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## IMPLEMENTATION OF PACKAGE IBR ANAEROBIC DIGESTER AT THE OHIO STATE UNIVERSITY

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### Abstract

The Induced Bed Reactor (IBR) is a high rate anaerobic digester designed to treat high-solids, high strength wastes, such as those found in dairy manures and mixed solid wastes. The IBR has been successfully operated at bench, pilot and full scale. The objective of this paper is to present design and implementation of a 3,800 L pilot scale facility at The Ohio State University's OARDC facility in Wooster, OH for testing and optimization of IBR systems at small dairies.

**Key words:** Anaerobic Digestion, Pilot, Induced Bed Reactor (IBR), Dairy.

### 1. Introduction

#### 1.1. Technology Description

Anaerobic digestion (AD) is widely used in wastewater treatment to stabilize sludge and reduce its volume. Anaerobic digestion is mediated by a diverse and dynamic microbiome, which consists of bacteria and archaeal methanogens. The relatively long doubling times (3 – 10 days) of methanogens, especially acetoclastic methanogens, require either long residence times (20-40 d) to allow for development of sufficient methanogen populations, or decoupling of hydraulic retention time (HRT) and solids residence time (SRT) to retain the active microbial solids in the digesters for significant treatment. Methods for accomplishing this include: 1) separating the active solids from the effluent and recycling them back to the digester, 2) immobilizing microbial populations on inert physical matrix as biofilm, and 3) formation of a bed or blanket of solids that self-select to remain in the reactor as the substrate passes through (Gerardi, 2003; Tchobanoglous et al., 2003). Processes using each of these three methods generally require a relatively low suspended solids concentration in the influent to avoid dilution of the active biomass and other operational problems in the digester (plugging, sedimentation, short circuiting, etc).

The high suspended solids concentrations inherent to feedstocks like livestock manures and food wastes create unique challenges for design and operation of high rate reactors. To address these issues the Induced Bed Reactor (IBR) was proposed by Dr. Conly Hansen (Hansen and Hansen, 2005). By decoupling HRT from SRT, the IBR design enables high rate reduction of high-solid feedstocks (Figure 1).

The IBR relies on biomass retention in the digester to provide an accumulation of active solids, similar to the operational principles first proposed by Dr. Gatzke Lettinga (1980) for his highly successful Upflow Anaerobic Sludge Blanket (UASB) reactor design (Figure 1, left). UASBs operate on the principle of decoupling of SRT and HRT via granulated biomass retention.

The IBR is also an upflow design. Influent enters at the base of the reactor; solids accumulate as an active sludge bed at the bottom of the vessel which acts as a filter for influent entering the reactor. The liquid volume below the septum is well mixed as a function of convective mixing and gas evolution.

There is a baffle (sometimes referred to as a septum) located at approximately 90% of the reactor height. The baffle is a mildly sloped cone, the peak of which is removed to leave an opening. It provides a contact surface to encourage separation of the suspended solids and biogas bubbles. An auger in the center of the cone opening keeps it clear of bridging solids and provides a downward motive force to encourage the denser solids to stay below the septum. The auger shaft also supports a bar which rotates about the central axis of the reactor, constantly sweeping the top of the wet volume to discourage foam and crust formation. Liquid reactor effluent exits via a submerged outlet in the upper reactor volume. Biogas exits the top of the reactor. Pressure in the reactor is maintained via two water columns, one on the liquid effluent line and one on the gas effluent line.

## 1.2. Reason for the Work

The IBR has been implemented at farm scale with over 4,000 m<sup>3</sup> of installed capacity in the US and Canada. While the core IBR digester technology works well, the digester's basic internal performance characteristics are not well understood – particularly with respect to the optimization of the controllable parameters such as temperature, feed rates and composition, pH, and retention times. Further, a more definitive understanding of the microbial populations and their dynamics in the reactor would be of great value to researchers interested in characterizing and optimizing anaerobic systems. Better understanding of these characteristics could lead to a better ability to “tailor” such systems both to more efficiently process “designer” feedstocks and to more effectively harness the energy and co-products resulting from metabolic activity within the reactor.

