**TECHNICAL PAPER**

# Pneumatic Injection of Bulk Solid Materials at High Rate Accuracies

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## SUMMARY

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# PNEUMATIC INJECTION OF BULK SOLID MATERIALS AT HIGH-RATE ACCURACIES

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## 1.0 INTRODUCTION

Pneumatic conveying systems are generally regarded by most designers/engineers as a means of transport of bulk materials. There is, in fact, a growing segment of the pneumatic conveying technology that deals with an increasingly sophisticated demand for accurate injection of solid materials often into complex processes.

There are many processes into which solid bulk materials are required to be "injected". The reason for injection may be to fuel a combustor, or the controlled injection of solid materials into a reactor process. In the last few years, the types of processes requiring injection have greatly multiplied; and consequently, the types of materials injected have become diverse to the extent that so called "difficult" materials are now being injected.

For many years bulk materials were injected by gravity or by mechanical means with just a few isolated cases where pneumatic injection methods were used. Now, as the applications become more demanding, pneumatic injection is becoming the first choice for most designers and users.

Most engineers are aware of the advantages that pneumatic systems generally provide over mechanical systems, i.e., totally enclosed, spillage-free operation, low maintenance, etc. The major advantages for the use of pneumatic systems for injection purposes, however, is accurate, smooth delivery of material into the process, and the flexibility provided in plant layout.

The need for accurate, smooth, unpulsed and homogeneous flow is becoming paramount for many processes. For instance, fluidized bed combustors (FBC) require a non-pulsed delivery to insure that the conditions for proper combustion are met.

In the case of FBC's using a sorbent such as limestone in the bed, reliable and accurate flow is extremely important since any increase/decrease in the sulfur dioxide content of the flue gas must be met by a corresponding response in the flow of limestone into the bed. For processes which involve high back pressures, especially where that pressure fluctuates, the accuracy must be maintained regardless of back pressure changes. Unfortunately, many pneumatic injection systems do not compensate for such back pressure changes.

There is now an increasing trend to relate process demand changes directly to the injection system output by use of closed loop control. Also, many processes require flow rate accuracies as high as 1% of set point by weight, and the industry is now trying to respond to these process user

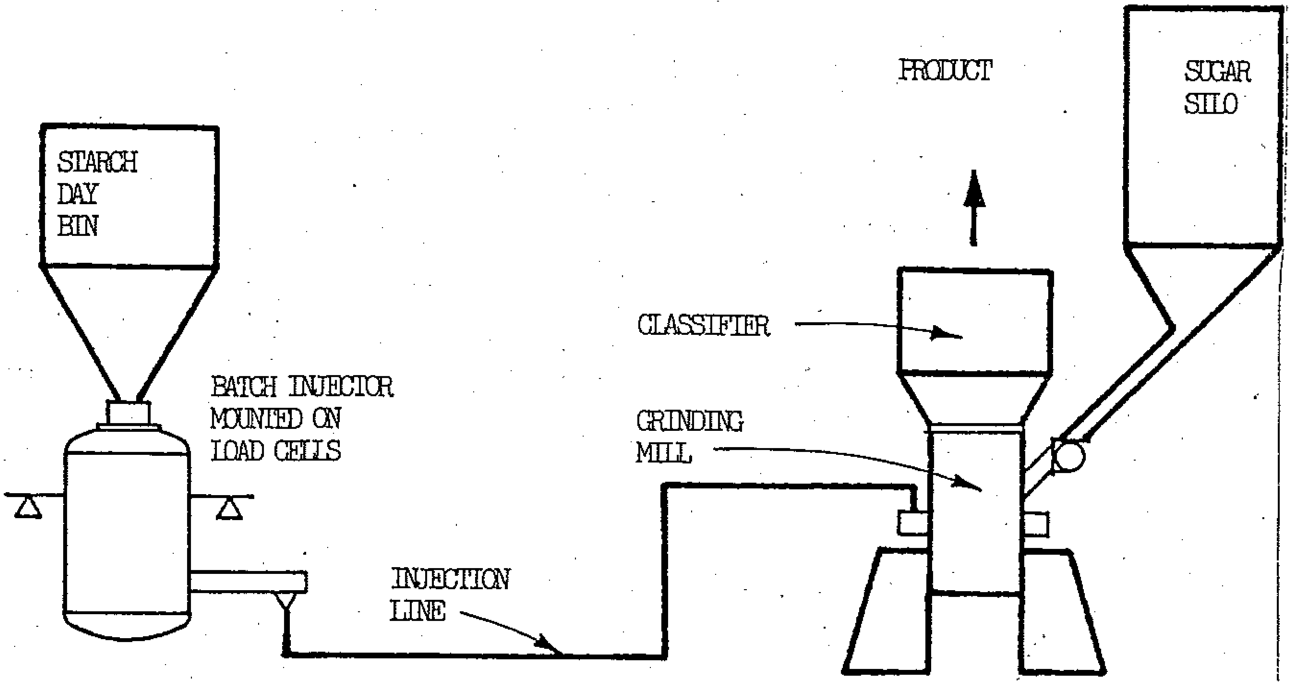


FIG. 1 – BATCH INJECTION TO GRINDING MILL

(b) Electric Arc Furnace Injection

Figure (2) shows a batch injector delivering coke breeze into an electric arc furnace. Batches in these applications are usually in the range of 2000 - 5000 lbs., and the injection time short (several minutes). The batch is either preweighed in tote bins, or weighed in the injector. Injection takes place into a slight negative pressure due to fume extraction from the hood of the furnace. In many cases the injection lance must be retractable or incorporate swivel and flexible joints to allow for the tilting action of the furnace when slag and metal are being tapped.

requirements. This paper will make a general review of many of the applications now frequently being encountered, and some of the methods of injection that have and/or are being used.

The paper will conclude with a section on material characterization and its importance to application analysis with specific reference to testing requirements.

## 2.0 REVIEW OF APPLICATION TYPES

Applications for injectors can be classified into five main groups:

(i) Batch injection into low-pressure environments
(ii) Batch injection into high-pressure environments
(iii) Continuous injection into low-pressure environments
(iv) Continuous injection into high-pressure environments
(v) Very high-pressure injection applications

Each of these application areas include variations such as multiple injection points, turndown range, injection accuracy, etc.

## 2.1 BATCH INJECTION INTO LOW PRESSURE ENVIRONMENTS

This is perhaps the most simple and easiest of applications. The term "low pressure environment" would be one which is at or within a few inches water gauge of atmospheric pressure. The process would call for a specific quantity of material to be injected in a specified time period.

Examples:

### (a) Blending Process

Figure (1) describes the batch injection of starch into a sugar mill. The starch is being added in quite small quantities relative to the sugar being ground, and must be accurately dosed according to a process recipe. The batch is preweighed in the injector before being injected over a specified period of time during which a known quantity of sugar is being milled. The blending takes place at a slight positive pressure due to the mill being air swept during the milling process.

