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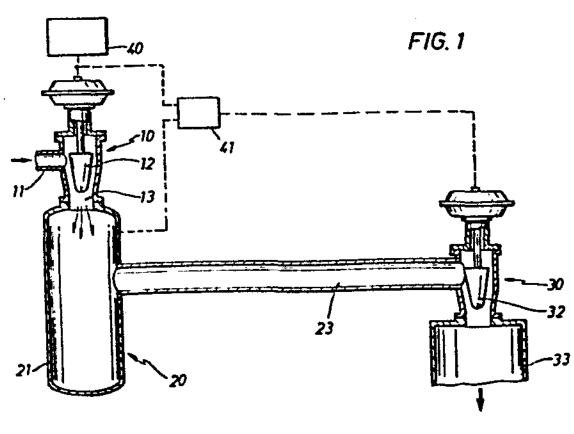
(54) **Apparatus and method for let down of a high pressure abrasive slurry.**

(57) A novel apparatus having a first let-down valve (10) in direct fluid communication with a deceleration zone (20) and the deceleration zone (20) in direct fluid communication with a second let down valve (30) permits elimination of a gas/liquid separation apparatus. In alternative embodiments the apparatus can be modified for addition of a quench liquid or cooling with a heat exchanger. By allowing the slurry to pass through successive let-down stages as a foam or foamy liquid, higher allowable flow velocities can be achieved. In operation, high pressure slurry will be flashed through a first valve (10) and reduced to an intermediate pressure. The slurry will exit from the first valve (10) at a very high velocity as a foam or foamy liquid and directly enter the deceleration zone (20). In the deceleration zone (20) the slurry will first contact other slurry so that by the time it reaches the walls (21) of the deceleration zone (20) its velocity will be low enough to avoid erosion. From the deceleration zone (20) the slurry will pass through a second valve (30) with a further decrease in pressure. It is possible to pass the slurry through many valves with a deceleration zone between the valves.

FIG. 1



EP 0 071 320 A2

Croydon Printing Company Ltd.

APPARATUS AND METHOD FOR LET DOWN OF A HIGH PRESSURE ABRASIVE SLURRY

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to process control of multi phase flowing streams. More particularly this invention relates to an improved method and apparatus for reducing the pressure of high pressure abrasive slurries.

2. The State of the Art

The present invention will be particularly useful in processes designed to convert naturally occurring carbonaceous material having high ash and sulfur content to low-ash, low-sulfur fuels wherein the effluent from the reactor includes gases, liquids, and abrasive solids. Solvent refined coal processes have been described in U.S. Patent Nos. 4,159,238; 3,892,654; 3,884,796; 3,884,795; 3,884,794; 3,808,119; and 3,341,447.

U.S. Patent No. 4,159,238 discloses separation of a product slurry from a coal liquefaction process into two components. The first component is recirculated for use as slurry at the beginning of the process. This recycled stream comprises solvent, normally dissolved coal and catalytic mineral residue. The non-recycled portion of this slurry passes to an atmospheric fractionator for separation of the major products of the process.

In order to effect the separation into two streams with a minimum of wear on the equipment, the slurry stream should be near atmospheric pressure. However, the product slurry leaves the vapor liquid separator upstream at a very high pressure and temperature. In the past, the pressure of the slurry has been reduced by passing the slurry through two or more let-down stages. It has been found that the slurry stream quickly wears out multiple stage let down valves. Gas/liquid separation systems are typically used after each let down to break the foam effluent from the let down valve. The apparatus for gas/liquid separation is expensive and its use in a coal liquefaction process has caused some operating difficulties.

The operational difficulties and expense of passing an erosive slurry through a pressure reducing system have been noted by others. U.S. Patent No. 4,219,403 issued to Nakako et al on August 26, 1980, addresses the problem. That patent teaches separation of the liquid and solid components of the reaction effluent prior to any pressure reduction. Thus, the stream which goes through the pressure reducing system would have no abrasive particles in the stream. The system disclosed in that patent is very useful where the reactant stream is completely purified with only portions being put back in the system for recycling. However, in the system where a portion of the product stream is recycled without any purification, the additional separation steps would decrease the overall efficiency of the system.

