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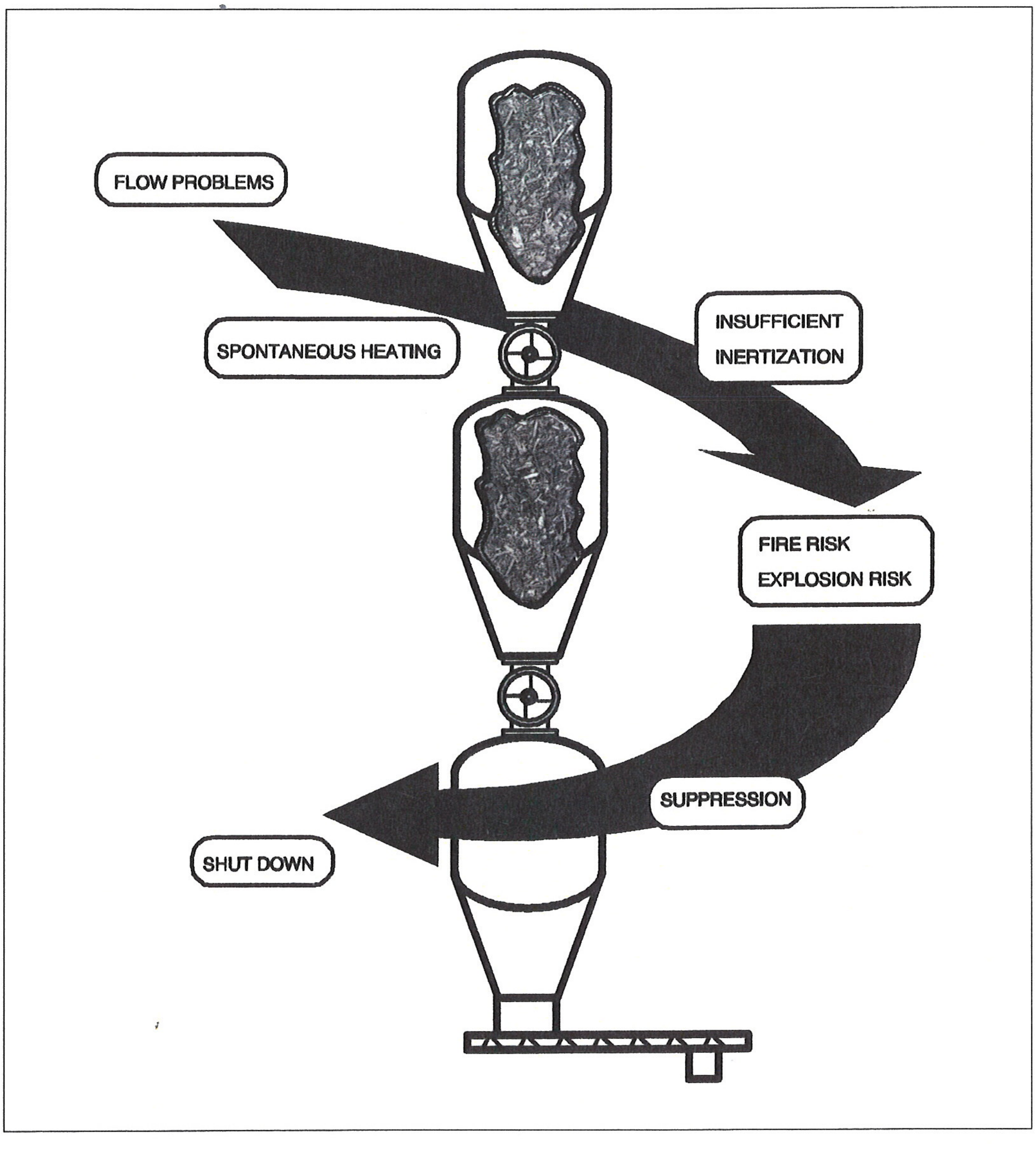
Aimo Rautalin & Carl Wilén

Feeding biomass into pressure and related safety engineering



TECHNICAL RESEARCH CENTRE OF FINLAND
ESPOO 1992

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Feeding biomass into pressure and related safety engineering

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ABSTRACT

Malfunctions in the fuel feed and handling equipment could be cause for biomass gasification process upsets, and are of major concern for pressurized gasification processes. One precondition for the development of handling and feed equipment for solid fuels and wastes and for the design of novel systems is a good knowledge of the characteristics and flowability of bulk materials, because the requirements for the equipment reliability, adjustability, economy, and lifetime are becoming more demanding.

Different methods of feeding biomass fuels into pressurized gasifiers, as well as limitations and special features of these methods, are discussed in this literature review. Examples of different systems for fuel feed and ash removal in pressurized gasification and combustion plants are given, and the available plant operational data are surveyed for a better understanding of the handling characteristics of bulk materials in biomass gasification plants. Unfortunately, there are only a few references to long-term operating experience with biomass feeders in the literature.

Safety engineering, including fuel flow characteristics, and dust explosion and spontaneous ignition properties, is also discussed with special attention given to the conditions in pressurized feeding systems. Results from dust explosion and spontaneous ignition tests with biofuels at elevated pressures are presented.

FOREWORD

This literature review on biomass fuel feed into pressurized processes has been based on a 1991 VTT report in Finnish. The work was funded by the IEA Project Bioenergy Agreement, Task 7, Activity 4 -- Thermal Gasification. The project is being led by Dr. Suresh Babu of the Institute of Gas Technology, Chicago, USA.

The work is a part of a research project on handling and safety aspects related to fuels used in pressurized processes, such as feed, spontaneous ignition and susceptibility to dust explosions. The work is also closely connected with a research project on pressurized gasification of low-grade fuels underway in Finland. This work was carried out in 1989-1990 and was funded by A. Ahlstrom Corporation, Imatran Voima Oy, Vapo Oy, Technical Research Centre of Finland (VTT), and the Finnish Ministry of Trade and Industry.

In addition to the authors, Prof. Kai Sipilä and Mr. Rabbe Thun, M.Sc., of the VTT Laboratory of Fuel and Process Technology have also participated in the work. Thanks are also due to Mrs. Maija Korhonen, B.Sc., of the VTT Laboratory of Fuel and Process Technology for translating and editing the report; and to Dr. Suresh Babu of Institute of Gas Technology, Chicago, USA, for valuable comments, revise and corrections to the report.

Espoo, August 1992

Aimo Rautalin
Carl Wilén

CONTENTS

1 INTRODUCTION

In biomass energy conversion plants the materials handling systems often are susceptible to malfunctions. Operating problems with the fuel feed and handling equipment are by far the most general reason for unforeseen shutdowns of gasification processes, and reliable solids handling systems are essential to the development of pressurized processes.

One essential aspect of the development of handling and feed equipment for solid fuels and wastes and for the design of advanced energy conversion systems is a good knowledge of the characteristics and flowability of bulk materials. In general, the requirements set for this equipment, including reliability, adjustability, economy, and endurance, are becoming more demanding.

Different methods of feeding fuels into high-pressure gasifiers, as well as limitations and special features of these methods, are discussed in this literature review. Examples of different systems for fuel feeding and ash removal from pressurized gasification and combustion plants are given. Unfortunately, there are very few references to long-term operating experiences in the literature. The feed systems are limited to 3.5 MPa pressure operation.

Fuels, in general, are often classified into granular and pulverized fuels on the basis of their flowability. However, a number of fuels such as biomass and peat cannot be classified in this way without extensive preparation. The extent of preparation must often be determined very cautiously. Fuels with different handling characteristics must be tested in the laboratory, and the general theories for the flow of bulk materials should be applied to the results to develop and design suitable feed systems for the fuels. For example, the application of laboratory results to the design of suitable feeder screws and to the determination of the minimum opening of hoppers and wall inclinations of bins have been discussed by Rautalin et al. /1,7/.

It is important that no residual fuel should be left in feeders, bins or lock hoppers, because this increases the probability of spontaneous ignition of fuels. It has been indicated /15/ that the susceptibility to spontaneous ignition is increased by pressure, which also increases the safety hazards and malfunctions of feed equipment.

Fuel handling also involves other safety factors, which are magnified under high pressures /16, 17, 18/. A hazard of dust explosion is involved in fuel handling, as the fuel usually contains an abundance of fines. This, combined with the possibility of contact with combustible gases, increases the risk of explosion; therefore, an efficient control of conditions and operation technology is required.

2 HIGH-PRESSURE FEEDING

2.1 GENERAL

Pressure causes changes in the tension and compression strength of the feed material. These changes affect its flow characteristics and, hence, also its behaviour in the feed equipment. The flow characteristics of the material should be maintained as uniform as possible, while the constant feed system pressure should be maintained, or the feed equipment should operate reliably over the pressure difference between the material and the reactor.

The handling characteristics of biomass, such as peat, wood and wood residues, are affected by quality, moisture content, particle size, and extraneous contaminants. Hence, feeding these bulk materials into a pressure vessel may sometimes differ greatly from feeding into a low-pressure process due to changes in the behaviour and properties of the material. Hence, a highly reliable operating fuel feed equipment is considered to be crucial to the successful operation of a pressurized combustion and gasification system. Removal of ash and other residues from the pressurized vessels is also one of the key factors in the operation of the pressurized plants.

2.2 FEEDING SYSTEMS FOR BULK MATERIALS

High-pressure feeders for bulk material have been developed mainly for coal. In addition to general equipment operability, a number of other equally important feed characteristics should be controlled. For example, the feed should be homogeneous and the feeder should measure and regulate the material flow. The principle of the pressurized solids handling and feeding system is shown in Figure 1.

In general, measurement of feed uniformity and rate is based on volume or weight; however, it should be kept in mind that the accuracy of gravimetric measuring is only ±2% /2/ when feeding into a pressurized system. A system based on volume flow is even less accurate due to

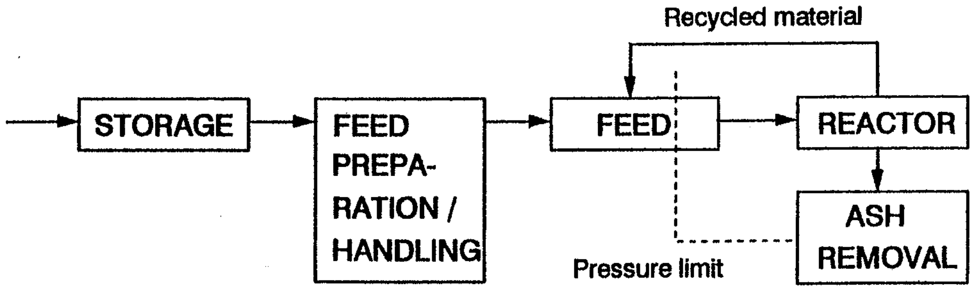


Figure 1. Fuel feed and ash removal in a pressurized system.

variations in the fuel properties, such as moisture content and particle size, and to changes in bulk density caused by these factors. Since feed preparation and handling equipment are often expensive, it is preferable to minimize the requirements for a gasifier feedstock. Consequently, the tendency is toward the use of coarse and moist fuels, which would increase inhomogeneity. This places additional requirements on the construction and operability of feed handling and solids feeding equipment.

The present gasification plants require a feed preparation system in which the fuel is sized, dried, milled, sieved, and stored for different types of feeders. The method of feed preparation and handling is dependent on the quality of the fuel, the type of the plant, and the method of feeding. The purpose of feeder design is to develop an ideal pressure feeder with the following properties: high reliability, low construction, maintenance and operational costs, low power consumption, and wide applicability. Other technical requirements are: smooth and continuous feed, suitability for handling a variety of bulk materials, insensitivity to variations in fuel quality, sufficient pressure seal against backstroke, accurate feed control, a construction suited for measuring the feed rate, durability, and availability. Usually, only a few of these requirements can be met, and compromises may have to be made. Commercial feeders are suitable for a narrow range of fuels.

3 DIFFERENT BIOMASS FEED SYSTEMS

3.1 GENERAL

Choise and applicability of the fuel feed system is dependent on the reactor pressure, which can be grouped, for example, as follows:
a) < 0.35 MPa, b) 0.35 - 3.5 MPa, c) > 3.5 MPa.

Gasification plants usually include a feed preparation system, in which the fuel is treated and stored according to the requirements of the plant and the feed method. Alternatives or requirements for feed preparation and handling are shown in Figure 2.

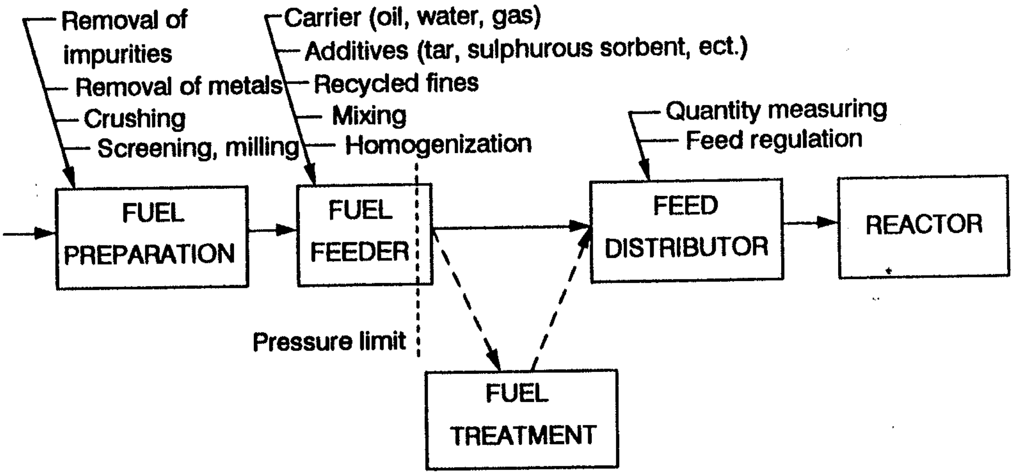


Figure 2. Requirements for the handling of pressurized fuel feedstocks.

3.2 DRY FEED SYSTEMS

3.2.1 Lock hoppers

The usual practice for feeding into pressurized gasifiers is mainly via pressurized lock hoppers and by gravity flow. This feed system is simple and operates as follows:

1. The fuel is conveyed after preparation and measuring, via a feed hopper into the lock hopper, and the valve between the feed hopper and the lock hopper is closed.

2. The lock hopper is pressurized to the pressure level of the reactor or a little higher.
3. A connection is opened between the lock hopper and the reactor.
4. The fuel flows by gravity into the reactor.
5. The feeder pressure is released to the level of the ambient pressure, and then a connection is opened for fuel conveying.
6. This sequence is repeated for cyclic feeding.

The principle described above has been used in lock hoppers for feeding reactors with an operating pressure of < 3.5 MPa. Problems may arise at a high operating pressure or higher feed capacities:

- The consumption of pressurizing gas increases sharply as the reactor pressure rises.
- At higher feed capacities and pressures the number of feed cycles will be high, which results in considerable wear of valves and high operating and maintenance costs. To reduce wear and gas costs, double lock hoppers have been used and, hence, the number of cycles is reduced and the pressure release gas of one lock hopper can be used for partial pressurizing of the other.

Different applications for lock hoppers are shown in Figure 3. Examples of the applications, grouped according to their operating principle, are discussed in the following sections. Operating information for these lock hopper feeders is given in Figure 4.

