Method and apparatus are provided for a novel continuous, automated melt-pour process for high explosives, such as TNT, wherein flaked high explosive is continuously introduced into a vessel containing an agitated pool of the molten explosive and providing a high ratio of heating surface to volume of explosive and the molten explosive is continuously pumped to a remote shell loading station through a heated pipe system provided with detonation traps which prevent propagation of an explosion.

The invention described herein may be manufactured, used and licensed by or for the Government for governmental purposes without the payment to us of any royalty thereon.
APPARATUS FOR CONTINUOUS MELT-POUR OF HIGH EXPLOSIVES

This is a division of application Ser. No. 174,078, filed Aug. 23, 1971.

BACKGROUND OF THE INVENTION

This invention relates to a novel, safe and efficient, continuous melt-pour process for high explosives, and apparatus thereof, wherein a solid high explosive is melted and the molten explosive is pumped through a pipe system heated, for example, with jacket steam or hot water, to a remote shell loading station where it is poured into a shell and allowed to solidify.

The present method of melting and loading high explosives, such as TNT (trinitrotoluene) is basically unchanged from that used prior to the second World War. Some improvements have been made but the method, which consists of a batch process using gravity feed from multistory buildings, still exists. In the batch process, solid explosive is introduced gradually into a large heated kettle containing the molten high explosive located at the top of a multistory building. When the batch is complete and fully melted, the molten explosive is allowed to flow by gravity to a loading station where it is poured and cast into shells.

The batch process presents serious dangers in view of the large concentrations of explosive which are being processed at one time. Some melt kettles contain up to 3,600 pounds of explosive and some melt towers contain a total of 40,000 pounds of explosive in a three story building. Great damage to plant and personnel could result if an explosion occurred. To minimize the potential damage resulting from an explosion, it is customary to locate equipment behind heavy masonry walls, etc., or to separate equipment and processing stations by substantial distances from one another as much as possible.

To overcome the aforesaid disadvantages of batch operation the industry has sought for many years to develop a safe and practical method for carrying out the operation continuously. A continuous process would have the advantage of treating relatively small amounts of explosive at any time with obvious reduction of hazard. However, to be commercially practical, it would have to be able to melt and transport substantial amounts of explosive per unit of time. Further, it would be necessary to provide a method whereby the molten explosive could be safely pumped through pipelines to a remote loading station, thus eliminating the aforesaid gravity flow operation conventionally employed. The resulting advantages would be considerable, including for example, use of one-story buildings in place of costly multistory buildings and improved safety of operation resulting from separation of melting and loading areas by greater distances. To date, the industry has not succeeded in devising a practical, safe, continuous melt-pour process for high explosives, such as TNT.

SUMMARY OF THE INVENTION

An object of this invention is to provide a novel, safe, practical and efficient continuous process for melting a solid high explosive and pumping the molten explosive through a heated pipe system to a remote loading station.

A further object of the invention is to provide a novel continuous process, wherein the molten explosive is pumped through a heated pipe system provided with detonation traps for safety.

Another object is to devise novel apparatus for carrying out a continuous melt-pour process of the aforesaid type.

Other objects will appear or be obvious from the following description of the invention.

Our invention is directed to a method for carrying out a continuous melt-pour process for high explosives, which comprises:

- continuously introducing solid particles of the explosive into a pool of the molten explosive,
- continuously heating and agitating said pool to melt solid explosive introduced,
- continuously pumping molten explosive from said vessel to a shell loading station through a pipe system provided with detonation traps and
- continuously controlling the feed of solid explosive into said pool and flow of molten explosive therefrom to the loading station.

Our invention is also directed to novel apparatus for carrying out the continuous melt-pour process for high explosives, which comprises in combination:

1. a vessel for melting a solid high explosive which provides a high ratio of heating surface to volume of explosive charge;
2. means for feeding solid explosive into said vessel;
3. a pipe system for conducting molten explosive from the melter to a shell loading station and preferably adapted to recycle same to the melter, if desired;
4. means for pumping molten explosive through said pipe system;
5. detonation traps in said pipe system adapted to detect a wave and detonation interrupt the pipe system so as to arrest the detonation wave therein; and
6. means for continuously controlling the feed of solid explosive into said vessel and flow of molten explosive therefrom.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated in the drawings, in which FIG. 1 sets forth a schematic flow diagram of the novel melt-pour process and apparatus;

FIG. 2 illustrates a detonation trap for arresting an explosion wave in the pipe system for transporting molten high explosive in the novel process; and

