ANAEROBIC TREATMENT OF LOW STRENGTH WASTEWATER

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SEMINAR OUTLINE

- INTRODUCTION
- PREVIOUS WORK
  - Anaerobic Contact Process
  - Anaerobic Filter (AF)
  - Upflow Anaerobic Sludge Blanket Reactor (UASB)
  - Hybrid reactors
- MODELING
- FUTURE RESEARCH
- CONCLUSIONS

INTRODUCTION

- Advantages of anaerobic treatment
- Why is anaerobic treatment not generally accepted for wastewater treatment?
- First attempts to use anaerobic treatment
- Objective of this seminar

ADVANTAGES of ANAEROBIC TREATMENT

- Low production of waste biological solids
- Low nutrient requirements
- No effluent recycle
- Production of methane
- No energy requirement for aeration (net energy producer, not a consumer)

SOME REASONS FOR POOR ACCEPTANCE

- Anaerobic reaction rates are slow – needed elevated temperatures to obtain reasonable rates in complete mixing reactors
- Process complexity and instability
- Break through occurred when reactors were able to retain biomass independent of hydraulic retention time (analogous to the activated sludge process)

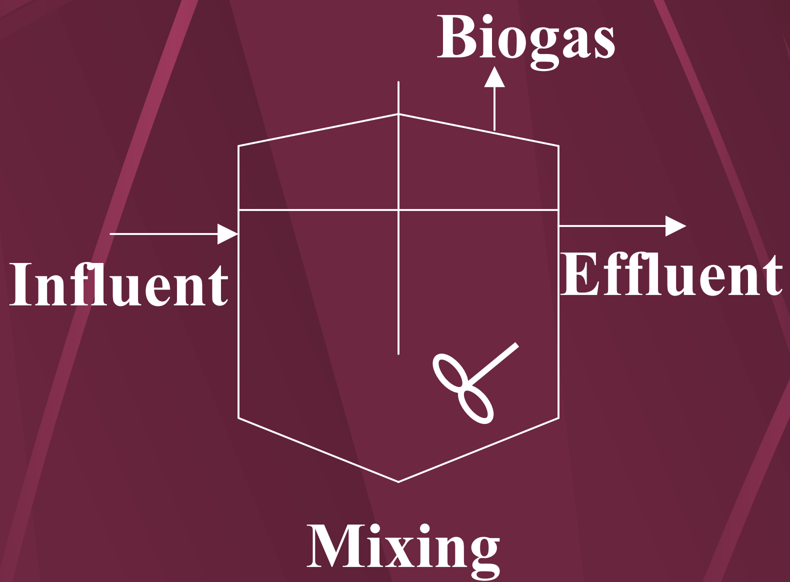
FIRST ATTEMPTS

- Anaerobic Contact Process
  - SCHROEPFER (1955)
- Anaerobic Filter
  - COULTER (1957)
  - YOUNG & McCARTY (1969)
- Upflow Anaerobic Sludge Blanket
  - LETTINGA (1980)

OBJECTIVE

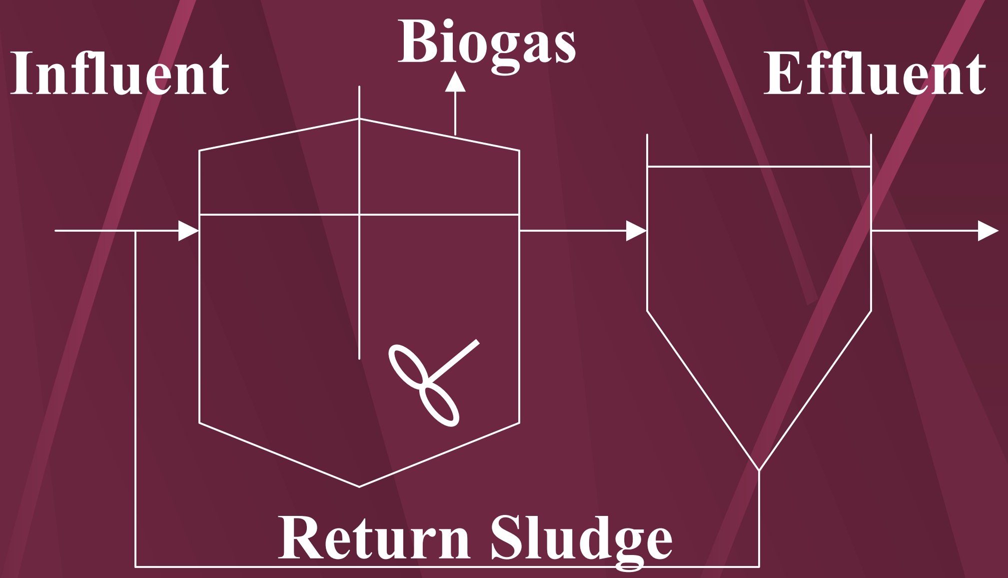
- DESCRIBE PREVIOUS WORK
  - Conventional Process
  - Anaerobic Contact Process
  - Anaerobic Filter (AF)
  - Upflow Anaerobic Sludge Blanket (UASB)
  - Hybrid reactors
- OUTLINE RESEARCH PLAN
  - Modeling
  - Future Research

CONVENTIONAL PROCESS



- Mesophilic (~37^{o}C) & thermophilic (~55^{o}C) operation possible
- Used for stabilizing sludge mainly from activated sludge process

ANAEROBIC CONTACT PROCESS



- Retains biomass in digester independent of HRT
- Problems encountered in separating sludge