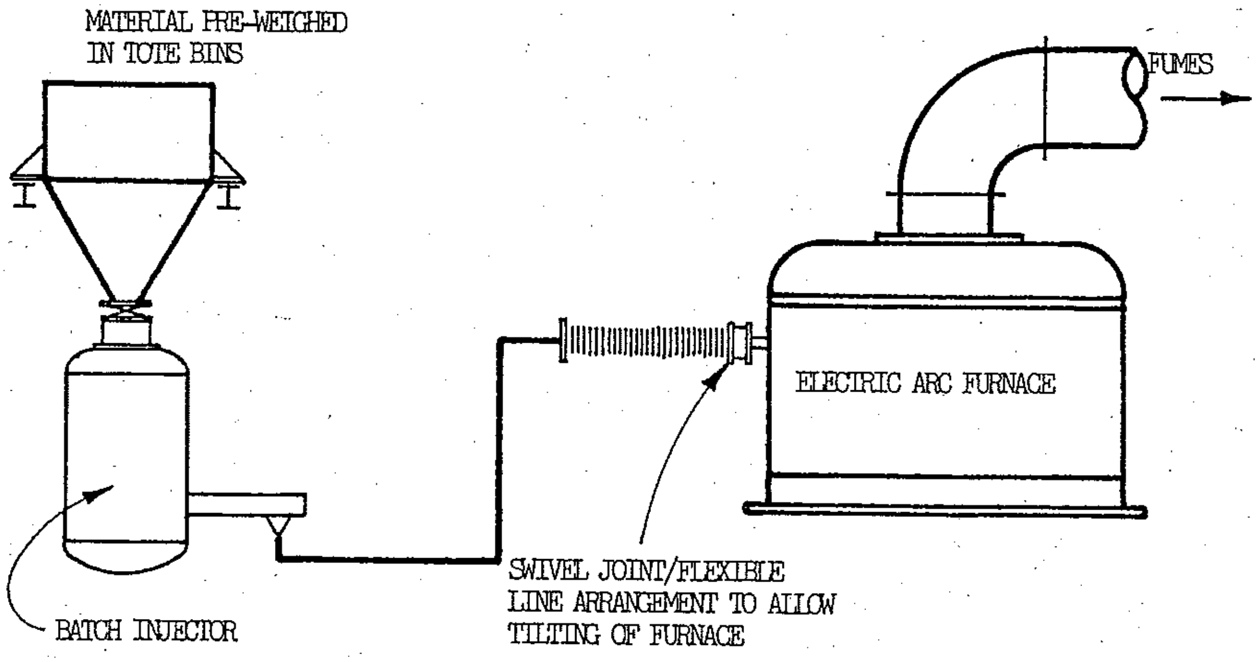


FIG. 2 – BATCH INJECTION TO ELECTRIC ARC FURNACE

## 2.2 BATCH INJECTION INTO HIGH-PRESSURE ENVIRONMENTS

This application is similar to that described in (2.1) except the process back pressure is considerably higher than atmospheric. In these applications, such pressures can be up to 60 psig.

Examples:

(a) Ladle Injection

Figure (3) describes the injection of a carburizing agent into a large ladle containing molten metal in a foundry. The agent must be injected well below the surface of the metal to insure good dispersal into the ladle. The static head of the metal can produce back pressures in the range 5-15 psig. Often the lance depth is varied during injection to assist dispersion of the agent, and this causes the back pressure to be variable. The batch must be injected smoothly and evenly over varying time periods, depending upon the size of the ladle and according to the metallurgical demands of the process. Additionally, during the injection process the operator needs to vary the rate of injection to avoid metal "boiling" while maintaining the highest acceptable rate of injection.

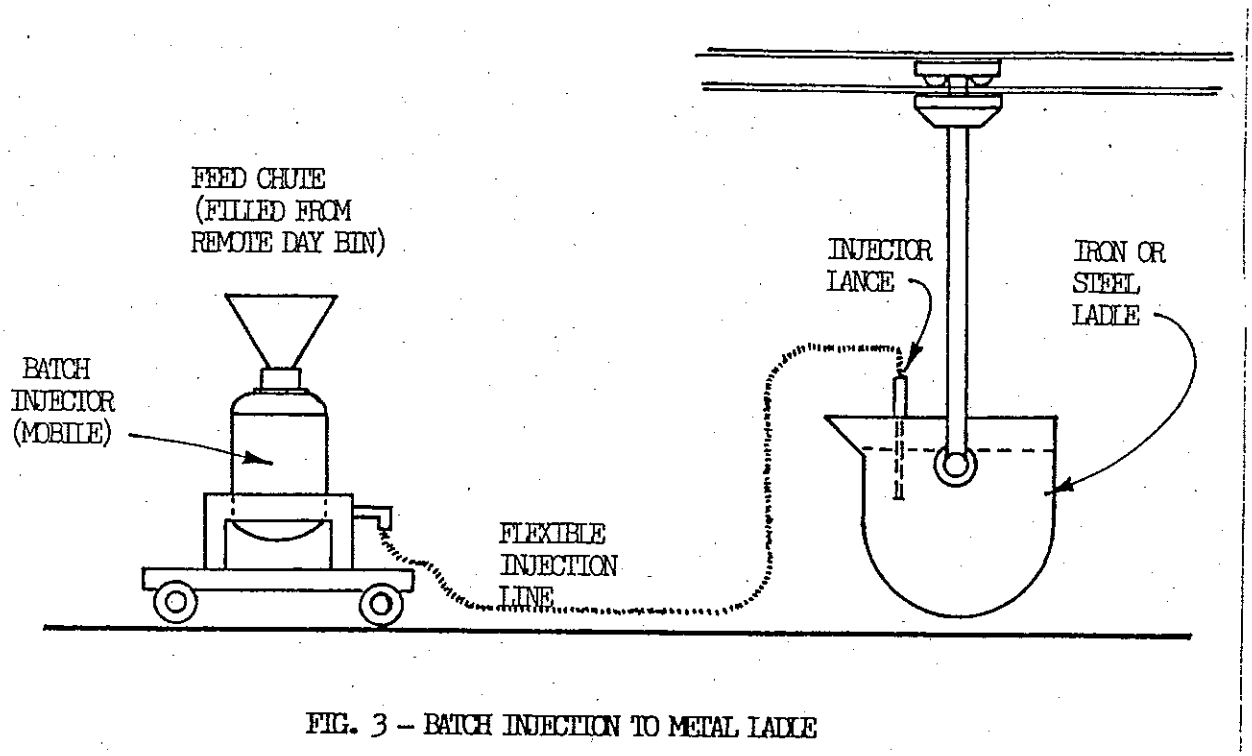


FIG. 3 – BATCH INJECTION TO METAL LADLE

(b) <u>Chlorinator Injection</u>

As part of the process of manufacturing Titanium Dioxide, rutile ore is injected in batch form into a process reactor known as a chlorinator (Figure 4). Injection takes place over several minutes and is repeated regularly, alternating with injections of various types of slag ore and coke breeze.

