

# STATE OF THE ART WASTE WATER TREATMENT PLANT WITH INNOVATIVE SOLUTIONS FOR BAPCO REFINERY BAHRAIN

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# Introduction

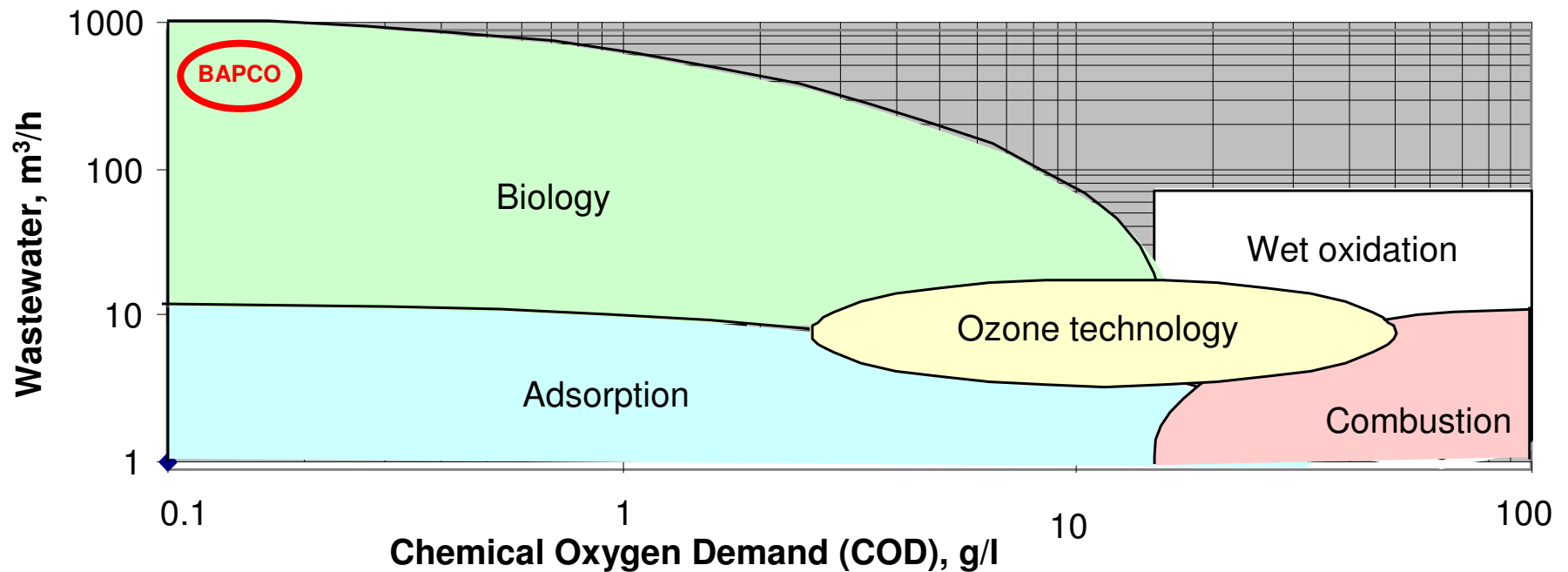
- Bapco identified a need to install secondary treatment to improve the quality of the waste water being discharged from the Refinery to the Gulf.
- At present the waste water undergoes primary treatment in a system which consists of American Petroleum Institute (API) oil separators followed by Induced Air Flotation (IAF) units.
- Bapco's waste water was considered a challenge to treat because of:
  - high temperature
  - high and variable salinity
  - stringent water quality regulations.
- Initially the use of a process based on physical-chemical treatments was considered a possibility because there was no definitive reference in the literature to indicate that the waste water with these characteristics was treatable biologically.

# Introduction (Cont'd)

- Biological secondary treatment was favored because of its lower cost.
- Biological secondary treatment has been common practice for a long time in Oil Refineries because of the high flow rates and the nature and concentration of the contaminants.
- This presentation describes how and why the biological process technology that will be used in the new plant was selected.

