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# Recent Progress in Development of the Pelletized Cold Neutron Moderators for the IBR-2M Reactor

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ABSTRACT

Project of elaboration of a complex of cold neutron moderators at the IBR-2M research reactor was presented at the ICANS XVII in 2005. Cold moderators were planned to be of a pelletized type based on methyl derivatives of benzene in solid phase at 25-30 K. Currently, R&D of the project is completed, and units of the priority moderator for six neutron beams are fabricated. Shortly, results of the theoretical and experimental study of solid beads conveying are presented. Before assembling of the facility, parameters of solid mesithylene pellets conveying by cold helium gas into the moderator chamber are planned to be checked at the full-scale model of the transporting part of the facility.

## 1. Introduction.

The complex of neutron moderators for the pulse research modernized reactor IBR-2M includes three "cold neutron moderators" [1-3]. Each of them is a chamber, filled with the working medium in the form of balls made of frozen mixture of aromatic hydrocarbons - mesithylene and m-xylene, cooled by gaseous helium at a temperature 20-30 K. Advantages of this type of moderators are determined by the high radiation durability of aromatic hydrocarbons (10-20 times higher than in methane, [4-6], by large inelastic scattering cross section of low energy neutrons [7, 8, 15], by the possibility of a good cooling and rapid remote replacement of the working medium of the moderator after the completion of its resource. The filling of the camera of the moderator with balls in the process of reactor operation will be produced via their pneumoconveying by helium or nitrogen gas, and removal - via the melting of balls and self-drainage of liquid phase.

The main problems, which have been solved in the project, are following:

1. Selection of the optimal geometry of the camera of cold moderators;
2. Method of the generation of solid mesitylene balls;
3. Technology of the metered charging of balls into the conveying tube;
4. Selection of pneumatic line and parameters of the transportation gas.

Currently, R&D works are finished, equipment and pipelines of the system of the helium cooling of the first, priority cold moderator on the neutron beams 7, 8, 10 and 11 are prepared and partly installed, the chamber of cold moderator is mounted on a special trolley of biological shield and will be set up at the reactor position (see in Fig.1), two helium refrigerators of 500 and 700 W at a temperature of helium 15-20 K are being prepared to be used. Installation of the full-scale model of the conveying lines from the metered charging device down to the chamber of cold moderator, on which the design parameters of the transportation gas will be selected, is close to completion. Start-up of the first pelletized cold moderator with the reactor at full power is planned to the beginning of 2012.

In the article, the results of some experimental and theoretical works, which associate the creation of the pelletized cold moderators for the IBR-2M reactor, are briefly presented.

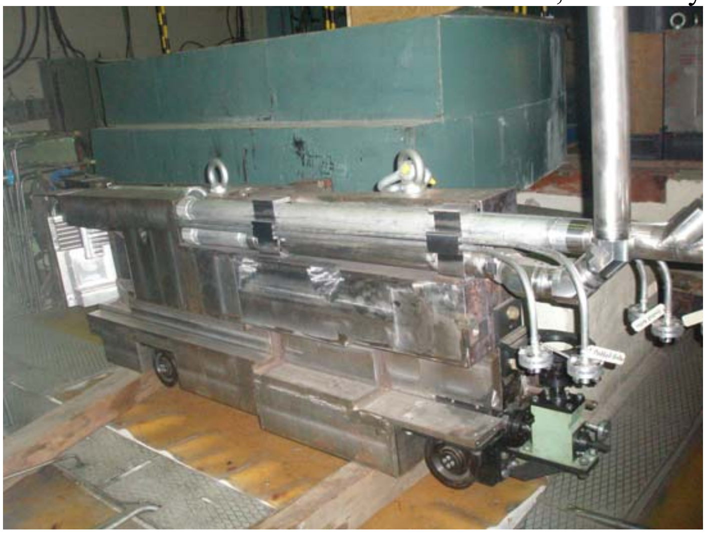

Fig.1. The chamber of cold moderator with a special trolley of biological shield of the IBR-2M reactor

## 2. Problems of pneumoconveying of solid mesithylene balls.

Besides complicated geometry of pipes in plane (see Fig.2), there are ascents and downgrades along the line. Accounting for brittleness of mesitylene beads, this creates difficulty with the transportation of balls along the pipe. Mesithylene beads should come into the moderator chamber intacted and without traffic jam.

