Chapter 48
Monitoring of Performance of Deammonification Process in Treating Wastewater in a Pilot Study, KTH, Sweden

M. T. Ur Rahman, U. R. Siddiqi, Md. A. Habib, and Md Rasheduzzaman

Abstract Due to the escalating demand of the sustainable biological nitrogen removal processes nowadays, deammonification has been investigated by several research groups in many developed countries. Since 2001, deammonification involving less energy and chemical demand has been studied in a laboratory scale pilot plant consisting of two reactors filled with Kaldnes rings as the carrier for biofilm development at the Royal Institute of Technology, Stockholm, Sweden. Based on the models developed for the collected data of this pilot plant, this article is concerned with the evaluation of the deammonification process using Multivariate Data Analysis (MVDA) software package SIMCA-P. Mainly four years' operational data including all physical, analytical, and derived parameters have been evaluated with MVDA in developing six trial models with PCA (principle component analysis) and then with PLS (partial least squares with latent structures). Interpretation of the output of these models would suggest the researchers to consider influencing operational parameters, which have the strongest positive or inverse relationships with other variables. However, overall efficiency of the pilot plant has been proved as the important assessing parameter while evaluating the performance of the deammonification process. Conductivity measured in reactor two, on the other hand, has been identified as the most important monitoring parameter during operational time period.

Keywords Efficiency · Multivariate Data Analysis (MVDA) · PCA · PLS

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48.1 Introduction

Nitrogen removal is the main feature of wastewater management often carried out by microbial progression including nitrification and denitrification (Jetten et al. 1997; Rahman 2006). In recent times, a novel microbial procedure for nitrogen elimination was studied in a fluidized bed reactor in Delft (The Netherlands) (Mulder 2003). The treatment of nitrogen-rich water can be taken place fruitfully by an amalgamation of the Sharon and Anammox processes (Tsushima et al. 2007). In this joint process, more than 50% of the aeration energy is saved, no COD is needed, and the least amount of sludge is produced. This newer development could lessen the release of the greenhouse gas CO_2 during wastewater treatment by 88% while lowering the running cost of current treatment systems by 90% (Plaza 2003; Hulle 2005) compared to conventional methods.

In the Land and Water Resources Eng. Department of Royal Institute of Technology (KTH), pilot plant-scale experiments have been carried out to study the Anammox for nitrogen removal from wastewater since 2001 (Plaza 2003; Gut et al. 2007; Rahman 2006). Collected data of different physical and chemical operating parameters for the successive years have been utilized as the input in the Multivariate Data Analysis software with a view to obtaining a model to evaluate the performance of this Anammox conducting at the laboratory-scale pilot plant (Hulle 2005).

Amaralab et al. (2005) conducted a research related with activated sludge monitoring of a wastewater treatment plant using image analysis and partial least squares regression. They utilized PLS (partial least squares) multivariate statistical technique to treat the morphological data of the operating parameters (ex. TSS and SVI) of the biomass attending in the wastewater treatment plant.

Recently, the research group (Gut et al. 2007) of Water management of Land and Water Resources Dept. at KTH, Stockholm, Sweden, has applied the multivariate data analysis to make an assessment of a two-step partial nitration/anammox system. Both PCA and PLS have been utilized to obtain relationships between different controlling variables. Their findings show that nitrite to ammonium ratio (NAR) appears to be the key factor in the process control and monitoring. They have concluded that multivariate data analysis provides a powerful tool in assessing the partial nitration/anammox system.

The key target of this study is to evaluate the nitrogen removal system with partial nitration/anammox process investigated at the laboratory-scale pilot plant with application of Multivariate Data Analysis.

