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Enchantment CD

Process Modeling IFAS and MBBR Systems Using LinPor™

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ABSTRACT: The WERF report on “The Investigation of Hybrid Systems for Enhanced Nutrient Control” (Project 96-CTS-4) kicked off interest in IFAS (Integrated Fixed Film Activated Sludge) and MBBR (Moving Bed Biological Reactors) systems in North America. The LinPor™ process was developed in Europe by Linde AG. It operates in either the IFAS or MBBR mode using a suspended media of highly porous polymer foam cubes that serve as a mobile carrier material for accumulation of microorganisms. This porous media allows the biological reactor to operate at 2 to 3 times greater total biomass concentration than a conventional air activated sludge process. In addition, because most of the biomass is retained in the media, the mass loading imposed on the secondary clarifier is minimized. The LinPor™ system can be configured according to the level of treatment required (carbonaceous, ammonia reduction, or total nitrogen reduction, with phosphorus reduction if necessary) and the process is ideally suited for the upgrade of existing plug flow diffused air systems to increase capacity, or to achieve higher levels of treatment, while minimizing modifications to existing facilities.

This presentation will address the development and evolution of the LinPor™ process from initial process design concepts, beginning pilot plant studies, and operation and performance results from installed full scale facilities. All the various process configurations for nitrogen control will be described and depicted, including those with biological phosphorus removal. A complete development of the methodology of the Linde’s empirical process design will be illustrated. The BioWin® process simulation software can be adapted to model LinPor™ using this empirical process design basis. Data for the first North American LinPor™ plant at Westerly, RI, USA, where nitrification and simultaneous denitrification occur in the oxic reactor stage and denitrification occurs in the anoxic stage will be presented along with data for several European plants.

A complete list of world wide LinPor –CN and –N™ installations is included.

KEYWORDS: IFAS process design, MBBR process design, Simultaneous Denitrification,

INTRODUCTION

Linde laboratory legend has it that LinPor™ arose from an accident when Uwe Fuchs accidentally dropped some foam packing cubes into an activated sludge reactor during a test run in the late 1970s. The cubes were retrieved when the reactor was shut down for cleaning; they were over grown with biomass. The staff pondered the cubes and their possibilities. The commercialization of this accidental technology discovery was done by Hans Reimann PhD and Alfred Wildmoser. Initial laboratory tests at Linde AG's research center at Hollreigelskreuth in the Bavarian Province of Germany established the structure and material of construction of the foam carrier necessary for its successful operation; then bench scale testing was done to understand its capabilities as a biological treatment process. A demonstration size reactor was used for field testing; first at Wolfratshausen, DEU and then at other facilities. Finally a process configuration, which is now known as LinPor-CN™ (IFAS), was started up at Friesing, DEU in 1984 the intent was to solve a sludge bulking problem and further explore the possibilities of the process. The unintended nitrification and simultaneous denitrification that occurred at Freising was then fully defined and that process configuration would provide an excellent retrofit solution to the soon to be promulgated German BNR laws. Commercialization of the process continued under the direction of Manfred Morper PhD. Following the developmental activity at Freising of LinPor-CN™ (IFAS) there was the development of the LinPor-N™ (MBBR) process to provide an ammonia conversion “polishing” process step for existing plants. The first commercial LinPor-N™ (MBBR) plant started up in 1988 at Stadt Wyk auf Fohr, DEU ⁽¹⁾.

MEDIA, PHYSICAL CHARACTERISTICS

The purpose of IFAS and MBBR systems is to increase the amount of biomass in a biological treatment reactor by providing a media upon which it can grow. Thus the media of an IFAS or MBBR system is central to its operation. It must perform the required task of acting as a carrier or residence for the biomass while also giving a long service life. The media used in the LinPor™ processes are cut from a polyurethane or polyethylene foam material with proprietary properties to ensure long service life. The cuboids produced are 15 mm, 0.59” X 15 mm, 0.59” X 12 mm, 0.47”.



Figure 1 “virgin” media carrier material

The blank carrier material has a very high surface to volume ratio, 853 ft² / ft³. The LinPor™ cuboids are very open structures with 30-40 entrance pores per inch leading to an internal volume that is 97% open.

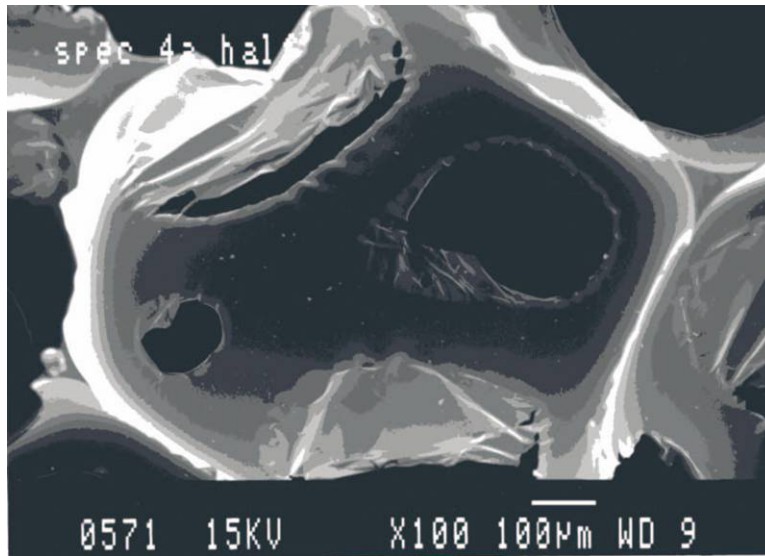


Figure 2 “virgin” carrier material at 100 X magnification

One of the early difficulties encountered with the media was that it filled with biomass and due to dissolved oxygen limitations went anaerobic; that difficulty was solved by developing the means to slough off the biomass on a regular basis. Present day LinPor-CN™ IFAS systems do this by means of jostling the media in a high level turbulence (high “G”) zone near the exit screens and with an impingement plate at the end of the air lift media recirculation lines.



Figure 3 high “G” turbulence zone (left) impingement plate (right)

The media does wear; as time goes by the sharp edges of the cuboids round. This rounding causes a volume loss of about 1% per year over the first few years of operation. This wearing soon stabilizes and there are in operation with media that is 18 years old where media has not been replaced. The expected service life of the LinPor™ media produced to its proprietary specification is over 20 years.

