Advanced pelletized cold moderators for the IBR-2M research reactor for condense matter research

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Abstract. The wold first advanced pelletized cold neutron moderator is prepared to be put into operation at the pulsed research reactor IBR-2M. It is just the first stage of moderator development for the IBR-2M reactor. The project of complex of moderators consists of three independent cold moderators that will be installed at three sides of the reactor core. This composition provides long wavelength neutrons to the most of neutron spectrometers at the beams of the IBR-2M reactor. Aromatic hydrocarbon (mixture of mesitylene with *m*-xylene) is used as material for cold moderators. It is very attractive material: high radiation resistance, good moderating properties, incombustible etc. It solidifies at about 228 K and can form beads of three-four millimeters in diameter. The special mock up of pneumoconveying line has been developed to receive knowledge of operating conditions (temperature, gas flow rate, etc.) required for beads delivery down to a moderator chamber. It is shown, that the idea of beads transport by helium flow at cryogenic temperatures works properly. More than 27000 beads have been delivered repeatedly from charging device to the imitator of the chamber of the cold moderator through 15 meters path. This pipeline is very close, both in geometry and length, to the real one, which is now mounted at the reactor position. The recent progress and plans for moderator development at the IBR-2M reactor as well as experimental results of beads transport will be discussed at the paper.

1. Cold moderator for the IBR-2M reactor

Cold (long wavelength) neutrons have come to play a dominating role in the frontier research carried out with neutrons, and in all likelihood this is going to be even more so in future applications of neutron scattering technique. Utilization of cold neutron sources can improve many characteristics of experiments on neutron beams. As examples, one may refer to research of matter surface properties, to small angle scattering method, to investigation of large scaled structures etc.

Aromatic hydrocarbons were chosen as a moderating substance in the proposed pelletized cold neutron moderator. There were some convincing reasons of our choice. Currently, the standard cold moderators used in high power neutron sources are based on circulating liquid or supercritical hydrogen to ensure satisfactory heat removal and absence of radiation damages [1]. The main deficiency of these moderators is a complexity of technology that needs to meet strong demands for radiation and nuclear safety, especially, when using at nuclear pulsed research reactors. Other prospective hydrogenous materials (solid or liquid methane, methane hydrate) suffer bad radiation resistance [2, 3]. Using aromatic hydrocarbons gives us opportunity to avoid a lot of problems related to irradiation effects, such as spontaneous release of accumulated radicals energy, polymerization, high pressure of radiolytic hydrogen on a moderator chamber walls during heating up. Hardness of toluene and mesitylene (1,3,5 – threemethylbenzene) to neutron and gamma irradiation at low temperature have been proved at the cryogenic irradiation facility of the IBR-2 reactor [4]. Mesitylene appeared to be twenty times more stable than solid methane – it keeps integrity and temperature at least up to 10^{18} n/cm^2 fast neutron fluence. Besides, mesitylene and its mixture with m-xylene have appropriate neutron moderation properties. This was proven by Dr. I. Natkanec [5]; the data libraries for this material at different conditions have been prepared by group of Dr. Granada [6]. Preliminary consideration including Monte Carlo optimization of the IBR-2M research reactor complex of moderators in which the mesitylene pelletized cold moderator plays an important part, showed that 20 K mesitylene optimized moderator is preferable to solid methane if accounting all inputs – neutronic, thermal and radiation.

Frozen mixtute of mesitylene+ m-xylene was supposed to be used as separated pieces (small beads) fulfilling the volume of a moderator's chamber. Such a decision avoids a problem with heat exchange (low thermal conductivity of mesitylene) and prevents the moderator chamber from destruction due to internal pressure of radiolytic hydrogen stored during irradiation. Mesitylene balls will be delivered into the moderator chamber by helium flow, which will be used as coolant as well [7].

The principal scheme of the cold moderator and its equipment is shown in the Fig. 1. Beads are dosed into the charging tube (2) from the charging device (3), and then delivered down to the moderator (1) by flow of helium gas which circulates by helium blower (6) through the loop from heat exchanger (5) to the moderator. Two helium loops (one from the cryogenic machine (4) to heat exchanger (5) and the other (7) from heat exchanger to the moderator) prevent the cryogenic machine from pollution by mesitylene. The helium is also supposed to cool the beads down during the moderator operation. After several days of operation the helium blower is to be switched off, beads are to be melted and the liquid is to be collected in the receiver (8) through discharging pipeline. The moderator can be recharged afterwards.

