Pelletized cold moderator of the IBR-2 reactor: current status and future development

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Abstract. Current status and future development of the pelletized cold moderator of the IBR-2 reactor in Neutron Physics Laboratory of JINR are represented. Nowadays cold moderator works for physical experiments and allows conducting experiments in the region of wavelengths more than 4 Å up to 10-13 times faster in comparison with the warm water moderator. Future development of the pelletized cold moderator is aimed at increasing the time of its operation for experiments and is based on three components: creation of a system of continuous charging and discharging of beads, supplementation of various additives, and use of new materials, such as triphenylmethane.

1. Current status of the pelletized cold neutron moderator of the IBR-2

The IBR-2 is a fast pulsed research reactor intended for investigation of condensed matter at external neutron beams. Fast neutrons generated in the reactor lose their energy in the moderators located around the reactor core. Combined bi-spectral neutron moderator is a part of the equipment of the IBR-2. It provides with neutrons of broad spectrum (cold, thermal or mixed) for spectrometers at four neutron beams: number 7, 8, 10 and 11.

The combined moderator consists of a pelletized cold neutron moderator [1] based on aromatic hydrocarbons, and of a set of thermal moderators and pre-moderators, which are based on room-temperature water (Fig. 1).

Figure 1. Combined moderator of the IBR-2 reactor
Chamber of the pelletized cold moderator is of rectangular shape. The area of its surface facing the neutron beams is of 314 cm$^2$. The chamber is charged with beads of 3.5 mm in diameter each (Fig. 2), made of mixture of aromatic hydrocarbons: mesitylene and m-xylene. Charging volume for the beads is 1 L. Operation temperature of beads is 30K. The temperature is maintained by cold gaseous helium circulating through the chamber filled with beads. The moderator can operate without recharge of beads during one reactor cycle of 9-10 days. After the reactor cycle is over, cooling of the moderator is stopped, the frozen beads are melted and the irradiated liquid is removed from the moderator chamber. The chamber of the moderator is charged with frozen beads again before the new reactor cycle starts.

![Figure 2. Beads of the mixture of mesitylene and m-xylene in liquid nitrogen](image)

Cold neutron flux at the surface of the pelletized moderator in the range of long wavelengths (more than 4 Å) is 10-13 times greater than that from the surface of the water moderator (Fig. 3) [2].

![Figure 3. (color online) Neutron spectra (experimental data via TOF) of the combined moderator (a) and gain factor of the flux of cold neutrons to thermal neutrons (b) for beam №8 (spectrometer «REMUR») of the IBR-2.](image)
Since 2013 many physical experiments have been successfully implemented using the combined bi-spectral moderator of the IBR-2 reactor. They included the study of spatial beam-splitting by reflection from a magnetically non-collinear film, producing microbeams by a layered waveguide (REMUR reflectometer of the IBR-2 reactor, Dubna, Russia), neutron diffraction texture analysis of the sample of slate composed of five minerals (SKAT diffractometer, IBR-2 reactor, Dubna, Russia), etc. [3].

2. Future development of the pelletized cold moderator

Currently, the main problem of the cold moderator based on a mixture of mesitylene and m-xylene is duration of its operation cycle. At the moment, the operation time is 9 days, while a standard reactor cycle of thermal water moderator lasts up to 11 days. The operation time limit of the cold moderator is determined mainly by an increase of viscosity of the mixture of mesitylene and m-xylene because of irradiation. After 10 days of irradiation (510 MW·h or 156 MGy, essentially, due to fast neutrons, about 90%, the rest - γ radiation), the viscosity increases by 23 times (Fig. 4.). Kinematic viscosity of irradiated liquid was measured by capillar viscosimeter based on standard technics ASTM D 445. Therefore, the future development and improvement of the pelletized moderator is aimed primarily at solving the problem of increasing the time of its continuous work in a physical experiment.

![Relative kinematic viscosity for different doses of mesitylene and m-xylene irradiation (100 MWh=30.6 MGy). Dots correspond to experimental data of viscosity. Dashed line shows approximation.](image)

Figure 4. Relative kinematic viscosity for different doses of mesitylene and m-xylene irradiation (100 MWh=30.6 MGy). Dots correspond to experimental data of viscosity. Dashed line shows approximation.

There are several ways to solve this problem. The first one is to create a system of continuous charging and discharging of beads. This system will remove frozen beads that have already received high radiation dose, and charge the new, i.e. non-irradiated ones. Thus,
we can control viscosity of the mixture during irradiation. Creation of such a system for the cold moderator at the IBR-2 involves a complex of engineering challenges. Up to date, the works on development of a prototype of such a system for a special test stand have been started.

The second way is the supplementation of various additives to the original mixture in order to minimize the viscosity induced by radiation. There are at least two possible mechanisms to reduce viscosity using additives. The first one is based on substitution of a part of mesitylene molecules with more radiation-resistant aromatic hydrocarbons. These can be molecules of naphthalene or anthracene consisting of benzene rings. Using these additives, radiation resistance of the mixture may be increased up to 1.5 times with a slight decrease in cold neutron flux. The second mechanism is based on supplementation of the mixture with a non-hydrogen substance, on which a certain part of recoil protons received from neutron moderation can be inhibited. Small volumetric replacement of molecules of mesitylene with uniformly distributed microparticles will not be essential for neutron moderation. Such additives, which should not absorb slow neutrons, may be nanopowders of diamond, zirconium or lead. Presently, the work to study the efficiency of the additives has been initiated.

The third way of increasing the operation time of the cold moderator is to replace the working mixture of mesitylene and m-xylene with another material with a better radiation resistance and proper neutron moderation. This substance might be triphenylmethane. In the literature there are indications that triphenylmethane is not inferior to mesitylene in terms of its neutron-physical properties (flux of cold neutrons, etc.) [4]. Radiation resistance of triphenylmethane is much higher than that of mesitylene [5]. In the end of 2015, the first experiment to study the radiation resistance of triphenylmethane is planned at the irradiation facility of the IBR-2 reactor [6, 7].

![Figure 5. Triphenylmethane beads](image-url)
The main advantage of triphenylmethane over mesitylene, from the point of view of manufacturing of beads, is that triphenylmethane is solid at room temperature, whereas mesitylene is liquid. The melting point of triphenylmethane is 92 °C, while that of mesitylene is -50 °C. Consequently, triphenylmethane beads can be kept at room temperature, while mesitylene beads – in liquid nitrogen only. So that, it is possible to manufacture beads of regular shape and size, good hardness and durability in advance for their further transportation to the cold chamber of the moderator. At the same time, the main disadvantage of triphenylmethane within the existing technology of charging/discharging of beads is the need for additional heating of the moderator system up to 92 °C to melt the solid beads and remove them as liquid, whereas mesitylene beads melt and can be removed at room temperature.

In the summer of 2015, in FLNP the works were performed proving the possibility to manufacture solid beads of triphenylmethane [Fig. 5]. The first experiments on charging the triphenylmethane beads into the chamber of the test stand of the cold moderator are planned for 2016.

3. Conclusion
Since 2013 the pelletized cold moderator as a part of the first combined (bi-spectral) moderator at the IBR-2 is working successfully for physical experiments at external neutron beams. Neutron flux of the cold moderator allows conducting experiments in the region of wavelengths (of more than 4 Å) up to 10-13 times faster in comparison with the warm water moderator; at the same time, the thermal neutrons flux does not decrease dramatically. The future development of the pelletized cold moderator is aimed at increasing the time of its operation in experiments and is based on three components:

- creation of a system of continuous charging and discharging of beads;
- supplementation of various additives;
- use of new materials, such as triphenylmethane.
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