SYSTEM CONFIGURATIONS

In 2000 the Water Environment Research Foundation published its review of emerging hybrid biological treatment technologies used to increase biomass in biological reactors and provide nutrient removal- Investigation of Hybrid Systems for Enhanced Nutrient Control ⁽²⁾. This report created the classifications and definitions called IFAS and MBBR for such hybrid systems. To quote the document:

Integrated Fixed-Film Activated Sludge (IFAS)

“The IFAS type of hybrid process includes any activated sludge system that incorporates some type of fixed film media in a suspended growth reactor for the purpose of increasing the amount of biomass available to affect treatment. The type of media incorporated into the mixed liquor also differentiates IFAS systems.” ⁽³⁾ The listing is rope, ring, sponge, plastic carrier, rotating biological contactor, and trickling filter media.”

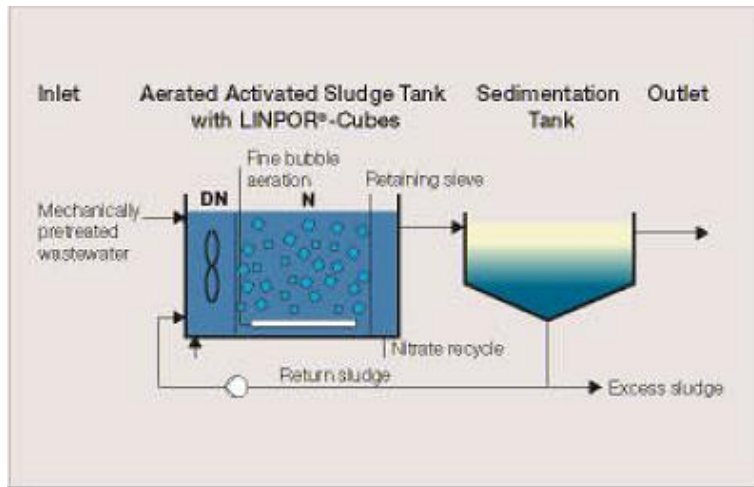


Figure 4 LinPor -CN™ in IFAS Configuration

Moving Bed Biofilm Reactor (MBBR)

“The MBBR process uses small plastic carrier elements placed in a continuously mixed basin to provide surface area for the growth of attached biomass. The media can be used in aerobic, anoxic, and anaerobic zones. The MBBR does not incorporate return sludge.” ⁽⁴⁾

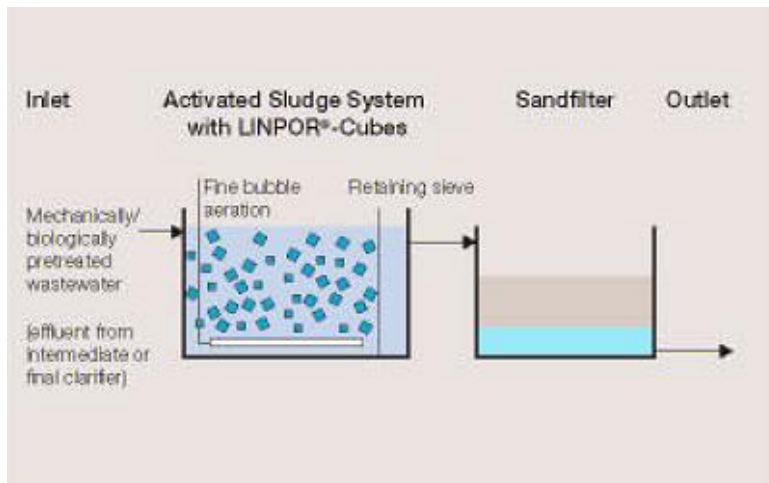


Figure 5 LinPor-N™ in MBBR Configuration

The report indicates that the MBBR process was originally developed solely by the Norwegian Company Kaldness Miljøteknologie a dubious claim and statement; considering that the report ignored the nine plants which had installed LinPor-N™ systems by Linde AG and that were operating in Germany with a combined capacity of 67 MGD and an operating history of 79 years at the time of publication; the oldest plant having been on line for thirteen years. The report further erred in classifying all LinPor™ systems as IFAS systems; the correct classification is included further on in this paper.

IFAS, LinPor-CN®

PROCESS CHARACTERISTICS

There are presently eleven plants with LinPor-CN™ systems installed running with a combined capacity of 49.6 MGD and having an operating history of 70 years. The process has free and fixed biomass by definition, with the fixed biomass on the media which can range from 15-30% of the contents of the reactor volume. The reactor average free and fixed biomass concentrations are generally between 9000-12,000 mg/l; the upper limit is controlled by both the attainable oxygen transfer capacity in the reactors and the solids flux capacity of the clarifiers. The high total free and fixed biomass provides an SRT which can readily provide nitrogen conversion to nitrate at low temperatures and this allows the use of reactor volumes 50% or less than those without the contained media. In addition 40- 70% simultaneous denitrification occurs in the oxic zone inside the media; the amount is dependent upon the F/M ratio, ratio of BOD₅ to TKN, and dissolved oxygen concentration. Thus if denitrification is required for total nitrogen control the anoxic volume required for denitrification can be made smaller in proportion to the simultaneous denitrification that occurs. LinPor-CN™ plants operating in the IFAS configuration world wide are:

<u>LOCATION</u>	<u>TYPE APPLICATION</u>	<u>FLOW</u>	<u>LENGTH of OPERATION</u>
Gemeinde Illmensee/DEU	Carbonaceous/Nitrogenous	0.3 MGD	18 Years Since 1987
Stadt Freising/DEU	Carbonaceous/Nitrogenous	16.5 MGD	12 Years Since 1993
Hinterstoder/OST	Carbonaceous/Nitrogenous	0.6 MGD	11 Years Since 1994
Gemeinde Unterfohring/DEU	Carbonaceous/Nitrogenous	3.0 MGD	7 Years Since 1998
AV Schotten-Nidda/DEU	Carbonaceous/Nitrogenous	4.5 MGD	6 Years Since 1999
Vilsbiburg/DEU	Carbonaceous/Nitrogenous	2.4 MGD	5 Years Since 2000
Murau/OST	Carbonaceous/Nitrogenous	3.8 MGD	4 Years Since 2001
Braunau/OST	Carbonaceous/Nitrogenous	6.0 MGD	2 Years Since 2003
Westerly, RI, USA	Carbonaceous/Nitrogenous	3.3 MGD	2 Years Since 2003
Schwarachgruppe/DEU	Carbonaceous/Nitrogenous	5.8 MGD	2 Years Since 2003
Lengede/DEU	Carbonaceous/Nitrogenous	3.4 MGD	1 Year Since 2004

THE REACTOR

A typical conversion of an existing activated sludge system consists of setting up separate zones for denitrification, and nitrification-simultaneous denitrification in the biological reactors depending upon the amount of treatment needed.