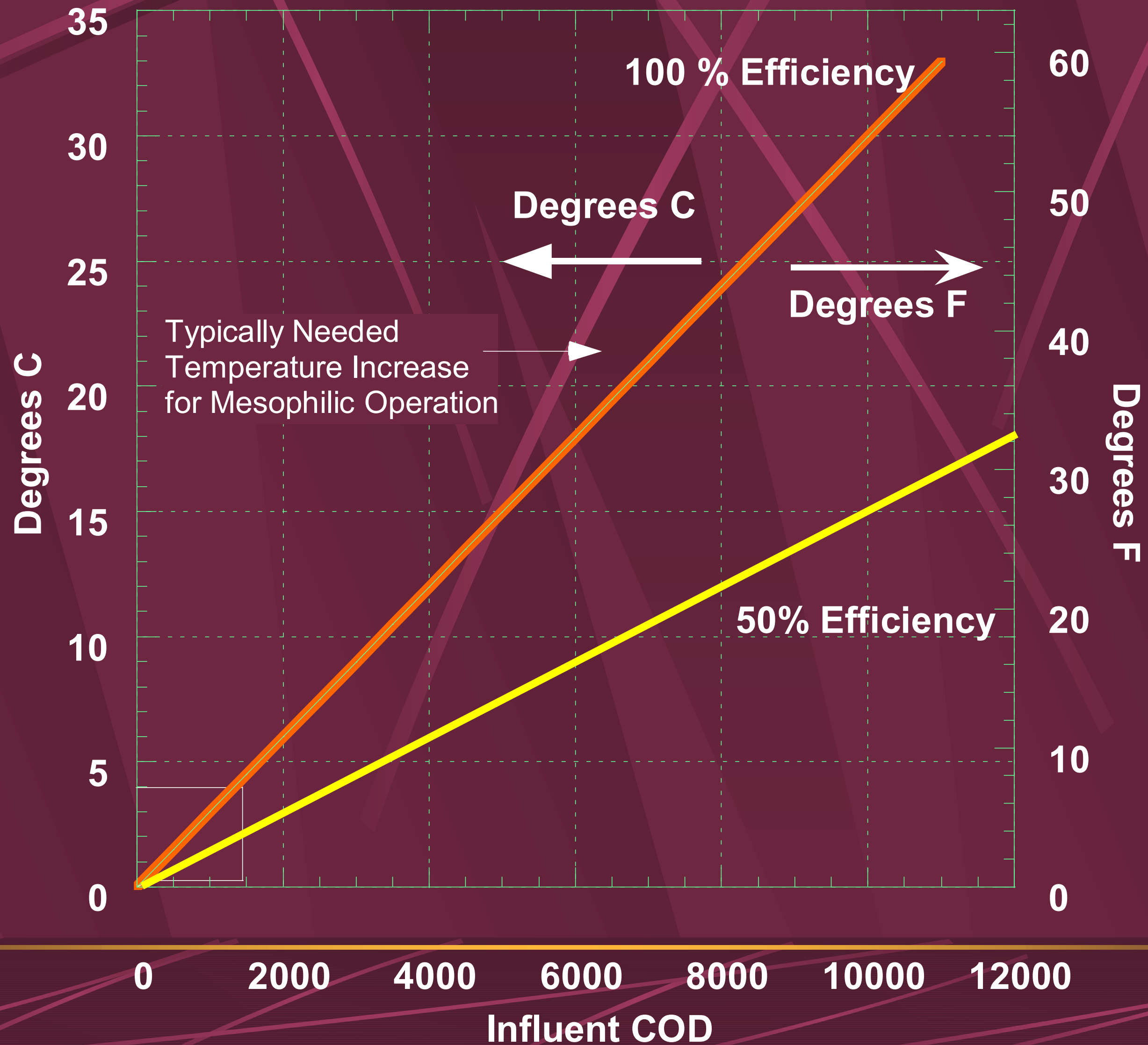
SCHROEPFER *et al.* (1955)

- Developed anaerobic contact process
- CHARACTERISTICS:
  - Packinghouse waste (~1500 ppm BOD_5)
  - 16 ft*8 ft*6 ft digester, 8 ft*4 ft* 2ft 11in liquid depth separator
  - Separation problem encountered in the reactor

SCHROEPFER *et al.* (1955)

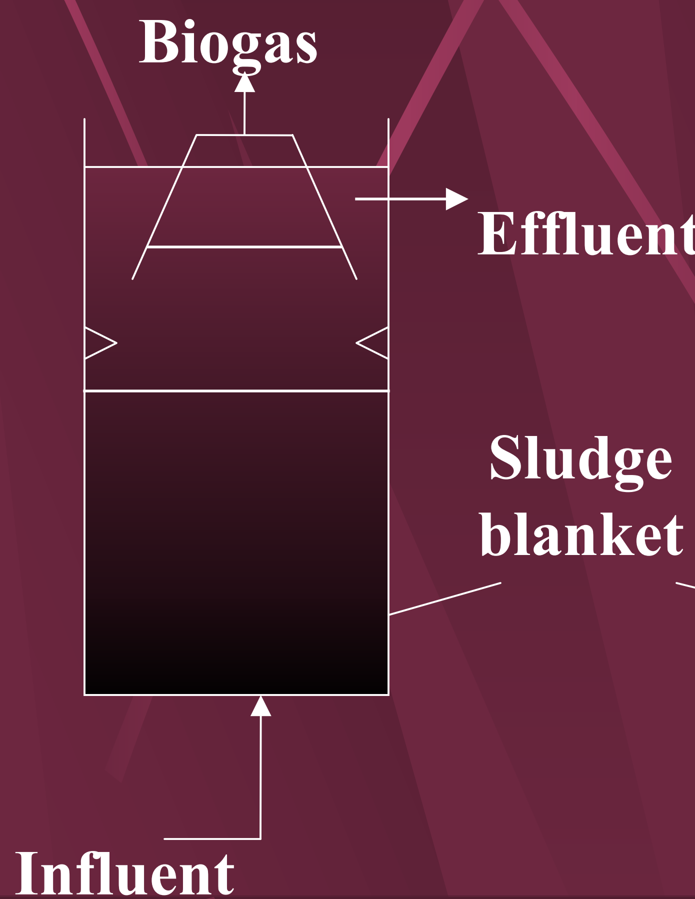
- RESULTS:
  - OLR up to 0.2 lb BOD/ft^3 day
  - RR=95 % BOD_5 at HRT < 12 hr
  - Applies degasifier to evacuate the gas before separator
  - Maintains high contact between waste and biological solids

