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Neutronic Performance on A Mixed Cold Moderator of Polyethylene Particles and Liquid Hydrogen

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ABSTRACT

We measured the neutronic performance of a mixed moderator of polyethylene particles plus liquid hydrogen as the first test of a mixed type moderator. The energy spectrum from the mixed moderator looks like a linear combination of each spectrum from the polyethylene particles and from liquid hydrogen. We obtained 1.2~1.4 times higher cold neutron intensity, but with a longer pulse width than a decoupled liquid hydrogen moderator in the cold neutron region. In the slowing-down region it gave much higher intensity with almost the same pulse width. We found that this type of moderator exhibits better characteristics as a narrow pulse thermal neutron source.

1. INTRODUCTION

Methane and liquid hydrogen (L-H_2) have widely been used as cryogenic moderator materials. However, as well known, the radiation induced decomposition and resulting polymerization or carbonization causes many troubles in using methane moderators in MW class pulsed (spallation) neutron sources. Solid methane can not be used, in spite of its superior performance, because of the so-called burp. Liquid methane does not work, too, because higher-order polymers deposited in the moderator chamber prevent the circulation of the fluid and degrade the neutronic performance. An unique material which can stably be used under high radiation fields in MW sources is L-H_2. However, the neutron intensity from a L-H_2 moderator is lower than that from a solid methane moderator due to a lower number density of hydrogen atoms in the former.

Liquid methane moderators, which have been used for supplying short (narrow) pulses of thermal neutrons, have been proved to be very useful for high resolution applications such as powder diffractions and inelastic scattering experiments in the thermal neutron region. The development of a new method to use liquid methane in a MW-class source or an alternative moderator is one of the most important issues for next generation high-power pulsed neutron sources.

If we consider a narrow pulse moderator, the use of an ambient temperature premoderator is nonsense because of the pulse width broadening. If we can compensate the shortage in the number density of L-H_2 by mixing proper hydrogenous solid particles, we could expect a narrow thermal neutron pulses together with a higher cold neutron intensity. A mixed moderator concept of solid methane particles plus L-H_2 has been proposed, aiming at a higher cold neutron intensity and narrow pulses of thermal neutrons[1-2].

We examined a mixed moderator of polyethylene particles plus L-H_2 in order to understand the mechanism of neutron thermalization in this kind of mixed moderators, aiming at a higher intensity in the thermal and cold neutron regions, with a narrow pulse of thermal neutrons. Although polyethylene particles were selected mainly for simplicity (not as the best candidate for a narrow pulse moderator), we expected a better performance compared with a pure L-H_2 moderator.

The present results will also provide useful information for the development of a mixed moderator of solid methane plus L-H_2.

2. EXPERIMENTS

We performed the experiments by using a cold neutron source at the Hokkaido linac facility. We used a 45 MeV electron linac as a fast neutron generator. Figure 1 shows the target-moderator-reflector assembly used. The moderator chamber has a viewed surface of 12 cm x 12 cm and a thickness of 5 cm. We used a graphite reflector about $1 m^3$. The moderators were decoupled from the reflector by 0.5 mm thick cadmium plates. The flight-path length between the moderator surface and a ^{3}He detector was 6.0 m for energy spectrum measurements and 7.8 m for pulse shape measurements.