Screw feed

Thomas R. Miles Consulting Engineers has developed a pressurized feeder for biomass based on the lock hopper system illustrated in Figure 5. The biomass is fed into a lock hopper, pressurized, and discharged into a metering bin equipped with a multiscrew system for metering the fuel to the injector screw of the pressurized reactor. Such a feeder was successfully tested at the high-pressure fluidized-bed gasification plant of ASCAB in Clamecy, France. The capacity of the feeder is 5 tonnes/h of wood chips into 10 - 25 bar pressure fluidized bed gasifier /21/.

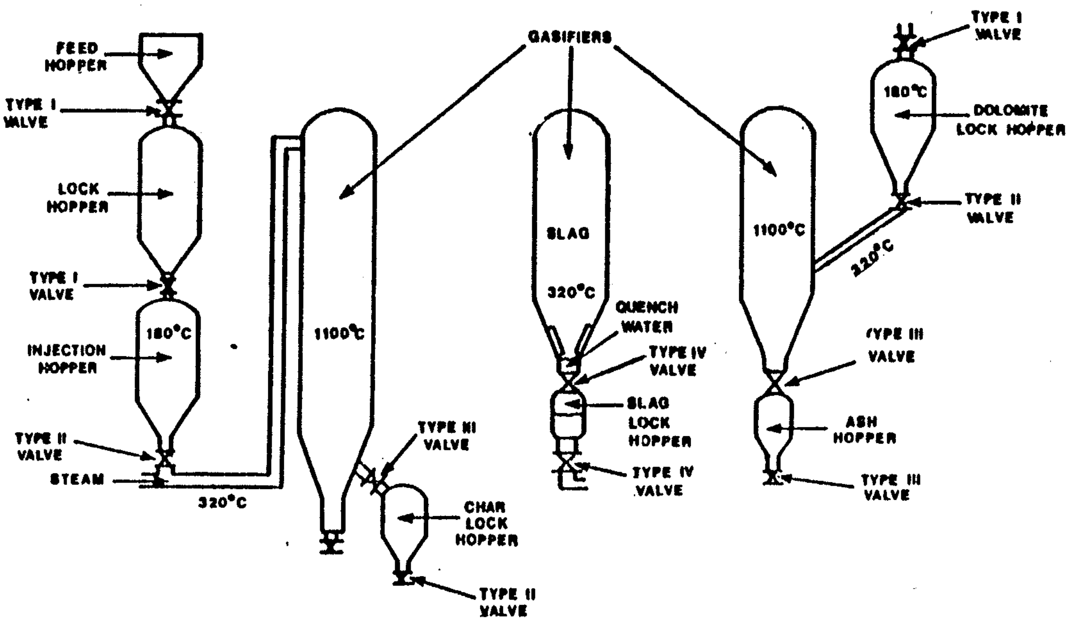


Figure 3. Different lock hopper applications /3/.

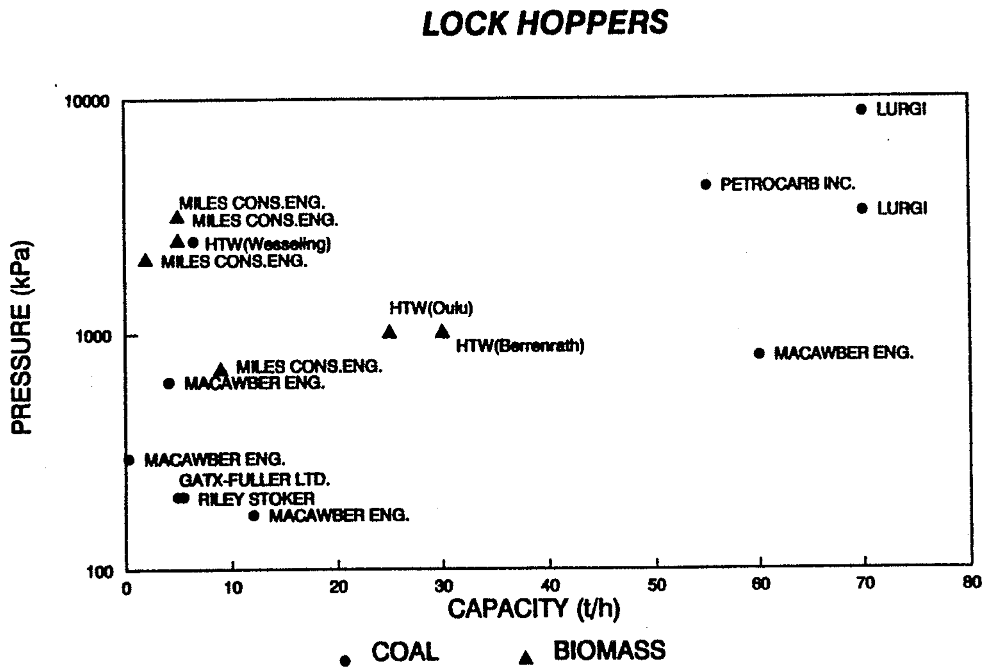


Figure 4. Operational information for some lock hopper feeders.

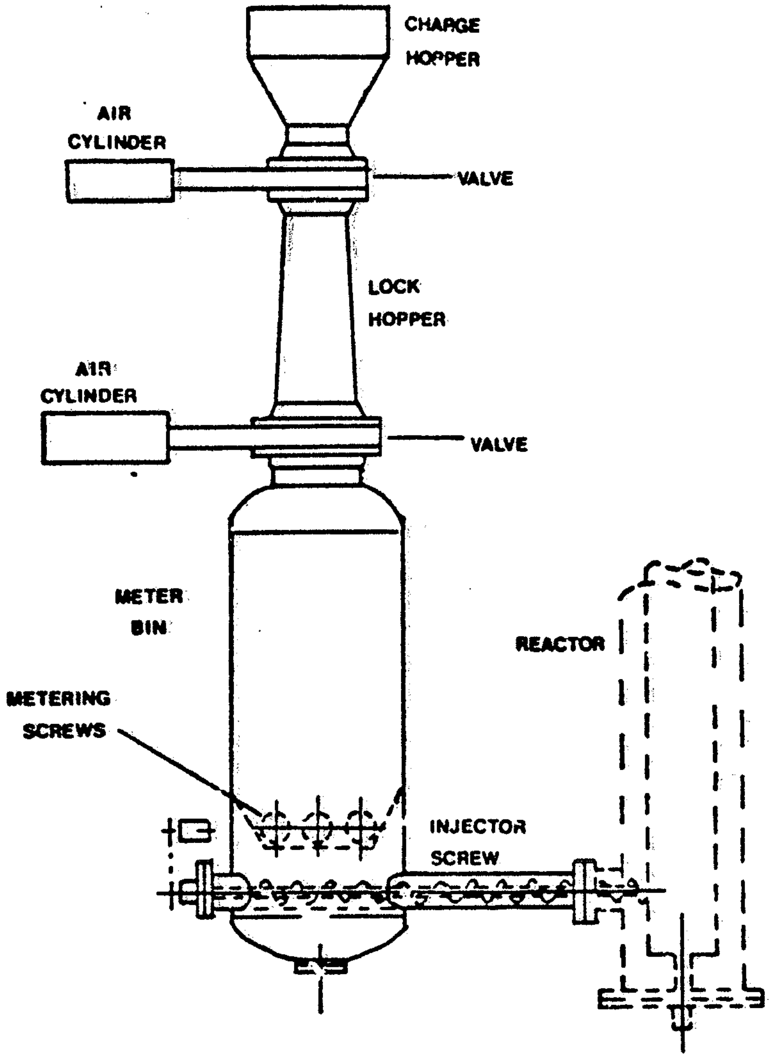


Figure 5. Miles' biomass feeder /4/.

3.2.2 Rotary valve feeders

In rotary valve feeders, the fuel is conveyed from an unpressurized space into a pressurized space in a pocket between the blades of the rotor and the frame of the feeder. Pressure sealing is secured by accurate adjustment of the rotor blades in the frame of the feeder and the total discharge of the feeder pockets by blowing with high-pressure steam. The principle of a rotary valve feeder used by A. Ahlstrom Corporation for feeding wood chips into a 1.2-MPa pressure vessel is shown in Figure 6.

Advantages of these feeders are:

- The feed capacity is easy to control by regulating the speed of the rotor.

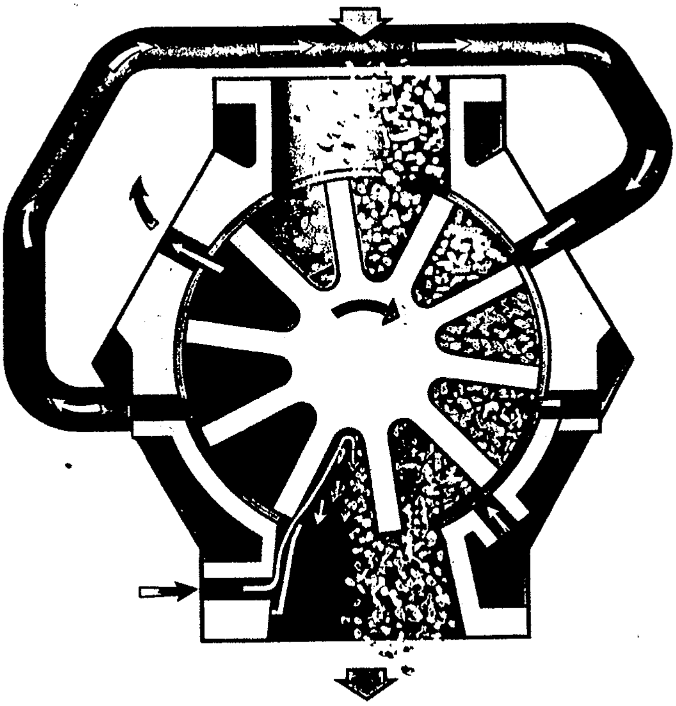


Figure 6. A rotary valve feeder for wood chips (A. Ahlstrom Corporation) /14/.

- The clearance between the rotor and the frame can be controlled by adjusting the position of the conical rotor in the axial direction.
- The energy requirement of the feeder is small.

Problems can be caused by an incomplete discharge of the pockets, especially when sticking fuels are used.

The feeder of Ingersoll-Rand's IMPCO Division is suitable for feeding both low and high pressure vessels. The high-pressure feeders are designed to feed into 965 kPa digesters. The discharge of the feeder pockets is accomplished by blowing with steam (Figure 7).

Kamyr Inc. has designed its "Asthma" feeder (Figure 8) especially for sawdust, wood residues and other biomass species such as jute, bagasse, straw and bamboo. The operating principle of the feeder differs in many respects from the rotary valve feeder: when the pocket of the feeder opens into the digester, the pocket is immediately blown empty by high-pressure steam /13/. The feed pressure of the high-pressure Asthma feeder is 1 MPa.

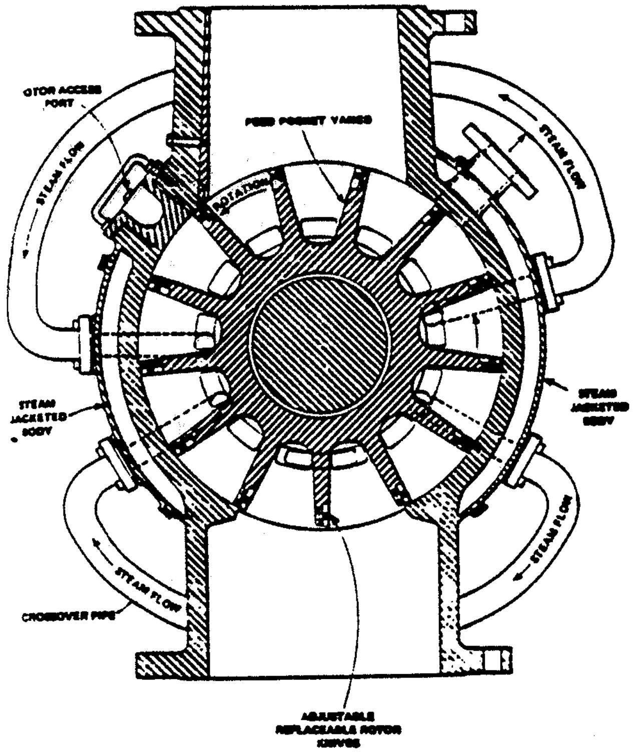


Figure 7. High or low-pressure feeders (Ingersoll-Rand, IMPCO Division /13/.

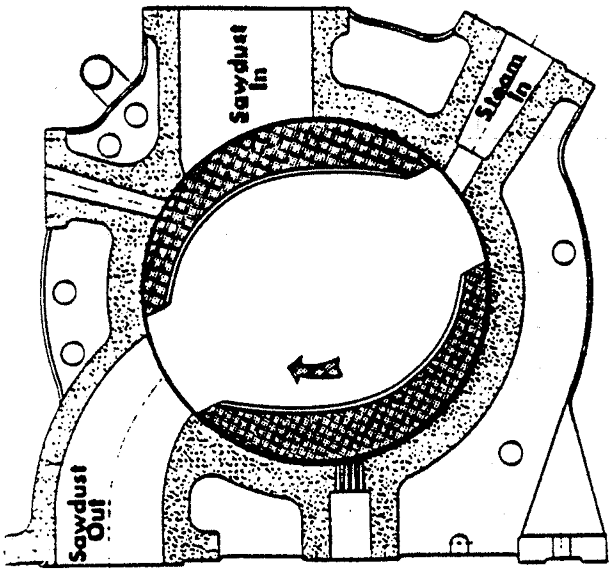


Figure 8. High-pressure "asthma" feeder for continuous sawdust pulping (Kamyr) /13/.

Typical capacities of feeders of this type with wood chips are presented in Figure 9.

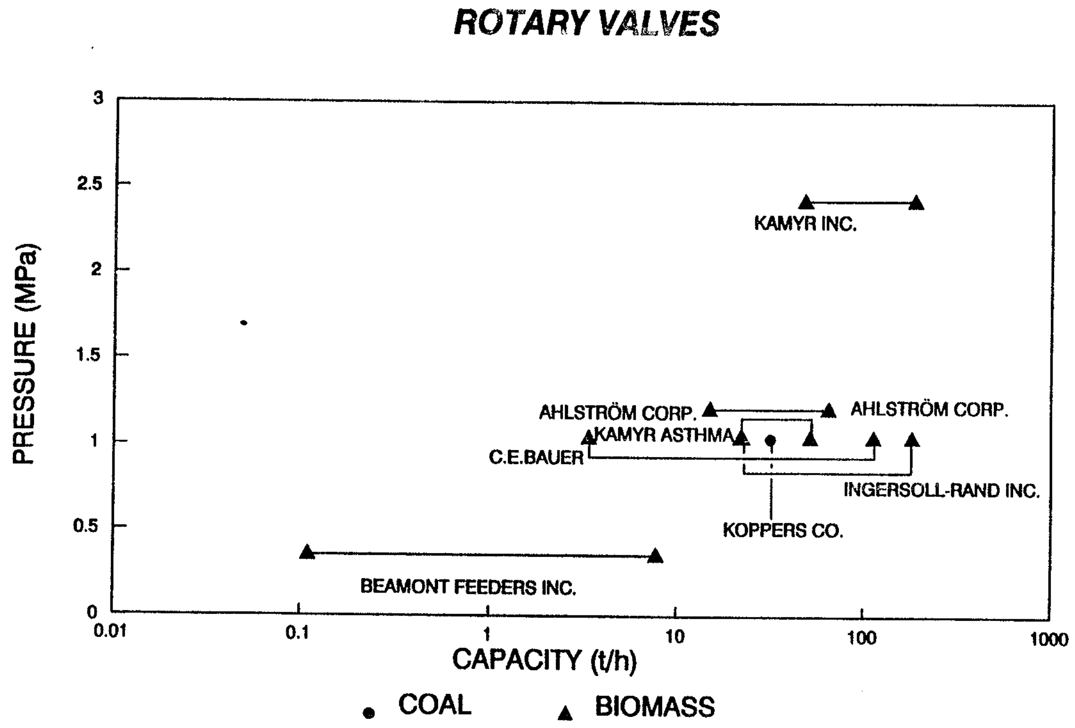


Figure 9. Typical capacities of rotary valve feeders.

