Evaluation of the dual digestion system: Part 2: Operation and performance of the pure oxygen aerobic reactor

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Abstract

In a comprehensive study of the performance of a full-scale (45 m3) pure oxygen autothermal thermophilic aerobic reactor of a sewage sludge dual digestion system, it was found that: Biological heat generation rate was directly proportional to the biological oxygen consumption rate at 13,1 MJ/kgO; respiration quotient (mol CO_2 generated per mol O_2 consumed) was 0,66; vent gas was saturated with water vapour even at the high vent gas flow rates; COD and/or VS removal rates were poor parameters for quantifying the biological heat generation rate and controlling the reactor temperature. Increases in reactor temperature could be completely and virtually instantaneously controlled by means of the oxygen supply rate (OSR) for as long as the reactor was oxygen limited. The rapidity of response and close correlation between the oxygen transfer rate (OTR) and the biological heat generation rate make the OTR and the OSR pivotal parameters in the operation, control, design and simulation of oxygen limited autothermal thermophilic aerobic reactors in dual digestion.

Nomenclature and abbreviations

ATAD = autothermal thermophilic aerobic digestion.
C_p = specific heat at constant pressure [MJ/(t-°C)]. Additional subscripts s and g refer to sludge liquid and vent gas respectively.
COD = chemical oxygen demand.
f_{mech} = mechanical heat generated per power utilised ratio of recirculation pump.
H = general term for heat flow (MJ/h). Last subscripts i and e denote heat sources (influent) and sinks (effluent). First subscripts b, m, v and w refer to biological, mechanical, vent gas and wall respectively.
OCR = oxygen consumption rate.
O_c = mass OCR by the sludge mass (kgO/h).
OCR_{sys} = volume specific OCR by the sludge [kgO/(m^3h)] (equals O_c/V_p).
OCR_{bio} = volume specific OCR capability of the sludge [kgO/(m^3-h)].
O_s = mass OSR by the oxygenation system (kgO/h).
OSR = volume specific oxygen supply rate by the oxygenation system [kgO/(m^3-h)] (equals O/V_p).
OTR = volume specific oxygen transfer rate to the liquid phase by the oxygenation system [kgO/(m^3-h)].
OTE = oxygen transfer efficiency of the oxygenation system (equal to O_c/O_s or OTR/OSR).

Note: Under oxygen limiting conditions OTR < OCR_{bio} and the sludge OCR_{sys} is limited by oxygenation system OTR i.e. OCR_{sys} = OTR. Under oxygen sufficiency conditions OTR > OCR_{bio} and the sludge OCR_{sys} is limited by OCR_{bio} i.e. OCR_{sys} = OCR_{bio}. The number of terms pertaining to oxygen supply and consumption may seem excessive, but this is necessary to distinguish between the oxygen transfer characteristics of the oxygenation system from the oxygen consumption by the sludge.

R_H = hydraulic retention time (d).
U_{oa} = overall wall and pipework heat transfer coefficient [MJ/(m^2-h-°C)].
V = general term for volume (m^3). Subscripts p and b denote reactor operating and batch volumes respectively.
T = general term for temperature (°C). Subscripts s and g refer to sludge liquid and vent gas respectively. Subscripts i and e denote heat sources (influent) and sinks (effluent) respectively. Subscript amb refers to ambient atmospheric air temperature.
TS,VS = Total and volatile solids concentrations *(g/ℓ)* respectively where sludge samples are dried without prior dewatering.
Y_{CO_2} = respiration quotient on a molar basis - mol CO_2 produced per mol O_2 consumed.
Y_H = biological specific heat yield (MJ/kgO consumed).
ρ_s = density of sludge mixed liquor (t/m^3).

Introduction

In **Part 1** of this series of 4 papers, the justification and objectives of the Milnerton dual digestion project were set out, together with a general overview of the results (Messenger et al., 1993). In this paper, attention is focused on the operation, performance and control of the Milnerton pure oxygen aerobic reactor. In the subsequent 2 papers, the design and simulation of pure oxygen or air oxygenated aerobic reactors are considered (Messenger and Ekama 1993a; b).

Heat and oxygen mass balances around the aerobic reactor

In order to meet the objectives of the aerobic reactor investigation, accurate simultaneous heat and oxygen mass balances were required to be made across the aerobic reactor. Two types of heat balance can be made, a steady state and an

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