ACTIVATED SLUDGE PROCESS

PAST – PREZENT – FUTURE

OF THE MOST WIDE-SPREAD TREATMENT TECHNOLOGY

Jiří Wanner

UCT PRAGUE

CONTENT

- Development of biological treatment prior to Ardern and Lockett
- Invention of activated sludge process
- Historical periods of AS
  - First installations and patent disputes
  - Chemical engineering approaches
  - Population dynamics
  - Modern biology and microbial ecology
- Current activated sludge process
- Future expectations

Development of biological treatment prior to Ardern and Lockett

Progress in the understanding of biological treatment processes

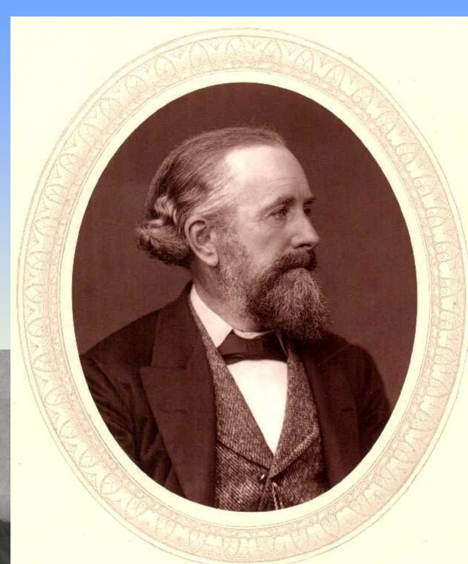
- increasing river pollution problems in England
- need of coordinated solution – 1865 Royal Commission on River Pollution
- impoprtance of microbial processes – Frankland, Dunbar, Winogradskii
- use of soil microoorganisms – „sewage farms"
- role of oxygen, aeration – Fowler

Sir Edward Frankland, 1825 – 1899

1865: Royal Commission on River Pollution

1868-1875 director of state wastewater treatment laboratory

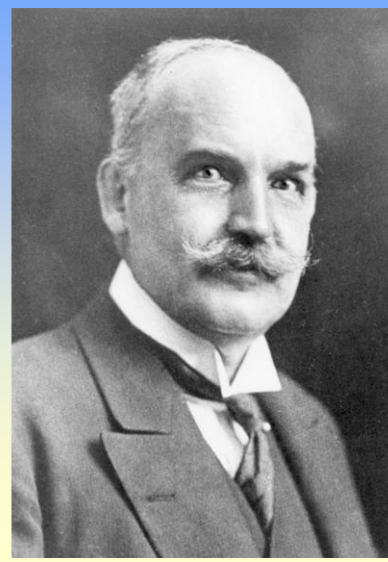
Inspired by **Pasteur's** research on functional groups of microorganisms.



William Philipps Dunbar, 1863 – 1922
director of hygienic service in Hamburg

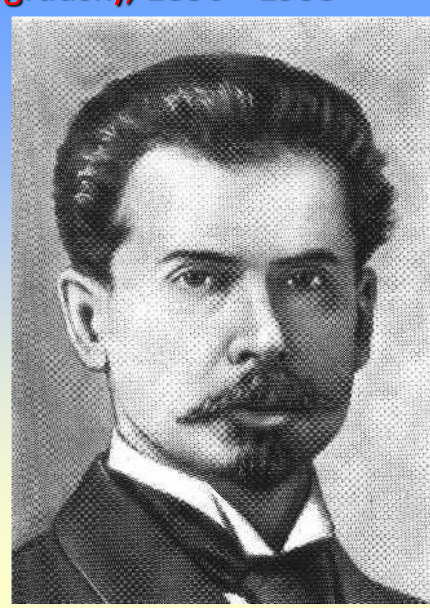
Dunbar, W.P. 1899.
First WW treatment handbook

Die Behandlung städtischer Abwässer mit besonderer Berücksichtigung neuerer Methoden,
Dtsch Vierteljahresschr. öffentliche Gesundheitspfl. 31, 136–218.



Sergei Nikolaievich Winogradsky, 1856 - 1953

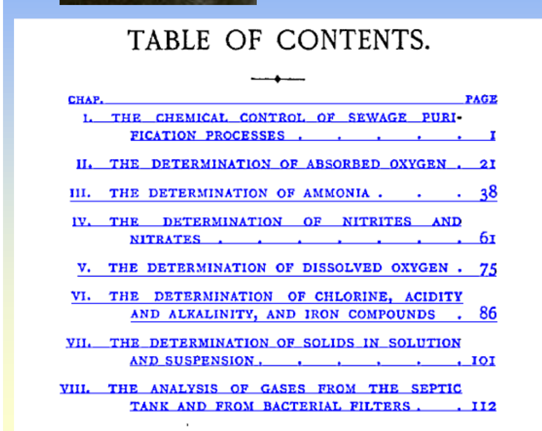
- Systematic studies of nitrification
- Identified the first nitrifiers
- genera *Nistrosomonas* and *Nitrosococcus*
- genus *Nitrobacter*



GILBERT JOHN FOWLER
1868-1953

- 1896 chemist and bacteriologist of Rivers Committee of the Manchester City Council
- 1899 superintendant a chemist, Manchester Corporation sewage works
- 1912 trip to do Lawrence Sewage Experimental Station, USA
- 1916 Professor of Applied Chemistry/Biochemistry at the Indian Institute of Science, Bangalore