COD REQUIRED FOR HEATING



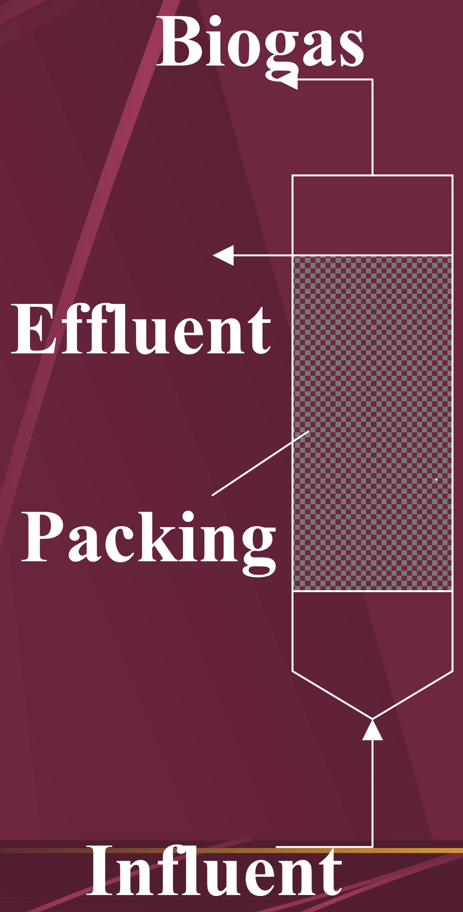
Anaerobic Filter

Upflow Anaerobic Sludge Blanket



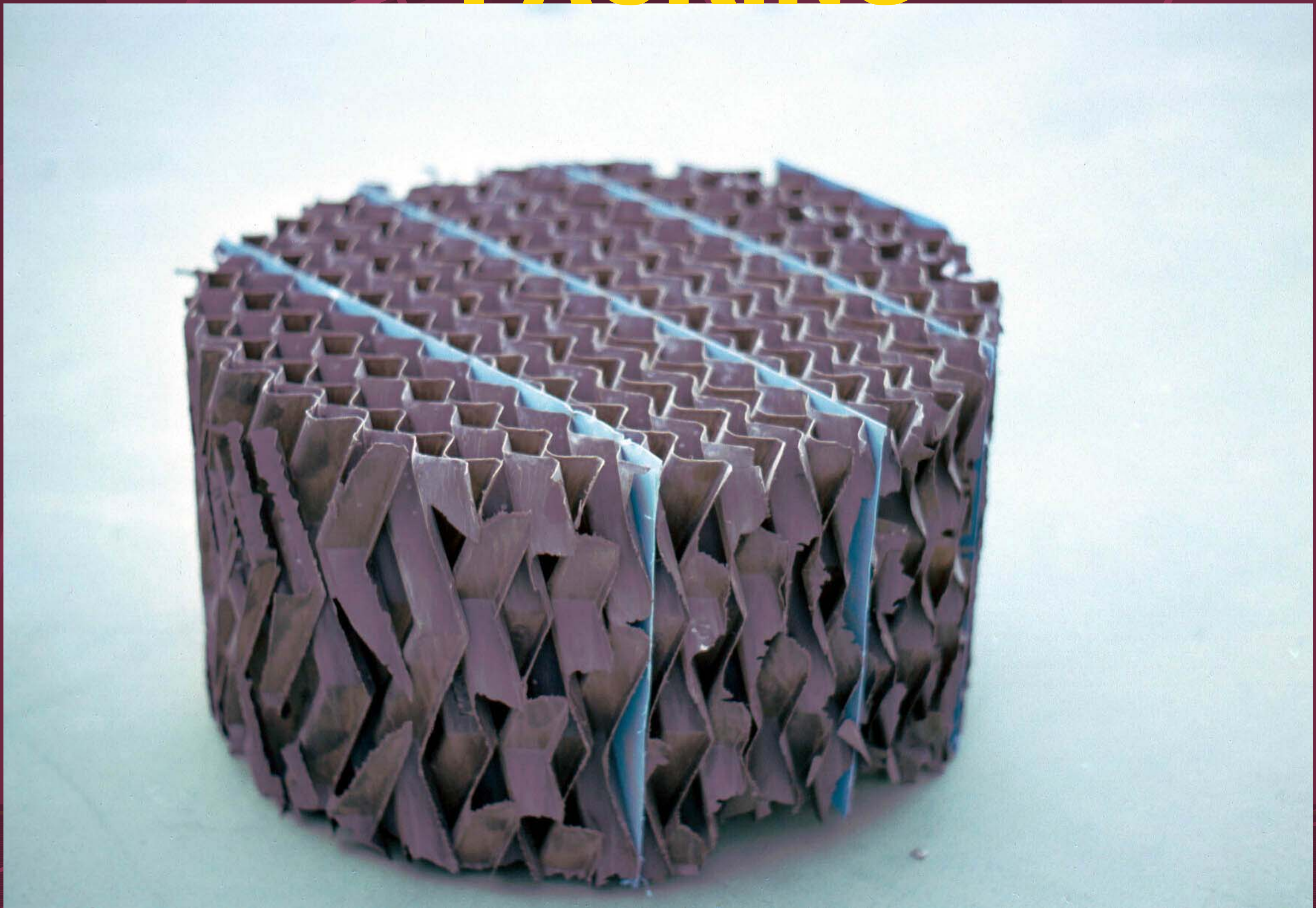
Hybrid Reactor

ANAEROBIC FILTER



- Fully packed filter
- Retains biomass
  - in voids
  - on surface of packing
- A high specific surface area & high void rate gives better treatment

TYPICAL AF PLASTIC PACKING



YOUNG & McCARTY (1969)

- Developed anaerobic filter
- CHARACTERISTICS:
  - Synthetic waste (1500-6000 mg/l COD)
  - OLR= 0.43-3.40 $kg/m^3.d$
  - HRT=4.5-72 hr, Temp=25^oC
- RESULTS:
  - RR=63-93%, efficient treatment for dilute soluble organic wastes

PRETORIUS (1971)

- A combination of a digester & anaerobic filter
- CHARACTERISTICS:
  - Raw sewage (500 mg/l COD)
  - Temp=20^{o}C, HRT=24 hr
  - Stone packing in filter with n=0.6
  - 8 liter digester compartment

PRETORIUS (1971)

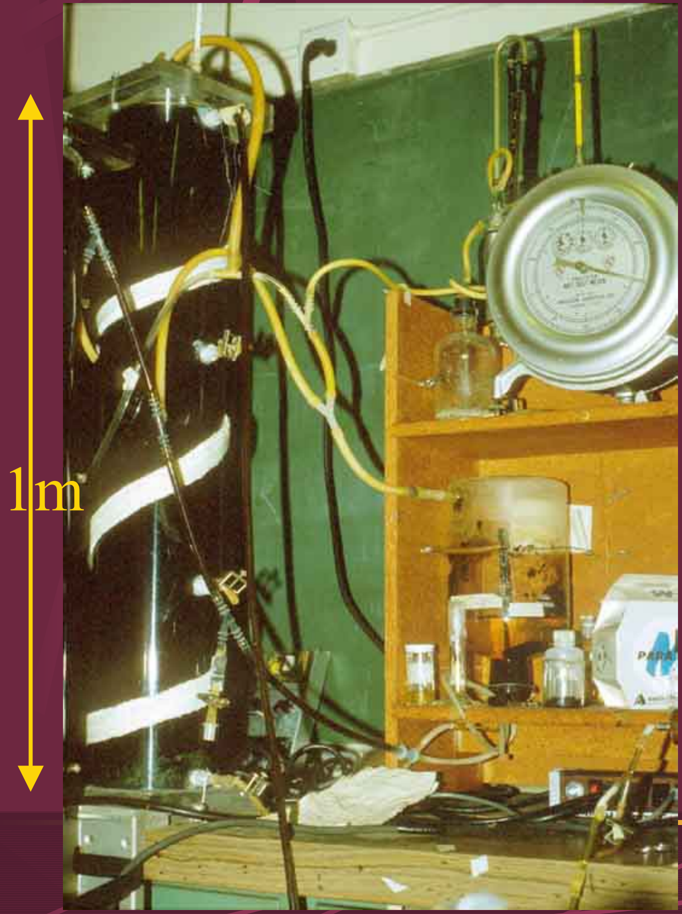
- RESULTS:
  - RR=90% achieved
  - Digester part responsible for solids concentration and hydrolysis