The chlorinator is under pressure in the range 1 to 2 bar, and this pressure is maintained at all times during the process. Therefore, special arrangements must be made to prevent blow back of hot gas and material from the reactor. This is usually achieved by inclusion of special high-temperature shut-off valves located close to the reactor.

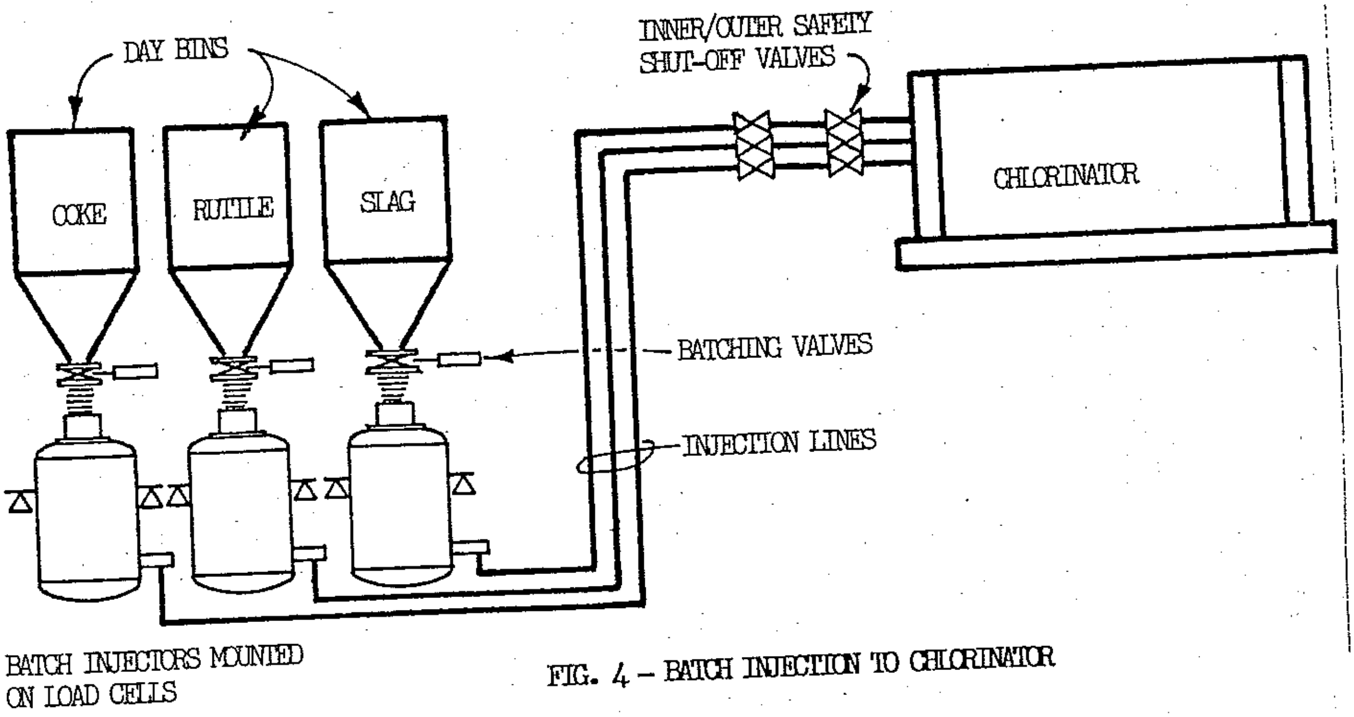


FIG. 4 - BATCH INJECTION TO CHLORINATOR

## 2.3 CONTINUOUS INJECTION INTO LOW-PRESSURE ENVIRONMENTS

Many applications require the bulk solid to be injected continuously, often 24 hours/day, 7 days/week.

Examples:

### (a) Pulverized Coal Injection to Cement Kiln

Figure (5) shows a typical "long flame" burner arrangement in a cement kiln. Most kilns are coal-fired directly from a pulverizing mill. However, some operators use indirect coal injection to allow for buffer storage in the plant. The coal is injected into the combustion air feed pipe, operating in a few inches of water column. Usually a single injection point is used, but rates can be quite high - up to 20 tons/hour with a turndown requirement of up to 5 to 1.