48.2 Material and Methods

48.2.1 Pilot Plant Description

In 2001, researchers of water engineering and resource management group of Land and Water Resources Engineering department at Royal Institute of Technology, Stockholm, Sweden set up a laboratory-scale pilot plant (Fig. 48.1) in order to investigate the nitrogen removal from wastewaters containing high nitrogen load and low biodegradable organic matter. The target of this experimental study is to investigate the nitrogen conversion pathways (deammonification method) and to assess the controlling factors having a role on the newly invented microorganisms' growth rate. Another important goal of this pilot plant is to apply the upshot of these experimental reactions for the treatment of the extremely ammonium-rich wastewaters such as leachate and supernatants from dewatered sludge in a larger scale. The pilot plant has two reactors filled with Kaldnes rings (Fig. 48.2) using as a carrier component for the biomass development in a fixed film. Table 48.1 present the characteristics of the pilot plant.

Mechanical stirrers are furnished in the reactors to provide proper oxygen supply and to discourage sedimentation process. Two heaters with thermostats in two reactors are installed to maintain the temperature at a constant level considering the seasonal variation and the indoor heating system of the plant room. The inlet tank of the pilot plant is continuously filled with diluted and dewatered supernatant collected from the industrial scale waste water treatment plant (WWTP) situated at Bromma.

Fig. 48.1 Laboratory-scale pilot plant (*Source* Plaza et al. 2003)

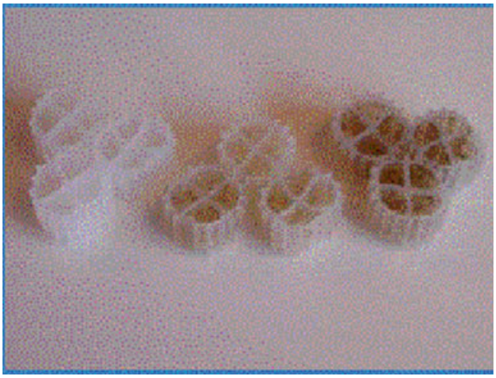

Fig. 48.2 Kaldnes ring used as a carrier

Table 48.1 Design characteristics for the pilot Plant at KTH (after: Plaza et al. 2003)

Item	Magnitude	
	R-1	R-2
Volume (dm^3)	9.81	7.06
Kaldness filling (%)	40	40
Active Volume (m^3)	3.92	2.82
Average Flow (liter per day)	4	4

For supplying sewage from the inlet tank to the first reactor, a peristaltic pump is employed. Gravitational method is used for supplying liquid from the first to the second reactor and then from the second reactor to the outlet tank (Plaza et al. 2003). To adjust the pH of the solution, reactor one has another peristaltic pump for applying Na_2CO_3 (0.5 M) dose time to time. Dewatered supernatant produced in the centrifuge sludge digesting system at Bromma WWTP is supplied to the laboratory-scale pilot plant situated at KTH. The supernatant contains 706.6 mg/L of NH_4-N and 321.7 mg O_2/L of COD on an average.

48.2.2 Measurement of Selected Parameters

Since July, 2001, researchers responsible for the laboratory-scale pilot plant have been conducting the measurement of selected parameters such as pH, temperature and dissolved oxygen. For measuring conductivity and nitrogen compounds (NH_4-N, NO_3-N, and NO_2-N) samples have been collected once per week. ORION (model 210A) is used for pH measurement, while RUSSLEL electrode (model RL425) is employed to take reading of DO. On the other hand, TEACTOR-AQUATEC 5400, ANALYZER is used for measuring nitrogen forms in the specimens.

48.2.3 Collected Data of the Parameters

The database of the laboratory-scale pilot plant consists of almost four years' data starting from July´2001 to July´2005. In this study, 235 days (04-07-2001 to 20-07-2005) out of 4 years are considered for analysis excluding the missing measurements to make a homogeneous data set for all of the parameters. With some missing values, the database is sufficient enough to provide the necessary information for analysis in the multivariate data analysis package software. Using Microsoft Office Excel program and applying the regression equations as algorithms, abundant data set for the parameters like NH_4-N, NO_2-N, NO_2-N/NH_4-N are computed.