SUMMARY OF THE INVENTION

The present invention provides a method and apparatus which effectively overcome the deficiencies in the processes noted above. According to the invention, the flow characteristics of a high temperature, high pressure slurry containing abrasive solids are modified in order to facilitate treatment of the slurry at reduced pressure. Use of the apparatus and method of the present invention will minimize the abrasive effect of the slurry on process equipment without a simultaneous decrease in mass flow rate and slurry velocity.

More specifically the method of the present invention comprises passing a slurry through a first pressure reducing stage for a first reduction of pressure to generate foamed slurry; immediately introducing the foamed slurry to a deceleration zone for reducing the velocity and abrasive characteristics of the foamed slurry; and passing the foamed slurry through a second pressure reducing valve for a second reduction of pressure.

This desirable result is accomplished by passing the slurry through two sequential pressure let down stages, each designed and sized to effect the desired pressure reduction and evolution of gas. The pressure reduction accomplished by the first let down stage should be sufficient to effect liberation of enough gas to create a homogenous foam or foamy liquid. This foam or foamy liquid should then behave as if it contained one phase rather than three. The two pressure reduction stages are separated by a deceleration zone. In the deceleration zone the velocity of the slurry, which is a foam or foamy liquid because of the gas evolved, is lowered to bring this foamed slurry to substantially non-turbulent flow as it enters the second pressure reduction stage. It is believed that reduction of the velocity of the foamed slurry causes dissipation of the foam in a thin layer immediately adjacent the walls of the deceleration zone. Thus the mixture can flow into the second let down stage without deleterious effect on the walls of the equipment. The technique of the present invention thus permits elimination of the gas/liquid separation apparatus, normally found between two pressure let down stages, without a deleterious effect on downstream equipment.

An apparatus built in accordance with the present invention will comprise a first pressure reduction control valve for receiving a high temperature high pressure flowing slurry and cause it to be flashed to an intermediate pressure and to generate sufficient gas to convert the slurry into a foam or foamy liquid travelling at or about sonic velocity. The first stage pressure reducing valve is in fluid communication with a deceleration zone. The deceleration zone has an exit conduit which communicates with a second pressure reduction control valve.

As mentioned above, the forward velocity of the slurry foam at the neck of the first stage valve is reduced in the deceleration zone such that at least in the area immediately adjacent the walls of the deceleration zone and at the exit conduit from the deceleration zone, the slurry flow is substantially non-turbulent whereby a protective film is created which reduces abrasion of the walls of the equipment.

From the deceleration zone, the foamed slurry is passed through a second stage pressure reducing control valve. The inlet of the second stage pressure reducing valve will be sized larger than the first stage valve in order to accommodate the increased volume of the foamed slurry. Also, the inlet and outlet of the second pressure reducing stage will be sized such that the mass flow rate and slurry velocity are substantially equal to the flow rate and velocity at the inlet of the first pressure reducing stage.

To summarize, the apparatus of the present invention comprises a first pressure reducing control valve for receiving a high temperature high pressure flowing slurry at a first pressure and discharging it at a lower pressure as a foamed slurry; a second pressure reducing control valve downstream of the first pressure reducing control valve for effecting a second reduction of pressure; a deceleration zone having an inlet in direct fluid communication with the low pressure side of said first pressure reducing control valve for receiving and reducing the effective forward velocity of the foamed slurry flow at the lower pressure, and being shaped to hold foamed slurry such that newly injected foamed slurry flows directly into previously injected foamed slurry, and further shaped to convey foamed slurry to the second pressure reducing control valve in a foamed condition.

The term deceleration zone as used throughout this specification and its claims should be interpreted to mean an apparatus constructed such that slurry injected into the zone through the first stage let down valve as a foam or foamy liquid comes into contact first with a pre-existing volume of foamed slurry rather than with the walls or bottom of the deceleration apparatus. In this manner, the kinetic energy of the injected slurry is dissipated within a swirling, mixing volume of slurry as opposed to impinging directly on the deceleration apparatus itself.

Although the evolution of gas upon letdown and concomitant generation of a foam or foamy liquid should decrease the viscosity of the slurry; the foamed mixture of slurry and gas behaves with an increased apparent viscosity. Without intending to limit the scope of this invention it is believed that this increased apparent viscosity of the foamed mixture of gas, liquids and solids is somehow related to the decreased density resulting from the presence of significant amounts of gas in the otherwise viscous fluids present in a coal liquefaction system. This increased apparent viscosity permits movement at a higher allowable velocity for the foamed mixture than would otherwise be acceptable through subsequent process equipment. The deleterious effect on downstream equipment previously experienced as a result of the abrasive characteristics of the slurry, is not only substantially eliminated, but the life of the equipment may be increased.

