Supplementary Materials: Ammonia Recovery from Livestock Manure Digestate through an Air-Bubble Stripping Reactor: Evaluation of Performance and Energy Balance

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1. Estimation of the volume of digestate evaporated

The calculation of the performance of the ammonium removal took into account the liquid evaporated during the process.

Based on the temperatures monitored in the reactors and the amount of insufflated air (20% in the pre-stripping reactor and 80% in the stripping reactor), the performance was calculated by taking into account the reduction in volume in the reactors due to the partial evaporation of the liquid phase (assuming that the gaseous flow exiting the reactors was saturated with water). Under these conditions, the Antoine formula was applied, to determine the vapour-pressure (6), to then calculate the water vapour of air (7, 8) in the pre-stripping, stripping, and external air.

$$P = 10^{-A+\frac{B}{C+T}} \tag{6}$$

where P is the vapour-pressure of the substance [mmHg]
A, B and C are coefficients depending on the nature of the substance; they were assumed as those of water, with A = 7.94917; B = 1657.642; C = 227.02 [41]
T is the temperature of the digestate in the reactors or of the external air measured during the tests [°C]

$$p = \frac{P * U}{100} \tag{7}$$

where p is the pressure of the saturated vapour [mmHg]
U is the relative humidity in the reactors (hypothesis 100%) or in the external air (measured) [%]

$$H = \frac{MM_{vapor} * p}{(MM_{air} * (p_{atm} - p))} \tag{8}$$

where H is the water vapour in the air [$kg_{water}/kg_{dry\ air}$]
MM_{air} is the average molecular mass of dry air [assumed as 29 g/mol]
MM_{vapour} is the average molecular mass of vapour [assumed as 18 g/mol]
p_{atm} is the atmospheric pressure at sea level [equal to 760 mmHg]

The difference between the water vapour in the air inside the reactors (pre-stripping and stripping) and outside (external air), multiplying the insufflated air, gave the evaporated volume.

$$V_{evaporation} = (H_{reactor} - H_{external\ air}) * Q * x * \rho * t \tag{9}$$

where $V_{evaporation}$ is the volume of liquid evaporated [m^3]
$H_{reactor}$ is the water vapour of the air in the reactor [$kg_{water}/kg_{dry\ air}$]
$H_{external\ air}$ is the water vapour of the external air [$kg_{water}/kg_{dry\ air}$]
x is the amount of insufflated air [20% in the pre-stripping and 80% in the stripping]
Q is the total airflow from the blower [1050 Nm^3/h]
ρ is the density of dry air [1.2 $kg_{dry\ air}/Nm^3$]
t is the time of pre-stripping or stripping [8 or 16 hours]

The volume of manure in the reactors at the end of the process, considering the evaporation (V_{out}) was calculated as the difference between the initial volume and the evaporated volume.

2. Consumption of thermal energy

The consumption of thermal energy was calculated as the sum of the four following contributions:

- the heating of the digestate mass in the stripping and/or pre-stripping reactor, and to a minimum, in the weighting tanks, (H_m), calculated as:

$$H_m = \Delta T * mass_{manure} * c_{water} \quad (10)$$

where ΔT is the difference between the minimum and maximum temperature in the reactors ($\Delta T = T_{max} - T_{min}$)
$mass_{manure}$ is the weight in kg of the liquid manure in input in the reactors
c_{water} is the specific heat of digestate (assumed as water, and equal to 4186 J/(kg °C))

- the compensation of heat dissipation from stripping and pre-stripping reactors to the external environment (H_d), calculated as:

$$H_d = (\Delta T_{1,ps} * A_{reactor} * \Phi_{reactor} * t_{ps}) + (\Delta T_{1,s} * A_{reactor} * \Phi_{reactor} * t_s) \quad (11)$$

where ΔT_1 is the difference between the weighted average of the temperature in the pre-stripping ($\Delta T_{1,ps}$) or stripping ($\Delta T_{1,s}$) reactors and the average external temperature ($\Delta T_1 = T_{reactors,weighted\ average} - T_{external,average}$)
$A_{reactors}$ is the area of external walls of the reactors
$\Phi_{reactors}$ is the transmittance of the walls of the reactors (assumed equal to 1 W/(m^2 K))
t is the duration of the pre-stripping (t_{ps}) and stripping (t_s)

