-TERM PEAK CONC. DURATION: [mins per cycle]                       | 7.328   |

CLIENT id:

DOCUMENT Nr:

Reference Nr:

// Rv.

// R2-1

PROJECT TITLE: WW Enterprises : BRFWF

STATUS:

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Date:

25/07/2025

SUBJECT /Elem.t: PDST OFF-GAS IED Compliance :: Element

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Date:

- - - - -

Ref:

&gt;&gt;&gt; References / Results

## P1-4.8.1 OVERALL SUMMARY

ESTIMATED PDST OFF-GAS EMISSIONS OF VOCs. - USED FOR PROCESS PLANT SIZING.

Applied F-o-S for Uncertainty of Estimates:

5.00%

Calc.d Emission Rate: [mg/m<sup>2</sup>/s]Factored Emission Rate: Incl. F-o-S: [mg/m<sup>2</sup>/s]Establish core criteria for any  
Abatement plant treatment  
process.

MINIMUM Rate:

19.9411

MIN Emission Rate: [mg/m<sup>2</sup>/s]

20.938

AVERAGE RATE:

32.591

AVERAGE Emission Rate: [mg/m<sup>2</sup>/s]

34.221

MAXIMUM RATE:

43.187

PEAK Emission Rate: [mg/m<sup>2</sup>/s]

45.346

AGGREGATE: SHORT-TERM PEAK EMISSION RATE DURATION: [mins per day]

58.621

Note(s):

[1] - VOCs Other than Methane assumed to be included within the overall Uncertainty, F-o-S.

DRAFT SUBJECT TO PEER REVIEW AND FINAL CHECKS.

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## P1-4.9 ASSESS AGAINST REQUIRED PERFORMANCE CRITERIA:

P1-4.9.1 Performance criteria dictated by IED BAT-53 and AEL (Assoc. Emission Levels). See below for Extraction of Table 6.10:

BAT 53 : EMISSIONS TO AIR - Table 6.10

**BAT-associated emission levels (BAT-AELs) for channelled emissions of HCl and TVOC to air from the treatment of water-based liquid waste**

| Parameter               | Unit               | BAT-AEL <sup>(1)</sup> |
|-------------------------|--------------------|------------------------|
| Hydrogen chloride (HCl) | mg/Nm <sup>3</sup> | 1-5                    |
| TVOC                    |                    | 3-20 <sup>(2)</sup>    |

<sup>(1)</sup> These BAT-AELs only apply when the substance concerned is identified as relevant in the waste gas stream, based on the inventory mentioned in BAT 3.<sup>(2)</sup> The upper end of the range is 45 mg/Nm<sup>3</sup> when the emission load is below 0,5 kg/h at the emission point

The associated monitoring is given in BAT 8

## P1-4.9.2 Available Abatement /Treatment Techniques Pertaining to Volatile Organic Compounds (VOCs):

**Adsorption.** Adsorption is a heterogeneous reaction in which gas molecules are retained on a solid or liquid surface that prefers specific compounds to others and thus removes them from effluent streams. When the surface has adsorbed as much as it can, the adsorbent is replaced or the adsorbed content is desorbed as part of the regeneration of the adsorbent. When desorbed, the contaminants are usually at a higher concentration and can either be recovered or disposed of. The most common adsorbent is granular activated carbon.

**Biofilter.** The waste gas stream is passed through a bed of organic material (such as peat, heather, compost, root, tree bark, softwood and different combinations) or some inert material (such as clay, activated carbon, and polyurethane), where it is biologically oxidised by naturally occurring microorganisms into carbon dioxide, water, inorganic salts and biomass. A biofilter is designed considering the type(s) of waste input. An appropriate bed material, e.g. in terms of water retention capacity, bulk density, porosity, structural integrity, is selected. Also important are an appropriate height and surface area of the filter bed. The biofilter is connected to a suitable ventilation and air circulation system in order to ensure a uniform air distribution through the bed and a sufficient residence time of the waste gas inside the bed.