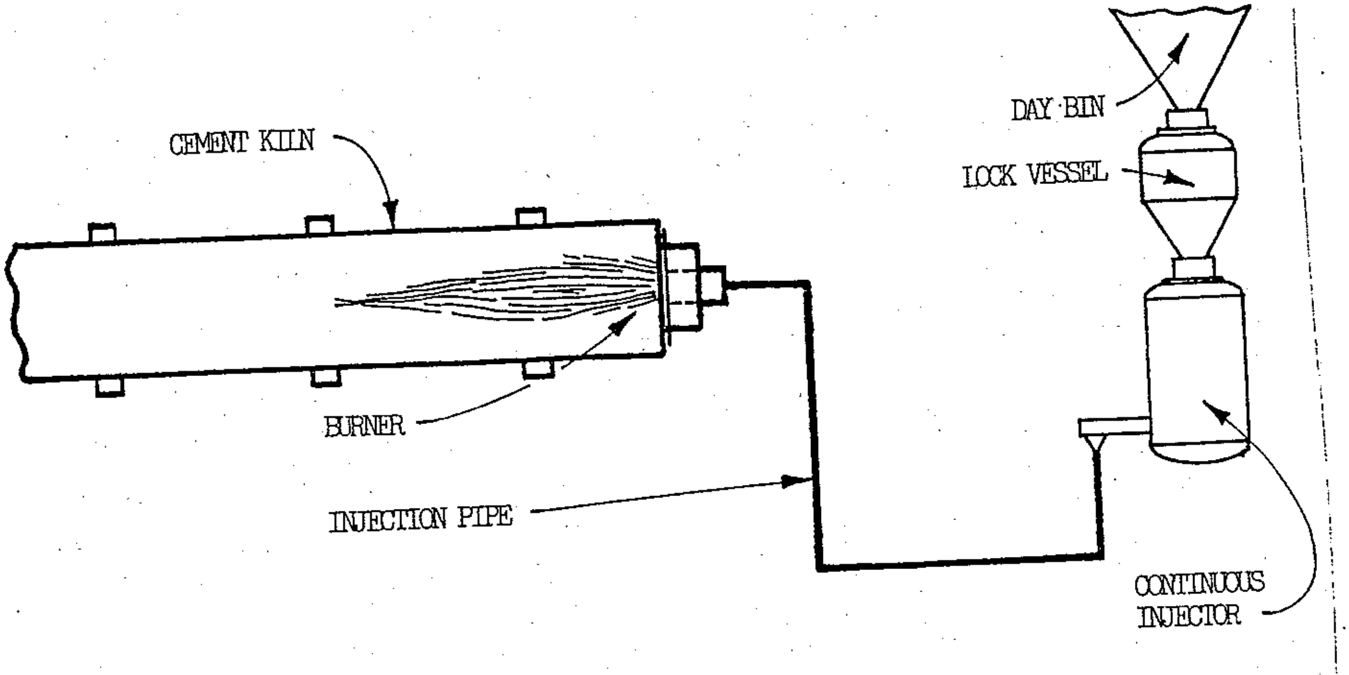


FIG. 5 – CONTINUOUS INJECTION TO CEMENT KILN

### (b) Concentrate Injection to Metal Converters

Many metal conversion processes require the concentrate (usually copper or lead) to be injected at a controlled rate into the converter vessel (Figure 6). The conversion process can vary considerably, and accuracies may also be different for different processes. These applications are usually more difficult due to the nature of the material which is usually cohesive with very high bulk densities - in the range 130-200 lbs./cu. ft., and injection rates are high - up to 60 tonnes/hour. The back pressure is normally quite low - usually less than 1 psig. However, some conversion processes can involve pressures of up to 30 psig.

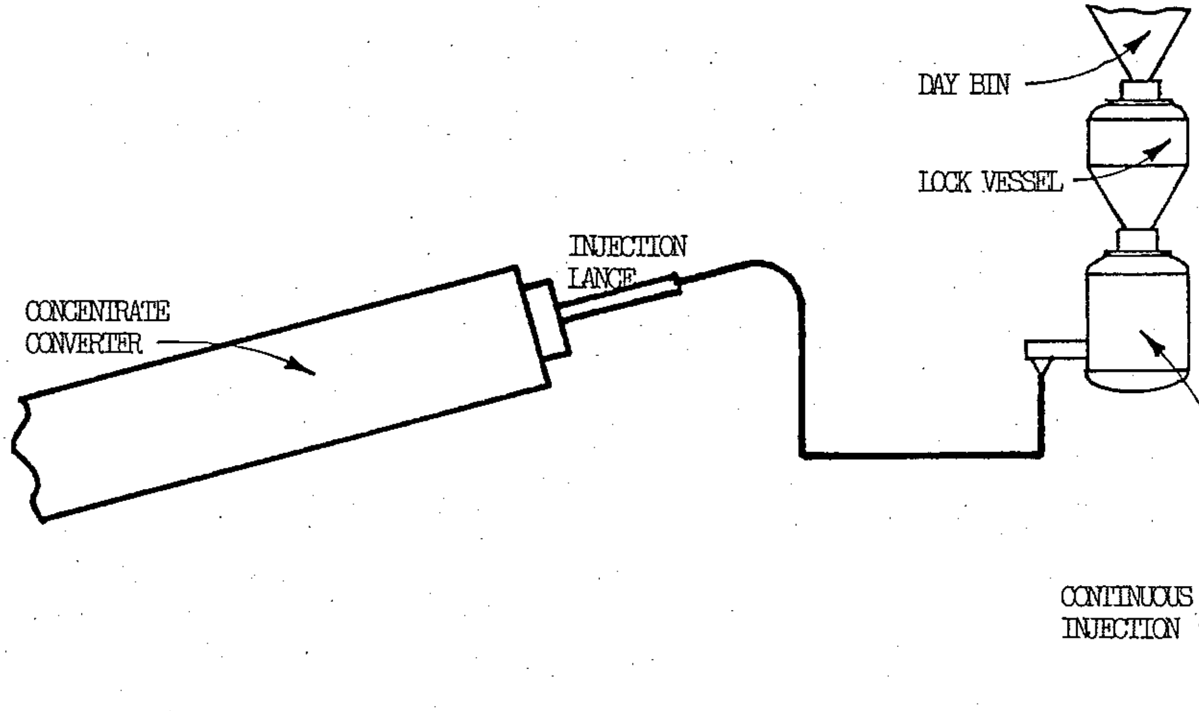


FIG. 6 – CONTINUOUS INJECTION TO CONCENTRATE CONVERTER

## 2.4 CONTINUOUS INJECTION INTO HIGH-PRESSURE ENVIRONMENTS

This group of applications is similar to (2.3); however, back pressures are normally above 2 psig and can be as high as 50 psig.

### (a) Recirculating Fluidized Bed Combustor

Many utility-sized fluidized bed combustors now routinely inject sorbents such as limestone and recirculate flyash back into the fluidized bed by pneumatic means. Several injection points may be required to achieve good dispersal into the bed (Figure 7). Many operators are also beginning to inject lump coal with high moisture contents.

Injection of these materials into FBC's must be smooth and unpulsed to avoid detrimental effects on the combustor conditions within the bed.