- the compensation of the latent heat of phase transition of the evaporating water (H_l), calculated as:

$$H_l = (h_{ps} * L_{ps}) + (h_s * L_s) \quad (12)$$

where h is the mass of evaporated water in the pre-stripping (h_{ps}) and stripping (h_s) reactors
L is the latent heat of water in the pre-stripping (L_{ps}) and stripping (L_s) reactors at the average weighted temperatures calculated during the tests

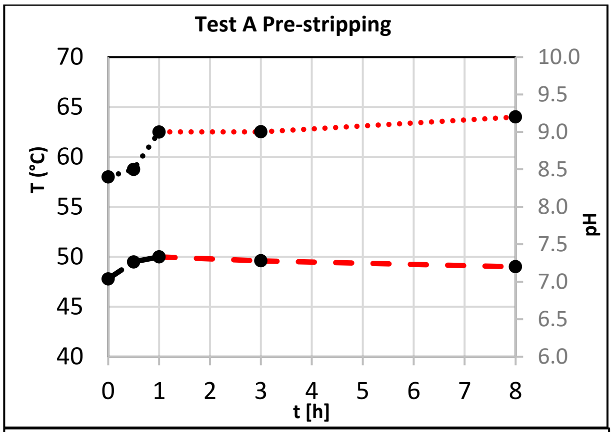
- the heating of the air entering the blower (H_a); it was included in favor of safety, as the air is heated with the heat dissipated by the engine, which would not be transferred to the water recovery circuit. It was calculated as:

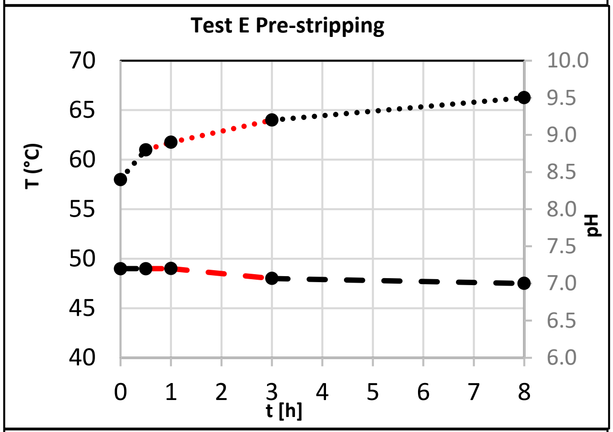
$$H_a = c_{air} * \Delta T_2 * mass_{air} \quad (13)$$

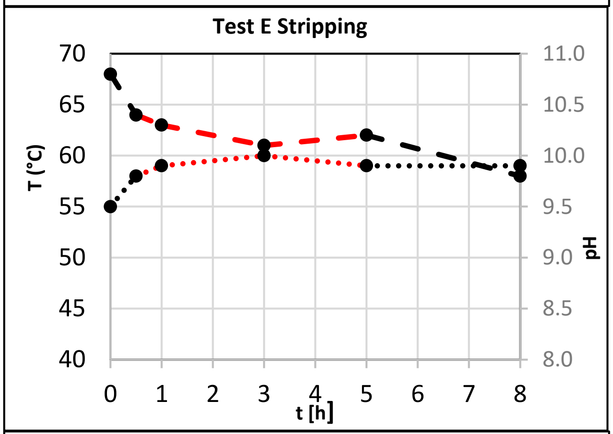
where ΔT_2 is the difference between the temperature of the air in inlet at the blower and the average external temperature ($\Delta T_2 = T_{internal,blower} - T_{external,average}$)
$mass_{air}$ is the weight of air transferred at the inlet temperature
c_{air} is the specific heat of air assumed equal to 1007 J/(kg °C)

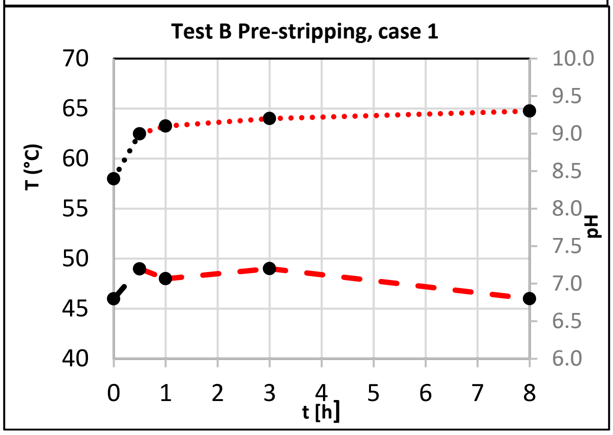
3. Graphical elaborations of the results for the identification of time intervals for the model for ammonium residual fraction decrease