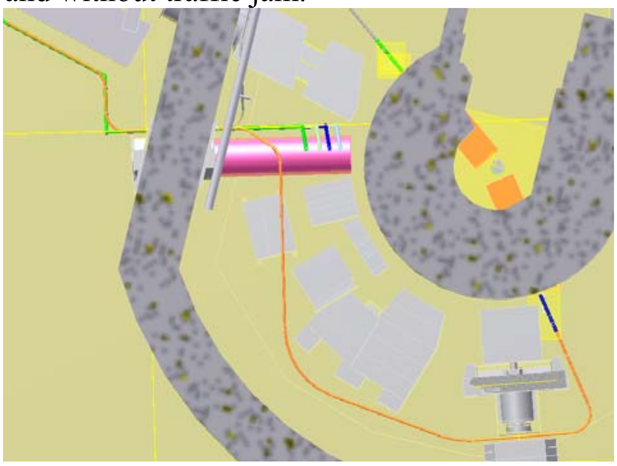

Fig.2. Plane view of the solid beads pneumatic pipeline of the first cold moderator of IBR-2M reactor.

The nature of the motion of ball in the pipe is fairly complicated in view of the possibility of deviating its trajectory from the vertical plane and the irregularity of the motion itself - leaps and the impacts about the wall of pipe - which can be caused by the roughness of a pipe and by the imperfection of the spherical form of a ball. Theory both regular and irregular motion of a single ball along a pipe, and results of computer simulation are in papers [9, 10]; in particularly, they are based on ref. [11-13 etc.].

The motion of a single ball along the conveyor tube is alternating on the acceleration with the random nature of its change. This is caused by the jumps of ball on the roughnesses of a pipe and by the subsequent collisions with walls. The ball losses a part of its kinetic energy in each collision due to friction. Therefore, in principle, it is not possible to describe its motion by the determined equations. The theory of the pneumatic conveyance of ideal ball in the ideal- smooth pipe [ 9 ] can be used only on the stage of start-up acceleration and in the range speed from 0 up to 25-30% of the speed of the transportation gas, when the influence of roughness is insignificant. The approximate theory of the motion of ball after overcoming of threshold [ 10 ] is applicable only for of the ordered located thresholds and for the idealized case, when the trajectory of ball lies in vertical plane. For example, the change of acceleration of the ball of *d* mm diameter after stumbling on a low height threshold of *h* mm and after numbers of subsequent collisions with the walls, is calculated in [10] as

$$\Delta a = \frac{g}{1-2\chi\sqrt{h/d}} \cdot \left(\frac{a}{g}-\mu\right) \cdot \left[2 \cdot \left(\frac{a}{g}-\mu\right) \cdot \frac{1+k}{1-k} \cdot \sqrt{h/d} + 1\right]$$

where $k$ is a factor of restoration of a ball speed after orthogonal collision with a wall, $\mu$ is a slide friction factor (for solid mesithylene, $k \approx 0.6$, $\mu \approx 0.5$), $\chi = \mu(1+k)$, and $a$ is the acceleration of the ball due to the conveying ghas dynamic pressure. In the reality, it is possible to measure only the distribution of the speeds at any selected point of a route.

To evaluate the influence of the irregularity of motion, we compared the results of the mathematical simulation of the regular motion of an ideal ball with the data of the test simulation experiments, carried out under laboratory conditions [9, 14]. Model experiments were made with glass balls of 5 mm diameter conveying along 16 mm diameter pipe with room temperature nitrogen. Results were then interpreted for mesithylene balls because two criteria factors – geometry parameter $d_{ball} / d_{pipe}$ and Reynolds number - are close to that of the real mesithylene line but the third criteria dimensionless complex $\left(\rho_{gas} V_{gas}^2 / \rho_{ball} d_{ball} g\right)$, which comes into the ball motion equation in explicit form. Below some results and conclusion are given:

Due to the irregularity, considerable variations of speed of balls were observed when the ball speed is greater than 1.5 m/s (Fig. 3, Table 1). Variability in time along the same length is less than the range of speeds, indicating not monotony of motion of each individual ball. In Graph. 4 one can see the obvious lack of dependence of end speed on time, unlike that one depicted in the figure by triangles.

