Acid-Stimulated Biological Phosphorus Removal

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Summary

- QUESTOR Centre
- Microbial phosphorus (P) cycling
- Exploit microorganisms to remove and recover P
- Polyphosphate metabolism

QUESTOR Centre
Water & Wastewater Cluster

- Cluster covers all aspects of water / wastewater treatment
- All treatment processes (biological, chemical, physical, thermal etc.)
- Pollution prevention, reuse/recycling
- Effects of discharges on the environment
- Reduction/elimination of associated sludges/residuals
- Public Health Issues
- Sustainability – energy, carbon emissions
- Pathogen tracking

Membership

- McAllister Brothers Ltd.
- ExxonMobil R. & E.
- Enva Ireland Limited
- Central Chemical Supplies Ltd.
- T.E. Laboratories Ltd.
- Modern Water plc
- Wilson’s Country Ltd.
- Northern Ireland Water
- Glenfarm Holdings Ltd.
- Williams Industrial Services
- Cleanfields Technologies Ltd.
- Colloide Engineering Systems
- Bombardier Aerospace
- Chevron North Sea Ltd.
- Northern Innovation Ltd.
- NI Environment Agency

Membership

- Queen’s University Belfast
- IWW Water Centre
- University of Duisburg Essen
- Dalhousie University
- Stevens Institute of Technology
- Cranfield University
- Dublin City University

Phosphorus (P)

- P one of the most essential nutrients present within the biosphere
- Found in the environment in both inorganic form (as orthophosphate; Pi) and in a variety of organic compounds
  - organophosphates (which contain a C-O-P ester bond)
  - organophosphonates (which contain a direct C-P bond and are often potent antimetabolites)

P an Introduction

There was taken a considerable quantity of Man's urine (because the liquor yields but a small proportion of the desired Quintessence) and of this good part at least, had been for a pretty while digested before it was used. Then this Liquor was distilled with a moderate Heat, till the Spiritous and Saline parts were drawn off'

Introduction

The Alchemist in Search of the Philosopher's Stone (1771) by Joseph Wright

Introduction

- P is a scarce natural resource for which there is intense competition between life forms
- Those organisms which can scavenge, store and recycle P have a natural advantage
- Unlike nitrogen which can be replenished from atmospheric sources, the only natural source of P is from rock
- Conserving and re-using this resource is important

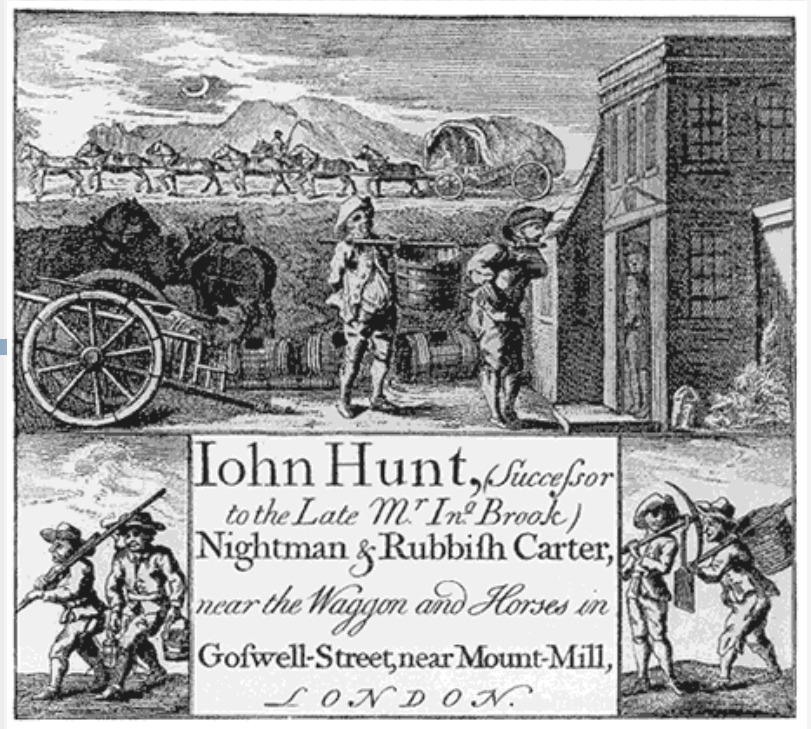
Discovery of phosphorus

Robert Boyle or Hennig Brandt

Albright

Sir John Laws developed superphosphate and founded the oldest agricultural research station in the world – Rothamsted, where some of his classical experiments are still being maintained.

Adults excrete 98% of the P in their diets (because they are turning over cells) this ends up in urban wastewater. It can be responsible for eutrophying inland waters.