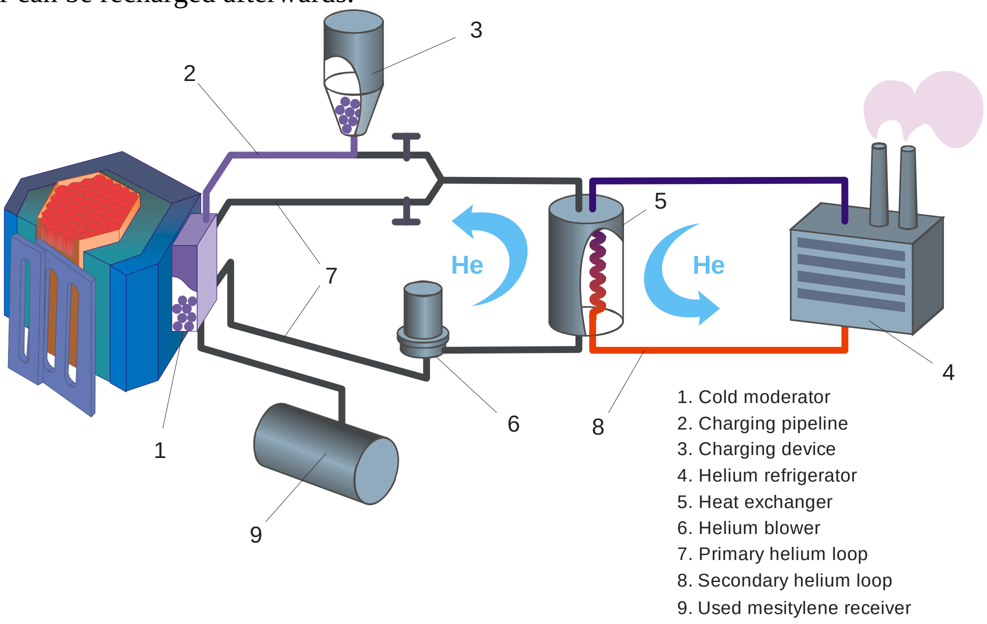

Figure 1. The pelletized cold moderator and its operating principle at the IBR-2M reactor.

The main problem with this principle is the transportation problem. It consists in the absence of both the experimental and theoretical data on elastic-plastic, adhesive and tribological properties of solid amorphous mesytilene (that is, the mixture of 70% mesytilene with m-xylene), along with the data on movement of a single ball through a wide cylindrical pipe, taking into account the rolling and sliding friction, as well as the deviations from sphericity. All this made it difficult to calculate the parameters of the conveying system. It was decided to solve this problem experimentally at the full scale stand with the cryogenic moderator prototype [8].

2. Experiments at full-scale stand of transport system of pelletized cold moderator

Main problem in transportation of solid mesitylene beads along the tube of complicated geometry is how to avoid fracture of the beads – its brittlement resistance is very poor – speed limit for 3.7 mm balls contracting the walls at right angles is ~7 m/s. Total amount of time required to fill the moderator chamber of 1 l volume with beads (about 27 thousand) was estimated based on the working plan of the reactor, should be less than 8 hours. To find appropriate conveying gas parameters for implementation of safe method of beads transportation, a full scale model of the conveying path and the IBR-2M cryogenic moderator's technological system was fabricated (Fig. 2) [9]. At the same time, main parameters of the cryogenic moderator's technology system, which is expected to provide working capacity and serviceability of the cold-neutron moderator based on solid mesitylene beads, have been tested.