This important advantage results because the slurry foam can be processed at acceptable velocities while the flow adjacent to the process equipment walls remains in a substantially non-turbulent condition since a thin layer of the foamed slurry is believed to dessipate creating a protective film flowing at a slower velocity than the stream in the middle of the lines.

As used throughout the specification and in the claims, the term allowable velocity is intended to indicate that maximum acceptable velocity at which the slurry can be moved through the system without undue erosion of the equipment. In addition, it should be understood that the slurry velocity within the deceleration zone should not reach below the level at which significant amounts of solid matter will no longer remain in suspension.

In the method of the present invention, therefore, the foam which is ordinarily produced as some of the liquid at the higher pressure is converted into the gas phase upon passing through the pressure reduction valve becomes a significant asset, rather than a liability, as was previously believed. Because of the higher apparent viscosity of the foam, as opposed to the liquid slurry, the foam can flow at a much lower velocity in the deceleration zone, substantially approaching non-turbulent flow, without a serious concern over loss of suspended particles. Moreover, as the foam approaches non-turbulent flow, a protective film of slurry liquid will be created adjacent the inner surfaces of the flow conduits and other process equipment, effectively inhibiting direct contact of the abrasive particles with the metallic surfaces. With appropriate process control and equipment design, this thin protective film of nonfoamed liquid which exhibits laminar flow will continue to exist when the velocity is first lowered substantially and thereafter increased to a velocity higher than the rate at which laminar flow first resulted as the velocity was decreased.

Thus, even when the velocity of the foamed slurry is returned to the velocity previously existing before the first pressure let down stage, or under appropriate conditions an even higher velocity, the flow through subsequent process equipment will be at reduced turbulence with a concomitant reduction of abrasion. The increased volume resulting from the production of the foam can be accommodated by adjusting the volumetric dimensions of the apparatus. The pressure drop at each stage can be regulated by upstream level controls and thus automatically split between the two stages to the degree suitable for process conditions. The portion of the total pressure drop effected by the individual valves can be adjusted by a secondary or bias control between the valves. At the same time, the overall mass flow rate and process velocity can be maintained.

In one alternative embodiment of the apparatus of the present invention, the deceleration zone apparatus may be equipped with means for introducing a quench liquid or adapted to include a heat exchange cooler. It will be understood by those skilled in the art that these modifications may only be desirable for special system reasons, such as the provision of extra control over process variables and corrosion reduction. Ordinarily, the energy loss associated with quenching, or cooling the slurry stream will decrease the overall efficiency of the coal liquefaction system and should be otherwise avoided. Additionally, use of a heat exchanger may result in clogging of the exchanger lines because the slurry tends to cool at different rates.

The exact configuration of the pressure reducing valves of the present invention is not critical to the invention. However, it should be clear that the concept of the present invention requires that the volumetric dimensions of the second stage valve be sized larger than those of the first stage valve. It should also be apparent that all equipment should be constructed of materials hard enough to resist the obvious abrasion characteristics of the slurry.

BRIEF DESCRPTION OF THE DRAWING

FIGURE 1 shows a schematic diagram of the apparatus incorporating the principles of the invention.

FIGURE 2 shows a schematic diagram of the apparatus of the present invention which has been modified to allow cooling of the slurry stream in the deceleration zone.

DETAILED DESCRIPTION

The exact dimensions of the apparatus of this invention and the exact operational parameters for its use will be dictated in large part by the system in which it will be incorporated. In the preferred embodiment the apparatus and process will be used in an integrated coal liquefaction-gasification process such as that described in U.S. Patent No. 4,159,238. In that system pulverized raw coal is mixed with a slurry feed and then with hydrogen prior to introduction through a tubular preheater furnace where the coal is partially dissolved in the recycled solvent. The effluent from the tubular preheater furnace is discharged to a dissolver for further reaction. The effluent from the dissolver passes to a vapor/liquid separation system. The hot overhead vapor stream is removed through one outlet while a liquid distillate from the separator is removed through another outlet. The slurry effluent of this first vapor/liquid separator can then be passed through the apparatus of the present invention for reduction of pressure. Once the pressure has been reduced the slurry stream can be split into two components, one for recycle and the other for separation of the major products of the process.