In 2010, Dr. Conly Hansen and the Energy Dynamics Laboratory (EDL) at the Utah State University Research Foundation (USURF) developed a pilot scale (3,800 L) IBR system. The pilot was built to facilitate research into IBR performance with different substrates at a scale that was relevant to the substrates encountered in typical agricultural and industrial applications. Two of these 3,800 L units were installed at the Logan, Utah (USA) Wastewater Treatment Plant (WWTP) (Figure 2). The systems have been successfully operated for the past 2 years digesting algal biomass, manure, and high strength mixed solid waste. Ongoing work at the facility is focused on AD of various substrates and development of appropriate material handling and pre-processing systems.

In 2012, The Ohio State University's (OSU's) Ohio Agricultural Research and Development Center (OARDC) approached Dr. Hansen and EDL to supply a functional research grade pilot scale system for implementation at their Wooster, OH (USA) facility. OSU's interest is in providing a platform for comparative microbiological characterization and system performance studies between the IBR and existing complete mix pilot systems at the OARDC dairy.

## 2. Materials and Methods

### 2.1. Process Overview

A summary process flow diagram is provided in Figure 3. The primary feedstock for the pilot is dairy manure from OARDC's dairy barns. Manure from the dairy barns is collected in a pit from which it is subsequently pumped to a gravity line that empties to an anaerobic lagoon system. Adding the new IBR research digester will require installation of a diverting pump, a substrate storage/mixing tank sized for the research requirements of the system (a mixing tank with a capacity of at least 1,000 L to provide one day's storage at a 4-day hydraulic retention time (HRT) is recommended), and a digester feed pump in order to divert feedstock manure to the digester.

From the feed pump, the influent crosses the system boundary and proceeds through a solenoid operated plug valve, a check valve, and then into the digester itself. The feed stream transits the sludge bed where the majority of the microbial fermentation action occurs, and the resulting metabolites pass upward through the liquid volume of the reactor, proceed through the septum opening, and exit in their respective liquid/solid and gaseous forms via the effluent ports provided as described above.

Systems are provided for process control and data acquisition, gas pressurization, sampling, and disposal, and temperature control. The system is configured to ship in a standard 6m intermodal shipping container. The digester and all supporting equipment are packed into the container at the assembly facility. The container is transported to the site, the digester vessel is unpacked and set up, and the shipping container becomes a climate controlled control room housing the power, data acquisition and control (DAQ/C) and temperature control systems. Being completely modular, the system is easily relocated. Process and power connections require coordination to ensure compatibility with systems in the field.

### 2.1.2 Process Feed

While outside the scope of the provided system, influent material handling is critical to the operation of IBR systems. The IBR's ability to process wastes as high as 12% solids (Dustin et al, 2011) make feed pump selection and material handling design high priorities in full and pilot scale system development. Pump power and size requirements are dictated by the material characteristics. Pump optimization for a steady state flow rate has to take into account the viscosity and particulate characteristics of the fluid. In the case of the feed for a small digester, this means that the optimal pump design, for the simple expedient of preventing solids deposition and plugging of the feed lines, may appear to be oversized for the required flow rate. Experience has shown that a 5 cm diameter minimum feed line to a digester processing agricultural or MSW slurries is advisable. In order to maintain a cleansing velocity of 60 cm/s, this dictates a pump flow rate of 70 L/minute. If other measures appropriate to the materials to be transported are taken, the pump size may be reduced, but designers and researchers should recognize that for work with steady state upflow digester operation with agricultural slurries, material handling is an operational constraint that impacts the isolation of process variables.

In the case of the OSU pilot, steady state feed is approximated by applying a control algorithm that allows researchers to set the HRT and the number of feed pulses per day. For example, if the desired HRT is 4 days and the system volume is 1000 L, the pump will need to supply 250 L/d. If the pump feed rate is 70 L/min the total pump run time for a 24-hr period is approximately 3.6 minutes. If the pump is an accurate metering pump, the system can be operated based on a timer. If not, flow meter feedback to a feed valve can be utilized to control feed. The number of pulses per day can be set at the user interface, although there is an obvious limit to the accuracy of the feed due to the relatively short pump on time per day, low flow rate, feedback delays and overshoot in valve closure and pump lead/lag. These issues can be mitigated by controlling feed characteristics to enable the use of lower flow rates and smaller feed pipe sizes, but this scaling of feed characteristics will have an impact on applicability of the results to full size systems that are intended to handle more heterogeneous substrates. Reactor feed is a factor that should therefore be given due consideration in experimental design to mitigate the impact of mechanical realities on observability of experimental variables.

