Methods and apparatus for determining the compressibility and/or moisture content of particulate materials are provided. The apparatus generally consists of a closed compression chamber, a piston in the compression chamber and a transducer for sensing the pressure generated within the compression chamber. In one aspect the piston is multi-part and has a concave face. The volume of the chamber is varied by varying the concavity of the piston face. In another aspect the peripheral wall of the chamber consists of a plurality of relatively movable wall sections which slide relative to one another when the volume of the chamber is varied. Also disclosed are methods of compressing particulate material and determining their compressibility and/or moisture content using the apparatus.
GRAIN MOISTURE TESTER

BACKGROUND OF THE INVENTION

The present invention relates to methods and apparatus for determining the compressibility and/or moisture content of particulate materials. More particularly, it relates to such methods and apparatus for determining the moisture content of grain.

Most commercially available grain moisture testers are not suitable for use by the average farmer: Those that have, in the past, provided satisfactory results generally require electric power, are not portable to the extent that they may be transported into the field, and are expensive.

To overcome the difficulties of this prior art, attempts have been made to determine the moisture content of grain by the compression method. Since it is known that the hardness of grain and many other compressible materials varies substantially in inverse proportion to the moisture content of the material, it was postulated that, by obtaining a measure of the compressibility of that material, one could obtain a measure of the moisture content. The apparatus used heretofore for determining the compressibility usually consisted of straight cylinders provided with a compressing piston. With such an arrangement the grain was not, however, uniformly compressed in that the grain adjacent the piston was overly compressed whereas the grain further from the piston was hardly compressed at all. This resulted in the large frictional forces exerted on the grain by the cylinder wall. Additionally, the previous apparatus of this kind were of a type wherein a predetermined force was exerted on the grain by the piston and the resulting deflection of the piston, i.e., the reduction in volume of the cylinder, was taken as an indication of the compressibility and therefore moisture content of the grain. With such an arrangement the deflection of the piston with respect to the cylinder was usually read directly from a mechanical scale arrangement so that the accuracy of the reading was limited by the accuracy and readability of the scale arrangement. The accuracy of any reading with such a device depended on the magnitude of the indicated value when compared with the possible error in reading the scale. Thus, the accuracy was inherently poor when the grain was very dry and hard such that the amount of deflection of the piston was small. Additionally, the calibration of any such tester was extremely difficult since it was difficult to ensure that the cylinder was filled with grain to precisely the same desired level prior to each test. Thus, the scale would rarely and randomly be at "zero" at the beginning of any given test.

SUMMARY OF THE INVENTION

It is an object, then, of one aspect of the present invention to provide improved methods for determining the compressibility, and preferably also the moisture, of particulate material.

It is an object of another aspect of the present invention to provide an apparatus for compressing, and preferably also determining the moisture content of, particulate material.

Accordingly, a method is provided for determining the compressibility of a particulate material. The method comprises first providing a first predetermined volume of the particulate material in an uncompressed condition. Then the particulate material is compressed to a second predetermined volume which is smaller than the first predetermined volume. Finally the pressure exerted by the compressed particulate material is measured. Preferably, also, that measured pressure is converted to a measure of the moisture content of the particulate material.

As used herein, the term "compressible particulate material" is to be construed as a generic term indicating all of those materials whose compressibility and/or moisture content can be determined by the present methods and devices. Thus, the methods and apparatus of the present invention have a particular utility in the field of determining the moisture content of cereal grain, as well as for determining the moisture content of other particulate materials such as, for example, soil, peas, sunflowers, saw dust and the like.

By an embodiment of this aspect of the invention, a method is provided for compressing particulate material in a substantially closed compression chamber having a piston with a substantially concave face. The method comprises the first step of filling the chamber with particulate material, and the second step of reducing the volume of the chamber by reducing the concavity of the piston face.

By yet another embodiment of this aspect of the invention, a method is provided for compressing particulate material in a substantially enclosed chamber having first and second axially spaced-apart ends and an axially extending peripheral wall. The method comprises the first step of filling the chamber with uncompressed particulate material; the second step of reducing the axial dimension of the chamber; and the third step of moving axially extending portions of the peripheral wall axially with respect to one another.