    Filter responsible for gasification

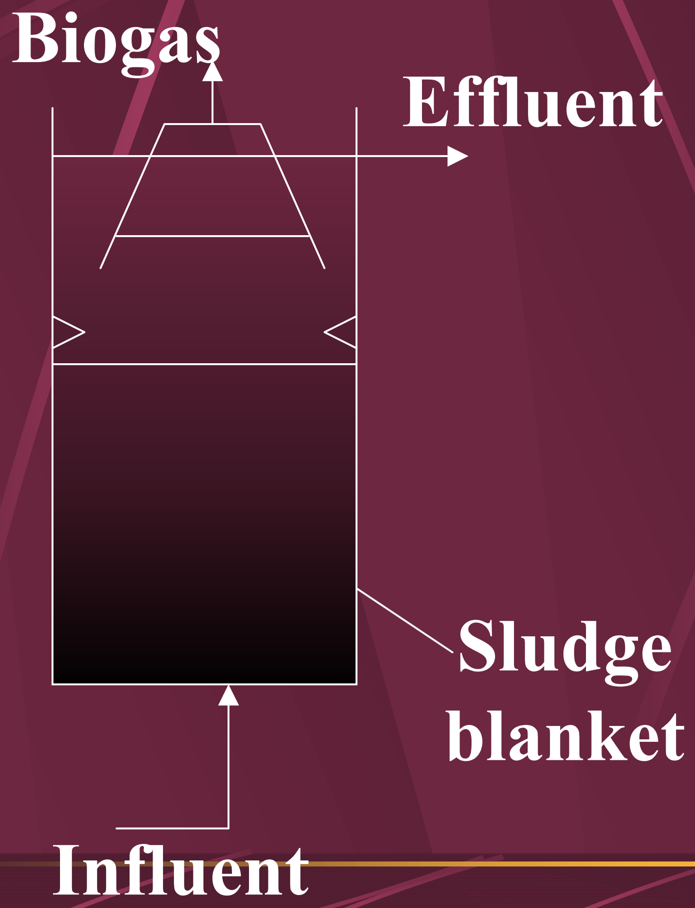
PREVIOUS WORK at UCLA

- CHUNG (1982)
  - 720 liter column
- KOBAYASHI *et al.* (1983)
  - 16 liter column
- ABRAMSON (1987)
  - Two columns (668 & 728 liter)

PILOT SCALE AF's



UPFLOW ANAEROBIC SLUDGE BLANKET



- Dense granular sludge bed at the bottom
- Full scale reactors in Europe, South America & South Asia in past 15 years
- GSS device at top

FULL SCALE UASB TREATING BREWERY

LETTINGA (1980)

- Developed UASB
- CHARACTERISTICS:
  - Raw domestic sewage (140-1100 mg/l COD)
  - Ambient temp: 8-20^{o}C
  - 120 liter reactor
  - Sugar beet waste cultivated seed sludge

LETTINGA (1980)

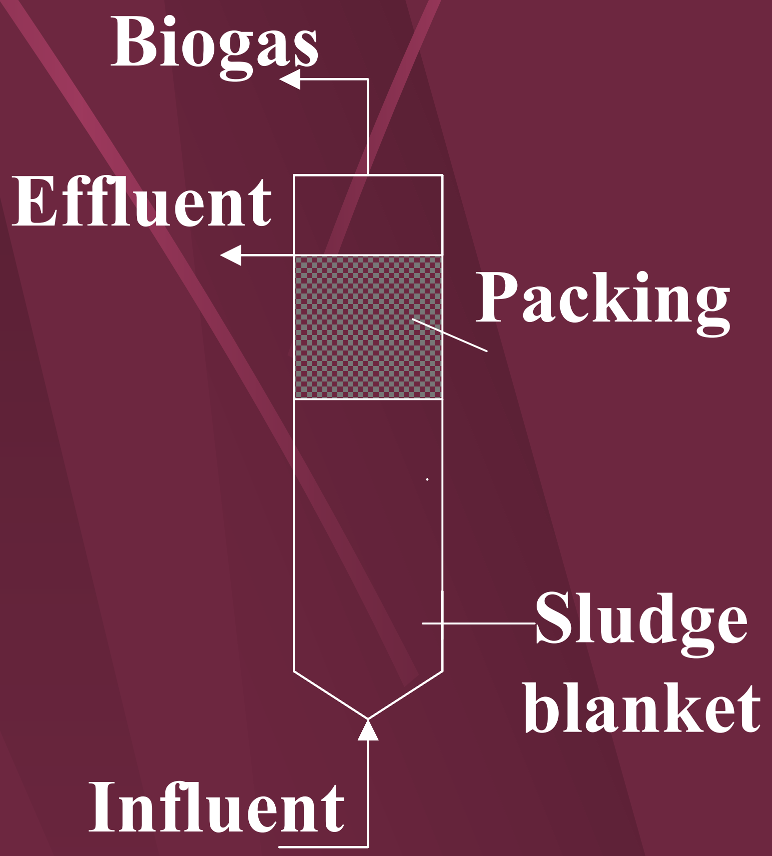
- RESULTS:
  - COD > 400-500 mg/l → RR=65-90%
  - COD < 300 mg/l → RR=50-65%
  - Use of granular sludge is suggested
  - RR slightly affected by temp

FOLLOW-UP WORK

- TARE *et al*. (1997)
  - India
- CHERNICHARO & CARDOSO (1999)
  - Brazil
- KARNCHANAWONG *et al*. (1999)
  - Thailand
- RODRIGUEZ *et al*. (2001)
  - Colombia

HYBRID REACTOR

- Combination of an UASB and AF
  - Sludge bed at the bottom
  - Packing at the top
- Save cost of packing
- Reduce clogging
- Prevent floatation of poor settling particles



PREVIOUS WORK

- MIYAHARA & NOIKE (1994)
  - Japan
- TILCHE *et al*. (1994)
  - Italy
- Di BERARDINO *et al*. (1997)
  - Portugal
- ELMITWALLI *et al*. (2001)
  - Egypt

CHUNG & CHOI (1993)