GILBERT JOHN FOWLER
1868- 1953



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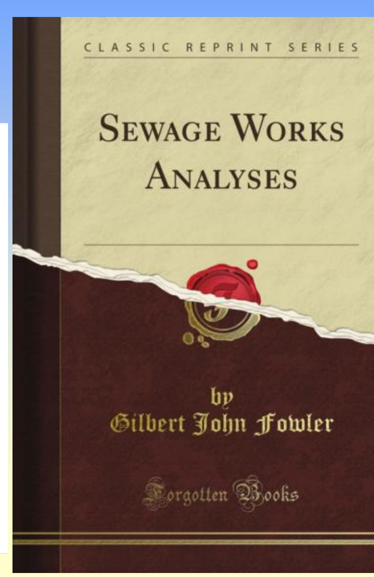
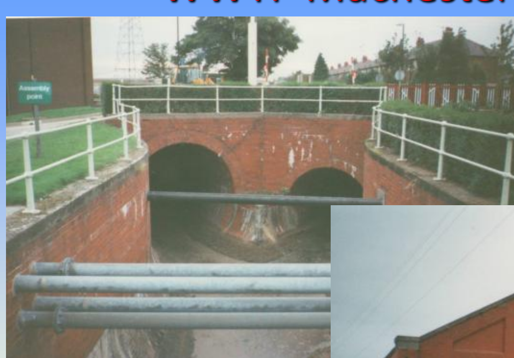
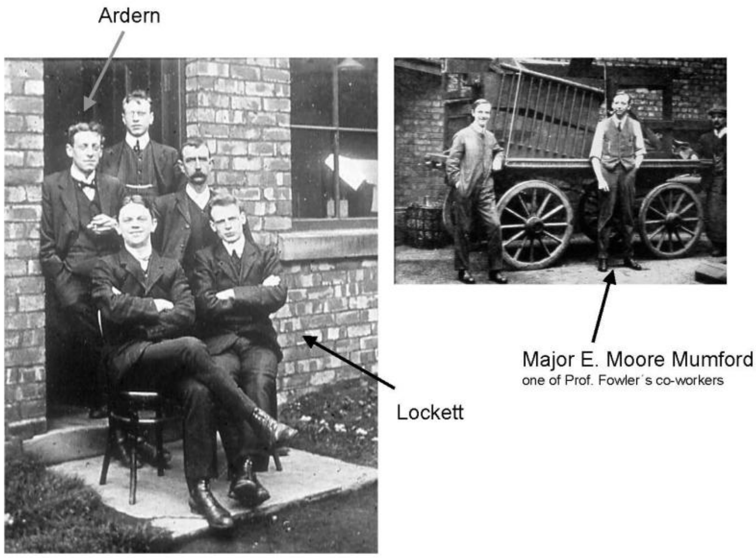


Invention of activated sludge process

- Experiments inspired by Fowler
- WWTP Manchester – Davyhulme
- chemist Edward Ardern a his assistant William T. Lockett, employee of Rivers Committee of the Manchester Corporation
- 1913 – lab/scale experiments at Davyhulme
- Evaluation od oxygen demand and full nitrification

WWTP Machester – Davyhulme

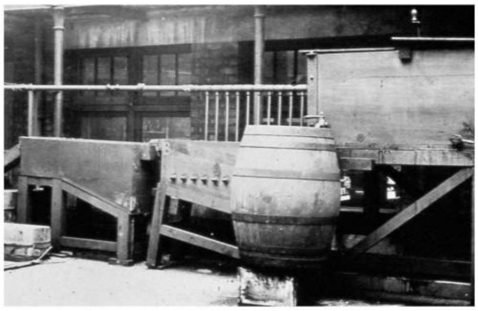




Ardern a Lockett

- Fine-bubble aeration
- “Activated sludge” sedimentation
- both „fill-and-draw“ system (SBR) and separated sludge sedimentation with continuous sludge recycle
- Experiments with wastewater from different plants than Davyhulme
- “mobile pilot-scale unit”

Manchester pilot plant, 14 Febr, 1914



experimental plant

aeration tank

Ardern and Lockett:
Formulation of basic principles of AS process

1. Aeration of water in presence of microorganisms
2. Removal of biomass from the treated wastewater
3. Recycle of the separated biomass back to new wastewater

Ardern and Lockett

Publication of results

Ardern and Lockett referred about their experiments form year 1913 at the meeting of the Society of British Chemical Engineers on 3rd April in Grand Hotel Manchester

Followed by three famous papers:

•Ardern, E., Lockett, W.T. (1914a) Experiments on the Oxidation of Sewage without the Aid of Filters. J. Soc. Chem. Ind., 33, 523.

•Ardern, E., Lockett, W.T. (1914b) Experiments on the Oxidation of Sewage without the Aid of Filters, Part II. J. Soc. Chem. Ind., 33, 1122.

•Ardern, E., Lockett, W.T. (1915) Experiments on the Oxidation of Sewage without the Aid of Filters, Part III. J. Soc. Chem. Ind., 34, 937.

First full-scale applications

- Sill during the First World Waar
- 1916: firt full-scale plant in Worcesteru (7 570 m^3/d)
- Transfer of technology to overseas (USA, India, South Africa, Australia)
- Clogging problems with fine bubble ceramic aerators
- Development of mechanical aerators (Haworth, Kessener, Bolton)

WWTP Stockport, Haworth (Sheffield) system

WWTP Stockport, Kessener brushes

WWTP Stockport, inserted settling "pockets'

TIME Partners with CNN

Activated Sludge, Inc.