### 2.1.2 Process Control and Data Acquisition

A Campbell Scientific CR-1000 datalogger (Campbell Scientific, Logan, Utah USA) provides data acquisition and control (DAQ/C) for the system. The CR-1000 is designed for reliability taking environmental and process measurements under extreme conditions. We have found it to be an effective system for use under the challenging conditions found around anaerobic digestion work. The logger accepts 8 differential or 16 single ended analog inputs, 2 pulse

counters, 8 I/O or 4 RS 232 COM digital ports, 3 switched excitation channels, and a switched 12V output. CS Loggernet (ibid) is used to program the system.

The feed control logic is as outlined in Section 2.1.1. Table 1 shows default monitoring and control parameters. The DAQ/C is customizable and expandable with more than half of the channels available for customized data acquisition. The CR-1000 also serves a web page that archives the data and makes it available for remote monitoring and download. A local PC provides additional backup and a direct interface with the logger.

### 2.1.3 Tank Construction

The IBR tank is fabricated from carbon steel and powder coated for corrosion protection. The tank is supplied with a water jacket and closed cell foam insulation to facilitate outdoor temperature control. Fittings smaller than 5 cm diameter are threaded while fittings larger than 5 cm are groove-lock style couplers. Access ports are provided at 50 cm intervals vertically on the tank wall. A 25 cm viewport is provided at the top of the tank to facilitate visual observation of the headspace. The mechanical components are mounted to a 25 cm blind flange; internal mechanical components can all be removed through the 25 cm flange. Access to the interior of the tank for reconfiguration/inspection is provided by unbolting and removing the entire tank lid. The interior septum/baffle is also removable and reconfigurable.

### 2.1.4 Temperature Control

Temperature control is provided by a Sentra LE 1035 closed loop temperature control system (Advantage Engineering, Indiana, USA). The Sentra LE is essentially a package heating system incorporating a controller, a circulating pump, and an immersion heater. The temperature control and insulation systems are sized to be capable of maintaining thermophilic (55 °C) operating temperatures under sustained environmental temperatures of -30 °C.

The systems can also be paired with a cold water source to provide process cooling as required. Similar controllers have been used successfully at the Logan WWTP demonstration project since 2010.

Full scale IBR's typically use pre-heaters to bring the influent material up to process temperature prior to injecting it into the digester, but given the material handling constraints outlined in Section 2.1.2, heating the influent is problematic. The system can be operated with an external heat exchanger if this is critical to the experiments under consideration.

### 2.1.5 Flow Measurement

Gas Flow: Gas flow is monitored using Alicat M-250SLPM-D-30PSIA/5M (Alicat Scientific, Arizona, USA) calibrated to 40 SLPM of a 65% CH<sub>4</sub>, 35% CO<sub>2</sub> mixture.

Liquid Flow: Influent flow rate is monitored via an Omega FMG-3000 series Magmeter magnetic flowmeter (Omega Engineering, Connecticut, USA) calibrated for a 5 cm pipe flowing full.

### 2.1.6 Gas Handling

Gas exits the reactor via a 32 mm pipe. Sampling fittings are provided prior to and after the water column. Systems can be configured with gas dryers and gas conditioning systems including H<sub>2</sub>S and CO<sub>2</sub> removal. A SolarSpark CF-5 gas flare is provided (LSC Environmental Products, New York, USA).

## 3. Summary and Conclusions

Implementation of the pilot scale IBR at the OSU OARDC represents an opportunity for independent review of IBR performance and study of the microbial communities in the digester. As experimental work progresses with the systems, results will be published.