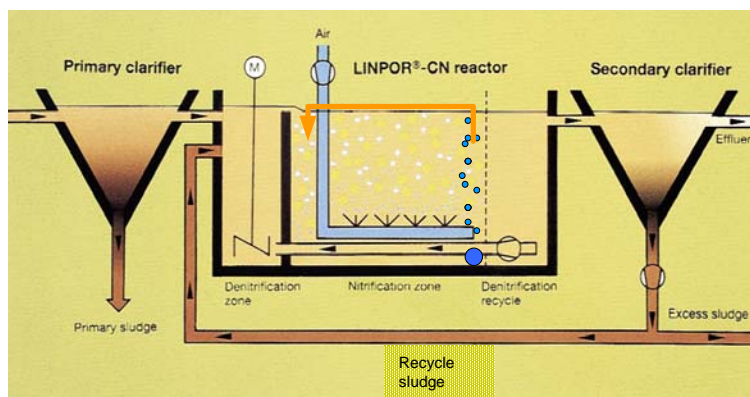


Figure 6 Cross Section of Reactor Configured as LinPor-CN™

IMPLEMENTATION

Pretreatment with fine screens, 8mm, 0.31", is required to remove material that would blind the media containment screens. Over and under flow walls would be used to separate the zones. Mixers would be supplied to keep biomass suspended in the anaerobic zone for phosphorus release, as well as in the anoxic zone for denitrification. Media would not be provided in those zones. In the zone for nitrification and simultaneous denitrification containing the LinPor™ media a screen is used to contain the media within the reactor. The screen usually consists of a floor to surface stainless steel plate with 8 mm, 0.31" holes; although cylindrical screens can be used. The sizing criteria for the screen is 368 gallons/ ft²/day at peak flow; which of course must include all expected recycle flows in addition to the main stream peak flow. The plate screen is mounted off the walls of the reactor by about a foot along the side walls and by several feet at the end wall. The plate screens take the shape of a U running along the side walls and end wall of the reactor. All along the inside edge of the screens just off the floor of the reactor runs an air feed line equipped with coarse bubble diffusers. These diffusers are used to keep both the LinPor™ media and debris off of the screens. In addition the "knife" of rising air bubbles jostles the media and sloughs off biomass which then passes thru the screen and into the clarifiers. The air flow required is 5 scfm peak for "bumping" and 2 scfm normal scouring flow. Inside the plate screens before the end wall are located air lift media capturing hoods which collect the media, lift it, and transport it to the head of the reactor. At the end of each recirculation line is an impingement plate which again jostles the media and causes slough off. If further denitrification is required beyond that attainable with simultaneous denitrification a separate denitrification zone is set up prior to the oxic zone. Internal recycle pumps for this process step are located on the outside of the plate screens before the end wall. They transport the mixed liquor back to the start of the anoxic zone. Mixers must be provided in that zone to keep the biomass suspended. If phosphorus removal is required an additional anaerobic zone is established prior to the anoxic zone, again mixers are required in this zone to keep the biomass suspended ⁽⁵⁾. Oxygen for use by the biomass is provided by either fine or coarse bubble diffusers located along one wall set up to provide a spiral roll in the reactor. Full floor fine bubble diffusion can not be used as it will cause the media to float in the upper portion of the reactor. It is important to take into consideration the oxygen transfer provided by the air lift media return lines and the air scour along the media containment screens when calculating the oxygen transfer requirements.

PLUG FLOW BASIN CONVERTED TO NUTRIENT REMOVAL

anaerobic (phosphorus release), anoxic (denitrification), and oxic (nitrification) zones