Monday, Jul. 05, 1937

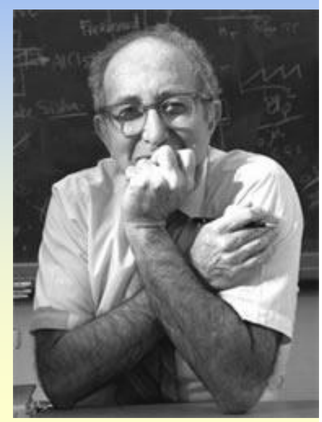
- Back royalties and settlements secured since 1934 include: Cleveland $85,000, Houston $75,000, Indianapolis $73,000. San Antonio $58,000, Columbus $40,000, Peoria $23,000, Cuba, Mo. $80.
- Patent claims of Activated Sludge Inc. led gradually to closing of existing plants, the new plants were postponed till patent expiration
- Further delay because of **World Warr II**

Activated sludge adter WWII

- Rather massive development for both municipal and industrial wastewater
- Further development of mechanical and air diffusion aeration
- Application of chemical engineering approaches
- Octave Levenspiel:

Chemical Reaction Engineering

- Methods of reactor engineering, e.g.,
- Hydraulic regime and measurement of hydraulic characteristics
- Reaction kinetics and stoichiometry, conversion equations
- Parameters like sludge age, loading, etc.



Limits of chemical enginering approach

- New problems appeared with spreading the AS process, especially in AS separation
- Gradual understanding of separation problems
- Filamentous bulking becoming the most urgent problem
- Study of the causative filamentous microorganisms and their morphology and physiology
- Problems with detergent foams replaced by biological foams
- 1969 – „Milwaukee Mystery“

Limits of chemical enginering approach

- Introducing of new D – N AS system
- Process like Phoredox or A-A-O for biological phosphorus removal
- Problems with unstable nitrification
- Competition for organic substrate between PAO a GAO in bio-P removal systems
- *Water Environment Research*
  Vol. 65, No. 5 (Jul. - Aug., 1993), pp. 690-692

Competition between PolyP and non-PolyP bacteria in an enhanced phosphate removal system

Jakub S. Čech, Petr Hartman, Jiři Wanner

Activated sludge population dynamics

- These problems revealed the limits of chemical engineering approach
- More detailed knowledge of microbiology and biochemistry needed
- Development and definition of activated sludge population dynamics

Pergamon

Wat. Sci. Tech. Vol. 30, No. 11, pp. 159–169, 1994.

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ACTIVATED SLUDGE POPULATION DYNAMICS

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Prague Institute of Chemical Technology, Department of Water Technology and Environmental Engineering, Technicka 5, CZ-166 28 Prague 6, Czech Republic

Activated sludge population dynamics

1988: ASPD specialist group founded in **IAWPRC/IWA**

IAWPRC

SPECIALIST GROUP ON ACTIVATED SLUDGE POPULATION DYNAMICS

Chairman: Prof. Dr. Petr Grau

Honorary Secretary: Prof. Dr. Jiří Wanner

PRAGUE INSTITUTE OF CHEMICAL TECHNOLOGY

Department of Water Technology and Environmental Engineering

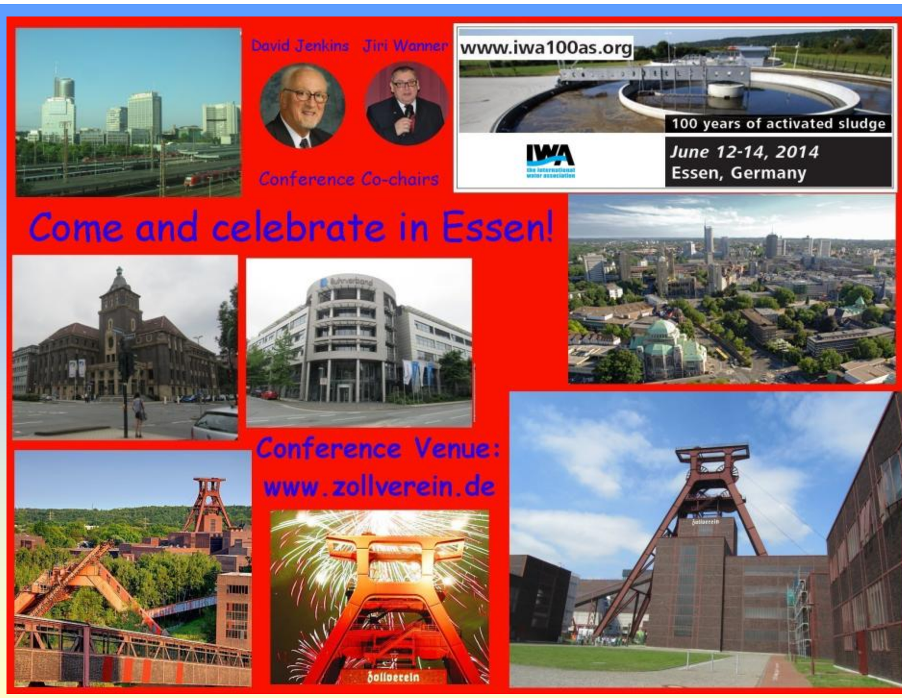
166 28 Prague 6, Suchbátarova 5, Czechoslovakia

