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Frable

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[54] **CRYOGENIC COMMINUTION SYSTEM**

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[51] **Int. Cl.** **B02c 21/00**
[58] **Field of Search** 241/17, 23, 65

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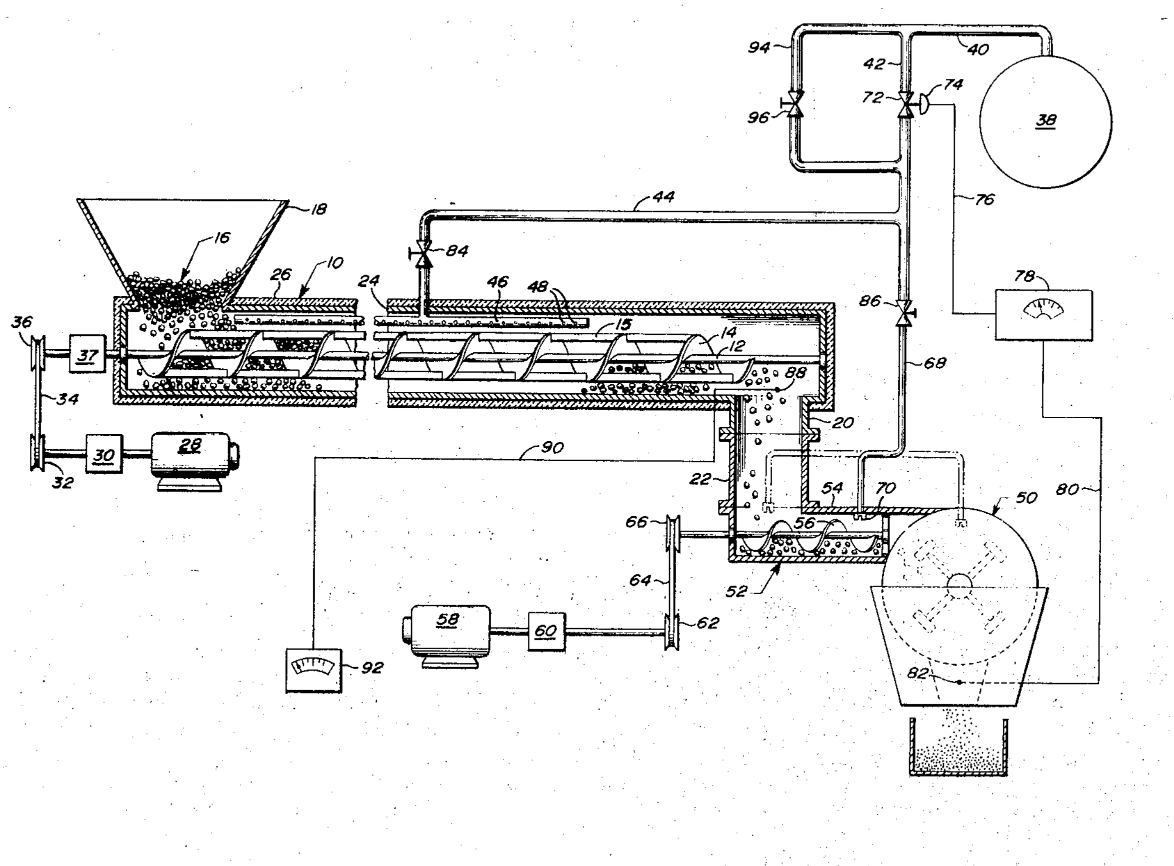
[57] **ABSTRACT**

A cryogenic comminution system is disclosed including a mixer-conveyor and a comminution mill wherein cryogenic liquid refrigerant is introduced into the mixer-conveyor to embrittle the material to be comminuted before the material is fed into the mill; and wherein auxiliary cryogenic liquid refrigerant is separately introduced into the mill in order to overcome heat generated in the mill, and thereby maintain the internal components of the mill at a predetermined low temperature.