**Condensation and Cryogenic condensation.** Condensation is a technique that eliminates solvent vapours from a waste gas stream by reducing its temperature below its dew point. For cryogenic condensation, the operating temperature can be down to – 120 °C, but in practice it is often between – 40 °C and – 80 °C in the condensation device. Cryogenic condensation can cope with all VOCs and volatile inorganic pollutants, irrespective of their individual vapour pressures. The low temperatures applied allow for very high condensation efficiencies which make it well-suited as a final VOC emission control technique.

**Direct Fired Thermal Oxidation (DFTO).** The oxidation of combustible gases and odorants in a waste gas stream by heating the mixture of contaminants with air or oxygen to above its auto-ignition point in a combustion chamber and maintaining it at a high temperature long enough to complete its combustion to carbon dioxide and water

|                          |                     |              |                                       |
|--------------------------|---------------------|--------------|---------------------------------------|
| Operating Temperature    | HIGH 900°C - 1200°C | Application: | Low off-gas flows with high VOC Load. |
| Gas residence time: Typ. | 2.0 secs or less    |              |                                       |
| Thermal Efficiency       | Medium              | HEX Material | N/A                                   |
| Energy Consumption       | High                |              |                                       |

**Recuperative Thermal Oxidation.** In addition to the basic Direct-Fired, DFTO: Recuperative thermal oxidisers use metallic heat exchangers (HEXs) to recover heat from the exhaust gases and transfer it to the incoming off-gas stream. Typically recovering around 50-75% of the heat input energy.

|                          |                      |                   |                                            |
|--------------------------|----------------------|-------------------|--------------------------------------------|
| Operating Temperature    | MEDIUM 750°C - 850°C | Application:      | Medium off-gas flows with medium VOC Load. |
| Gas residence time: Typ. | 0.5 ... 1.0 secs     |                   |                                            |
| Thermal Efficiency       | Good (70%-80%)       | HEX Typ /Material | Shell Tube. Metallic - St. Stl or exotic   |
| Energy Consumption       | Medium               | VOC destr.n Eff.c | 99% DRE - Destr.n Removal Eff.c            |

**Regenerative Thermal Oxidation (RTO).** An RTO features a ceramic media bed HEX that captures heat from the hot, VOC-laden exhaust stream, which is then used to preheat the incoming off-gas before it enters the combustion chamber, thereby significantly reducing fuel consumption. Suitable for continuous operation.

**High-Heat.**

|                          |                     |                   |                                                                       |
|--------------------------|---------------------|-------------------|-----------------------------------------------------------------------|
| Operating Temperature    | HIGH 815°C - 980°C  | Application:      | Large off-gas volumes with variable composition and/ or low VOC load. |
| Gas residence time: Typ. | 0.6 ... 1.0 secs    |                   |                                                                       |
| Thermal Efficiency       | Very High (95%-97%) | HEX Typ /Material | Packed Bed. Ceramic bead /fibre.                                      |
| Energy Consumption       | Low                 | VOC destr.n Eff.c | 99% DRE - Destr.n Removal Eff.c                                       |

**Wet scrubbing.** The removal of gaseous or particulate pollutants from a gas stream via mass transfer to a liquid solvent, often water or an aqueous solution. It may involve a chemical reaction (e.g. in an acid or alkaline scrubber). In some cases, the compounds may be recovered from the solvent.

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CLIENT id:

DOCUMENT Nr:

Reference Nr:

// Rv.

// R2-1

PROJECT TITLE: WW Enterprises : BRFWF

STATUS:

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Date:

25/07/2025

SUBJECT /Elem.t: PDST OFF-GAS IED Compliance :: Element

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Date:

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P1-4.9.3 INITIAL ASSESSMENT: (DRAFT - to test viability of available abatement techniques using dilution air).