- CHARACTERISTICS:
  - Naked barley distillery wastewater (3000-6000 mg/l)
  - HRT=3-6 days, Temp=35^{o}C
  - Polyethylene rings
  - Lab scale in Korea
- RESULTS:
  - RR=89-94 % → 1/7 packing
  - RR=91-94 % → 1/2 packing

TILCHE *et al.* (1994)

- CHARACTERISTICS:
  - Piggery wastewater
  - HRT=3 days, Temp=31-36^{o}C
  - Polypropylene random packing
  - Full scale in Italy
- RESULTS:
  - RR=55 %

BORJA *et al.* (1995)

- CHARACTERISTICS:
  - Slaughterhouse wastewater (2450 mg/l COD)
  - HRT=2-12 hr, Temp=35^{o}C
  - 1/3 clay-ring support medium (bentonite)
  - Lab scale in UK
- RESULTS:
  - RR=69-98 %

ELMITWALLI *et al.* (1999)

- CHARACTERISTICS:
  - Raw and pre settled sewage (344-456 mg/l COD)
  - HRT= 8 hr, Temp=13^{o}C
  - Polyurethane foam sheets as packing
  - Lab scale in Netherlands
- RESULTS:
  - RR=61-66 %

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MODELING WORK

- ANDREWS (1969)
- LINDGREN (1983)
- HANAKI & MATSUO (1985)
- McCARTY & MOSEY (1991)
- JEYASEELAN (1997)
- WILSON *et al.* (1998)
- BATSTONE *et al.* (2000)

ANDREWS (1969)

- Anaerobic digestion model
- KEY FEATURES:
  - Use of an inhibition function to relate volatile acid concentration and specific growth rate
  - Un-ionized acid as the growth limiting substrate and inhibiting agent
  - Dynamic model to predict failure

JEYASEELAN (1997)

- Anaerobic digestion model
- KEY FEATURES:
  - Monod kinetics is applied to individual components (carbohydrate, lipids, proteins, others)
  - Steady state model for acid formation and methane formation steps
  - Kinetic coefficients chosen from literature

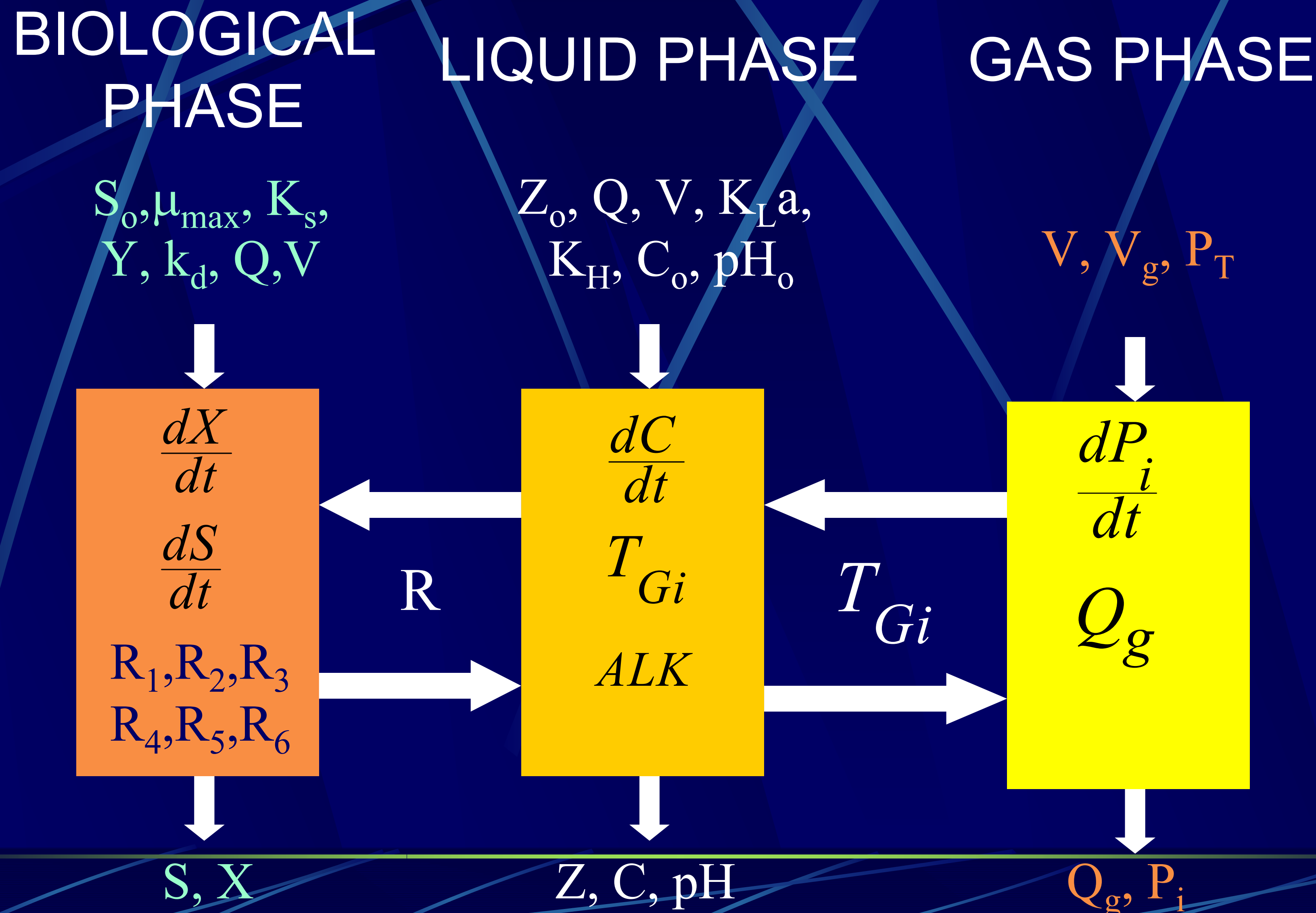
WILSON *et al.* (1998)

- An empirical model for anaerobic filter
- KEY FEATURES:
  - Si and HRT are used as variables to predict effluent COD
  - Modification of Young & McCarty’s model
  - Lab scale experiments on domestic and soybean processing wastewater

OUR MODEL

- Anaerobic filter model
- KEY FEATURES:
  - Biomass balance equation is modified to include the biomass retained in the filter
  - Dynamic model
  - Temperature effects on growth rate and Henry's constants are included
  - System of ODE is solved using MATLAB

OUR MODEL


BIOLOGICAL PHASE
LIQUID PHASE
GAS PHASE
S_o, μ_{max}, K_s, Y, k_d, Q, V
Z_o, Q, V, K_La, K_H, C_o, pH_o
V, V_g, P_T
$\frac{dX}{dt}$
$\frac{dS}{dt}$
R_1,R_2,R_3 R_4,R_5,R_6
R
$\frac{dC}{dt}$
T_{Gi}
ALK
T_{Gi}
$\frac{dP_i}{dt}$
Q_g
S, X
Z, C, pH
Q_g, P_i

