On the role of nuclear binding energy in understanding the E-CAT energy liberation and isotopic change mechanisms

(Sub title: Nickel – the future heat energy resource)

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Abstract: During E-CAT test run some hidden and unknown energy is being coming out in the form of heat energy in large quantity. Based on the principle of conservation of energy and from the well known nuclear fusion and fission reactions it is possible to guess that, the E-CAT hidden energy may be in the form of binding of protons and neutrons of the Nickel and Lithium atomic nuclei. By considering the nuclear binding energies of $^{58}_{28}Ni$, $^{62}_{28}Ni$ and $^{7}_{3}Li$ an attempt is made to understand the energy liberation mechanism in E-CAT. With reference to the net energy production of (5825 ± 10%) Mega Joules liberated from one gram Ni of the E-CAT's 32 days third party test run, it can be suggested that, for every transformation of $^{58}_{28}Ni$ to $^{62}_{28}Ni$ via $^{7}_{3}Li$, liberated heat energy is 3.64 MeV and for one gram of $^{58}_{28}Ni$ liberated energy is 5984 Mega Joules. For each transformation of $^{58}_{28}Ni$ to $^{62}_{28}Ni$ via $^{7}_{3}Li$, 3 hydrogen atoms can be expected to be emitted. Note that, energy liberated for one gram of Nickel 58 in cold fusion is 1.66 MWh and energy liberated for one gram of uranium 235 in nuclear fission is 22.6 MWh. Clearly speaking, energy released in E-CAT is just 13.6 times less than the energy released in Uranium 235 fission.

Keywords: Cold fusion, Low energy nuclear reactions, E-CAT (Energy Catalyzer)

1. Introduction

One can see the pathetic history and current golden status of Cold fusion or Low energy nuclear interactions (LENR) in the Wikipedia. Since 1989 many scientists proposed many interesting proposals for understanding the observed excess heat generation with various experimental setups [1-11]. Many researchers and scientists around the world have reported successful experiments at a number of international conferences, and selected articles are collected in an on-line data base. The results, however, have not been taken seriously by main stream science, even after full support by two Nobel laureates, Julian Schwinger and Brian Josephson. Julian Schwinger (1918-1994), a Nobel prize winner in Physics, 1965, who also worked with Oppenheimer, was a strong advocate of cold fusion [12]. Brian Josephson, a Nobel prize winner in Physics, 1973, is a discoverer of the Josephon effect in the field of superconductivity. He is presently a strong supporter of cold fusion [13].

These new interactions are exclusively based on 'excess heat generation' and are absolutely free from the currently believed alpha, beta and gamma radiations. Experts believe that, LENR could use 1% of the Nickel mined to produce current world energy at a price four times cheaper than coal. Joseph Zawodny, a senior research scientist with NASA 's Langley Research Center says: "It has the demonstrated ability to produce excess amounts of energy , cleanly , without hazardous ionizing radiation, without producing nasty waste". It is not a surprise to say that, very soon LENR will dominate all the current leading research areas of physics in the near future.

2. History of the E-CAT

Kanarev [14] and Japanese researcher Dr. T. Mizuno [15] provided measurable proof of fusion and fission products. In Italy, the cold fusion research pioneered by Francesco Piantelli in 1989 has been extended and supported by the local inter-university centers in Bologna (Focardi, Campari) and Sienna (Piantelli, Gabbani, Montalbano, Veronesi). A detailed report about this research was published by the Italian National Agency for New Technology, Energy and Environment in 2008. Piantelli filed two patents WO9520816 (1997) and WO2010058288 (2010), describing different methods, and published an article ITSI920002 about cold fusion of nickel with deuterium or hydrogen. Recently, interest in cold fusion as an alternative to nuclear energy was raised by the successful demonstration of the Rossi cold fusion device called E-cat. E-CAT (Energy Catalyzer) seems to be the most promising apparatus in this regard [16-20]. It is invented and being developed by Andrea Rossi. The Focardi-Rossi method of nuclear reaction Ni + H -> Cu is based on the preliminary research of Focardi and colleagues. Sergio Focardi is an emeritus professor at the University of Bologna while Andrea Rossi is a skilled researcher and inventor. After years of successful collaboration, they gave on January 14, 2011, the first public demonstration of a nickel-hydrogen fusion reactor, called E-cat, capable of producing more than 10 kilowatts of heat power, while only consuming a fraction of that. In 2008 Rossi filed International patent application WO 2009/125444 A1 entitled Method and Apparatus for Carrying out Nickel and Hydrogen Exothermal Reaction. Ignoring the skepticism in the main stream science, Rossi proceeded further with the development and manufacturing of his E-cat generator. Public demonstrations of the E-cat reactor with some invited experts were made on January 14, March 29, April 19 and 28, September 7, October 6 and October 28, 2011. During the larger public demonstration on October 28, 2011, Rossi invited a few dozen people, including a group of engineers from an unnamed potential US customer, as well as a handful of journalists. According to Rossi, each module received an initial energy input of 400 watts and produced a self-sustaining, continuous output of about 10 kilowatts per hour for the next few hours.