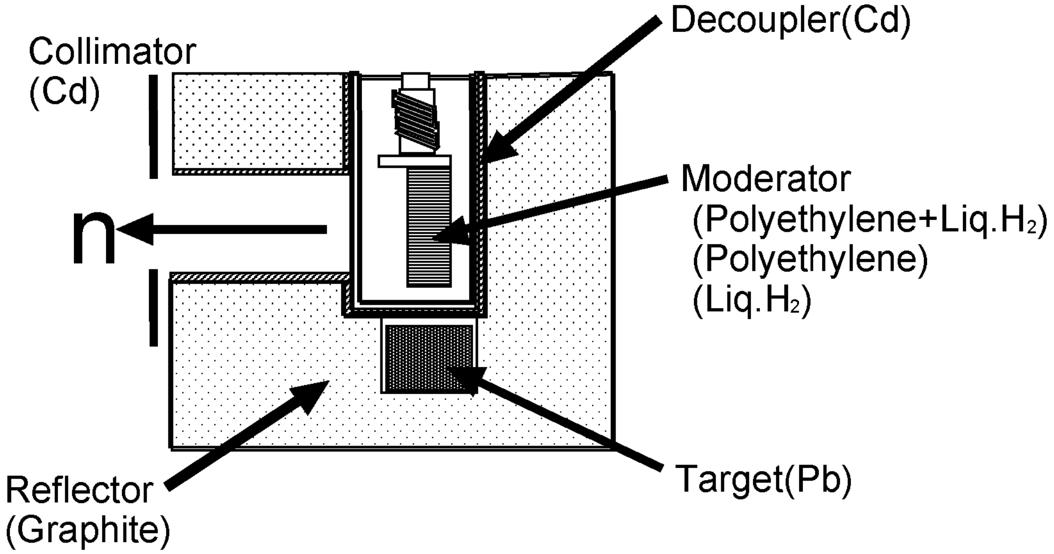

Figure 1. Experimental setup of target-moderator-reflector assembly.

Table 1. Main parameters of polyethylene in a mixed moderator.

Material:	Low Density Polyethylene (Hydrogen Number Density $6.7 \times 10^{22} H/cm^3$)
Particle Size Distribution:	0.85 - 1.18 mm
Packing Factor:	64.5 %
Overall Hydrogen Number Density: in the mixed moderator:	$6.7 \times 10^{22} H/cm^3$ $(7.9 \times 0.645 + 4.2 \times 0.355 \times 10^{22})$
in P. E. particle moderator:	$5.1 \times 10^{22} H/cm^3$ $(7.9 \times 0.645) \times 10^{22}$
in Liq. H_2 moderator:	$4.2 \times 10^{22} H/cm^3$

Main parameters of the polyethylene particles used in the present experiment are listed in Table 1. The hydrogen number density of polyethylene is almost the same as that of solid methane. The mean free path of cold neutrons in polyethylene at the Maxwellian peak energy (~3 meV) is about 1 mm. Therefore, we decided to use the particles of about 1 mm in diam., and chose the particles with diameters from 0.85 to 1.18 mm by using testing sieves carefully. We determined the packing factor from the weight and the volume measurements. The overall hydrogen number density of the mixed moderator was about 6.7 x 10^{22}(H/Cm^3), almost the same as that in light water (about 6.8 x 10^{22}).

We also measured the energy spectra from two pure moderators, L-H_2 and polyethylene particles for comparison. For the measurement of a polyethylene particle moderator (not containing L-H_2), we introduced a small amount of helium gas into the moderator chamber to improve the heat transfer. After the surface temperature of the cryogenic chamber reached at 20K, we waited for a few hours before the measurement of the energy spectrum. So, we are sure that the temperature of polyethylene particles was 20K.

3. ENERGY SPECTRA

Figure 2 shows the measured energy spectra. The peak energy of the spectrum from the polyethylene particle moderator is about 6-7 meV, which is higher than the other moderators, because polyethylene has no effective energy exchange mode at lower energies. The energy spectrum from the mixed moderator looks like a linear combination of each spectrum from the polyethylene particle moderator and the L-H_2 moderator. In the slowing-down region, the intensity is mainly determined by the polyethylene particles, while in the equilibrium region mainly by L-H_2. The intensity ratio of the mixed moderator to the L-H_2 moderator is somewhat larger around the peak energy (6-7 meV) in the polyethylene particle moderator than that at the cold neutron region. The ratio reaches about 1.7 around 0.1 eV (see Figure 7).

The average hydrogen number density in the polyethylene particle moderator and the mixed moderator were about 1.1 times and 1.5 times higher than that of the L-H_2 moderator, respectively. However, there is almost no difference in the neutron intensities in the slowing-down region. This result shows that in polyethylene not only the increase in the hydrogen number density but also the decrease of the moderating power play an important role to determine the intensity.

