

BM Respirometry for energy optimization in the aeration system of activated sludge processes



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Nomenclature

ASP: Activated Sludge Process

OUR: Maximum Oxygen Uptake Rate values in the global ASP ($\text{mg O}_2/\text{L/h}$)

SOUR: Specific Oxygen Uptake Rate ($\text{mg O}_2/\text{g VSS/h}$) = $\text{OUR} / \text{MLVSS}$

Unfed SOUR: SOUR corresponding to the effluent sludge ($\text{mg O}_2/\text{g VSS/h}$)

Rs: Exogenous respiration rate ($\text{mg O}_2/\text{L/h}$)

DO high: DO high set point in the aeration control (mg/L)

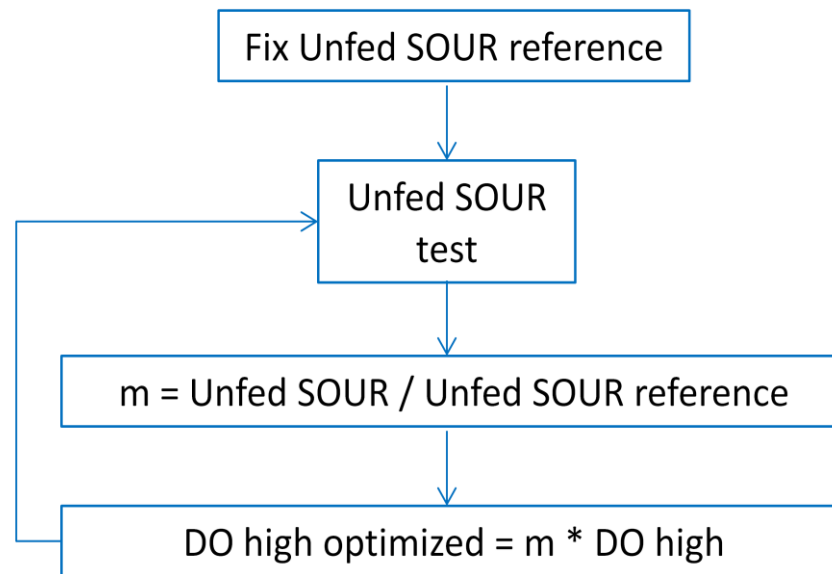
SN: Ammonium-nitrogen concentration to nitrify ($\text{mg N-NH}_4/\text{L}$)

AUR: Nitrification rate ($\text{mg N-NH}_4/\text{L/h}$)

1. Practical procedure to optimize the DO high set-point in the aeration control for the global activated sludge process

This procedure can be applied to any activated sludge process (ASP) where the aeration is controlled by DO set-points and it is based on the optimization of the DO high set point (DO high)

This is a procedure that can be applied to any ASP



1.1. Unfed SOUR reference

The Unfed SOUR reference is fixed according to the type of process and desired Performance that we want to select for it. That is to say, for each selected Performance % it correspond one specific Unfed SOUR reference For that purpose we have to go to some SURCIS table based on bibliography.

ASP Classification	F/M (kgBOD/kg MLSS.d)	SRT (d)	Unfed SOUR (mg/g.h)	Performance vs Unfed SOUR
High Loading	> 0.4	2 - 4	8 - 18	
Medium Loading	$0.2 < F/M < 0.4$	4 - 10	4 - 14	
Low Loading	$0.7 < F/M < 0.2$	10 - 30	2 - 12	
Very Low Loading (Extended Aeration)	> 0.7			