# Application of Waste Water Treatment Technologies Based on Flow and COD Concentration

The range of different wastewater treatment methods



# Discharge Specifications

Effluent specifications as required by EWP

Parameter	Units	Final Effluent Specification Monthly Average <sup>(a)</sup>	Final Effluent Specification Maximum <sup>(b)</sup>
<b>General Properties</b>			
pH	-	6 to 9	Not specified
Temperature	°F (°C)	$\Delta T \pm 3^{\circ}\text{C}$ for receiving water	$\Delta T \pm 3^{\circ}\text{C}$ for receiving water
Total Suspended Solids	mg/l	20	35
Turbidity	NTU	25	75
BOD	mg/l	25	50
COD	mg/l	150	350
Total Kjeldahl Nitrogen	mg/l	5	10
Oil and Grease	mg/l	8	15
Phenols	mg/l	0.5	1
Total Coliforms	MPN/100ml	1000	10000
TOC	mg/l	50	-
MBAS	mg/l	0.1	0.1
<b>Inorganic</b>			
Oxygen	mg/l	Not specified	Not specified
Ammonia nitrogen as N	mg/l	1	3
Sulfide as H <sub>2</sub> S	mg/l	0.5	1
Residual Chlorine	mg/l	0.5	2
Cyanide as CN	mg/l	0.05	0.1
Chloride as NaCl	mg/l	Not specified	Not specified
Nitrate [NO <sub>3</sub> ] – N	mg/l	Not specified	10
Nitrite [NO <sub>2</sub> ] – N	mg/l	Not specified	1
Total phosphorus	mg/l	1	2
<b>Metals</b>			
Aluminum	mg/l	15	25
Arsenic	mg/l	0.1	0.5
Cadmium	mg/l	0.01	0.05
Total Chromium	mg/l	0.1	1
Copper	mg/l	0.2	0.5
Iron	mg/l	5	10
Lead	mg/l	0.2	1
Mercury	mg/l	0.001	0.005
Nickel	mg/l	0.2	0.5
Zinc	mg/l	2	5

## 1 – Discharge specification:

- severe specifications on 4 different nitrogen forms (TKN, N-NH<sub>4</sub>, N-NO<sub>3</sub>, N-NO<sub>2</sub>);
- combined with specifications on organic carbon (COD, TOC, BOD);