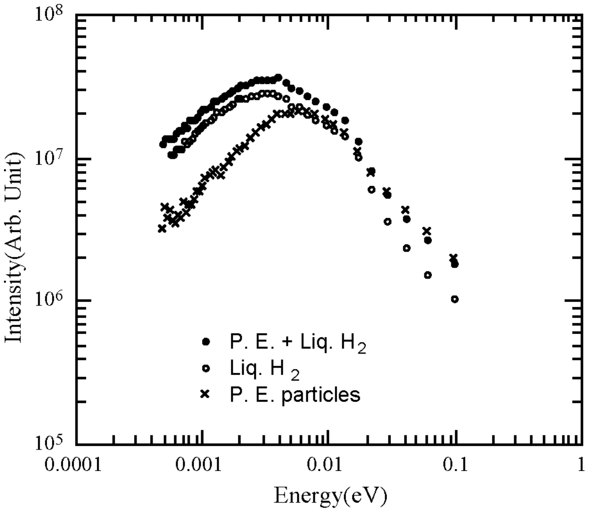

Figure 2. Energy spectrum from the mixed moderator, compared with those from two pure moderators.

4. TIME DISTRIBUTIONS

Figure 3 shows measured pulse shapes from the mixed moderator and the reference L-H_2 moderator at three different energies: slowing-down, thermal and cold regions. The left sides are the linear plots while the right sides are the semi-logarithmic plots. In these figures, the intensities were normalized using the time-integrated intensities shown in Figure 2. Figure 4 shows the measured pulse widths from the mixed moderator compared with those from various moderators so far measured.