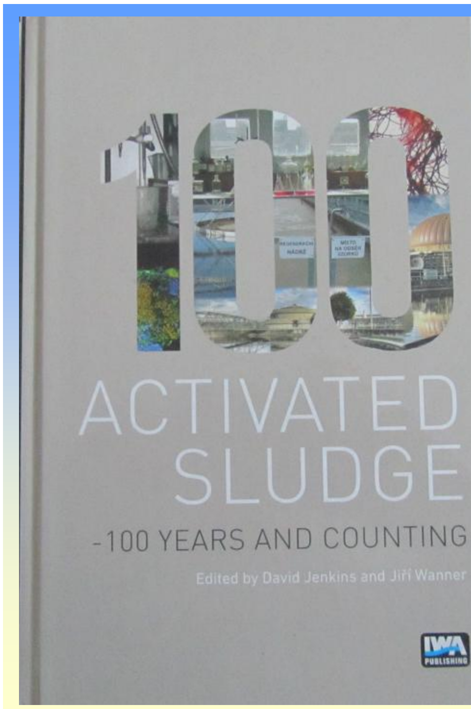
NEWSLETTER OF THE GROUP

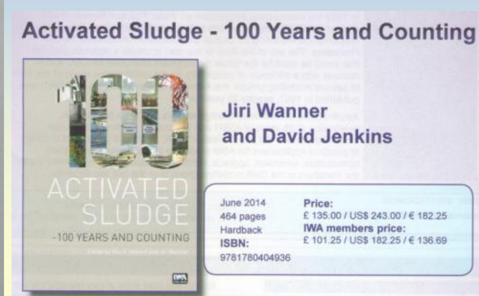
Vol. 1, No 1, March 1989

Now the group is called

Microbial Ecology in Water Engineering







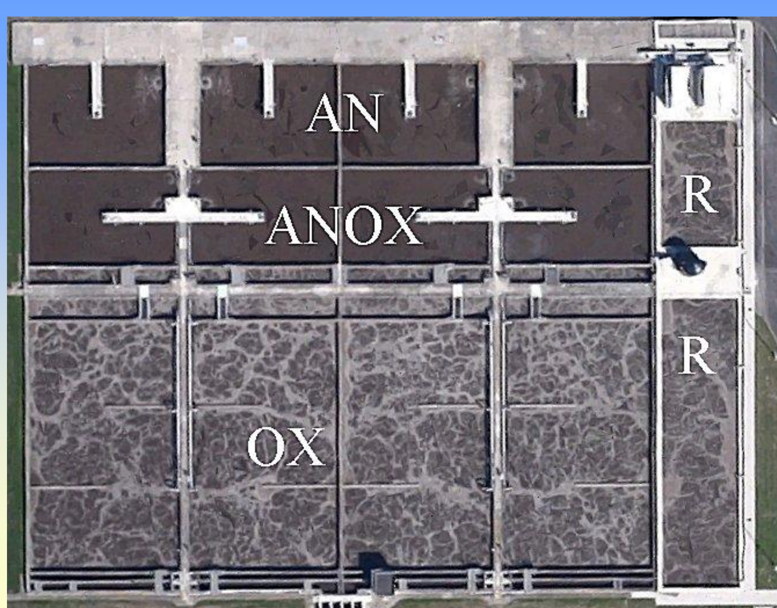
Current activated sludge process

- Long sludge age for nitrification, combined with denitrification and often with bio-P removal
- Modern machinery – high speed rotating blowers, fine bubble diffusors, mixers with specially formed blades)
- Continuous measurement of basic process parameters and constituent concentrations
- Use of basic mechanistic models like ASM1 for process control
- High and stable effluent quality

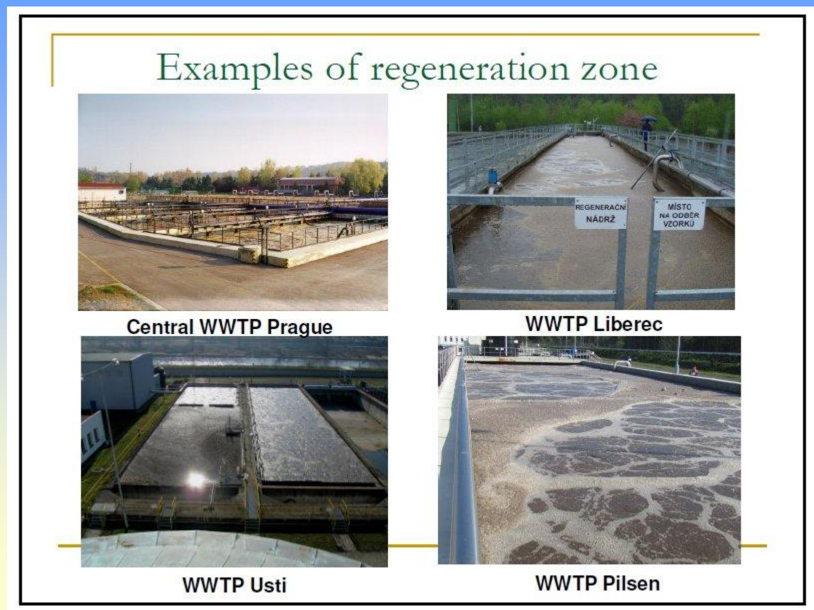
Current activated sludge process

- Carrousel plants with intermittent aeration
- Corridor-type basins with separated reaction zones, individual zones compartmentalized in order to approach plug-flow
- Regeneration zone with nitrification bioaugmentation *in-situ* for processing reject water from sludge digestion

Current activated sludge process



Current activated sludge process



Current activated sludge process

Current activated sludge process

Achievable effluent quality:

Today's most modr AS plants can achieve the effluent quality like this:

COD_{Cr}	< 40 mg/l
N_{TOTAL}	< 10 mg/l
from it $N\text{-}NH_4$	1 – 2 mg/l
from it $N\text{-}NO_3$	< 7 mg/l
P_{TOTAL}	< 1 mg/l *