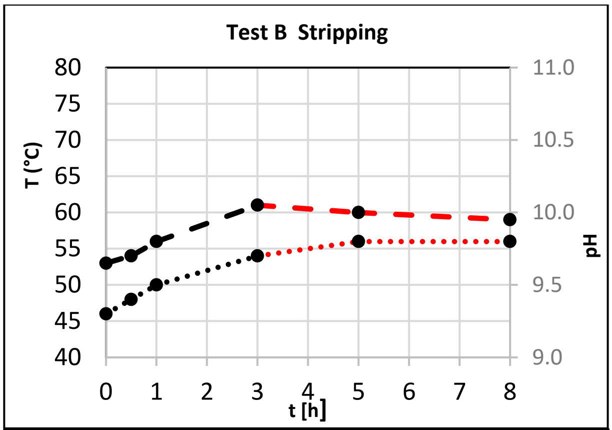
In the following graphs, the dashed line indicates the temperature, the dotted line the pH. The considered intervals are highligheted in red.

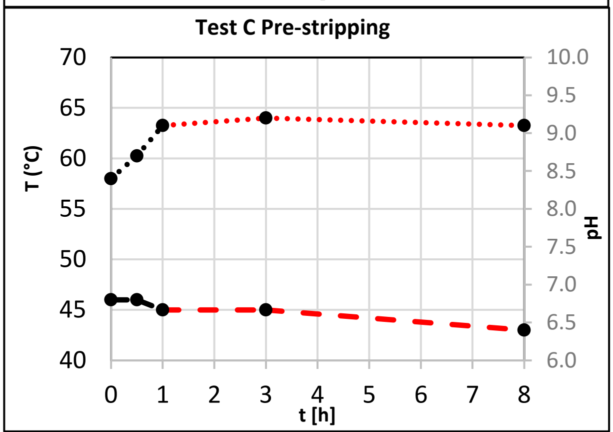


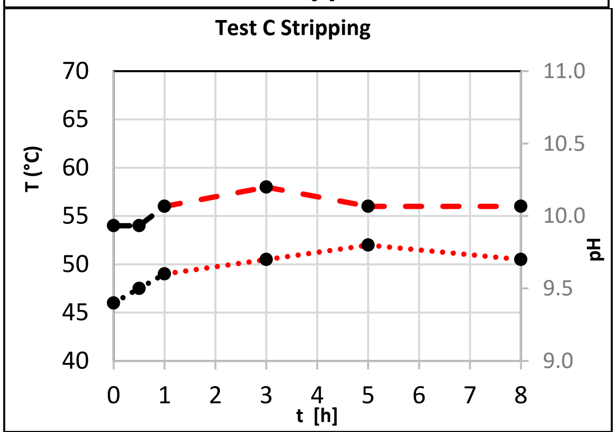


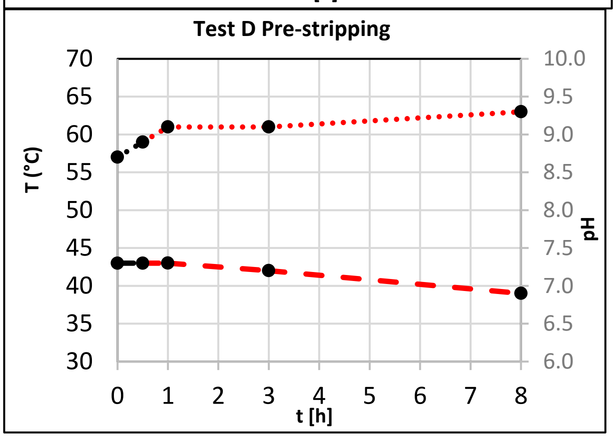


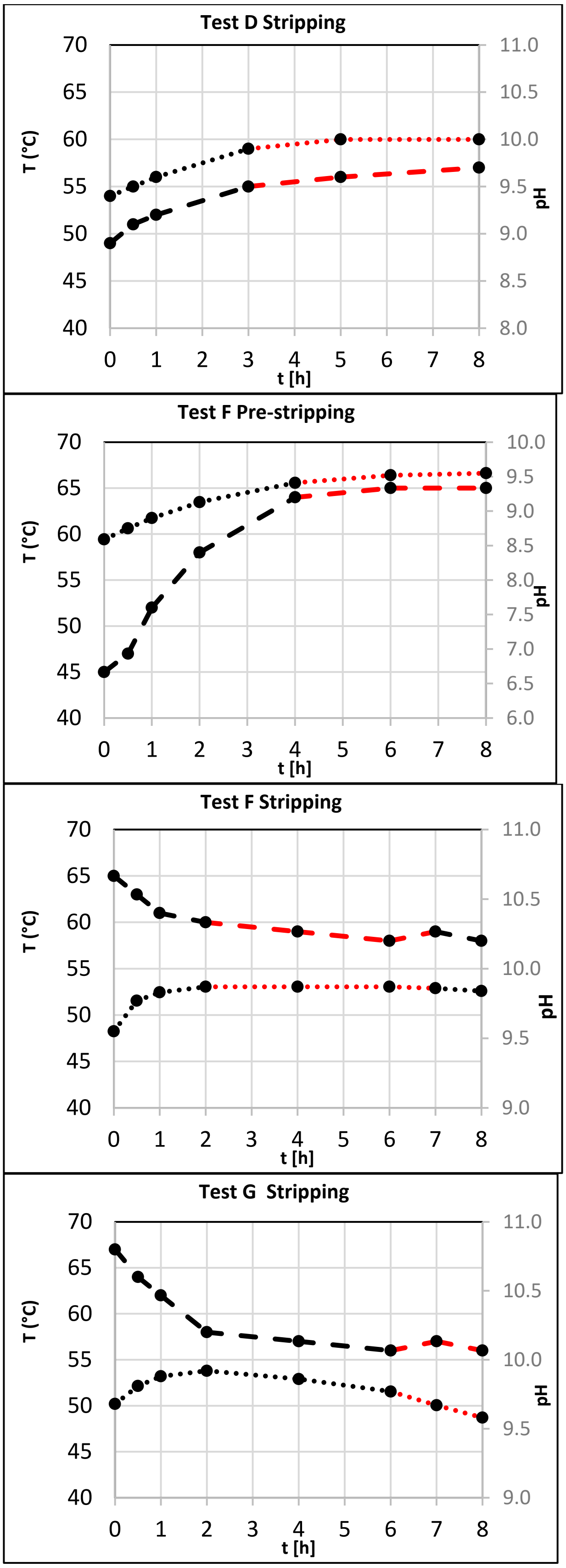



Test B Stripping
T (°C)
pH
t [h]
80
75
70
65
60
55
50
45
40
11.0
10.5
10.0
9.5
9.0
0 1 2 3 4 5 6 7 8

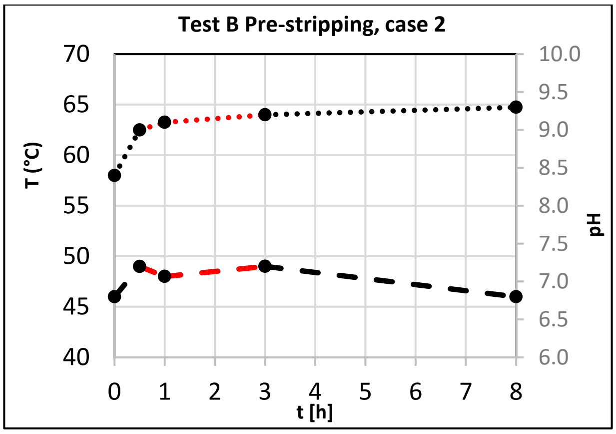

Test C Pre-stripping
T (°C)
pH
t [h]
70
65
60
55
50
45
40
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0 1 2 3 4 5 6 7 8


Test C Stripping
T (°C)
pH
t [h]
70
65
60
55
50
45
40
11.0
10.5
10.0
9.5
9.0
0 1 2 3 4 5 6 7 8


Test D Pre-stripping
T (°C)
pH
t [h]
70
65
60
55
50
45
40
35
30
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
0 1 2 3 4 5 6 7 8



Test D Stripping
T (°C)
pH
t [h]
Test F Pre-stripping
T (°C)
pH
t [h]
Test F Stripping
T (°C)
pH
t [h]
Test G Stripping
T (°C)
pH
t [h]



Reference

41 De Nevers, N. Appendix A: Useful Tables and Charts. In *Physical and Chemical Equilibrium for Chemical Engineers*; John Wiley & Sons: Hoboken, NJ, USA, 2012. https://doi.org/10.1002/9781118135341.app1.