By another aspect of this invention, apparatus is provided for testing the compression of particulate material. The apparatus comprises substantially closed chamber means having a volume which is variable between a first predetermined volume and a second predetermined volume smaller than the first predetermined volume. Pressure sensor means are provided for sensing the magnitude of pressure within the chamber. Indicator means are provided which are coupled to the pressure sensor means for indicating the magnitude of such pressure. Preferably, the indicator means may also indicate the moisture content of the particulate material being tested.

By one embodiment of this aspect of the invention, an apparatus is provided for compressing particulate material, the apparatus being of the type having a substantially closed compression chamber and a piston slideable in such chamber. In such apparatus, the piston has a substantially concave face and comprises a plurality of telescopically interengageable members relatively movable with respect to one another. Such movement varies the concavity of the piston face and thereby also the volume of the chamber.

By yet another embodiment of this aspect of the invention, an apparatus is provided for compressing particulate material. The apparatus comprises a plurality of members movably interengageable with one another to define a substantially enclosed variable volume chamber. Such chamber has first and second axially spaced-apart ends and an axially extending peripheral wall. The peripheral wall includes a plurality of axially extending peripheral wall sections which are axially
movable with respect to one another in response to variation in the volume of such chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings which illustrate embodiments of the present invention,

FIG. 1 is a perspective view of one form of grain moisture tester in accordance with an aspect of the present invention;

FIG. 2 is a cross-sectional view of the compression tester of FIG. 1, assembled and in which the particulate material is in an uncompressed condition;

FIG. 3 is a cross-sectional view of the compression tester of FIG. 1 corresponding to that of FIG. 2, in which the particulate material is in a compressed condition;

FIG. 4 is a cross-sectional view of a grain moisture tester in accordance with another aspect of the present invention in assembled form, in which the particulate material would be in an uncompressed state;

FIG. 5 is a cross-sectional view of the tester of FIG. 4 in which the particulate material would be in a compressed state;

FIG. 6 is a view along line VI—VI of FIG. 5; and

FIGS. 7 and 8 are views similar to FIG. 6 of yet another embodiment of grain moisture tester in accordance with another aspect of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the embodiment of the tester shown in FIGS. 1 through 3, there is illustrated a tester 10 for determining the moisture content of grain. The tester includes a pressure sensor and indicator section 12, a compression chamber section 14, and a piston actuator section 16.

As can be most readily seen from the cross-sectional views of FIGS. 2 and 3, the main body of compression chamber section 14 consists of a cylindrical sleeve 18 having opposite ends, i.e. upper end face 20 and lower end face 22, a reduced diameter, externally threaded upper portion 24 adjacent end face 20 which ends at an annular shoulder 25 and a reduced external diameter lower portion 26 adjacent end face 22 terminating at an annular shoulder 28 facing in the same direction as end face 22.

The internal diameter of sleeve 18 is reduced in a stepwise manner from upper end face 20 to lower end face 22 so as to provide four coaxial cylindrical surfaces 30, 32, 34 and 36 of sequentially smaller diameters and three annular shoulders 38, 40 and 42, each facing in the same direction as upper end face 20 of sleeve 18.

A cylindrical block 44 is positioned within sleeve 18. Block 44 has a smaller diameter cylindrical portion 45, which is dimensioned to be a snug fit within cylindrical surface 36 and which extends downwardly from shoulder 42 towards lower end face 22 of sleeve 18 and terminates at a lower annular face 48, which is planar with lower end face 22 and is parallel to shoulder 42. Block 44 also has a larger diameter cylindrical portion 47 which is dimensioned to be a snug fit within cylindrical surface 34 of sleeve 18 and which has an annular face 46 abutting against shoulder 42. Block 44 terminates at an upper face 49 which is directed oppositely to lower end face 22 of sleeve 18 and is parallel to shoulder 42.