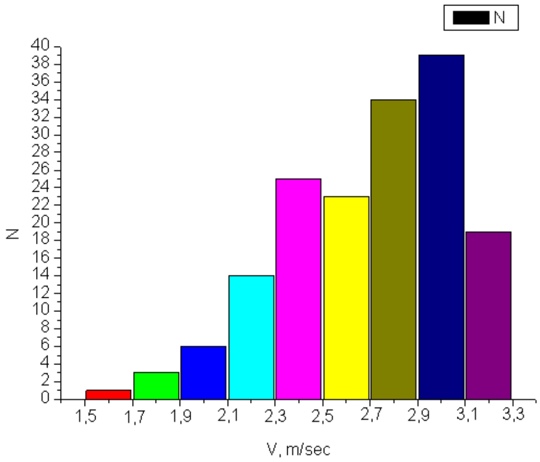


Fig.3. Distribution of the finite speed of balls in the tube length 11.4 m at transported gas velocity 6 m/s (N is the number of balls in the interval speed 0.2 m/s; the total number of balls-164).

Table 1. Dependence of end speed of ball of 5 mm diameter on gas velocity

| Gas velocity, m/s | $V_{min}$, m/s | $V_{average}$ m/s | $V_{max}$, m/s | $V_{min}$ /$V_{gas}$ | $V_{ave}$ /$V_{gas}$ | $V_{max}$ /$V_{gas}$ |
|---|---|---|---|---|---|---|
| 6 | 1,62 | 2,69 | 3,26 | 0.27 | 0.45 | 0.54 |
| 8 | 2,01 | 3,34 | 4,14 | 0.25 | 0.42 | 0.52 |
| 10 | 2,88 | 3,88 | 4,95 | 0.29 | 0.39 | 0.50 |

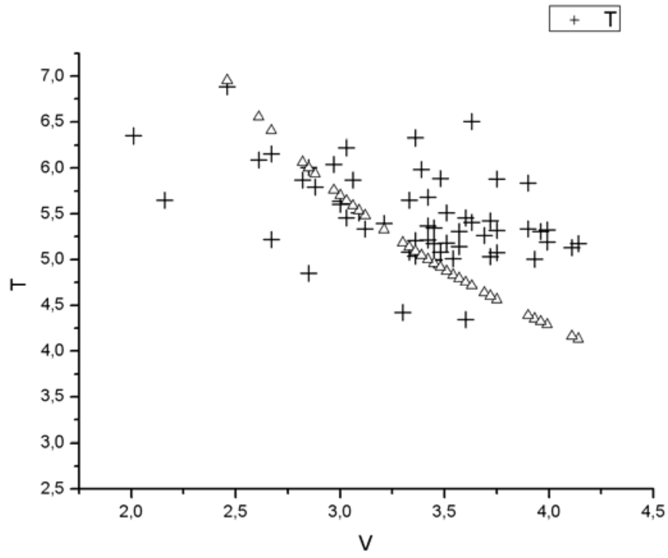


Fig.4. Graph of finite velocity (v, m/s) and time of balls motion (T,) on the way 11.4 m (speed of gas -8 m/s). Crosses - experiment, triangles-calculation for deterministic movement of the ball (the value of efficient friction coefficient is strictly linked with the ultimate speed of ball).

In experiments, linear dependence of both a minimum and a maximum terminal speed of balls on gas flow rate (see in Table. 1) were observed. Such law can exist only if an effective dynamic friction factor, i.e. that accounting for losses of speed due to roughness of the tube and non-sphericaliity of balls, is a square-law function on the current speed of a ball. Proportion factor between square speed and friction, estimated at modelling experiments, can vary up to 15-16 times. Evidently, for smooth walls of the transporting tube and ideally spherical ball the effective dynamic friction factor does not depend on speed of ball but is actually a rolling friction factor.

- The totality of theory (for the ideal conditions and with the presence of thresholds) and of experimental data, obtained in the mock-up of conveying route, made it possible to make the parameters of the motion of mesithylene balls: in pneumatic conveyance of the mesithylene balls with a diameter of 4 mm in the pipe with a diameter of 16 mm by cold helium of 40 K temperature the minimum speed is expected to be equal to 0.35 of the gas velocity, and maximum - 0.69.
- To lift the stopped mesithylene ball upwards the pipe, inclined at angle of 30 degrees, by the flow of cold gas helium, the minimally necessary gas velocity should be 6.0 m/s.
- To prevent congestion balls before ascent part of the pipe, rate of filing balls into the transport pipe shall be not more than one ball in 2 seconds.