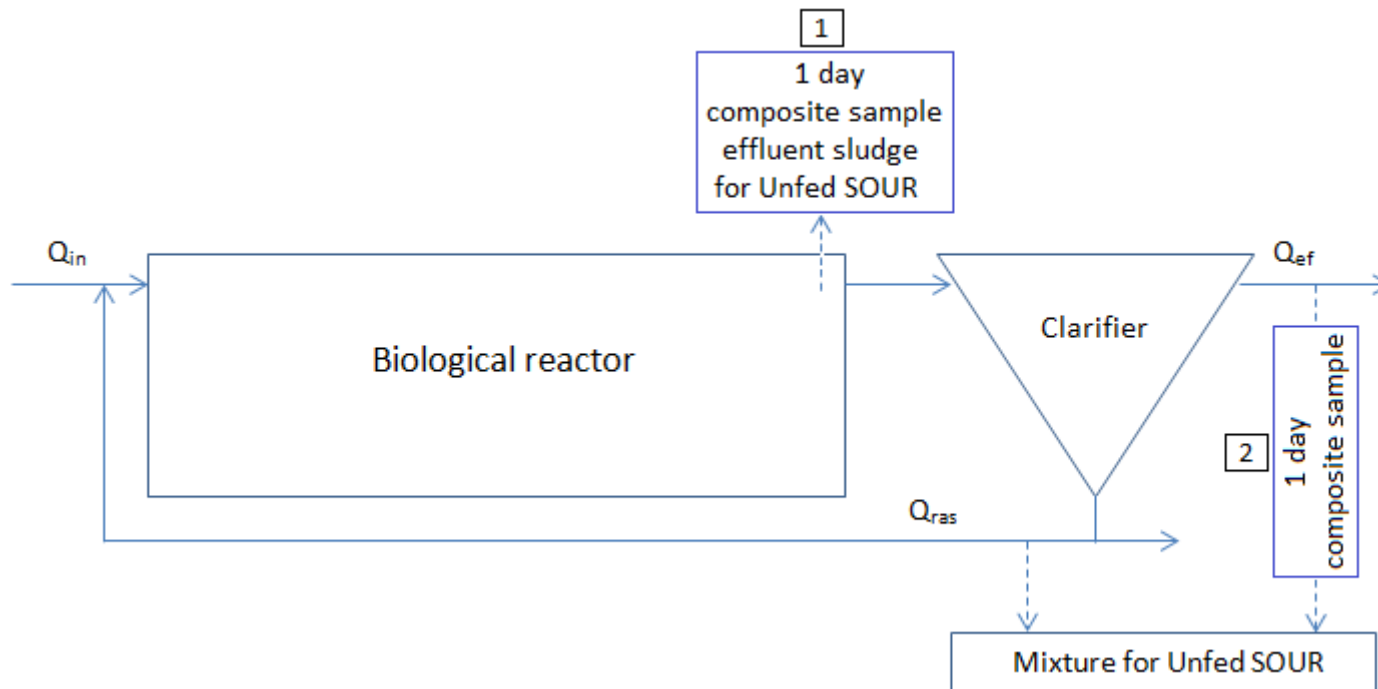
Table to fix de Unfed SOUR reference according to a selected Performance

1.2. Unfed SOUR Test

This is a representative SOUR test of one day composite effluent activated sludge in the biological reactor.

In case that the plant permits to get one liter of one day composite sample of the effluent sludge we can do it with that sludge sample. If not, we can carry out the test with one liter of mixture composed by one day composite sample of effluent (V_{ef}) + returned sludge (V_{ras}) on equivalent volumes to the effluent flow (Q_{ef}) and RAS flow ratio (Q_{ras})

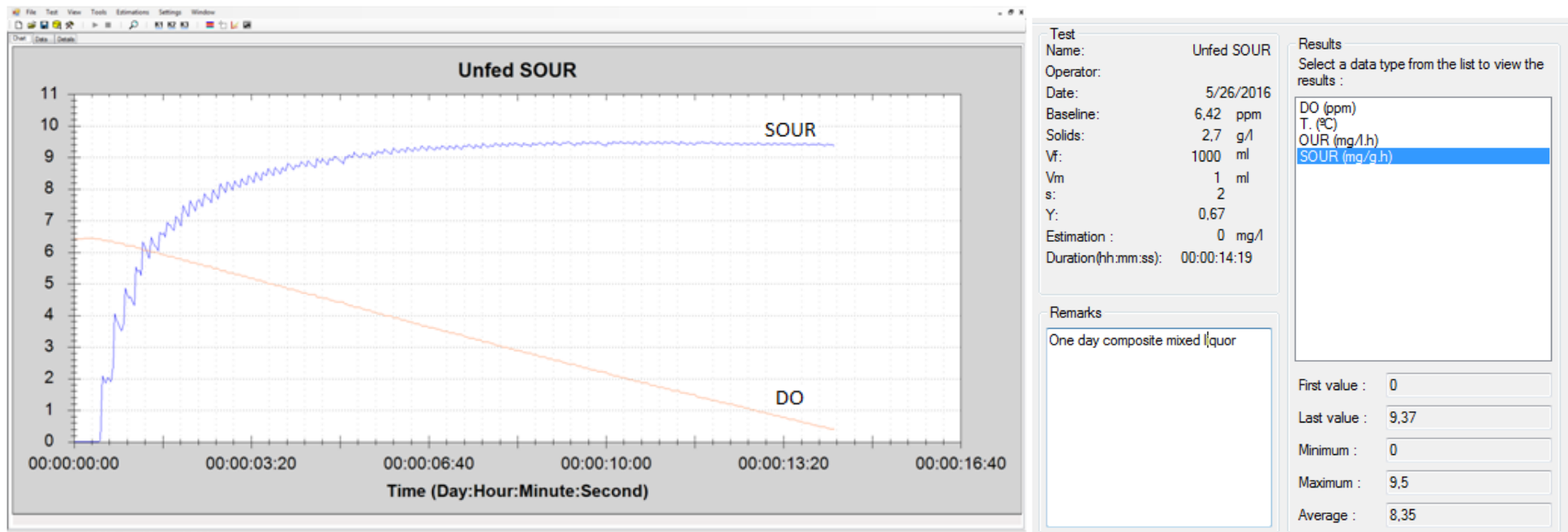
$$\frac{Q_{ef}}{Q_{ras}} = \frac{V_{ef}}{V_{ras}}$$
$$V_{ef} + V_{ras} = 1000 \text{ mL}$$