The details of an apparatus built in accordance with the present invention and designed for integration in the system as described above will now be described with reference to FIGURE 1 for a system designed to process slurry at a rate of 10,000 lbs./min. (4,545 Kg/min), where the slurry exiting from the hot separator upstream at 2000 p.s.i.g. (140 Kg/cm^2) and 790°F (421°C) is to be let down in two stages to 150 p.s.i.g. (10.6 Kg/cm^2). The apparatus has three distinct zones: a first valve 10 for reducing pressure, a deceleration zone 20, and a second valve 30 for reducing pressure. Persons of ordinary skill in the art will appreciate that the apparatus dimensions, flow rates, pressures, and temperatures described in the specification are adapted to a particular coal liquefaction product stream of a particular size. Applicant believes that a person or ordinary skill will be able to calculate the dimensions, flow rates, and pressures required for any given stream of materials with knowledge of the approximate composition of the stream the pressures at which sufficient gas is liberated to generate a foam or foamy liquid.

The first valve 10 for reducing pressure will have an inlet conduit 11, a valve mechanism 12, and an outlet conduit 13. The interior diameter of the conduit 11 at its entrance to the valve mechanism 12 must be sufficient to accommodate the volume of slurry at the desired flow rate. Thus, in the system to be described 160 cubic feet per minute (4.53 cubic meters/min) of slurry will be processed at a rate of 20 f.p.s. (6.1 M/sec). The cross-sectional area of the opening to conduit 11 must be 0.1333 square feet (0.012 square meters) which requires an inside diameter of approximately 5 inches (12.7 cm). The type of valve mechanism 12 used in the first valve 10 to reduce the pressure of the slurry is not critical to the present invention. The preferred valve mechanism 12 will be a blunt needle valve having a throat diameter of two to three inches (5 cm to 7.6 cm).

The first stage valve will be sized to achieve a pressure drop to 550 p.s.i.g. (38.8 Kg/cm^2), which is sufficient to liberate gas and create a foamy liquid or a foam. In designing a system apparatus for a stream with a different composition the valve should be sized to effect sufficient pressure drop to generate a foam or foamy liquid. As explained above enough gas is liberated when the stream, at the flow rate throughout the letdown apparatus, thereafter behaves effectively as one phase even though it in fact contains three phases. The volume of liquid in the stream will remain approximately the same at 160 cubic feet per minute (4.53 cubic meters/min). However, because the decreased pressure will have caused some of the slurry stream which was liquid at the higher pressure to be converted to gas at the lower pressure the overall volume of the stream will increase. The amount of gas liberated upon flashing the slurry will of course depend upon the nature of the slurry. A slurry rich in very volatile molecules will liberate more gas than one rich in non-volatile molecules. The outlet 13 from the first valve 10 will lead directly into the deceleration zone 20.

The slurry which enters the deceleration zone 20 will have a pressure reduced from 2000 p.s.i.g. (140 Kg/cm^2) to 550 p.s.i.g. (38.8 Kg/cm^2) The velocity of a slurry flashed through a valve like the one described above will be in excess of a 100 f.p.s. (30.48 M/sec) and more likely approximately 500 f.p.s. 152 (M/sec). Accordingly the slurry will enter the deceleration zone as a jet of foam or foamy liquid.

In the system described the volume of the deceleration zone 20 must be sufficient to accommodate an additional 237 cubic feet per minute (6.7 cubic meters/min) of gas. Thus the deceleration zone 20 must be able to accommodate a combined volume of 397 cubic feet per minute (11.23 cubic meters/min). In the preferred embodiment the deceleration zone 20 will be constructed as a closed cylinder with an inlet from the first valve 10 at the top of the cylinder in the vicinity of its axis. The cylinder will be constructed wide enough to allow the jet of foam to turn on itself so that the velocity of slurry moving near the walls will be approximately 5 f.p.s. (1.52 M/sec). It is believed that a small portion of the foam will dissipate in the region immediately adjacent the walls of the deceleration zone. This thin layer of nonturbulent slurry will substantially eliminate erosion. The flow characteristics of the foam will change from very turbulent at the valve outlet to laminar at the slow velocity of 5 f.p.s. (1.52 M/sec).

