Project Title	Evaluating role of microjet plasma interactions with slurry to mitigate ammonia volatilisation
University (where student will register)	University of Warwick
Which institution will the student be based at?	As above
Theme (Max. 2 selections)	Climate & Environmental Sustainability ☒ Organisms & Ecosystems ☐ Dynamic Earth ☐
Key words	Plasma jet, slurry, fertiliser, ammonia
Please explain how the project fits within the NERC remit	This project addresses on aspects related to atmospheric emissions related to ammonia. Ammonia is a pollutant in the atmosphere and following deposition to soils can be converted into nitrous oxide, a potent greenhouse gas. This project covers the terrestrial part on the impact of slurry that has been treated using plasma on soil health. This is related to building soil carbon which is important as a store to mitigate climate change.
Supervisory team (including institution & email address	PI: Prof Evgeny Rebrov (University of Warwick, e.rebrov@warwick.ac.uk) Co-I: Prof Ruben Sakrabani(Cranfield, r.sakrabani@cranfield.ac.uk) Co-I: Dr. Rob Lennox (Eblana Photonics Ltd., rob.lennox@eblanaphotonics.com) Co-I: Dr. Thomas Benoy (University of Warwick, thomas.benoy@warwick.ac.uk)

Project Highlights:

- Microjet plasma will create a vortex in slurry to improve absorption of plasma species to liquid
- pH of slurry will reduce leading to conservation of N, mitigating ammonia losses
- first ever study of 2D/3D mid-IR micro-imaging of plasma jets
- visualisation of the interaction between plasma and slurry to validate the hydrodynamic models.

Overview (including 1 high quality image or figure):

Ammonia (NH_3) losses from use of animal slurry and digestate in agriculture is a cause of environmental concern and a loss of valuable resource. If the NH_3 loss can be minimised, it can tackle these challenges and the nitrogen from NH_3 can be utilised as a valuable source of renewable fertiliser for crops. With escalating price of natural gas, which is directly influencing fertiliser prices, alternative solutions are urgently needed. This project is timely to tackle this challenge as it entails using microjet plasma technology to create reactive N species such as nitric oxide (NO) and create an acidic environment which minimises losses of NH_3. However, what is less known is the detailed chemistry of what happens when these N species interact with the animal slurry or digestate liquor.

In this study, a non-thermal atmospheric pressure plasma jet will be used to generate reactive oxygen species such as OH, superoxide, and reactive N-species, including nitric oxide, NO_2, N_2O_5, etc. In the plasma jet, the energy impact collision of accelerated electrons with neutral gas is responsible for excitation of the neutral gas in accordance with the energy of the electron which in turn can be regulated via voltage, and frequency of plasma and the type of carrier gas. After excitation and recombination short-lived reactive species such as OH, and NO are formed. Some of these reactive species immediately combine with other reactive species, neutrals, and water molecules. Once they reach the plasma/liquid interface they form other reactive species such as NO_2, NO_3^-, etc.

Mixing argon, oxygen, nitrogen, and water vapor to the working gas maximizes NO2 production which can be easily absorbed by water. However, the mixing of gases to the working gas (Ar or He) causes severe increase in the breakdown voltage and decreases energy efficiency. Therefore, a better design of mixing section is needed. The air can be fed to the jet downstream of the main discharge region which should keep the breakdown voltage and the power consumption level similar to that of Ar plasma. Another goal of this study is to minimise the flow rate of noble gas which should reduce the evaporation at the plasma/liquid interface. A focal planar array camera, and a IR laser will be used for measuring the NO species inside the plasma jet.

The specific objectives are:

1. To characterise the formation of reactive nitrogen species when plasma gas interacts in the liquid phase of digestate and animal slurry

2. To model and optimise the plasma technology to increase the potential to retain N in the slurry and digestate liquor.

3. To characterise the interaction of the reactive nitrogen species in plasma treated animal slurry and digestate liquor with organic compounds and their potential for mineralisation in soil

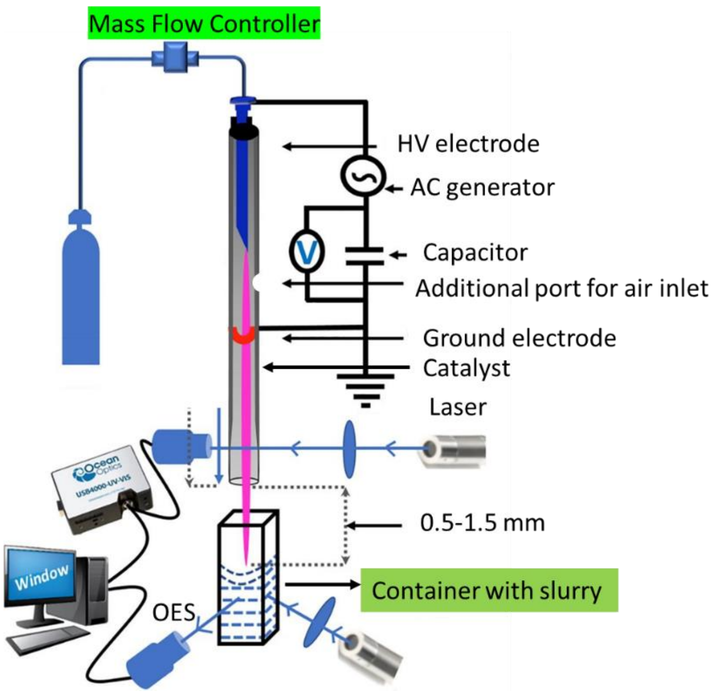

Figure 1: Schematic showing components of the experimental setup where microjet plasma will be to treat slurry