Two ways of getting the sample for the Unfed SOUR test

1.2.1. Unfed SOUR test performance in a BM respirometer

If the one day composite sample is coming from the effluent sludge, it can go directly to the respirometer. In case we have to prepare the one litre mixture from one day composite effluent water and returned sludge, then the returned sludge should be continuously aerated during 30 minutes before making the mixture.



Unfed SOUR & DO respirogram in BM respirometer

Results

1.3. Unfed SOUR / Unfed SOUR reference ratio

$$m = \text{Unfed SOUR} / \text{Unfed SOUR reference}$$

1.4. DO high set point optimization

DO high optimized = $m * \text{DO high (actual)}$

1.5. Example

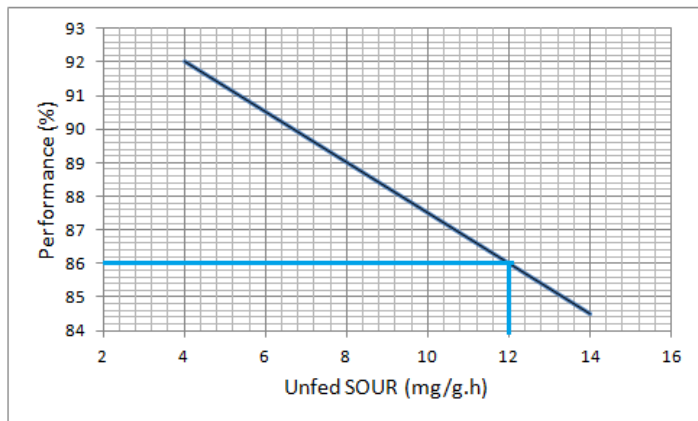
ASP Type = Medium loading

Desired Performance = 86%

Unfed SOUR reference = 12

Actual Unfed SOUR = 9.37

Actual DO high = 1.7 mg/L



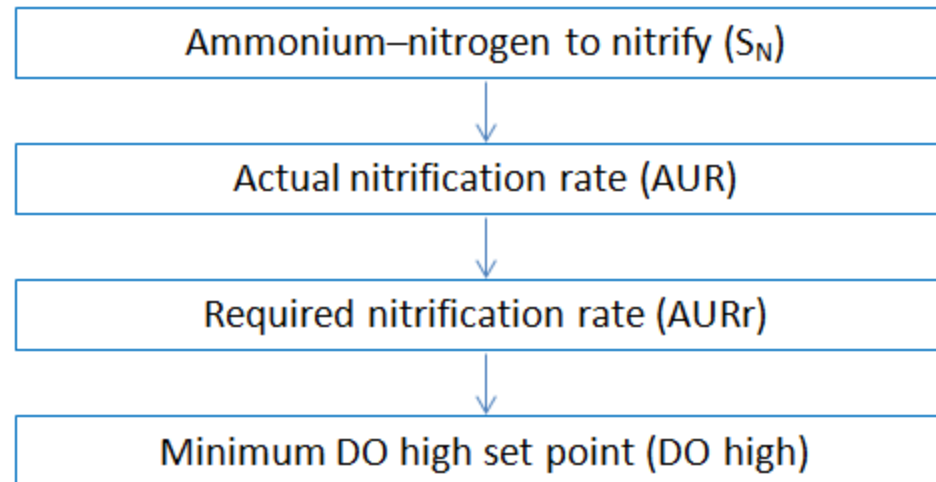
$$m = 9.37 / 12 = 0.78$$

$$\text{DO high optimized} = 0.78 * 1.7 = 1.3 \text{ mg/L}$$

The new DO high optimized is about 20% less than the one it was for a performance of 86%. Although this is not a lineal mathematic correlation, this could represent a significant energy-saving.

