ENGINEERING JUSTIFICATION OF CONCENTRATOR AND DOSING PARAMETERS IN AN ANAEROBIC BIOGAS UNIT

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Abstract. This paper develops a calculation-based methodology for selecting and coordinating a feedstock concentrator and a metering unit in a continuously fed anaerobic digester. The concentrator adjusts slurry total-solids content, whereas the doser delivers a controlled volumetric or mass flow. The study establishes coupled balances for water removal, volatile-solids (VS) input, hydraulic retention time (HRT), organic loading rate (OLR), and dosing error. A transparent numerical design example is provided for a 20 m^3 working-volume reactor. The values in the example are assumed design inputs rather than measured experimental observations. The proposed approach identifies feasible concentration and dosage combinations, highlights the inherent trade-off between water savings and slurry pumpability, and defines an experimental verification protocol.

Keywords: biogas; anaerobic digestion; concentrator; dosing unit; organic loading rate; hydraulic retention time; total solids; design calculation.

Introduction

Anaerobic digestion transforms biodegradable feedstocks into biogas and digestate through linked microbial processes. Its practical efficiency depends not only on the digester vessel but also on preparation and delivery of the incoming feed. Uncontrolled dilution increases the liquid volume that must be heated and held inside the reactor; excessive thickening, by contrast, may cause sedimentation, clogging, and unstable distribution. Accurate dosing is equally important because irregular substrate addition changes organic loading and may disturb biological balance [1, 3].

The term “concentrator” in this paper denotes a mechanical or process unit that changes the solids concentration of a feed slurry, primarily by removing a controlled fraction of its liquid. It is not a solar-energy concentrator. A “doser” is a feed-metering device that delivers a prescribed amount of slurry per unit time. Their parameters must be selected together, since a reduction in feed flow changes HRT and volumetric organic load simultaneously.

This research addresses the engineering question: how can solids concentration and daily dosage be calculated to satisfy a target OLR and an acceptable HRT while respecting

the physical handling limits of the substrate? The contribution is a unified preliminary sizing method, not a claim of experimentally proven improvement.

Scientific basis and calculation method

Let F_0 denote the incoming wet-feed mass per day (kg d^{-1}), x_0 its total-solids (TS) mass fraction, x_1 the TS fraction after concentration, and η_s the fraction of original dry solids retained in the concentrated stream. Assuming no solids decomposition within the concentrator, the daily concentrated mass and separated water are calculated as follows:

$$F_1 = F_0 \times x_0 \times \eta_s / x_1 \quad (1)$$

$$W_r = F_0 - F_1 - F_0 \times x_0 \times (1 - \eta_s) \quad (2)$$

Equation (2) treats the rejected dry solids as a separate mass stream. When $\eta_s = 1$, the expression simplifies to $W_r = F_0 - F_1$. Actual separation performance should be determined by weighing both outlets and measuring TS concentrations. The concentrator mass-flow capacity should exceed the maximum expected incoming feed by a suitable engineering margin.

For a homogeneous slurry with approximate density ρ (kg m^{-3}), the daily volume is $Q = F_1/\rho$. If fVS represents the volatile fraction of retained TS, the introduced VS mass is $MVS = F_0\ x_0\ \eta_s\ fVS$ (kg VS d^{-1}). The working digester volume V gives the principal design indicators:

$$HRT = V / Q \quad (3)$$

$$OLR = MVS / V \quad (4)$$

The design must satisfy simultaneously $HRT \geq HRT_{min}$ and $OLR \leq OLR_{max}$, where the admissible limits are selected from substrate-specific tests, operating temperature, mixing regime and inoculum performance. HRT and OLR cannot be optimized independently: modifying concentration changes Q, whereas increasing original feed mass raises MVS. BMP characterization should use a documented test protocol rather than an assumed universal biogas yield [2].

For an intermittent dosing system delivering n portions daily, nominal portion mass $m_s = F_1/n$. If a positive-displacement pump has effective rate q (kg min^{-1}), dosing duration $t_s = m_s/q$. The signed relative dosing error is $\varepsilon = (m_{actual} - m_{target})/m_{target} \times 100\%$. Reliable operation requires calibration over the range of actual slurry viscosities and solids concentrations.

Illustrative design case (calculated, not experimentally observed)

A hypothetical feed of 500 kg d^{-1} at 8% TS, dry-solids retention $\eta_s = 0.98$, VS/TS = 0.80, slurry density $\rho = 1{,}000$ kg m^{-3}, and an anaerobic reactor with $V = 20$ m^3 is considered.