3.2.3 Piston feeders

Simple piston feeders are lock hoppers with a changing volume. Their feeding tank, separated from the reactor, is fed under normal atmospheric pressure. After filling, the volume of the feeding tank is reduced as the piston moves forward. As a consequence, the pressure increases and the material moves forward in the cylinder. When reaching the required pressure level the valve is opened and the fuel is fed by the piston into the reactor. The piston-type feeders have a number of advantages compared with the lock hopper feeders:

- The amount of gases required for pressurizing is reduced or not needed at all.
- The feed cycles can be increased to the point that continuous feeding is possible.
- The feed system is compact and integrated.

The principle of a simple piston feeder is shown in Figure 10 and the development of forces in the compression process for mass materials in Figure 11 /5/.

Due to these factors, the investment and operation costs of this system are favorable. The feeder is suited for dry fuels of all kind; however, at present, data on the reliability and wear resistance of the feeder in continuous operation in commercial-scale facilities is limited. Feeders of this kind have been developed by the following manufacturers:

● Lurgi	Schlepper piston feeder
● Ingersoll-Rand	Single-acting piston feeder
● Conspray Construction Systems	Conspray feeder
● Foster Wheeler	Linear pocket feeder

The Conspray feeder is actually a version of an industrial concrete pump. The other feeders have been developed from normal piston feeders.

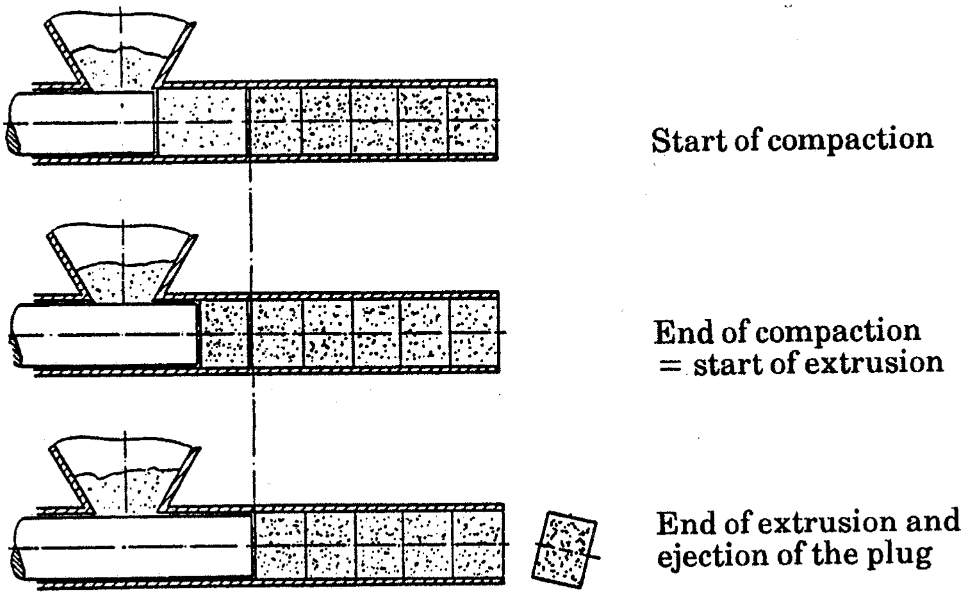


Figure 10. The operating principle of a piston feeder /5/.

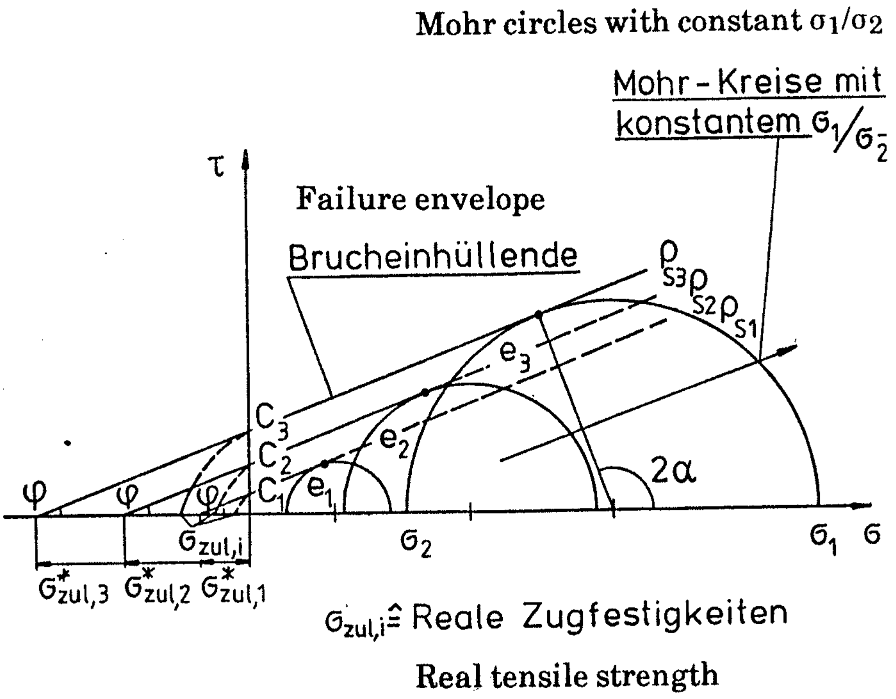


Figure 11. Forces developed in the compression process of bulk materials /6/.

The performance of the piston feeders and the feedstock characteristics are further discussed in /6/. Corresponding aspects for peat have been presented in /22/, which concerns the production of peat briquettes. The operation ranges of the piston feeders are shown in Figure 12.

Other related feeders

Putzmeister GmbH of Germany has developed feed and conveyor pumps, which are also able to feed into high-pressure vessels. These pumps are of the piston type, either single piston or double piston pumps. The screws conveying the fuel into the piston part of the feeder are of double-screw type. The screws rotate reversibly and are also self-cleaning when conveying rather difficult and sticking fuels /23/. The operating area of these pumps is very wide, with capacities ranging from 11 m^3/h to 115 m^3/h, and feed pressures from 4.5 to 15 MPa. The principle of a double piston pump of Putzmeister KOS Series is shown in Figure 13. In Finland, the Putzmeister feeder has been tested by for feeding peat (moisture content 75 wt %) into 2 MPa pressure. The feeder operated well during a rather short test period.

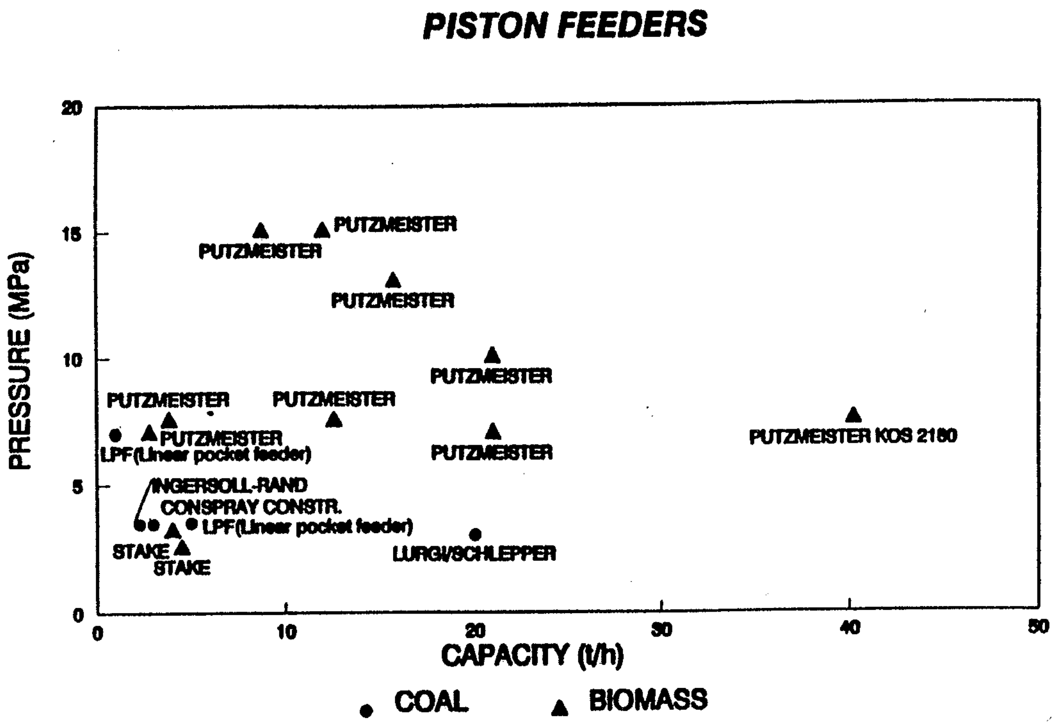


Figure 12. Operation ranges of the piston feeders.

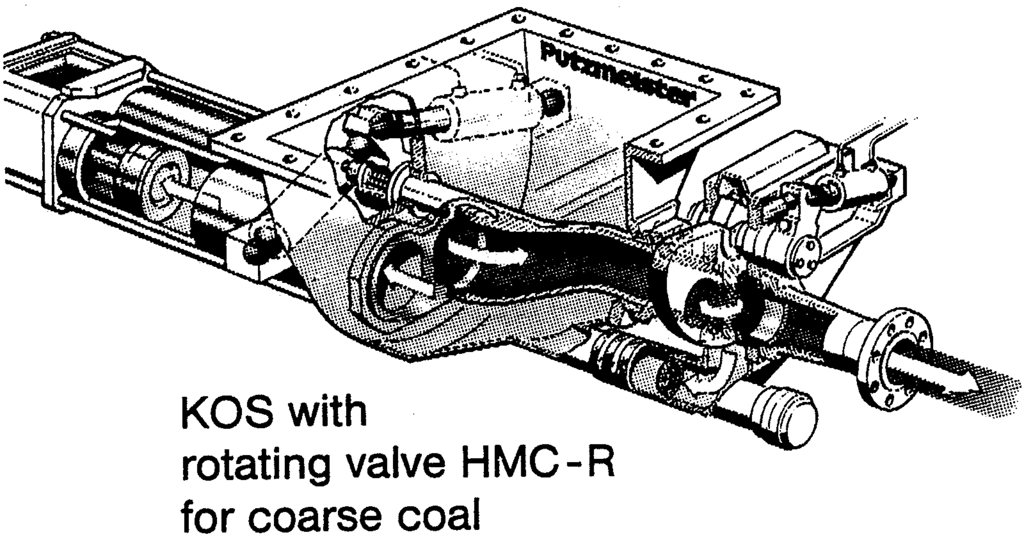


Figure 13. The principle of Putzmeister Kos double-piston pump /23/.

The feed hopper of the Stake feeder (Figure 14) is equipped with two screws, of which one feeds the material to the other, located at the hopper bottom and feeding the material further into a plug compression channel. The feed screw rotates within the hollow reversibly-moving piston and feeds material to the front of the piston, while the piston is in its back position. The hollow piston compresses the fuel plug, especially on the surface while the interior remains less compact. To get the interior of the plug sufficiently compact, the tapering of the plug channel must be adapted to each particular fuel. The back pressure required by the start-up is developed by an adjustable counter cone, which is removed after the formation of a sufficiently compact plug.

At Cultor Oy, Finland, the conical shape of the plug channel is slightly enlarged toward the plug's direction of travel. The maximum capacity of the feeder is about 200 kg/h dry wood chips. The diameter of the plug channel is 150 mm and the stroke frequency of the compressing piston is 250 strokes/min. The wood material is heated to approximately 50 - 100 °C in the co-axial feeder. The heating temperature has not been measured, but it has been estimated on the basis of observed starch gelation; however, heating is dependent on the surface friction between the plug and the wall and on the friction between and within the fuel particles.

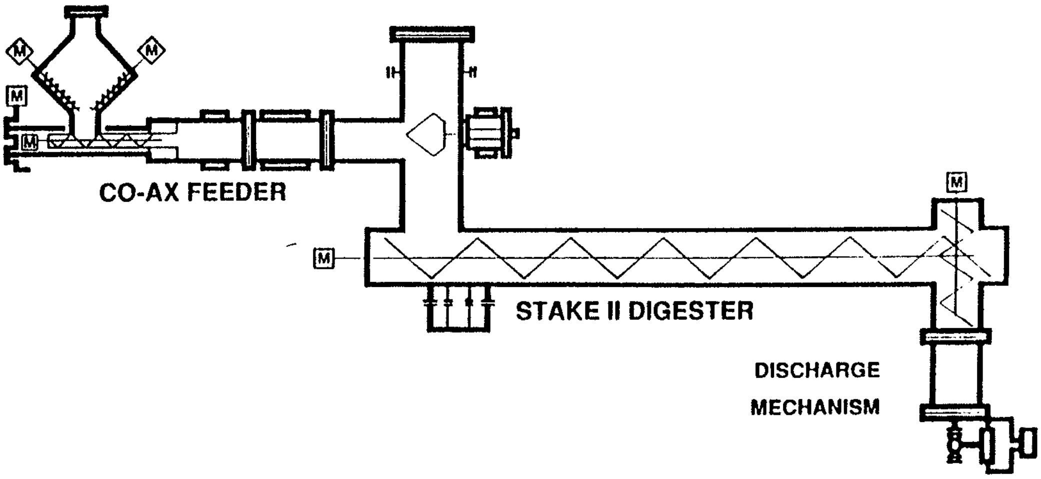


Figure 14. The principle of the Stake feeder /8/.

The propulsion force has been measured at about 35 - 40 MPa. This indicates that the forces required are high and the frame and supporting structure of the feed should be sturdy. Because of heavy equipment wear, high maintenance is required. The gas-tightness has been good when feeding birch chips over 25-bar back-pressure. Other materials have also been tested in this feeder with fairly good success. The availability of the larger feeder in operation at Cultor Oy in Finland has been about 80 %. There are only a few Stake feeders in operation at the present time..

3.2.4 Extrusion and injection systems

Extrusion and injection feeders are also suited for feeding biomass fuels. However, they differ from many other feeders in such a way that the fuel is not necessarily in the same dry form after the feeder as it is prior to it.

Screw feeders

In the screw feeders the screw forms a compact, pressure-retaining plug from the feedstock in the feed channel. The plug moving forward during the feed prevents gases from flowing back from the pressurized reactor. The compacting parts may be of different design, for example, direct pipe with an enlarging mouth, venturi, converging, or enlarging. These compacting parts form a solid plug and maintain a steady flow of solids.

