

APPLICATIONS OF LITHIUM IN NUCLEAR ENERGY

Glaucia A. C. de Oliviera, José O. V. Bustillos, João C. Ferreira, Vanderlei S. Bergamaschi, Rafaeli M. de Moraes, Maíse P. Gimenez, Flavia K. Miyamoto and José A. Seneda

Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP

glauca.oliveira@ipen.br/ovega@ipen.br/jcferrei@ipen.br/vsberga@ipen.br/
rafaeli.medeiros.moraes@gmail.com/maisepastore@hotmail.com/fla.kimiyamoto@gmail.com/
jaseneda@ipen.br

ABSTRACT

Lithium is a material of great interest in the world, it is found in different minerals on Earth's crust (spodumene, lepidolite, amblygonite and petalite) also in salt pans. This element belongs to alkaline group and has two natural isotopes: Li-6 and Li-7. In the nuclear field, lithium isotopes are used for different purposes. The Li-6 is applied in the production of energy, because its section of shock is larger than the other isotope. The Li-7 regulates the pH in refrigerant material in the primary circuits of the Pressurized Water Nuclear Reactor (PWR). In nuclear reactor, lithium is used as a heat transfer due its boiling temperature (1342°C), making it an excellent thermal conductor. However, to reach all these applications, lithium must have high purity (> 99%). The main processes to reach a high purity level of lithium employ a combination of solvent extraction and ion exchange process, to obtain its salts or ending with chemical electrolysis of its chlorides to obtain its pure metal. This work presents a review of new applications of Lithium in Nuclear Energy and its purification and enrichment processes.

1. INTRODUCTION

The lithium (Li) of the greek líthos (stone), belongs to the group of alkali metals, is the third chemical element of the periodic table with atomic number $Z = 3$, lithium is the lighter metal of all metals, with a density of 0.534 g cm^{-3} . In nature, it is found with a mixture of two stable isotopes (non-radioactive) lithium-6 and lithium-7 [1].

José Bonifácio de Andrada e Silva, mineralogist and Brazilian statesman, in 1800 made the discovery of petalite mineral and spodumene. Johan August Arfwedson, a Swedish chemist, decomposed the petalite mineral with barium carbonate, obtaining lithium carbonate and analyzing it as Lithium, "Lithos" which in Greek means stone, due to its extraction in minerals, differing from oxides of sodium and potassium that are made by extraction in vegetables [2]

Johann Nepomuk von Fuchs, German mineralogist, investigating the colors of various substances, by flame test, noticed that the spodumene had a pink / magenta color. The production of lithium metal was elaborated by Sir Humphry Davy, a British chemist, for the

electrolysis of lithium carbonate, in small quantity, and it was not possible to verify its chemical and physical properties. The highest quantity was obtained only in 1855, Robert Bunsen and Augustus Matthiessen, both Germans, by means of the electrolysis technique of the lithium fused lithium, next saved in petroleum to prevent the rapid combustion in the air and to make the appropriate analyses for its complete determination of a new chemical element [3, 4].

Lithium ore deposits, in the United States in 1901, were first exploited commercially when Maywood Chemical Works (New Jersey) started production of lithium chemicals in the country. However, the fact that contributed to the growth of the lithium market was the development and application, in 1918, in Germany, of an alloy called Bahnmittel (lithium / lead). The German company Metallgesellschaft was the first producer of lithium metal and lithium carbonate on an industrial scale, from the year 1923 [5]. In the time of the cold war (1946-1991), in addition to the uranium exploitation, lithium was used as a source of nuclear weapons [6].

Lithium is the twenty-seventh most abundant metal of the Earth with a concentration between 0.002% and 0.006% it is possible to find it next to another element, like iron and manganese, forming ores like spodumene, lepidolite, micas and others [8].

Lithium deposits are found in the form of brines, pegmatites and sedimentary rocks [9]. The world's distribution, 62% are brines and 38% mineral rocks. The largest lithium reserves are found in the countries Bolivia, Chile and Argentina [10].