PERFORMANCE LIMIT: From BAT-53, Table: 6.10:

TVOC Limit: [mg/Nm<sup>3</sup>] 20.000

Target: TVOC Limit: [%] 75.00%

Design TVOC Limit: [mg/Nm<sup>3</sup>] 15.000PDST OFF-GAS STEADY-  
STATE /STATIC  
/MINIMUM EMISSION OF  
VOCs:

MEAN CH4 Emission over PDST-HRT period: [mg/h] 5900560.06

Equates to: Mean CH4 Emission: [m<sup>3</sup>/d] 220.99

Minimum Required Ventilation Air (aka. BioFilter): [m3/h] 393370.67

ASSESS VENTILATION  
DUCT SIZE BASED ON  
AIR DILUTION ONLY.

LIMIT VENTILATION AIR VELOCITY TO: [m/sec] 15.00

Min. Ventilation Duct Eqv. Dia. [mm] Not viable.

Dilution of Calc.d TVOCs to Design Target Limit :: Not viable.

PDST OFF-GAS FILLING  
PHASE MEAN EMISSION  
OF VOCs:MEAN EQUIVALENCE VALUES  
Back-Calculated.

MEAN CH4 Emission over PDST-HRT period: [mg/h] 2368905597.70

Equates to: Mean CH4 Emission: [m<sup>3</sup>/d] 88722.99

Minimum Required Ventilation Air (aka. BioFilter): [m3/h] 157927039.85

ASSESS VENTILATION  
DUCT SIZE BASED ON  
AIR DILUTION ONLY.

LIMIT VENTILATION AIR VELOCITY TO: [m/sec] 15.00

Min. Ventilation Duct Eqv. Dia. [mm] Not viable.

Dilution of Calc.d TVOCs to Design Target Limit :: Not viable.

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DOCUMENT Nr:

Reference Nr:

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// R2-1

PROJECT TITLE: WW Enterprises : BRFWF

STATUS:  
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- - - - -

Ref:

&gt;&gt;&gt; References / Results

P1-4.10 HYDROGEN SULPHIDE, H2S - HISTORIC SAMPLE DATA.

BASED ON DIGESTER: D1 OVER PERIOD:

FROM: 01/07/2022

TO: 30/12/2022

Reference: Email dated:15/07/2025, 09:55

DATASET:

D1 and D3 removed from Service on  
05/07/2023

| SAMPLE<br>DATE:<br>[dd/mm/yyyy] | SAMPLE<br>TIME:<br>[hh:mm:ss] | Vol.<br>Conc.<br>[ppm] | Mass : Vol.<br>Conc.<br>[mg/m <sup>3</sup> ] |
|---------------------------------|-------------------------------|------------------------|----------------------------------------------|
| 31/10/2022                      | 12:59:59                      | 801.0000               | 1104.7776                                    |
| 24/10/2022                      | 12:59:59                      | 736.0000               | 1015.1265                                    |
| 17/10/2022                      | 12:59:59                      | 731.0000               | 1008.2303                                    |
| 10/10/2022                      | 12:59:59                      | 689.0000               | 950.3019                                     |
| 03/10/2022                      | 12:59:59                      | 733.0000               | 1010.9888                                    |
| 26/09/2022                      | 12:59:59                      | 754.0000               | 1039.9530                                    |
| 19/09/2022                      | 12:59:59                      | 729.0000               | 1005.4718                                    |
| 12/09/2022                      | 12:59:59                      | 819.0000               | 1129.6041                                    |
| 05/09/2022                      | 12:59:59                      | 663.0000               | 914.4414                                     |
| 29/08/2022                      | 12:59:59                      | 881.0000               | 1215.1175                                    |
| 22/08/2022                      | 12:59:59                      | 885.0000               | 1220.6345                                    |
| 08/08/2022                      | 12:59:59                      | 1007.0000              | 1388.9027                                    |

