# USE OF NANOTECHNOLOGIES IN PIG FARMING

***Dolejš J., Toufar O., Knížek J., Adamec T., Kosová M.***

*Institute of Animal Science Prague Uhrineves, Czech Republic*
dolejs.jan@vuzv.cz

## Abstract

A year-long study was conducted to evaluate the use of titanium dioxide ($TiO_2$) in pig farming. Two identical barns, each with a housing capacity of 100 pigs, slotted floors and continuous flow production were used in the study. The walls and the ceiling of one of the barns were treated with a prime sealer. The surfaces were left to dry and then a coat of paint containing $TiO_2$ nanoparticles was applied. Twenty measurements were taken during the test period to determine levels of ammonia ($NH_3$). Average $NH_3$ emissions (converted to 100 kg live weight) were 5,04 kg in the control group and 3.92 kg in the experimental group, respectively, which corresponds to the reduction in emissions in the latter by 22.3 % ($NH_3$). The multiple linear regression model of the relationship between $NH_3$ emissions and ambient conditions showed the greatest dependence on the weight of animals. This was corroborated by correlation statistics. The closest bond was found between $NH_3$ emissions and the weight of pigs, and it was negative (r -0.7 to -0.9).

**Key Words:** pig finishing, nanotechnologies, $TiO_2$, ammonia, emissions

One of new elements of the modern trend is the use of nanotechnologies in various industries. Certain elements originating in nanotechnologies are also being tested in agriculture. For instance, tests are carried out using titanium dioxide ($TiO_2$) to remove ammonia from livestock buildings. In this method, the property of metal oxides to act as catalysts in chemical processes is utilized. Chemical reactions take place on the surface of oxide molecules. Titanium dioxide is routinely used as a bleaching agent in a number of food products (E 171).

The reaction starts when $TiO_2$ is exposed to sunlight. $TiO_2$ absorbs sunlight and generates two types of carriers, electrons (e-) and holes (h+). As Fujishima et al. (1999) explained, one of important properties of $TiO_2$ is the oxidation capability of the holes, which is stronger than the reduction capability of the excited electrons. This property is utilized in industrial applications for the reduction of emissions of harmful substances into the atmosphere. In advanced research, photocatalytic properties of $TiO_2$ were utilized for sterilization and in hygiene and anti-emission applications (Li et al. (2004)). Photocatalytic oxidation can be used for the decomposition and destruction of many types of both organic and inorganic pollutants in the environment. For instance, Malloy (1999) and Watanabe et al. (1995) mentioned the use of self-cleaning floor tiles for hospitals, toilets and other places where cleanliness is of vital importance. Allen et al. (2005) demonstrated possible uses of compounds containing $TiO_2$ in city agglomerations for the reduction of nitrogen ($NO_x$) produced by vehicles.

## Material and Methods

### Barn description and experimental setup modifications

The animals chosen for the testing of titanium dioxide effects in livestock farming were finishing pigs. Two identical barns each with a housing capacity of 100 pigs and continuous flow production were used A service alley divides each barn into two halves with three pens, i.e. there is a total of 6 pens in each barn. Pigs are housed on slats. Liquid manure from storage under slotted floor is pumped to a storage tank on a weekly basis. Two exhaust fans are situated in a channel in each of the two halves of the barns. The air enters via windows along the length of one side and the door to a corridor that runs lengthwise between not only these two barns, but also a number of other barns in a row (7). Wet feed is used in all of the barns. The two barns selected are used as pig finishing facilities.

### Experimental setup modifications

The walls and the ceiling of the experimental barn were first treated with a layer of a bonding primer. When it had dried, i.e. about a week later, the surfaces were treated with a layer of Detoxy Color paint containing $TiO_2$ nanoparticles. A paint roller was used to apply 14.5 L of the paint (= 1 L per 13.02 $m^2$) on the pre-treated surfaces. During the experiment, the same standard type vacuum tube lighting and the same lighting schedule were used in both barns.

Because the facility was a continuous production operation, the barns housed different numbers of pigs of different weights when individual emission measurements were taken.

### Ammonia emission measurement

Two systems, i.e. Aseko and Innova, were used to measure gas concentrations. The Innova system, which employs the photo-acoustic principle to measure concentrations of a given gas, is used as a reference system in emission measurements. The Aseko system uses electrochemical sensors. The sensors were adjusted using the Innova system. The gas monitored was ammonia ($NH_3$). Sample collection sites with sensors were located near underpressure fans at each of the channels in the barns monitored. Concentrations of the gas monitored were measured continuously at 7 - 10 min intervals. To determine the second component of the emission flow, ambulatory measurements of air flow were taken 4x in 24 h by the Testo 425.

