NITROGEN REDUCTION IN LIVESTOCK SLURRY THROUGH AMMONIA AIR STRIPPING AT HIGH TEMPERATURE

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1 INTRODUCTION

Air stripping in combination with absorption, can be used to remove and recover ammonia from animal slurry. The efficiency of the process is dependent on pH and temperature. Some previous studies on ammonia air stripping at ambient temperature and high pH have shown a number of drawbacks that limit the applicability of the technique (Cheung 1997 and Liao et al. 1995). In this study, an ammonia air stripping process at high temperature without chemically increasing pH was studied in a pilot plant. The combination of the technique with anaerobic digestion and energy production was also assessed. The activities were carried out to establish the feasibility of the removal of nitrogen from pig and cattle slurry by stripping, without changing the slurry pH.

2 MATERIALS AND METHODS

An experimental study was conducted to verify the effectiveness of the operation of an air stripper pilot plant, consisting of the following functional elements (Figure 1):

- airtight ammonia stripping reactor of 1 m3, made of insulated stainless steel, diameter of 900 mm and height of 2100 mm, including a slurry mixing system and insufflation system to force air bubbles into the stripping process, with a free head space for handling foam;
- acid washing scrubber counterflow of air outflowing from the stripping reactor in polypropylene cylindrical tower for a maximum capacity of 100 m3/h and crossing speed of 0.14 m/s, with a tank for storing ammonium sulphate salt. At the beginning of the tests the scrubber's tank for the storage of the acid solution was filled with about 185 dm3 of a 20% sulphuric acid (H_2SO_4) solution;
- hot water generator (replaceable by a co-generator in full scale);
- monitoring device to measure ammonia emission, temperature of air and slurry and flowmeter.

In addition to working at high temperatures, the slurry was air-blown and mixed to facilitate the ammonia removal process. During the planning stage it was envisaged that this combination of physical treatments might give rise to the formation of large quantities of foam in the reactor head space. A slurry mixing system was designed to reduce this problem, which also acts as a foam reducer. This mixing system takes the slurry from the bottom of the reactor and sprays it into the head space against a series of disks which have the effect of breaking the jets and creating a rain of slurry falling on the foam.

All tests were carried out with a fully self-contained air circulation system: the entire flow of air coming from the stripping reactor is sent to the scrubber first and the air outflowing from there is sucked up by the pump and then blown back into the reactor. The absence of atmospheric emissions and/or airflow collection from the environment, significantly cuts-down atmospheric emissions of possible organic malodorous compounds that are not captured by the scrubber.

The study was performed at a pig farm and a dairy farm in Parma (Italy) over two years. Seven treatments were carried out (three replications of each, amounting to a total of 21 experiments). The following slurries were treated: the liquid fraction of fresh swine slurry obtained from a solid-liquid separation carried out with a helical compressor (3 treatments; 50,60 and 70°C); the clarified fraction of fresh cattle slurry (1 treatments), obtained from a solid-liquid separation treatment with opposed straight rollers, and the same clarified fraction of cattle slurry downstream of anaerobic digestion (3 treatments). Three repeated experiments were conducted for each series of test. The duration of each test was 6 hours of consecutive insufflation under steady-state temperature of 60°C.

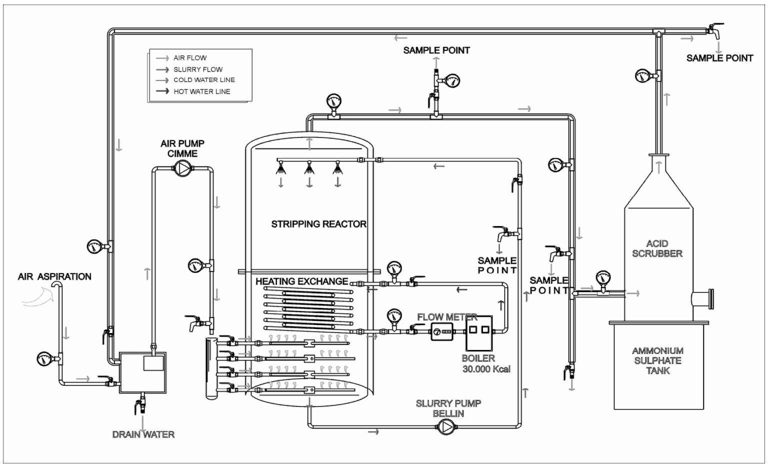

FIGURE 1 **Layout of experimental stripping pilot plant.**

The main parameters monitored during each test were the following:

- chemical characteristics of slurry (pH, NH4+-N, TS and TKN: analysed by standard methods APHA, 1995): at the beginning and at the end of the test and every hour of operation
- air temperature at 8 points of the plant and pressure upstream and downstream of the stripping reactor
- ammonia nitrogen concentration in the airflow used for stripping, upstream and downstream of the stripper and downstream and upstream of the scrubber
- nitrogen concentration and volume of ammonium sulphate solution present in the scrubber tank
- electrical consumption and heat consumption

