

# Evaluation of the dual digestion system: Part 3: Considerations in the process design of the aerobic reactor<sup>1</sup>

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## Abstract

In this paper, design considerations for pure oxygen and air oxygenated aerobic reactors in dual digestion are outlined based on the steady state heat balance. Accepting that the objectives of the aerobic reactor are sludge pretreatment through oxygen limitation and pasteurisation, it is demonstrated that 3 parameters are of crucial importance to design which centres around minimising the reactor retention time: (1) the oxygen consumption rate of the sludge ( $OCR_{bio}$ ) which fixes the maximum biological heat generation rate; (2) the oxygen transfer rate (OTR) of the oxygenation system which should be less than  $OCR_{bio}$  to ensure oxygen limitation; and (3) the oxygen transfer efficiency of the oxygenation system (OTE) which determines the vent gas volumetric flow rate at a given OTR. For a given OTR, if OTE is high (attainable with pure oxygen), vent gas heat losses (through water vapour and sensible heats) are small and most of the heat generated is lost via hot effluent sludge thereby allowing pasteurisation temperatures to be attained at short retention times; if OTE is low (which usually is the case with air), vent gas heat losses are high, and much less heat can be lost via hot effluent sludge thereby forcing longer retention times to attain pasteurisation temperatures. However, with heat exchange between reactor effluent and influent sludge flows and with increased mechanical heat input, heat sources are increased without increasing heat losses in the vent gas and pro rata reductions in retention time are allowed.

## Nomenclature and abbreviations

(For those not listed hereunder, see Messenger et al., 1993a on p. 185-191 in this issue)

A	= wall and pipework heat loss surface area ( $m^2$ ).
a	= vent gas mass to moles multiplying factor for air, oxygen enriched air and pure oxygen systems.
$\text{fia}_2$	= mass fraction of oxygen in influent gas.
$H'_e, H'_{ge}$	= net sensible heat loss rate between influent and effluent sludge and vent gas flow rates (i.e. $H_{sc}-H_{si}$ and $H_{ge}-H_{gi}$ ) respectively (MJ/h).
$H_e$	= total vent gas heat loss rate (MJ/h). = sum of the net sensible $H'_e$ and water vapour ( $H_{ve}$ ) heat loss rates.
$h_{fg}$	= latent heat of vaporisation of water (MJ/kg).
$M_{we}$	= vent gas water vapour mass flow rate (kg/h).
$M_{dg}$	= dry vent gas molar flow rate (kmoles/h).
$P_T$	= total atmospheric (barometric) pressure (mmHg).
p	= partial pressure (mmHg). Subscripts w and dg denote saturation water vapour and dry gas respectively.
$Q_s$	= influent and effluent sludge flow rate (mVd).
$T_{diff}$	= difference between reactor sludge and exit vent gas temperatures ( $^{\circ}C$ ) (= $T_{sc}-T_{ge}$ ).

## Design and simulation of the aerobic reactor

Aerobic reactor design and simulation procedures were derived from the results of the Milnerton aerobic reactor performance (Messenger et al., 1992;1993a). These are founded on fundamental heat and mass balance principles and therefore they

are general and apply to reactors oxygenated with air, oxygen enriched air or pure oxygen.

The design procedure is based on the solution of the steady state heat balance over the reactor. Such a heat balance yields a constant temperature for the reactor sludge and is applicable only to reactors that are continuously fed. In practice, however, to avoid recontamination of pasteurised sludge, the reactor is batch fed which causes the sludge temperature to vary with time in a saw-tooth pattern between 2 and 4 $^{\circ}C$  per cycle. To predict the cyclically varying temperature profile requires a moment by moment solution of an unsteady state heat balance. However, this cyclic temperature variation is so small relative to the difference between the feed and reactor sludge temperatures (i.e.  $\pm 40^{\circ}C$ ) that the mean reactor sludge temperature is completely adequate for design. Accordingly the steady state approach is adopted for design because it greatly simplifies the design procedure. The small error that this introduces is readily corrected with the aid of a simulation computer program which solves the moment by moment unsteady heat balance, using the steady state estimate as a starting point. The general simulation algorithm and computer program ATASIM for solution of the unsteady state heat balance is presented in the fourth and final paper in this series (Messenger and Ekama, 1993). A list of symbols is given by Messenger et al. (1993a).

## Aerobic reactor design objectives

Two objectives need to be met by the aerobic reactor in dual digestion, viz.

- **Pasteurisation:** By exposure of the sludge to a minimum temperature for a minimum length of time, generally above 60 $^{\circ}C$  for 2 h or above 70 $^{\circ}C$  for 30 min.
- **Pretreatment:** The thermophilic aerobic environment in the reactor apparently pretreats the sludge leading to an enhanced performance of the anaerobic digester. Mason (1986) suggests that this pretreatment is improved by operating the reactor

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