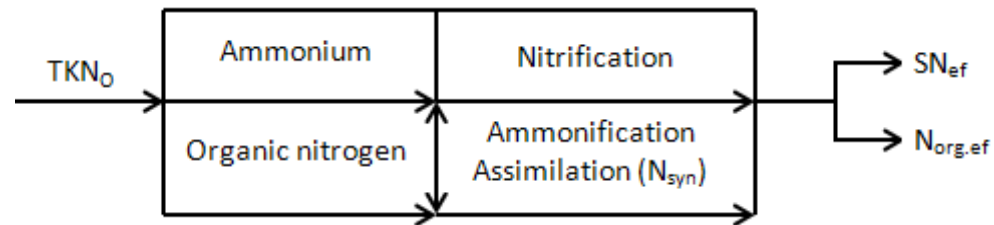
2. Procedure to optimize the minimum DO high set-point in the aeration control for nitrification

The goal in this procedure is to get the minimum DO high set-point (DO high) in the DO control system for a specific ammonium-nitrogen that we want to achieve in the final effluent.



2.1. Ammonium-nitrogen to nitrify

Because of the ammonification process, where part of the organic nitrogen is going into ammonium form, the effective ammonium to nitrify can be calculated as follows:



TKN flow diagram in a process with nitrification

$$SN = TKN_0 - SN_{ref} - N_{org,ef}$$

SN: Ammonium-nitrogen to nitrify (mg NH₄-N/L)

TKN₀: Total Kjeldahl Nitrogen in the influent to biological reactor (mg N/L)

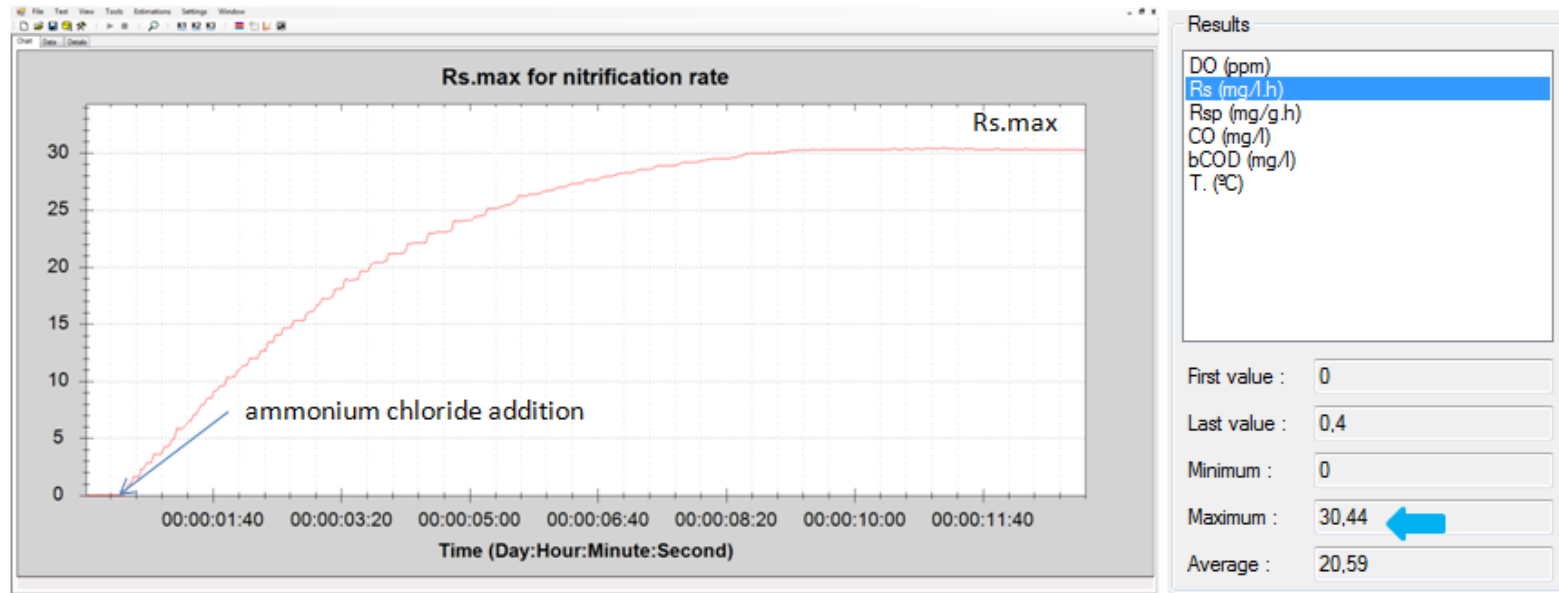
SN_{ref}: Required Ammonium-nitrogen in the effluent (mg NH₄-N/L)

