

- [54] **SYSTEM FOR FEEDBACK CONTROL OF CASTING SPEED**
[75] Inventor: **Ronald G. Schultz**, Bay Village, Ohio
[73] Assignee: **United States Steel Corporation**, Pittsburgh, Pa.
[22] Filed: **Oct. 31, 1972**
[21] Appl. No.: **302,466**
[52] U.S. Cl.: **164/155, 164/254, 164/259, 164/281**
[51] Int. Cl.: **B22d 11/10**
[58] Field of Search: **164/155, 154, 151, 156, 164/281 US, 282 US, 88, 87, 77, 283, R, 283 MS, 283 MT, 64, 63, 62, 83, 273, 82 US, 253, 254, 255, 256, 258, 259**

- [56] **References Cited**
UNITED STATES PATENTS
3,480,073 11/1969 Wilson 164/64

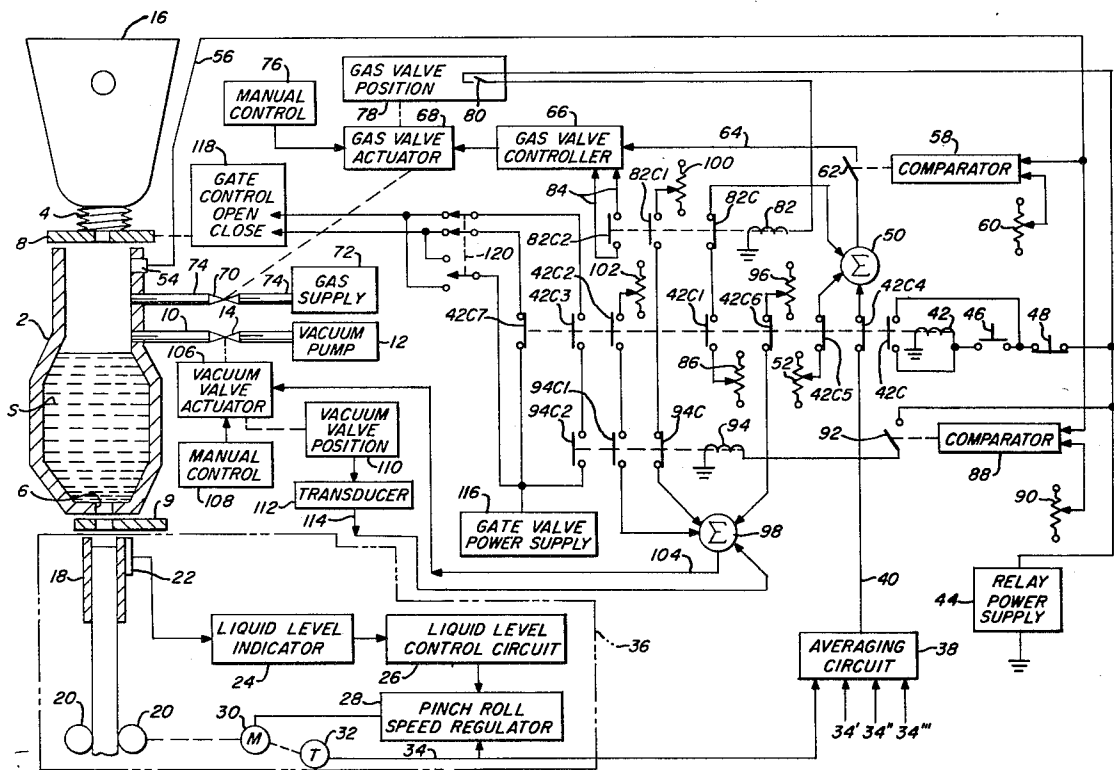
3,627,021 12/1971 Schultz 164/281

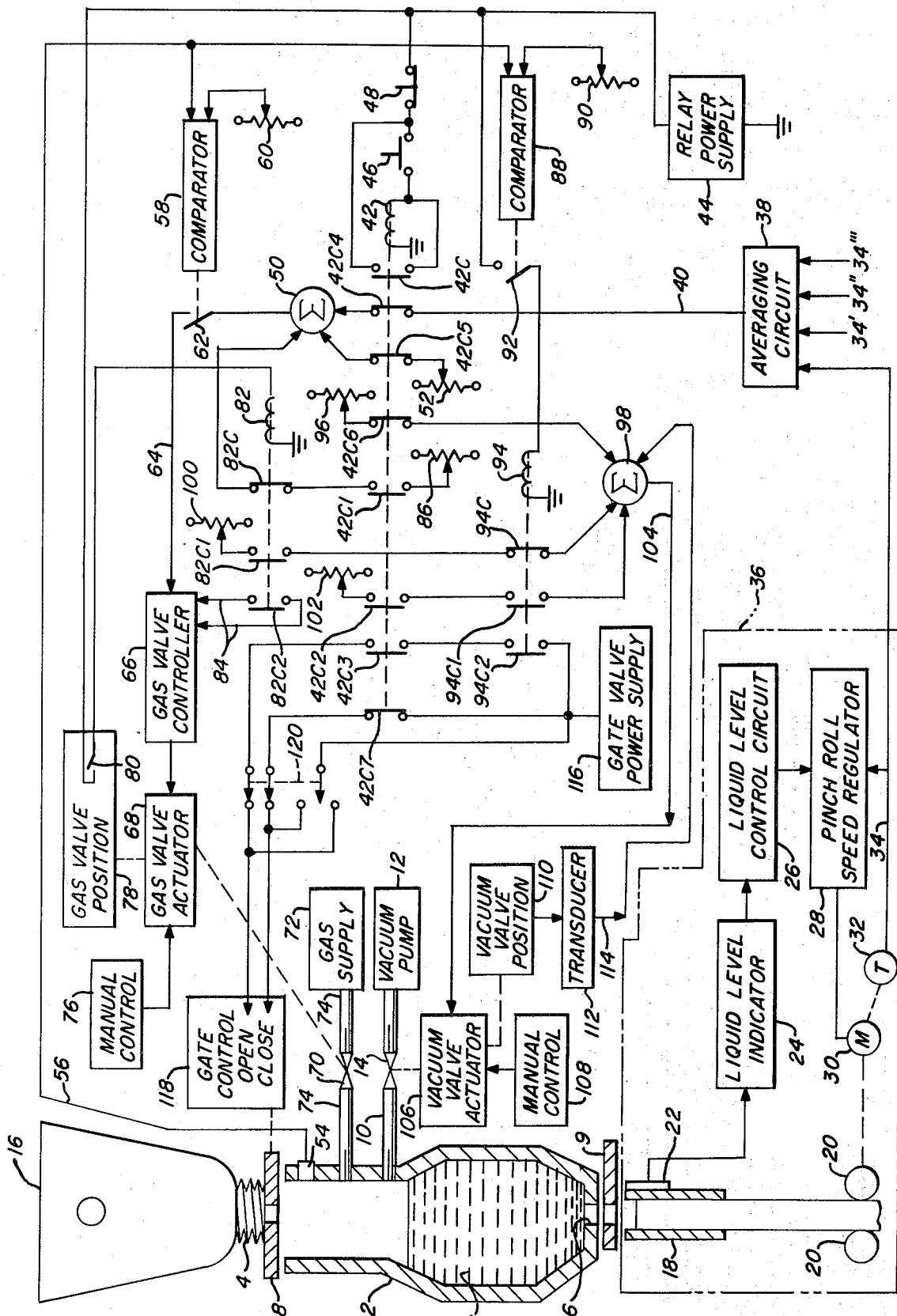
Primary Examiner—R. Spencer Annear
Attorney, Agent, or Firm—Rea C. Helm

[57] **ABSTRACT**

A string casting process with vacuum degassing uses vessel repressurization to provide uniform outflow of molten metal to a continuous-casting mold, a first operator initiated signal controls the pump-down of a degassing vessel, the admission of metal to the vessel at a desired pump-down pressure and the rate of degassing. When the degassing of each batch is complete, a second operator initiated signal controls the closing of a sliding gate valve to seal the vessel, the admission of repressurization gas into the vessel and the repressurization of the vessel to provide a uniform flow from the vessel by comparing the actual casting speed with a desired casting speed.