FIG. 3 illustrates pumps of the peristaltic and diaphragm types suitable for pumping molten explosive in the process of our invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1, there is shown a hopper 1 from which flaked TNT (or other high explosive) feeds through a continuous weigh feeder 2 comprising an endless belt 3 driven by pulleys 4. The weigh feeder can control the mass flow rate to within 0.5 accuracy of a remotely dialed in set point. A suitable weigh feeder is an electrical-mechanical type, which senses the weight of explosive over a given length of belt and multiplies this by the belt speed to obtain the weight flow. The thickness of the material on the belt is controlled by an adjustable shear gate. The weigh feeder indicates the weight flow and automatically adjusts the belt speed to maintain the desired rate. Other types of weight flow control means are known and can be used, e.g., a nuclear device, wherein gamma radiation from a cesium
source is sent through the flaked explosive on the belt. The amount of radiation sensed on a detector is proportional to the mass on the belt. The device is connected to a control which automatically adjusts the belt speed. From the continuous weigh feeder the TNT flakes flow into a preheater 5 wherein they are heated to a temperature of about 125° to 150°F by means of hot air forced through a vibrating perforated conveyor deck 6 transporting the solid TNT. An alternative type of preheater can be used, wherein the flakes are fed onto an endless metal belt in which heat is transferred to the flakes by conduction from a hot water bath. The preheater provides two important benefits:

1. the TNT flakes entering the melt unit will always be at a controlled temperature regardless of the ambient storage temperature, which can vary widely.

2. by preheating the TNT flakes to about 125°-150°F, higher melting rates can be achieved in the melt unit, since the flakes are already heated up to about 75 of their melting point.

The TNT flakes should not be preheated to a temperature such that they become tacky.

From the preheater the TNT flakes are introduced via top opening 7 into a melt unit 8 consisting of a vertical, steam jacketed, elongated cylindrical vessel of stainless steel, which is provided with an axially aligned agitator 9 rotated by a pressurized hydraulic system (not shown). The agitator consists of a hollow shaft having a number of hollow paddles 10 affixed thereto and is heated by circulating steam through the hollow shaft and paddles. The agitator is mounted and turns in two bearings at the top of the vessel and terminates short of the bottom of the vessel. Thus the agitator has no bearings etc in contact with the molten explosive which might develop dangerous local friction an heat.

By virtue of the agitator design and relatively small diameter to height ratio in the continuous melt unit 8, the latter affords a considerably larger ratio of heat transfer area to volume of explosive and hence greater production rate than provided by kettles currently used in the batch process.

To start the operation the melt unit 8 is charged with a small amount of TNT flakes (e.g., to about one-fifth of its capacity). Steam heating is then applied to the jacket and agitator (which is not rotated) and the flakes are melted to provide a pool of molten TNT. Thereafter, the agitator and feed of TNT flakes are started, and the level of the molten explosive is allowed to rise to the desired operating level 20, e.g. about 6 inches from the top of the melt unit.

An optional startup procedure can be employed, wherein steam is introduced via valve 14 directly into a charge of TNT flakes (which may equal 75 percent or more of the melt units capacity) to accelerate the melting process while maintaining steam heating on the jacket and agitator. When the contents are molten and stirrable, the agitator is started. Condensate water, which separates as a supernatant layer above the relatively dense, water-insoluble TNT, is removed via vacuum distillation by means of a jet ejector 15 after closing steam valve 14. Thereafter the feed of TNT flakes is commenced.

When the desired operating level 20 is reached and the melter contents are at the desired temperature, preferably about 190°F (14° above the melting point of TNT), valve 12 is opened to permit the molten TNT to flow through a hot water jacketed conduit 11 to pump 13, which functions to pressurize and transport the molten TNT through said conduit and valve 17 to the loading station (not shown). A pump 13 of the diaphragm or peristaltic type is suitable for this purpose.

To insure safety and protection against propagation of an accidental detonation, the pipe system comprising hot water jacketed conduit 11 and recycle conduit 19, noted below, is provided with detonation traps 21, as described in greater detail below. The detonation traps are preferably located so as to protect the areas of greatest concentrations of explosive in the system, e.g., in conduits 11 and 19 so as to arrest a detonation wave therein before it reaches the melter and/or the loading station.