48.2.4 Modelling Software

Umetrics AB- Software like MODDE suitable for design of experimental and optimisation purpose and SIMCA for multivariate data analysis are the cutting edge products of Umetrics AB. MODDE and SIMCA are the windows based software and easy to operate and build models (Pell and Ljunggren 1996).

SIMCAP, the sophisticated "point and click" software for multivariate modeling and analysis, is capable of squeezing the huge data set into a few concrete graphical presentations. This software supports file formats like EXCEL, MATLAB 4.0, LOTUS JCAMP-DX, Image analysis and direct import from databases. Statistical parameters like sampling numbers, variables, minimum, maximum, mean, median, standard deviation, skewness, frequency histogram are used as built in functions in this software for data viewing purposes. Moreover, data sets having missing values up to 50% can be possible to handle with this tool. It is possible to generate new variables with this program. Transformation of variables and quick information about variables are possible to perform in the spreadsheet of the work set. There is an option to include or exclude the variables and observations, when it is required to do that operation. In model developing, PCA (Principal Component Analysis), PLS (Partial Least Squares), PLSDA (Partial Least Squares Discriminant Analysis), automatic fit of class model, Scores, Loadings, Coefficient plots and VIP are considered for analysis. In model validation, cross validation and permutation test are particularly performed.

48.3 Results and Discussion

48.3.1 Trial with PCA

Taking into consideration all available homogeneous data (04-07-2001 to 20-07-2005), trial was designed to get an overview of the whole observation data set by

PCA and then attempts were made to develop further model with PLS to obtain the interconnection between different physical parameters and derived variables (factors and responses). After accomplishing the data pre-treatment including both scaling and transforming, data are handled with PCA to develop PC model. Data are fitted with four principal components (A = 4). Model explained 81.4% (R^2X) and predicted 53.6% (Q^2). Two separated clusters of the observation data (total observation data = 232) are presented clearly in the Fig. 48.3, which need to classify the whole data in two classes such as class-one and class-two, and this two classes are plotted successfully with the help of Cooman's plot (Fig. 48.4). Strong outliers are eliminated from the data set to increase the predictive capability of the model. Distribution of observations of the influent ammonium nitrogen concentration (NH4-Nin-R1) is plotted as the score scatter plot (Fig. 48.5). Most of the concentrated data are skewed in the North-West direction. Then, score scatter plot showing distribution of observations of the overall efficiency (OA Effic.) of the pilot plant were plotted to get an idea of the distribution of the efficiency data for the selected experimental period. Temperature and oxygen in reactor two were discarded from the final model, as they were identified as insignificant. The score scatter plot (Fig. 48.6) of overall efficiency shows that most of the data are in the higher efficiency range (60–90%). It means that the efficiency of the pilot plant in removing the nitrogen is satisfactory enough.

