Zeszyty Naukowe Politechniki Częstochowskiej
Budownictwo
ISSN 0526-5916

Zeszyty Naukowe Politechniki Częstochowskiej nr 28 (2022), 67-72
DOI: 10.17512/znb.2022.1.10

The future of the economy lies in nuclear energy, electric propulsion and hydrogen energy sources

Marlena Rajczyk[1]

ABSTRACT:
The article is devoted to the prospect of obtaining electricity from nuclear energy technology obtained in fast neutron reactors cooled with liquid lead. The paper presents an analysis of the methods of accumulating electricity in battery systems through the development of innovative technologies, as well as technical and material solutions for prospective batteries. It also identifies alternative methods of mass storage of efficient hydrogen energy sources.

KEYWORDS:
technologies and sources of electricity; technical solutions for generating and supplying electricity

1. Introduction

In Poland, the basic energy sources are: oil, gas, coal, and energy from renewable sources; sun, water and wind. When will the exhaustion stage come, and with what can we replace these sources in the coming years. The energy of water, wind and sun is able to replace no more than 40% of the energy demand. As a result, humanity is counting on nuclear and thermonuclear energy. Perhaps this can be achieved on the international ITER platform in France, which is currently under construction. For the time being, the future seems to consist only of traditional energy and nuclear energy based on splitting the nuclei, therefore the question arises as to what to expect in the coming years [1-3].

2. Current nuclear technology

The first designs of reactors with a liquid metal coolant appeared in the 1950s, works were carried out in the USSR and the USA. Most nuclear reactors are so-called slow or warm neutrons that work on the basis of uranium "235", which is rarely found in nature, it is obtained from uranium ore from the isotope, in the amount of only 0.07% of the mass of uranium ore, the remaining 99.93% is uranium "238", which as fuel for the so-called reactor water neutrons is not used. Why are neutrons in reactors free? Neutrons are slowed down by water, which in the so-called thermal reactors are used as heat carriers. Passing through the water, neutrons generate energy, and only certain nuclei of the uranium isotope "235" are capable of this state, and the uranium isotope "238" remains in this category as unsuitable waste. Without the use of a water slowing diaphragm, the neutrons that are absorbed by the uranium "238" nucleus further develop into unstable plutonium nuclei that can be used as fuel. In the reactor with the so-called fast neutrons, the remaining 99.93% of the uranium ore "238" can be used as fuel. Currently, this material as a fuel is not entirely useless waste in the new technology, it remains

[1] Czestochowa University of Technology, Faculty of Civil Engineering, ul. Akademicka 3, 42-218 Częstochowa, Poland, e-mail: marlena.rajczyk@pcz.pl, orcid id: 0000-0002-4893-0931

the basis for a new type of fuel. In order to build a "SN" (fast neutron) reactor, it is necessary to change the neutron flow process through the water diaphragm, replacing it with another material that will not slow down the neutrons. For the world's first reactors with the so-called fast neutrons, such material was a liquid soda solution. To build a reactor (SN), you must replace the water with another coolant that does not slow down the neutrons. The Beloyarsk nuclear power plant is the first industrial high-speed reactor in the world to select liquid sodium [4-6].

3. Closed cycle in a fast neutron system

The main advantage of (MV) reactors is not that they can use uranium "238" which is not used in thermal plants. Their main advantage is that, unlike slow reactors, they can burn up nuclear fuel used in slow-neutron reactors. Having a fast neutron reactor in a nuclear power plant, it is possible to create a closed circuit.

By organizing a closed cycle where all fissile material can be burned in one. The output will be a small amount of waste, the level of radioactivity of which will not exceed the level of uranium ore extracted from the ground. In this form, radioactive waste can be safely returned to nature.

A closed loop is just one of the goals of the ongoing project "Turn". Another task is to create the fourth generation reactors, the design of which will meet the principle of natural safety. This means that it will not be people, machines and engineering structures that will protect us from failures in nuclear power plants, but the laws of physics and technology will be responsible for safety in new reactors. Natural safety is based on the use of materials that are safe in themselves, of course, including such structures that basically exclude the possibility of an accident.

The name of the future reactor is "BREST-300". It differs from the existing SN-600 and SN-800 primarily in the choice of coolant: instead of sodium, the BREST core will be immersed in liquid lead. Pure sodium, although suitable for use in fast reactors, requires very careful handling due to its high reactivity. Sodium burns in air and reacts with water, so special safety systems for sodium reactors must be built [7-9].