In the above described system the inside diameter of the cylinder must be 15.5 inches (39.4 cm) in order for the desired velocity drop to occur. The deceleration zone should be large enough to cause a significant velocity drop; however, if the velocity drops too much, significant amounts of solid will fall out of the slurry. Thus, the deceleration zone should be constructed so that only a small amount of solid falls out of suspension. As will be apparent to those skilled in the art, a small build up of solid matter in the deceleration zone resulting from a slightly oversized deceleration zone will be better than undue wear caused by a too small deceleration zone. The cylinder should be long enough to accommodate the volume of material passing through the cylinder.

The cylinder will also be fitted with an exit conduit 23 leading from the side of the cylinder near its top to the second pressure reducing valve 30. The inside diameter of this exit conduit 23 will be approximately 8 inches (20.32 cm) to accommodate a flow of 397 cubic feet per minute (11.24 cubic meters/sec) at a velocity of 20 f.p.s. (6.1 M/sec).

The velocity of the foam can be increased from the very slow velocity in the deceleration zone to the allowable velocity for the foamy slurry at an intermediate pressure. This allowable velocity will be higher when the velocity has been reduced to a very low rate causing dissipation of foam in a thin layer along the walls of the equipment, and creation of a protective slurry film rather than merely reduced to an acceptable velocity directly from the sonic velocity at the valve outlet. When the velocity is increased from a low velocity, the wall film described above can be maintained at a velocity higher than the velocity at which a wall film develops when the rate of the slurry is decreased from a sonic velocity. Since the slurry will move through the conduit 23 as a foam having only moderate turbulence and an apparent viscosity much higher than the actual viscosity of the liquid, a velocity equal to or higher than the velocity at the inlet 11 to the first valve 10 can be used. In the solvent refined coal process described a velocity of 20 f.p.s. (6.1 M/sec) is sufficiently low to avoid breaking the wall film of the fluid.

The construction of the valve mechanism 32 for the second let down valve 30 is not critical to the present invention. However, in the preferred embodiment the valve mechanism 32 will be a blunt needle valve having a throat diameter approximately the same size or slightly larger than that for the valve mechanism 12 of the first valve 10. The slurry stream which enters the second pressure reduction valve 30 at a pressure of 550 p.s.i.g. (38.80 Kg/cm^2) will exit with a reduced pressure of 150 p.s.i.g. (10.6 Kg/cm^2). The exit conduit 33 for the second pressure reduction valve 30 must be constructed with sufficient volumetric dimensions to accommodate the increased volume associated with further liberation of gas from the liquid slurry. In the system described the volume of the liquid in the stream will decrease to 150 cubic feet per minute (4.23 cubic meters/min) after passing through the second let down valve 30. At the same time the gas volume will increase to 811 cubic feet per minute (22.95 cubic meters/min) on the down side of the second let down valve 30. Accordingly, the inside diameter of the exit conduit 33 should be 27.5 inches (69.9 cm) to accommodate this volume of material at a flow rate of 5 f.p.s. (1.5 M/sec).

In the preferred embodiment the opening of the two valves 10 and 30 will be controlled by a regulator 40 which automatically adjusts both openings to accommodate changes in flow conditions upstream of the let down apparatus. Additionally, the portion of the total pressure drop effected by each valve can be adjusted by a bias control 41. There may be occasions where it would be undesirable to split the drop equally between the two stages. For example, a slurry with non-volatile components may need a very large pressure drop at the first stage in order to liberate sufficient gas to form a foamy liquid. Conversely, in a system with a large portion of volatile components it may be desirable to have a small pressure drop at the first stage, thereby increasing the life of the first valve.

In an alternative embodiment the deceleration zone can be modified for introduction of a quench liquid. In such a modification the quench liquid will be introduced through inlet 24 shown in Fig. 2. Suitable quench liquids would include water at 80°F (26.7°C) and heavy oil at 200°F (93°C). Use of an oil as a liquid quench at a rate of 33 cubic feet per minute (0.94 cubic meters/min) would be deleterious to valve sizing, because the volume of liquid would be increased to 193 cubic feet per minute (5.46 cubic meters/min) while the gas volume would be increased to 251 cubic feet per minute (7.1 cubic meters/min). Use of the water quench adds little to the vapor volume and thus would not effect the valve and line sizes. However, use of any quench is only desirable for a specific reason such as reduction of corrosion or process control. The energy loss associated with use of a quench liquid decreases the overall efficiency of the process. Accordingly, in the preferred embodiment a quench liquid would not be used.