5 Claims, 1 Drawing Figure





SYSTEM FOR FEEDBACK CONTROL OF CASTING SPEED

This invention relates to a continuous-casting control system using vacuum vessel vacuum pressurization and more particularly, to a control system for controlling casting speed by controlling vessel pressurization and vessel pump-down to provide a uniform flow rate in the outflow of molten metal from a vacuum degassing vessel used in string casting.

In string casting with vacuum degassing, a ladle of molten metal is positioned over the vacuum vessel. The vessel is sealed, and when pumped down, the ladle is opened admitting the molten metal into the vessel. A sliding gate at the bottom of the vessel is opened to allow the metal to flow through the gate nozzle into a mold. When the ladle is emptied, but before the vessel is emptied, the ladle is removed, another ladle positioned over the vessel, the vessel pumped down again, and the ladle is opened admitting more molten metal into the vessel while the metal continues to flow out of the vessel. The process continues for the desired string of ladles.

The metal head in the vacuum vessel falls after a ladle is emptied and continues to fall until a new ladle is in place and begins to empty into the vessel. This fall in head due to the continuous outflow of metal causes a decrease in flow since flow rate is determined from the equation

$$F = AK \sqrt{H}$$

where

F is the rate of flow

A is the area of the vessel nozzle

K is the vessel nozzle constant, and

H is the effective head, the height of the metal above the vessel nozzle less the barometric height of molten metal due to the difference in pressure inside and outside the vessel. Between ladles, the effective head drops which decreases the metal flow and the casting speed. If the vessel has a large cross-sectional area above the barometric height of the liquid metal, there is a relatively small change of head between ladles and a correspondingly small change in casting speed. If the cross-sectional area of the vessel is small, there is a large change of head and a correspondingly large change in casting speed.

Corrective action can be taken to minimize drop in head between ladles by pressurizing the vessel to compensate for loss in head and thus improve the throughput of the system. An inert pressurized gas is admitted into the vessel at a controlled rate so that as it expands at the higher temperature and lower pressure in the vessel, it causes an increase of pressure in the vessel and adds to the effective head. The ratio of gas flow into the vessel must be a function of the change in casting speed since the object is to maintain as nearly uniform flow as possible.

If the vessel has a small cross-sectional area and if there is considerable time between ladles, pressurization may result in reaching the upper limit of the vacuum seal while compensating for the decreasing head. If a new ladle is not ready when this limit is reached, the effective head decreases, causing a decrease in flow and casting speed.

When the next ladle arrives and is in place over the vacuum seal, the gas supply must be shut off and the

vacuum system opened to allow the vessel to be pumped down to a vacuum necessary for degassing of the incoming stream. During this time of pump-down and until the new ladle begins to empty, there is a greatly reduced flow and casting speed since the effective head has been reduced through loss of gas pressure. Since the incoming ladle must empty at a faster rate than the flow from the vacuum vessel, the head increases causing an increase in flow and casting speed. When the ladle is empty and removed from the vacuum seal, pressurization can again take place to compensate for the decreasing head.

The system dynamics are too sluggish to allow complete manual operation of the pressurization and pump-down cycle. The long time constants in the system cause an operator to over-correct the system for any observed change in casting speed and hence make the system more oscillatory.

It is therefore an object of my invention to provide a system for control in continuous casting with vacuum degassing of a string of heats.

Another object is to provide such a control system having automatic control of degassing.

A further object is to provide an automatic repressurization system between degassing of each heat in a string.

A still further object is to provide such a control system that provides a uniform throughput between degassing of each heat.

Still another object is to provide such a system with improved throughput rate.

These and other objects will become more apparent after referring to the following specification and drawing in which the single FIGURE is a schematic drawing of the control system of my invention.