Lead is much easier to handle; it does not burn or explode, and besides, together with concrete, it forms coatings and reliably covers the core, thanks to which the natural radiation background is preserved on the other side of the metal and the concrete wall of the reactor without any additional forms of protection.

The new generation of reactors will cooperate with existing thermal reactors and will supply electricity within the framework of two-component nuclear energy. System safety is ensured by complex engineering structures designed for the worst-case scenarios – i.e. loss of control of the nuclear reaction and loss of cooling.

In the event of a coolant leakage from the core, the reactors (SN) are equipped with water supply systems with emergency pumps. In extreme cases, if incandescent fuel will melt through the concrete bottom, it will be captured by a trap capturing the molten fuel, the so-called safe cavity into which the molten core material must drain and cool.

The fuel itself is responsible for the stability of the nuclear reaction in the concept of natural safety: its isotopic composition is calibrated so that in no case can it heat up above the permissible values. This choice of material excludes overheating of the core and melting of the fuel rods.

Currently, the construction of a pilot energy complex is underway, the heart of which will be the BREST-300 reactor. A plant has already been built to produce fuel from reprocessed spent nuclear fuel containing hazardous radionuclides and other fine actinides. These elements are the most dangerous part of spent nuclear fuel, but they can be successfully burned in a fast neutron reactor. In 2020, the main equipment of the plant for the production and regeneration of fuel began to be assembled. The construction of the reactor itself will begin in the near future, and its commissioning is planned for 2026. BREST-300 will be the world's first lead-cooled reactor [10]. In an experimental energy complex with a new reactor, with unique installations for the production and processing of fuel, Russian nuclear scientists declare that the nuclear complex with a closed fuel cycle will be launched at the planned time [11].

4. In search of a way to accumulate energy

Fuji Pigment has developed an aluminum-air battery under the working name "Alpha" – batteries. It is expected that, according to the publications, the new design is 40 times larger than the lithium-ion battery. Additionally, this type of battery is charged with a lightly salted water refill. The battery can work for about 2 weeks on a single charge [12].

The company Jenax [13] built a so-called flexible battery that can be folded like a sheet of paper. The design increases the volume of energy in relation to the geometry of the accumulator. The constructors found that the prototype withstood 200,000 folds without losing capacity [13].

At Harvard, the technology of organic batteries was developed with energy production costs of $ 27 per KWh, 96% cheaper than metal-based batteries. The designs use hinomow materials. The efficiency index of organic batteries is not inferior to traditional batteries and can be scaled to unlimited sizes [11, 14].

Energy storage in the energy system causes the need for seasonal energy storage, which is especially visible when analyzing energy obtained in the renewable energy and nuclear systems. To ensure a reliable supply of electricity, hybrid systems supported by diesel engines or an energy storage system are often used. The question is whether hydrogen technology can be used as an alternative to energy storage.

Mass production of hydrogen is only just beginning, and visible technologies are already appearing that increase the efficiency of its use around the globe. Researchers, who have published information on the possibility of using hydrogen in the form of the so-called Hydrogen paste report that the energy capacity is compared to that of gasoline. Hydrogen paste is considered as an alternative fuel for means of transport, but it can also be an energy fuel in heating applications, while the combustion of hydrogen paste takes place after a reaction with water, as a result of which hydrogen is released, accompanied by compounds that are not harmful to humans and the environment [15, 16].

The hydrogen trapped in the paste is convenient for transportation and storage technology. The paste substance produced from magnesium is a compound of magnesium and hydrogen. Instead of a hydrogen tank, small means of transport will be equipped with toners with hydrogen paste, and when refueling, it will be enough to flood the tank with water, which will release hydrogen in reaction with the paste. The energy efficiency of hydrogen paste is compared to gasoline, which is significantly more effective than battery systems as an alternative storage of previously generated electricity.

The Fraunhofer Institute – Manufacturing Technology and Advanced Materials presented an innovative material for the accumulation of hydrogen with subsequent use in energy elements. Such a paste is able to store hydrogen at atmospheric pressure and at an ambient temperature, where it is enough to add water to the substance to generate gas [8, 10].

The production process of the "POWERPASTE" paste consists in the production of magnesium hydride from powdered magnesium and hydrogen at a temperature of 350°C and a pressure 5-6 times higher than atmospheric pressure. Then the resulting substance is combined with esters and metal salts. The process is an alternative form for storing electricity generated, for example, in nuclear technology on fast reactors, for a place where it is necessary to obtain and use energy, e.g. in the vehicle's propulsion system. The paste in the system, where it is necessary to obtain energy, is dosed into the working chamber, into which water is introduced, which leads to the formation of hydrogen. By adjusting the feed of the starting materials, it is easy to change the amount of gas produced according to the energy needs of the fuel cell.