A piston assembly 50 is slidably fitted within sleeve 18 between its upper end face 20 and upper face 49 of block 44. The piston assembly consists of three telescopically engageable elements 52, 54 and 56. Element 52 is generally cylindrical, and has its outer cylindrical face 51 slidably fitted within surface 30 of sleeve 18. It includes a substantially frusto-conical inwardly directed end face 58 which tapers inwardly in a direction from upper end face 20 towards lower end face 22 of sleeve 18 to an inner cylindrical surface 55. The lower face 53 of element 52 abuts shoulder 38.

Piston element 54 is also generally cylindrical and has its outer cylindrical surface 57 fitted within element 52 in sliding contact with inner cylindrical surface 55 of element 52. It, too, includes a substantially frusto-conical inwardly directed end face 60 which tapers inwardly in a direction from end face 20 towards end face 22 to an inner cylindrical surface 61. Element 54 also includes an annular collar 62 which fits slidably within cylindrical surface 32 of sleeve 18 and has a lower face 63 engaging shoulder 40 and an upper face 65 adapted to abut lower face 53 of element 52. The slope of end face 60 is substantially the same as the slope of surface 58 of element 52 and, consequently, surfaces 58 and 60 are adapted to be aligned with one another, as can be seen most readily from FIG. 3.

Piston element 56 is a cylindrical plug having an upper, smaller diameter cylindrical portion 67 slidably fitted within piston element 54 and in sliding contact with the inner cylindrical surface 61 and has a concave face 64 directed towards upper end face 20 of sleeve 18. Element 56 also has a lower, larger diameter cylindrical annular collar 66 slidably fitted within surface 34 of sleeve 18 and having a lower face 69 engaging upper face 49 of block 44. Collar 66 also includes an upper face 71 adapted to engage face 63 of element 54.

As can be seen from FIGS. 2 and 3, collars 62 and 66 of piston elements 54 and 56, respectively, are shorter in axial dimension than the associated cylindrical surfaces 32 and 34, respectively, of sleeve 18 in which they slide. Thus, element 56 may slide freely between a lower limiting position where face 69 engages face 49 of block 44 and an upper limiting position where face 71 of collar 66 engages face 63 of piston element 54. Similarly, piston element 54 may slide freely between a lower limiting position where face 64 of collar 62 engages shoulder 40 and an upper limiting position wherein face 65 of collar 62 engages face 53 of piston element 52. Finally, piston element 52 may slide freely between a lower limiting position where face 53 engages shoulder 38 and an upper limiting position where the upper rim 73 approaches an end plug 116 on the pressure sensor and indicator head 12, as will hereinafter be described. The limit position is actually defined by engagement of shoulder 28 with face 76 of hand knob 72 as will be described hereinafter. It is seen, further, that piston elements 52, 54, 56 thus combine to form a variable volume chamber 75.

The piston actuator section 16 comprises a bolt 70 threaded into internally threaded aperture 77 in block 44 and a cup-shaped hand knob 72 secured to the head of bolt 70 by screws 74. Hand knob 72 fits slidably over reduced external diameter portion 26 of sleeve 18 and has an end face 76 facing towards and engageable with shoulder 28. To reduce friction between bolt 70 and piston element 56, bolt 70 and piston element 56 are provided with opposing recesses 78 and 80, respec-
The pressure sensor and indicator section 12 consists of a main cylindrical member 90 having an internally threaded recess 92 in the lower end thereof, a recess 94 in the upper end thereof, and a bore 96 extending through the web 95 between recesses 92 and 94. Recess 92 is threaded inwardly over a part of its depth from the end of member 90 and is engaged with the threaded end 24 of sleeve 18, with the remaining part of recess 92 having a smooth cylindrical wall 98. A cup-shaped piston 100 having an upper annular collar 102 at its open end is disposed within recess 92 with the collar 102 fitted slidably within cylindrical wall 98 of recess 92. Collar 102 has an annular groove 104 in its peripheral surface and an O-ring seal 106 is fitted into groove 104 to form a seal between the collar 102 and wall 98.