In the Werner & Pfleiderer feeders, there are two parallel co-rotating screws that convey the feedstock forward, while the material moves downstream following a figure-eight path by being transferred from one screw to the other after each revolution. A heater is usually integrated to the feeder, and the throughput time, pressure, and conveying time are accurately controlled. It is also possible to add intermediate processing units for the feedstock. The extrusion unit is changeable according to the requirements of the feedstock or the process. The feeder can consist of a strong moulding, cutting, or pressure-maintaining part. These feeders have been used, for example, for feeding sawdust into pressurized reactors; however, the feeder can wear out easily when highly abrasive fuels are used.

Sunds Defibrator in Sweden has developed a plug-screw feeder that is based on the pressure sealing of the fuel plug. The cross-section of the feeder is a reducing screw feeder with a hydraulically adjustable throttle. The feeder, with a standardized screw, can feed wood chips into about 0.3 MPa back- pressure. A back-pressure adjuster can regulate the strength of the plug formed in the feeder and also its pressure sealing against back-pressure. Due to the conical shape of the back-pressure adjuster, which also breaks extrudates, no extrudate breaker is required in the side of the reactor when feeding wood chips. This commercial feeder is used in the pulping industry for feeding wood chips into pressurized processes. The principle of the feeder is shown in Figure 15.

At the Sveg peat briquette factory in Sweden, a screw feeder developed from the plug-screw of Sund's Defibrator has been used. Peat is fed into a 300 kPa back-pressure dryer. The compressed peat is crushed again into fines by rotating blades in the dryer.

At the pressurized biomass gasification demonstration plant of BIOSYN in Quebec, Canada, a modified version of the Sunds plug screw feeder was used for feeding biomass at a 7 tonnes/h rate into a 1.7 MPa pressurized reactor. The feeder operated relatively well. For safety

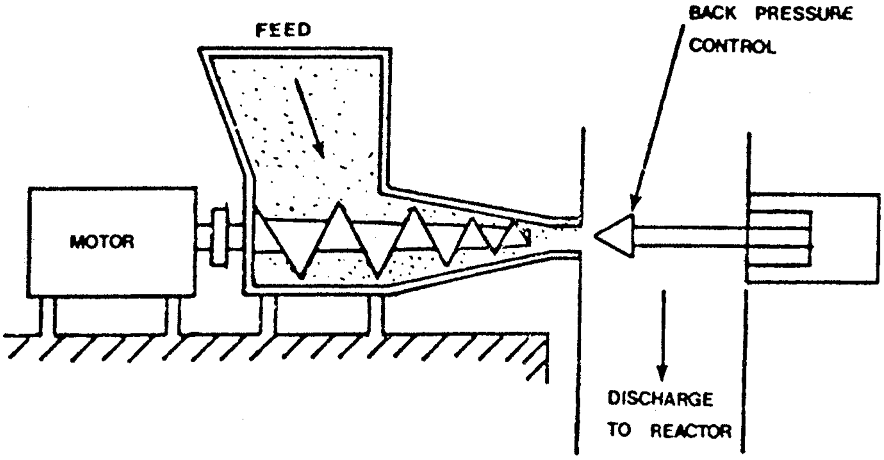


Figure 15. Principle of the Sunds feeder screw.

reasons, a large ball valve was installed between the reactor and the feeder.

Kamyr Inc. has developed a screw feeder for feeding wood chips into a pressurized digester. The chips form a tight plug against the digester pressure. The feed is controlled by regulating the speed of the screw (Figure 16).

C. Bauer has manufactured double screw feeders (Helipress) with counter-rotating intermeshing screws (Figure 17). The twin screw operates a wedge wire-bar draining screen. It is also possible to feed very difficult-to-handle, for example, fibrous materials. The feeder is used for medium-pressure dewatering (thickening of pulp, fruit, grain, and oil seed industries). It has also been used as a pre-feeder for the high-pressure Pressafiner feeder (C. E. Bauer Process Engineering Group), which is a conical feeder with a dewatering cage. Each series of screw flights is spaced on the shaft to provide compression zones to maintain uniform discharge pressure as well as keep the plug intact. This commercial feeder was primarily designed for dewatering, but it is also possible to feed wood chips and wood residue into very high counter pressure vessels /2/. One drawback of the feeder is the need of a pressure pre-feeder.

Operating ranges of screw feeders and some screw and piston feeder combinations are shown in Figure 18. The large feeders used at large wood-processing plants are not included in the figure.

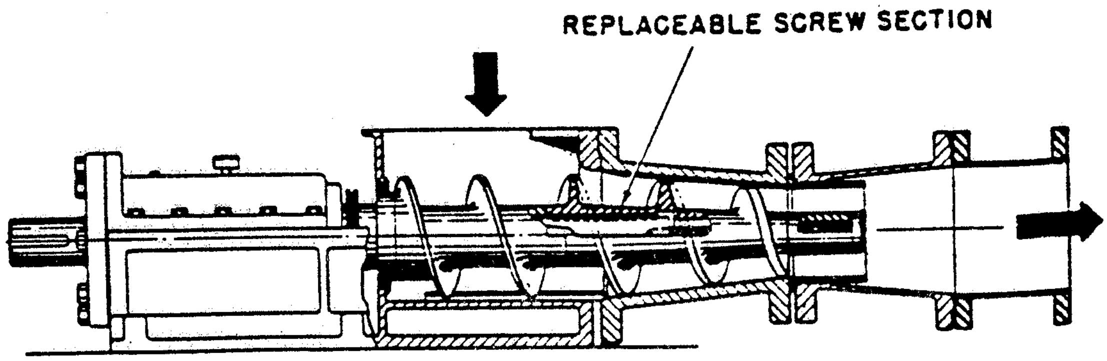


Figure 16. Kamyr Inc. screw feeder for wood chips /13/.

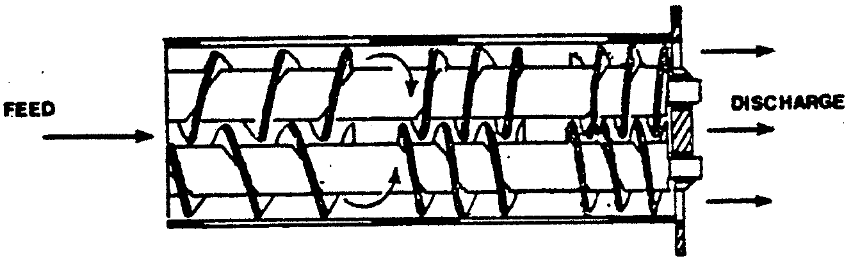


Figure 17. Helipress double screw feeder.

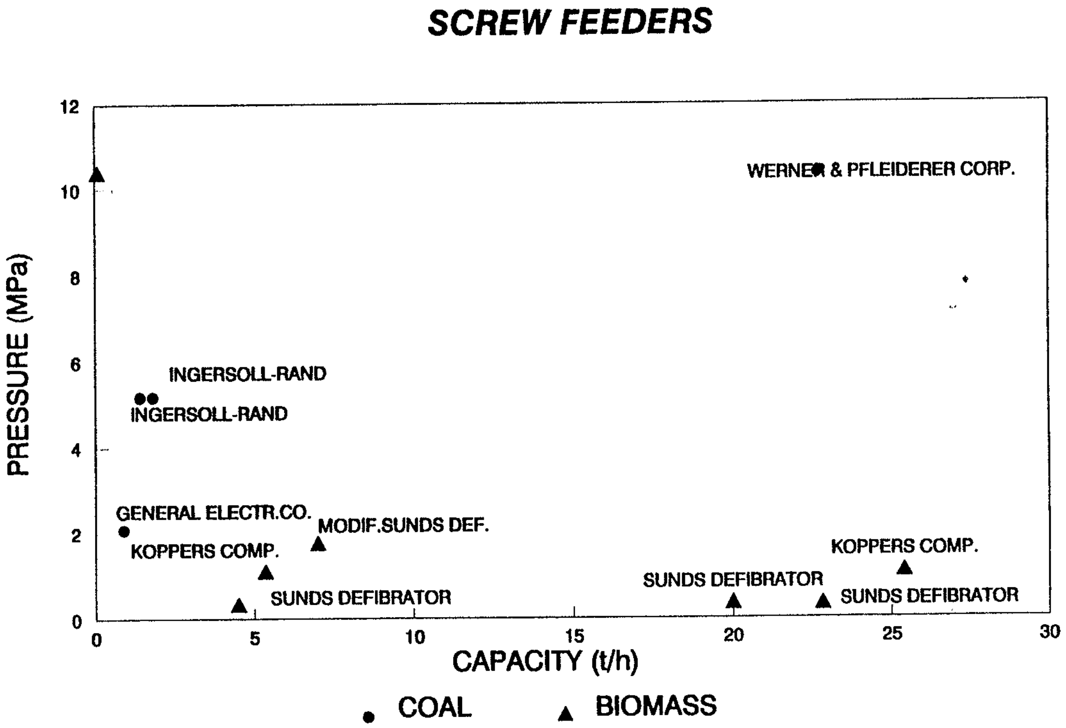


Figure 18. Operating ranges of screw feeders for different fuels.

3.2.5 Pneumatic feed systems

In a pneumatic system, the solid material can be conveyed and pressurized in a dilute-phase or a dense-phase system. Improvements are required for both systems, especially for pressurized applications. The dense-phase system has several shortcomings. Certain requirements have to be placed for pneumatic conveying of solids into a pressurized reactor, both for the fuel to be conveyed and for the carrier gas. The particle size distribution should be suitable and the range of variation should be small. The moisture content of the fuel should be relatively even and fairly low; hence, extensive feed preparation (crushing, sieving, drying) is required, before the fuel can be fed or conveyed pneumatically (Figure 19). The carrier gas should also be compatible with the process.

In the present systems, the pneumatic feed is carried out via lock hoppers, and it is therefore not necessary to feed the carrier gas into the process, but it can be recycled or discharged, if necessary. Problems will often arise, especially if the fuel flow must be divided into several streams. In the few processes currently in operation, it has been found that it is very difficult to divide the fuel flow evenly.

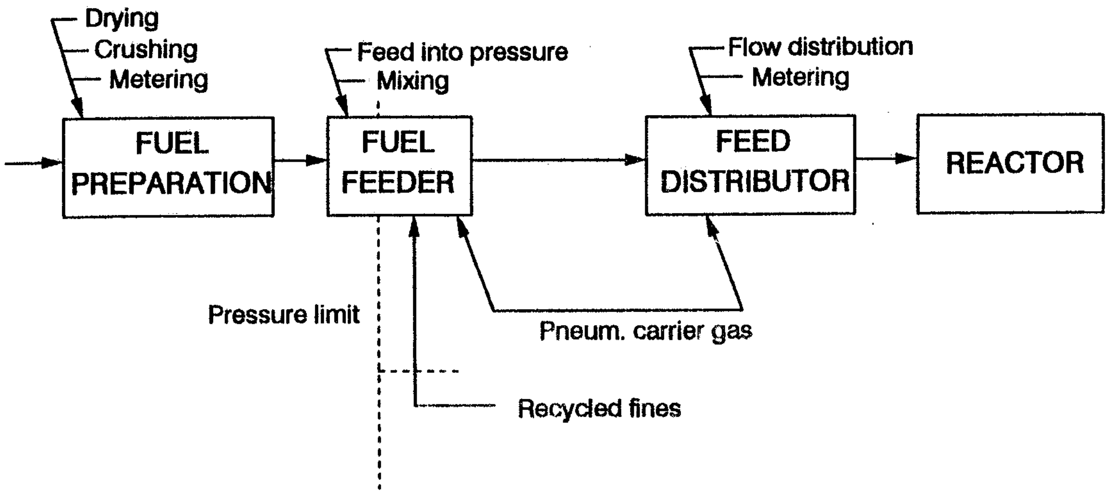


Figure 19. Principle of pneumatic feed systems.

3.2.6 Operating ranges for pressurized feeding systems

Pressurized feeding systems have been developed by a number of manufacturers, mostly for coal; however, some systems have been tested with biomass, primarily wood-derived fuels like wood residue, sawdust, and chips. Application of high pressure feeders in different ranges of operating pressure along with some observations from their operation are presented in Table 1.

Table 1. Summary of operational information for pressurized feeders.

Feeder type	Status	Feedstock	Suitability for wood cm	Pressure difference kPa	Remarks
Lock hopper	C	All types < 5 cm	< 15	3 200 (max. 8 500)	Discharge, e.g. gravity, pneumatic, screw. Problems: sticking valves, bridging, loss of compression gases
Pneumatic feeder	C	All types < 5 cm	< 5	70	Air lock required. Poor with abrasive and fibrous materials. Good for long distance conveying. Noisy operation.
Rotary feeder for low/medium pressures	C	< 5 cm wood chips, sawdust	< 5	1 030	Compact equipment. Leakages by wear. Problems due to sticking.
Rotary feeder for high pressures	C	<2.5 -5 cm coal, wood chips	< 5	2 400	Developed mainly for use of <2.5 mm coal. Part of the wet feed of Kamyr system.
Screw feeder for low/medium pressures	C	< 5 cm wood chips	< 5	1 030	Used for metering/dewatering wood chips. Problems with fibrous materials. Different models.
Screw feeder for high pressures	C/D/K	< 0.6 - 5 cm wood chips	< 5	2 400 - 20 000	Expensive. Problems with fibrous materials. Tendency to clog.

C = Commercial D = Demonstration stage K = Testing stage

A summary of the types of feeders for feeding moist and poorly flowing fuels either directly or with appropriate changes into a pressure vessel are presented in Table 2. Their operating characteristics and experiences are also presented.

The energy consumption of the feeders ranges over wide limits. The energy consumption is much more dependent on the method of feeding in pressurized applications than for normal operations. Typical energy consumption values for solid biomass fuel feed systems are presented in Table 3.

Cost estimate for feeders

On the basis of the present prices and operating cost estimates of some commercial feeders, the estimated costs are presented in Table 4 (presented by Mr. J. Isakson of Ahlstrom Corporation at the Jalo Seminar on May 21, 1991, Espoo, Finland).

Table 2. Characteristics of different types of feeders.

Type of feeder	Operating principle	Self metering	Self feeding	Self distributing	General material characteristics
Lock hopper	Feed bin with inlet and outlet feed valves	+	+	+	All materials. Used for wood residues < 15 cm.
Pneumatic feeder	Pneumatic conveyor	-	+	+	Sander dust, wood residue < 8 cm. Good for chips, not for hogged fuel. Good for non-abrasive materials and fines
Screw feeder	Closed rotary screw	+	+	-	< 8 cm wood residues and granular materials. Not suited for fibrous, sticky materials

Table 3. Nominal energy consumption of different feeders /2, 4, 6, 10/.

Feeder	Back-pressure bar	Energy consumption kJ/kg	Reference and remarks
Kamyr feeder	10	18	/10/ moist fuel
Stake feeder	20 - 23	72	Birch chips, Cultor Oy, Finland
Miles biomass lock hopper feeder	25	7	/4/ wholetree chips, only screw energy
Sunds defibrator	2.75	24*	/2/ wood chips

This value appears low. For the latest information, contact the manufacturer, Sunds Defibrator LTEE/Ltd., 4900 Blvd. Thimens, Ville Saint-Laurent, Quebec, Canada H4R 2B2.