1.1 Lithium Brines

Brines are saline waters with a high salt content due to the evaporation of water, minerals, such as lithium, are trapped in the porosities of rocks [9]. The extraction of lithium in brines has a lower cost compared to minerals, and is less harmful to the environment, because the climate of the place, usually desert. [10].

1.2 Lithium Minerals

Pegmatites is the designation given to an igneous rock of coarse grain. Some common lithium based minerals are Spodumene - $\text{LiAlSi}_2\text{O}_6$ (8.03%), Lepidolite $\text{K}(\text{Li},\text{Al},\text{Rb})_2(\text{Al},\text{Si})_4\text{O}_{10}(\text{F},\text{OH})_2$ (7.7%), Petalite - $\text{LiAlSi}_4\text{O}_{10}$ (4.5%) and Amblygonite $(\text{Li},\text{Na})\text{AlPO}_4(\text{F},\text{OH})$ (7.4%). It has been studied that concentrations exceeding 0.5% are feasible to extract lithium [11].

2. LITHIUM IN NUCLEAR ENERGY

Lithium in nuclear energy has been gaining prominence in recent years, as it represents the main element for fusion reactions. Lithium has two isotopes, one of them is lithium-7, which contributes 92.41 % to the composition of natural lithium. The other isotope is lithium-6, which although responsible for only the remaining 7.59 %, consists of the isotope used in the production of nuclear energy. The use of the mineral in the nuclear area involves a particularity: as lithium is very diluted in nature, it needs to be enriched by means of chemical routes that result in the production of its derivatives [1].

2.1. Lithium 6

The lithium-6 has been used as shield against the effects of radiation and in applications in the control of the nuclear reactors since it has high shock section for absorption of thermal neutrons of the order of 947 barns [14]. The advantage of absorbing neutrons without, however, emitting gamma rays [1].

When this isotope is irradiated with thermal neutrons the reaction occurs: ${}^6\text{Li}(n,\alpha){}^3\text{H}$. A tritium atom is formed which can be used as fuel in nuclear fusion reactors by the reaction between tritium and deuterium, yielding 17.6 MeV per reaction [1].

In the first generation fusion reactors two hydrogen isotopes, deuterium (D) and tritium (T) will be introduced at high temperature plasma to fuse to produce thermal energy according to the nuclear fusion reaction as equation 1[1]:



The most suitable material for the preparation of the tritium in a fusion reactor is lithium, making it imperative that there is sufficient supply of tritium to maintain the melting reaction.

It is possible to note that lithium is very important for the generation of thermonuclear energy. Lithium has a promising future as the thermonuclear reactors fuel for the fusion process, and can be used for the production of alpha particles, according to the reaction as equation 2 [1]:



Unfortunately, tritium is not available naturally and therefore must be produced by the transmutation of lithium. The three compounds: LiAlO_2 , Li_2TiO_3 e Li_2ZrO_3 , are known as advanced materials for the fusion reactor [1].

Lithium-based ceramics have long been recognized as promising materials for tritium production in the blankets of fusion reactors. Because of their desirable overall properties, the type of ceramics are: Li_2O , LiAlO_2 , LiTiO_3 , Li_2ZrO_3 e Li_4SiO_4 , considered for their suitability as acceptable materials for the blanket and source of tritium for the fusion reactor.

While Li_2O and Li_4SiO_4 show the highest density in lithium atoms, it also has the highest vaporization rate and higher sensitivity to moisture. Li_2ZrO_3 shows excellent irradiation and breeding in several worldwide tests with up to 10% lithium burn-up.

The overall behavior of Li_2TiO_3 is excellent with respect to tritium release, moisture insensitivity and low activation. Emphasis on materials with low activation gives great importance to ceramics such as Li_2O , Li_4SiO_4 e Li_2TiO_3 [12].

2.2 Lithium 7

The lithium-7 isotope is used as a coolant in high temperature reactors because it combines thermodynamic and heat transfer characteristics with a low shock section for thermal neutrons [1,13].

Nuclear reaction (n, α) at a target containing the boron-10 isotope produces lithium-7, this reaction is used for the detection of thermal neutrons.