A further alternative embodiment requires modification of the exit conduit 23 leading from the deceleration zone 20 to the second let down valve 30. In this embodiment the exit conduit is fitted with a heat exchanger 25 to cool the slurry as it passes through the exit conduit 23. In the preferred embodiment the heat exchanger 25 will not be used because of operational difficulties associated with heat exchangers. In operation, heat exchangers tend to cool the liquid unevenly. Clogging of the lines can result.

In operation, 160 cubic feet per minute (4.53 cubic meters/min) of slurry will enter the first let down valve 10 at a pressure of 2000 p.s.i.g. (140 Kg/cm^2). On the down side of the pressure reducing valve 10 the stream will have a pressure of 550 p.s.i.g. (38.8 Kg/cm^2), a velocity approaching sonic velocity, a liquid volume of 160 cubic feet per minute (4.53 cubic meters/min) and a gas volume of 237 cubic feet per minute (6.71 cubic meters/min). The slurry will pass into the deceleration zone 20 as a jet of swirling foam or foamy liquid. In the deceleration zone 20 the entering stream will first contact other slurry so that the swirling action of the slurry will be accommodated by the slurry rather than the walls of deceleration zone 20. The velocity of the mixture will slow down to 5 f.p.s. (1.52 M/sec) near the walls of the deceleration 20. Overflow from the deceleration zone 20 will exit through conduit 23. This exiting stream will pass to the second let down valve 30 at a rate of 20 f.p.s. (6.1 M/sec) and exit with a pressure of 150 p.s.i.g. (10.6 Kg/cm^2). After the pressure has been let down from 2000 p.s.i.g. to 150 p.s.i.g. (140 Kg/cm^2 to 10.6 Kg/cm^2) the volume of liquid going through the system will be decreased to 150 cubic feet per minute (3.4 cubic meters/min) while the volume of gas going through the system will have increased to 811 cubic feet per minute (22.6 cubic meters/min).

Although the above description has been restricted to an apparatus with only two let down valves connected by a deceleration zone, the present invention encompasses systems where many let down valves are connected in series with a deceleration zone between each one. The foregoing description has been directed to the particular preferred embodiment for the purposes of illustration and explanation. It will be apparent however, to those skilled in the art that many modifications and changes in the procedure set forth will be possible without departing from the scope and spirit of the invention. It is the applicant's intention that the following claims be interpreted to embrace all such modifications and variations.

WHAT IS CLAIMED IS:

1. A method for reducing the pressure of a high temperature high pressure flowing abrasive slurry in which slurry is passed through a first pressure reducing stage for a first reduction of pressure, characterized in that:

the pressure reducing stage is adapted to generate a foamed slurry discharge;

in that the foamed slurry is immediately introduced to a deceleration zone for reducing the velocity and abrasive characteristics of the foamed slurry; and

in that the foamed slurry is thereafter passed through a second pressure reducing valve for a second reduction of pressure.

2. The method of claim 1 further characterized in that the flow of foamed slurry into the deceleration zone is controlled such that newly injected foamed slurry flows directly into previously injected foamed slurry.

3. The method of claims 1 or 2 further characterized in that the velocity of foamed slurry flowing through the deceleration zone is reduced and controlled to maintain a wall film to protect the walls of the deceleration zone.

4. The method of claims 1 or 2 further characterized in that:

the velocity of foamed slurry flowing through the deceleration zone is reduced and controlled to maintain a wall film to protect the walls of the deceleration zone;

the foamed slurry is discharged from the deceleration zone into an exit conduit at an increased velocity; and

the foamed slurry is thereafter introduced to the second pressure reducing valve.

5. The method of claims 1, 2 or 4 further characterized in that the slurry is comprised of solid carbonaceous material in a hydrocarbon solvent.

6. The method of claims 1, 3, or 4 further characterized in that the freshly injected foamed slurry enters the deceleration zone at about sonic velocity.

7. The methods of claims 1 or 2 wherein the flow of the foamed slurry in the deceleration zone is controlled such that it is nonturbulent at the walls of the deceleration zone.