An output solids target of 12% TS is assumed. The input parameters are selected to illustrate the method; they do not describe an installed biogas plant.

Table 1. Mass-balance and operating-parameter calculations for the illustrative biogas unit

Design indicator	Calculation	Result
Dry solids retained	500 × 0.08 × 0.98	39.2 kg TS/day
Concentrated slurry	39.2 / 0.12	326.7 kg/day
Separated liquid + solids losses	500 – 326.7	173.3 kg/day
Approx. dosing volume	326.7 / 1,000	0.327 m^3/day
VS loading	39.2 × 0.80	31.36 kg VS/day
HRT	20 / 0.327	61.2 days
OLR	31.36 / 20	1.57 kg VS/(m^3·day)
Per-dose mass, n = 4	326.7 / 4	81.7 kg/dose

At a nominal dosing capacity of 20 kg min^{-1}, each of four daily portions requires approximately 4.1 min of operation, excluding priming and line-flushing time. The 61.2-day HRT reflects feed volume alone and may be too long from an investment-utilization standpoint, depending on substrate kinetics. This is a reason to test alternative feeding scenarios, not evidence that 12% TS is universally optimal.

Sensitivity of design to the concentration target

Holding the incoming feed mass, solids-retention factor and reactor volume fixed, the concentration target modifies the volumetric flow and HRT without changing the estimated retained VS load. This distinction matters: raising TS does not inherently increase substrate organic matter when original feed supply is unchanged.

Table 2. Effect of target total-solids content on concentrated feed mass, HRT, and OLR

Target TS	Concentrated mass	Approx. HRT	OLR
8%	490.0 kg/day	40.8 d	1.57 kg VS/(m^3·d)
10%	392.0 kg/day	51.0 d	1.57 kg VS/(m^3·d)
12%	326.7 kg/day	61.2 d	1.57 kg VS/(m^3·d)
14%	280.0 kg/day	71.4 d	1.57 kg VS/(m^3·d)

These values do not include the electrical energy consumed by separation, agitation or pumping. They also do not capture changes in apparent viscosity with TS, which can sharply affect equipment suitability. Therefore, concentrator performance should be judged

using a combined criterion: liquid reduction, solids recovery, specific energy demand (kWh per tonne of feed), manageable rheology and net process stability [3, 4].

Proposed equipment selection and validation procedure

The concentrator should be characterized by throughput, solids recovery η_s, controllable outlet TS, specific electricity consumption, and risk of clogging. Candidate mechanisms (screening, screw pressing, or other separation processes) should be compared only after measuring the particle-size distribution and rheological behavior of the chosen feedstock. The dosing unit may employ a progressive-cavity, diaphragm or another solids-tolerant displacement principle; final selection depends on particle size, corrosiveness, allowable pressure and required cleanliness.

A pilot protocol is proposed with three controllable factors: output TS (for example, 8%, 10% and 12%), number of daily feeds (2, 4 and 6), and feed rate. At each condition, measure inflow and reject masses, TS and VS, pump calibration drift, energy consumption, temperature, pH, volatile fatty acids/alkalinity, total daily biogas, and methane fraction. Maintain comparable total VS input when testing only the concentration effect. Record a sufficient stabilization period before comparing biological response, and apply replicate measurements where feasible [2, 5].

A practical controller should compare measured daily VS dosage with its setpoint. If feedstock TS drifts, the requested wet mass can be recomputed as Fset = MVS,target/(TS × VS/TS), while respecting mechanical feed limits. Level sensors, pressure monitoring, non-return valves and emergency shutdown logic are necessary elements of safe implementation. Biogas-side equipment must meet applicable gas-safety and electrical requirements.

Limitations and conclusions

The analytical model assumes approximately constant slurry density, no biological conversion in the concentrator and fixed VS fraction of retained solids. It omits detailed reactor mixing dynamics and separator-specific energy balances. These simplifying assumptions must be checked in a pilot study before claims of yield improvement or commercial efficiency are made.

A consistent approach for sizing a concentrator–doser biogas unit has been formulated. For the stated hypothetical 20 m^3 reactor, changing the slurry from 8% to 12% TS with 98% solids retention reduces the estimated daily wet feed delivered to the reactor from 490.0 to 326.7 kg while preserving an estimated OLR of 1.57 kg VS/(m^3·day). The corresponding HRT rises from approximately 40.8 to 61.2 days. This demonstrates that

concentration and dosing must be co-designed, rather than chosen as isolated devices. Experimental verification is required to establish actual optimal settings and biogas-production benefits.

References

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