To hold piston 100 within recess 92, an annular collar 108 with an external thread 110 is threaded into recess 92 so that its upper face 103 engages lower face 105 of collar 102. Collar 108 is integral with a sleeve 112 whose inner peripheral surface 107 fits slidably about the outer peripheral surface 109 of cup-shaped piston 100. The outer peripheral surface 111 of collar 108 fits slidably within inner cylindrical surface 30 of sleeve 18.

An external thread 114 is provided on the lower surface of piston 100 at the end thereof remote from collar 102 and a plug 116 with a large, internally threaded recess 118 is threadedly engaged with thread 114. Plug 116 and sleeve 112 have the same diameter and are arranged coaxially with respect to one another. The outer peripheral surface 117 of plug 116 is also slidably fitted within inner cylindrical surface 30 of sleeve 18. The length of sleeve 112 is less than the spacing between collar 102 and plug 116 so that the assembly of piston 100 and plug 116 can slide to a limited extent with respect to sleeve 112. The lower face 119 of plug 116 also provides the upper limit of the variable volume chamber 75.

Piston 100, with its integral collar 102, defines with the end of recess 92 a pressure chamber 120 which communicates with recess 94 through bore 96. Pressure chamber 120 is filled with hydraulic fluid indicated by the reference numeral 118.

Bore 96 has a threaded counterbore 122 at its end adjacent recess 94. A threaded coupling sleeve 123 of a pressure gauge 124 is engaged within counterbore 122. Gauge 124 includes a gauge actuating element 126, an indicating needle 128 and a circular scale 130.

As will be apparent from the above, the gauge 124 indicates the pressure of hydraulic fluid 121 within chamber 120 applied through pressure on face 119 of plug 116. To "zero" the gauge 124, an axially extending bore 132 is provided extending from cahmber 120 into the end of a calibrating bore 134 extending radially into the web 95 of member 90. Bore 134 has an internally threaded outer end portion 136 and an inner smooth walled cylinder portion 138 thereof.

A plug 140 is disposed within bore 134 and has an inner piston end 142 with a peripheral O-ring seal 144 so as to engage the cylinder portion 138 of bore 134. An outer end 146 of plug 140 is in threaded engagement with outer portion 136 of bore 134. The outer end of plug 140 has a hexagonal recess 148 therein to receive an Allan wrench.

The end of member 90 surrounding recess 94 is threaded at 150 to receive an end of an internally threaded sleeve 152. The outer end of sleeve 152 has a closure plate 154 of glass, transparent plastic or the like material mounted thereon. A timer 156 is mounted on plate 154 and has an actuating knob-pointer assembly 158 disposed on the outer side of plate 154. The timer 156 is of a size and is positioned such that gauge scale 130 and needle 128 can be viewed through transparent plate 154 without difficulty.

The pressure sensor and indicator portion 12 is mounted on compression chamber portion 14 by inserting plug 116 and sleeve 112 slidably within cylindrical surface 30 of sleeve 18 and engaging the threaded end 24 of sleeve 18 with the threaded portion of recess 92. The end of member 90 engages shoulder 25 at the end of threaded portion 24 of sleeve 18 when the two sections are fully engaged.

The operation of the apparatus of FIGS. 1 – 3 will now be described, with particular reference to FIGS. 2 and 3.

To commence a test, the bolt 70 is withdrawn from block 44 by rotating hand knob 72 until faces 53, 63 and 69 of piston elements 52, 54 and 56, respectively, engage shoulder 38, shoulder 40 and face 49 of block 44, respectively. This initial condition of the piston 50 is illustrated in FIG. 2 and will be herein referred to as a condition of "maximum concavity". The term "concavity" is used herein as a quantitative term generally indicating the depth of the recess defined by the generally concave piston face provided at least in part by faces 58, 60 and 64 of piston elements 52, 54 and 56, respectively.

