Cost Effective Nitrogen Removal from Industrial Wastewaters

Author : Dr. Carl E. Adams, Jr., PE, BCEE
Soham Mehta

Nitrogen is commonly found in many industrial wastewater, esp. in industries such as fertilizers, organic chemicals, petrochemicals, refineries, pulp & paper, pharmaceuticals, coke-ovens, pigments, pesticides, etc. The common form of nitrogen in wastewaters from these industries are ammonium compounds, nitrates, nitrites or organic nitrogen compounds such as amines, triazines, pyridines, etc. At times nitrogen can even be present as dissolved ammonia gas.

Presence of nitrogen in wastewaters poses serious environmental hazards. Not only it can be toxic to organisms in the receiving body, its immediate effects are lowering of dissolved oxygen (resulting into septicity and foul odour) and eutrophication (excessive aquatics plant growth). Organic nitrogen compounds may be highly toxic or carcinogenic, and may end up in more concentrated forms up the food chain.

Existing technologies commonly used for removal of nitrogen from industrial wastewaters are:

(a) Air or steam stripping at high pH and temperature
(b) Ion Exchange
(c) Precipitation as Struvite
(d) Adsorption on activated carbon (organics only)
(e) Biological conversion to nitrogen gas

Of all these, the biological conversion is the only process that treats all forms of nitrogen and provides the most cost-effective nitrogen removal methodology.

Just as is the case of carbonaceous organic removal, the biological treatment can be configured in different ways like suspended growth or attached growth system, completely-mixed or plug-flow system, or even membrane-based MBR. Of all these, completely-mixed suspended growth bioreactors have been, globally, considered as most reliable configuration to treat nitrogen biologically. An advanced and innovative version of this was developed by The ADVENT Group of US in partnership with industries such as GE, Mitsubishi Chemicals & US Steel. Called the ADVENT Integral System, this operator-friendly maintenance-averse technology incorporates patented and globally acclaimed features such a biomass conditioning and forced sludge recirculation, thereby providing itself an ability to operate at much higher biomass concentrations than conventional in a single tank occupying one-third space.

Biological Nitrification – Denitrification Process

Nitrification is the process of converting ammonium compounds to nitrates, and is performed by group of microorganisms called “nitrifiers”.

$NH_4 + 2O_2 + 2HCO_3 \rightarrow NO_3 + H_2O + H_2CO_3 +$ New Bugs

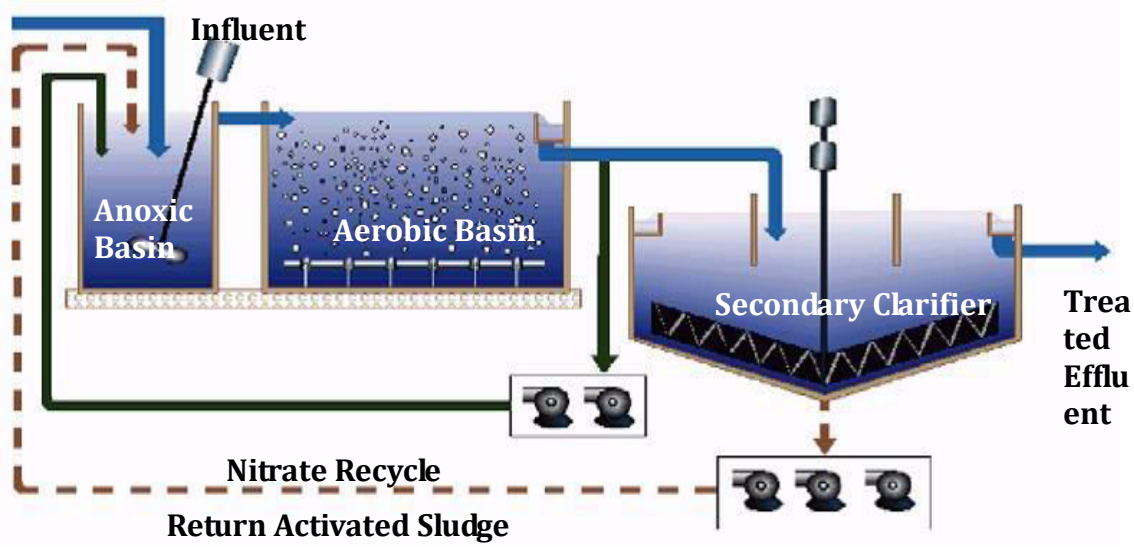
Nitrifiers are “autotrophic” organisms which require dissolved oxygen to convert ammonium compounds to nitrates. The process requires 4.86 kg of dissolved oxygen per kg of ammonical nitrogen. It also, requires substantial alkalinity to the tune of 7.14 kg alkalinity per kg of ammonical nitrogen, since conversion of ammonia to nitrate releases acidity in the system.