2 Claims, 1 Drawing Figure



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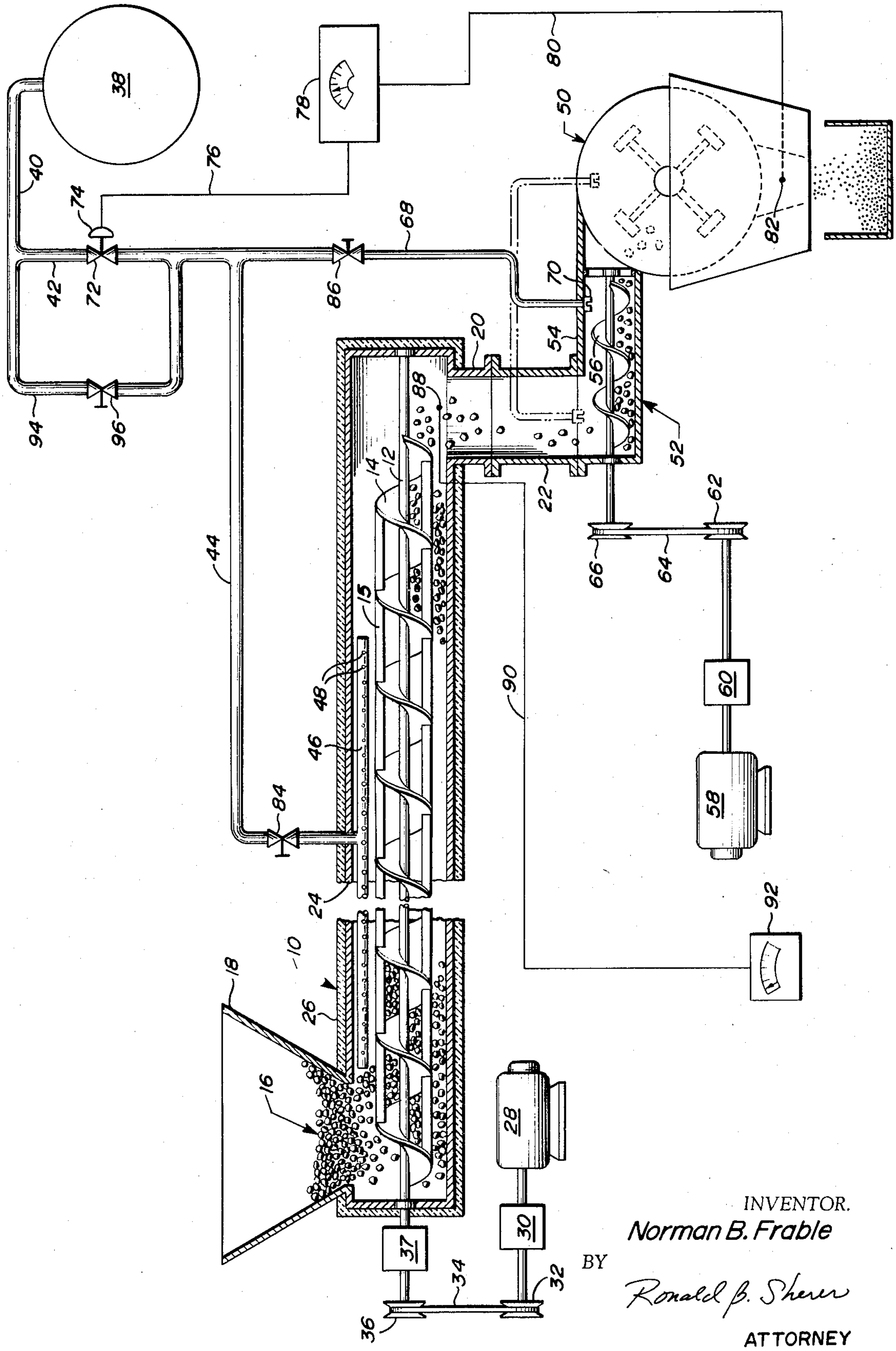

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CRYOGENIC COMMINUTION SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to the field of grinding, pulverizing or size reduction, hereinafter collectively referred to as comminution. More particularly, the present invention relates to the comminution of relatively soft or resilient materials which are difficult or impossible to comminute in high speed mills such as, for example, polymeric and rubber materials including polypropylene, polyethylene, polyvinylchlorides, polyisobutylenes and other natural or synthetic rubber materials, spices, pigments and color concentrates hereinafter collectively referred to as relatively non-brittle materials.