## 2 – Waste water (WW) composition out of existing units:

- high salinity
- carbon nitrogen combination proper for a biological system

## 3 - Large hydraulic flow: 27,300 m<sup>3</sup>/d (9,950,000 m<sup>3</sup>/y)



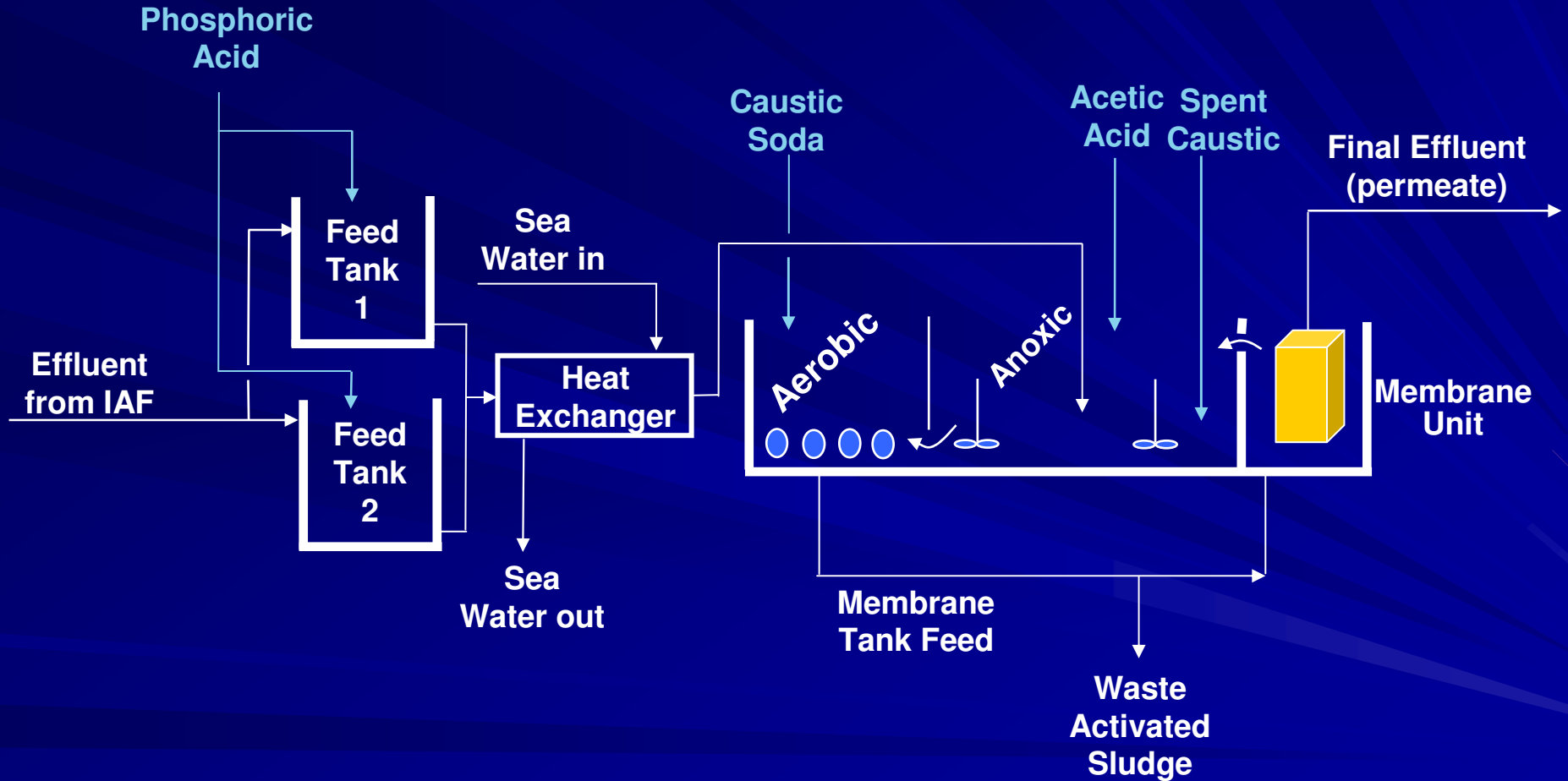
# First Steps

- It was necessary to use a fundamental approach since there were no plants working under similar conditions. Bapco decided to start with the basics.
- Samples of waste water were sent from Bapco to two independent consultants in the UK. These consultants performed bench scale treatability tests on the waste water using live activated sludge.
- The bench scale tests gave a good positive indication that the waste water from the existing primary treatment is biologically treatable.
- The bench scale tests did not provide any firm indication regarding which biological process would be best suited.
- The bench scale tests did not provide enough information to develop a plant design and what information there was, was unlikely to remain valid through scale-up.
- Following the bench scale tests Bapco concluded that the next step would be to conduct pilot scale tests on site in order to increase the level of confidence and provide further insight to the solution.

# Pilot Plant

- A pilot plant with anoxic and aerobic biological treatment zones followed by a membrane separation stage was established on site. It was fed with water from the primary treatment.
- The pilot plant was operated on a continuous basis by Bapco for several months and then for 7 months together with CH2M Hill.
- Pilot plant operation provided a range of fundamental process information. These parameters were used as inputs into process simulation programmes in order to:
  - select the most appropriate treatment technology
  - prove that the selected technology is effective, applicable and viable.
- In parallel to the pilot plant operation, on-site tests, analyses and investigations were carried out to characterize the waste water and the composite streams.