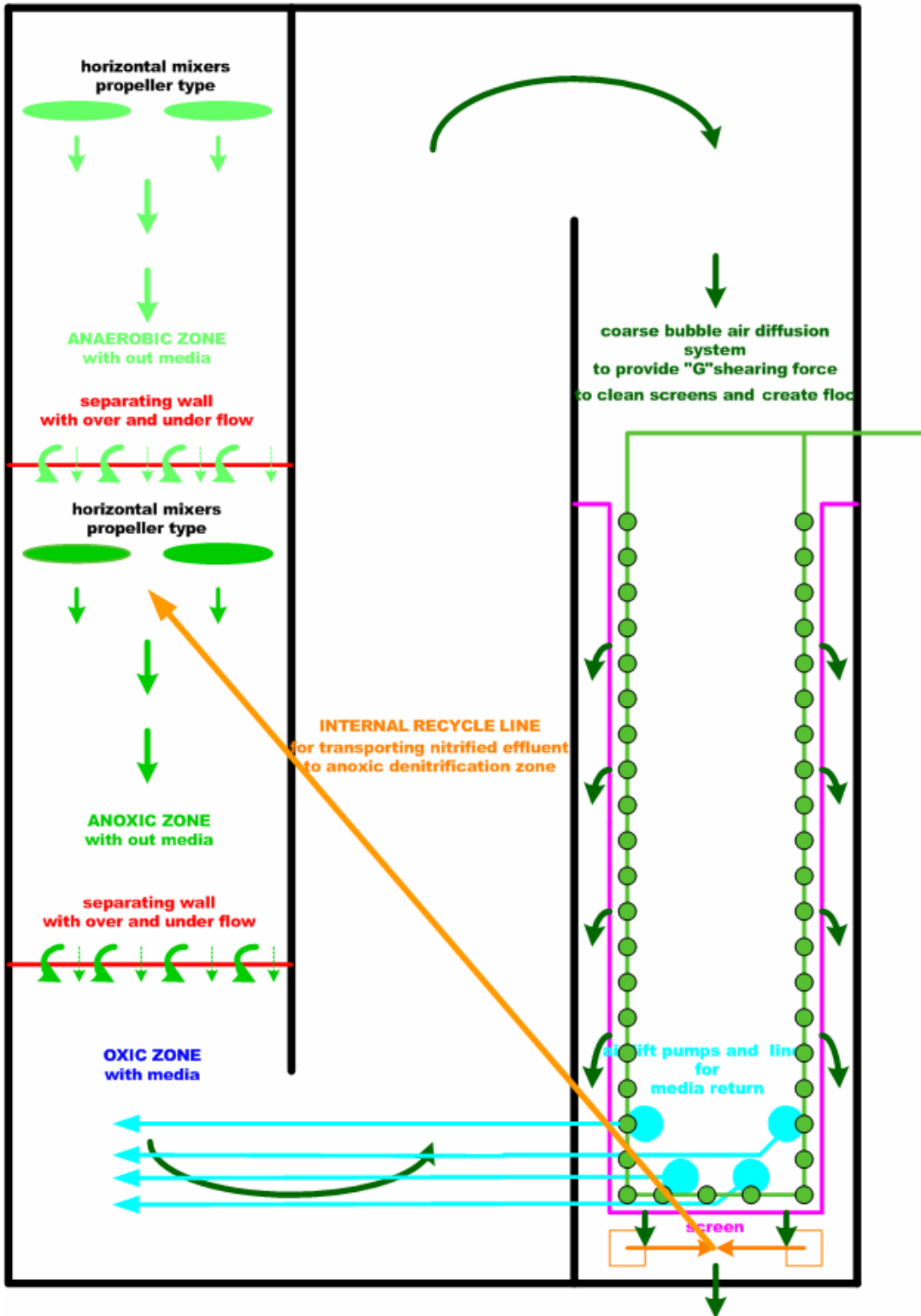


Figure 7 Classical Three Pass Plug Flow Diffused Air Basin Configured For Full Nutrient Removal (P and N) by Means of LinPor-CN™ IFAS

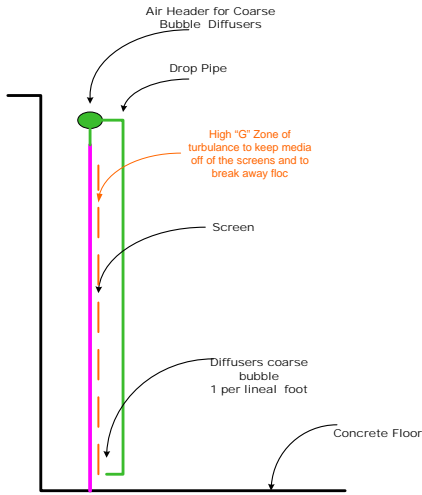


Figure 8 Cross Section showing high "G" shear zone

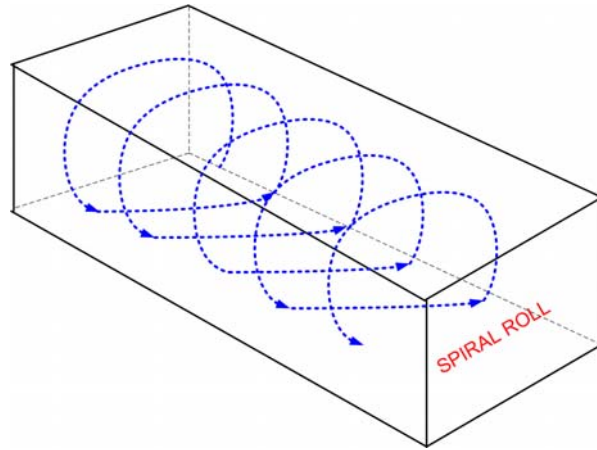


Figure 9 Isometric showing reactor spiral roll

BACTERIAL POPULATION

In actual operation the cubes do not fill with biomass due to the measures taken to jostle them and cause biomass sough off. Sectioning of the cubes and subsequent observations tell us that only a 1-5 mm, 0.03-0.19" outside layer of the media develops a biomass. If the operating conditions are controlled properly (DO, F/M, BOD/TKN) the inner portion of this layer lacks oxygen enabling denitrifying bacteria to convert nitrates to nitrogen.

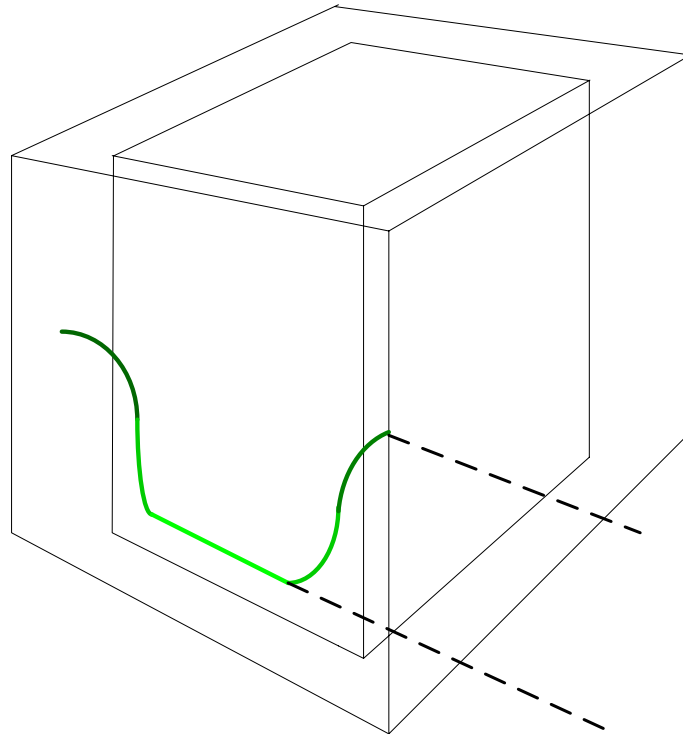


Figure 10 Isometric showing volume where biomass exists and DO gradient

Typical biomass development in a LinPor-CN™ IFAS system does not consist of a tightly packed fixed film of bacteria but instead consists of loosely contained flocs and lightly bound film; as stated previously this is due to the jostling in the high “G” zone before the media retaining screens and on the impingement plates at the end of the air lift media return lines.