Iohn Hunt, (Succeſſor
to the Late Mr Inº Brook)
Nightman & Rubbiſh Carter,
near the Waggon and Horſes in
Goſwell-Street, near Mount-Mill,
LONDON.

Eutrophication

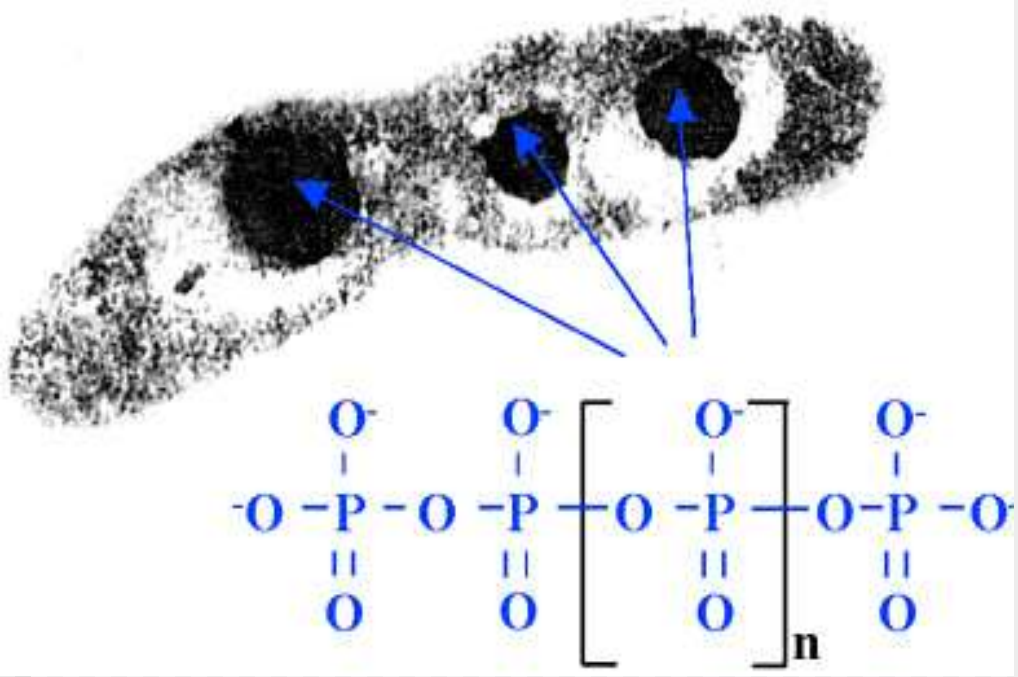
Compliance Limits

- Urban Wastewater Treatment Directive
- Designates areas as “eutrophication sensitive”
- Requires a sewage treatment works to remove 80% of the phosphorus coming in
- Normally a works will only remove 40%

Chemical Precipitation: Disadvantages

- Cost of precipitants
- Need for tertiary filtration due to potential for heavy metal contamination
- Necessity to dispose of excess volumes of sludge (sludge volumes may be increased 20 - 40% through chemical P precipitation)

Polyphosphate



- Consists of a linear chain of phosphate residues ranging in length from 3 to greater than 1000 residues
- Molecular fossil
- Wide range of biological roles

The reason why cells will accumulate polyphosphate is unknown. Some pathogens lose their virulence if their ability to accumulate poly-P is removed.

Research: Polyphosphate metabolism

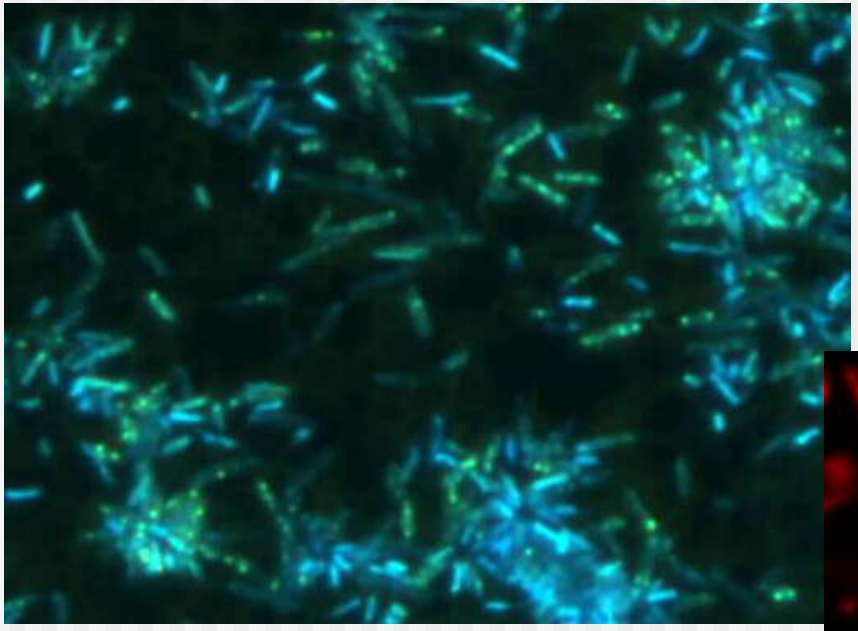
- Marine environment – involved in survival under varying nutrient conditions
- Medical – pathogenicity and virulence
- Stain any microbial sample visualise polyP
- Reservoir of energy and phosphate, chelator of metals, capsule material, and in the adaptation of microbial cells to growth and development
- Role in the response of microbial cells to nutritional and environmental stresses.