Table 4. Comparative prices for some feeders.

Feeder	Capacity m^3/h	Specific price FIM* 1 000/m^3/h	Manufacturer
Lock hopper	40	88	Ahlstrom
Rotary valve	200	9	Ahlstrom
Plug screw feeder	45	38	Modo Chemetics
Single acting piston feeder	125	13	Estimated (non commercial)
Piston pump	80	12	Putzmeister KOS 2180
Stake feeder	50	85	Stake Co.

**FIM = Finn marks, approximately 4.00 FIM/USD*

3.3 WET FEED SYSTEMS

3.3.1 Slurry feed

Systems for feeding solids as a slurry were developed earlier primarily for high-pressure coal conversion processes, but they may not be applicable to biomass gasification processes from heat balance considerations. Compared with pneumatic feed, the slurry feed system has certain advantages:

- Equipment and technology are commercially available.
- Feed distribution to several streams is considerably easier.
- Feed stability and control are easier to maintain.
- Instrumentation is simple.
- Pressures of about 6 bar can be reached by centrifugal pumps.

The disadvantages are:

- Erosion and corrosion may occur in pumps and other moving parts.
- Nominal energy consumption of feeding increases sharply with increasing back-pressure.
- For higher pressures, booster pumps are required in addition to the centrifugal pumps.

In feeding a fuel slurry the conversion process must, of course, accept such a moist material, or else intermediate drying would be required. For example, moist slurry fuels may be fed without intermediate drying to liquefaction processes. Flash drying could be applied before feeding the fuel into the reactor. This should be considered in choosing the feed techniques. The principle of slurry feeding is shown in Figure 20.

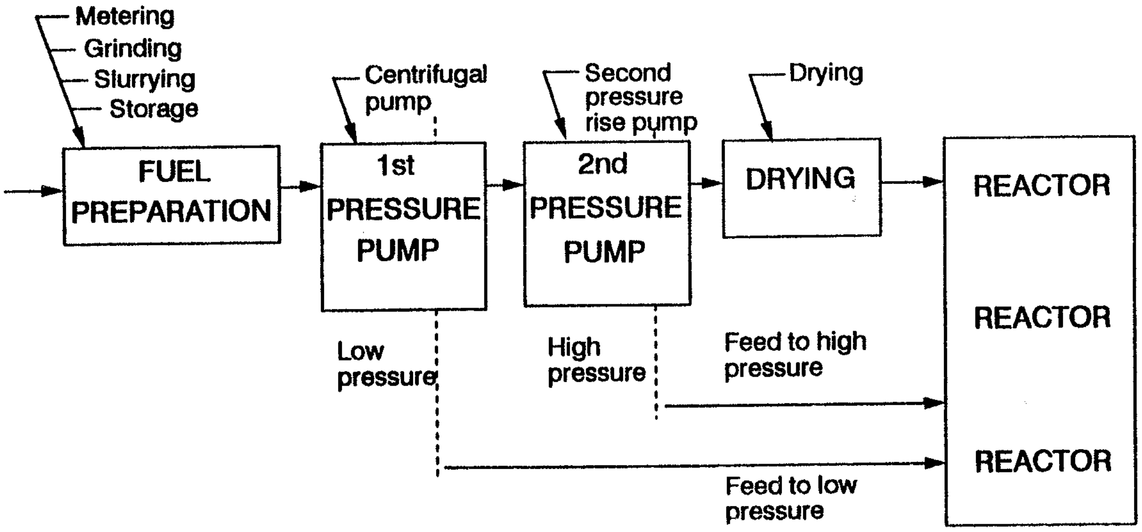


Figure 20. Principle of a slurry feed system.

3.3.2 Kamyr feeder

An ideal slurry feed system is based on the use of a lock feeder with recycling and quick-filling capability. The principle of a system of this kind is shown in Figure 21. The pipe shown in the figure is a pressurized system with an imaginary lock chamber. When the chamber is open for low pressure, the chamber is quickly filled by the mixture. Then, the feeder rotates quickly and opens the chamber for high-pressure liquid (water) flow, which pushes the slurry into the reactor. After this stage, the feeder rotates forward quickly, preventing the high-pressure liquid from entering the reactor. In the next stage the high-pressure liquid is drained before repeating the cycle.

A totally continuous operating system is difficult to construct, as this would require a perfect pressure seal and an accurate instantaneous

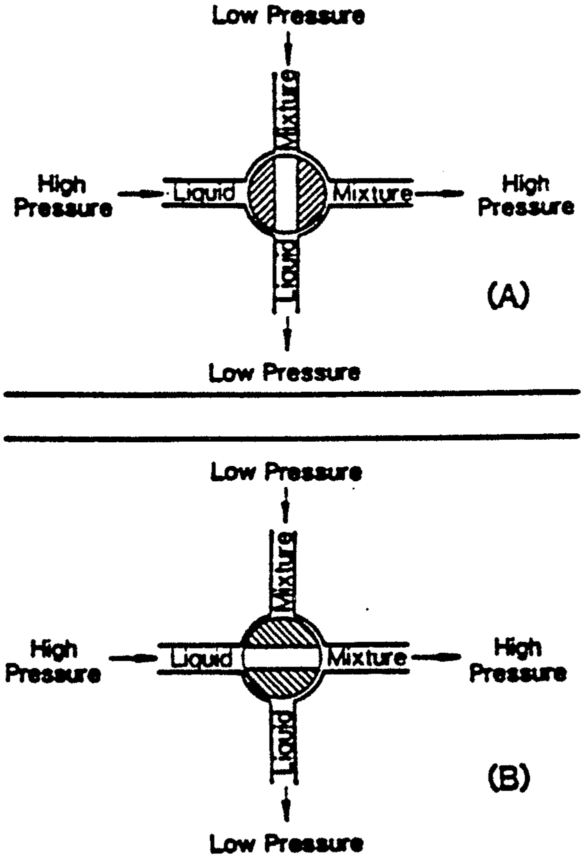


Figure 21. An ideal lock feeder system (Kamyr) /11/.

change of filling between the different stages. This is not achievable with the present mechanical equipment; however, a solution based on the principle of continuous operation (Kamyr, Inc.) has been developed wherein the lock feeder consists of several chambers with connecting channels. This system was developed by Mr. Johan Richter of Norway for feeding wood chips in a pulp process. The operating principle of the Kamyr lock feeder is shown in Figure 22.

The Kamyr high-pressure lock feeder is generally used for feeding chips into a pulp digester. A scheme of feeding chips and the cooking liquor into the Kamyr digester is shown in Figure 23. The chips are conveyed from the bin via a metering unit and a low-pressure feeder into a steaming vessel, and further via a screw and a tramp material separator into the inlet port of the Kamyr high-pressure feeder regulated by rotation speed. The feeder has four chambers at an angle of 90 degrees toward each other. There are four openings in the rotor housing, the lowest being equipped with a screen. The chips are flushed into the feeder by means of the chip chute circulation pump. As the rotor turns, chips and liquor are combined, and high-pressure impregnation begins. Within 1 minute, the chips and liquor are conveyed to the top of the digester by means of the top circulation system /11/.

Continuous four-lock rotary chamber.

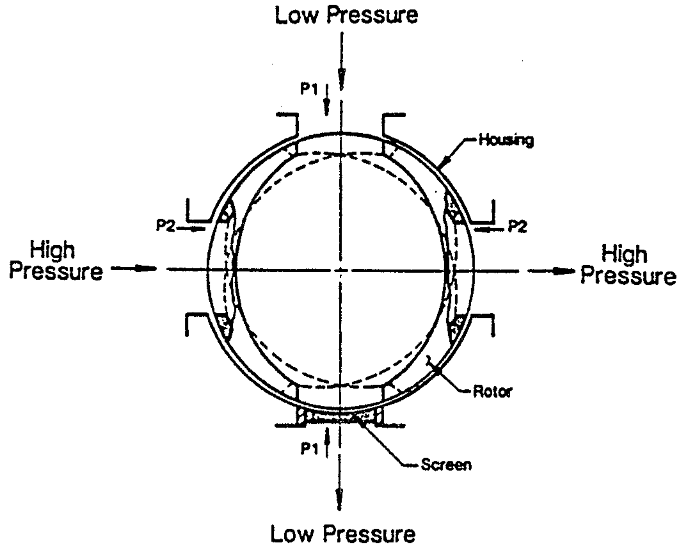


Figure 22. Principle of the Kamyr feeder /11/.

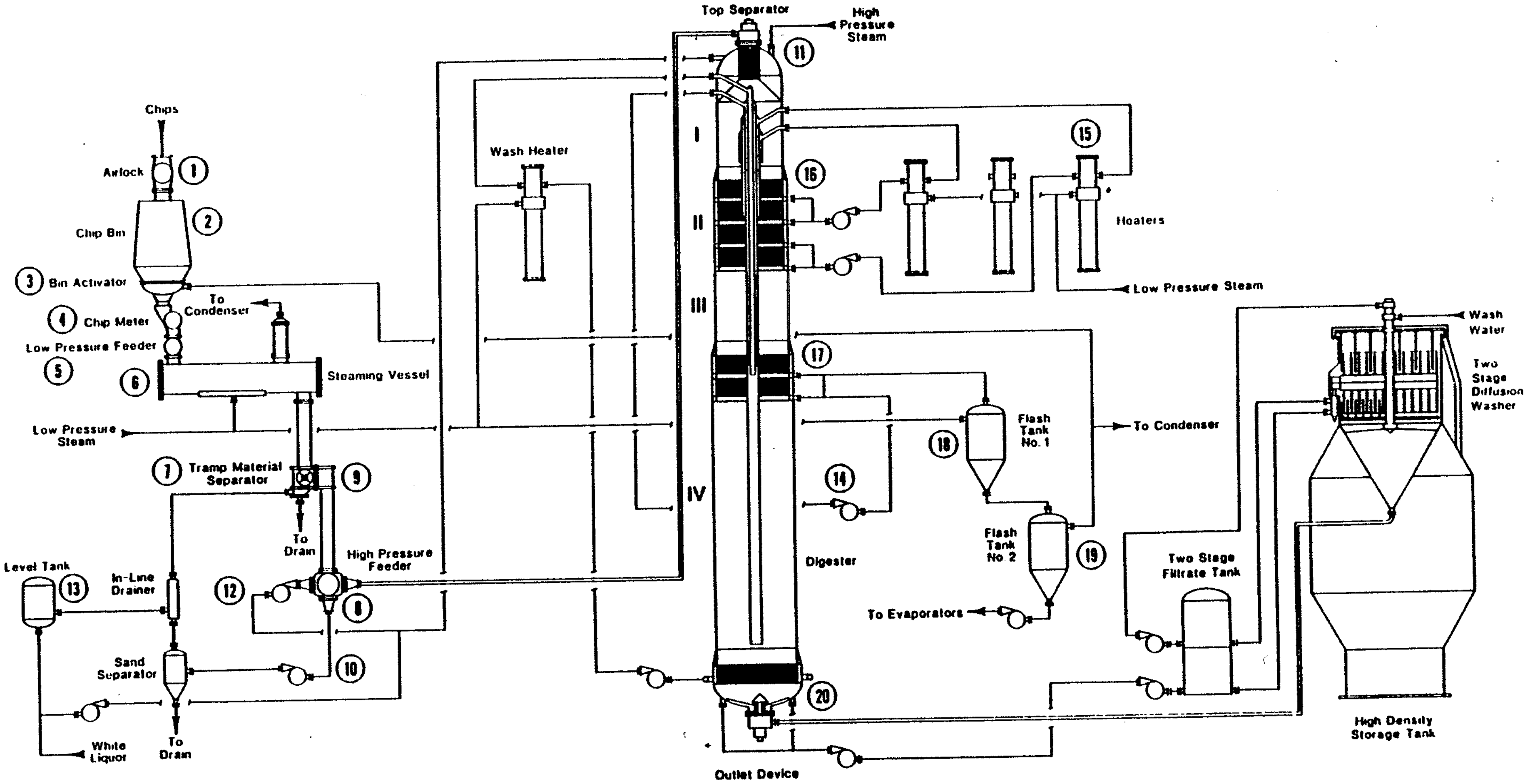


Figure 23. Feed of chips and cooking liquor into a Kamyr digester /11/.

3.3.3 Feeding of peat slurry

The Institute of Gas Technology in Chicago (USA), has constructed and operated a pilot plant for carrying out gasification tests with peat. In conjunction with pressurized gasification of peat, experience has also been gained on slurry feeding peat into a pressurized gasifier /12/. The aim of the project was to study the suitability of peat for producing fuel gas by pressurized gasification (pressure 3.5 kPa).

The system includes receiving, drying, grinding, sieving, and feeding (lock hopper) of peat. The first experiments were carried out by using an existing coal slurry feed system. The solids content of slurry feed (peat) was as high as about 30%. The principle of peat slurrying is shown in Figure 24. Dry sieved peat was slurried with light oil (byproduct of gasification, mainly a mixture of benzene, toluene and xylene).

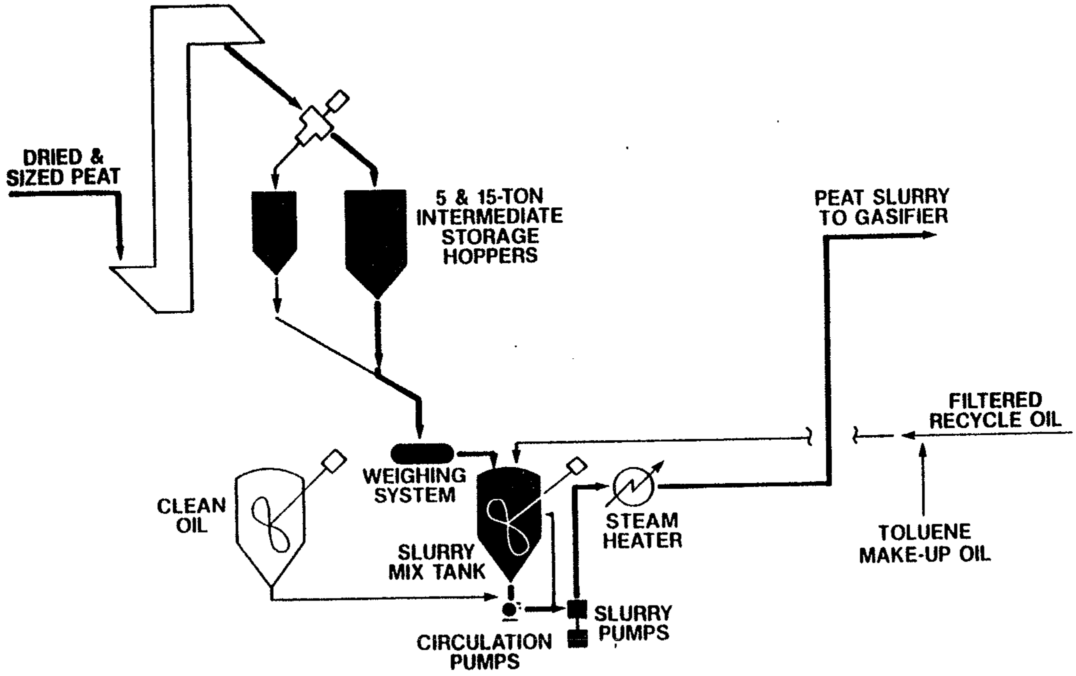


Figure 24. Principle of peat slurry preparation /12/.