**Illumination level measurements**

Illumination levels were measured continuously at 10 min intervals together with some gas concentration measurements for 24 hours using the Babuc/M system and the BSR 003 probe.

**Measurement conditions**

Effects of the $TiO_2$-containing coating on the walls of the experimental barn were monitored for almost a year (30 July, 2009 – 2 July, 2010). During the year, 20 measurements were made. Both external and transient external temperatures were recorded in that period. Differences in temperature and relative air humidity in the two barns monitored were minimal and unable to influence results of gas emission measurements. Air flow in the two barns ranged from 0.09 to 0.44 $m.s^{-1}$.

**Primary measured concentrations of ammonia monitored and air flow rates**

The data measured in the study included concentrations of the gas monitored and air flow rates, i.e. the data indispensable for the calculation of gas emissions.

**1. Determination of gas production**

Primary data obtained by measuring concentrations of the ammonia monitored and air flow rates in two barns were used to calculate the emission flow ($mg.h^{-1}$), which was then converted to the daily production of the individual gases monitored ($g.pig^{-1}.day^{-1}$). To exclude the effect of different weights of individual pigs in the two barns monitored, the number of pigs and their weight were expressed in kg in each group. In that case, gas production per 100 kg weight of pigs over a period of 1 year ($kg.100kg^{-1}.year^{-1}$) was calculated. Basic statistics were then calculated for each group of pigs (average of all measurements, standard deviation, index compared with the reference group, difference in % and the t-test). Emission measurements were complemented with illumination level measurements.

**2. The multiple linear regression model of the dependence of emissions of ammonia monitored on the ambient and animals**

In this model, emissions of is dependent variable in both the reference and the experimental groups of pigs. The independent variables are a set of ambient parameters (temperature, relative humidity, atmospheric pressure and illumination levels) and the average live weight of pigs at the time when gas emissions were measured. The model is expressed as follows:

$\mathbf{y = b_0 + ax_1 + ax_2 + ax_3 + ax_4 + ax_5}$ ……….. $r^2$ , where

y = emissions of a gas ($NH_3$) in both groups of pigs, as a dependent variable: $kg.pig^{-1}.day^{-1}$

$kg.100kg^{-1}.year^{-1}$

$x_1$ = average weight of pigs at measurement ($kg.pig^{-1}$).

$x_2$ = average daily temperature at measurement (°C),

$x_3$ = average relative air humidity (%),

$x_4$ = atmospheric pressure at measurement (hPa)

$x_5$ = average illumination level (lux)

$r^2$ = coefficient of determination

**3. Dependence of gas concentrations on ambient parameters - correlation statistics**

An analysis of the relationship between the values of emissions of the gas monitored in both groups of pigs and in both conversions, and the parameters of the environment and the pigs during the monitoring period.

***Table 1. Pigs housed in barns in the period of ammonia emission measurements***

| index | unit | group of pigs | |
|---|---|---|---|
| | | reference | experimental |
| average no. of pigs | one pig | 85.3 | 74.5 |
| standard deviation | | 14.25 | 16.64 |
| average weight | $kg.pig^{-1}$ | 55.6 | 71.8 |
| standard deviation | | 17.75 | 14.00 |
| minimum no. of pigs at time of measurement | one pig | 39 | 53 |
| maximum no. of pigs at time of measurement | one pig | 96 | 91 |
| minimum average weight | $kg.pig^{-1}$ | 33.2 | 47.5 |
| maximum average weight | $kg.pig^{-1}$ | 90.0 | 96.4 |

***Table 2. Microclimates in pig barns monitored***

| parameter | groups | | | | air pressure hPa |
|---|---|---|---|---|---|
| | reference | | experimental | | |
| | temperature | relative humidity | temperature | relative humidity | |
| | °C | % | °C | % | |
| daily average | 17.41 | 64.9 | 17.16 | 64.6 | 979.96 |
| standard deviation | 4.764 | 9.642 | 5.067 | 9.436 | 6.918 |
| daily minimum | 8.0 | 50.6 | 8.1 | 49.4 | 966.1 |
| daily maximum | 22.9 | 83.4 | 23.2 | 81.4 | 988.8 |

