On the possibility of using noble gases in the liquid phase in agriculture

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Abstract. The article substantiates the need to search for new solutions to increase crop yield through the use of new fertilizers. One of the options was proposed in this article. During the operation of nuclear power plants, by-products are formed in the form of inert gases, for example, an isotope nitrogen-16, or helium-3 and helium-4, or xenon-133 and xenon-135. They are quite difficult to filter out of the air. If they are filtered into the atmosphere, other gas formations will pass. Therefore, the design of a cryogenic unit was developed for their deposition on the walls of the pipeline (transfer to a liquid state). In this case, they are separated by using different temperatures. Each liquid mixture is placed in its container. In autumn, these mixtures are transported to agricultural fields and spread out. Experiments have shown that the use of these mixtures can increase the potato yield by two times compared to the case of no use of fertilizers. When comparing the results of the research of the potato yield grown using manure from domestic animals and compost with the yield obtained using a liquid mixture of the noble gas, it was established that the yield is lower by 60 % and 40 %.

1 Introduction

Currently, the problem of reducing the fertility of agricultural lands during their intensive exploitation is one of the state tasks of many countries [1-6]. The lack of products available for the population creates a difficult political situation in the country [7-10].

Studies showed that the use of chemical fertilizers leads to the destruction of the fertile soil layer [11-20]. Plants grown on this soil mutate, product quality decreases, and the crop contains substances that are hazardous to the body. In addition, during rains and floods,
hazardous substances are washed out of the soil and enter rivers and lakes [19-30]. The size of an environmental disaster is increasing. River and lake living organisms in a poisoned environment mutate or die.

Organic fertilizers (manure, compost, etc.) are very expensive. And their volume is not enough to restore the energy potential of the soil. Furthermore, the amount of land used for agricultural production is constantly increasing. The population of the Earth is increasing, and more and more products are required. Therefore, the task of finding new fertilizers to increase land fertility is extremely urgent.

The deterioration of the ecological state of the environment has led to increased requirements for fertilizers in many countries for a number of parameters [31-38]. The major one is the inability to accumulate in the soil and change the biota [39-44]. In addition, fertilizers should be affordable for farmers and agricultural enterprises. The latter results in the most promising is the development of fertilizers from waste of various industries [45-48]. Moreover, there should be a lot of these wastes, and they should appear regularly. In this case, one of the most interesting options is the waste of the energy facility. Energy production is increasing every year, waste from the operation of power plants is becoming more and more. Nuclear energy currently provides more than 30% of all necessary energy in developed countries [49-53]. In some countries, such as France, this figure reaches 70%. One of the by-products of nuclear power plants (NPPs) is a mixture of noble gases from the isotopes radon, xenon, krypton, argon, helium, and nitrogen. They are removed through the ventilation pipe of the nuclear power plant and deposited on special filters or traps. They need to be processed and stored in the future. These raw materials for fertilizers can be obtained free of charge and in large quantities.

2 Noble gases and the into liquid state their transformation method

During ventilation of various zones of the reactor, the noble gas of various isotopes formed in them is removed. Due to their physical and chemical properties, various noble gases are difficult to deposit on filters. It is possible to reduce their amount during air emission into the atmosphere using cryogenic technologies. The gas liquefaction temperature, as a function of their mass number, is shown in Figure 1.

![Fig. 1. Dependence of the temperature T of a noble gas on the relative atomic mass A. Points 1, 2, 3, 4, 5 and 6 on the graph correspond to the following noble gas: He, N, Ar, Kr, Xe and Rn.](image-url)
The presented results show that it is quite difficult and economically unjustified to obtain liquid helium in the conditions of a ventilation pipe. It is collected by circular air capture in the form of gas in specialized vessels. After passing through the filters, the remaining part of it gets into the atmosphere. For other gases, gradual cooling of the air flow is used to transfer to the liquid phase. Figure 2 shows a scheme of a ventilation pipe for gas separation under the influence of temperature when passing a gas mixture. The scheme contains 5 sections.