With piston 50 in its condition of maximum concavity as hereinbefore described, the pressure sensor and indicator section 12 is removed from the compression chamber section 14 by disengaging the threads of recess 92 from threaded portion 24 of sleeve 18. The particular material to be tested is then introduced into the variable volume chamber 75 within the interior of sleeve 18 through its upper end until a predetermined level which may be indicated by a reference line (not shown) marked on the inner surface 30 of sleeve 18.

The pressure sensor and indicator section 12 is then replaced on compression chamber section 14 by threading member 90 into engagement with threaded end 24 of sleeve 18 until the end of member 90 engages shoulder 25. With the apparatus in this condition, a completely closed variable volume chamber 75 is thus provided between plug 116 and piston 50, the chamber 75 being filled with the particular material to be tested. At this point the calibrating plug 140 is moved to the appropriate position within its bore 134 to ensure that the pressure gauge 124 is reading "zero". This movement of the calibrating plug adjusts the pressure of hydraulic fluid 121 in chamber 120 and may cause piston 100 to move slightly within the recess 92. While this movement of piston 100 does, in fact, alter the volume of chamber 75, this variation in volume is very small when compared with the entire volume of chamber 75 and therefore does not materially change the volume of the material within chamber 75. With the apparatus in this condition, there is therefore provided a variable volume compression chamber 75 closed by a piston 50 with a substantially concave face 64 and a plug 116 with a substantially flat face 119, the chamber
75 being filled with the particulate material to be tested, the material being in an uncompressed state. To compress the material within chamber 75, the hand knob 72 is rotated to thread bolt 70 through block 44 into engagement with piston element 56. Face 49 of piston element 56 is then moved upwardly out of engagement with face 49 of block 44 until face 71 of its collar 66 engages face 64 of piston element 54. This movement of piston element 56 initially compresses a central core section of the sample within variable volume chamber 75. Further rotation of hand knob 72 moves both of piston elements 54 and 56 together towards plug 116 further to compress the central core section of the sample and to compress portions of the sample disposed immediately around the previously compressed core section. This continues until face 65 of collar 62 of piston element 54 engages face 53 of piston element 52. Upon further rotation of hand knob 72, all three piston elements 54, 52 and 56 will be moved together towards plug 116 until end face 76 of hand knob 72 engages shoulder 28 on sleeve 18. The apparatus is then in the condition shown in FIG. 3. It is noted that rim 73 of piston element 52 does not necessarily abut plug 116.

With the apparatus in this condition, a substantially uniform pressure exists throughout the sample and this pressure is exerted upon piston 100 through plug 116. Since piston 100 is slidable within recess 92, the pressure exerted by the grain is, in turn, transmitted to hydraulic fluid 121 in chamber 120 and thence to pressure gauge 124.

Since particulate materials, such as, for example, grain, are not generally instantaneously compressible, the initial indication by gauge 124 is very high and will gradually decrease for a period of time until the condition of the grain has stabilized within variable volume chamber 75. Thus, the timer 156 is set for a predetermined time, for example, 1 or 2 minutes, immediately following the compression of the sample. The time to which the timer 156 is set is selected to be sufficient for the state of the sample to stabilize within variable volume chamber 75. When the condition of the sample has stabilized, gauge 124, through its indicating needle 128 and scale 130, gives a direct indication of the compressibility or moisture content of the sample, depending on the limits marked on scale 130.

By providing a concave piston in the variable volume compression chamber 75 and then compressing the particulate material by reducing the concavity of the piston, the detrimental effects of friction between the cylinder wall and the sample are minimized or even essentially eliminated by the elimination of a cylinder wall. The sequential compressing of the various areas of the sample results in a very uniform compression throughout the sample.

Turning now to FIGS. 4 through 6, another embodiment of compression or moisture tester 210 for particulate material is illustrated. The tester includes a pressure sensor and indicator section 212, a compression chamber section 214 and a piston actuation section 216.

The compression chamber section 214 consists of a generally cylindrical sleeve 218 having a reduced diameter externally threaded portion 224 adjacent the upper end face 220 thereof and a reduced diameter, externally threaded portion 226 adjacent the lower end face 222 thereof. It is preferred that the diameters of portions 224 and 226 be different to prevent their being threaded into the incorrect parts as will hereinafter become apparent.

