Analogical understanding of the Ragone plot and a new categorization of energy devices

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Abstract

The main function of energy devices is to generate power and store energy. The typical storage devices are battery and capacitor; generation devices are internal combustion engine (ICE), gas turbine, and fuel cell. Every kinds of energy devices can be compared together in the Ragone plot with respect to specific energy and specific power. Moreover, some difficulties to make position of solar cell in the Ragone plot are proposed. In this paper some analogical explanation is given to understand the underlined meaning. The barrel model is introduced to make analogy; the specific volume and area to the specific energy and specific power. The relationship between the curves depicted in axises of cell voltage with current and specific energy with specific power is tried to be shown in the viewpoint of device operation conditions. Also, the limitation of the Ragone plot is discussed to encompass the existing energy devices to be utilized as the standard benchmarking chart.

1. What is the Ragone plot?

Due to increasing energy consumption and environmental hazardous, the efficient and clean energy sources are urgently required in modern society. Thus, energy devices such as battery, fuel cell, solar cell, geo-thermal, and wind turbine are developed; also, their performance have been enhanced extremely. In addition, hybridization of two or more of them is seriously considered by many groups. The Ragone plot is a famous guide line for energy devices. The Ragone plot named by David V. Ragone has been

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originally used for the purpose of comparison among battery performance. [1, 2] Also, it is useful tool for comparing energy devices such as fuel cell, internal combustion engine, etc. [3, 4]

The Ragone plot clearly shows limitation and direction of energy devices development. The new developed batteries should be placed on the Ragone plot to higher position toward normal axis which refers high energy density. The point which represents fuel cell has to move right side of the Ragone plot which refers increasing power density. Even if the Ragone plot clearly and systematically expresses the guide line of energy device development, there are several problems for requiring enhancement. First, the Ragone plot cannot express all energy devices such as solar cell and wind turbine. Second, the plot cannot follow modern technology development. Thus, more accurate and extensive plot is urgently required for devoting energy device development.

1.1. Analogical understanding of the Ragone plot

For plotting the Ragone plot, the characteristics of devices have to be fully understandable such as energy density and power density of devices. Also, the ratio of energy and power density tells the characteristic of each energy device. So, devices, which are included in the same category, are followed the same slope. However, it is very difficult to intuitively understand the slope which is relationship between energy and power density. It can be simply understandable using simple analogy such as water barrel as shown in figure 1(a). In this analogy, the size of barrel and opening size of barrel are represent the energy density and power density of energy devices.
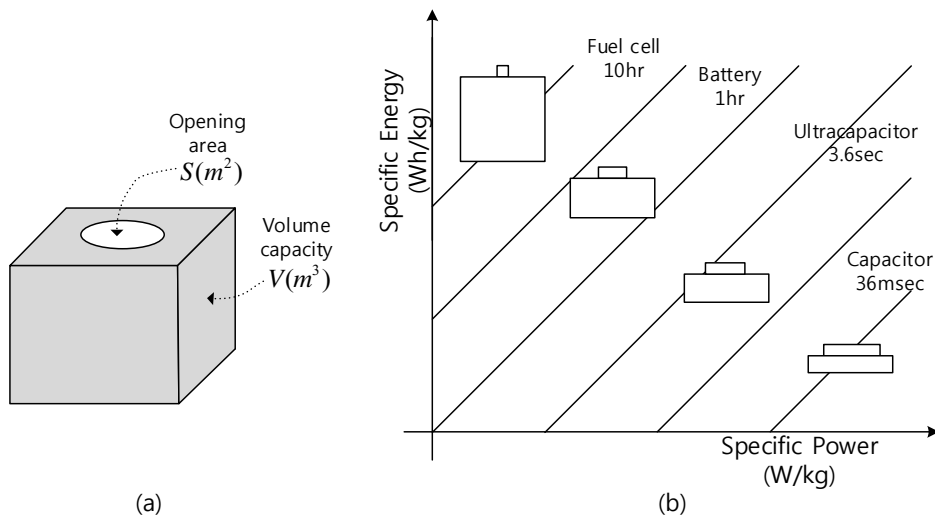

Fig. 1. (a) Barrel model for energy devices; (b) Specific area and specific volume plot

$$specific\ area = S/m\,(m^2\,/\,kg) \tag{1}$$

$$specific\ volume = V/m\,(m^3\,/\,kg) \tag{2}$$

Specific area is defined as the ratio of opening and mass of barrel as shown in equation (1). And, specific volume is defined as the ratio of barrel volume and mass of volume as shown in equation (2). The specific area and volume are corresponding power density and energy density respectively. The ultra-capacitors (super-capacitors) can deliver very high power but the storage capacity is very limited. It can be expressed the barrel which has large specific area and small specific volume. The ratio of the specific area and specific volume are constant for all batteries as shown in figure 1(b). Fuel cells can store large