*) when there is enough readily degradable COD in wastewater

Aspects of activated sludge future

- Automatic monitoring system coupled with process control by using calibrated mathematical model of the system
- Activated sludge separation by using membranes with the **reuse** of treated wastewater
- The solution of problem of competition for organic carbon between denitrifiers and PAOs, e.g., by better management of storage products
- Stabilization of nitrification:
  - In-situ **bioaugmentation** of nitrification bacteria
  - Combination with **biofilm** cultivation

Aspects of activated sludge future

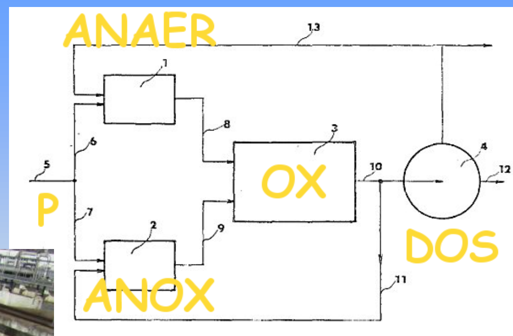
- Use of granular activated sludge – possible combination of three different cultivation conditions in one granule
- Combination of activated sludge process with chemical or physico-chemical processes fro the removal of specific organic pollutants like residual of hormones, medicals or even illegal drugs

Better management of degradable organic carbon

- Prevention of losses in sewers
- Reduction of losses in primary treatment (aerated grit chambers, no precipitation in primary clarifiers)
- To maximize the use of Corg. preferably in non-aerated zones to avoid simple oxidation with oxygen to carbon dioxide
- To prevent penetration of air oxygen through water level to activated sludge in anaerobic and/or anoxic zones
  - Biological foam
  - Surface cover

Better management of degradable organic carbon

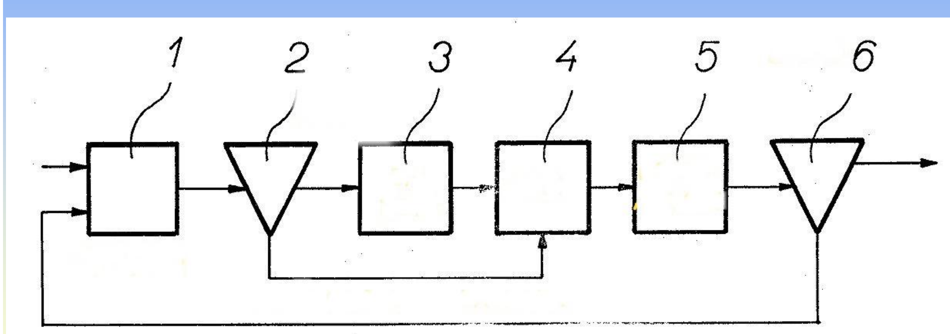
1986



2015

„Removal" of nitrification from activated sludge system

Process DEPHANOX – original scheme from 1992 (!!!)



„Removal“ of nitrification from activated sludge system

Process DEPHANOX

Modification 2012 Moscow – Kurjanovskaja, carrier ANOX-KALDNES

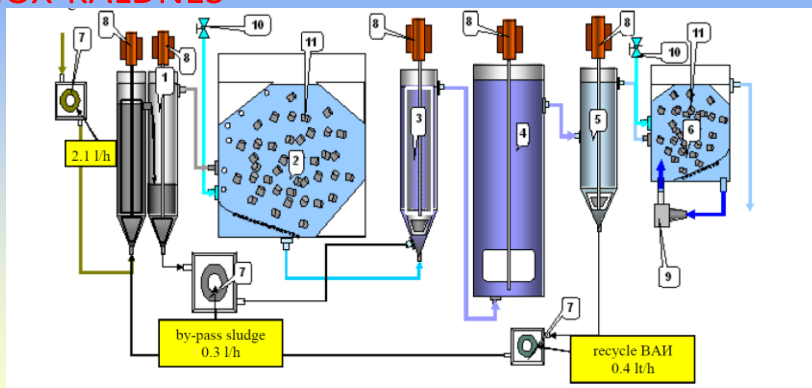


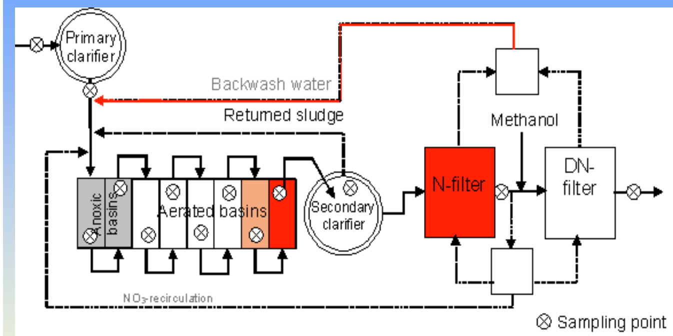
Figure 2. M-Dephanox plant process flow diagram. Identification: 1 - twin anaerobic reactor–sedimentation tank, 2 - nitrification reactor with plastic medium, 3 - anoxic reactor (pre-denitrification reactor), 4 - anoxic reactor, 5 – sedimentation tank, 6 - nitrification reactor with plastic medium, 7 - peristaltic pump, 8 - electro-mechanical agitator, 9 - centrifugal pump-agitator, 10 - air-supply mains, 11 - plastic medium 50% of the volume.