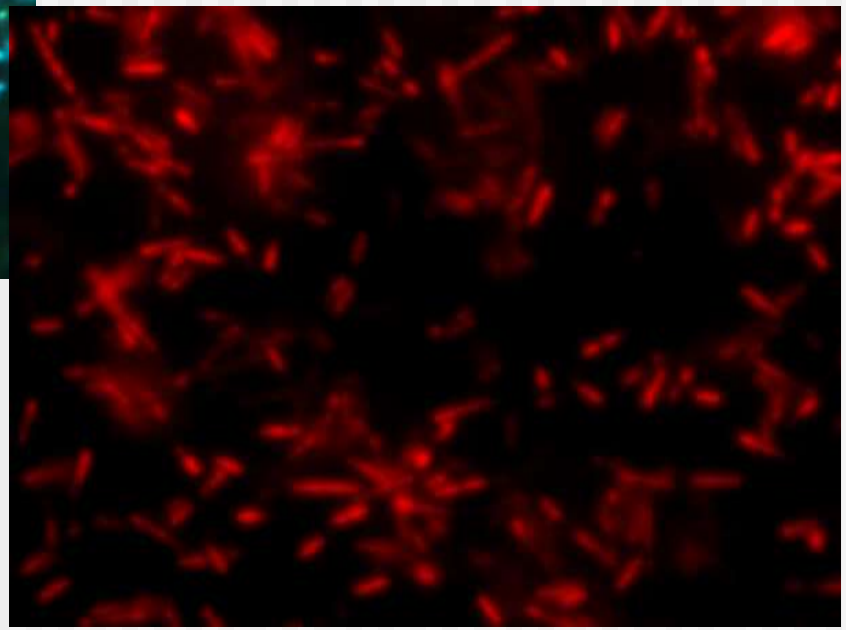
Enhanced Biological Phosphorus Removal

- Principle of EBPR is the cycling of the microbial biomass through anaerobic and aerobic stages
- Under favourable conditions EBPR plants can remove 80 - 90 % of influent phosphate
- Conventional activated sludge treatment removes only 20 - 40%