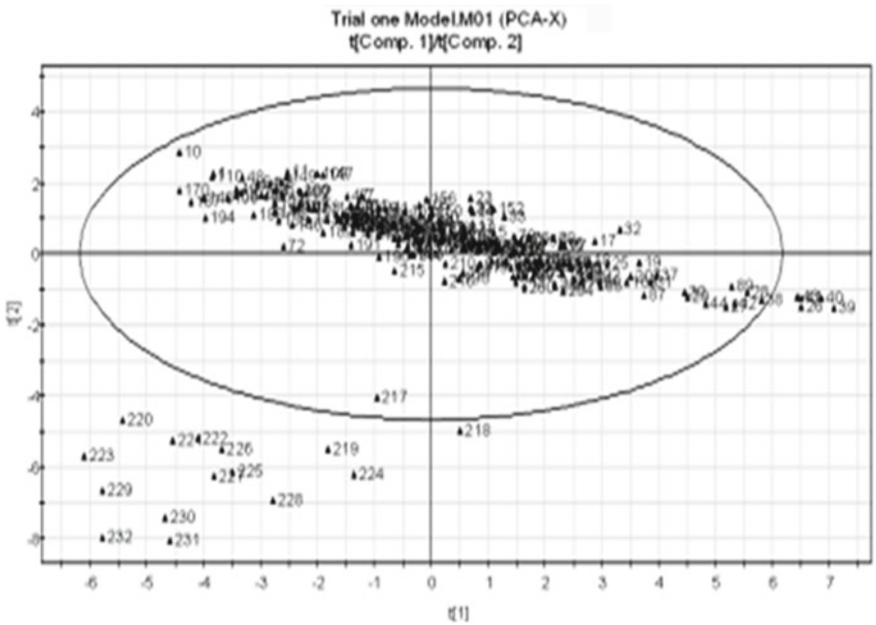

Fig. 48.3 Score plot of the data set by PCA

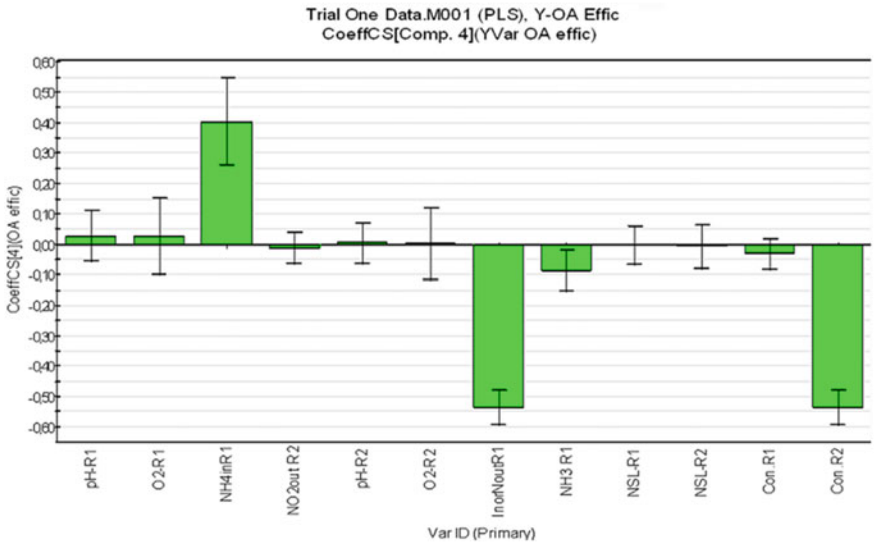

Fig. 48.4 Coefficient plot for OA efficiency

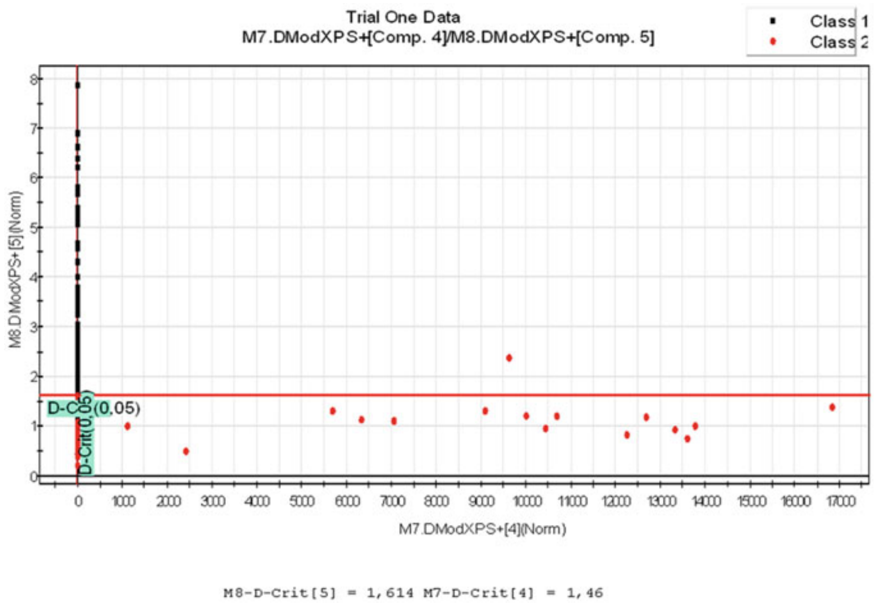

Fig. 48.5 Score scatter plot showing distribution of observations of the Over All Efficiency (OA Effic.) of the pilot plant