# Pilot Plant Flowsheet



# Pilot Plant Results

- The Pilot Plant demonstrated that an MBR can be used to treat Bapco's waste water and provide as complete a biological treatment as possible, leaving only hard/ non-biodegradable/ recalcitrant COD and TKN un-oxidized.
- Additional bench scale tests were performed in a on-site laboratory, using sludge from the pilot plant, to verify the bio-kinetic constants.
- Fundamental process information was used as input to process simulations used to optimize the design.
- Reference sites in Italy were visited. These sites were using similar technology in a tightly controlled discharge environment.
- All of this was translated into a practical design.

# Reasons for Selecting MBR Technology

- An MBR process, as BAT, was considered because
  - the low TSS limit
  - the low TKN limit
  - low sludge growth rate
  - low contaminant loading
  - Poor floc settling properties resulting from the high salinity.
- It was considered unlikely to meet the specs with anything other than an MBR.
- Despite rapid growth in the number of MBR installations, they have not been used in refinery applications because of the perceived risk of membrane fouling by oil. The pilot plant demonstrated the manageability of this risk.

# What the WWTP will achieve for Bapco

- The WWT project will enable Bapco to significantly improve the quality of the discharged process water and comply with the environmental regulations as specified by the Bahrain Government.
- Currently the Best Available Technology (BAT) for the secondary biological treatment of refinery waste water would be an MBR; a biological plant (anoxic and anoxic zones) followed by a membrane separation stage.
- This process offers the most complete biological treatment possible including nitrogen removal. The specification from the EWP is stringent on all forms of nitrogen.
- Further biological treatment is not possible and as a result of this the polluting nature of the treated water is at an absolute minimum. This was supported by toxicity testing.
- No problems with oil on the membrane or other issues concerning the membrane material have been encountered.

# Process Configuration

- Currently the Best Available Technology (BAT) for the secondary biological treatment of refinery waste water would be an MBR; a biological plant (anoxic and anoxic zones) followed by a membrane separation stage.
- This process offers the most complete biological treatment possible including nitrogen removal. The specification from the EWP is stringent on all forms of nitrogen.
- 4 biological stages (anoxic/ aerobic/ anoxic/ aerobic) are necessary to meet the stringent specifications.
- Further biological treatment is not possible and as a result of this the polluting nature of the treated water is at an absolute minimum. This was also supported by toxicity testing.
- No problems with oil on the membrane or other issues concerning the membrane material were encountered.