Referring now to the drawing, reference numeral 2 indicates a vacuum degassing vessel for degassing molten steel S. Vessel 2 has a ladle vacuum seal 4, a discharge nozzle 6, an entrance sliding gate valve 8, a discharge sliding gate valve 9, a vacuum line 10 connected to a vacuum pump 12 through a valve 14 for withdrawing gas released from molten steel as poured from a ladle 16. Metal S flows from ladle 16 through gate valve 8, vessel 2 and nozzle 6 into a mold 18 where it solidifies and is continuously withdrawn by pinch rolls 20. A mold liquid level detector 22 is connected to a liquid level indicator circuit 24. Circuit 24 is connected to a control circuit 26 which is connected to a pinch roll speed regulator circuit 28. Circuit 28 is connected to a pinch roll drive motor 30 which drives pinch rolls 20 and a tachometer generator 32. The electrical output 34 of generator 32 is connected to pinch roll speed regulator circuit 28. The parts thus far described are conventional with parts 18 to 34 constituting a casting control system 36 which may be the type described in Tiskus et al. U.S. Pat. No. 3,300,820 dated Jan. 31, 1967, but with no dead band in controller 26.

Tachometer generator output 34 is connected to an averaging circuit 38, which may have additional tachometer generator inputs 34', 34'' and 34''' when casting a multistrand system, for example, as shown with four strands. Circuit 38 may be any conventional averaging circuit such as summing the output from a potentiometer in each input set for $1/N$ where N is the number of inputs. Circuit 38 has an output signal 40 representative of the average casting speed.

A first relay 42 is connected to a relay power source 44 through a pump-down, normally open, push button 46 and a ladle empty, normally closed, push button 48 connected in series. Latching contacts 42C are connected across push button 46. Relay 42 has normally open contacts 42C1, 42C2 and 42C3 and normally closed contacts 42C4, 42C5, 42C6 and 42C7.

Signal 40 is connected to an input of a first summing amplifier 50 through contacts 42C4. A desired casting speed potentiometer 52 is connected to amplifier 50 through contacts 42C5.

A conventional pressure transducer 54 located in vessel 2 provides a vessel pressure signal 56 to a first input of a first comparator 58. A maximum allowable pressure potentiometer 60 is connected to a second input of comparator 58. Comparator 58 is connected to actuate a single pole single throw switch 62.

An output 64 of amplifier 50 is connected to a gas valve controller 66 through switch 62. Controller 66 is connected to a gas valve actuator 68 which sets a gas valve 70 in proportion to signal 64 to supply gas from a gas supply 72 to vessel 2 through a gas line 74. Actuator 68 has a manual control 76, and is connected to a gas valve position indicator 78 which has a switch 80 closed when valve 70 is closed.

A second relay 82 is connected to power source 44 through switch 80 and has a normally closed contact 82C and normally open contacts 82C1 and 82C2. A reset input 84 to controller 66 is connected to contacts 82C2. A fast close gas valve potentiometer 86 is connected to an input of amplifier 50 through contacts 42C1 and 82C.

Vessel pressure signal 56 is also connected to a first input of a second comparator 88. A degassing pressure potentiometer 90 is connected to a second input of comparator 88 which is connected to actuate a single pole single throw switch 92. A third relay 94 is connected to power source 44 through switch 92 and has normally closed contacts 94C and normally open contacts 94C1 and 94C2.

A close vacuum valve potentiometer 96 is connected to an input of a second summing amplifier 98 through contacts 42C6. An initial pump-down rate potentiometer 100 is connected to an input of amplifier 98 through contact 82C1 and 94C. A reduced pump-down rate potentiometer 102 is connected to an input of amplifier 98 through contacts 42C2 and 94C1. An output 104 of amplifier 98 is connected to a vacuum valve actuator 106 to actuate valve 14 in proportion to the signal 104. Actuator 106 has a manual control 108 and is connected to a vacuum valve position indicator 110. Indicator 110 is connected to a voltage transducer 112 which provides a voltage signal 114, proportional to the position of valve 14 to an input of amplifier 98.

A gate valve signal power supply 116 is connected to the "open" and "close" control signal inputs of a gate controller 118 for gate valve 8 through contacts 42C3 and 94C2 in the "open" position and contacts 42C7 for the "closed" position. A three position manually operated "close," "open" and "off" switch 120 is connected in parallel to the relay contacts in the open and close signal lines.