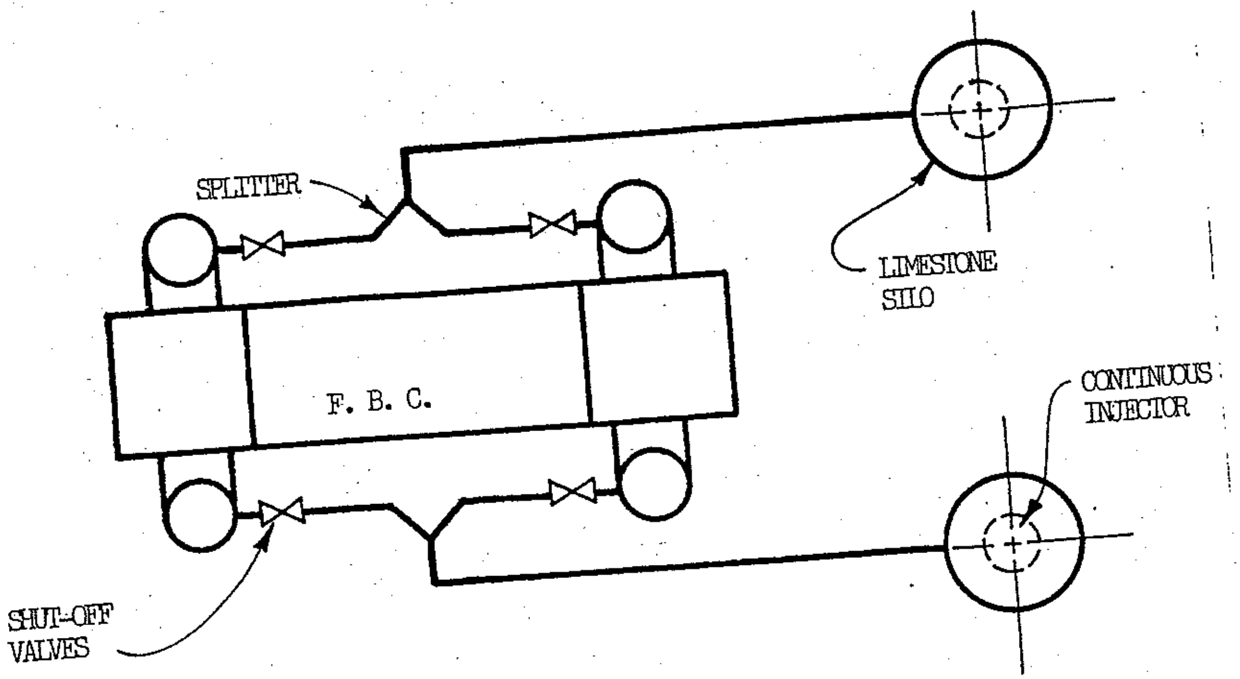


FIG. 7 – CONTINUOUS LIMESTONE INJECTION F.B.C.

(b) Blast Furnace Injection

Blast furnace operations can make considerable fuel cost savings by injecting pulverized or granular coal through the tuyeres of the furnace. Replacement rates of up to 150 Kg/THM are now routinely achieved. Blast furnaces normally operate at pressures in the 20-30 psig range. However, some furnaces equipped with high top pressure equipment can be up to 50 psig. Figure 8 shows a typical B.F. injection system where there are multiple tuyeres - sometimes as high as 20 per furnace. Fuel is injected through the tuyere elbows, and the amount of fuel entering each tuyere can be individually adjusted to suit specific tuyere pressure variations and/or blast temperature changes.

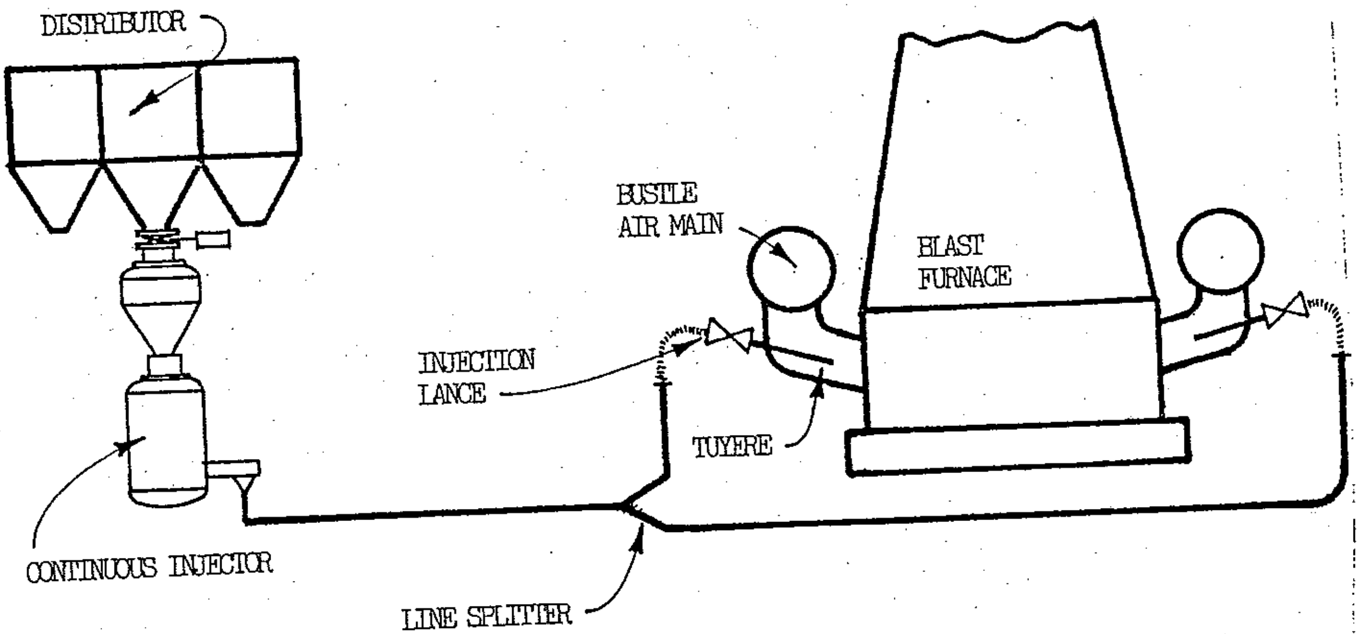


FIG. 8 – CONTINUOUS COAL INJECTION TO BLAST FURNACE

## 2.5 VERY HIGH-PRESSURE INJECTION APPLICATIONS

As fluidized bed technology advances towards high-pressure applications including combined cycle generation gasifiers, very high pressures can be expected in the future. Many of these applications are already exceeding 100 psig and are being planned for up to 300 psig. There are some applications including very high back pressures already in construction or start-up. One example is the process for the direct reduction of steel process. Here a reactor is used into which fuel (coke or coal), lime and pulverized iron ore are injected. The reactor operates at pressures in the 75-90 psig range with line pressure drops, due to the small injection lines, being up to 40 psig. High feed rate accuracy and control response is required by the process, and multiple feed points are involved.

## 3.0 METHODS OF INJECTION

Several means of injection of bulk materials into pressurized processes have been used over the last few years. Many of these have been successful, and when applied correctly can produce satisfactory results. However, as process and plant demands become more complex, many of these methods are no longer adequate or have become inflexible. Some pneumatic injection systems have produced poor results, while others although operating successfully, are either expensive or difficult to accommodate into plant layouts because of their size.

## 3.1 MECHANICAL/GRAVITY INJECTION METHODS

### 3.1.1 GRAVITY FEEDS

Many combustion processes have used a simple gravity feed system. Figure (9) shows a coal feed into a combustor from a day bin. The coal passes into a lock vessel of known volume and is filled on a fixed time basis. Alternately the vessel is filled to a level probe. Once the vessel has been filled, the lower valve is opened, and the material gravitates into the combustor. When higher back pressures are present, the lock vessel is first pressurized before the lower valve opens.