Methodology:

Task 1. Plasma-catalytic tests and plasma species characterization with be done at University of Warwick. Experiments will be performed in a plasma jet reactor. The electrical plasma characteristics will be investigated, the plasma composition and temperatures will be studied by OES, while the gas composition after plasma reaction will be measured with GC and MS. The gas conversion and energy efficiency for a wide range of operating conditions (including gas flow rate, applied power, frequency, gas mixing ratio etc). Experiments will be performed both without and with catalysts.

Task 2. Pot study with crop to determine nutrient use efficiency at Cranfield. Slurry treated plasma will be mixed with soil at various concentrations in an incubation experiment to determine the nitrogen mineralisation in soil and consequential ammonia volatilisation. This will be followed by a pot experiment where a target crop will be grown to measure the nutrient use efficiency and potential mitigation to release ammonia.

Task 3. The hydrodynamics of plasma-liquid interaction will be studied by a high-speed camera connected to an optical microscope. The information about the total interfacial surface area, droplet size distribution and other relevant hydrodynamics parameters will be obtained to get mass transfer rate for plasma species.

Task 4. Catalysts after plasma reaction will be studied for analysis of possible surface modifications. In parallel, the surface reaction mechanism will be studied by in-situ FTIR (and other techniques), in joint collaboration between two universities.

Task 5. Determination of temporal concentration profiles. Tunable diode laser absorption spectroscopy will be used for spatiotemporal data acquisition.

Training and skills:

Students will be awarded CENTA2 Training Credits (CTCs) for participation in CENTA2-provided and 'free choice' external training. One CTC equates to 1⁄2 day session and students must accrue 100 CTCs across the three years of their PhD.

The PhD student at Cranfield University will be trained in laboratory methods for specialist analysis in soil science and also use of specialist instrumentations such as ICPMS, GCMS. Student will also be trained on soft skills such as presentation and writing skills offered at key stages of research. This will be offered through our in-house training scheme organised under DATES (Cranfield portal for courses) and also through external input where necessary via specialist consultants. The student will also be encouraged to attend selected MSc modules at Cranfield University on soil science and analytical chemistry.

Training at Warwick is organized from CENTA admin in Birmingham based on the needs of the cohort. We suggest to include CH988-15 Circular Eco-design and Life Cycle Engineering postgrad course provided by department of chemistry at Warwick.

Partners and collaboration (including CASE):
Further information on partners and collaboration (including CASE):

Based in Dublin, Ireland, Eblana Photonics specialises in the near and mid-IR laser technology from 0.65-12 µm for the gas sensing and research sectors among others. Eblana Photonics will provide its newly launched mid-IR quantum cascade laser (QCL) technology based distributed feedback lasers and drive electronics for the measurement of NO and NO_2 species concentration and temperature in the plasma. They will work with the project partners for choosing the optimal laser parameters for the plasma experiments. Eblana photonics will also assist the project partners with the design and development of the mid-infrared imaging rig for plasma diagnostics and provide guidance on electromagnetic compatibility (EMC) shielding of equipment against the strong electromagnetic fields generated during direct current (DC) pulsed plasma operation.

Possible timeline:

Year 1: Design of laser plasma diagnostic rig., Selection of NO and NO_2 lasers, detectors and optics, camera etc. Plasma tests and plasma species characterization. Completion of soil incubation study to determine nitrogen mineralisation using slurry treated using various plasma conditions.

Year 2: Plasma-catalytic tests. Optimisation of plasma-slurry interaction. Implementation of gas chemical sampling strategies for plasma jet-slurry. Completion of pot study with crop to determine nutrient use efficiency.

Year 3: Scale-up studies with multiple plasma jets. Catalysts characterisation studies. The surface reaction mechanism studies to improve selectivity and energy efficiency.

Further reading:

M Simeni Simeni et al 2017 J. Phys. D: Appl. Phys. 50 274004

Quoc Hue Pho et al., 2022, Rational design for the microplasma synthesis from vitamin B9 to N-doped carbon quantum dots towards selected applications, Carbon, 198, 22-33

Further details:

Project/institutional contact details including a link to the application website if applicable

Prof Robin Allaby,

Email: R.G.Allaby@warwick.ac.uk

Phone: 024 765 75059

University of Warwick, Office: D128