3 RESULTS AND DISCUSSION

3.1 Stripping from fresh pig slurry at different temperature

On average, after about 6 hours of hydraulic retention time, the removal efficiency was 13% (St. Dev. 1%) for the 50° test, 27% in the 60° test (St. Dev. 3%) and 40% in the 70° test (St.Dev. 13%). The relation between temperature and the percentage of ammonia nitrogen stripped per hour, reveals that efficiency increases as the slurry mass temperature rises. If removal efficiency as a function of temperature is related to energy consumption, the best ratio of energy costs/benefits is achieved by keeping the process temperature at 60°C. Nonetheless, whenever surplus energy is sufficient, the process could still be carried out at temperatures higher than 60°.

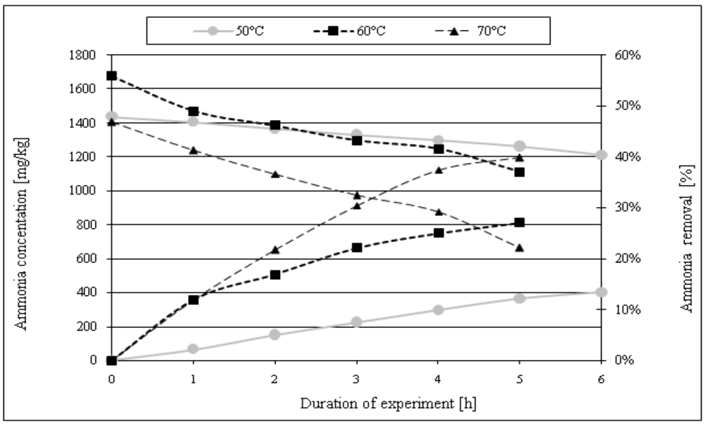

FIGURE 2 **Evolution of ammonia concentration (primary y-axis) and removal rates (secondary y-axis) under different processing temperature.**

A higher concentration of ammonia nitrogen in the fresh slurry increased the nitrogen percentage removed during the first hour of stripping. This fact is likely to have useful implications for management and stripping efficiency. Figure 2 shows the reduction of ammonia nitrogen [NH_4^+-N] in pig slurry over time (as compared with the initial ammonia nitrogen levels) together with the corresponding increase of removal efficiency during the experiment for the three temperatures tested (average of the three replications at the three temperatures).

3.2 Stripping from digested cattle slurry and fresh cattle slurry

Given the improved energy costs/benefit ratio at a process temperature of 60°C with the treating of fresh pig slurry, it was decided to maintain the process temperature at 60° C for all the subsequent stripping tests on cattle slurry. Furthermore, cattle slurry with equal test duration (6 hours) and equal process temperature (60°C) revealed that the efficiency for removing ammonia nitrogen increased considerably if the slurry loaded into the pilot reactor was collected after anaerobic digestion as opposed to the fresh slurry which had not been through the biogas plant.

Each test was made with the same amount of slurry (500 l) into the pilot reactor and maintaining the air-stripping flow constant at 130 - 140 m^3/h per m^3 of slurry loaded. Figure 3 shows the average trends for the removal of ammonia nitrogen over time for the tests involving digested slurry as compared with those using fresh slurry not already subjected to anaerobic digestion. The pilot system obtained an average stripping efficiency of 34.7% (St. Dev. 2.8) for the digested slurry. This reduced the amount of ammonia nitrogen from 1602 mg/kg (St. Dev. 24.4) to 1046 mg/kg (St. Dev. 50.6). When fresh, undigested slurry was used, the removal efficiency was only 17.0% (St. Dev. 2), lowering the total concentration of ammonia nitrogen in the fresh slurry from 1529 mg/kg (St. Dev. 145) to 1268 mg/kg(St. Dev. 114).

No technical problems were encountered in the stripping tests of digested cattle slurry. In contrast, the stripping process conducted on both fresh cattle slurry and fresh pig slurry proved more difficult from a practical point of view. There were greater difficulties in the air insufflation, there were some blockages of the porous components used for the diffusion of air, the accumulation of organic matter on the reactor walls and floor was greater and more cleaning of the equipment was required after the test. In the case of the digested cattle slurry, processed by mesophilic anaerobic digestion, the problems relating to foam formation were less. In the three test sessions when fresh, undigested cattle slurry had been loaded into the stripping reactor, foam formation was very much greater. Foam formation is caused mainly by the presence of compounds derived from fatty acids which are substantially reduced during anaerobic digestion.