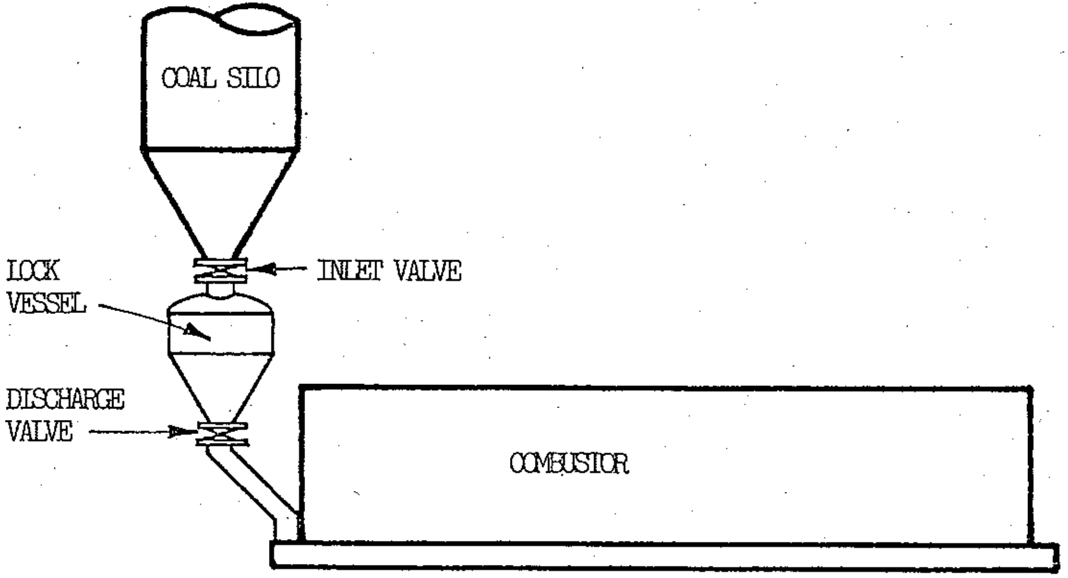


FIG. 9 – GRAVITY COAL FEED TO COMBUSTOR

This method operates quite well. It is simple and inexpensive, both to install and operate, providing care is taken over the design of the chamber and the drop chute to avoid bridging and poor flow into the combustor. The main disadvantages are:

(a) Flow is intermittent. If continuous injection is required, this method is clearly inadequate.

(b) The flow measurement is volumetric and somewhat crude. Accuracies are not reliable.

(c) It is difficult to vary the rate, and link it into the combustor controls.

(d) The day bin must be very close to the combustor to allow for gravity feed to be provided without the day bin being at an unreasonable height above the combustor.

(e) Usually the arrangement is limited to single feed points.

### 3.1.2 MECHANICAL FEEDERS

When continuous flow with a reliable accuracy is required, a positive feeding device must be used. A fairly successful method has been the use of gravimetric feeders. Figure (10) describes a typical arrangement for a gravimetric feeder for coal injection into a combustor.

If the process is at near atmospheric pressure, the arrangement is simple (Figure 10a), where coal supply gravitates into the feeder which then delivers the coal at the desired rate (by weight) into the combustor. The flow rate accuracy is good, and injection is continuous. The feeder can be easily connected into the combustor controls to provide good response to load changes.

If the combustor is operating at pressure, the feeder must also operate at the same pressure. Otherwise, hot gases will back flow into the feeder and possibly to the feed bin which could be hazardous and would affect the performance of the combustor. While this method can be successful, in many cases there are, again, several limitations.

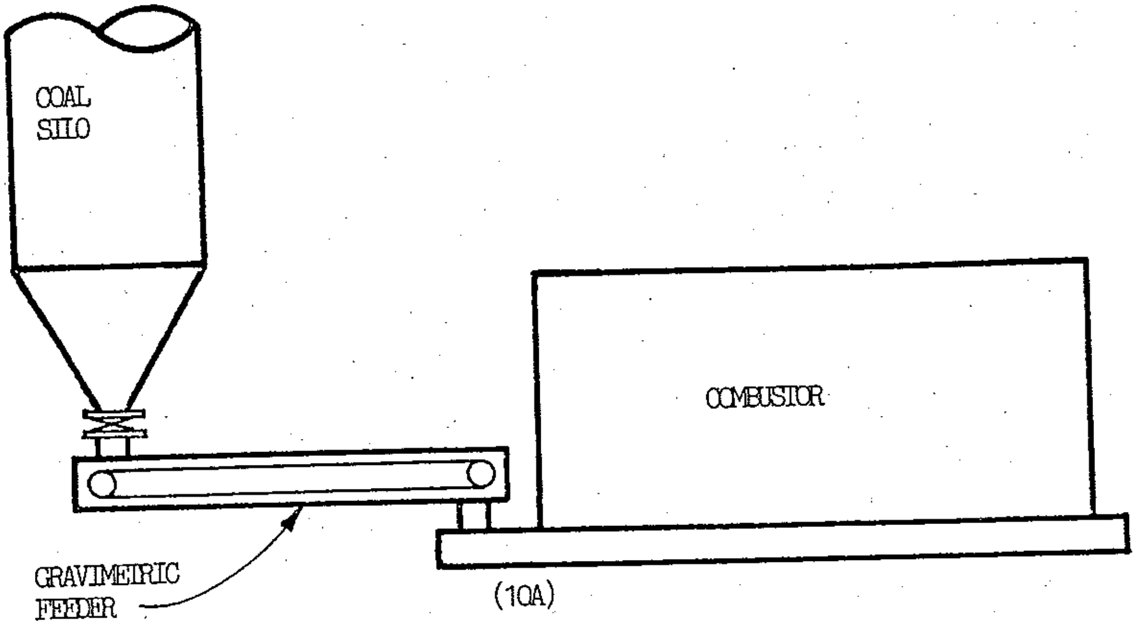
(a) To maintain the pressure in the feeder, a pressure leg must be incorporated into the system (Figure 10b). This requires a solid head of material to act as a seal above the feeder. In the case of wet coal, such pressure legs frequently experience bridging and are unreliable.

(b) The arrangement is still limited in terms of plant layout. Although feeders may be 50-60 ft. long, the day bins or silos must still be close to the combustors. This severely limits plant layout, especially if the silos are large and cannot be easily accommodated, or a retrofit installation is being planned.