4 SAFETY ENGINEERING

4.1 FLOW CHARACTERISTICS OF FUELS

4.1.1 General

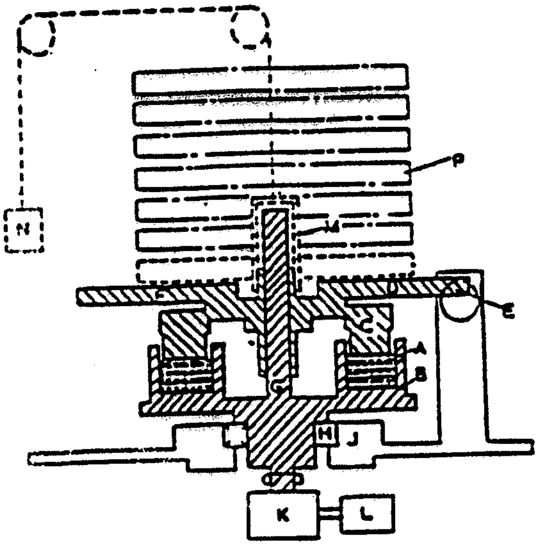
A prerequisite for feeding biomass into a pressurized vessel is a clear definition of the specifications for feed preparation and its flow characteristics. In pressurized feeding, the fuel is subject to higher compression and shearing stresses than in ambient pressure systems. These cause divergent stresses in the fuel, and these internal stresses contribute to arching and clogging, both in bins and handling equipment of the pressurized systems.

The gravity-operated bins and lock hoppers should be designed as mass flow bins with regard to their dimensions and operation. Another kind of flow, for example, funnel flow, would result in clogging which could lead to safety hazards as a source of spontaneous ignition and dust explosion. This dimensioning principle is of particular significance when handling solid fuels that are highly sensitive to flow and spontaneous ignition, such as biomass, peat, and lignite.

4.1.2 Determination and typical values of flow characteristics

Different kinds of shear equipment are used for determining flow characteristics of dry and granular bulk materials. The Jenike Shear Cell /7/, based on linear movement, and the Walker Annular Shear Cell (Figure 25), are generally used for shear testing; however, due to a short shear distance, the Jenike Shear Cell is less suited for flow determinations of moist and fibrous bulk material, as these require a rather long shear distance. Consequently, the Walker Annular Shear Cell has been chosen by the Laboratory of Fuel and Process Technology of VTT for testing moist milled peat /1/.

In practice, the sample is laid on the lower ring, and the desired consolidation is developed by changing the normal load applied to the upper ring. The lower ring is rotated until the sample is sheared. The power



A	**coal sample**
B	**annular cell**
C	**annular shoe**
D	**shear torque arm**
E	**strain gauges**
F	**calibration torque arm**
G	**central spindle**
H	**bearing**
J	**fixed frame**
K	**reduction gear**
L	**drive motor**
H	**counterweight attachment collar**
N	**counterweights**
P	**additional weights**

Figure 25. Walker Annular Shear Cell /32/.

required for shearing (and possible movement upward) is measured. By shearing the sample at several different normal loads the equivalent shear strengths are obtained. By carrying out the shear test series at several different consolidations, the flow limits of the fuel can be determined. The maximum stress (σ 1) due to divergent major stresses (shearing and compression stresses) in the material can be determined with the aid of so-called Mohr's circles. Unconfined yield strength, F_c, describing the tendency of the fuel to consolidation (to form a steady cake) when loaded, is also obtained. By carrying out these measurements at several different consolidations, the flow function, ff, can be determined on the basis of F_c and σ 1. In addition, the cohesion C, internal friction Φ, and effective internal friction δ, can be determined at each different consolidation. The subject is discussed in more detail in /7/ and /31/.

The derivative N_{ff} of the inverse value of the linearized flow function has generally been used for describing the flow of the material. The N_{ff} value indicates primarily the tendency of the fuel to consolidate while the load increases and the resistance of the fuel to consolidating pressure without disturbances in the flow; hence, the N_{ff} value is a good indicator of flow characteristics if the bins are otherwise designed correctly with respect to flow (Table 5).

Table 5. Classification of flow on the basis of N_{ff} *values /10/.*

N_{ff} value	Flow of fuel
$N_{ff} < 2$	Very cohesive, non-flowing
$2 > N_{ff} < 4$	Cohesive
$4 > N_{ff} < 10$	Easy-flowing
$N_{ff} > 10$	Free-flowing

In addition to shear testing, it is also possible to measure, with the same cell, dynamic friction characteristics of the bin wall or the handling equipment with the fuel concerned, and hence, to determine the critical dimensions of a bin or a lock hopper to guarantee a free mass flow. The bins can be designed for operation in mass flow principle with the assistance of the flow function determined for the fuels, the friction coefficient between the fuel and the handling equipment, and the flow-related specific curves for the bin. The shear and friction determinations should be carried out under conditions comparable to those currently in use, such as temperature and storing time. Possible changes in the fuel during the following handling effects should also be considered:

- changes in particle size due to grinding,
- changes in temperature due to drying
- moistening, drying
- condensation of moisture on bin walls.

N_{ff} values for a number of fuels are shown in Figure 26. It can be seen from this figure that the flow properties of the fuels clearly worsen when the moisture content increases. The flow properties are typically most dependent on the moisture content, particle size distribution, and quality of the fuel.

According to Jenike, gas pressure had no great effect on (coal) flow characteristics in pressurized conditions, as coal is hardly compressed by

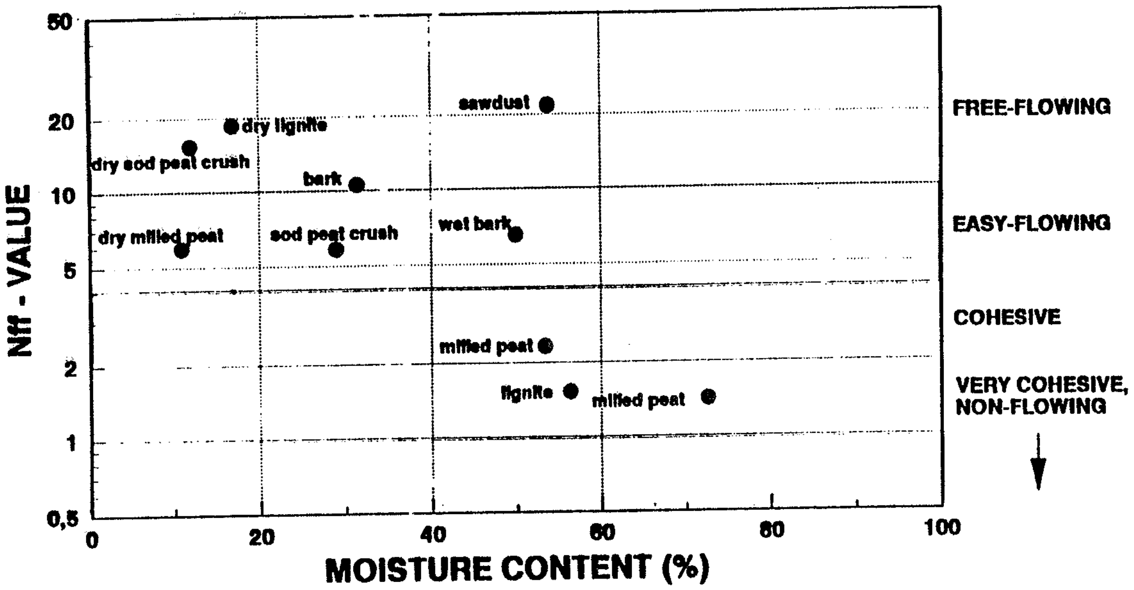


Figure 26. Dependence of the nff value on the moisture content of the fuel.

gas pressure /33/. The compression of biomass fuels may be considerable, however, and may cause significant impairment in flow properties.

4.2 SPONTANEOUS IGNITION OF FUELS AT PRESSURE

4.2.1 General

When storing and handling biomass fuel, its tendency to spontaneous ignition and the temperature required for ignition should be known. Primarily four factors contribute to spontaneous ignition:

1. oxidation tendency
2. ambient temperature
3. amount and characteristics of the material
4. shape of the material storage vessel.

Changes in the oxidation tendency of the material also affect its tendency to spontaneous ignition. The ambient temperature and the amount and form of the stored material are of significance, as heat generation typically occurs in proportion to volume and heat losses occur through the surface. As the volume increases according to the third power and the surface area according to the second one, there is a critical amount of material in which the generated heat is able to escape through the surface relatively quickly to prevent the temperature within the material from reaching the ignition point. The prevailing pressure also affects the tendency to spontaneous ignition via oxidation and heat transfer.

4.2.2 Determination of spontaneous ignition

Spontaneous ignition is usually studied on at least three samples of different volumes to be able to extrapolate the results for larger amounts. The samples are usually small, or else the time required by the tests would be too long. In small samples, the temperature changes quickly and hence the determinations can be carried out rapidly, although the accuracy is poor. The metal mesh sample vessel can be of any shape; however, cylindrical ones (according to bin shape) are most often used.

The following method is used at the Laboratory of Fuel and Process Technology of VTT for determining spontaneous ignition at an elevated pressure. The principle of the equipment is shown in Figure 27.

A cylindrical fuel sample is placed in a metal mesh vessel and then into an autoclave, which is pressurized (maximum 10 MPa), and the desired gas composition is fed in. Prior to feed, the temperature of the gas is raised to that of the autoclave to secure a steady temperature around the sample. The gaseous atmosphere is dynamic, as the gas flows slowly through the autoclave and the composition of the gaseous atmosphere is nearly constant. The temperature of the sample is raised stepwise. The sample is kept at each temperature stage a sufficiently long time (usually from one to several hours) to monitor whether the ambient temperature is sufficiently high for spontaneous ignition. The temperatures of the midpoint, and of one end of the sample as well as the tem-

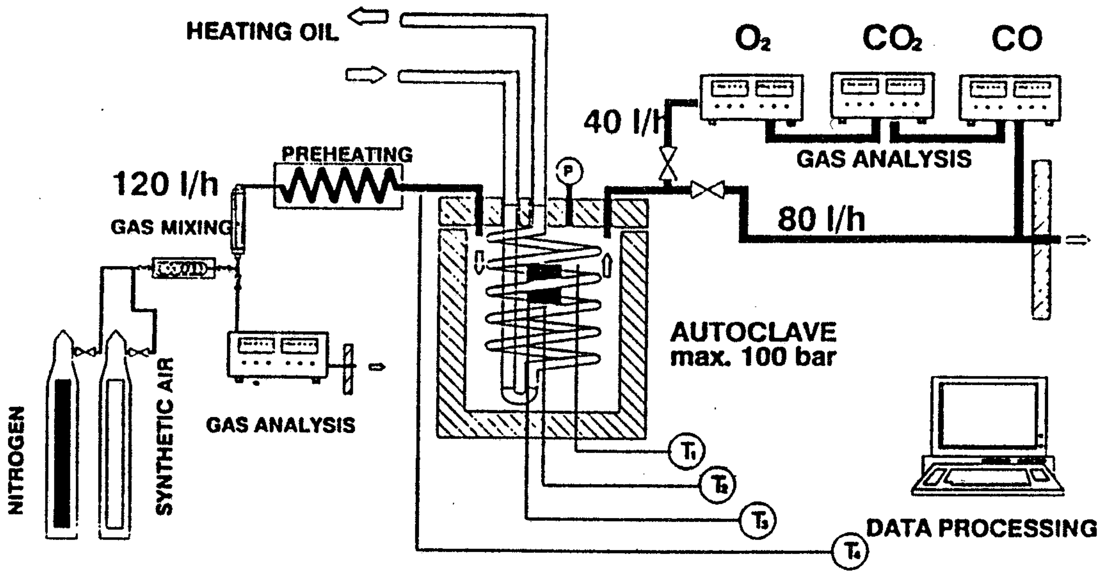


Figure 27. Schematic of test equipment for spontaneous ignition.

perature of the gas, are recorded. The temperature of the gas at the moment of spontaneous ignition is given as the result of the determination.

The composition of the inlet and outlet gas is measured with continously operating gas analyzers to control the stability of the gaseous atmosphere and also to record the moment of spontaneous ignition on the basis of change in the composition of the outlet gas. Nitrogen is used as an inert gas to dilute the oxygen concentration below ignition limits. The temperatures and gas analyses are recorded automatically by a data logger. The sample is changed rather often, depending on the temperature level, irrespective of whether it is ignited or not. The ignition characteristics can change, if the same sample is kept at the elevated temperature too long.

The ignition temperatures can be determined both at a normal oxygen content of air and at a very low oxygen content when determining the limit of inert gas content on ignition. VTT has used Finnish peat (crushed, sieved to < 6 mm) and bark, and German lignite as gasification fuels. Values of spontaneous ignition have been determined at

10 bar and 20 bar. Typical ignition values for samples of different size are presented in Table 6. The accuracy of the measured self-ignition temperature was about ±5 °C in these experiments.

Table 6. Ignition temperatures at pressure for different fuels.

Fuel	Ignition temperature °C		
	Peat	Bark	Lignite
10 bar/21 % O_2			
50 cm^3	151	159	146
100 cm^3	145	154	131
400 cm^3	139	146	116
20bar/21 % O_2			
50 cm^3	145	146	128
100 cm^3	136	142	123
400 cm^3	132	135	112

Figure 28 shows an output of a test carried out with Finnish sod peat at 10 bar to determine the effect of inert gas on preventing spontaneous ignition. At the ambient gas temperature, the peat did not ignite due to the low oxygen content (O_2 = 2.5 %), although the temperature of the sample was significantly high (about 270 °C).

4.2.3 Conclusions from spontaneous ignition at pressure

Small samples ignite quickly at elevated pressure (10 and 20 bar), and also at low oxygen contents (usually within 2 - 4 hours), while spontaneous ignition of larger samples may take several days. The reduction of the oxygen content can result in an increase in the ignition temperature. This effect seems to occur at low oxygen levels. German lignite ignited at clearly lower temperatures than bark and peat, both at 10 bar and 20 bar. The increase of pressure from 10 bar to 20 bar resulted in lower spontaneous ignition temperatures. In practice, with large amounts of material, spontaneous ignition temperatures are lower than these test values, and differences between materials are quite significant.