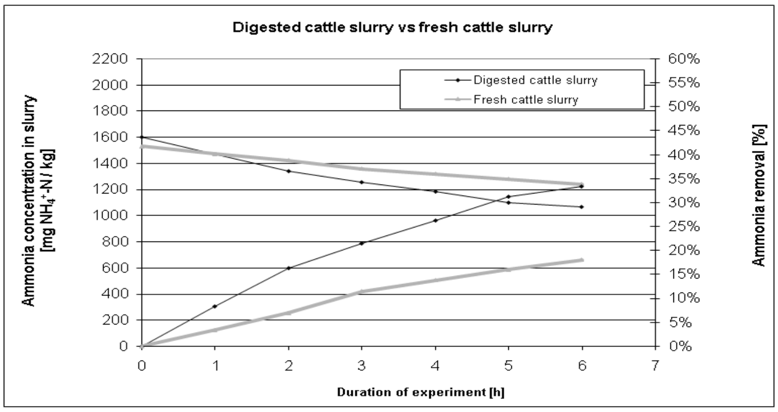

FIGURE 3 **Evolution of ammonia concentration (primary y-axis) and ammonia removal rates (secondary y-axis) during the experiment with fresh cattle slurry and digested cattle slurry.**

3.3 Stripping from digested cattle slurry at different air insufflation rates

The slurry used for these tests had all been subjected to anaerobic digestion. With average insufflation of 237 m^3/h (St.Dev. 46) per m^3 of slurry loaded into the pilot reactor, average stripping efficiency after 6 hours at 60°C was 51.9% (St. Dev. 1.9). When insufflation was reduced to 149 m^3/h (St. Dev. 4) per m^3 of slurry, the percentage of ammonia nitrogen removed reduced to 39.3% (St. Dev. 2.1) while with an average insufflation of 133 m^3/h (St. Dev. 35) per m^3 of slurry loaded, the percentage removed was 34.7% (St. Dev. 2.8). Figure 4 shows average trends for the removal of ammonia over time in relation to the insufflation rates of the slurry mass loaded.

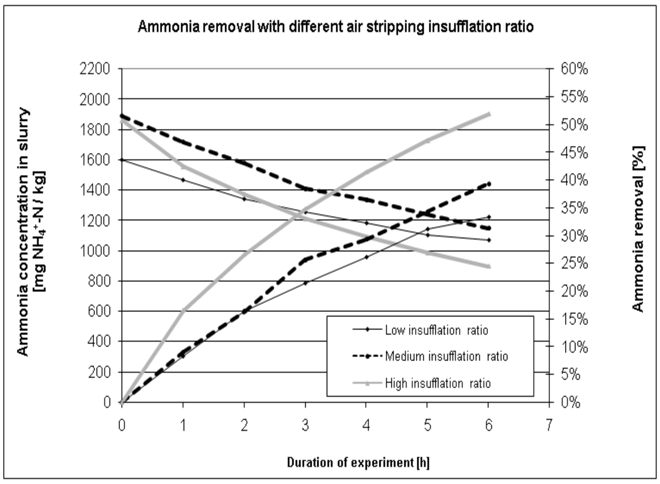

FIGURE 4 **Evolution of ammonia concentration (primary y-axis) and removal rates (secondary y-axis) with different air insufflation ratio.**

4 CONCLUSIONS

The results obtained from the experimentation showed the stripping process to be feasible by air insufflation and heating, without the need to chemically increase the pH value.

A considerable increase was seen in ammonia nitrogen removal efficiency, with same treatment time (6 hours) or temperature (60°C), when slurry processed by mesophilic anaerobic digestion was loaded into the pilot reactor rather than fresh slurry undigested.

The concentration of ammonia nitrogen was much higher in the digested cattle slurry (65% of TKN in digestate compared to 51.5% of TKN in fresh slurry), as was the efficiency for removing ammonia nitrogen. Furthermore, slurry dry matter loading to the reactor was less for the digestate (3.05% in digestate against 5.2% for fresh slurry), with a greater airflow capacity insufflated into the reactor to remove ammonia solute into the liquid fraction and to bring it into an ammonia gaseous state in the headspace. Suspended dry matter can adsorb ammonia nitrogen, decreasing stripping efficiency. The initial pH of loaded digested slurry in the stripping reactor was higher, associated with much greater: pH of digested slurries is typically higher than pH of fresh slurry, even by one point (pH 7,95 digested cattle slurry vs pH 7,2 fresh cattle slurry in these test).

Ammonia nitrogen removal efficiency increased significantly if the slurry was subjected to a high insufflation/bubbling rate and also when the process temperature was equal or above 60°C.

The stripping technique introduced in a chain with slurry anaerobic digestion and combustion of biogas produced through the co-generator, gives two benefits: energy recovery (specially thermal energy free) for energy demands of the process and the presence of digestate, which increases stripping efficiency compared to the raw slurry.

ACKNOWLEDGEMENTS

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