![Figure 2. Scheme of a ventilation pipeline section with cooling and noble gas runoff in a liquid state: 1 - pipe; 2 - cryogenic equipment; 3 - cooler; 4 - a special container for collecting condensate of noble gas; 5 - drain section.](image)

The difference in temperature over 10 K makes it possible to successfully implement this process. The small volume of the container and the continuous process of formation of liquid gas mixtures at NPPs require constant cleaning and storage. To measure the volume of liquid gas, NMR flowmeters – relaxometers can be used [54-58]. In this case, it is necessary to add a little water to the liquid mixture. Storage of these mixtures is quite an expensive process, so they must be used for a year. The seasonal preparation of fields is one of the promising options for using such mixtures. In autumn, the field is processed with this mixture, preferably before setting it under steam. Rain, snow, and meltwater create various climatic conditions and activate chemical reactions. Further in the summer, under the influence of sunlight, another chemical process takes place, which completely converts liquid gas mixtures into useful for the soil elements. A liquid mixture of argon from a NPP can be used in small generators to generate electricity. Liquid radon can be used to activate pet food.

### 3 The results of experimental studies and their discussion

To confirm the possibility of using liquid mixtures of noble gases (isotope of nitrogen-16 and isotopes of xenon-133 and xenon-135) as a fertilizer, the following experiment was carried out. In October, sections (1, 2 and 3, respectively) of land measuring 4 by 5 m that do not border each other were treated with liquid mixtures. Each mixture had its isotope. Two other sections of land were used in the experiment. One of them (section 4) was fertilized with manure in the spring (standard rate), the other (section 5) with compost (standard rate).
Section 6 was ploughed. The exposure dose of $P_{exp}$ in the sections (1-6) was measured before planting potatoes in the spring of next year. The $P_{exp}$ values did not exceed 22 $\mu$R/h. The seeds were identical. Figure 3 shows the results of the autumn harvest.

![Figure 3](chart1.png)

**Fig. 3.** The dependence of the potato mass $M$ change from the site number $N$.

As an example, figure 4 shows studies of yields under the same conditions, except that land sections were under steam for a year.

![Figure 4](chart2.png)

**Fig. 4.** The dependence of the potato mass $M$ change from the site number $N$.

Analysis of the results showed that the efficiency of increasing the yield of potatoes using a liquid mixture of noble gas is lower than that of manure and compost. However, their use makes it possible to increase the yield by 2 times compared to the case if the field is not processed. When using the steam method of field exposure, the efficiency of using a liquid
mixture of noble gas is reduced. It can be assumed that the first method of using a liquid mixture of noble gas is more cost-effective.

4 Conclusions

The results show the prospects of using a liquid mixture of noble gas as a fertilizer. If the fields are located at a distance of no more than 200 km from the NPP (the mixture can be immediately delivered to the fields), the efficiency of this method of increasing the yield in large production is obvious.

On the other hand, there is no information on how the biota of the soil will change after many years of using such fertilizers. Therefore, it is better to continue research in this direction in the experimental field. Based on their results, a final decision can be made over a period of 10 years.