8. A control apparatus for reducing the pressure of a flowing abrasive slurry the apparatus having a first pressure reducing control valve for receiving a high temperature high pressure flowing slurry at a first pressure and discharging it at a lower pressure, characterized in that:

the first pressure reducing control valve is adapted to discharge the slurry as a foamed slurry;

in that the apparatus comprises a second pressure reducing control valve downstream of the first pressure reducing control valve for effecting a second reduction of pressure; and

in that the apparatus includes a deceleration zone having an inlet in direct fluid communication with the low pressure side of said first pressure reducing control valve for receiving and reducing the effective forward velocity of the foamed slurry flow at the lower pressure, and being shaped to hold foamed slurry such that newly injected foamed slurry flows directly into previously injected foamed slurry, and further being shaped to convey foamed slurry to the second pressure reducing control valve in a foamed condition.

9. The apparatus of claim 8 further characterized in that the deceleration zone is shaped such that flow of foamed slurry immediately adjacent the walls of the deceleration zone is substantially nonturbulent.

10. The apparatus of claim 9 further characterized in that the apparatus comprises an exit conduit in direct fluid communication with the outlet of the deceleration zone and being shaped to deliver foamed slurry to the second pressure reducing control valve at a velocity faster than the velocity of the foamed slurry flowing immediately adjacent the walls of the deceleration zone.

11. The apparatus of claims 8, 9 or 10 further characterized in that means are provided to cool the foamed slurry downstream of the first pressure reducing control valve.