DATA ANALYSIS:

|                      |          |           |
|----------------------|----------|-----------|
| MEAN:                | 785.6667 | 1083.6292 |
| MEDIAN:              | 745.0000 | 1027.5398 |
| GEOMEAN DATA:        | 780.3684 | 1076.3215 |
| UPPER-QUARTILE DATA: | 834.5000 | 1150.9825 |

No. OF DATA PTs ABOVE UPPER-4tile: 3  
25.00%

Applied F-o-S for Uncertainty of sample data: 6.00%

ADOPTED DESIGN VALUE(s) FOR OFF-GAS  
ABATEMENT /TREATMENT PROCESS:Vol. Conc. [ppm] 885.00  
Mass : Vol. Conc. [mg/m<sup>3</sup>] 1220.63No. of Data Pts above DESIGN: 1  
8.33%

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CLIENT id:

DOCUMENT Nr:

Reference Nr:

// Rv.

// R2-1

PROJECT TITLE: WW Enterprises : BRWF

STATUS:

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Date:

25/07/2025

SUBJECT /Elem.t: PDST OFF-GAS IED Compliance :: Element

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Date:

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&gt;&gt;&gt; References / Results

## P1-4.11 FLAMMABILITY OF CHanneled OFF-GAS EMISSION WITHIN ROOF VOID, POST COVERING:

CH4: (Methane to : IEC60079-20-1)

LFL: [% v/v]

4.40%

UFL: [% v/v]

17.00%

LFL: [g/m<sup>3</sup>]

2900.00%

LFL: [g/m<sup>3</sup>]

11300.00%

MEAN CH4 Hourly Prod.n over PDST-HRT retention period:

Vol. Rate: [m<sup>3</sup>/h]

9.2081

MIXING AIR INJECTED Via. \*No. 25mm PE unconfined pipe nozzles:

Max. Air Vol. Rate: [m<sup>3</sup>/h]

300.0000

Min. Air Vol. Rate: [m<sup>3</sup>/h]

173.0000

OFF-GAS (METHANE) CONC.

At Max Air Mix Rate: 300m<sup>3</sup>/h: VOID Conc.: [ppm. v/v]

3.069%

Excludes any dilution through fugitive air leaks.

Below LFL. Gas Mix Lean.

At Min Air Mix Rate: 173m<sup>3</sup>/h: VOID Conc.: [ppm. v/v]

5.323%

Flammable Gas Mixture Conc.

## P1-4.11.1 OPTION(s) FOR DEALING WITH OFF-GAS FLAMMABILITY CRITERIA:

OPT-[1] ABATEMENT PROCESS INVOLVES THERMAL OXIDATION.

In general: No Action Required.

OPT-[2] ABATEMENT PROCESS INVOLVES CHEMICAL OR BIOLOGICAL TREATMENT.

Additional dilution air required to achieve a maximum of 50% LFL.

THUS:

LFL TARGET Limit:

FoS: [%]

25.00%

[% v/v]

1.10%

REQUIRED DILUTION AIR (TOTAL) INORDER TO ACHIEVE TARGET CONC.

Air Vol. Rate: [m<sup>3</sup>/h]

837.10

AT MIXING: MAX. Air Volume rate:

Additional dilution air to current Air Mixing Rate - Air Vol. Rate: [m<sup>3</sup>/h]

537.10

AT MIXING: MIN. Air Volume rate:

Additional dilution air to current Air Mixing Rate - Air Vol. Rate: [m<sup>3</sup>/h]

664.10

ASSESS PRACTICALITY:

LIMIT DILUTION /VENTILATION AIR VELOCITY TO:

[m/sec]

15.00

AT MIXING: MAX. Air Volume rate:

Ventilation Duct Eqv. Dia. [mm]

112.535

Vent.n Duct Eqv. Dia. [m]

0.113

AT MIXING: MIN. Air Volume rate:

Ventilation Duct Eqv. Dia. [mm]

125.134

Vent.n Duct Eqv. Dia. [m]

0.125