With regard to such relatively non-brittle materials, it has long been recognized that various refrigerants may be used to cool the material well below its embrittlement temperature, and thereby comminute the material at low temperatures. However, previous systems have been thermally and economically inefficient in that the material has been deeply subcooled well below its embrittlement temperature so as to attempt to overcome the large amount of frictional heat which is generated in a high speed mill. However, the residence time of the material in contact with the mill is so short that the material must be very deeply subcooled; i.e., 100°F to 150°F or more below its embrittlement temperature, in order to keep the mill sufficiently cold. Thus, the deeply subcooled material gives up only a small fraction of its refrigeration value to the mill, and is discharged at excessively low temperatures which is highly wasteful of costly refrigerant.

Attempts have also been made to introduce the refrigerant directly into the mill, however, the short residence time of the material in the mill produces highly inefficient cooling of the material, which is equally wasteful of the costly refrigerant. That is, optimum speeds of comminuting can only be achieved when the material has had sufficient time in contact with the refrigerant so as to be embrittled before it is comminuted.

SUMMARY OF THE INVENTION

The present invention substantially reduces the amount of refrigerant by carefully controlled cooling of the material to, or only slightly below, its embrittlement temperature in a cooling zone, and separately supplying a controlled amount of auxiliary refrigerant into the mill to directly cool and maintain the internal components of the mill at an optimum operating temperature. In the preferred embodiment of the present invention, the cooling zone includes a refrigerant injection zone, and a subsequent equilibration zone, whereby the temperature gradient between the surface and core portions of the particles is substantially reduced before they are fed into the mill.

BRIEF DESCRIPTION OF THE DRAWING

The drawing is a simplified illustration of one embodiment of the cryogenic comminution system showing some of the components in cross-section.

DETAILED DESCRIPTION OF ONE PREFERRED EMBODIMENT

Referring to the drawing, numeral **10** indicates one form of a conventional mixer-conveyor having a rotating shaft **12**, a screw **14** and a plurality of mixing blades **15** which operate to mix and convey the particulate material **16** from the left-hand inlet end adjacent hopper **18** to the right-hand discharge end adjacent discharge duct **20.** Of course, it is to be understood that other types of conventional mixer-conveyors may be employed, including, for example, plain or perforated screw conveyors, or vibratory conveyors so long as they are capable of agitating the particles and conveying them through an elongated, closed chamber such as that formed by housing **24** which may be of circular or U-shaped cross-section. In order to reduce wasteful heat leak and consequent loss of refrigerant, the housing **24** is preferably covered with a thermal insulation material **26,** such as sponge rubber, foamed polyurethane, or other well known insulation materials. The mixer-conveyor may be horizontal, or inclined, and may be in the order of 5 to 10 feet long. Shaft **12** is preferably driven at a relatively low and variable speed by a motor **28,** first gear reducer **30,** variable speed pulley **32,** belt **34,** pulley **36,** and a second gear reducer **37.** Thus, the rotational speed of mixer-conveyor **10** may be widely varied, and is preferably in the range of 5 to 10 RPM which results in a residence time of the material in mixer-conveyor **10** in the range of 1 to 10 minutes for a mixerconveyor having the above-indicated length of 5 to 10 feet.