Figure 11 Media @ 125X showing loose flocs in the interstitial volume

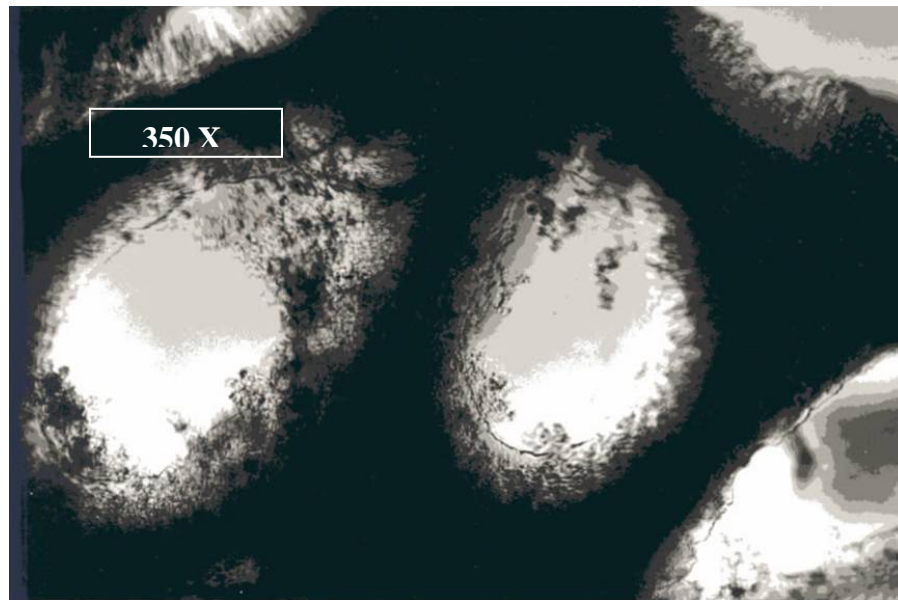


Figure 12 Media @ 350X showing loose fixed film in the interstitial volume

Florescence In Situ Hybridization, FISH, technology was used to study the relative bacterial populations in the free and fixed biomass of a LinPor-CN™ system in Starnberg Germany ⁽⁶⁾. The same proportion, 9-10%, of ammonia oxidizing nitroso-bacteria were found in the free and fixed biomass. The proportion of nitrite oxidizing nitro-bacteria differed with twice the proportion, 7%, in the fixed biomass as compared to the free biomass, 3%.

PROCESS DESIGN ⁽⁷⁾

In the procedure used for implementing IFAS LinPor-CN™ process designs a set of empirical correlations, based on demonstration and full scale plant operations, is used to determine the ammonia nitrogen removal rate, V_N in kg $N_{\text{removed}} / \text{kg TSS-day}$. The empirical correlations are expressed by a family of curves for specific temperatures between V_N and the ratio of $\text{BOD}_5 / \text{TKN}$ at given effluent $\text{NH}_3\text{-N}$ concentrations, DO level, and percent reactor media fill.

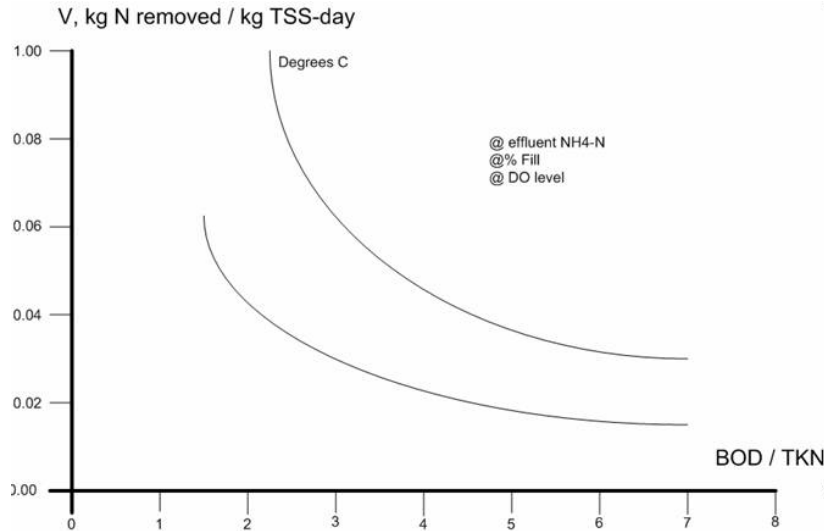


Figure 13 Empirical Correlations between V_N and BOD/TKN
@ varying waste water temperatures note adjustments for NH_4 effluent, DO, %Fill

Once V_N is determined a reactor volume can be calculated to achieve the desired ammonia conversion. Then a check is made on the available SRT, based on total free and fixed biomass, versus the critical SRT for nitrification with appropriate safety factor at the operating temperature is made and a volume adjustment is made if necessary. The amount of simultaneous denitrification is obtained by using a linear empirical correlation between percent denitrification and an empirical proprietary correlated function D , a power function where $D = (F/M)^X (\text{BOD}_5 / \text{TKN})^Y (\text{DO})^Z$.

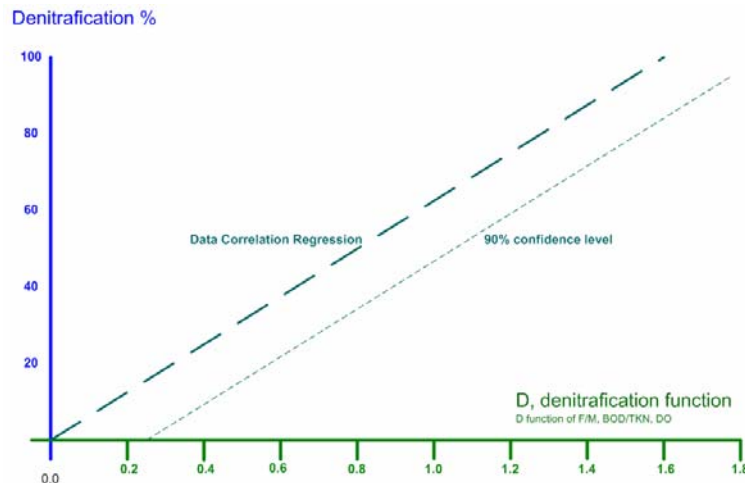


Figure 14 Empirical Correlation for Simultaneous Denitrification

Then the usual calculations are made for sludge production, oxygen consumption, and alkalinity balance.

Recent discussions with a major consulting engineer ⁽⁸⁾ has resulted in adapting the EnviroSim™ software BioWin™ for modeling and simulating the IFAS LinPor-CN process. The BioWin flow sheet for doing the modeling is illustrated.