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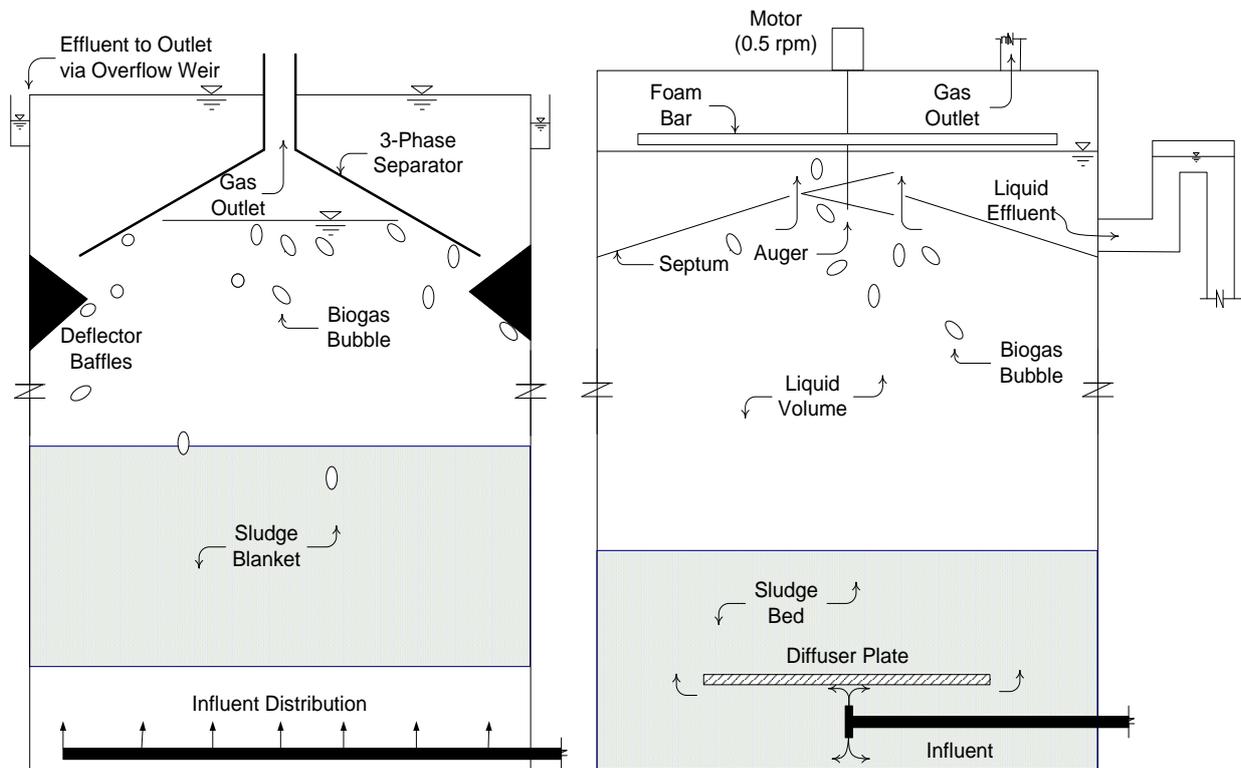


Figure 1: Cutaway view of an Upflow Anaerobic Sludge Blanket (UASB) reactor (L) and an Induced Bed Reactor, IBR (R).

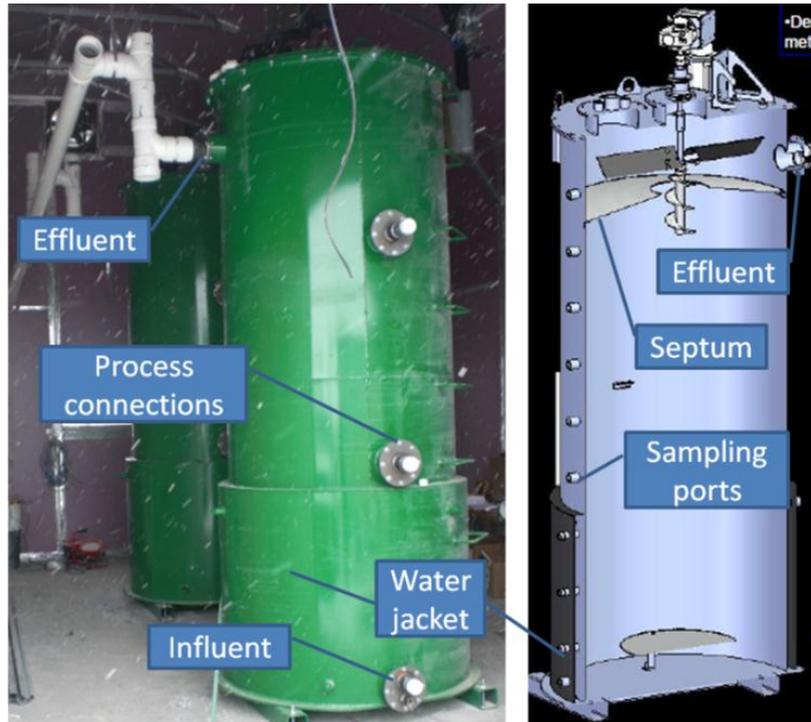


Figure 2: Installed 3,800 L IBR digesters at Logan WWTP and cutaway view of model.