N_{org,ef}: Soluble organic nitrogen in effluent (mg N_{org}/L)

2.2. Nitrification rate (AUR)

We are getting the actual nitrification rate through a R test by making use of an equivalent (*) dose of ammonium chloride in endogenous sludge, until reaching the maximum exogenous respiration rate (Rs.max)

(*) 1 mg/l of ammonium chloride = 0.26 ammonium-nitrogen



Rs respirogram in the R test of the BM respirometer

Rs results

$$AUR = (R_{S_{max}} / 4.57) * DO / (K_{OA} + DO)$$

AUR: Nitrification rate (mg NH₄-N/L/h)

Rs.max: Maximum exogenous respiration rate due to nitrification (mg/L/h)

4.57: mg of O₂ for each mg of NH₄- to be oxidized

K_{OA}: Half saturation constant = 0.5 (mg/L)

DO: Daily average of dissolved oxygen on which the process is currently operating (mg/L)

2.3. Required nitrification rate (AURr)

We can assume that the current nitrification performance is a direct consequence of the actual AUR and therefore, to meet any other performance, the first parameter we want to calculate is the required AUR (AURr) that the process would need.

Under that purpose, assuming the nitrification performance is linked to the difference between the influent TKN and effluent ammonium nitrogen, the required AUR could be estimated as follows:

$$\text{AURr} = \text{AUR} (\text{TKN}_o - \text{SN}_{\text{ref}}) / (\text{TKN}_o - \text{SN}_{\text{ef}})$$

AUR_r: Required AUR (mg NH₄-N/L/h)

AUR: Actual AUR (mg NH₄-N/L/h)

SN_{ref}: Required ammonium-nitrogen in the effluent (mg NH₄-N/L)

SN_{ef}: Actual Ammonium-nitrogen in the effluent (mg NH₄-N/L)

To achieve the AURr represents the first goal where control actions should be conducted