***Table 3. Input data for the calculation of ammonia emissions and illumination levels***

| parameter | unit | reference | | experimental | |
|---|---|---|---|---|---|
| | | mean | standard deviation | mean | standard deviation |
| air flow rate | $m^3.h^{-1}$ | 1875,8 | 476,2 | 1837,9 | 386,6 |
| gas concentration | | | | | |
| $NH_3$ | $mg.m^{-3}$ | 14,66 | 4,53 | 12,45 | 3,01 |
| illumination level | lx | 133,7 | 64,4 | 153,0 | 99,6 |

## Results and Discussion

### 1. Gas production

**1.1. Gas production per one pig**

In view of the differences in average weights of pigs at the time of emission measurements between the two barns monitored (see tab. 1), the differences in gas production ascertained were not relevant and although neither in the production of the gas monitored was observed in the experimental group. In both barns, a continuous flow system of moving pigs into and out of the facility for slaughter was used. See Tab. 4 for an overview.

**1.2. Ammonia production per 100 kg live weight of pigs per year**

Because weight of individual pigs in the barns was different, the numbers of pigs in each of the barns were expressed in pig units of 100 kg live weight as a common denominator for the purpose of gas emission calculations. In this case, differences in gas emissions were obvious and statistically significant. $NH_3$ emissions dropped by 21.3 % ($P < 0.001$). See Tab. 5 for an overview. For a comparison with the farrowing facility, the walls and the ceiling of which were treated with a paint containing $TiO_2$ nanoparticles. Sows were moved in 3 – 5 days prior to farrowing and moved out 21 days post farrowing, including about 10 piglets per sow, ammonia emissions were reduced by 30.4 % and nitrogen monoxide emissions by 3.9 % (Guarino et al. (2007)).

### 2. The linear regression model of the dependence of emissions of gas monitored on the ambient and animals

**2.1. Conversion per pig**

The multiple linear dependence model, where monitored ammonia emissions was the dependent variable and parameters of the environment and animals the independent variables, showed a relatively high degree of dependence ($r^2 > 0.82$). The calculated model equations are suitable for $NH_3$ emission predictions ($F < 0.05$). The statistical significance of live weight linear coefficients of the pigs ($x_1$) was very high in both groups of pigs ($P < 0.001$) for $NH_3$ emissions. In the $NH_3$ emissions model of the reference group, the atmospheric pressure $x_4$ was also important ($P < 0.05$). Effects of the other variables were not statistically significant.

**2.2. Conversion to 100 kg live weight of pigs**

It describes the dependence model for $NH_3$ emissions. The coefficients of determination ($r^2$) of the reference and the experimental groups were even higher than 0.98 and 0.89, respectively. The calculated equations are suitable for the predictions of $NH_3$ emission ($F < 0.001$) in the reference and ($F < 0.01$) in the experimental groups of pigs. As in the per one pig conversion, weight of the animals ($x_1$) plays an important role ($P < 0.001$) but has a contrary effect on emission levels, i.e. when this conversion is made, young animals produce the largest amounts of $NH_3$. In the reference group, relative air humidity ($x_3$) and atmospheric pressure ($x_4$) were also statistically significant ($P < 0.05$ and $P > 0.01$, respectively). In addition to the already-mentioned animal weight ($x_1$), parameters that also played a role in the experimental group were air temperature ($x_2$, $P < 0.05$ ) and illumination levels ($x_5$, $P < 0.05$). These relationships are presented in Tab. 6.

**3. Dependence of ammonia concentrations on ambient parameters and animals- correlation**

**3.1. Emissions per one pig**

By far the highest correlation was found between $NH_3$ emissions and animal weight. The correlation between these elements (with the exception of $NH_3$ in the experimental group) showed a very close relationship.

A relatively close relationship was also found in $NH_3$ emissions in the experimental group (r = 0.81). Only a loose relationship was found between other ambient parameters and emission of the gas monitored.

**3.2. Conversion of emissions per 100 kg weight**

The closest relationship between gas emissions calculated per 100 kg of pig weight and the weight of the pigs was found in $NH_3$: the relationship was very close (r = -0.97) in the reference group and close (r = -0.76) in the experimental group. The relationships are summarized in Table 7.