The paste does not need to be stored under high pressure and can withstand the temperature load of the storage container up to 250°C, which guarantees high safety during its operation.

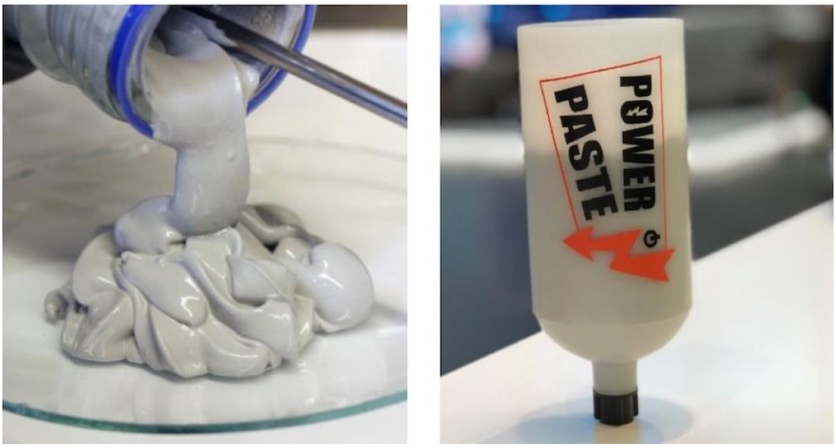

Fig. 1. The innovative material for the accumulation of hydrogen "POWERPASTE" [8, 10]

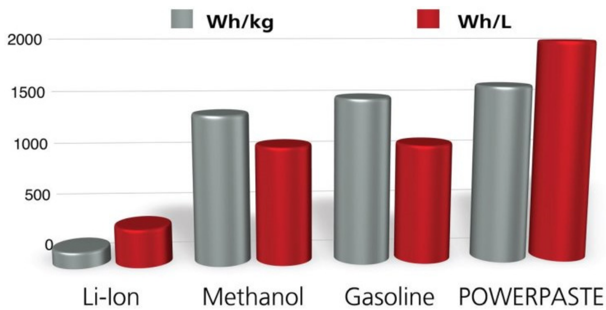

Fig. 2. A comparison of the properties of the innovative "POWERPASTE" paste with lithium-ion batteries, methanol, gasoline and the liquid hydrogen storage system used in hydrogen cars was presented [8, 10]

The high share of RES in the electricity system may result in the need for long-term and seasonal energy storage, for example to supply electricity.

The second industry is mobile communications, which is an example of a sector that needs backup and off-grid power. It is estimated that there are 7 million base stations in the world and their number is growing by over 100,000 annually, mainly in developing and emerging economies. In order to ensure a reliable electricity supply for regions with weak electricity infrastructure, they use their own electricity supply. Often they are provided by diesel generators or hybrid systems with diesel engines. Each such base station consumes from 10,000 up to 12,000 liters of diesel fuel per year. For example, India today has around 650,000 telecommunications towers, of which about 20 percent is based on diesel generators, resulting in an annual diesel consumption of 5 billion liters and CO_2 emissions of 5 Mt per year.

Fuel cells can also help provide backup power in the event of a power failure and electricity access, especially in schools and clinics. In South Africa, a small village of 34 households was electrified in 2014 as part of a mini-grid pilot project involving the supply of electricity from three 5 kW methanol fuel cells in combination with a 14 cubic meter methanol tank and a battery pack with a capacity of 73 kWh.

Hydrogen fuels are also options for large-scale and long-term energy storage to offset seasonal fluctuations in electricity demand or its fluctuating generation from RES.

The research shows that only 10 kg of "POWERPASTE" paste can store 1 kg of hydrogen, or about 11 m^3 in the form of gas. The specific capacity of the material is 1.6 kW·h/kg, and the energy density is 1.9 kW·h/kg. This is about 10 times more than that of lithium-ion batteries.

5. Conclusions

The benefits of using fourth generation reactors include:

- three times greater energy yield from the same amount of nuclear fuel,
- the possibility of using nuclear waste to generate electricity (which applies to many reactors of earlier generations in use using a closed fuel cycle),
- increased safety of use,
- the prospect of storing clean nuclear energy for clean forms of energy storage in hydrogen ports,
- the main goals of innovative activities in the energy sector are: improving nuclear safety, increasing resistance to proliferation, minimizing the amount of waste and using natural resources, and reducing the costs of building and commissioning this type of power plant,
- electrical energy in drives generates over 80% of the efficiency of tool and machine drives, which justifies the dynamic development of small mechanization used in construction by introducing battery tools to the market,
- the prospect of producing clean, safe nuclear energy for new forms of energy storage, for example in the form of hydrogen paste energy, will be a significant alternative to energy sources in the first stage of its practical application to drive mini propulsion units, e.g. scooters, as predicted by specialists working on the creation of "POWERPASTY".