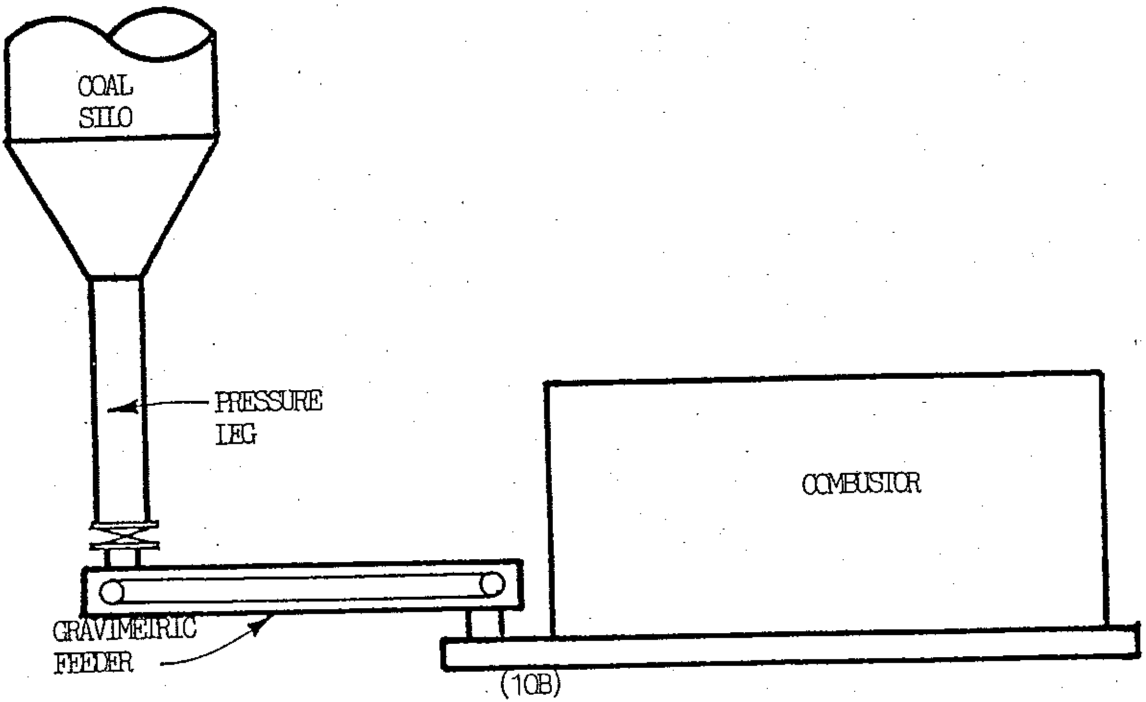
(c) At pressures above one bar, the feeder must be classified as a pressure vessel, and this further complicates the design and increases substantially the cost of installation.

In the case of reactive materials, various national safety standards require equipment to be encased with a shock pressure containment vessel or structure. This may be as high as 55 p.s.i,, depending on the standard adopted.

(d) Single, over bed feed point limitation also exists for this type of arrangement.



GRAVIMETRIC FEED TO COMBUSTOR



GRAVIMETRIC FEED TO COMBUSTOR

## 3.2 PNEUMATIC INJECTION

### 2.1 PNEUMATIC INJECTION - MECHANICAL FEEDING DEVICES

Pneumatic injection offers the immediate benefit of remotely located feed bins and silos, and the possibility of multiple injection points via line distribution devices.

(a) Screw Pumps

Attempts at injection into pressure environments using screw pumps have not been successful. The screw pump relies on the speed of the screw rotation, and a flap valve to provide a seal between the pipeline and the feed bin. If the pressure upstream varies, it is not possible for the screw pump to respond, and there is a severe affect on flow rate accuracy. Screw pumps also rely on the fact that fairly uniformly sized powders are being conveyed. In the case of materials with wide and variable particle analyses and those which are wet (such as coal), conveying becomes unreliable since the sealing action of the pump is severely affected. Other disadvantages are the high energy consumption due to the large pump motor and maintenance/wear problems on the pump's screw and bearings, especially when abrasive materials are being handled.

(b) Rotary Valves

Some installations have involved the use of variable speed rotary valves. Again where there are no back pressure changes and the material is not sticky, this method can produce reasonable results. However, as all rotary valves tend to "leak" conveying air, conveying efficiency becomes a problem, especially where large systems and/or high back pressures are encountered. Above 1 bar, rotary valves become "special", are not produced by many manufacturers. Above 3 bar, rotary valves do not appear available at all.

Rotary valves cannot respond to changes in back pressure. They also suffer from loss of feed rate control during back pressure changes. When sticky materials are conveyed, there is always the risk of the valve chambers not clearing properly, again leading to inconsistent material injection and loss of accuracy. Rotary valves, because of their tight clearances, also suffer from rapid erosion, especially with abrasive materials. This causes acceleration of air leakage to the point of unreliable conveying.

## 3.2.2 PNEUMATIC INJECTION - PRESSURE VESSELS

There have been many types of pneumatic injection systems using pressure vessels developed over the years. Figure (11 a-d) describe just a few examples.

All of these types of systems are able to inject materials continuously against high back pressure, although some are limited to fairly uniform powders. The principle of conveying is the dilute-phase regime. This is necessary to achieve smooth, continuous flow. Most processes do not respond well to slugging and cannot tolerate dense batches of material entering the process as may be expected in the discontinuous dense-phase regime. Also, flow rate accuracy and rate variation control cannot be achieved when operating with this regime. The main requirements of a successful injection system are as follows:

(a) The ability to inject solid materials in a smooth consistent manner.

(b) During injection (batch or otherwise) flow must be continuous.

(c) Flow rate must be settable and accurate to a reasonable level - in the range of say, 1-3%.

(d) Turn down capability must be provided at least to 3 to 1, and often up to 10 to 1 of maximum rate.

(e) Flow rate accuracy should not be affected by variations in back pressure.

(f) Delivery to multiple injection points may be required and achievable with significant compromise of flow rate accuracy to each injection point.

(g) Some means of response to varying demands of the process is required.

Most systems are able to satisfy (a) and (b). A positive means of introducing material into the conveying line, however, is required to satisfy (c). Systems which rely on redistribution of air between vessel and pipeline have not been reliable, and flow rates have not been repeatable or accurate. Some systems use a form of mechanical feed fitted either internally or externally to the pressure vessel. This can be a metering feeder or controlled orifice, or a combination of the two.

These types of feeding devices do produce controlled repeatable flow rates with good accuracies, and also provide turndown capability which satisfies item (d) above. Probably the most difficult task facing a solid materials injection system is that of maintaining flow accuracy during process back pressure changes (e). If the back pressure changes and there is no response from the system, the flow rate will be affected either by over pressure or under pressure in the system. Even slight changes in back pressure can seriously affect flow rate accuracies and repeatability.

To maintain flow rate accuracy during such process pressure changes, the pressure on either side of the feeder (regardless of what type of feeder) must be balanced so that if the pressure downstream should rise or fall, the pressure upstream also rises and falls accordingly. This will prevent inaccuracies in delivery into the pipelines occurring through the feeder; surging, flushing, resulting from a pressure gradient either side of the feeder. This is quite difficult to achieve in many systems, especially those that have multiple outlets.

Often delivery is required to many injection points (f), e.g., coal injection into a blast furnace through its tuyeres where as many as 20 injection points may be required. There are three choices that face the designer:

(i) Individual machines - one to each injection point.

(ii) Machines with multiple outlets.

(iii) Line splitting devices.

