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(19)

(54) METHOD OF MANUFACTURING A NUCLEAR FUEL ROD

(71) We, GENERAL ATOMIC COMPANY, a partnership organised under the laws of the State of California, of 10955 John Jay Hopkins Drive, San Diego, California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method of manufacturing a nuclear fuel rod.

Our earlier patent application No. 43525/74 (Ser. No. 1,484,698) is directed to a method of manufacturing a nuclear fuel rod, comprising partially filling a mould cavity with nuclear fuel particles, closing the mould cavity and reducing its volume to such an extent that the fuel particles substantially fill the mould cavity, injecting a solidifiable liquid binder into the mould cavity to fill the interstices between the fuel particles, and allowing the injected binder to solidify. Preferably, sufficient liquid binder is injected to cause it to flow out of a vent passage at the opposite end of the mould cavity from that at which it is injected to assure complete filling of the cavity. Compared with other methods of manufacturing nuclear fuel rods, this method allows a reduction in spillage of fuel particles and in the cost of collecting these.

It is the object of the present invention to provide an improvement of the above method, whereby spillage of nuclear fuel particles is still further reduced.

Accordingly, the invention provides a method of manufacturing a nuclear fuel rod, comprising partially filling a mould cavity with nuclear fuel particles, closing the mould cavity and reducing its volume such that the fuel particles substantially fill the mould cavity, and injecting a fluid solidifiable binder into the mould cavity to fill the interstices between the fuel particles, sufficient fluid binder being injected to cause it to flow out of a vent passage at the opposite end of the mould cavity from that at which it is injected to assure complete filling of the cavity, wherein the vent passage is dimensioned to prevent the passage of the nuclear fuel particles therethrough.

The invention will be explained by way of example with reference to the accompanying drawings, wherein:

Figure 1 is a full section view of apparatus illustrating the performance of an initial step in performing the method of the invention;

Figure 2 is a full section view illustrating the apparatus of Figure 1 showing a subsequent step of the method;

Figures 3, 4 and 5 are full section views of the apparatus illustrating further steps of the method; and

Figure 6 is an enlarged full section view illustrating a portion of the apparatus of Figures 1 to 5 in greater detail.

Referring now more particularly to Figure 1, a cast housing 11 is shown which contains several mould cavities 12 in the form of cylindrical cavities of circular cross section. The cavities may be machined to provide an interior smooth surface, and the housing is also provided with passages 13 and 14 through which a suitable heating fluid or coolant is circulated in order to heat or cool the mould as required during the moulding process. The cavities 12 are each of identical construction.

A horizontal bore 16 is provided in the housing 11 in a location where it intersects all of the cavities 12 near the lower ends thereof. The bore 16 terminates on the exterior of the housing 11 at a raised boss 18 in which a socket 21 is provided for purposes explained below.

The lower ends of each of the cavities 12 are closed by a piston 23 attached to the upper end of a piston rod 25 which passes through a suitable opening 27 formed in a lower closure plate 29. The closure plate 29 is suitably secured to the underside of the housing 11 by means not shown. The employment of the movable piston 23 enables the interior volume of the mould cavity 12 to be adjusted as desired.

Referring to Figure 6, the detailed construction of the piston 23 may be clearly seen, along with the upper end of the piston rod 25 which has an axial bore 31. The lower end of the piston has a cylindrical projection 33 which extends downwardly into the axial bore 31 and is held therein by a transverse pin 35 that is received in aligned openings in the upper end of the piston rod 25 and in the cylindrical extension 33. A land 37 is provided on the piston 23 which provides a close, sliding fit with the inner wall of the mould cavity 12. A second land 39 is spaced above the land 37 and also provides a close sliding fit with the cavity wall. The lands 37, 39 assure the piston slides smoothly up and down within the cylindrical mould cavity. An O-ring 41 is held between the lands 37 and 39 to provide a positive fluid seal between the piston and the walls of the cavity 12.