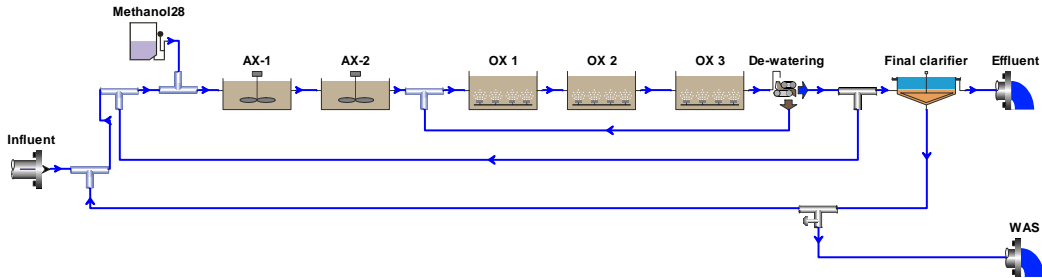


Figure 15 BioWin™ Flow Sheet for LinPor-CN™ IFAS Modeling and Simulations

The retention of biomass on the media is modeled by inserting a “pseudo” dewatering device with internal recycle into the process flow schematic, this allows a buildup of biomass to a level that is representative of an IFAS system. Both the anoxic and oxic zones are set up as complete mixed stages to simulate overall plug flow reactions. Denitrification in the oxic reactors can be simulated by adjusting the kinetic switching function for aerobic denitrification; in addition the model and simulator can be brought closer to representing the perceived reality by changing the kinetic function values for the anoxic hydrolysis factor, the ammonification rate, and hydrolysis rate. Thus to do modeling and simulations for LinPor-CN™ systems using EnviroSim’s™ BioWin™ software requires a good deal of empirical and practical knowledge of the denitrification, nitrification and IFAS processes. The advantage of using BioWin™ is that the calculation time is reduced.

OXYGEN, AMOUNT NEEDED and TRANSFER CALCULATIONS

The actual oxygen needed by a LinPor-CN™ IFAS system is substantially less than for IFAS systems that can not employ simultaneous denitrification. As the media pass down the reactor’s oxic zone oxygen used to cause nitrification is recovered as denitrification occurs. The effect is lessened as the biomass approaches the end of the reactor as biomass DO elevates and nitrogen is removed; but then the fixed biomass is recycled back to the head of the reactor via the air lift media return lines.

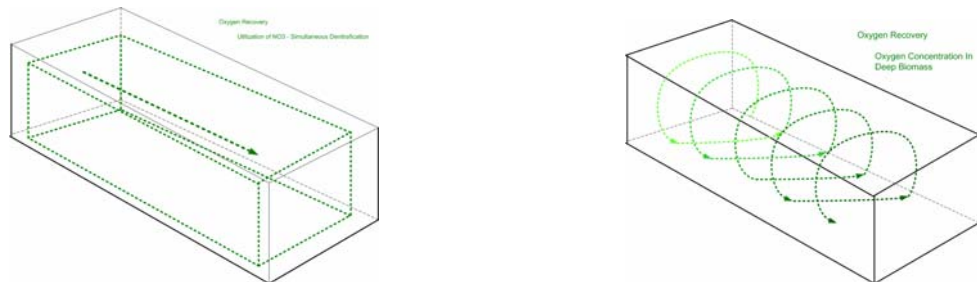


Figure 16 Isometrics illustrating oxygen recovery and DO gradient in a LinPor-CN IFAS reactor

In addition to the diffuser grid that provides oxygen transfer and imparts a spiral roll to the plug flow there are two other means of oxygen transfer.

- ✓ The airlift media recycle lines which return media in a mixed liquor at 75% of oxygen saturation⁽⁹⁾.
- ✓ The air scouring diffusers for the media retention screens along the walls of the reactor.

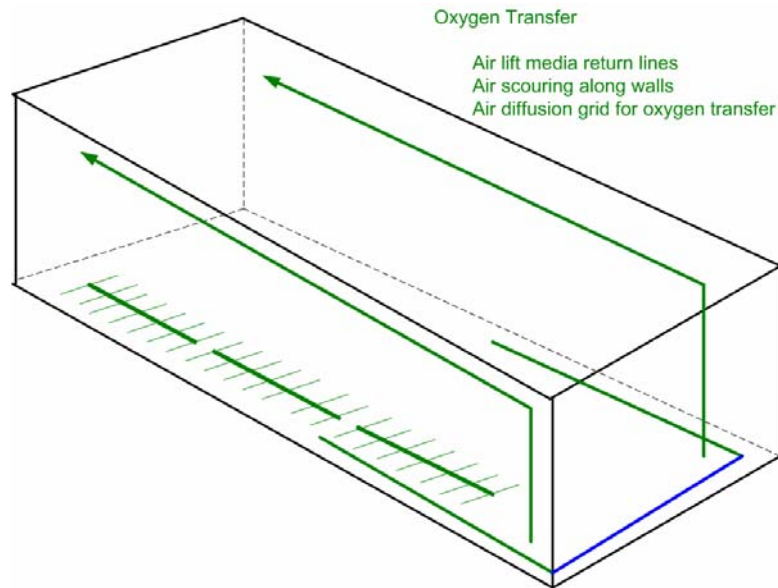


Figure 17 Isometric illustrating the means of oxygen transfer in a LinPor-CN™ IFAS system

Both of these other means of oxygen transfer have to be accounted for in the oxygen transfer design, especially in evaluated bids which have a net present value for power consumption. The air lift media recycle lines are operated intermittently or continuously at the option of the operator to return the media to the head of the reactor, control biomass slough off, and accomplish control of simultaneous denitrification. Thus while the blowers have to be sized to provide the air flow for the air lift media recycle lines this air flow may or may not account for substantial oxygen transfer depending on their mode of operation. The diffusers along the media retention screens are always operated. The normal scouring air flow is 2 scfm/ lineal foot of screen; however if there is a buildup of material or media in front of the screens the air flow can be raised to 5 scfm/ lineal foot of screen to “bump” the material or media off of the screens. Thus the sizing of the blowers must account for the 5 scfm/lineal foot of screen; but the allowance for oxygen transfer should be for 2 scfm/foot of screen along with the power thus consumed if the bid tender has an evaluated net present value for power. If a full net present value analysis is made it is critical that both capital and operating costs are properly evaluated. The net present value evaluation for the operating cost of the air blower power consumption should allow for the oxygen transfer accomplished by both the continuous operation of the air lift media recycle lines and the air scouring of the media retention screens along the reactor walls. This reduces the amount of oxygen transfer and thus air flow required of the main diffusion grid subsystem which induces the spiral roll of the biomass moving in the plug flow regime. In addition an analysis of process conditions for determining the alpha value used in the design of that diffuser grid subsystem providing oxygen transfer should be made to determine if fine or coarse bubble diffusers should be used.