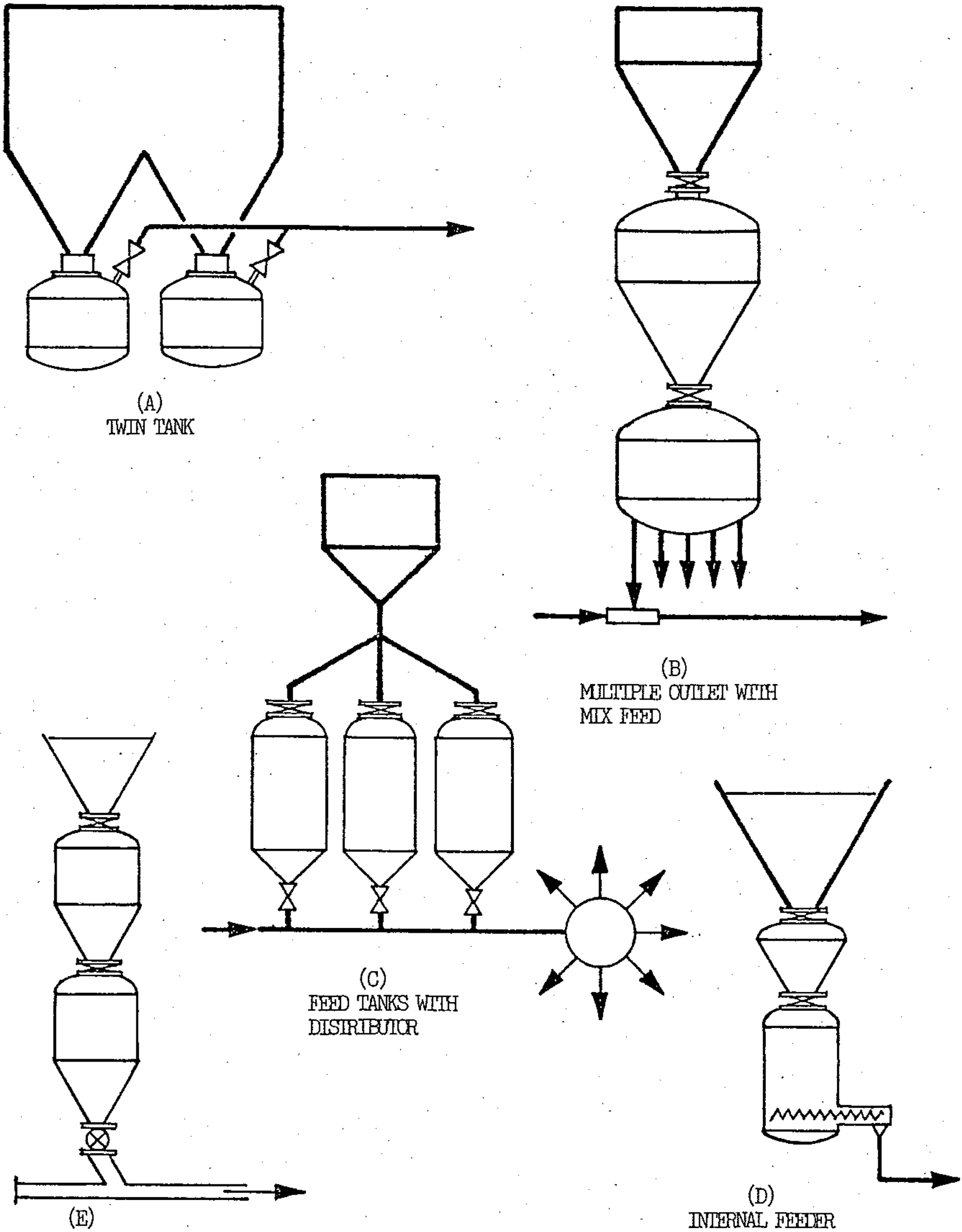
(i) is the most reliable since individual turndown can be provided along with highly accurate and repeatable flow which can be made independent of back pressure changes. It can be, however, expensive to install.

(ii) is less expensive, but requires usually very large vessels, and turndown is less easy to provide. These systems are also less flexible with regard to granular, lumpy or damp/wet materials. They are also less responsive to back pressure changes.

(iii) can be quite effective and economical. However, with the fixed type of splitter, accuracy of split may be in the range of plus/minus 3 to 5%. With rotary splitters, accuracy may be better, but the splitter is somewhat limited by material condition.

All injection systems must in some way respond to changing demands of the process they are injecting into (g). For instance, automatic turndown may be required for fuel injection into a fluid bed combustor. This can be achieved by use of 4-20 Ma closed loop signals with the changing load in the combustor automatically speeding up or slowing down the rate of injection.

Other processes may demand specific flow rates by weight. If the bulk density of the material is variable for any reason, the injection system must also respond. Therefore, different approaches on this ranging from load cell systems on the injection vessels to line flow measurement devices and combinations of both exist.



(A)
TWIN TANK

(B)
MULTIPLE OUTLET WITH
MIX FEED

(C)
FEED TANKS WITH
DISTRIBUTOR

(D)
INTERNAL FEEDER

(E)
EXTERNAL FEEDER

FIG. 11
INJECTION SYSTEM TYPES USING PRESSURE VESSELS

## 4.0 MATERIAL CHARACTERIZATION

Pneumatic injection systems rely on a dilute-phase, fully suspended flow to meet the demands of the processes into which the bulk solid is being injected. As with all pneumatic systems, due consideration must be given to the characteristics of the material being injected. Particle shape, size distribution, mean particle size and particle density will all have an effect on minimum conveying velocity, pressure drop, air flow, etc. Properties such as moisture content, cohesiveness and adhesiveness may cause flow problems through vessels and valves. Careful analysis of explosive powders, for instance, may require the use of inert gases for conveying.

## 5.0 NEED FOR TESTING

It is evident that with the wide range of variables of each material characteristic, a realistic means of testing is required. As with all types of pneumatic bulk material conveying systems, the need for reasonably scaled tests for injection systems is important. Not only is the designer accurately confirming air flows and pressure drops, but also flow of material through lock vessels, flow rate accuracy, the ability of the feeder to provide adequate turndown, and the effectiveness of the feeder to produce the flow conditions required by the process for the material being conveyed.

As the technology in high-pressure fluidized beds, gasifiers, etc., advances, the need for injection systems to provide controlled, accurate flow into very high-pressure environments becomes more and more commonplace. In these cases, there will also be a need to both demonstrate the effectiveness of injection systems for providing such flows, and also for more basic research into what has been a relatively poorly understood subject.

## 6.0 CONCLUSION

It is evident that, as with all pneumatic conveying system designs, pneumatic injection design is not excused from the need to address:

(a) System design requirements
(b) Material characteristics

There is a wide range of system design types available to the designer, who must review all calculations, supporting statements and data, previous experience, etc., before making a design commitment.

It is evident from work being performed in North America that in order for pneumatic injection systems to meet the increasing sophisticated demands of process injection, wider and greater expertise is needed.