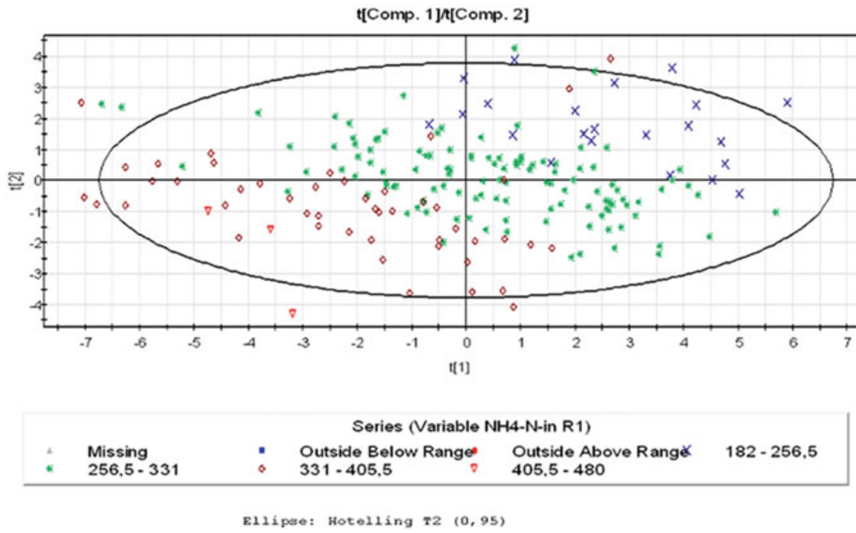

Fig. 48.6 Score scatter plot showing distribution of observations of the influent ammonium nitrogen concentration (NH4-Nin R1)