John Upton at Severn Trent pioneered EBPR at Stratford on Avon

Enhanced Biological Phosphorus Removal

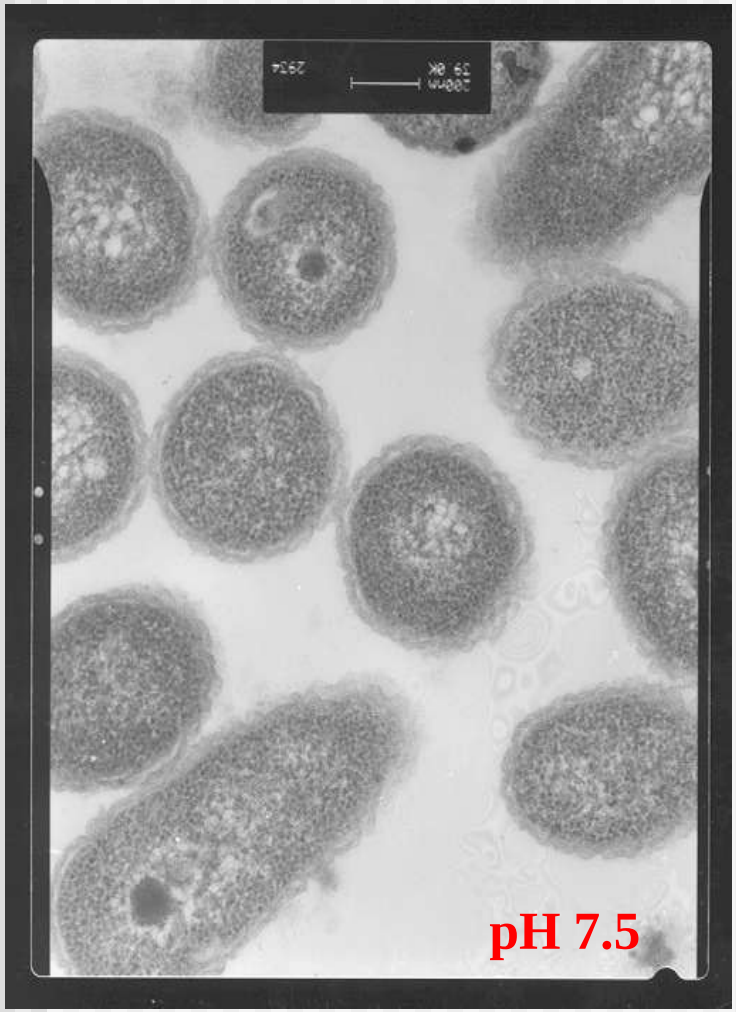


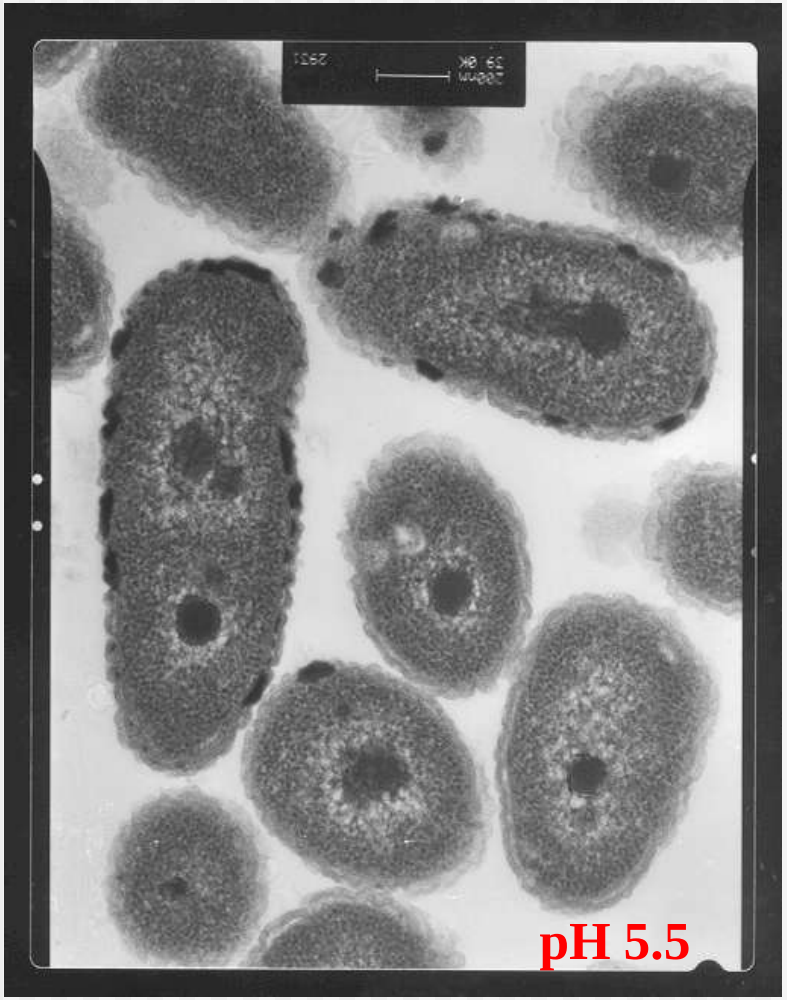


Rationale

- Anaerobic/aerobic cycling of EBPR elicits polyP response
- Accumulation of polyP be triggered by other stresses
- Identify a variety of conditions under which the ability to accumulate polyP is necessary for microbial survival
- Accumulation of polyP, by its very nature, will result in enhanced phosphate removal.
- Such conditions could be exploited to provide alternative treatment options for biological P removal.