In order to cool the relatively non-brittle material **16** to a temperature equal to or slightly below its embrittlement temperature, a liquefied cryogenic refrigerant is stored in a conventional cryogenic storage tank **38.** As used in the present specification and claims, the term "cryogenic refrigerant" is intended to denote a refrigerant fluid having a normal boiling point below minus 100°F which includes, for example, liquefied carbon dioxide, liquefied air, various liquefied halogenated hydrocarbons, liquefied nitrous and nitric oxide, and liquefied noble gases such as helium and argon. However, for thermodynamic, safety and economic reasons, liquefied nitrogen having a normal boiling point of minus 320°F is preferred as the most ideal cryogenic refrigerant.

The liquefied cryogenic refrigerant, such as liquid nitrogen, is conveyed through insulated transfer lines **40, 42** and **44** to elongated spray header **46.** Spray header **46** may comprise an elongated pipe having discharge ports **48** spaced along its length through which the cryogenic liquid refrigerant is injected into the mixer-conveyor. Alternatively, separate injection nozzles may be spaced along the mixer-conveyor so as to inject the cryogenic liquid into contact with material **16.** In either event, it has been discovered that for optimum efficiency, one end of the liquid injection system should be positioned immediately adjacent the product inlet end, and the points of liquid injection should extend toward the discharge end for one-half to four-fifths of the length of the mixer-conveyor. That is, it is preferred that the cryogenic liquid injection portion of the mixer-conveyor should terminate before the discharge end of the mixer-conveyor so as to provide a portion wherein the particulate material is in contact with only the cold refrigerant vapors resulting from the vaporization of the cryogenic liquid refrigerant, and the particulate material should have a sufficient residence time in the vapor zone to enable the temperature gradient between the surface and the core of the particles to at least partially equilibrate. Thus, the preferred mixer-conveyor includes a cryogenic liquid injection zone, and an equilibration zone so that the entire mass of the particle is cooled to its embrittlement temperature, or slightly therebelow.

As previously indicated, the discharge end of mixer-conveyor **10** is provided with a discharge duct **20** through which the embrittled particulate material is discharged into the impact mill **50** which is illustrated as being of the conventional high-speed rotating hammer type. Of course, other types of well known comminution mills may be used such as, for example, other types of rotary impact mills, pin mills, or ball mills depending upon the type of particulate material and the final size reduction desired. In any event, the feed inlets to such mills usually include either an inclined feed chute, or a feed conveyor which may be connected to the discharge duct **20** of the mixer-conveyor either directly, or through an optional intermediate duct **22.**

In the illustrated embodiment, the feed inlet to the mill comprises a relatively short feed conveyor **52** comprising a housing or duct **54** containing a feed screw **56** which is driven by motor **58** through gear reducer **60,** variable speed pulley **62,** belt **64,** and pulley **66.** Whereas, the mixer-conveyor is relatively long and rotates at low speed in order to provide a relatively long residence time in order to cool and embrittle the particulate material, feed conveyor **52** is relatively short such as, for example, in the order of two to ten inches, and the feed screw is driven at relatively high speed, such as in the order of 50 to 100 RPM. As a result, the residence time of the particulate material in discharge ducts **20, 22** and the feed conveyor **52** is very short, such as for example, in the order of one to ten seconds, and the volume of the feed conveyor filled by the particulate material is less than one-half of its total volume. Thus, the discharge ducts **20, 22** and high speed, partially filled, feed conveyor **52** provide an essentially open passage for the conduction of auxiliary cryogenic refrigerant directly into the mill as will now be described in detail.

Where an existing mill has such a feed conveyor, or an inclined feed chute, the preferred mode of auxiliary refrigerant injection is through an auxiliary transfer line **68** the discharge end of which is preferably provided with a spray nozzle **70** located within the feed conveyor or feed chute. However, if the mill does not have a feed conveyor or feed chute, auxiliary refrigerant line **68** may terminate within discharge ducts **20** or **22,** or it may terminate directly within the mill itself; the latter two locations being illustrated in phantom line. Thus, the point of auxiliary refrigerant injection may be anywhere downstream of the mixer-conveyor, so long as the auxiliary refrigerant does not have sufficient contact time with the particulate material so as to appreciably subcool the particulate material, but rather, such that the liquid refrigerant goes immediately into the mill and into direct contact with the internal components of the mill, Thus, the mill is directly cooled by the auxiliary liquid refrigerant and the heat generated in the mill is overcome without overcooling the particulate material substantially below its embrittlement temperature.