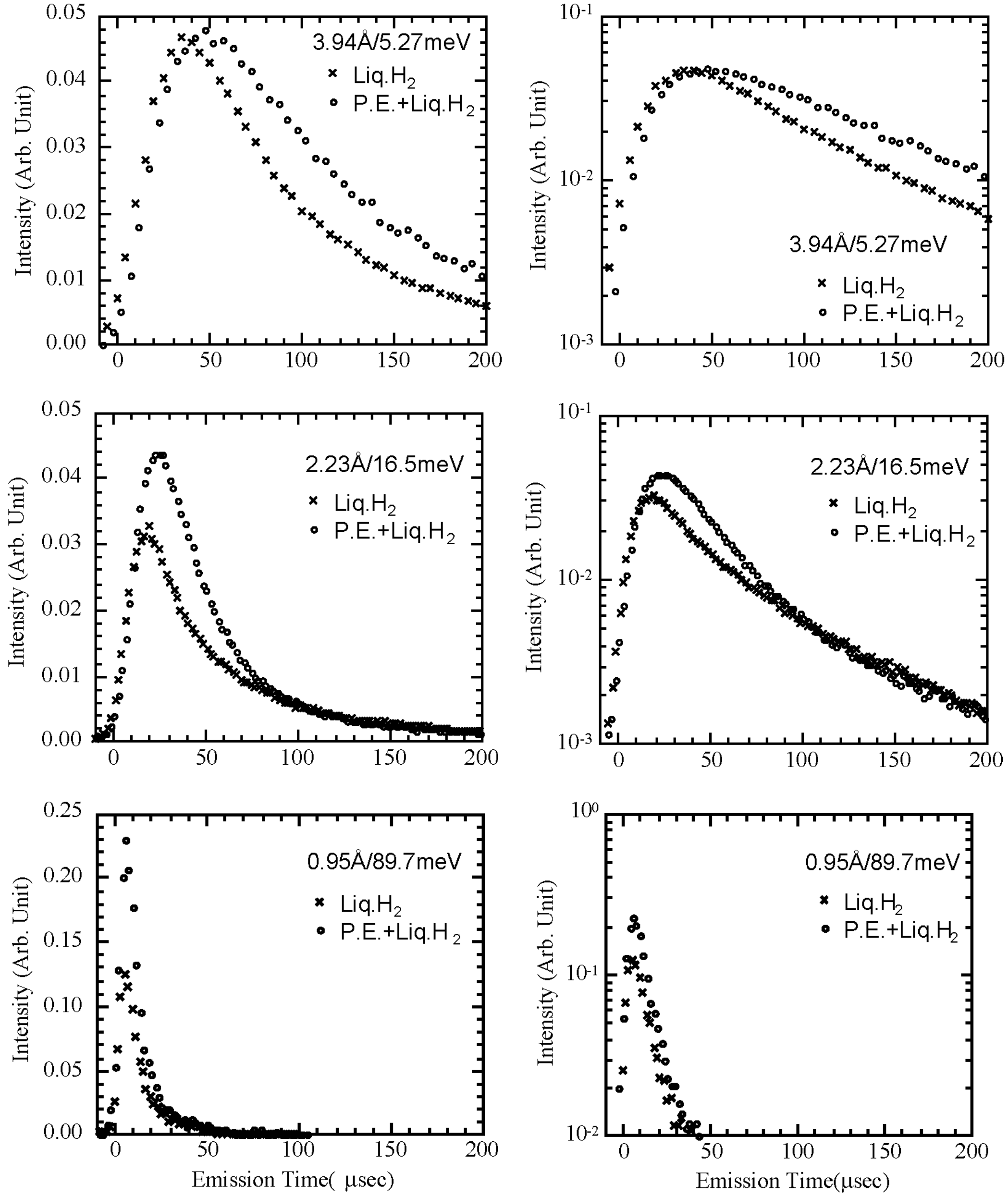

Figure 3. Pulse shapes at three different energies. Left sides are linear plots and right sides are semi-logarithmic plots.

In pure moderators, it is confirmed that the pulse shapes can generally be characterized as a sum of two components; slowing-down and storage, as reported by Ikeda and Carpenter[3]. In the mixed moderator we found that the pulse shapes can also be expressed by the Ikeda-Carpenter formula; no additional component, suggesting that the mixed moderator behaves like a homogeneous mixture. In the slowing-down region the pulse width from the mixed moderator is almost comparable to that from the pure moderator but the peak intensity increases to some extent. While in the cold region the pulse width increases without the increase in the peak intensity. From these results, it turns out that in the slowing-down region the gain in the intensity is due to the increase of the pulse height, but to the increase of the pulse width in the cold region.

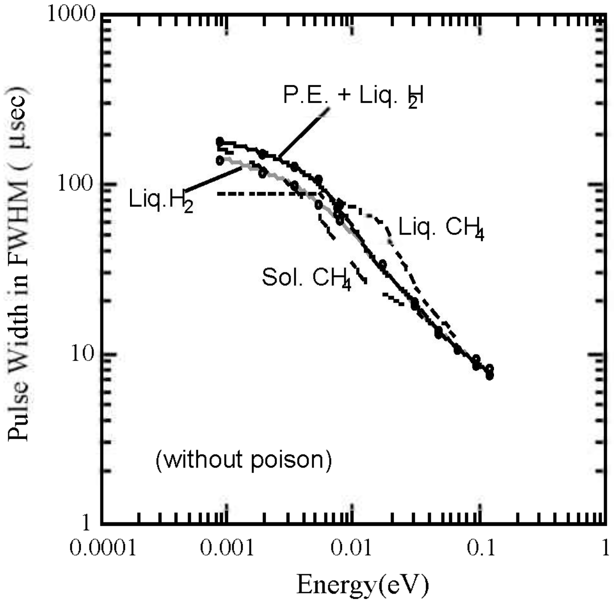

Figure 4. Pulse width (FWHM) of neutrons from the mixed moderator as a function of neutron energy, compared with those from other moderators. Lines are guides to the eye.

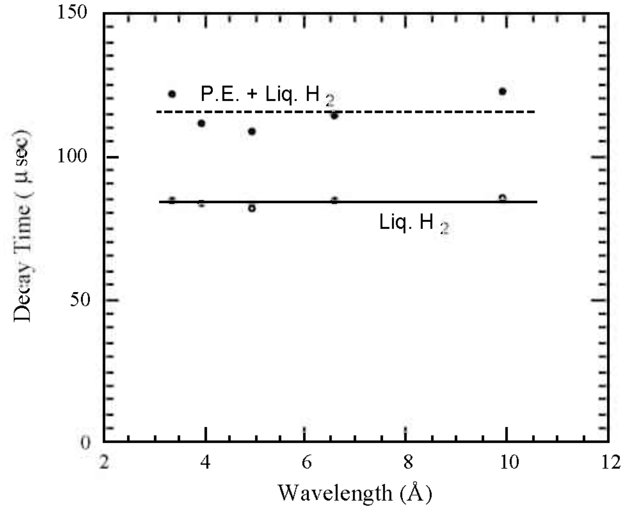

Figure 5. Decay times of neutron pulses in cold region as a function of neutron wavelength. Lines are guides to the eye.