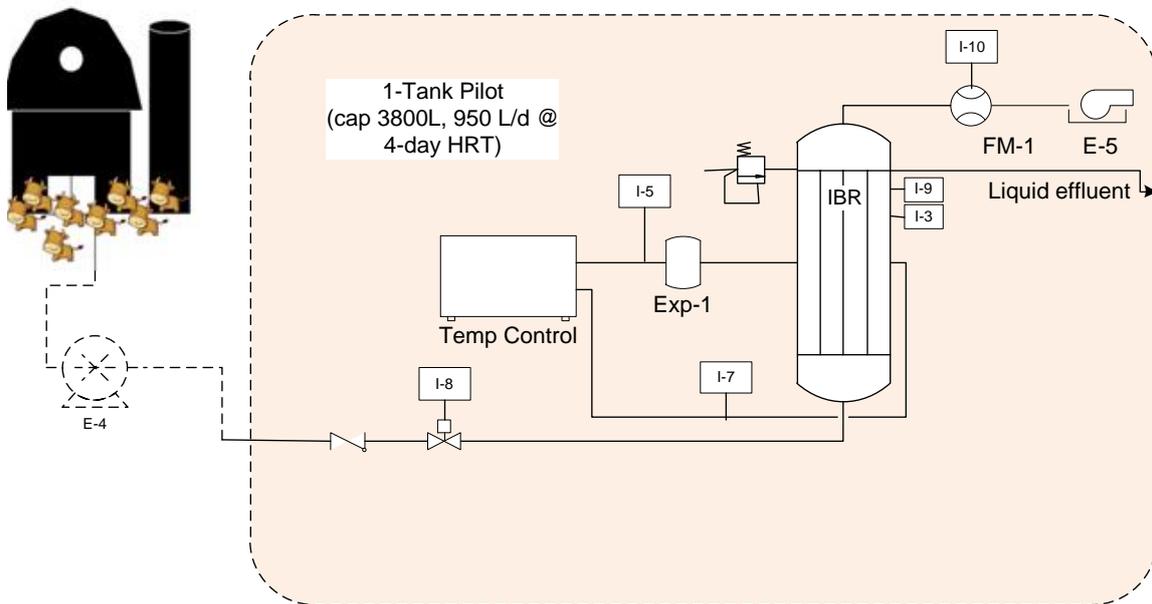


Figure 3: Typical process flow diagram for Pilot Scale IBR

Table 1. Process control and data acquisition I/O summary.

<b>Description</b>	<b>I/O</b>	<b>Software action</b>
Tank temp Thermocouple (K)	mv in	Read @ 1 min interval, report continuously to strip chart; record 4 hr summary to log (max, min, avg, st dev)
Solenoid feed valve	12v out	Digester feed control; Valve on--user adjustable timed intervals. Valve off--timer OR consider feedback from mag meter flowmeter via algorithm relating HRT to Pon and Q, GPM thru flowmeter
Tank pH	mv in	Read @ 1 min interval, report continuously to strip chart; record 4 hr summary to log (max, min, avg, st dev)
Heater feed Thermocouple (K)	mv in	Read @ 1 min interval, report continuously to strip chart; record 4 hr summary to log (max, min, avg, st dev)
Heater return Thermocouple (K)	mv in	Read @ 1 min interval, report continuously to strip chart; record 4 hr summary to log (max, min, avg, st dev)
Gas flowmeter	4-20 mA in	Read @ 1 min interval, report continuously to strip chart; record 4 hr summary to log (max, min, avg, st dev)
Influent flowmeter	4-20 mA in	Feedback to control I2. Read @ 1 min interval, report continuously to strip chart; record 4 hr summary to log (max, min, avg, st dev)
Motor encoder	Pulse in	Verifies auger motor operation; feedback and emergency stop capability