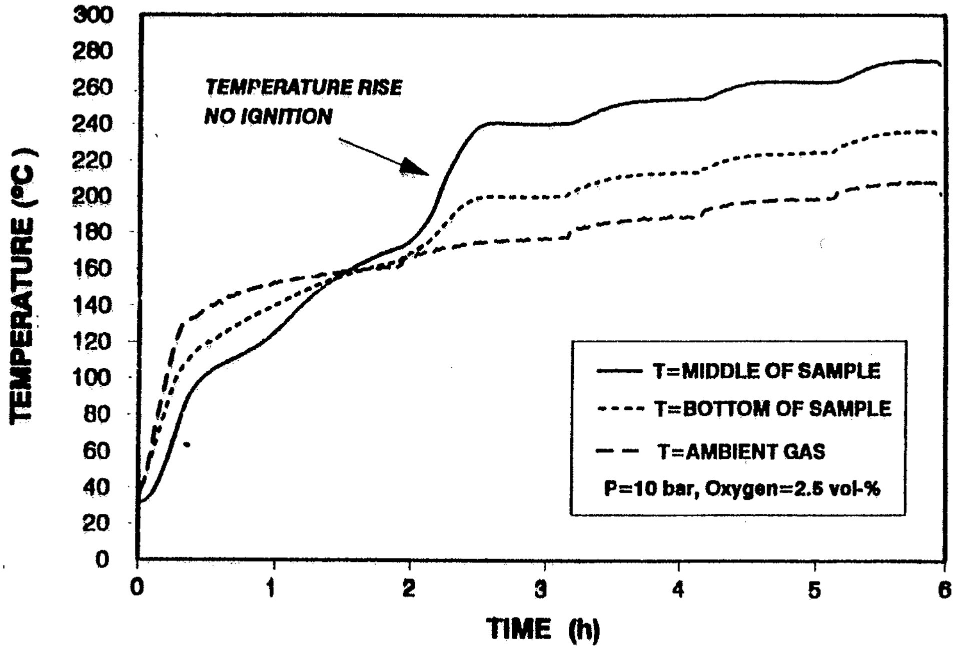


Figure 28. Development of temperatures in a self-ignition test with peat - the sample did not ignite.

If the determinations are carried out with several samples (at least three) of different size, the impact of factors involved in activation energy and standard limit value (Frank-Kamenitski parameter for spontaneous ignition) can be determined on the basis of the results. On the basis of this data, the results can also be extrapolated to full-size systems /24, 25, 26/. The temperature of spontaneous ignition can then be calculated on the basis of the volume and shape of the fuel vessel and of the ambient temperature. Results and calculations from recent ignition tests at VTT are presented in /34/.

4.3 DUST EXPLOSIONS AT NORMAL AND ELEVATED PRESSURES

4.3.1 General

The force of dust explosions in pressurized vessels increases sharply if the initial pressure is high. The solid fuels always contain powder material, which, mixed with air, presents a serious risk of dust explosion. If simultaneously flammable pyrolysis gas is also present, developed as a consequence of spontaneous ignition, the risk of explosion increases even more /20/. Consequently, a smaller dust concentration in the air is sufficient for ignition and a smaller ignition source can initiate the explosion.

The maximum pressure and the maximum rate of pressure rise caused by dust explosions are considerably higher in pressurized fuel handling. Therefore, more detailed data on the characteristics of dust explosions at high initial pressure and a tighter control of process conditions are required to avoid conditions favorable to dust explosions.

It is generally impossible to design large fuel handling equipment so as to withstand explosion pressures, but the equipment must be fitted either with a reliable explosion suppression system (for example, using an inert atmosphere) and/or with a pressure relief system that prevents the pressure from exceeding the tensile strength of the equipment. In the design of the explosion pressure relief system, the maximum rate of pressure rise (dp/dt_{max}) should be known in order to design proper relief vents. Relief of explosion pressure requires that the maximum pressure be lower than the pressure limitation of the handling equipment.

The rate of pressure rise is usually depicted by the K_{St} value, determined by laboratory test equipment of $\geq 20\ dm^3 < 1\ m^3$ in volume and then scaled for industrial vessels by the "cubic law" /27/. The K_{St} value is calculated as follows:

$$K_{St} \quad = (dp/dt)_{max} \times V^{1/3}\ [bar \times m/s] \qquad (1)$$

where

$(dp/dt)_{max}$ the maximum rate of pressure rise (bar/s)
V the volume of the explosion test equipment (m^3).

The K_{St} value has been found to be valid for the rate of pressure rise within a wide range of volume (20 dm^3 - 1 000 m^3, initial pressure ≤ 2 bar) in equipment and bins when calculating the size of pressure relief vents. The relief vents can be designed (subject to certain limitations) according to German VDI 3673 instruction /28/, if the following values are known:

- initial pressure
- reduced pressure
- volume and shape of handling equipment
- K_{St} value.

4.3.2 Factors affecting the hazard of dust explosion at normal pressure

The following technical characteristics of dust explosion should be known in the use of fuel handling equipment and bins:

- maximum pressure
- maximum rate of pressure rise as K_{St} value
- minimum oxygen content in inert gas rich atmosphere.

At VTT, the safety of peat-fired plants has been studied and factors contributing to peat dust explosions have been determined. These factors are in general also valid for other biofuels. The determinations of characteristics for peat dust explosions at plants with a normal pressure have indicated that the occurrence and severity of dust explosions are related to the following fuel characteristics:

- average particle size
- moisture content
- dust concentration in ambient air
- energy of ignition source.

Figure 29 shows the range susceptible to explosion for peat dust as a function of particle size and corresponding moisture content. In Table 7, The characteristics obtained from explosion tests with peat and lignite dusts at normal pressure according to ISO 6184/1 1985 /29/ in a test device of 20 liters in volume are presented. The results of maximum rates of pressure rise and the corresponding fuel characteristics are also given as K_{St} values.

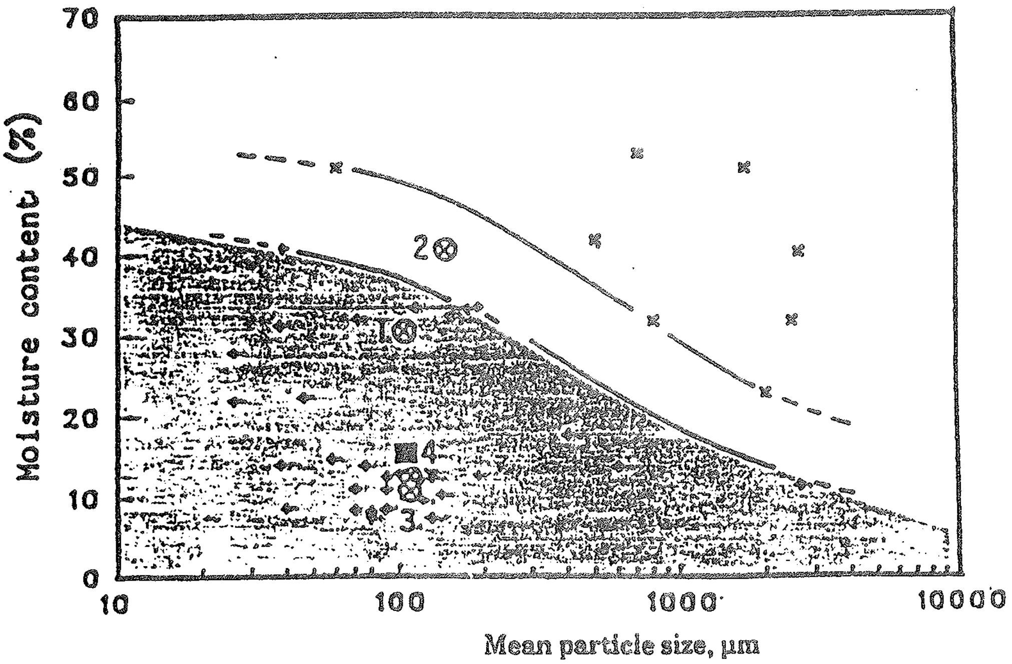


Figure 29. Effect of the particle size and moisture content of peat on the probability of dust explosion. + normal milled peat (explosion), x normal milled peat (no explosion), ▨ lignite dust, ⊗ 1. Kivineva, moist peat, ⊗ 2. Savaloneva, moist peat, ⊗ 3. Kivineva, dry peat, ⊗ 4. Savaloneva, dry peat /9, 30/.

Table 7. Characteristics of lignite and peat dusts.

Dust sample	Moisture content wt%	Average particle size µm	Max. explos. pressure bar	Max. rate of pressure rise bar/s	K_{St} value bar x m/s
Lignite	16.6	105	8	410	111
Peat 1, moist	30.1	115	7.1	186	50
Peat 2, moist	40.3	140	5.9	110	29
Peat 1, dry	11.1	110	7.9	320	86
Peat 2, dry	12.6	110	8	433	117

4.3.3 Effect of initial pressure on explosion characteristics

The rise of initial pressure also affects the following explosion-related characteristics:

- maximum pressure (P_{max})
- maximum rate of pressure rise (dp/dt_{max}).

The final pressure in pressurized equipment increases directly in the ratio of initial pressure and normal pressure. An example of the effect of initial pressure on the development of the maximum pressure of the peat dust explosion is shown in Figure 30 /17/. The average particle size of the peat used in the test, D_{50}, was 149 µm and the moisture content 15 %.

The rate of pressure rise does not increase in direct proportion to the rise of initial pressure, but the growth of the maximum rate of pressure rise begins to slow down at higher initial pressures /17/, and reaches an asymptotic value despite the increase in initial pressure. A comparison of maximum rates of pressure rise at normal pressure with those obtained at elevated initial pressures is shown in Figure 31.

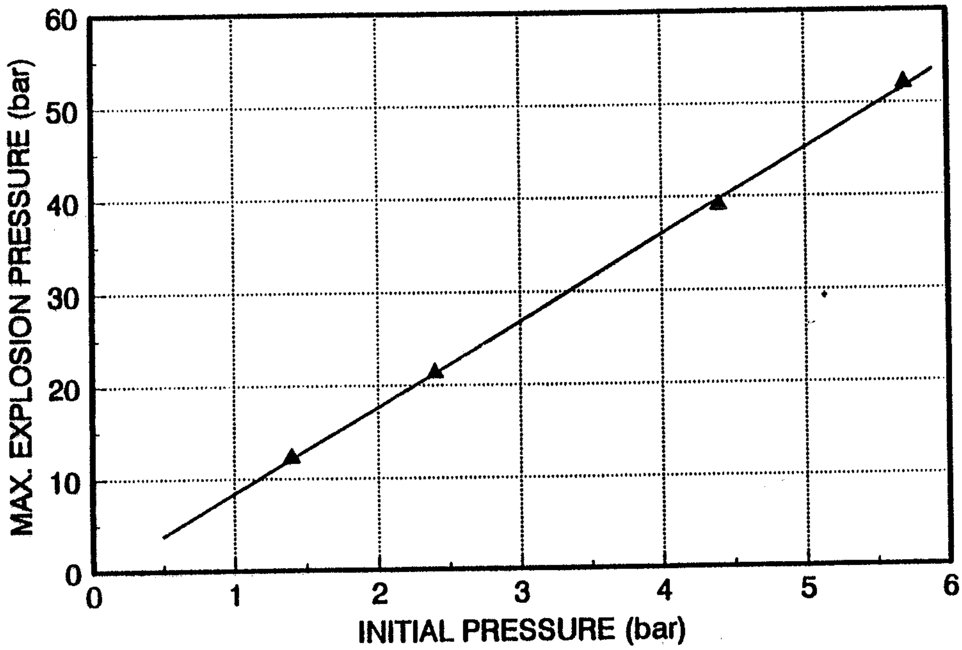


Figure 30. Maximum pressure of peat dust explosion as a function of initial pressure /17/.

4.3.4 Effect of oxygen content on explosion characteristics at elevated initial pressure

The initial pressure also affects the minimum oxygen content, below which an explosion is no longer possible. This minimum oxygen level is known as the inertization limit. For example, in peat dust experiments the inertization limit was found to decrease when the initial pressure

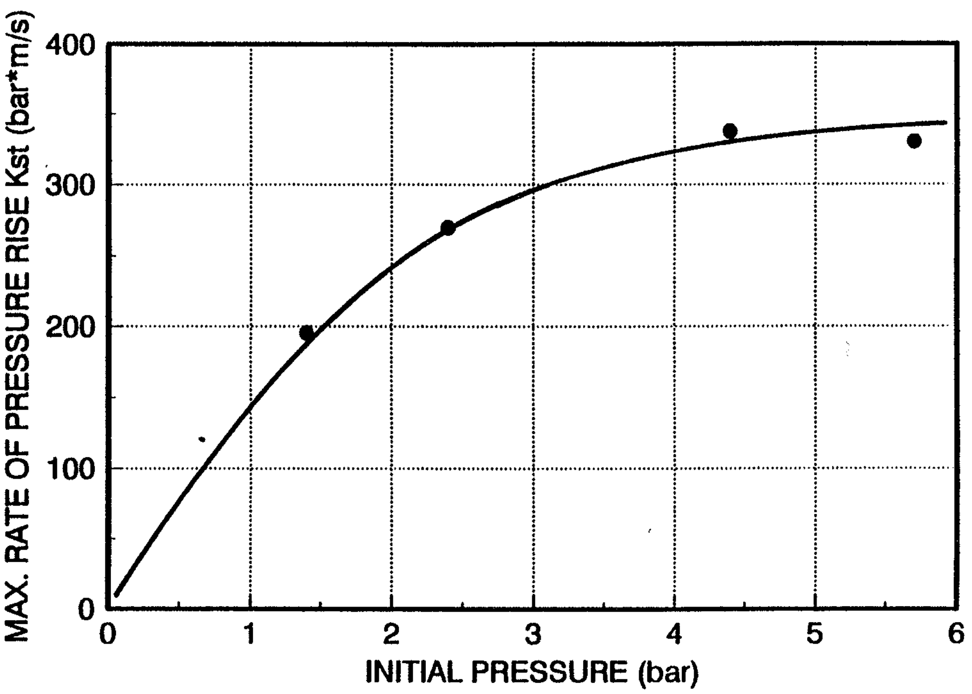


Figure 31. Effect of absolute initial pressure on explosion index /17/.

rose, but not as sharply as was expected /18/. However, this decrease should be considered in the determination of the inertization limit for eliminating the explosion hazard. Changes in the limit of minimum oxygen content and in the explosion severity at different initial pressures are shown in Figure 32. The average particle size of peat dust used in the experiments, D_{50}, was 130 µm and its moisture content was 16.2 %.

4.3.5 Effect of temperature and initial pressure on inertization limit

The rise of temperature has a significantly greater effect on the limit of minimum oxygen content than the rise of initial pressure. The rise of initial pressure combined with the simultaneous rise of temperature affects rather significantly the required inertization /19/. The effect of temperature on the inertization requirement of the peat dust air mixture at 150 °C at normal pressure, and the combined effect of slightly elevated initial pressure and temperature are shown in Figure 33 /19/.