When the process is in continuous, steady state operation, the TNT feed into melter 8 is in equilibrium with the flow of molten TNT therefrom. During such operation the level of the molten explosive is maintained more or less constant at 20 by suitable instrumented control devices e.g., of the ultrasonic or nuclear type (not shown) linked to the weigh feeder, which adjusts the flow automatically to maintain said level constant. Alternatively, or as a back up control, the TNT feed rate into the melter can be matched with the flow rate of molten TNT therefrom by use of a suitable flow meter in the molten TNT line. The flow rate, density and temperature of the molten explosive can be continuously monitored by means of suitable instrumentation, as schematically shown in FIG. 1. The principal control for the novel process is provided by the temperature of the molten explosive as it leaves the melt unit. Preferably, the average residence time of the TNT in the melt unit is adjusted such that the molten TNT leaving the unit is heated to 185°-190°F. This can be achieved under usual, constant heating rate conditions by suitable adjustment of the TNT flow into and out of the melt unit. The process can be automatically controlled to maintain the effluent molten TNT within the above described temperature range by linking the temperature monitoring device, e.g., a thermocouple (not shown), with the jacket steam control valves in the melt unit (not shown), pump 13, weigh feeder and liquid level controller, by suitable instrumentation. For example, if the temperature drops below the preferred range of 185°-190°F, the thermocouple will signal the steam control valves to provide more steam and therefore more heat input to the explosive. If the temperature rises above the preferred range, the thermocouple signal will reduce the heat input. When the heat input of steam is at a maximum, as it would be when initial tests to determine the maximum melting rate are made, the pump rate will be adjusted to maintain the desired molten TNT temperature and the weigh feeder will correspondingly change the flow of solid TNT to maintain an approximate constant liquid level 20 in the melt unit 8.

The system permits recycling the molten explosive, if desired. Thus, valve 17 can be closed and molten TNT can be recycled through valve 18 and hot water jacketed conduit 19 to the melter unit 8. Recycling in this manner can be used in start up, shut down or hold operations, wherein all or part of the molten explosive can be pumped back to the melter unit. For cleanup operations, the melter unit 8 can be drained of its liquid contents via outlet valve 16 to a receiver (not shown), and then cleaned out with steam.

FIG. 2 illustrates a suitable detonation trap, which comprises a detonation breakwire sensor 30 coiled
around conduit 31, and an in-line detonator-activated, explosion arresting valve 32 connected via leads 33 and 34 to output terminals 35 and 36 of an electronic switch circuit 37. Valve 32 comprises a cylindrical housing containing a tightly fitting, movable, piston-like steel plug 38 having a transverse bore 39 of the same size as conduit 31 which may have a diameter of 1/2 to 1 inch or more, and being normally in open position with respect to said conduit. The cylindrical housing of valve 32 possesses a lower tapered portion 40 adapted to stop the movable plug 38 at a position so as to completely close off conduit 31. Valve 32 also contains a small explosive charge 41, such as RDX plus an initiator, mounted in a removable cap 42 and connected to the leads 33 and 34. The detonation breakwire sensor 30 is electrically connected to a pair of input terminals 43 and 44 of electronic switch circuit 37, which maintains detonator-activated valve 32 inactive as long as the breakwire sensor 30 is intact. When a detonation wave DW in conduit 31 ruptures breakwire sensor 30, the electronic switch circuit 37 will supply a voltage pulse to leads 33 and 34, which explodes explosive charge 41, causing the steel plug 38 to move forward to block conduit 31 and thereby arrest the detonation wave. By installing the detonation sensor on both sides of detonator-activated valve 32 in conduit 31, the detonation trap will arrest a detonation from either direction. The detonation wave in the molten TNT travels at a speed of about 25 feet per millisecond. Since the detonator-activated valve 32 has a response time of less than 1 millisecond, the detonation wave DW must be sensed at least 25 feet from valve 32. In practice it is advantageous to coil the breakwire sensor around the entire length of the conduit transporting the molten TNT. Detonation traps having a response time of about 1 millisecond or less are described in copending U.S. Pat. application Ser. No. 139,337, "In-Line Explosion Arrester," Louis Jablansky, inventor, filed May 3, 1971, which is incorporated by reference into this application.

Aan be appreciated by those skilled in the art, the feed rate and preheat temperature of solid explosive, the temperature and flow rate of molten explosive, rate of heating, etc. can be varied to suit the particular explosive being processed according to our invention. As noted above, these process variables can be monitored and controlled via suitable instrumentation and devices schematically illustrated in FIG. 1. As shown in FIG. 1, information concerning such properties is taken at suitable points in the system and fed to a control panel, which is located at a safe distance from the equipment. The process operator can make adjustments of any of these process variables by remote controls. Closed circuit TV can also be used to monitor the process. The monitor-control system can be automated as much as possible so as to make adjustments automatically to maintain steady-state operating conditions.

Our novel melt-pour process for TNT and other high explosives provides high production rates, since it employs a melt unit having a high heat transfer coefficient and a high ratio of heat transfer area to volume of explosive. A suitable melt unit of this type includes a vertical, steam jacketed cylindrical vessel, which possesses a height, which is considerably greater, preferably about three or more times greater, than its diameter. Preferably, the melt unit contains a hollow agitator, which is heated by a circulation medium, such as steam or hot water, and possesses a heating surface area of at least about 50 percent of the total heating area in contact with the molten explosive in the melt unit.