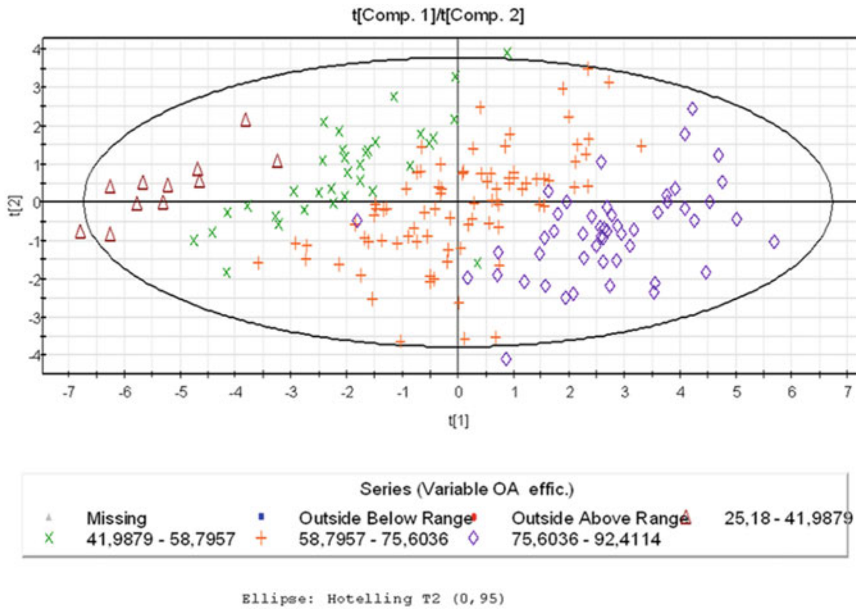

Fig. 48.7 Loading Scatter plot of the selected variables for the Trial one

Loading plot (Fig. 48.7) presents that conductivity has the strongest relationship with influent nitrogen concentration at R1 and effluent nitrite concentration (NO_2-N-R2), which shows that conductivity could be the important parameter to monitor the process performance. Oxygen in reactor one has a positive influence on both of the influent ammonium (R1) and effluent nitrite concentration (NO_2-N-R2). On the other hand, pH in reactor two might be another important parameter while measuring the performance of the Anammox process. The interesting finding of this figure is that overall efficiency has a strong adverse relationship with pH (both R1 and R2), which means increasing pH (R1 and R2) will ensure decreasing overall efficiency. And so, pH would be an important parameter while measuring the overall efficiency of the plant.

48.4 Trial one with PLS (Y = OA Efficiency)

Taking OA Efficiency as a response variable in the same trial for four PLS components, explained and predicted variables with the model such as R2X-77.5.7%, R2Y-95.8% & Q2-96.3% were found. Loading plot (Fig. 48.8) shows that efficiency of the pilot plant is strong negatively interrelated with inorganic nitrogen from reactor one and conductivity of the reactor two. Moreover, free ammonia in reactor two influences positively the overall efficiency. DO in reactor two also has negative influence on the efficiency. NO_2-N out from R2 has a strong negative influence on efficiency. Nitrite in effluent (R2) is found as the most important indicator showing inverse relationship in getting an idea about efficiency. Conductivity in the effluent (R2) is found as the most valuable monitoring parameter for the computation of the process