BIOLOGICAL PHASE

$$\frac{dX}{dt} = \frac{Q}{V}\left(X_o - X_E\right) + \left(\mu - k_d\right)X$$

$$\frac{dS}{dt} = \frac{Q}{V}\left(S_o - S\right) - \frac{\mu X}{Y_{XS}}$$

$$\mu = \frac{\mu_{\max} S}{\left(K_S + S\right)}$$

$$\mu_{\max} = f\left(Temp\right)$$

LIQUID PHASE

$$\frac{dC}{dt} = \frac{Q}{V}\left(Inf - Eff\right) + Rate$$

$$T_{Gi} = K_L a_i \left(C_i^* - C_i\right)$$

$$C_i^* = K_{Hi} P_i$$

$$ALK = \left[HCO_3^-\right] + 2\left[CO_3^{-2}\right] + \left[NH_3\right] + \left[OH^-\right] - \left[H^+\right]$$

RATES

R_1	$\mu XY_{CO_2X^1}$
R_2	$k_d XY_{CO_2X^2}$
R_3	$\mu XY_{CH_4X^1}$
R_4	$k_d XY_{CH_4X^2}$
R_5	$-\mu XY_{NH_3X^1}$
R_6	$k_d XY_{NH_3X^1}$

Dissolved Components	Rates
CO_2	$T_{G1}+R_1+R_2$
N_2	T_{G2}
CH_4	$T_{G3}+R_3+R_4$
NH_3	R_5+R_6

GAS PHASE

$$\frac{dP_i}{dt} = -P_T D T_{Gi} \left(\frac{V}{V_g} \right) - P_i \left(\frac{Q_g}{V_g} \right)$$

$$Q_i = -D V T_{Gi}$$

$$Q_g = \sum_{i=1}^{i=3} Q_i + Q_{H_2O}$$

$$P_{H_2O} = f\left(Temp \right)$$

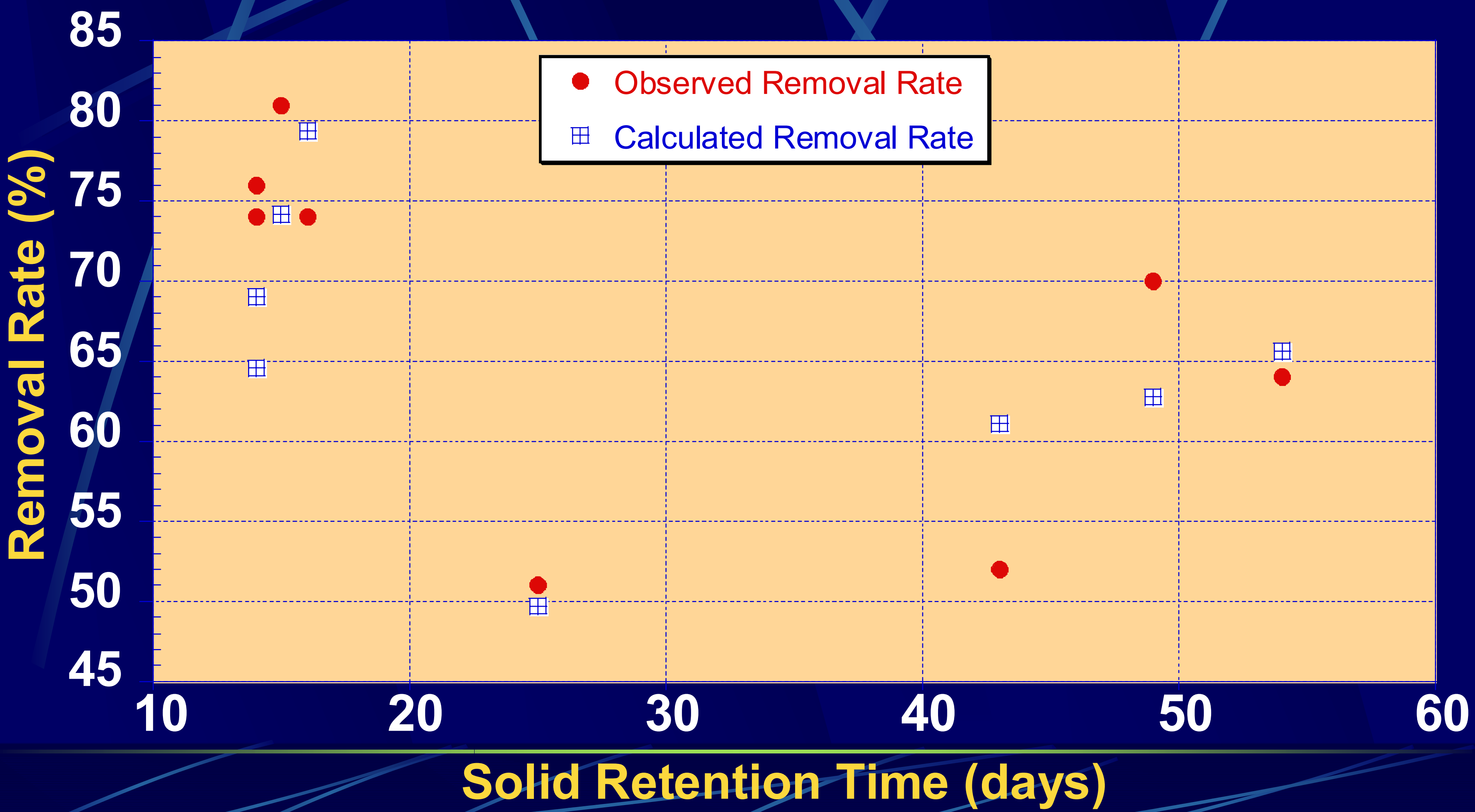
$$i = \begin{bmatrix} CO_2 \\ N_2 \\ CH_4 \end{bmatrix}$$