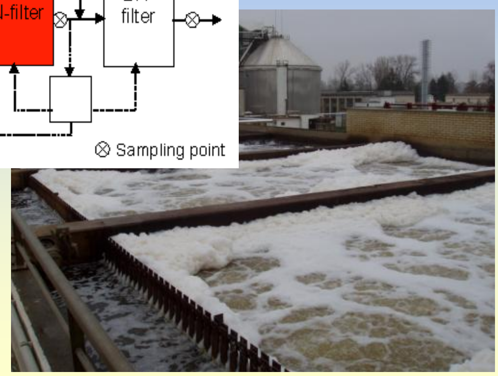
„Removal“ of nitrification from activated sludge system

- Cultivation of nitrifying biofilms directly in aeration tanks of AS system
- Porous carriers from 1985-1991 (LINPOR, etc.)
- Stratification of biomass – ANOX-KALDNES
- Fixation of nitrifiers into permeable carriers, e.g., capsules LentiKat‘s

„Removal“ of nitrification from activated sludge system

- Activated sludge process followed by fixed-film

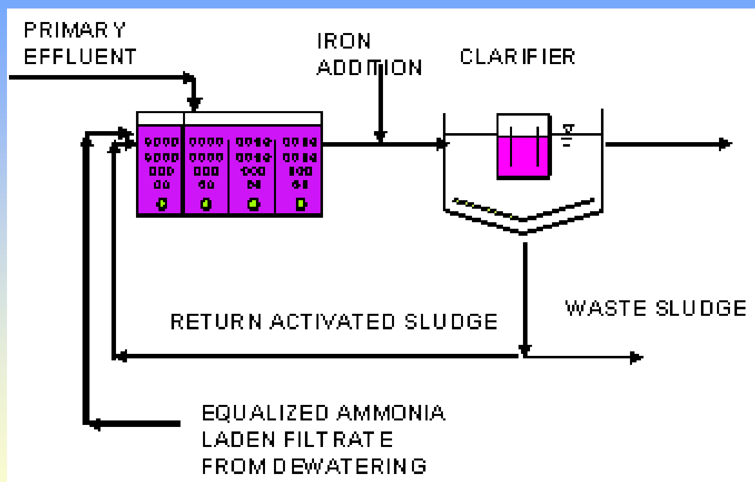




Reduction of ammonia load of AS system from anaerobic digestion

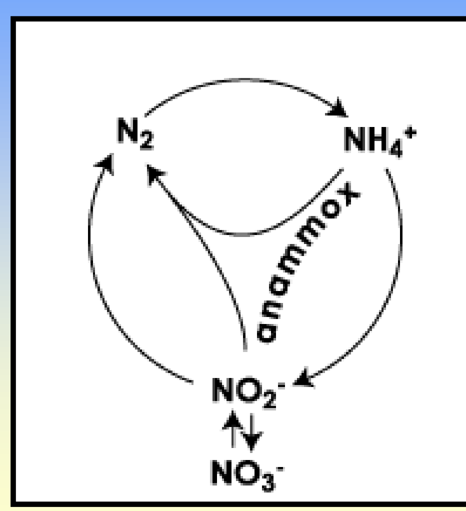
- Stop the production of reject water by other sludge processing than anaerobic digestion
- Use of ammonia from reject water to cultivate nitrification bacteria – bioaugmentation *in-situ* – suitable for AS system with regeneration zone
- Removal of ammonia from reject water by partial nitrification and denitrification – use of granulated biomass

Technology of BAR



ANAMMOX

(**AN**aerobic **AMM**onium **OX**idation)



ANAMMOX

(ANaerobic AMMonium OXidation)

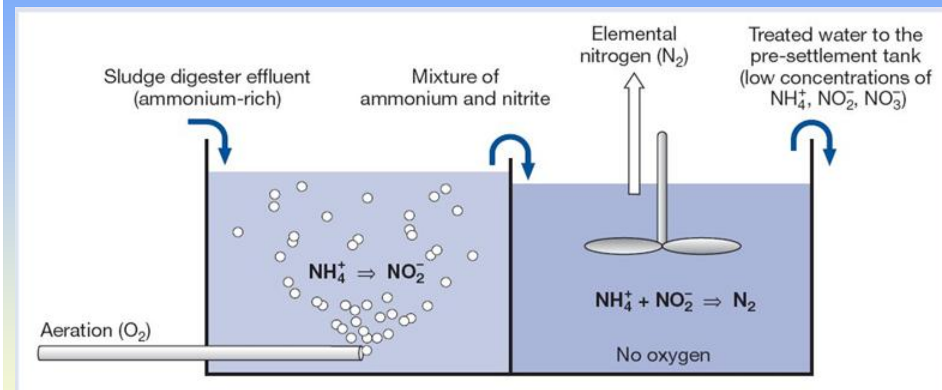
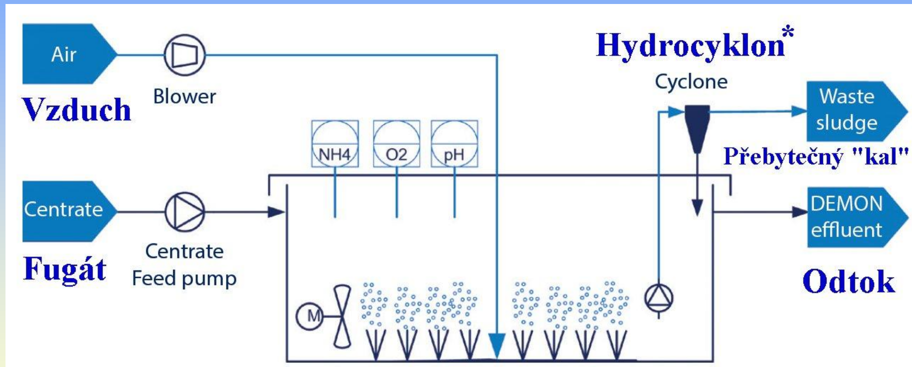


Fig. 2: The anammox process.