# 3. Full-scaled model of the technological system of the IBR-2M cryogenic moderator

Design of the model (goals, conception, drawings)

The full scaled model (Fig.5a) is assigned for testing and confirmation of main parameters of the cryogenic moderator technology systems which must provide working capacity and serviceability of the cold neutron moderator based on solid mesithylene beads. In a case of some malfunctions, modification of some elements of technology systems would be made.

Main goals to be achieved with the full scaled model are as these:

1. To check how a process of charging mesithylene beads into a moderator chamber goes: whether beads can come without jamming and keep its integrity or not, what is an optimal feeding rate of beads, what is a repeatability of geometric shape of a heap of beads inside the moderator chamber.
2. To find out parameters of transporting gas (flow rate, temperature)
3. To estimate heat loads onto every part of the cooling loop (to have a sufficient information for calculation of real temperature of mesithylene during normal operation at the reactor) .

Conception of the full scale model based on the very close relation to the facility in operation. Some parts of the model are just the real units of the facility – cryostat with heat exchanger, gas blower and vacuum valves, cryogenic machine, mesithylene beads metering device, vacuum technology etc. Construction of pipelines and of the cold chamber principally repeat the working version in the sense of operability, that is, having some deviations from the original, they follow exactly working functions.

The full scaled model is installed in the experimental hall of neutron beams of the IBR-2 reactor in the area of the #3 neutron beam at out of beam position, Fig. 5b.

Because of lengths and configuration of real pipelines don't fit in the area of the hall available, it was proposed to make pipelines a little bit shorter and more compact but keeping unchanged the parts of a principal importance such as ascents, degrades etc. Angles of the tight turns and their number are copied one to one. As to fair turn, the number of them is reduced with sum of angles remained untouched.

Diameters of all pipes (both of pneumoconveying and of vacuum casing) are in 1:1 scale. Parameters of pneumoconveying of beads through the pipelines of the model were calculated based on theory and semiempirical data derived in earlier experiments. Minimal and maximum speed of beads at the crucial points of the passage way (at an ascending slope, at the gate into the chamber) is to be the same as in working facility.

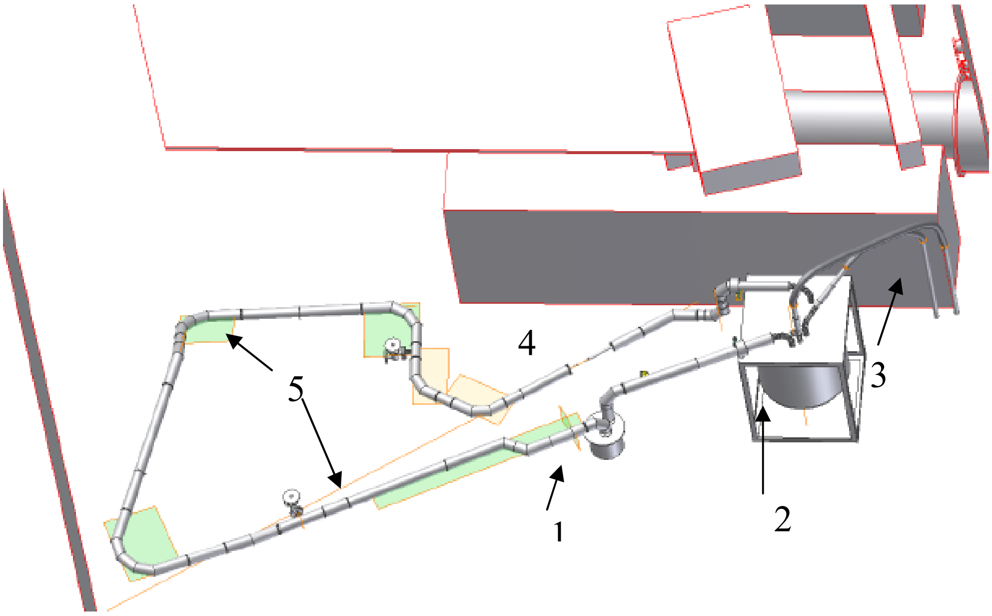


Fig. 5 a General view of the full scale model of technological system of cold moderators. 1 –cold moderator chamber, 2 - heat exchanger with a helium blower, 3 - cryogenic pipes from/to a helium cooler, 4 –charging device site, 5 – beads conveying pipes.