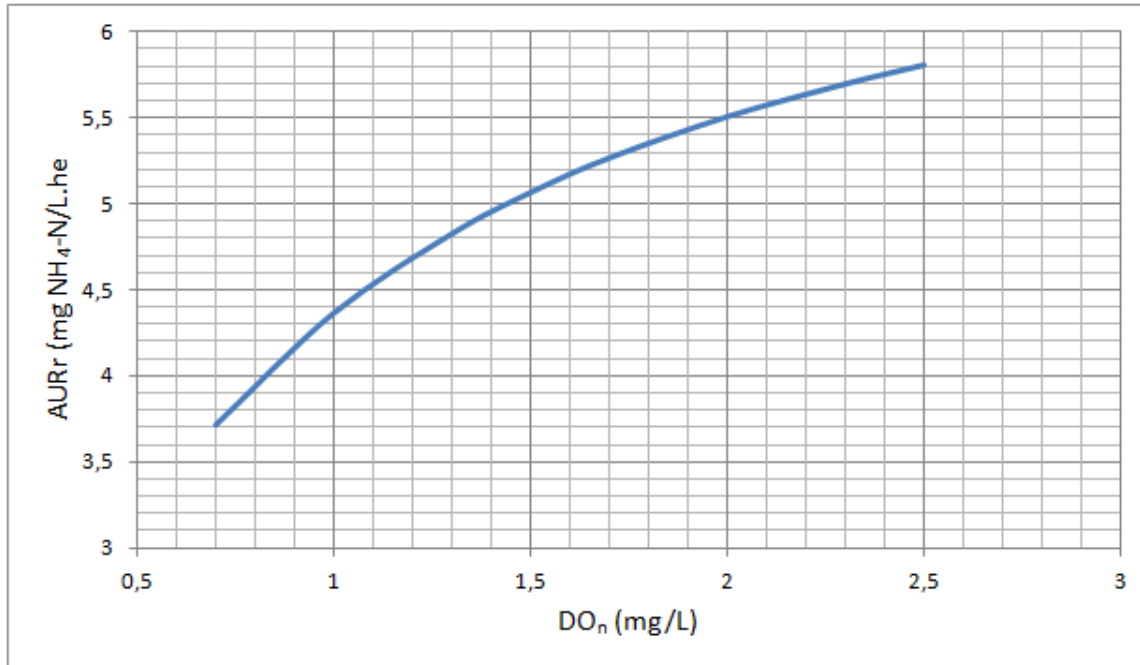
2.3.1. AURr vs different DO values

$$\text{AURr} = (\text{R}_{\text{smax}} / 4.57) * \text{DO}_n / (\text{K}_{\text{OA}} + \text{DO}_n)$$

DO_n: Any DO value that could be in the process (mg/L)

2.4. Minimum DO high set-point (DO high) calculation

The strategy here is to get a set of DO_n coherent values on which the process could operate, in order to figure out the corresponding AURr



AURr vs DO_n plot

Then, once we have got the DO_n value that fits the AURr, we can fix it in the real process as OD high set-point to make its effect after giving a coherent time to grow its nitrification activity.

The main advantage of this procedure is that making use of it we open the door to the ability of selecting the minimum DO for a sufficient nitrification performance and, in this way, go for the maximum possible energy saving in the aeration system of the biological reactor.

2.5. Example

Current daily average data in the ASP

$R_{s,max} = 30$

Current DO = 2.3

$SN_{r,ef} = 3 \text{ mg NH}_4\text{-N/L}$

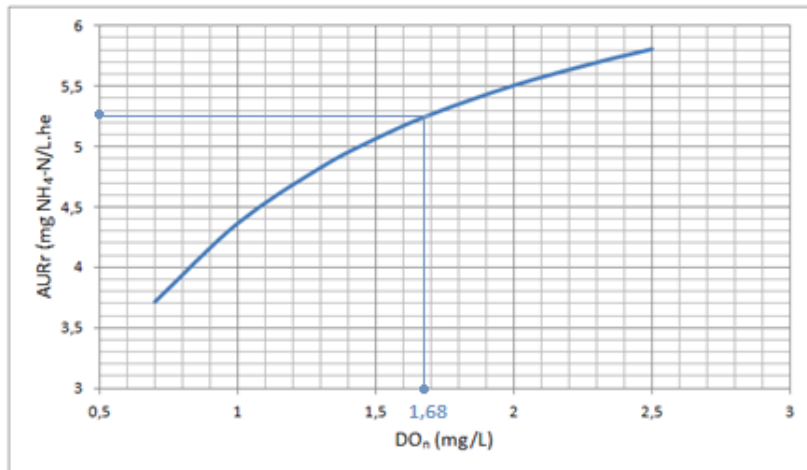
$SN_{ef} = 2 \text{ mg NH}_4\text{-N/L}$

$TKN_o = 42 \text{ mg/L}$

$$AUR = (R_{s,max} / 4.57) * DO / (K_{OA} + DO) = (30 / 4.57) * 2.3 / (0.5 + 2.3) = 5.39 \text{ mgN-NH}_4\text{/L/h}$$

$$AURr = AUR (TKN_o - SN_{r,ef}) / (TKN_o - SN_{ef}) = 5.39 (42 - 3) / (42 - 2) = 5.25 \text{ mgN-NH}_4\text{/L/h}$$

$$AURr = (R_{s,max} / 4.57) * DO_n / (K_{OA} + DO_n) = (30 / 4.57) * DO_n / (0.5 + DO_n) \rightarrow \text{for } DO_n = 0.7 \rightarrow 2.5$$



Minimum DO high set-point determination from the AURr vs DO_n plot

Minimum DO high set-point to achieve 4 mg/L ammonium-nitrogen in effluent: DO high = 1.68 \approx 1.7 mg/L

DO set-point reduction = $1 - 1.7 / 2.3 \approx 40 \%$

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