The piston 23 is formed with an uppermost head 43 which is dimensioned so there is some clearance between its periphery and the inner surface of the cavity 12. In the region between the head 43 and the land 39, the piston 23 is necked down to a stem portion 45 to provide an annular space 47 between the piston and the walls of the cavity 12.

Prior to moulding fuel rods, the mould 11 is primed. An injection device 61 having a nozzle 63 is brought in mating engagement with the socket 21 in the boss 18 of the mould housing. At the same time, a suitable heated liquid is circulated through the passageways 13 and 14 in the mould to bring it up to the desired temperature. When the appropriate temperature is reached, a suitable fluid binder is injected into the horizontal bore 16 with the pistons located at the vertical levels shown in Figures 3 and 4.

The illustrated fuel rods are designed for use in a graphite-moderated reactor, and a binder is used which can be subsequently carbonized to produce a substantially carbon matrix, wherein the nuclear fuel particles will be individually supported. The binder is usually a pitch material, such as coal tar pitch, and may contain additional fillers, such as graphite flour or the like, as is known in this art. In general, the binder may be any type of plastic material which can be rendered fluid by the application of heat and which can be solidified by cooling to about room temperature. Because the moulding process contemplates heating, cooling and re-heating of the binder, it should have thermoplastic properties, as opposed to being based upon a resin which will cross-link or otherwise rigidify upon initial application of heat and thereafter resist softening.

The binder injected into the main bore 16 flows about each of the stems 45 of the pistons through each annular space 47 and into the next continuation section of the horizontal bore 16. The binder also flows upward through the clearance provided about the head 43 of each piston to fill the mould cavity 12. After the cavities are all filled with binder, which will mean that the annular spaces 47 about the piston stems 45 are likewise filled, injection of binder is halted, as is heating of the mould 11. Coolant is then circulated through passageways 13 and 14 to cause solidification of the binder in the mould cavities. Thereafter, the top of the mould cavities is removed, and the piston rods 25 are driven upward, as by the application of hydraulic pressure, to eject the cylindrical slugs of solidified binder from the mould cavities 12. Because of its thermoplastic character, the binder material can be salvaged and re-used, if desired. After ejection, the pistons 23 are retracted to their lowermost position depicted in Figure 1, and moulding of fuel rods is ready to begin.

First, nuclear fuel particles 51 are metered into the cavities from a suitable hopper 53 to only partially fill each cavity. As can be seen in Figure 2, after filling with the metered charge of fuel particles, a temporary excess space 54 is left at the top of each mould cavity. Because the mould was primed with binder, the binder occupies the clearance between the piston head 43 and the inner wall of the cavity 12, as well as all of the sections of the horizontal bore 16 and thus confines the fuel particles to the cylindrical cavities.

After the mould cavities have each received their metered charges of fuel particles, a mould cover plate 55 is attached to the top of the housing 11 and suitably secured thereto by means not shown. The pistons 23 are then raised to an intermediate position by moving the piston rods 25 upward, by the application of hydraulic pressure or the like, in order to substantially eliminate the temporary excess space 54 within each mould cavity so that the particles 51 substantially completely fill the space in the mould cavity between the piston 23 and the mould cover plate 55. Preferably, the piston is moved upwardly with sufficient force to slightly compact the bed of fuel particles therewithin, as depicted in Figure 3. However, the fuel particles preferably have individual fission-productretentive coatings, as for example pyrolytic carbon coatings, and care is taken not to fracture the coatings. Generally, coated fuel particles between about 500 and 1200 microns in size are used. Usually, the piston 23 will not be driven to exert a pressure of more than about 42 kg/cm^2 upon the particles at this time. The cover plate 55 is provided with a plurality of apertures 57 therein which are not aligned with the mould cavities but which communicate with large circular recesses 59 on the underside of the mould cover plate, that are positioned in the areas between the mould cavities, the purposes of which are explained below.