MODEL CALIBRATION DATA

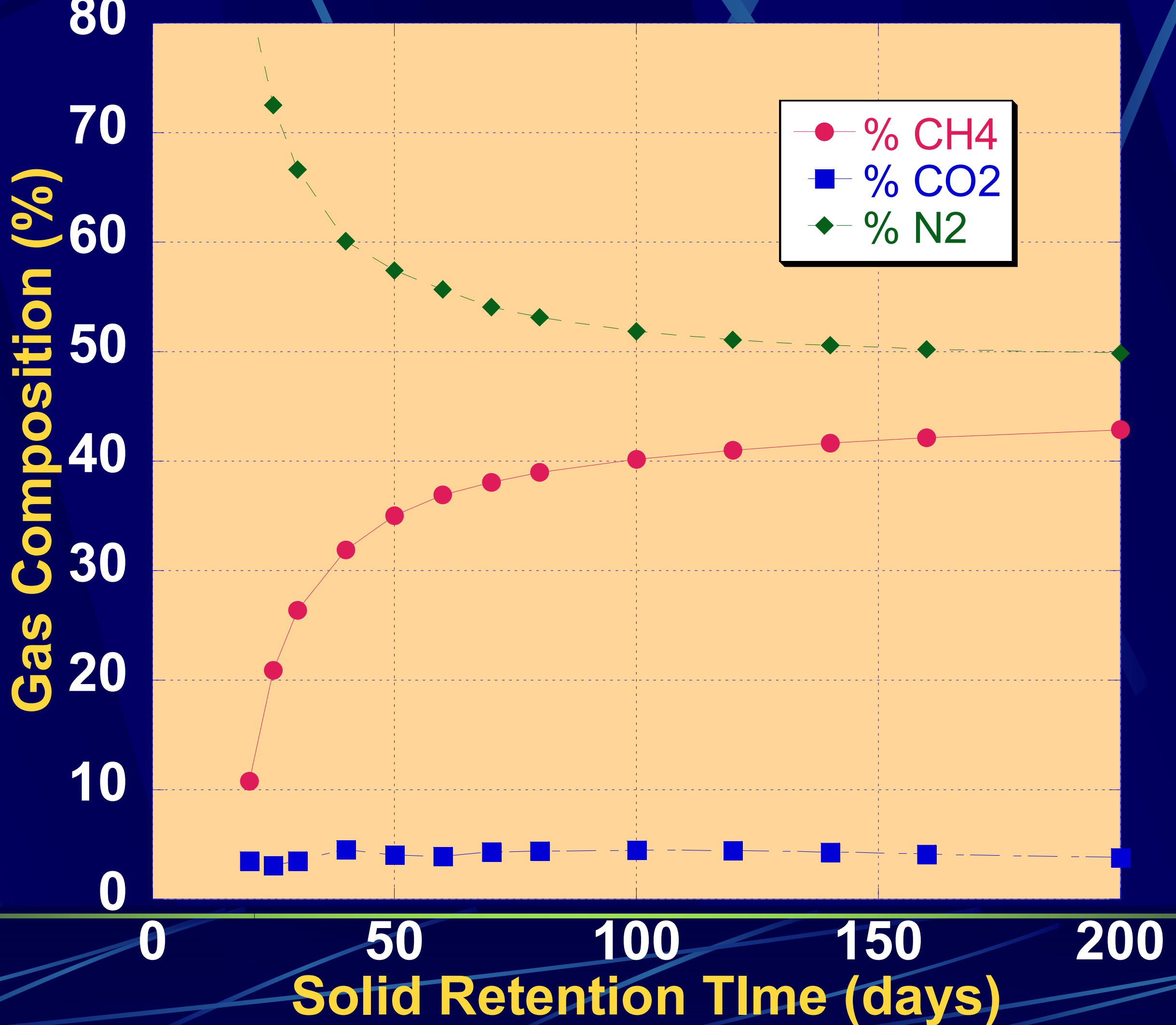
SRT (days)	Temp (F)	HRT (days)	So (mM)
14	68	1	5.66
14	77	1	3.90
16	95	1	3.75
25	84	0.5	1.22
43	84	0.75	0.98
54	80	1.0	1.00
49	80	1.5	1.00
15	80	1.75	4.53