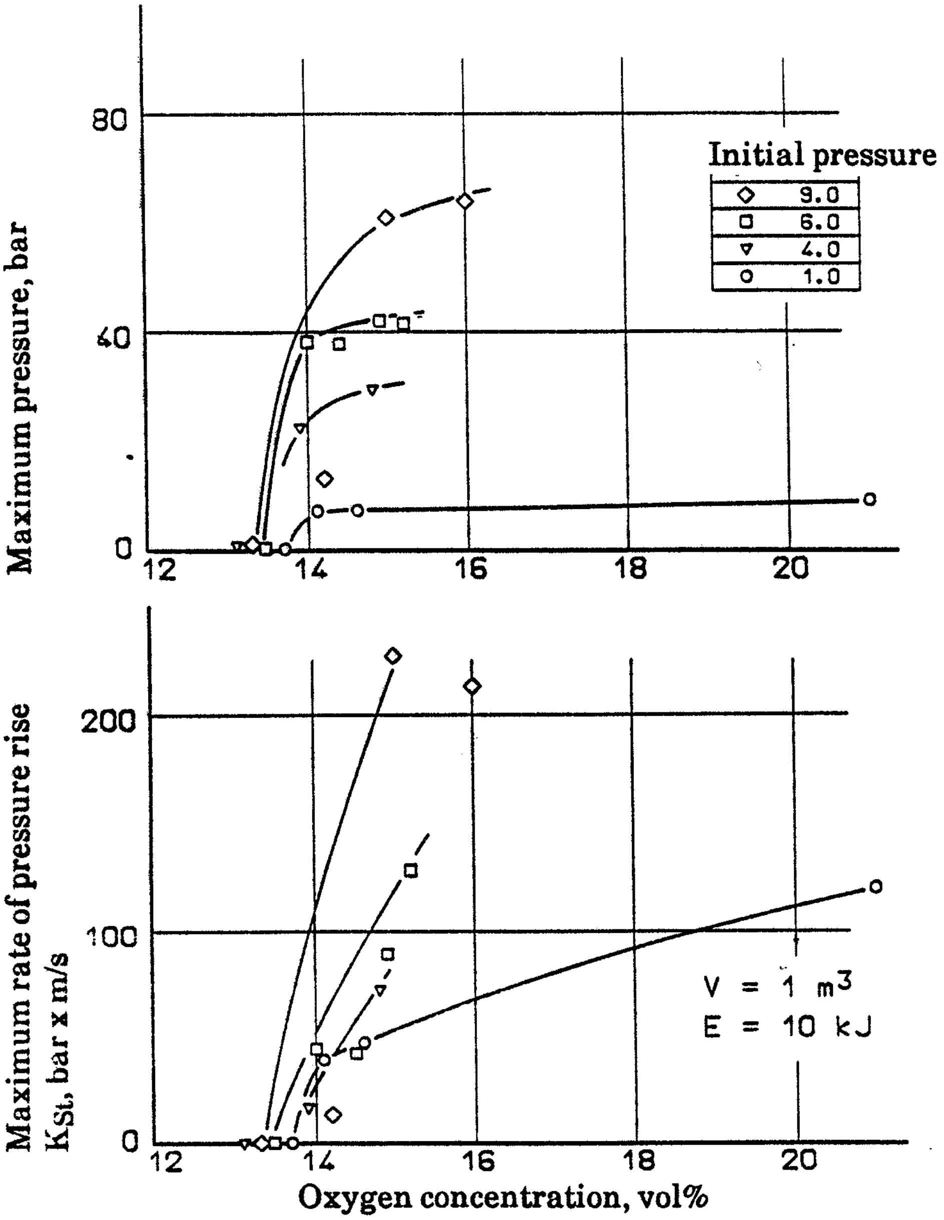


Figure 32. Changes in the inertization limit and explosion severity of peat dust at different initial pressures /18/.

4.3.6 Conclusions from dust explosions at normal and elevated pressures

Dust and fines are formed in the handling of biofuels by mechanical handling (crushing, drying), by internal friction in the fuel, and when feeding it into pressurized fluidized-bed gasification or combustion equipment. This should be considered in the design of bins and handling equipment, as the fuel fines significantly affect both its flow charac-

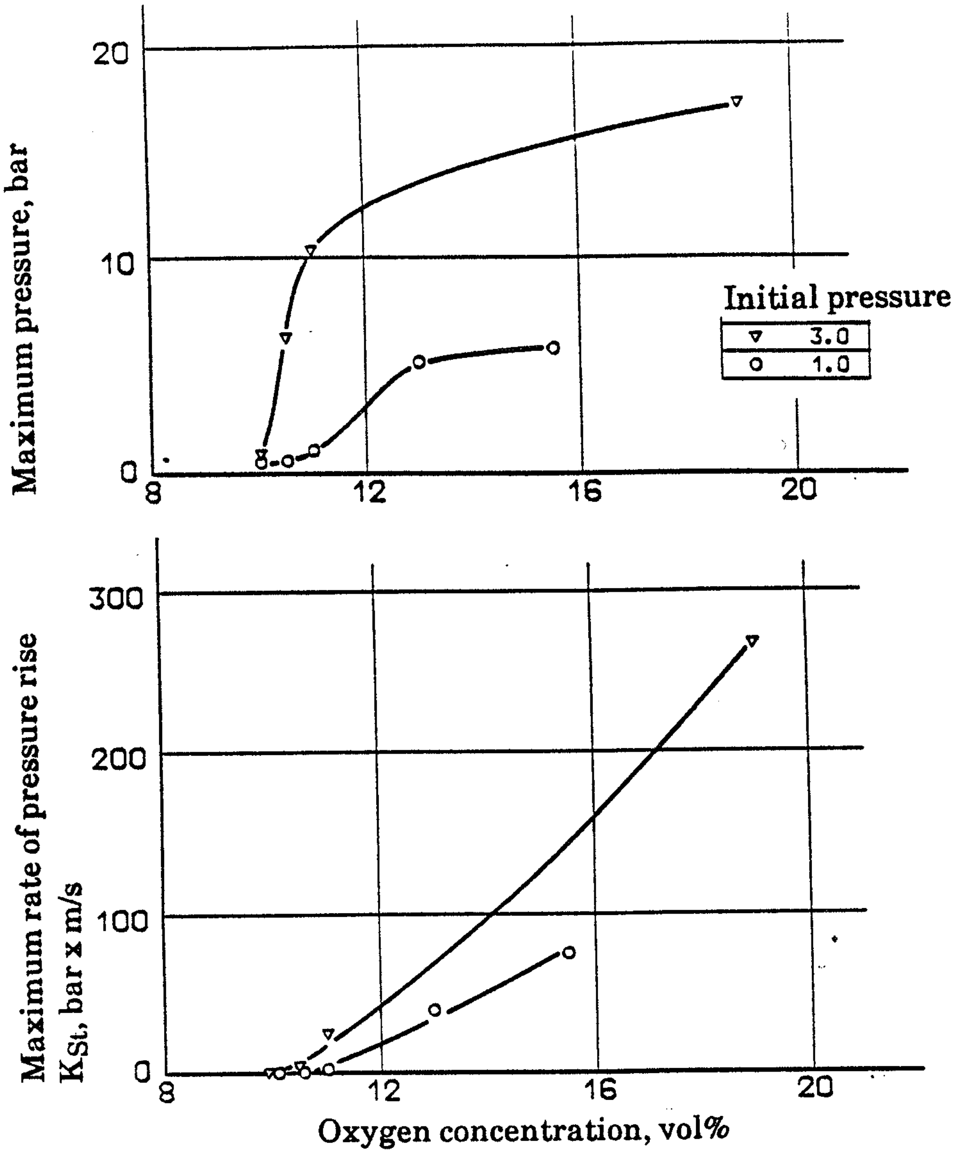


Figure 33. Effect of temperature and initial pressure on the inertization limit of peat dust-air mixture at 150 °C /19/.

teristics and the safety of the process. The biofuels (peat, wood, and lignite) are, due to their powdery state, very susceptible to dust explosions. This susceptibility is reduced if the moisture content and/or the particle size of the fuel increases. The elimination of ignition sources in handling equipment and the stability of inertization are also of significance. The maximum pressures and the maximum rates of pressure rise of dust explosions increase very sharply if the initial pressure is increased, and hence, set greater requirements on the design and use of handling equipment than those required at normal pressure. Dust explosions at elevated pressures are discussed in more detail in /35/.

5 CONCLUSIONS

There are several types of high-pressure feeders for feeding solid biomass fuels, including wood materials, from atmospheric or low-pressure into high-pressure vessels. There are very few feeders available for operation at pressures of >10 MPa. Novel and promising alternatives may result from the development work underway.

The following different types of feeders are available:

- *Screw with a variable cross-section* (Sunds Defibrator, Ltd.) is well-known in the pulping industry. It is used for feeding wood chips into pressurized steam digesters. It is a promising low-pressure feeder for large volume flows, but requires further development use for feeding wood waste, bark, peat. The following problems have been observed:
    - Plugs have jammed in the channel due to variations in the quality of the fuel and bridging caused by oversized wood pieces.
    - The screw cone has been plugged when using fibrous fuels.
    - Leakage of back-pressure gases has occurred due to a relatively short plug, especially if the particle size of the fuel has varied.
- *Twin screw feeders (counter-rotating screws)* (C. E. Bayer Helipress) have been used as intermediate medium-pressure prefeeders to remove water for feeding pulp into a high-pressure compacting screw. Operating problems include:
    - relatively intensive wear (due to counter rotation)
    - jams due to impurities and large pieces.
- *Twin screw feeders (co-axial screws)* (Werner & Pfleiderer) are commercially available for medium-pressure and high-pressure applications. This feeder seems to be feasible, as the system can move the plug between the screws through a channel into high pressure; however, testing with materials of different type (bark, etc.) is required to verify the operational reliability of the system. The following problems can arise:
    - Oversized particles may cause jams or a poorly formed plug.

  - Excess gas permeation at high pressure is possible when using bark and wood waste.
  - Impurities like sand in bark and peat may erode the screws.

- *One-stage screw feeder* ('air lock') (Fuller-Kinyon screw pump) seems to be a promising alternative for feeding into medium-pressure systems. The feeder is suited for feeding freely flowing materials in large quanties into pneumatic systems; however, its suitability for feeding coarse wood fuels has not yet been tested. The following problems are possible:
  - The feeder may not be able to feed coarse material.
  - The high-speed screw and its operating mechanism may be damaged by impurities (jamming).

- *Plug screw feeders* commercially available for high-pressure processes are manufactured by Koppers Inc., Sprout-Waldron, Division, Fuller-Kinyon Gard Inc. (modified), and General Electric Co.; however, in most cases additional tests are required to determine their suitability for biomass. For example, the following problems may arise:
- Compacting screws may be jammed (large pieces, impurities).
- The pressure seal of the plug can be poor (compared to coal use) when using biomass or peat in high-pressure processes.

- *Cone-shaped feeders* (with dewatering) are manufactured by Pressafiner (C. F. Bauer Process Engineering Group). The system is primarily a dewatering unit, but can also be used as a high-pressure feeder suitable for wood chips, etc. It is a continuously operating high-pressure unit and, therefore, may be a preferable alternative system; however, the following problems may be of concern:
  - The feeder requires a pressurized prefeeder.
  - The screw casing requires dewatering, which may result in gas leakages at high back pressures.
  - The frame of the feeder should be modified for high-pressure feed (to reduce gas leakages), if the unit is used as a direct feeder.

- *Co-axial feeders* equipped with a compacting piston (Stake Tech. Ltd) seem to be a promising commercial alternative for feeding wood materials; however, certain problems may arise:
    - The feed screw or piston can be jammed.
    - The compacting part can be jammed by larger pieces or impurities.
    - The pressure seal against gas leakages is poor when porous and coarse fuels are used.

- *Piston pumps* (Putzmeister GmbH) are very promising feeders for feeding into high-pressure vessels and they have already been commercialized. Their operation has already been tested in coal and peat feeding. They have proved to operate well, but any long-term experience with wear resistance and possible feed malfunctions due to wear is not yet available.

- *Reciprocating screw pistons* (Ingersoll Rand Res. Inc.) are also promising high-pressure feeders; however, their operation with biomass or peat has not been tested. Probable difficulties with the system include:
    - It will be difficult to form a sufficiently compact plug especially from wood and other coarse biofuels .
    - The screw may be jammed during compaction due to impurities and variations in fuel quality.

- *High-pressure feeders* with a pressure difference of <1 000 kPa have often been used for feeding wood to pressurized steam digesters, for operating at pressures of as high as 2400 kPa.

- *Rotary feeders and screw feeders* are most generally used and tested for feeding sawdust and wood chips. The problems that have arisen with rotary feeders include jamming, sticking, and gas leaks due to large-piece materials and impurities. The total unexpected discharge of the fuel from the feeders in the discharge stage and variations in back-pressure may also cause problems in pressure feeding. Advantages are low energy consumption and the simple operating principle of the feeders. In the screw feeders, jamming due to variations, fibers, or impurities in the fuel are the greatest problem, while the gas leaks are clearly easier to manage.

- *Lock hoppers* are also often used successfully for feeding peat and wood materials into low and medium-pressure reactors. In regard to leakages and pressure levels, these feeders are easier to manage than many other types of feeder. The quality characteristics of the fuel are not changed to any noteworthy degree during the feed (for example, compacting feeders). Problems are caused by the fuel flow in lock hoppers (arching, jamming), high consumption of compression gases, and probable non-continuous feed.

- Some novel *screw and piston feeders* developed for high pressures are also suitable for low and medium pressures. *Reciprocating screw piston feeders* are of great interest, as good properties of both the screw and the piston feeder are combined in this type of feeder. It is easy to regulate the length (and compactness) and the pushing distance of the plug according to the requirements of the fuel and hence to optimize both the pressure seal of the plug (gas leakages) and the consumption of energy. The feeder is not yet commercially available.

- In *pressurized slurry feed systems* it is often easier to reach a high pressure level and a reliable prevention of gas leakages than in the dry systems. The energy consumption is often low. Drawbacks are feed preparation requirements, slurry preparation, and additives. In addition, the moisture content of the fuels often hampers the process, and drying may be required prior to feeding the fuel into the process.

- The *feeder type equipped with a lock hopper* is most commonly used for handling free-flow materials. The feed is continuously moved by gravity, by screws, or pneumatically. However, problems in the lock hopper system are often due to the lack of homogeneity of the feed. A disadvantage of the lock hoppers is consumption of pressurizing gases at higher feed capacities; however, the energy requirement could be significantly less compared to extrusion feeders.

- *Pneumatic feed* is useful for long distance transport, but its use is limited by the particle size distribution and the maximum allowable moisture content of the material to be conveyed. A lock hopper is usually needed for pressurizing, and the conveyor gas should be suitable for the process, or else it must be removed prior to the process and the material must be fed into the reactor by some other system.

All the feed systems discussed have some limitations, and there is little information available on their reliability, durability, and operation costs. Most pressurized feeders have actually been developed for feeding coal, and hence they often cannot be used for feeding other fuels, such as peat and biomass, because of their unique handling characteristics.

It should be considered in the design and use of pressurized feeding equipment that an increase in initial pressure contributes to the susceptibility to, and severity of, dust explosion. Both the maximum pressure and the maximum rate of pressure rise increase sharply if the initial pressure rises. The tendency of fuels to spontaneous ignition also increases if the initial pressure rises, hence, an accurate sizing of bins and lock hoppers to guarantee free mass flow is essential.

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Title

Feeding biomass into pressure and related safety engineering

Abstract

Malfunctions in the fuel feed and handling equipment could be cause for biomass gasification process upsets, and are of major concern for pressurized gasification processes. One precondition for the development of handling and feed equipment for solid fuels and wastes and for the design of novel systems is a good knowledge of the characteristics and flowability of bulk materials, because the requirements for the equipment reliability, adjustability, economy, and lifetime are becoming more demanding.

Different methods of feeding biomass fuels into pressurized gasifiers, as well as limitations and special features of these methods, are discussed in this literature review. Examples of different systems for fuel feed and ash removal in pressurized gasification and combustion plants are given, and the available plant operational data are surveyed for a better understanding of the handling characteristics of bulk materials in biomass gasification plants. Unfortunately, there are only a few references to long-term operating experience with biomass feeders in the literature.

Safety engineering, including fuel flow characteristics, and dust explosion and spontaneous ignition properties, is also discussed with special attention given to the conditions in pressurized feeding systems. Results from dust explosion and spontaneous ignition tests with biofuels at elevated pressures are presented.

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