***Table 4. Ammonia production per one pig per year ($g.pig^{-1}.day^{-1}$)***

| n | groups | | | | index | Δ (%) |
|---|---|---|---|---|---|---|
| | reference | | experimental | | | |
| | mean | standard de-viation | mean | standard de-viation | | |
| 20 | 7.540 | 0.943 | 7.540 | 1.394 | 1,000 | 0,0 |

***Table 5. Ammonia production per 100 kg of pig weight per year ($kg.100^{-1}.year^{-1}$)***

| n | groups | | | | index | Δ (%) | statistical significance P < |
|---|---|---|---|---|---|---|---|
| | reference | | experimental | | | | |
| | mean | standard deviation | mean | standard deviation | | | |
| 20 | 5.037 | 1.104 | 3.916 | 0.570 | 0.777 | -22.3 | 0.001 |

***Table 6. The linear model of the dependence of emissions of ammonia monitored on ambient conditions and animals***

| | group | independent variable | | | | | $b_0$ | $r^2$ | F |
|---|---|---|---|---|---|---|---|---|---|
| | | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | | | |
| **per one pig conversion** | | | | | | | | | |
| **$NH_3$** | **ref.** | $0.041^{***}$ | -0.030 | -0.032 | $-0.066^{*}$ | 0.001 | 73.04 | 0.873 | 0.05 |
| | **exp.** | 0.015 | 0.154 | 0.003 | 0.036 | -0.008 | -30.78 | 0.840 | 0.05 |
| **per 100 kg weight conversion** | | | | | | | | | |
| **$NH_3$** | **ref.** | $-0.055^{***}$ | -0.008 | $-0.044^{*}$ | $-0.036^{**}$ | -0.001 | 47.01 | 0.981 | 0,001 |
| | **exp.** | $-0.051^{***}$ | $-0.089^{*}$ | -0.003 | 0.019 | $-0.006^{*}$ | -12.58 | 0.892 | 0,01 |

$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$, NS = statistically not significant

***Table 7. Correlation dependence between $NH_3$ emissions and ambient parameters***

| **group** | **ambient parameters** | | | | |
|---|---|---|---|---|---|
| | **pig weight** | **temp.** | **relative humidity** | **air pressure** | **illumination level** |
| | **$kg.pig^{-1}$** | **°C** | **%** | **hPa** | **lux** |
| $g.pig^{-1}.day^{-1}$ | | | | | |
| reference | 0.848 | -0.283 | 0.197 | -0.344 | -0.149 |
| experimental | 0.604 | 0.811 | -0.612 | 0.417 | 0.252 |
| $kg.100kg^{-1}.year^{-1}$ | | | | | |
| reference | -0.970 | 0.262 | -0.263 | -0.037 | 0.173 |
| experimental | -0.761 | -0.110 | 0.150 | 0.137 | -0.256 |

## Conclusion

A year-long monitoring of the effects of $TiO_2$ nanoparticles demonstrated the functionality of this approach to the reduction of ammonia concentrations. Ammonia emissions were reduced on average by 22.3 % , ($P< 0.001$). It is not yet quite clear, how long the $TiO_2$ coating will retain its functionality on the wall plastering. Monitoring of the nanopartlicle coating will continue and, moreover, light of different wavelengths will be used for its illumination with the objective to improve the efficiency of ammonia and greenhouse gases elimination.

## References


Allen,N.S., Edge,M., Sandoval,G., Verran,J., Stratton,J., Maltby,J. (2005): Photo catalytic coatings for environmental applications. Photochem.Photobiol. 81 (2):279-290

Fujishima,A., Hashimoto,K., Watanabe,T.(1999): $TiO_2$ photo catalysis: fundamentals and applications. BKC,Inc., Tokyo.

Guriano,M., Costa, A., Porro,M.(2007): Photocatalitic $TiO_2$ coating to reduce ammonia and greenhouse gases concentration and emission from animal husbandries. Bioresour.Technol.,(2007),doi:10.1016/ j.biortech.2007.04.025.

Li,F.B., Li,X.Z., Ao, C.H., Hou, M.F., Lee, S.C.(2004): Photo catalytic conversion of NO using $TiO_2$ – $NH_3$ catalysts in ambient air environment. Appl. Catal. B: Environ.54:275-283.

Malloy,H.(1999): Environmentally friendly ceramic tile. Ceram.Ind.149. (10):37-42.

Watanabe,T., Kojima,E., Norimoto,K, Saeki,Y.(1995): Fabrication of $TiO_2$ photo catalytic tile and practical applications. Fourth Euro Ceramics, 11:175-180.


This paper is based on results of the research project NAZV QH 921 95.
Financial assistance of the Czech Ministry of Agriculture is gratefully acknowledged.