Burkholderia cepacia AM19

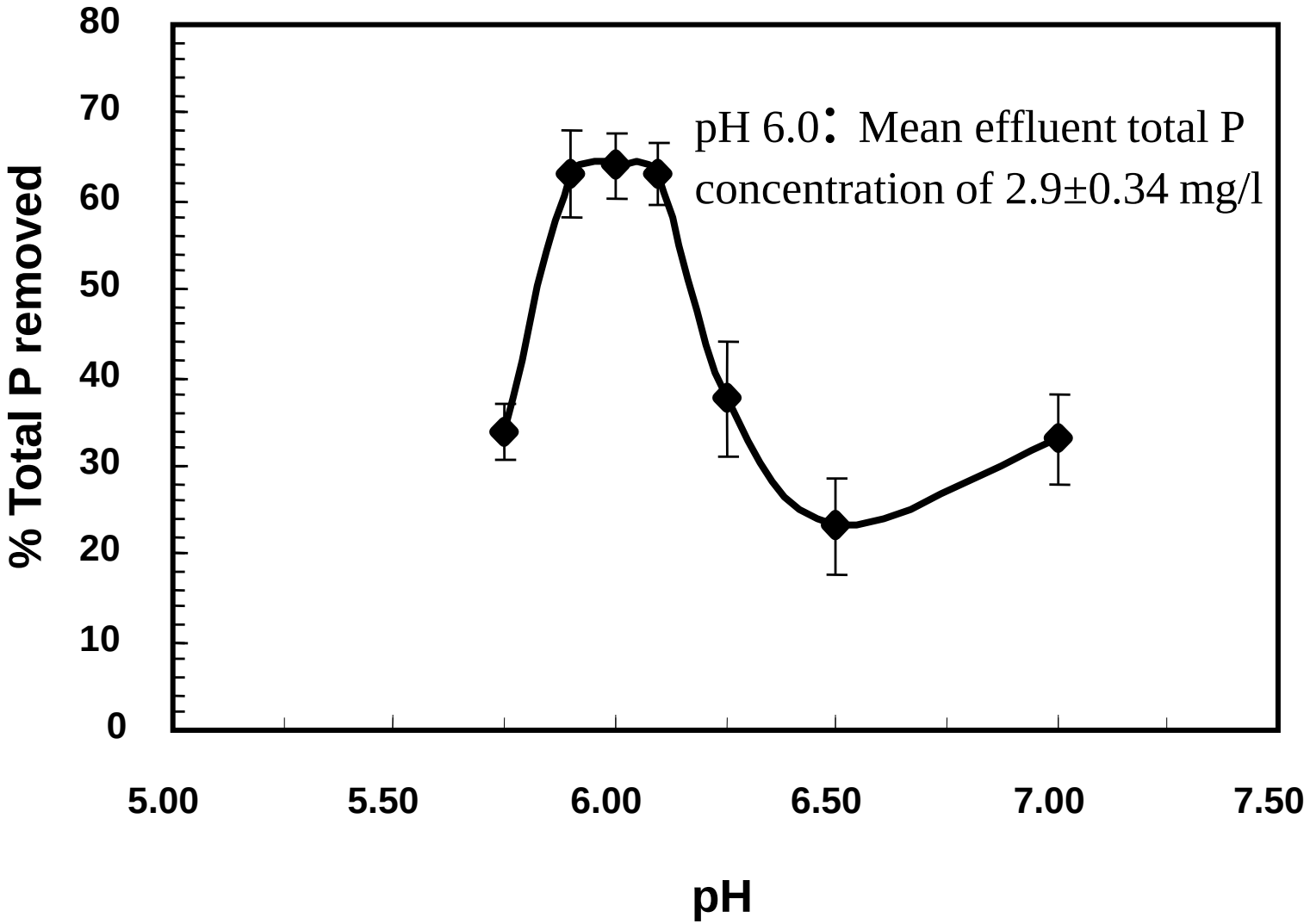




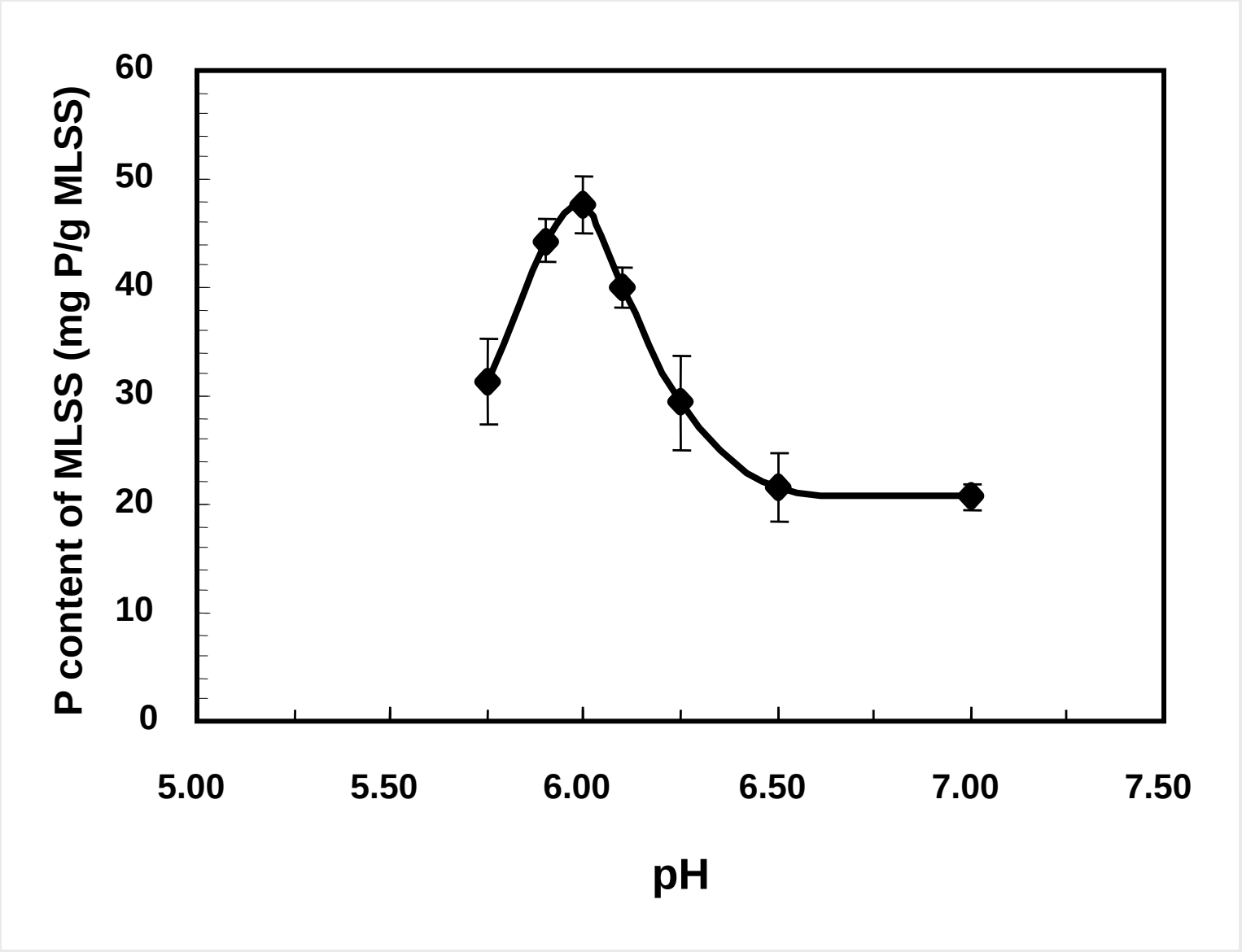
2000 litre pilot plant at New Holland WwTW, Belfast. 