The lithium-7 regulates the pH in refrigerant material in the primary circuits of the Pressurized Water Nuclear Reactor (PWR) [14].

2.3 Purification and Enrichment of Lithium

The energy requirement for the separation of isotopes of the lithium need not be any larger than that needed to overcome the entropy of mixing of the isotopes provided a thermodynamically reversible system is employed. In addition to being slow at times, thermodynamically reversible processes are difficult to obtain. Processes carried out at chemical equilibrium offer this opportunity.

The separation of isotopes by chemical equilibrium methods is possible with two phase systems such as a gas and a liquid, two immiscible liquids, a liquid and a solid, or a gas and a solid. Since compounds of lithium which remain gaseous at room temperature are unknown, the separation of lithium isotopes by chemical methods has been limited to liquid-liquid and liquid-solid systems [15].

3. CONCLUSIONS

Nuclear energy from thermonuclear lithium, being competitive and having a release of small carbon dioxide, contributes to the sustainability of the planet. In this work, we present relevant information for this to be accomplished.

ACKNOWLEDGMENTS

We would like to thanks for the Instituto de Pesquisas Energéticas e Nucleares and Companhia Brasileira de Lítio – CBL to support this research.

REFERENCES

1. A. Abrão, "Uses of lithium in nuclear energy". Institute of Energy and Nuclear Research, São Paulo (1995).
2. M. A. Weeks, M. E. J.A Larson, Arfwedson and His Services to Chemistry. "Journal Of Chemical Education", pp. 403-407 (1937).
3. P. F. A. Braga, J. A Sampaio, "Lítio". *Industrial rocks and minerals*. 2. ed. Rio de Janeiro: Cetem, pp.19 (2008).
4. F. N. Johnson, *The history of lithium therapy*. 1st ed. Macmillan (1984).

5. A.J. Ober, *Commodity Report: Lithium*. United States geological survey (1994).
6. T.F. Hamilton, “Chaper 2 Linking legacies of the Cold War to arrival of anthropogenic radionuclides in the oceans through the 20th century”, *Marine Radioactivity*. Monaco, Pergamon, **6**, pp. 23-78 (2005).
7. K. Fiori, “Nuclear energy and sustainability: Understanding ITER”. *Energy Policy*, Cedex, **34**, n. 1, p.3334-3341, (2005).
8. G. F. Ribeiro, “Diagnóstico sobre o lítio, Situação Brasileira”. Rio de Janeiro, CNEN, (1984).
9. P. W. Gruber, P. A. Medina, G. A. Keoleian, *Global Lithium Availability*. (2011). http://www.eenews.net/assets/2011/07/27/document_gw_02.pdf (2017).
10. C. Grosjean, P. Miranda, M. Perrin, P. Poggi, “Assessment of world lithium resources and consequences of their geographic distribution on the expected development of the electric vehicle industry”. *Renewable and Sustainable Energy Reviews*, **16**, pp. 1735-1744 (2012).
11. S. Kosaraju, “A review of the importance of recycling lithium-ion batteries for lithium, in view of impending electric vehicle industry”. <http://publications.lib.chalmers.se/records/fulltext/165368.pdf> (2012).
12. K. Tsuchiya, H. Kawamura, “Trial fabrication of tritium breeders for fusion blanket with lithium recovered from seawater”. *Oarai Research Establishment, JAERI, Japan Fusion Engineering and Design* (1998).
13. “Evaluated Nuclear Data File (ENDF) Retrieval & Plotting-National Nuclear Data Center” <http://www.nndc.bnl.gov/sigma/index.jsp?as=6&lib=endfb7.0&nsb=10> (2017).
14. T. Ault, K. Brozek, L. Fan, M. Folsom, J. Kim, J. Zeisner, “Lithium Isotope Enrichment: Feasible Domestic Enrichment Alternatives”. *Department of Nuclear Engineering University of California*, Berkeley (2012).
15. V. D. Allred, I. B. Cutler, *Technical report: Chemical Methods for the Separation of Lithium isotopes*, ORNL (1953).