Sleeve 218 has formed on its interior surface a plurality of longitudinally extending radial slots 228 so as to provide therebetween a plurality of radial blades 230 uniformly distributed around the inner periphery of sleeve 218. (see FIG. 6). Slots 228 terminate at a common plane 223 spaced slightly from end face 220 of sleeve 218. In addition, the portions of blades 230 end at a position spaced from end face 220 of sleeve 218 and indicated, in FIG. 4, by broken line 219.

A cylindrical sleeve 232 is integral with sleeve 218 and extends downwardly a short distance from end face 220 towards end face 222 and ends at an annular end face 234.

A hollow cylindrical sleeve 240 having a lower annular flange 241 thereon is disposed slidably within sleeve 218 adjacent its end face 222. A plurality of blades 236 project upwardly from flange 241 and are disposed slidably within respective ones of slots 228 of sleeve 218. Together with blades 230, these blades 236 define a variable volume cylinder 237 having a multi-part cylindrical surface 238. The blades 236 are of substantially the same length as blades 230 and terminate at a common plane 221 spaced from the plane 223 defined by the ends of slots 228. Thus, the chamber 237 is composed of an upper portion, comprising sleeves 218 and 232 including blades 230, and a lower portion comprising sleeve 240 and blades 236 projecting upwardly from flange 241 between blades 230.

At the upper portion of cylinder 237, a plug 244 is provided having one cylindrical portion 246 thereof that is a close sliding fit within cylindrical surface 238 and a smaller diameter cylindrical portion 248 that is fitted slidably within sleeve 232 and which projects upwardly beyond end face 220 of sleeve 218 and terminates in face 249. An annular shoulder 250 extends between portions 246 and 248 and is adapted to abut end face 234 of sleeve 232.

At the lower portion of chamber 237, a piston 252 is provided which is generally cylindrical and has a major, smaller diameter portion 253 in close sliding fit within sleeve 240. Piston 252 has an integral annular collar 254 projecting radially outwardly therefrom so as to engage with the bottom of flange 241 to hold the piston in position with respect to sleeve 240 and cylinder 238. The length of piston 252 is such that its inner end face 251 is coplanar with the inner end 255 of sleeve 240. An end member 256 is provided which has a neck 257 and a large threaded recess 258 therein which is threaded onto externally threaded portion 226 of sleeve 218. A central threaded bore 260 extends through neck 257 of end member 256. The bottom face 259 of recess 258 is engageable with the bottom face 261 of the collar 254 of piston 252 to limit the movement of piston 252, sleeve 240 and blades 236 with respect to sleeve 218.

The piston actuating section of this embodiment of tester is similar to that previously described with reference to the embodiment shown in FIGS. 1 through 3 and includes a bolt 270 threaded into bore 260 in element 256 and a hand knob 272 fixed to the head of bolt 270 by bolts 274. Hand knob 272 has an annular end face 276 engageable with the end of shoulder 273 between recess 258 and neck 257 of end member 256 to limit the movement of bolt 270 with respect to the
compression chamber section of the device. Hand knob 272 is also provided with an annular recess 271, into which neck 257 of end member 256 is adapted to nest.

As described for the embodiment of FIGS. 1 and 3, to reduce friction between the end of bolt 270 and piston 252, piston 252 has a central cylindrical recess 278 in its end adjacent bolt 270 and two mating recesses 280 and 282 are formed respectively in recesses 278 of piston 252 and in the end of bolt 270. A ball 284 of steel or the like material is engaged between recesses 280 and 282. The recess 278 aids in the proper placement of ball 284 as will hereinafter become apparent.