References

1. M. Kozar, L. Sabliy, M. Korenchuk, S. Makeev, A. Korshunov, and V. Kosolapov, IOP Conference Series: Earth and Environmental Science 390(1), 012002 (2019)
2. N. Rumyantsev, O. Bondareva, S. Makeev, and V. Krasnoshekov, IOP Conference Series: Earth and Environmental Science 390(1), 012037 (2019)
3. M. Petrichenko, N. Vatin, D. Nemova, N. Kharkov, and A. Staritcyna, Applied Mechanics and Materials 627, 297-303 (2014)
4. K. Artem'ev, L. Kolik, I. Podkovyrov, V. Meshalkin, and M. Diuldin, IOP Conference Series: Earth and Environmental Science 390(1), 012039 (2019)
5. R. Davydov, V. Antonov, S. Makeev, V. Dudkin, and N. Myazin, E3S Web of Conferences 140, 02001 (2019)
6. E. Stepanov, S. Kotelnikov, G. Ratushnyk, E. Nikulina, and M. Diuldin, IOP Conference Series: Earth and Environmental Science 390(1), 012033 (2019)
7. V. Yushkova, G. Kostin, V. Dudkin, and L. Valiullin, IOP Conference Series: Earth and Environmental Science 390(1), 012016 (2019)
8. S. Van, A. Cheremisin, R. Davydov, and V. Yushkova, E3S Web of Conferences 140, 09008 (2019)
9. S. Van, A. Cheremisin, A. Chusov, and F. Switala, IOP Conference Series: Earth and Environmental Science 390(1), 012011 (2019)
10. V. Mushchanov, V. Sievka, A. Veshnevska, and D. Nemova, Procedia Engineering 117(1), 1018-1026 (2015)
11. G. Shafeev, E. Barmina, L. Valiullin, A. Korshunov, and R. Denisov, IOP Conference Series: Earth and Environmental Science 390(1), 012016 (2019)
12. N.N. Kabal'nova, S.A. Grabovskiy, N.M. Andriayshina, L.R. Valiullin, I.S. Reginov, and Y.U. Murinov, Letters in Drug Design and Discovery 14(12), 1409-1414 (2017)
13. T. Akimov, O. Beloshapkina, M. Diuldin, and J. Molnár, IOP Conference Series: Earth and Environmental Science 390(1), 012015 (2019)
14. N.S. Myazin, Measurement Techniques 60(5), 491-496 (2017)
15. N. S. Myazin, V. V. Yushkova, and T. I. Davydova, Journal of Physics: Conference Series 917(4), 042017 (2017)
16. A.Yu. Karseev, and V.A. Vologdin, Journal of Physics: Conference Series 643(1), 012108 (2015)
17. A. Korshunov, N. Gaitova, M. Gaitov, A. Cheremisin, and A. Gerner, IOP Conference Series: Earth and Environmental Science 390(1), 012009 (2019)
18. E. Gryznova, N. Grebenikova, D. Ivanov, and V. Bykov, IOP Conference Series: Earth and Environmental Science 390(1), 012044 (2019)
19. M. Nikitina, N. Grebenikova, V. Dudkin, and Y. Batov, IOP Conference Series: Earth and Environmental Science 390(1), 012024 (2019)
20. E. Gryznova, Y. Batov, and N. Myazin, E3S Web of Conferences 140, 09001 (2019)
21. R. Davydov, V. Antonov, D. Molodtsov, A. Cheremisin, and V. Korblev, MATEC Web of Conference 245, 15002 (2018)
22. V.I. Antonov, V.L. Badenko, V.I. Maslikov, and D.V. Molodtsov, Journal of Physics: Conference Series 1135(1), 012049 (2018)
23. V.I. Antonov, and D.V. Molodtsov, Journal of Physics: Conference Series 769(1), 012060 (2016)
24. V.I. Antonov, Journal of Physics: Conference Series 1124(8), 081037 (2018)
25. R.V. Davydov, V.I. Antonov, V.V. Yushkova, N.M. Grebenikova, and V.I. Dudkin, Journal of Physics: Conference Series 1236(1), 012079 (2018)
26. V. Antonov, and N. Kalinin, Journal of Physics: Conference Series 643(1), 012107 (2015)
27. R.V. Davydov, and V.I. Antonov, Journal of Physics: Conference Series 769(1), 012060 (2016)
28. V.I. Antonov, Journal of Physics: Conference Series 1124(8), 081037 (2018)
29. R.V. Davydov, and V.I. Antonov, Journal of Physics: Conference Series 1135(1), 012087 (2018)