Prior to casting, potentiometer 52 is set to supply a signal to amplifier 50 representative of the desired casting speed. Potentiometer 60 is set to supply a signal to comparator 58 representative of the maximum allowable gas pressure inside vessel 2. Potentiometer 86 is

set to supply a signal to amplifier 50 which will cause controller 66 to rapidly close valve 70. Potentiometer 90 is set to supply a signal to comparator 88 representative of the pressure in vessel 2 at which it is desired to begin degassing. Potentiometer 96 is set to supply a signal to amplifier 98 which will close valve 14. Potentiometer 100 is set to supply a signal to amplifier 98 which will open valve 14 to the desired initial high rate of pump-down. Potentiometer 102 is set to supply a signal to amplifier 98 which will open valve 14 to the desired subsequent reduced rate of pump-down.

Assuming that control circuit 36 is ready to operate, switch 62 is closed, switch 92 is open, all relays are de-energized and a ladle is in position to be emptied, the operator then momentarily closes the "pump-down" push button 46. This energizes relay 42, latching it on through contacts 42C. Contacts 42C4 and 42C5 open disconnecting signals from potentiometer 52 and averaging circuit 38 from amplifier 50. Contacts 42C1 close connecting potentiometer 86 to amplifier 80 to rapidly close gas valve 70.

When gas valve 70 is finally closed, switch 80 closes to energize relay 82. Contacts 82C open which disconnects potentiometer 86 from amplifier 50 and contacts 82C2 close which resets controller 66. Contacts 82C1 close connecting potentiometer 100 to amplifier 98 opening valve 14 to begin the initial desired high rate of pump-down. Feedback signal 114 stops continued opening of valve 14 when signal 114 indicates valve 14 is in a position corresponding to the setting of potentiometer 100. Pump-down continues at this rate until the vessel pressure is low enough to degas incoming metal. At this low pressure, as set on potentiometer 90, comparator 88 closes switch 92 and relay 94 is energized.

Contacts 94C open disconnecting potentiometer 100 from amplifier 98 and contacts 94C1, in series with contacts 42C2 which were closed by closing of push button 46, close connecting potentiometer 102 to amplifier 98 partially closing valve 14 to the desired reduced rate of pump-down so that the rate of pump-down does not exceed the buildup of head in the vessel. Contacts 94C2, in series with contacts 42C3 which were closed by closing of push button 46, close connecting the gate valve signal power supply to gate valve control 118 for opening gate valve 8 thereby admitting metal from the ladle into the vessel.

As the ladle empties into vessel 2, degassing takes place and when sufficient metal has built up in vessel 2, discharge gate valve 9 is opened to allow metal to flow through nozzle 6 into mold 18 beginning the cast. Control apparatus 36 begins to operate providing signal 40.

When the ladle is empty, the operator momentarily opens "ladle empty" push button 48 which de-energizes relay 42. Contacts 42C1 open disconnecting the gas valve fast close signal of potentiometer 86 from amplifier 50. Contacts 42C4 and 42C5 close connecting the desired casting speed setting of potentiometer 52 and the average casting speed of circuit 38 to amplifier 50 which opens valve 70 admitting gas into vessel 2. Contacts 42C2 open disconnecting the reduced pump-down rate potentiometer from amplifier 98. Contacts 42C6 close connecting potentiometer 96 to amplifier 98 which closes vacuum valve 14. Contacts 42C7 close connecting the gate valve signal power sup-

ply 116 to gate valve control 118 thereby closing gate 8 and sealing vessel 2 for gas pressurization.

As soon as the gas valve begins to open, switch 80 opens de-energizing relay 82. Contacts 82C2 open to disconnect the reset portion of controller 66. Contacts 82C1 open to disconnect the initial pump-down rate potentiometer 100 from normally closed contacts 94C and thus from amplifier 98. Contacts 82C close which connects amplifier 50 to open contacts 42C1 so that the close gas valve signal of potentiometer 86 will be available for the next pump-down sequence.