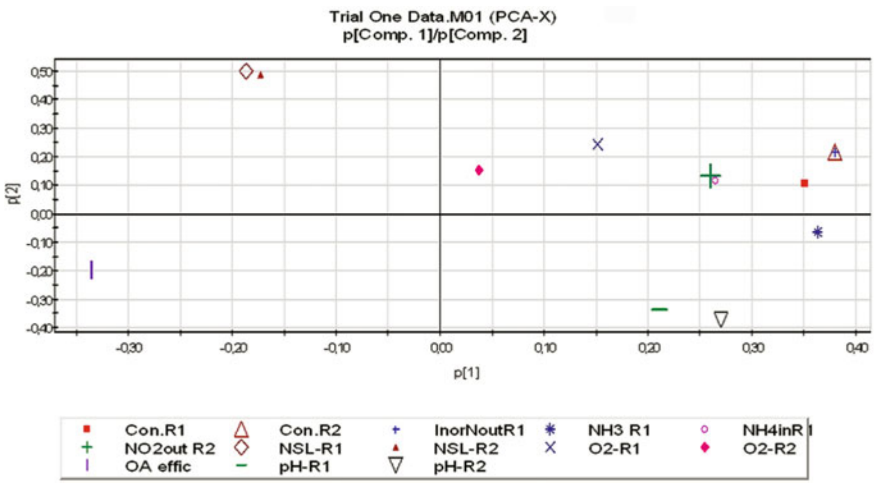

Fig. 48.8 Loading scatter plot for OA efficiency

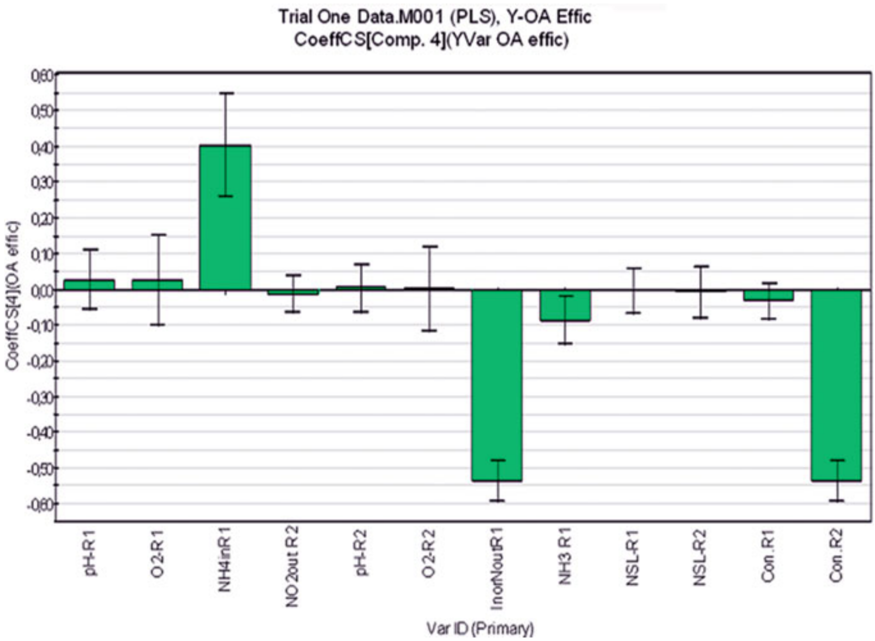

Fig. 48.9 Coefficient plot for OA efficiency

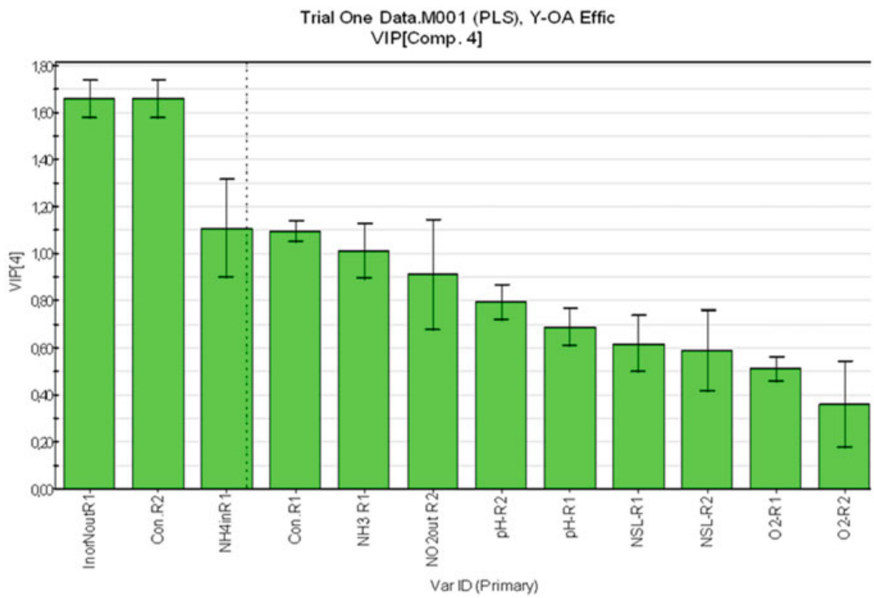

Fig. 48.10 VIP plot for OA efficiency

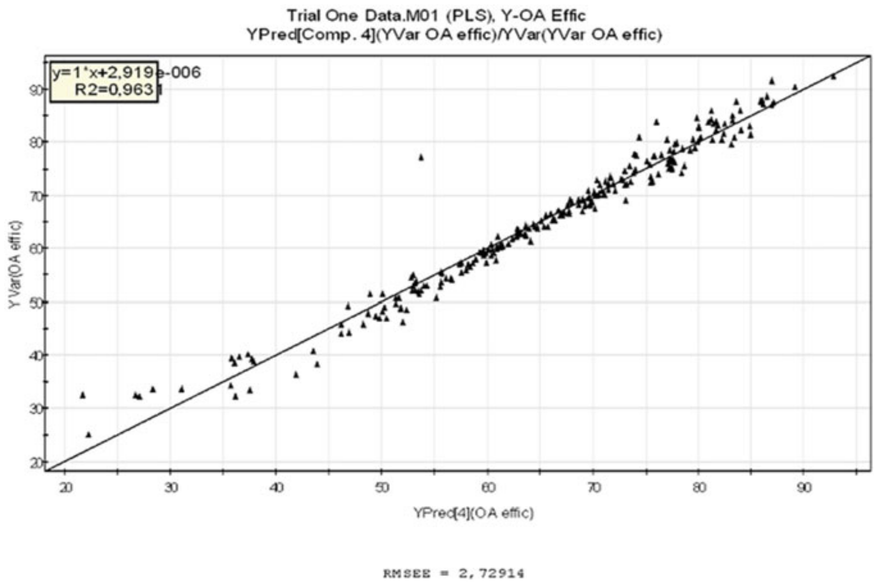

Fig. 48.11 Observed vs Predicted plot for OA efficiency

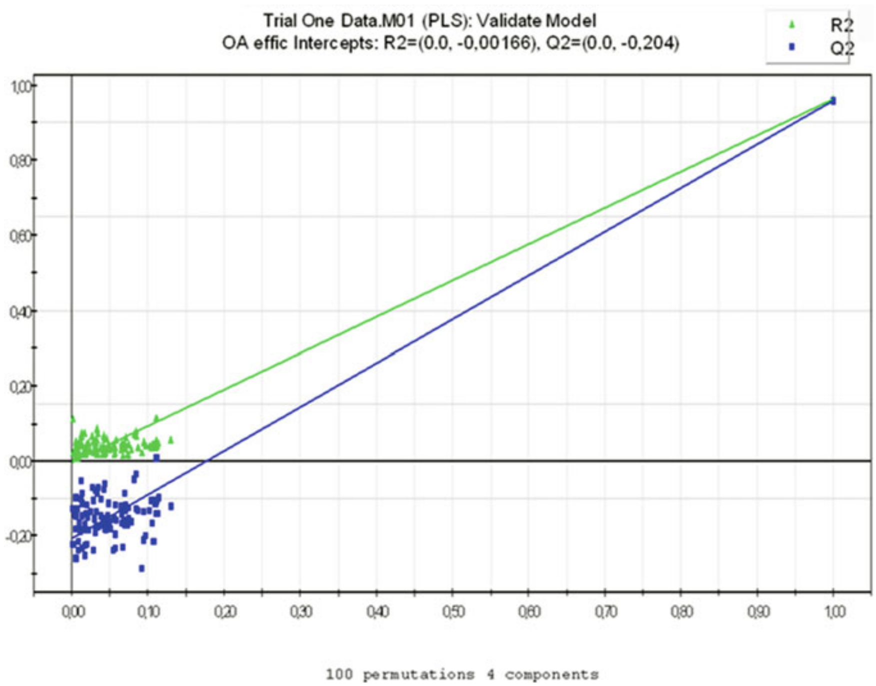

Fig. 48.12 Validation of model with OA efficiency

efficiency. Coefficient plot (Fig. 48.9) and VIP plot (Fig. 48.10) present the influencing variables on efficiency. The regression coefficient (R2) for the observed vs. predicted graph is found as 96%, which shows excellent fitting of the data considered (Fig. 48.11). Figure 48.12 presents that the model is excellently valid according to the model validation perspective.

48.5 Conclusions

Finally, it can be concluded that these six trials were devoted to explain the process performance of the partial nitration/Anammox process of the pilot plant. After critically interpreting the outputs of the six trail models, it can be stated that during the initial stage of the selected time period, partial nitration process was run successfully in the first reactor. Then, partial nitration (in R1) and Anammox process (in R2) have been running separately for the time being. After that, both processes have been occurring simultaneously (in the CANON form) in both of the reactors having a stable condition with a moderately nitrogen removal efficiency. Outcome of all trials harmonized in one idea that overall efficiency was the best parameter considering it as the response variables while assessing the process performance.

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