Denitrification is the second step in biological nitrogen removal whereby nitrates formed earlier, or present in the wastewater, are converted to nitrogen and released into the atmosphere.

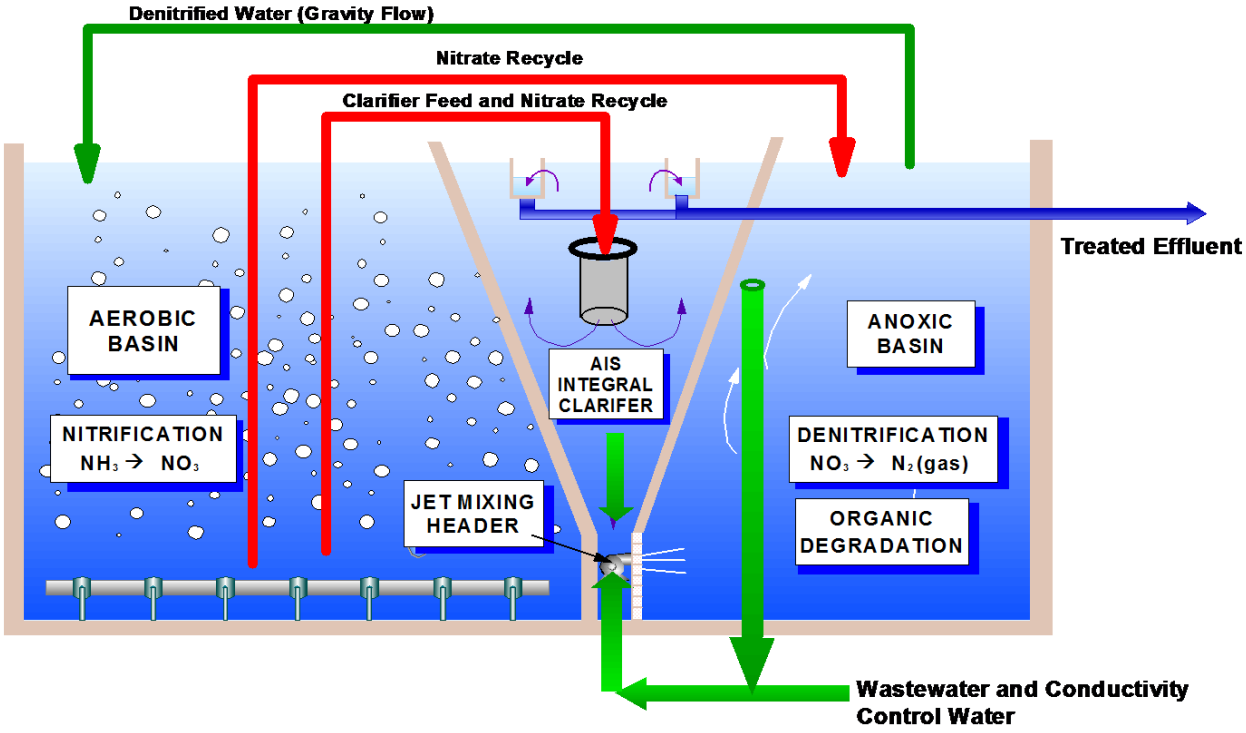
$NO_3 +$ Organics $+ H_2CO3 \rightarrow N_2 + H_2O + HCO_3$

Denitrification is done under “anoxic” conditions, without presence of dissolved oxygen. It is done by same organisms that “eat” away organics, called heterotrophs. In absence of dissolved oxygen but in presence of organics, the heterotrophs can utilize molecular oxygen from nitrates and thus convert nitrates to nitrogen. In the process, the organics get removed too while alkalinity gets generated on reaction.