2 l/min inflow. Worked well. pH was controlled. HRT 15 h; sludge age 10-14 days.

Pilot Plant

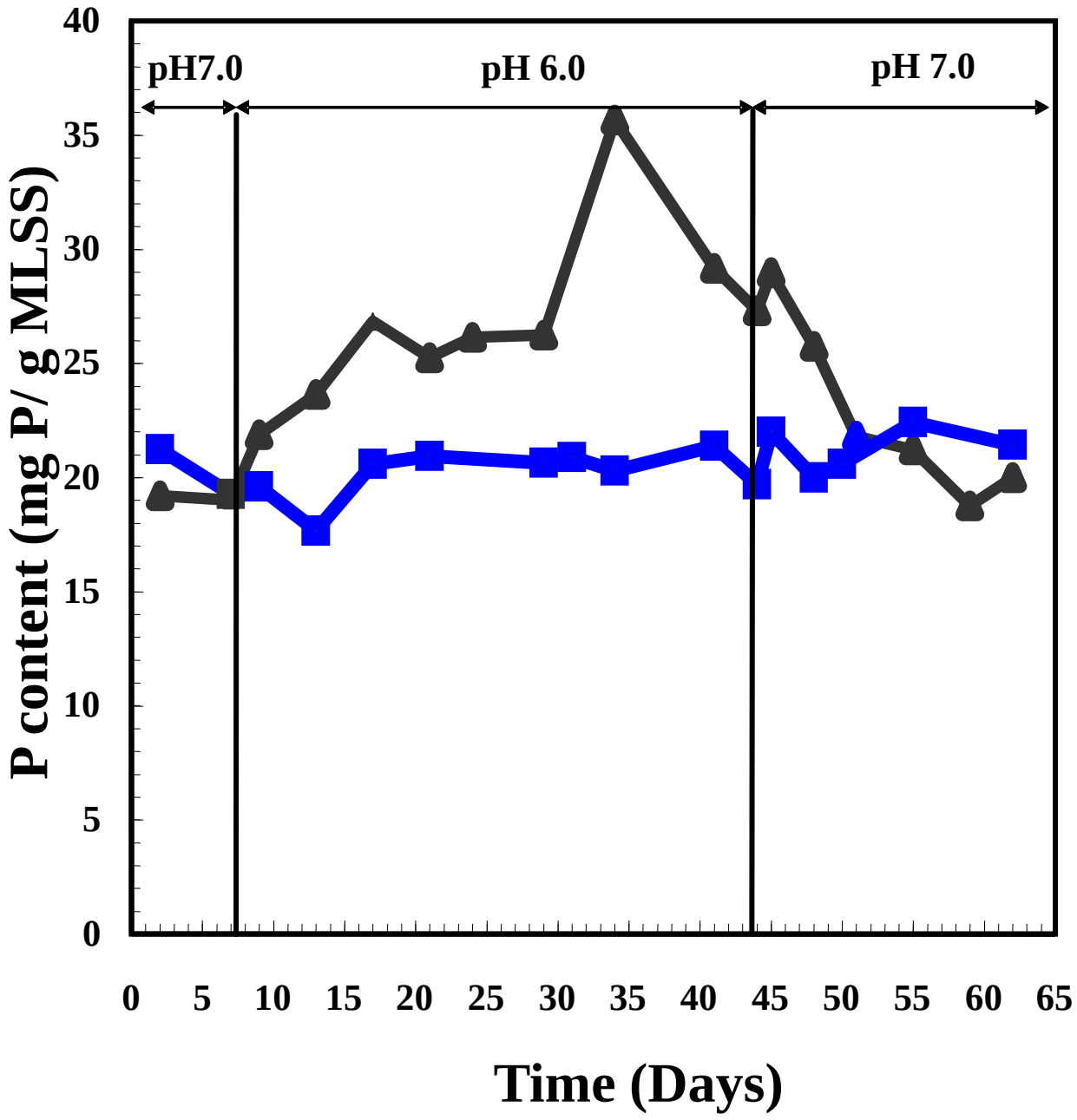
- Influent characteristics: Total P 6-14mg/L, NH_3-N 15-25mg/L COD 200-500mg/L.