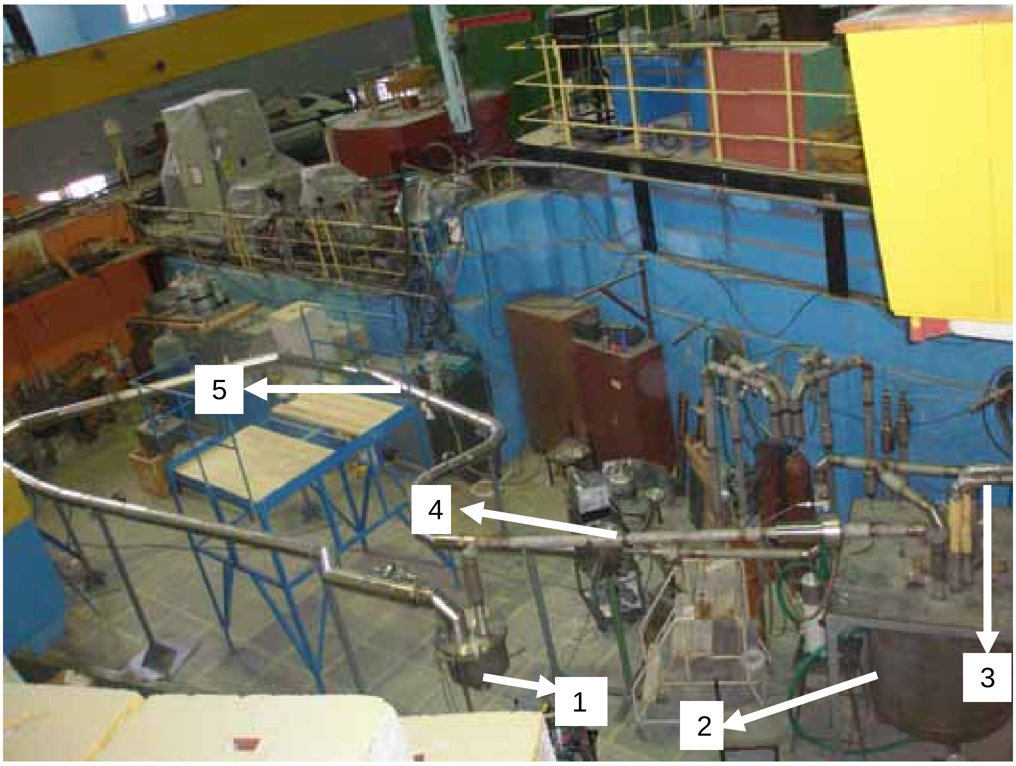

Figure 2. The full-scaled model of the conveying path and technological system of the IBR-2M cryogenic moderator installed at experimental hall of the IBR-2 reactor (1– the chamber-imitator of the cryogenic moderator, 2 – the cryostat (with the heat exchanger and the helium blower inside), 3 – the cryogenic pipeline from\to the refrigerator, 4 – the charging device, 5 – the cryogenic pipeline for conveying mesitylene beads.

To meet the objectives listed above, the following was arranged: detecting the ball movement, monitoring the process of filling the chamber with beads, measuring the flow rate and temperature of the gas, supplying sufficiently high vacuum, providing the cryostat with cool helium from cryogenic machine etc.

Experiments on the full-scaled model gave a lot of information. Some parts of the installation were modified during experiments. The most essential consequences are as following:

- The metering tank was modified to make its operation easier and enhance loading beads into the conveying pipe faster.
- The hydrodynamical method of counting the number of balls coming into the conveying pipe was also modified using mathematical processing of shape of differential pressure pulse.
- Procedure to remove nitrogen penetrating into the helium volume has been optimized.

The main result is that reliable and fast pneumoconveying of solid mesitylene beads into the moderator chamber is feasible [10]. In the Fig.3 one can see a heap of cold solid beads charged into the model of the moderator chamber.

Figure 3. Photo of the cold solid beads of mesitylene at T~40K inside the chamber-imitator of the moderator chamber.

Some important results of the investigations on the full-scale model of the conveying path and the IBR-2M cryogenic moderator's technological system are shortly summarized below:

– Applicable parameters of the conveying helium gas: – 2 g/s, 50 K, 10 m/s.

– Applicable rate of charging beads into the conveying pipe – 6-8 beads/s.

– Total amount of time required to fill the moderator chamber with beads – 1÷1.5 h.

– A diagram *(p, G)* of the helium blower is restored (see in Fig.4).

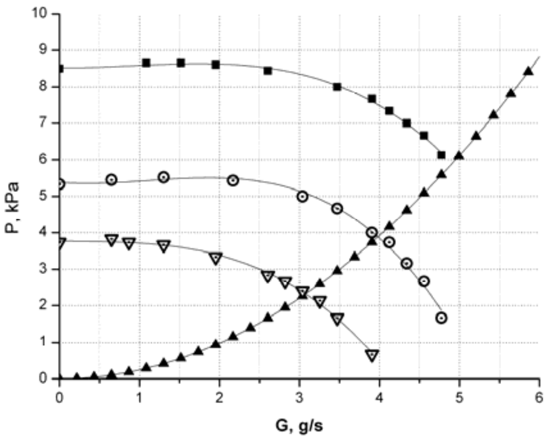

Figure 4. "Flow rate – pressure drop" diagram of the helium blower at some values of the blower rotation speed: squares - 22500 rev/min, circles - 18000 rev/min, void triangles - 15000 rev/min; solid triangles – hydrodynamic resistance of the conveying pipe.

3. Current status with cold moderator at the IBR-2M reactor

We have just finished work with installation of cold moderator to the IBR-2 reactor after the success in experiments with beads transport. The composition of cold moderator vessel with pre-moderator and water moderator [7, 11] have been mounted onto the moveable trolley with biological shielding and supplying pipelines (in/out water, beads, in/out gas of cold helium, liquid mesitylene drain) Fig.5.

Figure 5. Moveable trolley with cold moderator and biological shielding installed in the rails in ready to move to active core position. (1- cold moderator with vacuum shielding and water pre-moderator, 2- cold helium and beads support pipelines, 3- trolley onto the rails, 4 - the entrance of passing through the stationary biological shielding of reactor to the active core, 5- drain pipeline of liquid mesitylene)

Cryogenic pipelines and other parts of the installation (heat exchanger, charging device, helium blower, flowmeter as well as over technological equipment) are already mounted at their places and connected.

In the next couple of months we are going to test new refrigerator KGU-700, to finish installation of control equipments and software and start tests with beads transport down to the chamber of the moderator. First tests of the cold moderator with the reactor on power are planned to start in the end of May 2012.

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