A conventional two-stage Nitrification / Denitrification system contains an anoxic basin, and aerobic basin, a secondary clarifier and sludge recycle pumps. The process of Denitrification is done first by recycling 2 to 10 times the feed flow from aerobic basin to anoxic so as to minimize consumption of alkalinity and dissolved oxygen.



The ADVENT Integral System (AIS) performs entire Nitrification – Denitrification process in a single tank with a simplistic and reliable approach. The primary treated wastewater enters the anoxic zone and is mixed with recycled sludge. Nitrates are brought in from the aerobic zone by a large recycle flow, usually tow to ten time the feed. Nitrates get converted to nitrogen and incoming COD gets reduced to match the nitrate chemistry without any oxygen supply (aeration). The denitrified effluent flows under gravity to adjoining aeration zone wherein the ammonical compounds that remain untreated in anoxic zone and balance organics are removed by heterotrophs and nitrifiers in an aerobic environment. The mixed liquor from aerobic zone is transferred to the integral clarifier using an air-lift pump (no rotating parts). The biomass settles in the clarifier and is forced out into the anoxic zone to mix with the incoming primary effluent. The clear supernatant overflows out from weirs at the top of integral clarifier.



Operations

The raw primary treated influent having ammonia and organics is mixed with recycled nitrate flow from the aerobic basin in the anoxic zone. The anoxic zone is adequately sized to provide sufficient residence time for biological denitrification. BOD and nitrates get removed in the process. Post denitirification, the wastewater (influent + recycled flow) overflows under gravity to the adjacent aerobic reactor for nitrification. The aerobic zone has a diffused aeration system at the bottom to provide requisite oxygenation. Under low NH_3/VSS conditions and in presence of air, the nitrifiers convert ammonia to

nitrates. The biomass present in the system comprises of a mixed culture of nitrifiers as well as other generated species like Pseudomonas and Bacillus. Since this acclimatized biomass is important, it is recycled back using the integral clarifier. A flow equivalent to actual raw influent plus recycled activated sludge is pumped using a simple air-lift pump from the aerobic basin to the integral clarifier. The activated sludge flow is drawn into the anoxic zone by the force induced by jet-mixers. The actual influent flow equivalent overflows through an outlet weir at the top of the clarifier.

Advantages

1. Economical Construction
2. Low Operating Cost
3. Simple Operations
4. No maintenance within the system
5. No sludge bulking (because of forced recycle)
6. Better effluent clarity

Economics

The capital and operating costs are site-specific based on flow, COD, Nitrogen and space availability. In general, the capital cost is 50-75% more as compared to extended aeration activated sludge plant for COD removal while the operating cost is about 25-50% higher than that and depends upon nitrogen content and presence of alkalinity.

The earlier mentioned oxygen, substrate and alkalinity requirements are theoretical and need to be adjusted for various other factors like influent nitrate and DO levels, residual DO levels, influent alkalinity, etc. For the purpose of estimates, the following requirements may be adopted:

(a) 3.5 to 4.5 kg alkalinity as $CaCO_3$ (3.15 to 4.05 kg lime) per kg of NH_4-N.

(b) 2.2 to 2.5 kg oxygen per kg NH_4-N, if the BOD is readily degradable in anoxic conditions and if BOD: NH_4-N is 3.0 or lower. This will amount to about 2.5 to 3.0 units of power per kg NH_4-N treated.

(c) Methanol/Ethanol/Acetone/Acetate/Distillery Waste as organic source if the BOD: NH_4-N ratio is less than 3.0.

AIS has been successfully used or is under installation for Nitrification – Denitrification application around the world. Few major installations of AIS for nitrogen removal are:

Client	**Industry**	**Flow (m^3/day)**	**Influent N (mg/L)**
US Steel	Steel (Coke-oven)	2200	4000
Fluorochemicals	Organic Chemicals	10000	100
Exxon Mobil	Refinery	28800	30
Marathon Ashland	Refinery	4800	50
Masisa	Paper & Board	200	140
COSIPA	Steel	2400	400
CNPC	Acrylic Fibres	9600	150
Procter & Gamble	FMCG	1000	200
Tata Steel	Coke-oven	5500	300