- Main New Holland Works pH 7.0 - 7.3: 34±5% (effluent total P concentration 5.9±0.3 mg/l)



- Main New Holland Works pH 7.0 - 7.3: 20±3 mg P/g MLSS



Pilot Plant

Main Works

Pilot Plant Summary

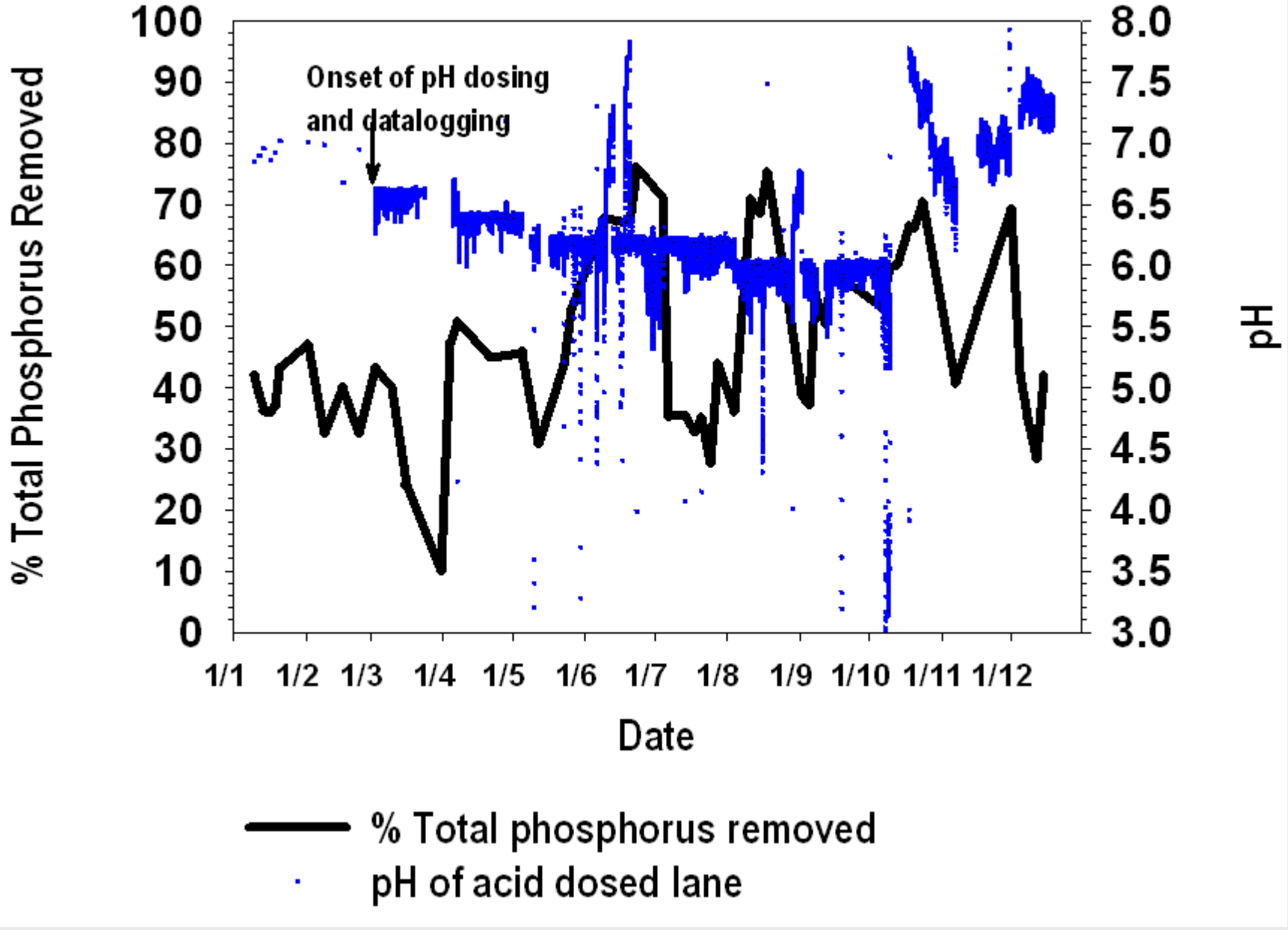
- Operation of pilot plant at pH 6.0 achieve a total effluent P concentration of 2.9mg/l
- Equates to 64% total P removal
- UWWT Directive requires an effluent total P standard of:
  - 2.0 mg/l for STW serving up to 100,000 p.e.
  - 1 mg/l for installations greater than 100,000 p.e.
  - 80% P removal across the system as a whole.