Sharon – Anammox process

DEMON



DEMON reactor

ANAMMOX a DEMON

- Procesy opředené řadou legend
- Postoje od zcela zamítavých až po jisté zbožnění jako jediné cesty vpřed
- Rozporuplné informace z provozních jednotek, např. Rotterdam či Budapest Csepel, např. článek: **Moderní řešení kalového hospodářství čistíren odpadních vod**

Ondřej Beneš, Pavel Chudoba, Radka Rosenbergová

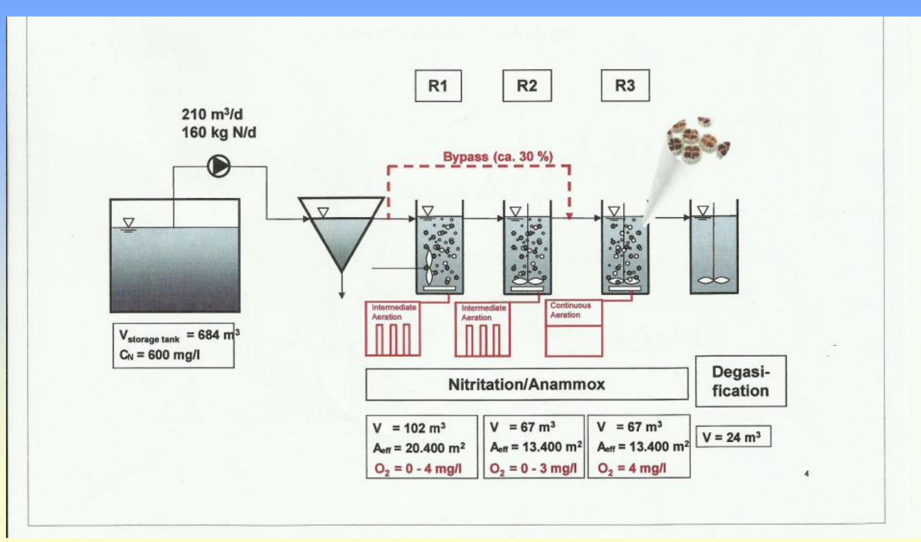
Vodní hospodářství č.6/2014

- *„…aplikace selektivní deamonifikace DEMON na ČOV Budapešť Csepel určitě není učebnicovou ukázkou efektivity zvoleného řešení, neboť oproti předpokladu projektanta nebylo doposud zdaleka dosaženo požadované úrovně deamonifikace.“*

ANAMMOX a DEMON

- Z těchto důvodů jsme podnikli v roce 2015 exkursi na tři provozní aplikace projektů provozované společností Ruhrverband