Referring now to Figure 4, the mould cavities 12 are ready for the injection of the solidifiable binder, and the mould is heated by circulating a hot liquid therethrough to soften the binder with which the mould was earlier primed. With the mould at the desired temperature, binder is supplied from an injection device 61 through the nozzle 63 and flows through the bore, through the annular space 47 around each of the piston stems 45, upwards past the piston head 43 and into the mould cavity 12. The annular space around each piston registers with the next section of the bore 16 and thus serves as a feeder connection to the next adjacent mould cavity 12. The clearance between the head 43 on each piston 23 and the wall surface of the cavity 12 is dimensioned to prevent the passage of fuel particles therepast, and it acts as a gate through which the fluid binder material enters the mould cavity where the particle bed is located.

As the binder enters the particle bed, its lubricity allows the coated fuel particles to readjust their positions and settle still further. This setting is accompanied by upward incremental movements of the piston which, due to the continued upward hydraulic biassing, applies a constant pressure, preferably at least about 42 kg/cm^2 on the particle bed, keeping it compacted. The piston is also free to move to accommodate any minor shifts in the particle bed due to differential thermal expansion. Because the gate which is formed between the piston head 43 and the inner surface of the mould cavity also travels with any movement in the bed, the effect is one of a moving gate in the moulding process, which is possible even though the horizontal bore 16 is stationary, because the axial length of the annular recess 47 is sufficient to remain in registration with the sections of the bore 16.

At the beginning of the injection of the fluid binder material, air is expelled from the cavity via an air vent 64 in the form of a shallow groove provided at the top edge of the mould cavity. The circular recess 59 in the underside of the cover plate 55 overlaps the air vent 64, and the aperture 57 leads upward from this recess and out through the plate. Typically, one recess 59 and one aperture 57 serve each pair of cavities, and the air vent 64 is dimensioned, e.g., about 3.175 mm long by 0.127 mm deep to prevent the entry of fuel particles thereinto. Air is expelled from the cavity during injection of the fluid binder via the air vent 64, the recess 59 and the aperture 57 to the atmosphere. Once the cavity 12 is completely filled, excess binder material can flow into the recess 59 through the vent 64 and up into the aperture 57, as shown in Figure 4. However, the vent 64 is sized so that the coated fuel particles cannot pass therethrough so that there can be no loss of fuel from the metered charge. Once the fluid material reaches the vent 64, the back pressure in the mould cavity rises, which in turn restricts the flow of fluid material into that particular cavity, routing it instead through the bore 16. Thus, the vents 64 are also used as a control device to ensure the complete filling of all cavities.

Upon completion of the injection process, cooling and consequent solidification of the binder material is effected. The cover plate 55 is then raised, and the piston rods 25 are driven further upward in the cavities to eject the fuel rods, indicated at 67 in Figure 5. At the same time, the excess binder material which has escaped into the recess 59 and the bore 57 is ejected by bringing the plate 55 up sufficiently to cause an ejector pin 69 to contact the machine frame, indicated at 71. The solidified excess binder material, indicated at 73, then falls for suitable collection and possible re-use. The binder will, preferably, become sufficiently fluid for moulding purposes when heated to a temperature of about 150°C to 190°C. At relatively low shear rates, i.e., about 20 to 40 sec.$^{-1}$, binders having a viscosity between about 300 and 1,000 poises, at 175°C, may be used with coated fuel particles having a minimum size of about 300 microns. However, if higher shear rates are to be employed in the injection, binders having lower viscosities, e.g., 40 to 90 poises, may be selected.

WHAT WE CLAIM IS:

1. A method of manufacturing a nuclear fuel rod, comprising partially filling a mould cavity with nuclear fuel particles, closing the mould cavity and reducing its volume such that the fuel particles substantially fill the mould cavity, and injecting a fluid solidifiable binder into the mould cavity to fill the interstices between the fuel particles, sufficient fluid binder being injected to cause it to flow out of a vent passage at the opposite end of the mould cavity from that at which it is injected to

assure complete filling of the cavity, wherein the vent passage is dimensioned to prevent the passage of the nuclear fuel particles therethrough.