For industrial operation, it is preferred to employ a melt unit of the design illustrated in FIG. 1. A pilot size stainless steel melt unit of such design, comprising a jacketed cylindrical tank, having a 1 foot diameter and height of 3 feet internal dimensions, an active working volume of 1.54 cubic feet (i.e., the volume of molten TNT in the melt unit), an active heating surface of 20 square feet (i.e., the total heating area in contact with the molten TNT in the melt unit, 9.1 sq. ft. provided by the wall jacket and 10.9 sq. ft. by the agitator including paddles), and heated by circulating steam at 250°F, can melt about 450 lbs. per hour of TNT preheated to 125°F. A production size stainless steel melt unit of similar design, comprising a cylindrical tank having a 1.5 ft. diameter and 12 ft. height I.D., an active working volume of 15.9 cu. ft., an active heating surface of 182.8 sq. ft. (125 sq. ft. provided by the agitator and 57.8 sq. ft. by the wall jacket), and heated with circulating steam at 250°F, can melt about 9000 lbs. per hour of TNT flakes preheated to 125°F.

The invention is not limited to the design of melt unit illustrated in FIG. 1. Other means for providing a high ratio of active heating area to active volume of molten explosive in the jacketed melt vessel can be employed, e.g. hollow coils, hollow baffles, hollow agitators of various designs, etc., heated by a circulating heating medium.

The melt unit employed in the process of our invention possesses a ratio S/V which is preferably greater than 5, wherein S represents the heating surface area in square feet in contact with the molten explosive and V represents the volume in cubic feet of molten explosive. In the pilot and production size melt units noted above the S/V ratios are approximately 13 and 11.5 resp.

For reasons of safety, economy and efficiency, steam is used as the indirect heating medium, although other media can also be employed, e.g., hot water, Dowtherm, etc.

The type of pump used for pressurizing and moving the molten explosive through pipelines is a critically important feature of the novel system. As noted above, pumps of the peristaltic type of diaphragm type are suitable, since they are capable of forcing the molten explosive through a pipe without the application of dangerous sudden localized high pressures or friction forces, such as are imparted by metal to metal contact, rotary seals, etc., present in impeller, centrifugal and other conventional pumps, which are unsuitable. Diaphragm pumps are preferred over peristaltic pumps in our invention, since they are capable of generating higher line pressures and possess longer operating life of flexible parts. A suitable diaphragm pump is known commercially as Pulsafeeder Pump with Hydratube Head, manufactured by Lapp Insulator Company, Inc., Leroy, N. Y. Flexible parts, viz. tubing and diaphragms, in contact with the molten explosive must be compatible with the molten explosive and possess adequate operating life at elevated temperatures. Silicone rubber, fluorocarbon rubber (e.g., a copolymer of hexafluoropropylene and vinylidene fluoride sold under the trademark Viton A by the E. I. du Pont de Nemours Co.) and butyl rubber, illustrate suitable materials for such
flexible parts which can be used for pumping molten TNT.

Besides TNT, other solid explosives suitable for use in a melt pour process can be employed according to this invention, e.g., mixtures of TNT with other explosives, such as Composition B (40 percent TNT and 60 RDX (cyclotrimethylenetetranitramine)).

It can thus be seen that the novel continuous melt pour process and apparatus of this invention represent a significant advance in the art and provide a number of important safety and economic advantages over the prior batch process, notably:

1. Exposure of personnel to explosives is minimized by automation of the process.
2. Explosive allowance per operating bay in a commercial plant is reduced considerably down to about 2000 pounds for a production rate of 9000 lbs. per hour — some melt towers in existing plants contain about 40,000 pounds of explosive.
3. Need for costly, undesirable multistory buildings now used is eliminated. The melter, pipe system, loading station and controls can all be located underground or in one story buildings.
4. The melting and loading operations are separated from each other by safe distances, as required in Safety Manual AMC 385-100.
5. The process can be considered as a module in a production facility; additional modules can be used in combination to meet various capacities required by different end items.
6. Maximum safety from propagation of explosions is provided by installation of detonation traps in the pipe system.
7. Production efficiency is improved because the novel process provides inherent advantages of continuous operation.
8. Higher production rates are realized by use of a preheater and a more efficient melt unit than employed in the batch process.
9. Quality of cast explosive is improved by better controls over the process, which eliminate human error and produce a uniform output of explosive.
10. Operating costs are lowered by reduction of direct labor costs. Melt towers now require approximately six operators on the second and third floor to run three melt kettles. The continuous melt unit of the present invention having an equivalent production capacity can be operated at a remote control center by one person.

We wish it to be understood that we do not desire to be limited to the exact detail of construction shown and described for obvious modification will occur to a person skilled in the art.

What is claimed is:

1. Apparatus for continuously melting and pumping a molten high explosive such as TNT to a remote load-