OPERATING PLANTS

FREISING, GERMANY

The IFAS system at Freising DEU has been in operation continuously since 1992 and has under gone several expansions; it is presently treating 16.5 MGD. The results of operation have reported by both Hegemann ⁽¹⁰⁾ and Morper ⁽¹¹⁾.



Figure 18 LinPor-CN™ Plug Flow Reactors at Freising DEU

Parameters	DESIGN	OPERATION May-June 1995
Influent:		
Flow, MGD	5.2	6.9
BOD, mg/l	222	225
COD, mg/l	397	425
TKN, mg/l	45.6	28
NH ₄ N, mg/l	35.9	22
NO _x N, mg/l	2.6	5
Total N, mg/l	49.2	24
Effluent:		
BOD, mg/l		2
COD, mg/l		20
TKN, mg/l		
NH ₄ N, mg/l	< 5	0.3
NO _x N, mg/l		7.3
Total N, mg/l	18	7.4
IFAS Reactor		
MLSS _{suspended} , mg/l	3800	7600
MLSS _{fixed} , mg/l	15,000	18,000
MLSS _{average} , mg/l	5,800	9,680
Media Used, % fill	22	20

WESTERLY, RHODE ISLAND and PROVIDENCE PLANTATIONS

The IFAS system at Westerly, RI, USA, has been in operation continuously since 2003; it is presently treating 3.3 MGD. The papers concerning selection of the process and on operation have reported by both Federico ⁽¹²⁾ and Duerr ⁽¹³⁾.



Figure 18 LinPor-CN™ Plug Flow Reactors at Westerly RI USA

Parameters	DESIGN	OPERATION	
		August 2003	September 2003
Influent			
BOD ₅ , mg/l	169	152	315
SS, mg/l	105	155	192
TKN, mg/l	30	-	26.9
NH ₃ , mg/l	20	-	15.1
Effluent			
BOD ₅ , mg/l	30	6.3	5.5
SS, mg/l	30	8.8	11.5
TKN, mg/l		4.7	2.7
NH ₃ , mg/l	5	1.8	0.5
NO _x , mg/l		2.4	3.9
TN, mg/l	15	7.1	6.6

Winter Performance (WW Temperature 12-13^o C)
Effluent

	NH ₃ , mg/l	Total N, mg/l
October 2003	0.50	4.9
November 2003	0.45	3.7
December 2003	0.65	3.5
January 2004	0.55	4.5
February 2004	0.45	2.8

PROCESS CHARACTERISTICS

There are presently nine plants with LinPor-N[™] systems installed running with a combined capacity of 67 MGD and having an operating history of 124 years. The process has only fixed biomass by definition, the average overall biomass concentrations in the reactors are generally between 1000-2000 mg/l.

LinPor[™] plants running in the MBBR configuration world wide are:

<u>LOCATION</u>	<u>TYPE of APPLICATION</u>	<u>FLOW</u>	<u>LENGTH of OPERATION</u>
Stadt Wyk auf Fohr/DEU	Final Step Nitrification	2.2MGD	17 Years since 1988
Gemeinde Halblech/DEU	Final Step Nitrification	0.5MGD	16 Years Since 1989
Hohenlockstedt/DEU	Final Step Nitrification	0.3MGD	16 Years Since 1989
Stadt Aachen/DEU	Final Step Nitrification	33.0MGD	13 Years Since 1992
Stadt Heinsberg/DEU	Final Step Nitrification	5.0MGD	13 Years Since 1992
Stadt Koln-Weiden/DEU	Final Step Nitrification	7.5MGD	13 Years Since 1992
Aachen-Eilendorf/DEU	Final Step Nitrification	13.0MGD	13 Years Since 1992
Stadt Erkelenz/DEU	Final Step Nitrification	4.5MGD	12 Years Since 1993
Walfeucht-Haaren/DEU	Final Step Nitrification	1.7MGD	11 Years Since 1994

THE REACTOR

The reactor is quite simple; consisting of a tank with 30% media fill and coarse or fine bubble air diffusion system to provide oxygen to the biomass. Again, like the LinPor[™] IFAS system, the air diffusers are set up to provide a spiral roll to the reactor flow. There is no recirculation of media or flow. If there is a stringent limitation on solids a filter must be provided.

BACTERIAL POPULATION

Like with LinPor-CN[™] in actual operation the cubes do not fill with biomass. Sectioning of the cubes and subsequent observations tell us that only a 1-5 mm, 0.03-0.19” outside layer of the media develops a biomass. However unlike with LinPor-CN[™] IFAS systems the cuboids in a LinPor-N[™] MBBR are completely oxic due to low nutrient levels. Because there is little jostling of the media a true fixed film develops.