Sources: Kobayashi *et al.* 1983, Abramson 1987

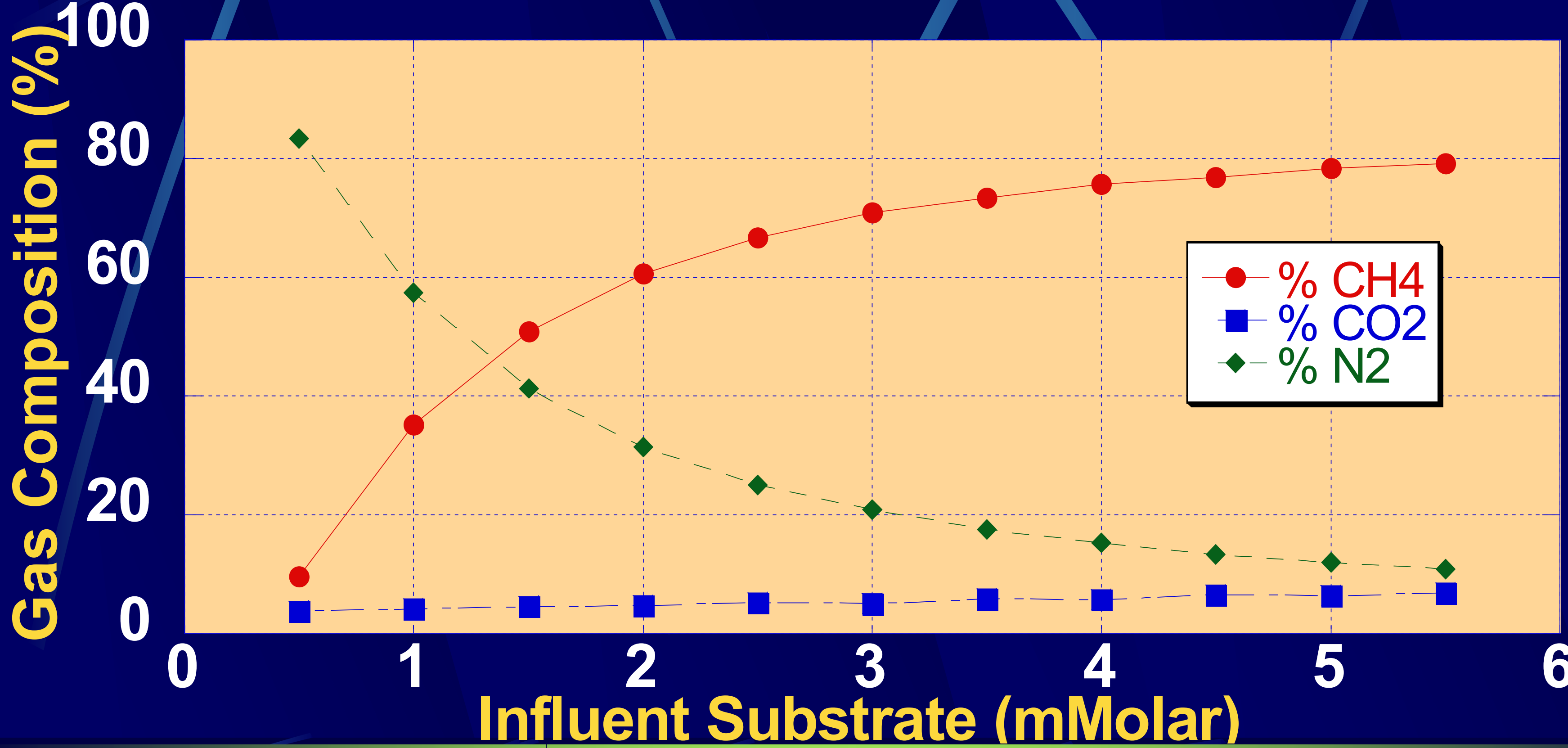
REMOVAL RATE vs SOLID RETENTION TIME



SIMULATED GAS COMPOSITION vs SRT



SIMULATED GAS COMPOSITION vs INFLUENT SUBSTRATE



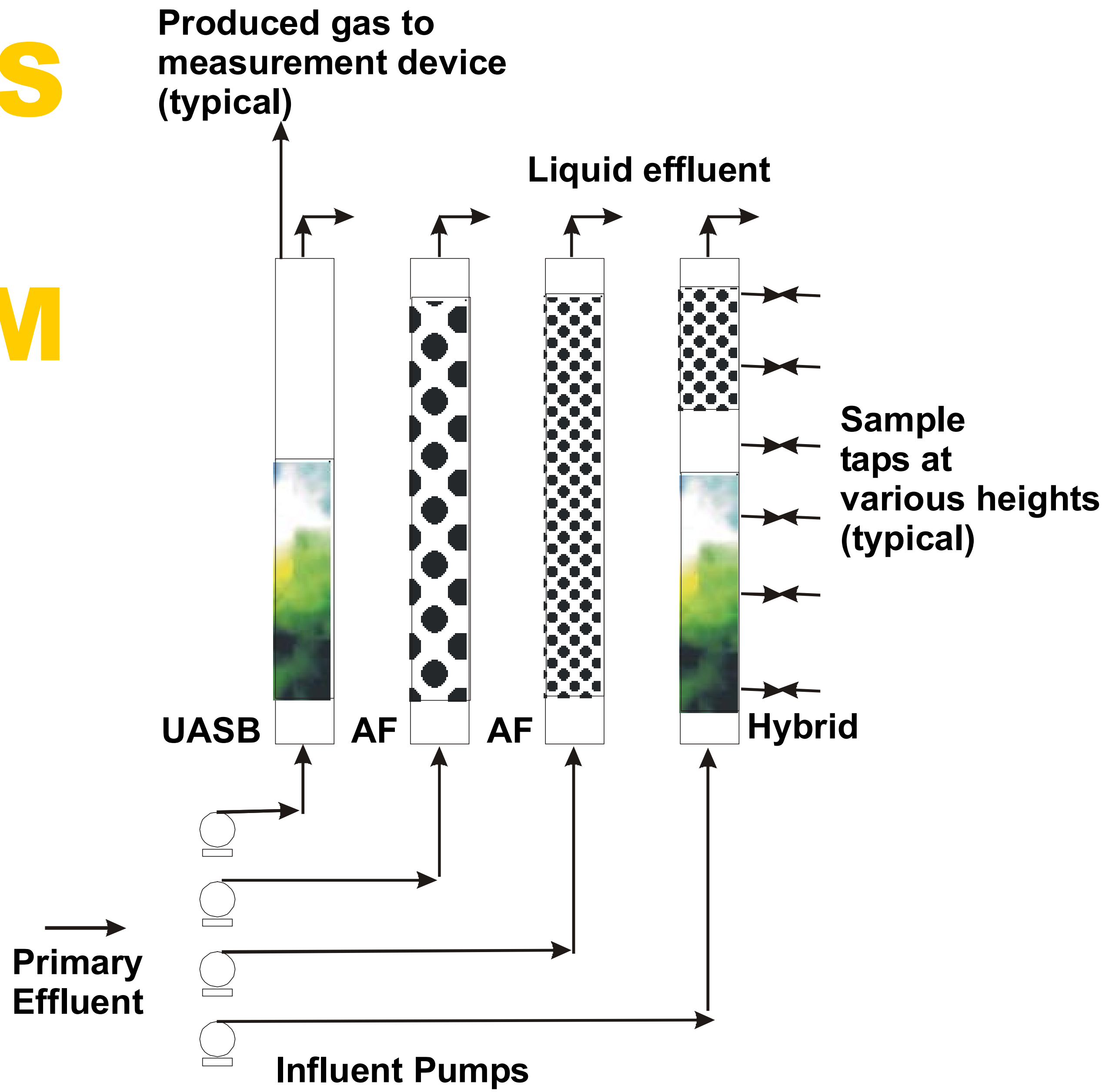
CONCLUSIONS

- Previous pilot scale data are predicted well with our model
- Anaerobic treatment is feasible & economical for low strength wastewater
- Further research is needed in pilot & full scale
- Post treatment is necessary to comply with secondary treatment & for nutrient removal

FUTURE RESEARCH

- PILOT SCALE EXPERIMENTS
  - 4 columns (6 in i.d * 5 ft long)
  - Locate at Terminal Island Treatment Plant
- CHARACTERISTICS of COLUMNS:
  - Anaerobic filter with low-tech packing (AF_1)
  - Anaerobic filter with high-tech packing(AF_2)
  - Hybrid reactor (HAF)
  - Upflow anaerobic sludge blanket reactor (UASB)

PROCESS FLOW DIAGRAM



ME, MYSELF and the COLUMNS

DESIGN PARAMETERS

Type of reactor	HRT (hr)	OLR (kg/m^3d)	Packing
AF_1	12-60	0.16-0.8	low-tech n:0.6
AF_2	12-60	0.16-0.8	high tech 44 ft^2/ft^3
HAF	12-60	0.16-0.8	high tech 44 ft^2/ft^3
UASB	6-24	0.4-1.6	no packing

EXPECTED OUTCOME OF FUTURE RESEARCH

- Improved model of AF to predict performance
- Documented performance of AF, UASB and hybrid reactors treating primary effluent
- Improved understanding of the choice of AF as compared to UASB reactors
- Improved understanding of the advantages of combining AF and UASB reactors in a hybrid configuration

EXPECTED OUTCOME OF FUTURE RESEARCH

- Improved understanding of the applicability of AF, UASB and hybrid reactors for treating domestic wastewater
- Improved understanding of the effect of packing type (properties) on reactor performance
- Predictions of AF, UASB and hybrid reactor effectiveness for partial treatment, secondary treatment, load reduction in an existing secondary treatment system

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THANK YOU