Pilot Plant Summary

- Not yet in a position to claim compliance
- Limitations of the pilot plant system e.g. continuous influent flow rates
- **Inconsistent**
- Also only if there is a firm understanding of its scientific basis
- pH 6.0 total P removal increases by approximately 31%

Mulduglass is a very small WwTW, with very frequent rain.

Full Scale Trial


% Total Phosphorus Removed
100
90
80
70
60
50
40
30
20
10
0
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
pH
Onset of pH dosing
and datalogging
1/1
1/2
1/3
1/4
1/5
1/6
1/7
1/8
1/9
1/10
1/11
1/12
Date
% Total phosphorus removed
pH of acid dosed lane

Full Scale Trial

Flushed bra causes sewer collapse

A bra and a pair of knickers have been blamed for a flood and road collapse in County Durham. Northumbrian Water said the underwear was flushed down a toilet and caused a blockage in a sewage pipe in Middleton-St-George, near Darlington.

- A spokeswoman said: "If the underwear had not been flushed down the toilet, this would not have happened. It was very irresponsible behaviour”.
- "These pipes are not designed to carry bras and knickers." (BBC, 19 June 2007)

Implications for P removal

- In contrast to EBPR P accumulation occurs in a fully aerobic environment
- Uptake does not appear dependent on presence of VFAs
- Existence of a widespread natural phenomenon, whereby exposure to stress elicits a polyP accumulation response.

35% of the bugs in activated sludge exhibit poly-P accumulation if under pH stress. Nitrification performance dips at pH 6.8 but then recovers as pH decreases further. It is conceivable that a granulated bacterial with acid producers on the outside (nitrifiers) and poly-P accumulators on the inside (or layered biofilms) in he manner of ANAMMOX granular biomass could be effective.

Phosphorus: the disappearing nutrient

- 161 million tonnes of P are extracted each year
- Current reserves to last only next 45 - 100 years
- P supply concentrated in China, Morocco, the US and Russia: more than 70% of the global P deposits
- P prices – 2008 $500 per tonne, five fold higher than 2007
- Oil: alternatives can be found. No substitute for P.
- Biggest P gains from recovery - recycling of P from waste
- Canadian study: P recovery from activated sludge could meet 30% of its current needs
- For this to be viable high sewage P content.

Current Research

- Research to develop in a number major areas:
- Recently identified additional stress which significantly increases P removal
- Other stresses which may elicit the polyP response

Current Research

- P recovery: Can we release this stored P from the cells?
  - In what form is this P stored?
  - Is it suitable for recovery?
  - What triggers its degradation / release from cells?
  - Can we capture the released P or indeed polyphosphate?
  - Can it be scaled – using 2 litre and 20 litre bioreactors?

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