Referring now to the refrigerant control system, main transfer line **42** is provided with a flow control valve **72** which may be of the on-off or modulating type, and which includes an actuator **74** for controlling the opening and closing movements of the valve. Actuator **74** is connected by an electrical or pneumatic signal line **76** to an indicator-controller **78** which is connected through a signal line **80** to a temperature sensor **82,** such as a thermocouple, which is preferably located in the mill outlet. Thus, sensor **82** detects the discharge temperature of the comminuted particles, which is also an indication of the internal mill temperature, and indicator-controller **78** actuates controller valve **72** to increase or decrease the flow of refrigerant through main line **42** so as to maintain the discharge temperature of the comminuted material as warm as possible while still maintaining optimum size reduction of the material. That is, depending upon the composition of the material and the final size desired, the discharge temperature is preferably maintained within 30°F above or below its embrittlement temperature.

In order to properly proportion the amounts of refrigerant supplied to spray header **46** and auxiliary nozzle **70,** refrigerant transfer line **44** includes a flow control valve **84,** and auxiliary refrigerant transfer line **68** includes a flow control valve **86.** A second temperature sensor **88** is positioned in the discharge portion of the mixer-conveyor adjacent discharge duct **20** and is connected via signal line **90** to a temperature indicator **92.** Thus, the temperature of the embrittled material discharged from the mixer-conveyor can be closely monitored and valve **84** may be regulated so as to cool the material to, or slightly below, its embrittlement temperature while also maintaining an optimum temperature of the internal components of the mill by regulating valve **86.**

While the size of flow control valve **72** is selected such that its maximum flowrate is more than sufficient to supply the required flowrate of cryogenic refrigerant during steady-state operation, a substantially larger flowrate is highly desirable during start-up when the complete system is at ambient temperature and must be cooled down to operating temperature. Accordingly, the preferred embodiment of the invention provides a by-pass line **94** having a manual by-pass valve **96** which permits higher refrigerant flowrates during cooldown of the system. In addition, valve **96** permits a steady flowrate to be established in lines **44** and **68,** regardless of the action of temperature responsive valve **72,** so that the optimum settings of proportioning valves **84** and **86** may be established. In this regard, extensive tests have indicated that between one-third to one-fifth of the total cryogenic refrigerant should be injected through auxiliary line **68,** and that optimum efficiencies for most materials are obtained by injecting approximately one-fourth of the total refrigerant through auxiliary line **68.**

OPERATION

In the preferred mode of operation, by-pass valve **96** is opened to permit a high flowrate of cryogenic liquid refrigerant to both spray header **46** and nozzle **70.** Since the system is initially warm, a substantial portion of the cryogenic liquid is initially vaporized in cooling the lines, mixer-conveyor **10,** and mill **50.** Once all of the components have been cooled down to a predetermined temperature, the material to be comminuted is introduced into hopper **16** and motors **28** and **58** are energized. Temperature indicators **92** and **78** are monitored and valves **84** and **86** are initially adjusted so as to proportion the flow of refrigerant between spray header **46** and nozzle **70.** By-pass valve **96** is then closed, and the temperature indicators are further monitored as the system approaches steady-state operation. Final adjustments of valve **84** and **86** are then made so that the temperature of the material at the discharge end of the mixer-conveyor is at, or slightly below, the embrittlement temperature of the material to be comminuted. That is, valve **84** is adjusted such that the average equilibrated temperature of the material in the discharge end of the mixer-conveyor is held in the range of 0 to 50° below its embrittlement temperature; while valve **86** is adjusted so as to provide the optimum amount of additional refrigerant which is necessary to overcome the frictional heat generated in the mill and keep the internal components of the mill at or near the embrittlement temperature of the material. Of course, it will be understood that the precise temperature of the material is not absolutely determinable by sensors **88** and **82** since there is always a mixture of material and vaporized refrigerant at the sensor locations. However, operating experience quickly enables the operator to determine the relationship between the sensed temperatures and the actual temperatures of the material and the mill. Also, it will be apparent that the embrittlement temperature varies significantly with different compositions of material, and that the optimum residence time in the mixer-conveyor is also dependent upon the initial size and mass of the material fed into hopper **16.** Thus, the residence time of the material in the mixer-conveyor may also be adjusted by varying the rotational speed of shaft **12** through variable speed pulley **32** which, in turn, optimizes the amount of refrigerant supplied to spray header **46** in order to maintain the average equilibrated temperature of the material discharged from the mixer-conveyor between zero to 50°F below the embrittlement temperature of the material being processed.