The pressure sensor and indicator section 212 of this embodiment of tester is similar to the pressure sensor and indicator section 12 of the embodiment of tester illustrated in FIGS. 1 through 3. Section 212 includes a main cylindrical member 290 having a threaded recess 292 in the lower end thereof, a recess 294 in the upper end thereof, and a bore 296 extending through the web 295 between recesses 292 and 294. In this embodiment, a diaphragm 300 extends across the end of recess 292 and has an enlarged and thickened annular edge 302 which engages an O-ring seal 304 in an annular channel 305 in the end of recess 292 to seal the diaphragm 300 peripherally to the end of the recess 292. The enlarged edge 302 also ensures that the central portion of the diaphragm 300 is spaced from the end of recess 292 so as to provide a sealed chamber 306 which is filled with hydraulic fluid 308 or the like.

To retain diaphragm 300 in position, an externally threaded annular collar 310 is threaded into recess 292 into face-to-face engagement with diaphragm 300. As with the previously described embodiment, the bore 296 has a threaded counterbore 293 to receive a coupling sleeve 323 of a pressure gauge 324 which also includes a gauge actuating element 326, an indicating needle 328 and a circular scale 330. The end of recess 292 is closed by a closure plate 354 held in place by an annular element 352 threaded onto member 290. No timer has been shown as incorporated into this embodiment of tester although this may be done.

The operation of this embodiment of tester will now be described with particular reference to FIGS. 4 and 5.

Initially, the end member 256 is removed from sleeve 218 by unscrewing, the piston 252 is removed and sleeve 240 is retracted to the position shown in FIG. 4. Retraction of sleeve 240 also retracts blades 236 as these blades are attached to the sleeve. It will be noted that, with the apparatus in this condition, the ends of blades 236 are positioned at a point represented by line 221 intermediate the end of plug 244 and end face 220 of sleeve 218 and the ends of blades 236 are at a point represented by broken line 219 intermediate the end of sleeve 240 and the end face 222 of sleeve 218. If desired, the blades may be provided with appropriate marks to indicate when the parts are properly aligned. The tester is then inverted and the chamber 237 then filled, through the bore through sleeve 240 resulting from the removal of piston 252, with particulate material to be tested up to the level of the inner end face 253 of sleeve 240.

Piston 252 is then reinserted in sleeve 240, ball 284 is placed in recess 278 which thereby facilitates its location in recess 280, and end element 256 is threaded onto sleeve 218. Bolt 270 has, of course, been previously threaded out of element 256 prior to reassembling element 256 and sleeve 218.

In this embodiment of apparatus, the end element 256 forms the "zero" adjustment mechanism of the tester. As element 256 is threaded onto sleeve 218, it engages piston 252 to move piston 252, sleeve 240 and blades 236 towards end face 220 of sleeve 218 and thus reduces the volume of the variable volume compression chamber 237 until a "zero" reading is achieved on pressure gauge 324.

It will be noted that the smaller diameter part 248 of plug 244 is sufficiently long to engage diaphragm 300 and yet leave a small spacing between the end face 234 of sleeve 232 and shoulder 250 of plug 244, so that plug 244, in effect, "floats" between the sample in the variable volume compression chamber 237 and the diaphragm 300.

To compress the sample, hand knob 272 is rotated to thread bolt 270 into engagement with piston 252 and thus force piston 252, sleeve 240 along sleeve 218 towards its end face 220 while at the same time urging blades 236 between blades 230 in interlocking relation. When annular face 276 of hand knob 272 engages shoulder 273 of end member 256, the compression has been completed. The pressure generated by the sample is then transmitted through "floating" plug 244, diaphragm 300 and hydraulic fluid 308 to pressure gauge 324 so as to indicate the compressibility or the moisture content of the compressed sample.

The relative movement between the interleaved blades 230 and 236 greatly minimizes and even essentially eliminates friction between the particulate material being compressed and the wall 238 of the variable volume cylinder 237 so that the compression of the sample is substantially uniform.

A cross-sectional view of a modified embodiment is illustrated in FIG. 7. In one modification of this latter embodiment of tester, the blades 230 are not integral with the sleeve 218 but are connected to a sleeve and annular plate arrangement similar to sleeve 240 and annular plate 242.