3. E-CAT – recent test run observations and understanding its hidden mechanism

In a third party inspection, the E-CAT subject to testing was powered by 360 W for a total of 96 hours, and produced in all 2034 W thermal [18]. In this context experts say:

1) Something "REAL" is happening and we are certainly dealing with a new source of energy.
2) There are efforts ongoing to explore the validity of the theories and the weak interaction theories suggest what the physics might be.

Recent third party test run at Switzerland [19], authors of the test run conclude that,

1) "A 32-day test was performed on a reactor termed E-Cat, capable of producing heat by exploiting an unknown reaction primed by heating and some electro-magnetic stimulation. In the past years, the same collaboration has performed similar measurements on reactors operating in like manner, but differing both in shape and construction materials from the one studied here. Those tests have indicated an anomalous production of heat, which prompted us to attempt a new, longer test. The purpose of this longer measurement was to verify whether the production of heat is reproducible in a new improved test set-up, and can go on for a significant amount of time. In order to assure that the reactor would operate for a prolonged length of time, we chose to supply power to the E-Cat in such a way as to keep it working in a stable and controlled manner. For this reason, the performances obtained do not reflect the maximum potential of the reactor, which was not an object of study here".
2) "In summary, the performance of the E-Cat reactor is remarkable. We have a device giving heat energy compatible with nuclear transformations, but it operates at low energy and gives neither nuclear radioactive waste nor emits radiation. From basic general knowledge in nuclear physics this should not be possible. Nevertheless we have to relate to the fact that the experimental results from our test show heat production beyond chemical burning, and that the E-Cat fuel undergoes nuclear transformations. It is certainly most unsatisfying that these results so far have no convincing theoretical explanation, but the experimental results cannot be dismissed or ignored just because of lack of theoretical understanding. Moreover, the E-Cat results are too conspicuous not to be followed up in detail. In addition, if proven sustainable in further tests the E-Cat invention has a large potential to become an important energy source. Further investigations are required to

guide the interpretational work, and one needs in particular as a first step detailed knowledge of all parameters affecting the E-Cat operation. Our work will continue in that direction".

From current known physics point of view it is quite shocking, quite bitter and demands the need of review and revision of our known physical laws and concepts. Based on the principle of conservation of energy it is clear that, during LENR and Cold fusion some hidden and unknown energy is being coming out in the form of heat energy. From the well known nuclear fusion and fission reactions it is possible to guess that, the hidden energy may be in the form of binding of protons and neutrons of the Nickel and Lithium atomic nuclei.

4. Estimating the possible liberated heat energy in E-CAT

Authors of the recent E-CAT test run say:

1) "The fuel generating the excessive heat was analyzed with several methods before and after the experimental run. It was found that the Lithium and Nickel content in the fuel had the natural isotopic composition before the run, but after the 32 days run the isotopic composition has changed dramatically both for Lithium and Nickel. Such a change can only take place via nuclear reactions. It is thus clear that nuclear reactions have taken place in the burning process. This is also what can be suspected from the excessive heat being generated in the process".
2) "The unused fuel shows the natural isotope composition from both SIMS and ICP-MS, i.e. 58Ni (68.1%), 60Ni (26.2%), 61Ni (1.1%), 62Ni (3.6%), and 64Ni (0.9%), whereas the ash composition from SIMS is: 58Ni (0.8.%), 60Ni (0.5%), 61Ni (0%), 62Ni (98.7%), 64Ni (0%), and from ICP-MS: 58Ni (0.8%), 60Ni (0.3%), 61Ni (0%), 62Ni (99.3%), 64Ni (0%).We note that the SIMS and ICP-MS give the same values within the estimated 3% error in the given percentages. Evidently, there is also an isotope shift in Nickel. There is a depletion of the 58Ni and 60Ni isotopes and a buildup of the 62Ni isotopes in the burning process. We note that 62Ni is the nucleus with the largest binding energy per nucleon. The origin of this shift cannot be understood from single nuclear reactions involving protons".
3) "The Lithium content in the fuel is found to have the natural composition, i.e. 6Li 7 % and 7Li 93 %. However at the end of the run a depletion of 7Li in the ash was revealed by both the SIMS and the ICP-MS methods. In the SIMS analysis the 7Li content was only 7.9% and in the ICP-MS analysis it was 42.5 %. This result is remarkable since it shows that the burning process in E-Cat indeed changes the fuel at the nuclear level, i.e. nuclear reactions have taken place. It is notable, but maybe only a coincidence, that also in Astrophysics a 7Li depletion is observed".
4) "Our measurement, based on calculating the power emitted by the reactor through radiation and convection, gave the following results: the net production of the reactor after 32 days' operation was (5825 ± 10%) [MJ], the density of thermal energy (if referred to an internal charge weighing 1 g) was (5.8 · 106 ± 10%) [MJ/kg], while the density of power was equal to (2.1 · 106 ± 10%) [W/kg]. These values place the E-Cat beyond any other known conventional source of energy. Even if one conservatively repeats the same calculations with reference to the weight of the whole reactor rather than that of its internal charge, one gets results confirming the non-conventional nature of the form of energy generated by the E-Cat, namely (1.3 · 104 ± 10%) [MJ/kg] for thermal energy density, and (4.7 · 103 ± 10%) [W/kg] for power density".

From above points and with reference to the net energy production (**5825 ± 10%**) MJ (of the reactor for 32 days run with one gram of Ni) - quantitatively it can understood in the following way. Binding energy of $^{58}_{28}\mathrm{Ni}$ is 506.6 MeV and binding energy of $^{62}_{28}\mathrm{Ni}$ is 544.1 MeV. Similarly binding energy of $^{7}_{3}\mathrm{Li}$ is 41.45 MeV. For a moment guess that, $^{7}_{3}\mathrm{Li}$ joins with $^{58}_{28}\mathrm{Ni}$ forming $^{62}_{28}\mathrm{Ni}$ and emits 3 hydrogen atoms. Clearly speaking, $^{7}_{3}\mathrm{Li}$ transforms to 4 neutrons and 3 hydrogen atoms. 4 neutrons joins with $^{58}_{28}\mathrm{Ni}$ forming $^{62}_{28}\mathrm{Ni}$. To have stability $^{62}_{28}\mathrm{Ni}$, must gain an effective binding energy (544.1-506.6)=37.81 MeV [20,21]. It can be gained from the binding energy 41.45 MeV of

$^{7}_{3}\mathrm{Li}$. If so the remaining binding energy of $^{7}_{3}\mathrm{Li}$ is **[41.45-(544.41-506.6)]=3.64 MeV** and it may be liberated out in the form of heat energy. For every transformation of $^{58}_{28}\mathrm{Ni}$ to $^{62}_{28}\mathrm{Ni}$ via $^{7}_{3}\mathrm{Li}$, liberated heat energy is 3.64 MeV and for one gram of $^{58}_{28}\mathrm{Ni}$ liberated energy is **5984 Mega Joules**. This can be compared with the observed E-CAT's 32 day output energy with one gram Ni fuel. If it is possible to design the E-cat to have mole transformations of $^{58}_{28}\mathrm{Ni}$ to $^{62}_{28}\mathrm{Ni}$ via $^{7}_{3}\mathrm{Li}$ for second, then for every second, **0.3512 Tera Joules** of energy can be liberated.

In general, the number of successful transformations $^{58}_{28}\mathrm{Ni}$ to $^{62}_{28}\mathrm{Ni}$ will depend on the quantity of Ni powder, fineness of the nickel powder, working temperature, working pressure and volume of the E-CAT, kinetic energy of Nickel and Hydrogen, melting points of nickel and lithium, unknown catalyst, efficiency of the E-CAT etc. Keeping all these parameters, instead of mass of Nickel, it is possible to consider number of $^{58}_{28}\mathrm{Ni}$ to $^{62}_{28}\mathrm{Ni}$ transformations per second. Design capacity of E-CAT can be fixed in this way for different large scale, medium scale and small scale applications. So, number of transformations, $n \cong f \cdot N_A$ where $f \approx 10^{-6}$ to 1 and can be called as the working factor. Now in a simplified view, proposed mechanism can be expressed in the following way.