From the foregoing description it will be apparent that the present invention provides for carefully regulating the degree of cooling of the material to, or only slightly below, its embrittlement temperature, and thereby prevents significant waste of refrigerant which results from subcooling the material 100°F to 150°F below its embrittlement temperature in order to overcome the heating effects of the mill. Thus, instead of attempting to rely upon the inefficient heat exchange between substantially subcooled material and the mill components, the present invention separately injects auxiliary refrigerant into the mill for direct contact and heat exchange with the components of the mill. As a result, extensive tests have shown that the present invention requires 10 to 20 percent less refrigerant, which represents a substantial savings in operating costs as compared with all known prior systems.

From the foregoing description of one preferred embodiment of the invention it will be readily apparent that numerous variations and modifications will become readily apparent to those skilled in the art, such as, for example, the substitution of an automatic indicator-controller for temperature indicator **92,** whereby valve **84** may be automatically varied in response to the temperature sensed by sensor **88.** Therefore, it is to be understood that the foregoing description is intended to be illustrative of the principles of the invention, and that the invention is not to be limited other than as expressly set forth in the following claims.

I claim.

1. A cryogenic system for comminuting relatively non-brittle material comprising:

a. elongated rotary mixer-conveyor means including inlet means, discharge means spaced at least 5 to 10 feet from said inlet means, and variable speed conveyor means for varying the residence time of material conveyed through said mixer-conveyor within the range of one to ten minutes,

b. a source of liquid nitrogen,

c. first refrigerant injection means connected to said source for introducing liquid nitrogen into said mixer-conveyor, said injection means comprising a spray header positioned within the interior of said mixer-conveyor and extending from adjacent said inlet means throughout the major portion of the length of said mixer-conveyor,

d. a comminution mill including feed inlet means connected to said mixer-conveyor discharge means, and internal comminution means for comminuting the embrittled material fed to said mill from said mixer-conveyor,

e. temperature sensing means positioned in the discharge portion of said mixer-conveyor for determining the temperature of the material discharged from said mixer-conveyor,

f. first flow control means connected to said first refrigerant injection means for regulating the flowrate of liquid nitrogen supplied to said mixer-conveyor such as to maintain the temperature of the material discharged therefrom within a range of 0°F to below 50°F below the embrittlement temperature of said material,

g. second refrigerant injection means positioned downstream of said mixer-conveyor for supplying additional liquid nitrogen into direct liquid contact with said internal comminution means,

h. second temperature sensing means in said comminution mill for determining the temperature therein, and

i. second flow control means connected to said second refrigerant injection means for separately regulating the flowrate of liquid nitrogen supplied to said mill such as to remove substantially all of the heat generated by said mill.

2. The cryogenic system as claimed in claim **1** wherein said comminution feed inlet means comprise a high-speed feed conveyor and said second refrigerant injection means are positioned such as to inject liquid nitrogen into and through said high-speed feed conveyor into direct liquid contact with said internal comminution means.

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