In yet another embodiment, illustrated in FIG. 8, blades 230 and 236 are replaced by cylindrical rods (i.e. 236a, 236a) which interleave to form the peripheral wall of the compression chamber 237. The rods 236a are secured to an annular ring 241a for movement independently of sleeve 218a. Similarly, the rods 236a are secured to another annular ring (not shown) also for movement independently of sleeve 218a.

It will be noted that the length-to-diameter ratio of the compression chamber 237 defined by cylindrical peripheral walls 238, end plug 244 and piston 252 is fairly large and thus, when zeroing the gauge 324 by movement of member 256 and thereby piston 252, the change in the length of the chamber results in a very small percentage change in the chamber volume. Additionally, the movement of plug 244 at the opposite end of the chamber 237 reduces this percentage with the result being that the initial volume of the sample in uncompressed state is maintained at a substantially constant initial volume during zeroing of the gauge.

In both of the above-described embodiments, an hydraulic fluid chamber is operatively associated with a plug provided within the compression chamber to generate a fluid balancing the pressure generated by the compressed material on the plug. These chambers therefore act as transducers operatively associated with
the plugs to provide pressure signals representative of the pressure generated by the material within the associated compression chamber. Alternative forms of transducers may, however, be incorporated in these tests, such as, for example, piezo-electric crystals and the like. Regardless of the type of transducer incorporated in the tester, the following criteria must be met: (1) the forces exerted by the compressed material on the plugs must be resisted such that only small displacements of the plugs are permitted regardless of the magnitude of the pressure within the compression chamber; and (2) the transducers must be operatively associated with the plugs to provide a signal indicative of the pressure within the compression chamber. In the described embodiments, the pressure indicator has been shown and described as a pressure gauge connected to the hydraulic fluid chamber. In the case that another form of transducer is incorporated in the tester, another form of gauge must also be incorporated such as, for example, an electric gauge where piezo-electric crystals are used as transducers.

I claim:

1. An apparatus for determining the moisture content of particulate material by compressing said particulate material said apparatus comprising: (a) a substantially closed variable volume compression chamber; (b) a hollow piston slideable in said chamber, the interior of said piston including a substantially concave face and comprising a plurality of telescopically interengageable hollow piston elements relatively movable with respect to one another, whereby the interior of said hollow piston provides a generally frusto-conical compression chamber, and whereby the volume of said generally frusto-conical chamber may be varied; (c) a plug disposed movably therein to provide a wall of said generally frusto-conical chamber facing said concave piston face and movable towards and away from said concave piston face; (d) piston actuating means for moving said piston elements relative to one another, thereby to vary the volume of said generally frusto-conical chamber, said piston actuating means comprising means for sequentially moving said piston elements relative to one another; and (e) a transducer means operatively associated with said plug to resist movement of said plug in response to a pressure generated within said compression chamber, and to provide a signal indicative of a pressure generated within said compression chamber, said signal being indicative of the moisture content of said particulate material.

2. An apparatus for determining the moisture content of particulate material by compressing said particulate material, said apparatus comprising: (a) a substantially enclosed variable volume chamber having first and second longitudinally spaced-apart ends; (b) a peripheral wall extending between said ends, said peripheral wall forming a piston including a plurality of members movably interengageable with one another, and including a substantially cylindrical sleeve, provided on its inner face with a plurality of longitudinally extending peripherally spaced apart slots, directed radially outwardly, and a plurality of longitudinal, peripherally spaced apart, radially outwardly extending blades, the blades being intermeshed with the slots and being interdislably longitudinally movable with respect to the slots; (c) said piston, closing said first end of said chamber, and movable towards and away from said second end of said chamber and engageable with said blades for movement of said blades with said piston in movement of said piston towards said second end of said chamber; (d) piston actuating means for moving said piston towards said second end of said chamber; (e) a plug, disposed movably in said chamber, thereby closing said second end of said chamber and movable towards and away from said second end of said chamber and the plug operatively associated with said plug to resist movement of said plug in response to a pressure generated within said compression chamber, and to provide a signal indicative of a pressure generated within said chamber, said signal being indicative of the moisture content of said particulate material.

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