References

[1] Leszczyński P., Perspektywy rozwoju energetyki jądrowej w Polsce, [in:] Bezpieczeństwo energetyczne wyzwaniem XXI wieku, Z. Lach (ed.), AON, Warszawa 2013.

[2] Macuk R., Transformacja energetyczna w Polsce. Edycja 2020, Forum Energii, marzec 2020.

[3] Madej Ł., Elektrownia atomowa w Polsce – pomoże nam potentat?, Inżynieria.com. 6.02.2020, https://inzynieria.com/energetyka/wiadomosci/57743,elektrowniaatomowa-w-polsce-pomoze-nam-potentat. Access date: 9.03.2020.

[4] Akatov A.A., Koryakovsky Yu.S., Przyszłość energetyki jądrowej. Szybkie reaktory 2012.

[5] Reaktor powielający chłodzony ciekłym metalem. https://ru.wikipedia.org/wiki/.

[6] Klimow A.N., Fizyka jądrowa i reaktory jądrowe. 1985.

[7] Orlov V.V., Filin A.I., Lopatkin A.V., Glazov A.G., Sukhanov L.P., Volk V.I., Poluektov P.P., Ustinov O.A., Vorontsov M.T., Leontiev V.F., Karimov R.S., The closed on-site fuel cycle of the brest reactors, Progress in Nuclear Energy 2005, 47, 1-4, 171-177.

[8] Sayeda Aqsa Amin, Hydrogen as a source of clean energy in Finland, a new dimension to using reliable energy sources combined together for a sustainable future. Bachelor's thesis, Centria University of Applied Sciences, December 2021.

[9] Rodina E.A., Egorov A.V., Rachkov V.I., Khomiakov Iu.S., Modeling and comparative analysis of changeover of homogeneous and heterogeneous core of BN-1200 reactor to equilibrium mode, Nuclear Engineering and Design 2022, 386, January, 111549.

[10] Hydrogen and aluminum-hydrogen storage in the power industry. Posted on 04 February 2021 in Hydrogen, Hydrogen Storage, https://www.greencarcongress.com/2021/02/20210204-powerpaste.html.

[11] Nowikow N.L., System magazynowania energii elektrycznej zapewniający niezawodność działania EES, Energoexpert 2017, 2, 34-43.

[12] Baterie Alpha wytrzymują do 14 dni na zwykłej wodzie i trafią do sprzedaży pod koniec tego roku. http://novteh.com/akkumulyatory-alfa-rabotayut-do-14-dnej-na-obychnoj-vode-i-postupyat-v-prodazhu-uzhe-v-konce-etogo-goda/.

[13] W Korei wymyślono baterie taśmowe. https://hightech.plus/2020/01/15/v-koree-pridumali-lentochnie akkumulyatori.

[14] Created the world's first "eternal" battery. It is cheaper than lithium batteries. https://www.cnews.ru/news/top/2020-08-26_sozdana_pervaya_v_mire_vechnaya.

[15] Baterie nowej generacji, https://ichip.ru/tekhnologii/akkumulyatory-novogo-pokoleniya-49237.

[16] Gerboni R., 11 – Introduction to hydrogen transportation, [in:] Compendium of Hydrogen Energy, Volume 2: Hydrogen Storage, Transportation and Infrastructure, Woodhead Publishing Series in Energy 2016, 283-299.

Przyszłość gospodarki leżąca w energetyce jądrowej, napędzie elektrycznym i wodorowych źródłach energii

STRESZCZENIE:
Artkuł poświęcony jest perspektywie pozyskania energii elektrycznej w technologii energetyki jądrowej otrzymywanej w reaktorach szybkich neutronów chłodzonych ciekłym ołowiem. Przeprowadzono analizę sposobów gromadzenia energii elektrycznej w systemach akumulatorowych w wyniku rozwoju innowacyjnych technologii rozwiązań technicznych i materiałowych perspektywicznych rodzajów akumulatorów. Wskazano alternatywne sposoby masowego magazynowania efektywnych źródeł energii wodorowej.

SŁOWA KLUCZOWE:
technologie i źródła energii elektrycznej; rozwiązania techniczne wytwarzania i zasilania energią elektryczną