2. A method according to claim 1, wherein the vent passage is dimensioned to prevent the passage of such nuclear particles therethrough which have a particle size of at least 300 microns.

3. A method according to claim 1 or 2, substantially as described with reference to the accompanying drawings.

4. Nuclear fuel rod, manufactured by the method of any one of claims 1 to 3.

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1546242 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

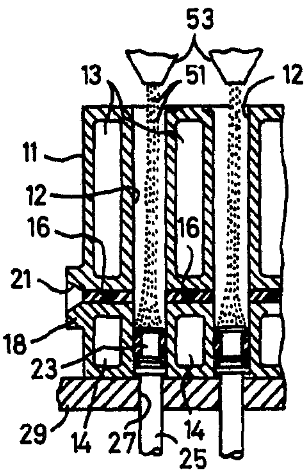

FIG.1

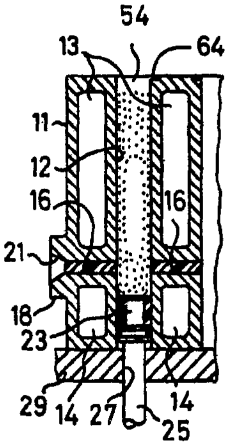

FIG.2

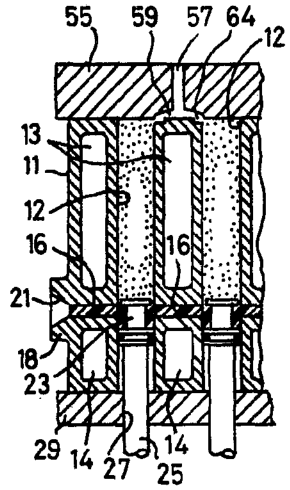

FIG. 3

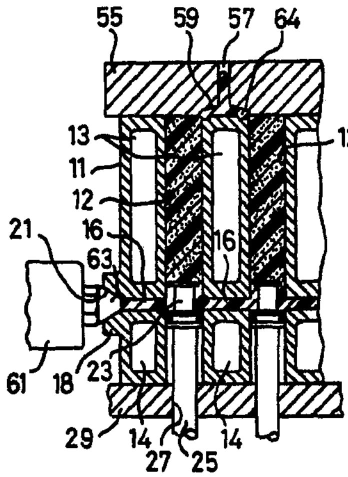

FIG. 4

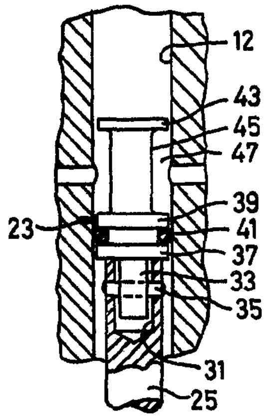

FIG. 6

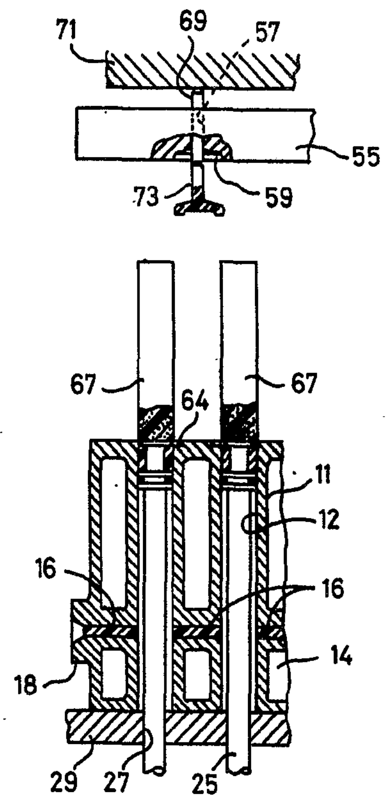

FIG. 5