The pulse width broadening at lower energies is due to a higher hydrogen number density (effectively equivalent to a thicker moderator; a longer decay time) and a poor energy exchange mechanism in polyethylene, resulting in a longer rising time as shown in Fig. 3.

Figure 5 shows the measured decay times from the mixed moderator as a function of neutron wavelength, compared with those from the reference L-H_2 moderator. The reason for a longer decay time comes from the same reason mentioned above.

5. COMPARISON WITH LIQUID AND SOLID METHANE MODERATORS

We compare the energy spectrum from the mixed moderator with those from the methane moderators. Figures 6 and 7 show the energy spectra and the intensity ratios to the reference decoupled L-H_2 moderator (note that all moderators are unpoisoned). At higher energies above 50 meV, the mixed moderator gives the highest intensity. In the range from 10 to 50 meV liquid methane is the best, while at lower energies below 10 meV the solid methane moderator gives the highest intensity. However, in the energy range where the liquid methane moderator gives the highest intensity, the pulse widths are broader than those from the others as seen in Fig. 4. This indicates that the higher intensity is due to a broader pulse width.

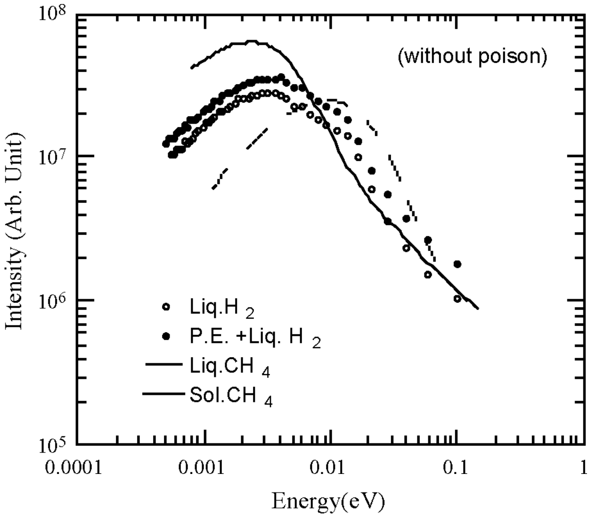

Figure 6. Comparison of the spectral intensities from various moderators.

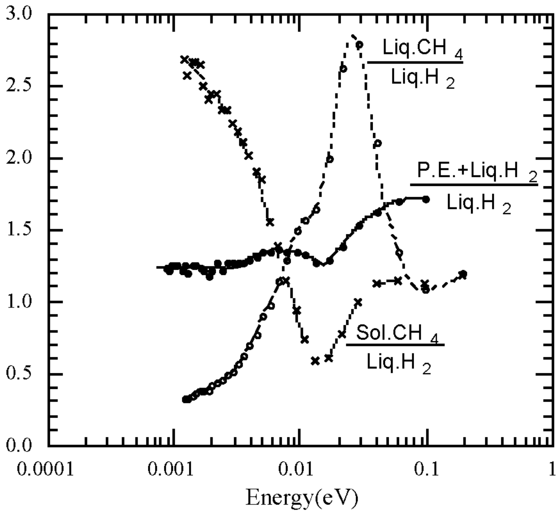

Figure 7. The ratio of the spectral intensities from various moderators to that from the reference decoupled moderator of liquid hydrogen.

6. CONCLUSION

From the present results, it can be concluded that the neutronic performance of the mixed moderator of polyethylene particles plus liquid hydrogen is fairly good as a narrow pulse thermal moderator, and that the replacement of polyethylene particles by another hydrogenous particles, for example light water ice, will be useful in spite of the serious radiation damage in the solid component, provided that an useful way to circulate such mixed moderator can be developed.

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