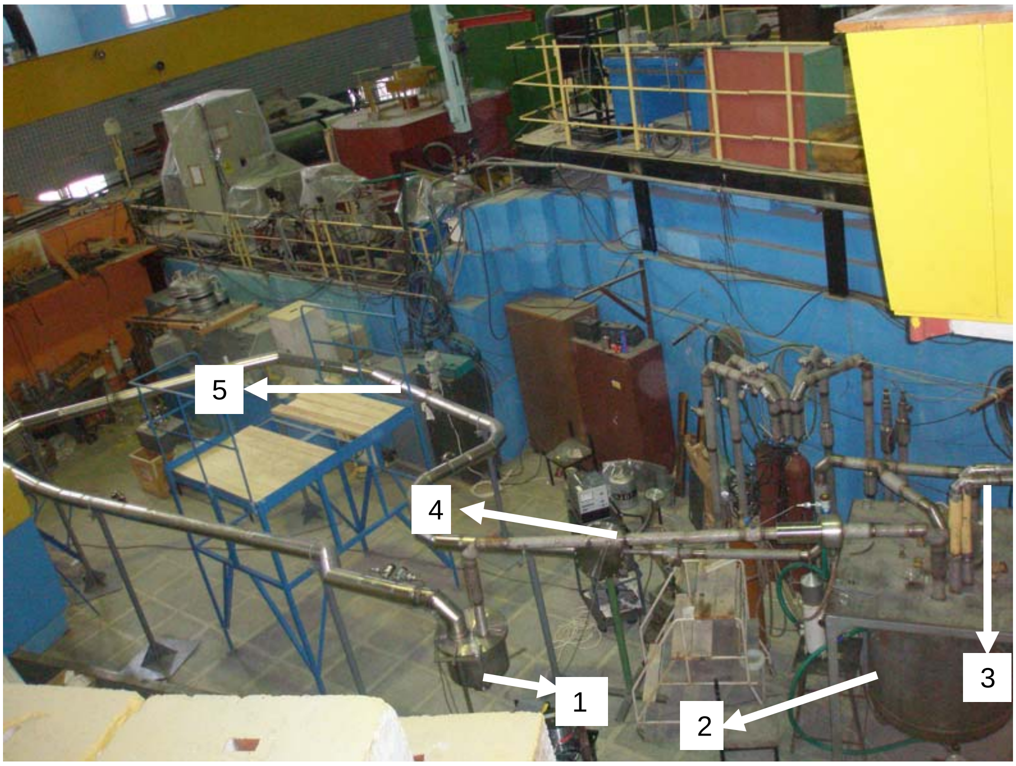


Fig.5 b. Mounted cryogenic pipeline at the full scale model position. 1 –cold moderator chamber, 2 - heat exchanger with a helium blower, 3 - cryogenic pipes from/to a helium cooler, 4 – charging device site, 5 – beads conveying pipes. Total length of the model ~ 15 m.

The cold moderator chamber maid in a such a way that it is completely repeated dimensions and construction of cold moderator chamber of the IBR-2M reactor except of vacuum jacket and material of one of its wall. It is maid of glass as well as some glass windows installed at vacuum jacket. So as it is possible to look to mesithylene beads in the chamber during their charging. (Fig. 6)

Fig. 6. Cold moderator chamber without vacuum jacket. a) Model, b) Manufactured

Mesithylene balls will be prepared at a special developed device The device (Fig.7) works on a principle of formation of a solid sphere of mesithylene and m-xylene mixture on the surface of liquid nitrogen. During freezing, droplet of mixture is hold on the surface by vapor of boiling nitrogen. Then, after formation of solid round shell, it sinks down. Until formation of solid hull, balls may adhere to one another if there is more than one on the surface. This makes limit of productivity of the device: one ball per one channel for 10 sec (this is a maximal time for freezing of a droplet). 19 channels were chosen to reach overall productivity two balls per sec.

Fig.7. The device for mesithylene balls preparation (a vacuum housing is removed).

## 4. Acknowledgements

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