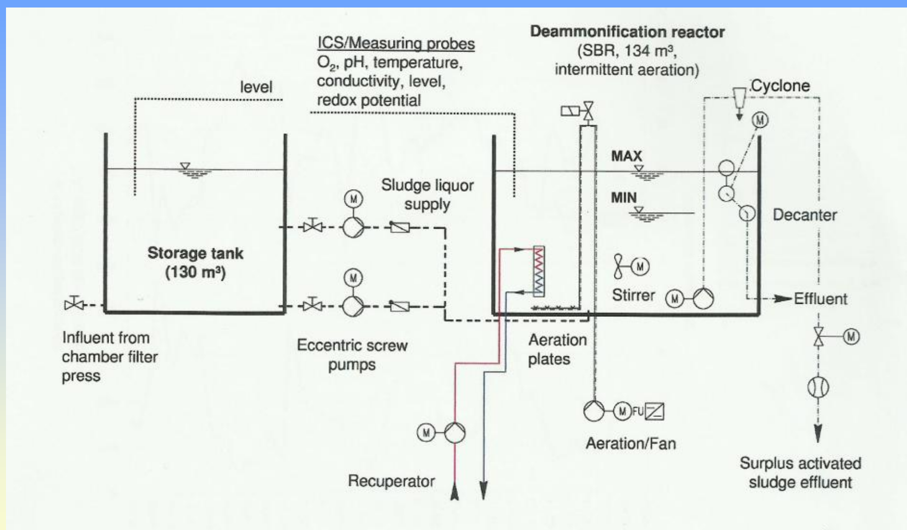
ČOV Hattingen, 100.000 EO



ČOV Hattingen, 100.000 EO

ČOV Hattingen, 100.000 EO

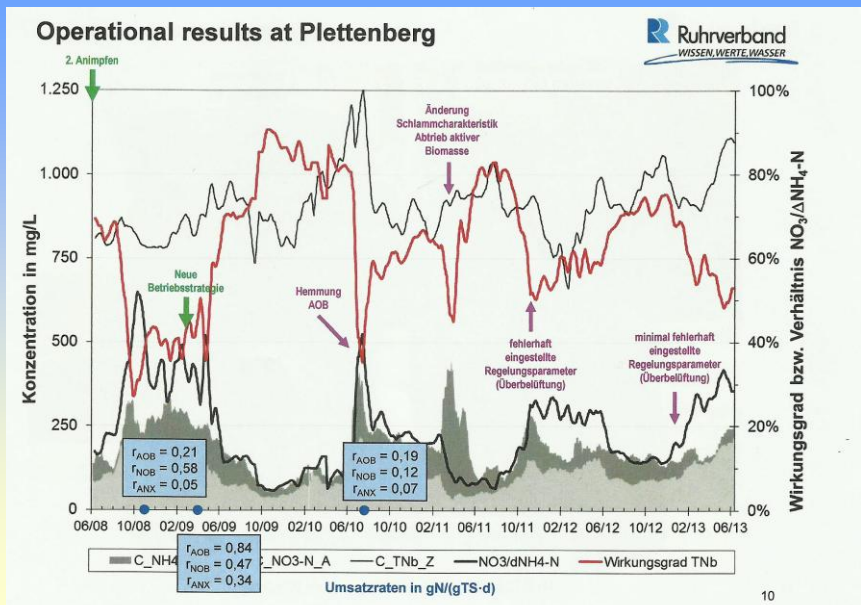
ČOV Plettenberg, 34.000 EO



Demon typu SBR se selektivní separací anammoxových granulí

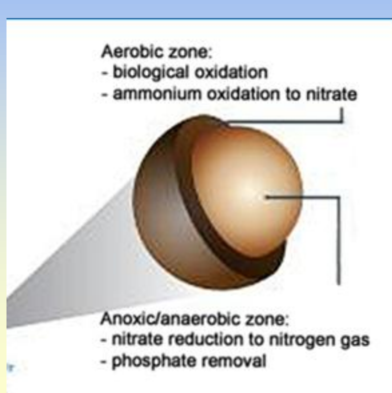
ČOV Plettenberg, 34.000 EO

ČOV Plettenberg, 34.000 EO

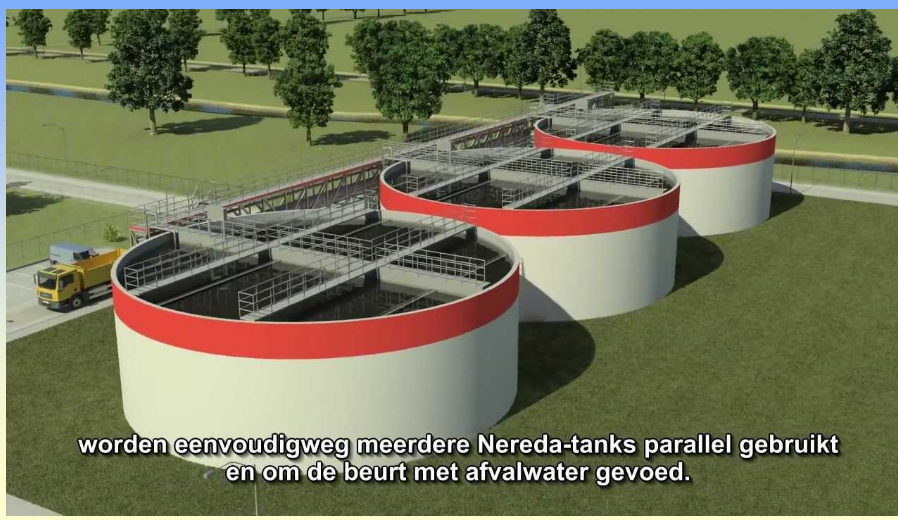


Stratifikovaná granulovaní biomasa

- Analogická koncepce jako u dříve používaných polyuretanových nosičů v disperzi.
- Stratifikace na základě difuze kyslíku

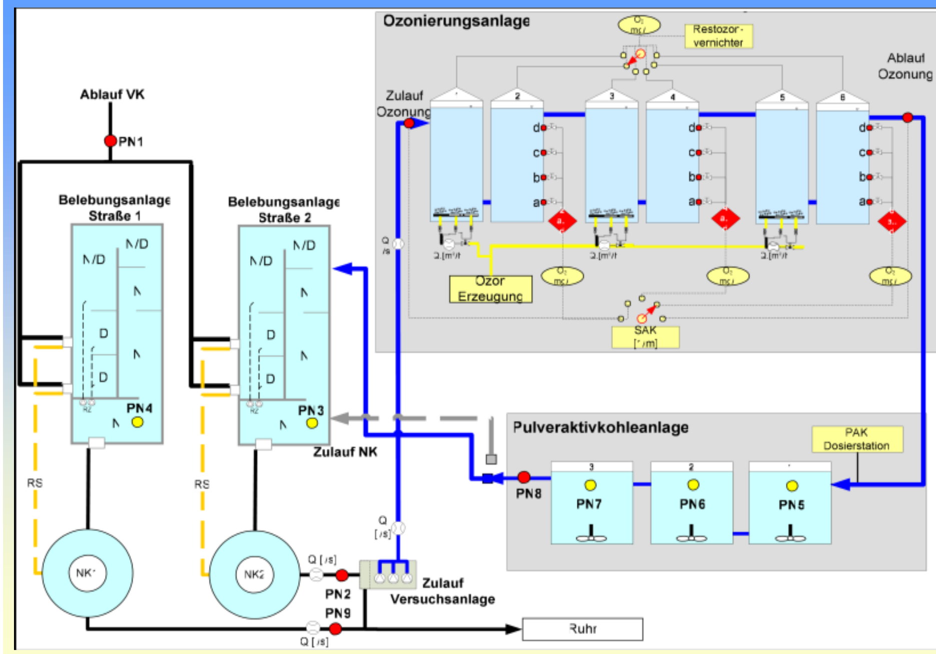


NEREDA - granular sludge



Emerging challenge for AS process

- Simultaneous removal of org. C, N & P plus **PPCP**
- Example of possible solution: WWTP Schwerte – combined AS process with chemical treatment by ozone and physical sorption of ozonation products



WWTP Schwerte
Ruhrveband,
Germany

Further development of the AS porcess in its 2nd century

- The effect of new legislation, e.g., concerning the removal of PPCP from wastewater
- Improvement of the quality of the “product” in connection with its reuse - lack of fresh water

→