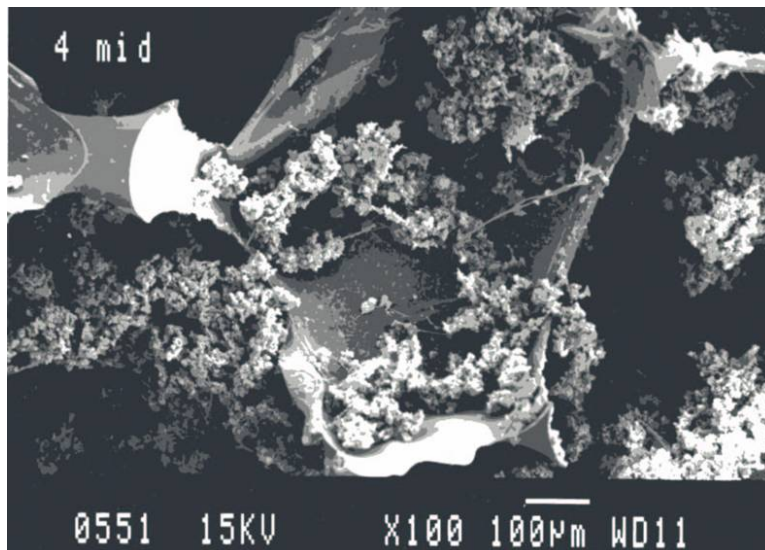


Figure 19 MBBR Biomass @ 100X @ mid-film depth

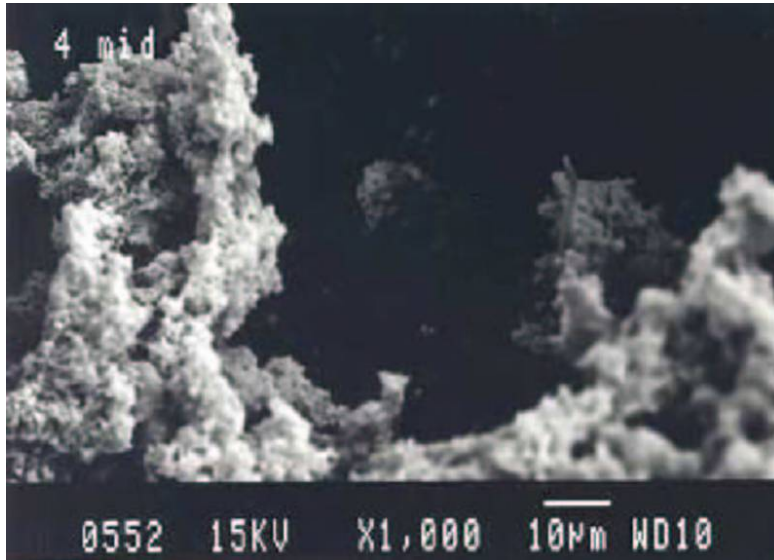


Figure 20 MBBR Biomass @ 1000X @ mid-film depth

PROCESS DESIGN ⁽¹⁴⁾

In the procedure used for implementing MBBR LinPor-N™ process designs a set of empirical correlations is used to determine the ammonia nitrogen removal rate, V_N in $N_{\text{removed}} / \text{liter-day}$. The empirical correlations are expressed by a family of curves for V_N and temperature.

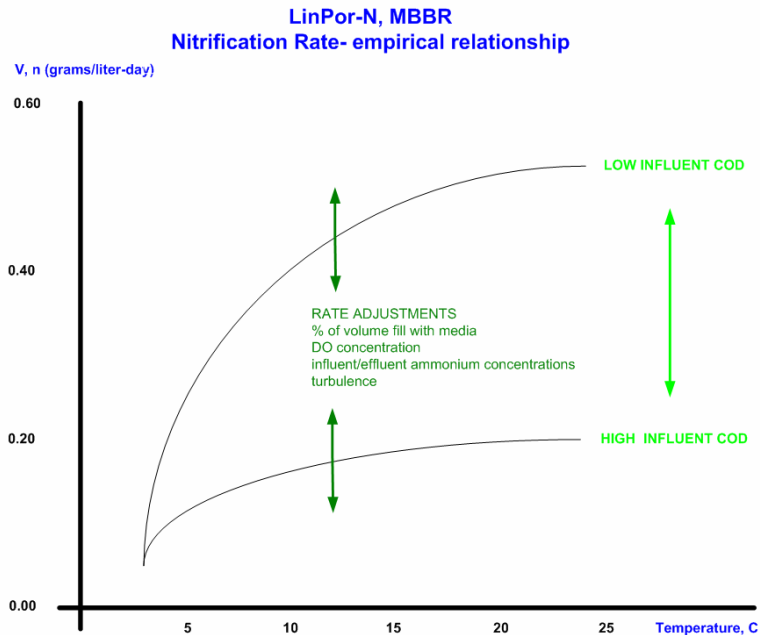


Figure 21 Empirical Correlations of V_N and Temperature

The value of V_N can be adjusted for values for % volume fill, DO level, influent/effluent ammonia concentrations, and turbulence if necessary. Once V_N is determined a reactor volume can be calculated. Then a check is made on the available SRT versus the critical SRT with appropriate safety factor for nitrification at the operating temperature and adjustments to volume are made if necessary. Then the usual calculations are made for sludge production, oxygen consumption, and alkalinity balance.

OPERATING PLANTS

AACHEN, GERMANY

The IFAS system at Aachen, DEU has been in operation continuously since 1992; it is presently treating 33 MGD. An existing on site Schreiber plant was converted to make the LinPor-N system. The old Schreiber clarifier now serves as a clarifier for the secondary step, while the outer annulus was retrofitted with new air diffusers and LinPor™ media was installed. The results of operation have reported by Morper ⁽¹⁵⁾.

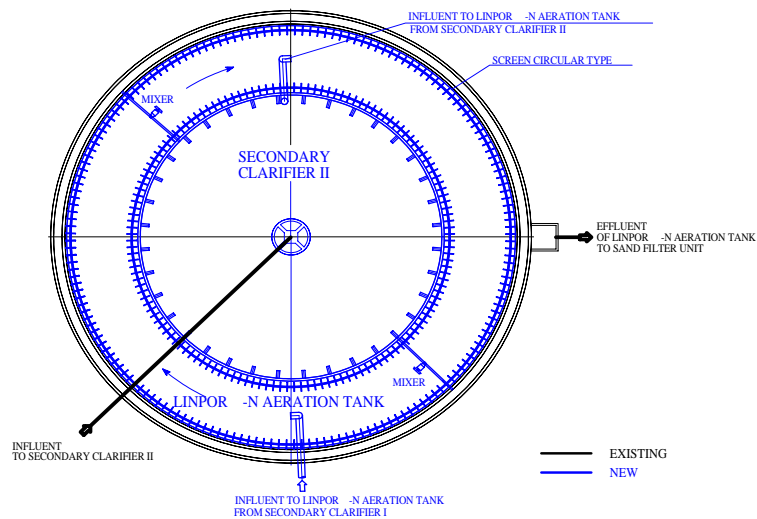


Figure 22 Linpor MBBR at Aachen, DEU

Capacity:

Design Flow	=	33 MGD
Peak Flow	=	68 MGD
TKN Load	=	2750 lbs/day, 10 mg/l

Effluent Quality:

BOD5	=	<7.0 mg/l
NH ₄ N	=	<1.0 mg/l

CONCLUSIONS

- LinPor –CN™ (IFAS) and –N™ (MBBR) process technology for the conversion of ammonia to nitrate and complete removal of nitrogen from wastewater by denitrification is proven and not in the development stage.
- The longevity of the LinPor™ media is proven.
- The phenomenon of simultaneous denitrification in the oxic portion of a LinPor-CN™ IFAS reactor is proven and can be designed for with confidence.
- Modern commercial software (EnviroSim™ BioWin™) for modeling and simulating wastewater treatment processes can be adapted to hybrid processes if realistic adjustments are made to the default values used in the software programs. The software allows for rapid process design calculations.

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LICENSEE

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