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FIG. 2

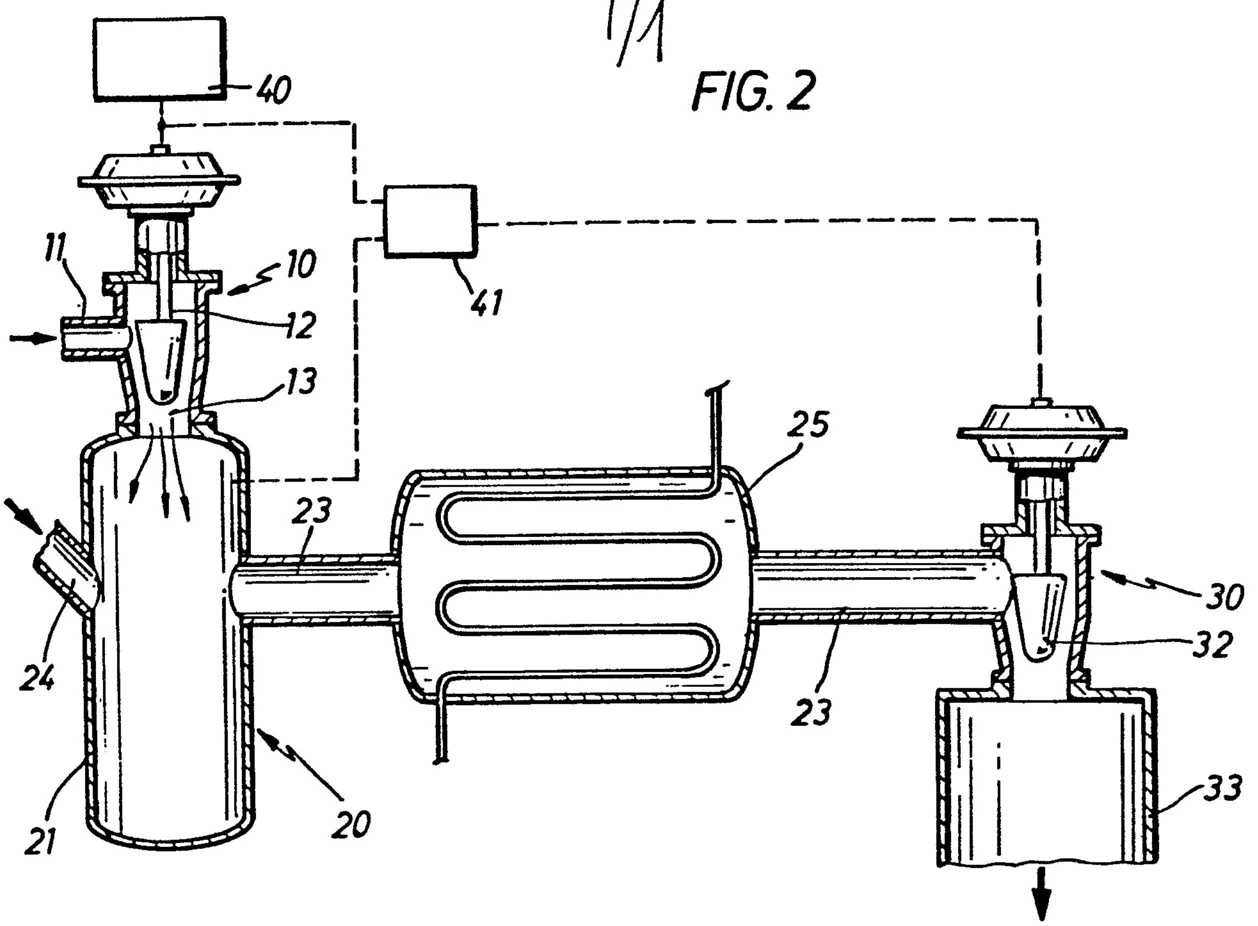
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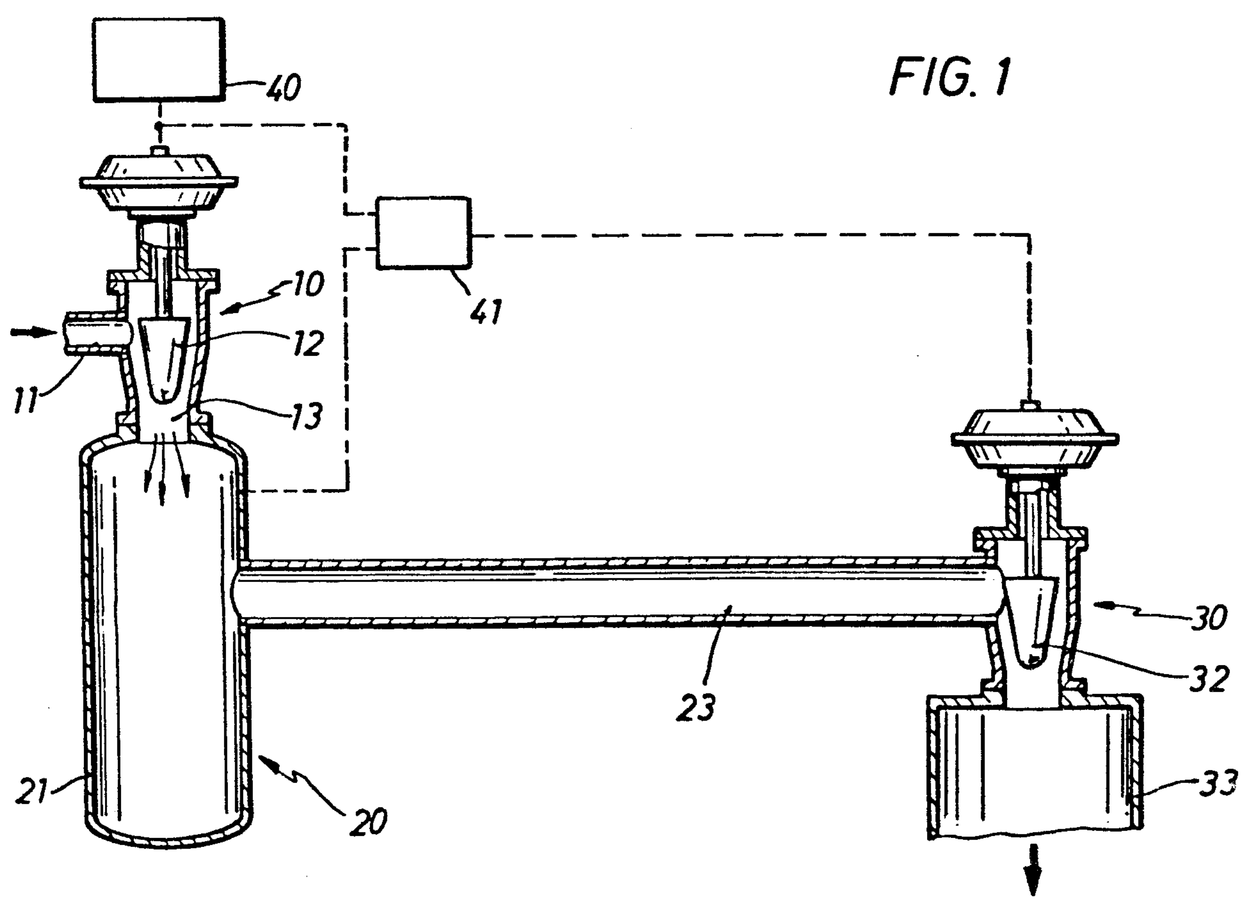
FIG. 1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