If chosen time unit is One second,

$$\text{Energy liberated/sec} \cong f \times N_A \times 3.64 \text{ MeV/sec}$$
$$\cong f \times 0.3512 \text{ Tera J/sec}$$

where $f \approx 10^{-6}$ to 1.

If chosen time unit is One hour,

$$\text{Energy liberated/hour} \cong f \times N_A \times 3.64 \text{ MeV/hour}$$
$$\cong f \times 0.3512 \text{ Tera J/hour}$$

where $f \approx 10^{-6}$ to 1. Note that for one gram of Ni fuel, number of transformations can be understood as follows.

$$n \cong \frac{1\times10^{-3} \text{ (kg)}}{58.69334\times1.66053892\times10^{-27}\text{(kg)}} \cong 1.02603\times10^{22}$$
$$\Rightarrow f \cong \frac{n}{N_A} \cong \frac{1}{58.69334} \cong 0.01703768$$

Note that, energy liberated for one gram of Nickel 58 in cold fusion is 1.66 MWh and energy liberated for one gram of uranium 235 in nuclear fission is 22.6 MWh. Clearly speaking, energy released in E-CAT is just 13.6 times less than the energy released in Uranium 235 fission.

5. Characteristic applications of E-Cat

1) **Mini power plants for 5 to 10 Villages or two Towns or one City**
2) **Medium scale industrial power generation**
3) **Power generation for Busses, Lorries, Trucks, Cars and Bikes**
4) **Power generation for Trains, Ships, Submarines and Aero planes (if possible)**
5) **Power generation for medium and big residential and commercial apartments**
6) **Cold room heating, hot water generation and direct food cooking with hot water.**
7) **Farm field mini alternators for 2 to 3 successful crops per year with high yield**
8) **Hose hold and special purpose laboratory mini alternators**

9) **De-centralized, Uninterrupted, Pollution free and Risk free power supply**
10) **Slow and gradual stopping of coal and oil usage for power generation and minimizing their transportation charges.**
11) **Converting the closed and intermittent running biomass based power plants into E-CAT type power plants**
12) **In future, Uranium based nuclear power plants can be converted to Ni based E-CAT power plants.**

6. Discussion

From the 32 day experimental run of E-CAT, (measured) liberated energy for one gram of Nickel-58 is 5825 MJ with ±10% error. With the proposed method, (estimated) liberated energy for one gram of Nickel-58 is 5984 MJ. This is an excellent fit. If one is willing to consider the proposed methodology, E-CAT working mechanism and isotopic change mechanism both can be understood. Not only that, by considering the number of transformations of $^{58}_{28}\mathrm{Ni}$ to $^{62}_{28}\mathrm{Ni}$ per hour it is possible to decide the design capacity of E-CAT. Thus it may be helpful in designing the future E-CAT with all possible controls like E-CAT reactor volume, E-CAT working temperature, E-CAT working temperature, frequency of addition quantity of Nickel, frequency of addition quantity of Lithium etc.

On the E-CAT's recent third party test run, one can see various positive and appreciating comments in Andrea Rossi's blog, http://www.journal-of-nuclear-physics.com/. Andrea Rossi personally appreciated authors current approach on E-CAT mechanism and published the basic idea of this paper as a comment in the blog. No doubt, E-CAT can be considered as the most promising equipment for future power generation with plenty of available nickel, low working temperatures, no nuclear radiations, no pollution and no risk. Currently Andrea Rossi is seriously concentrated on developing E-CAT in all respects. Mean while Indian government, scientists, professors, industrialists and engineers may focus their attention on E-CAT design for fulfilling the infinite demand of electric power generation in India.

7. Conclusions

So far no model is successful in understanding and estimating the energy liberated in Cold fusion phenomenon. Considering the proposed concepts, it is possible to fit, estimate and design a cold fusion based apparatus like E-CAT for different energy level applications. With further research and analysis basics of 'cold fusion' can be established.

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