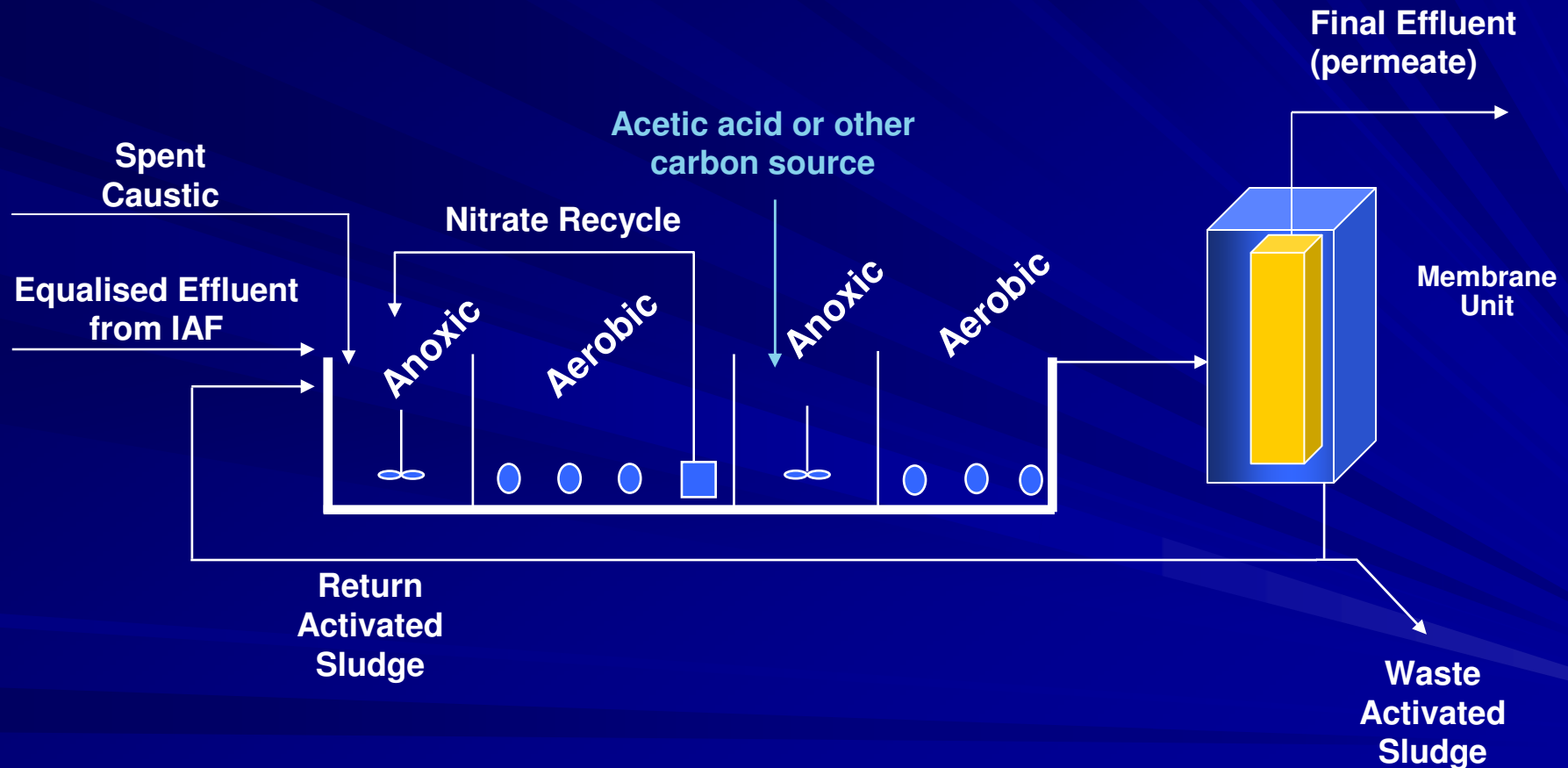
# Final Process Configuration

- The final process configuration is:
  - Max capacity 5000 USgpm
  - Unit feed pit
  - Equalization system
  - Cooling system
  - Integrated 4-stage flexible biological system (organics removal, nitrification and denitrification)
  - Membrane tanks for liquid/solid separation system
  - Sludge treatment (storage and dewatering system)
  - Chemical storage and dosing systems.

# Spent Caustic

- Bapco has a waste stream of spent caustic, and ways of handling it in an environmentally acceptable way were being investigated.
- During the waste stream characterization it was confirmed that the spent caustic from the refinery was problematical because of its very odorous and toxic nature.
- Following experiments on the pilot plant it was demonstrated that the spent caustic, when added in a controlled manner could be processed by without a problem.
- The Pilot Plant mass balance showed a COD shortfall as required by the de-nitrification reaction. As an additional benefit, the spent caustic could help reduce the shortage by providing COD. This saves acetic acid addition as COD source.
- As another benefit, the alkalinity provided by the spent caustic reduces the alkalinity required for nitrification. This saves fresh caustic addition.

# Process Flowsheet



# Project Status

- The EDP has been completed.
- Flowsheet, P&IDs have been developed.
- Front End Engineering Design (FEED) has started.
- Engineering Procurement and Construction (EPC) will follow.
- Options for further treatment to allow water reuse are being examined.

# Summary

- From a position of no one knowing anything about the best process, if any at all, to treat its problematic waste water and spent caustic, Bapco first established a knowledge base and then developed that further to a practical design based on an MBR, a state of the art technology.