30. R.V. Davydov, V.I. Antonov, V.V. Yushkova, N.M. Grebenikova, and V.I. Dudkin, Journal of Physics: Conference Series 1236(1), 012079 (2019)
31. N. S. Myazin, and T. I. Davydova, Russian Journal of Nondestructive Testing 53(7), 520-529 (2017)
32. V. V. Davydov, V. I. Dudkin, N. S. Myazin, and V. Yu. Rud’, Instruments and Experimental Techniques 61(1), 140–147 (2018)
33. V.V. Davydov, E. N. Velichko, N. S. Myazin, and V. Yu. Rud’, Instruments and Experimental Techniques 61(1), 116–122 (2018)
34. N.S. Myazin, S.E. Logunov, N.M. Grebenikova, and V.V. Yushkova, Journal of Physics: Conference Series 929(1), 012064 (2017)
35. N. Myazin, Y. Neronov, V. Dudkin, and V. Yushkova, MATEC Web of Conference 245, 11013 (2018)
36. N. S. Myazin, Journal Physics: Conference Series 1135(1), 012061 (2018)
37. N. M. Grebenikova, N. S. Myazin, and V. Yu. Rud, Proceedings of the 2018 IEEE International Conference on Electrical Engineering and Photonics, EExPolytech 2018, 8564409 295-297 (2018)
38. V. Fadeenko, I. Fadeenko, V. Dudkin, and D. Nikolaev, IOP Conference Series: Earth and Environmental Science 390(1), 012022 (2019)
39. N.S. Myazin, V.V. Yushkova, and V.I. Dudkin, Journal of Physics: Conference Series 1400(6), 066008 (2019)
40. S.E. Logunov, I.Yu., Podkovyrov, and V.Yu. Rud, Journal of Physics: Conference Series 1410(1), 012113 (2019)
41. S.A. Grabovskiy, R.S. Muhammadiev, L.R. Valiullin, I.S. Raginov, and N.N. Kabafnova, Current Organic Synthesis 16(1), 160-164 (2019)
42. N.N. Kabal’nova, S.A. Grabovskiy, N.M. Andriayshina, I.S. Raginov, and Y.I. Murinov, Letters in Drug Design and Discovery 14(12), 1409-1414 (2017)
43. I.I. Idiyatov, L.R. Valiullin, V.V. Biryulya, M.V. Lekishvili, and A.I. Nikitin, Genes and Cells 12(1), 41-46 (2017)
44. N. S. Myazin, Measurement Techniques 60(2), 183-189 (2017)
45. L. Molodkina, D. Tryastsina, and A. Cheremisin, IOP Conference Series: Earth and Environmental Science 390(1), 012005 (2019)
46. M. Andrianova, E. Bondarenko, S-P. Reinikainen, and A. Cheremisin, IOP Conference Series: Earth and Environmental Science 390(1), 012006 (2019)
47. E.V. Rukin, N.S. Myazin, and V.I. Dudkin, Journal of Physics: Conference Series 1368(4), 042011 (2019)
48. V.V. Elistratov, M.V. Diuldin, and R.S. Denisov, IOP Conference Series: Earth and Environmental Science 180(1), 10 (2018)
49. T. Bugaeva, A. Khabarov, O. Novikova, and U. Plotkina, IOP Conference Series: Materials Science and Engineering 497(1), 012056 (2019)
50. N.S. Myazin, V.I. Dudkin, N.M. Grebenikova, and A.S. Podstrigaev, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 11660 LNCS, 744-756 (2019)
51. I.A. Zharkov, V.Yu. Rud, and N.N. Bykova, Journal of Physics: Conference Series 1410(1), 012088 (2019)
52. V.V. Davydov, N.S. Myazin, and A.V. Kiryukhin, Atomic Energy 127(5), 274-279 (2020)
53. V. Antonov, and M. Angelina, Proceedings of the 2019 IEEE International Conference on Electrical Engineering and Photonics, EExPolytech 2019, 8906791 42-45 (2019)
54. N.S. Myazin, V.V. Yushkova, and N.I. Taranda, Journal of Physics: Conference Series 1410(1), 012130 (2019)
55. V. I. Dudkin, and A. Yu. Karseev, Russian Physics Journal 58(2), 146-152 (2015)
56. V.I. Dudkin, and A.Yu. Karseev, Measurement Techniques 57(8), 912-918 (2014)
57. V.I. Dudkin, and A.Yu. Karseev, Technical Physics Letters 41(4), 355-358 (2015)
58. S. Chirikov, A. Shkirin, I. Savchenko, N. Bunkin, and M. Diuldin, IOP Conference Series: Earth and Environmental Science 390(1), 012030 (2019)