As soon as pressure begins to build up in vessel 2, the signal 56 will exceed the signal from potentiometer 90 and comparator 88 will change state, opening switch 92 and de-energizing relay 94. Contacts 94C2 open, but the associated circuit has been de-energized by a series connection to contacts 42C3 which opened when push button 48 was opened. Contacts 94C1 open, but the associated circuit has been de-energized by a series connection to contacts 42C2 which opened when push button 48 was opened. Contacts 94C close but the associated circuit has been de-energized by a series connection to contacts 82C1 which opened with the de-energization of relay 82.

All relays are now de-energized and gas valve 70 is now controlled by controller 66 in a normal manner. The signal from circuit 38 and the signal from potentiometer 52 are connected to amplifier 50, and their difference, the casting speed error 64, is passed through contacts 62 to controller 66 setting valve 70 to allow the flow of gas to compensate for the decreasing head and thus maintain uniform casting speed.

Comparator 58 compares the vessel pressure 56 from transducer 54 with the maximum allowable value set on potentiometer 60. If this upper limit is reached, comparator 58 changes state, opening switch 62 and thus applies a zero error signal to controller 66. When this happens the gas valve remains at its setting until the vessel pressure drops to the level where switch 62 closes, again supplying gas to the vessel. In this way, the vessel is protected against damage from too high a pressure.

In the event of an emergency or a breakdown, manual control 76 can control gas valve 70, overriding any other signal to actuator 68. Manual control 108 can control vacuum valve 14 overriding any other signal to actuator 106, and switch 120 may be moved to an "open" or "closed" position, i.e., up or down which disconnects contacts 42C3, 42C7 and 94C2 from gate controller 118.

Metal continues to flow out of vessel 2 while another full ladle is positioned over vessel 2. When the metal level in vessel 2 has dropped to the level where the next ladle of the string may be emptied into the vessel, the operator momentarily closes push button 46 which begins a new sequence.

I claim:

1. In a string casting process, apparatus for controlling the degassing of molten metal and flow rate from a bottom pour degassing vessel into a continuous casting mold having means for controlling pinch rolls withdrawing the strand from the mold comprising

a gate valve for admitting molten metal into the vessel,

means connected to said valve for opening and closing the gate valve,

means connected to said vessel and responsive to a first operator initiated signal for exhausting gas from the vessel,

means for determining the gas pressure inside said vessel,

means connected to said means for determining pressure and said means for opening and closing said gate valve for opening said gate valve in response to the exhausting of gas below a first desired vessel pressure thereby beginning the discharge of a batch of molten metal into the vessel,

means connected to said vessel for admitting gas under pressure into said vessel,

means connected to said means for opening and closing the gate valve, said means for exhausting gas and said means for admitting gas and responsive to a second operator initiated signal at the conclusion of the discharge of a batch of molten metal into the vessel for closing the gate, discontinuing the exhausting of gas and beginning the admitting of gas under pressure into the vessel, and

means connected to said means for admitting gas and the means for controlling the pinch rolls for admitting gas in response to withdrawal of the strand from the mold.

2. Apparatus according to claim 1 in which said means for admitting gas includes a source of pressurized gas, a gas line connecting said source to the vessel and a valve in said line and which includes means responsive to said first signal for closing said valve.

3. Apparatus according to claim 2 in which the means for exhausting gas includes means connected to said means for determining the gas pressure in said vessel for reducing the rate of exhausting gas established in response to said first signal when the vessel pressure is below said first desired vessel pressure.

4. Apparatus according to claim 3 which includes means connected to said means for determining the gas pressure inside said vessel for maintaining the rate of admitting gas whenever the vessel pressure exceeds a second desired vessel pressure.

5. Apparatus according to claim 4 which includes manual means for controlling said gas valve, manual means for operating said means for exhausting gas and manual means for opening and closing said gate valve.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,830,282 Dated August 20, 1974

Inventor(s) Ronald G. Schultz

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 45, "contact" should read -- contacts --.

Column 4, line 20, "amplifier 80" should read -- amplifier 50 --.

Signed and sealed this 26th day of November 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents