International Standard ISO 4174

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Cereals and pulses — Measurement of unit pressure losses due to single-dimension air flow through a batch of grain

Céréales et légumineuses — Mesurage des pertes de charge unitaires dues à l'écoulement unidimensionnel de l'air à travers un lot de grains

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 4174 was developed by Technical Committee ISO/TC 34, *Agricultural food products*, and was circulated to the member bodies in September 1978.

It has been approved by the member bodies of the following countries :

Australia	France	Libyan Arab Jamahiriya
Brazil	Germany, F.R.	Mexico
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The member body of the following country expressed disapproval of the document on technical grounds :

United Kingdom

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Cereals and pulses — Measurement of unit pressure losses due to single-dimension air flow through a batch of grain

0 Introduction

Application of the law proposed by Kozeny-Carman for flows within a porous medium has been considered for grain (in particular for cereals and pulses), and such application appears sufficiently well verified.

The value of the unit pressure loss depends on certain quantities characterizing the grain and the air :

— for a given type of grain (see figure 1), the pressure loss is largely influenced by its dimensions, its porosity (see figure 2), its water content (see figure 3) and, in particular, its apparent density at a point (see figure 4);

— for a given type of air, the pressure loss depends on its temperature, its relative humidity, its density and, in particular, the velocity at which it enters the grain.

Experiments carried out by dimension categories allow two parameters to be eliminated : the water content and the shape (granulometry). The parameters which remain enable the characteristic coefficients of the medium to be determined : porosity and specific area. The results obtained may be used to forecast the pressure losses for various densities at a point.

1 Scope and field of application

This International Standard specifies a method of measuring unit pressure losses due to single-dimension air flow through a mass of grain, permitting calculation of the total pressure of a ventilation unit. This is equal to the sum of the pressure losses

a) in the ventilation system (ducts, etc.);

b) in the grain;

c) due to the passage of the air from the duct into the grain.

The pressure losses in the ventilation system and those due to the passage of the air from the duct into the grain can be considered as negligible in relation to the pressure losses in the grain if the air flow speed does not exceed certain limits :

— 8 m/s in the main duct;

— 4 m/s in the secondary duct;

— 0,25 m/s when entering the grain.

2 Reference

ISO 3507, *Pyknometers.*

3 Principle

An air flow under uniform conditions through a mass of grain gives rise to a pressure loss per metre of grain passed, which can be expressed as a function of the velocity at which the air enters the grain.

The corrected flow equation, which gives the unit pressure loss through the grain, is determined from the experimental curve.

4 Apparatus

4.1 Device for measuring unit pressure losses (see figure 5).

The grain is placed in a transparent plastic cell consisting of a cylindrical tube containing two pressure meters 300 mm apart, each comprising two tubes with an internal diameter of 1 mm communicating with the grain and of diameter (d) greater or equal to five times the equivalent diameter (d_{eq}) of the product ($d > 5d_{eq}$). At the base is a pressure chamber and a fine mesh on which the grain can be packed.

A membrane compressor forces the air into a shock-absorbing bottle. The air then passes into a pressure chamber fitted with a needle-valve tap which can be opened and closed to adjust the air flow through the grain. The air flow is measured by a flow meter (for example a rotary meter).

Finally, the air pressure before the flow meter is measured by a manometric U-tube, and the pressure loss over 300 mm by a miniscope[1)].

4.2 Thermometer recorder, to measure the temperature of the air entering the grain.

4.3 Ventilated psychrometer[2)], to record the wet- and dry-bulb temperatures of the air during the test.

1) "Miniscope" ia s French term for an apparatus used for measuring pressures with great accuracy ($\approx$ 0,1 Pa).

2) An International Standard concerning ventilated psychrometers is in preparation.

4.4 Barometer.

4.5 Pyknometer, complying with ISO 3507.

5 Procedure

5.1 Preliminary operations

The cell is filled in layers of 40 mm; a constant mass is applied over the whole surface of each layer for a certain period so that the product is regularly and uniformly settled (for example, for a cell of diameter 400 mm, a mass of 150 g for 2 min is suitable).

After filling the cell, it is necessary to wait 3 to 4 h to allow initial settling of the grain, and to carry out a preliminary ventilation intended to put the apparatus in a condition in accordance with settling.

5.2 Drawing of experimental curves to show the pressure loss as a function of the air velocity

5.2.1 General

Determination of the pressure loss (Δp) as a function of the air velocity (U_0) requires repetition of measurements for each curve drawn (the cell being refilled each time) :

— a first curve is drawn while the flow is being reduced;

— a second curve is drawn while the flow is being increased.

This is necessary to take account of the slight settling which occurs during the experiment and which, at the end of the experiment, might result in points above the true theoretical points.

From these two curves, a theoretically more accurate mean curve is drawn, especially if the apparent density at a point is taken as the mean of the apparent densities measured.

The experimental curves given by way of example (see figures 1, 2 and 3) each represent the means of the two curves obtained.

5.2.2 Measurements to be made

For the various flow-rates q_0, in litres per minute, used during the experiment and measured by the flow meter, determine :

— TU, the excess pressure in the measuring box, in conventional millimetres of mercury (mmHg), measured using the manometric U-tube (see 4.1);

— Δp, the pressure loss, in conventional millimetres of mercury or in pascals, recorded by the miniscope (see 4.1).[1)]

5.2.3 Parameters to be determined

5.2.3.1 Parameters depending on the grain

ϱ_s : Apparent density at a point in the grain, in kilograms per cubic metre.

When drawing each curve, weighings must be taken both before and after settling, and the amount of settling which has occurred must be measured.

The value adopted is the mean of the apparent densities measured.

ϱ_v : Density of the grain, in kilograms per cubic metre.

This is determined using the pyknometer (4.5).

5.2.3.2 Other parameters

p_a : Atmospheric pressure, in conventional millimetres of mercury.

This is measured using the barometer (4.4) or is given by a nearby meteorological office.

θ : Dry ambient air temperature, in degrees Celsius.

This is measured using the thermometer recorder (4.2).

θ_c : Temperature of the air entering the grain, in degrees Celsius.

This is measured using the thermometer recorder (4.2).

w : Water vapour content of the air, in grams per kilogram.

This is determined using the psychrometer (4.3) and a humidity graph.

v : Specific volume of the air, in cubic metres per kilogram.

This is determined using the humidity graph.

A : Cross-sectional area of the cell, in square metres.

The following are calculated :

ϱ_a : Density of the ambient air, in kilograms per cubic metre

$$\varrho_a = \frac{1 + w \times 10^{-3}}{v}$$

1) The pressure loss is often expressed in conventional millimetres of water (mmH_2O) :

1 mmH_2O = 9,806 65 Pa (exactly)

and

1 mmHg = 133,322 Pa

where

w is the water vapour content of the air, in grams per kilogram;

v is the specific volume of the air, in cubic metres per kilogram.

ϱ_o : Corrected density of the air, in kilograms per cubic metre.

For further calculations, it is necessary to correct all the physical measurements to 21 °C and 760 mmHg :

$$\varrho_o = \varrho_a \times \frac{T}{T_o} \times \frac{p_o}{p}$$

where

ϱ_a is the density of the ambient air, in kilograms per cubic metre;

T_o is the reference thermodynamic temperature, in kelvins (= 294 K);

T is the ambient air thermodynamic temperature, in kelvins ($T = 273 + \theta$);

p_o is the reference atmospheric pressure, in conventional millimetres of mercury (= 760 mmHg);

p is the corrected atmospheric pressure, in conventional millimetres of mercury.

5.2.4 Calculations to be made to determine U_o and ΔP

ϱ_r : Density of the air in the flow meter, in kilograms per cubic metre

$$\varrho_r = \varrho_o \times \frac{p_1}{p_o}$$

where

ϱ_o is the corrected density of the air, in kilograms per cubic metre;

p_o is the reference atmospheric pressure, in conventional millimetres of mercury (= 760 mmHg);

p_1 is the pressure measured before the flow meter, in conventional millimetres of mercury ($p_1 = p$ + TU).

q_r : Real flow on leaving the flow meter, in litres per minute

$$q_r = q_o \sqrt{\frac{\varrho_o}{\varrho_r}}$$

where

q_o is the flow in the flow meter, in litres per minute;

ϱ_o is the corrected density of the air, in kilograms per cubic metre;

ϱ_r is the density of the air in the flow meter, in kilograms per cubic metre.

p_c : Pressure in the cell, in conventional millimetres of mercury

$$p_c = p + \frac{1}{2}\Delta p$$

where

p is the corrected atmospheric pressure, in conventional millimetres of mercury;

Δp is the pressure loss recorded by the miniscope, in conventional millimetres of mercury.

ϱ_c : Density of the air in the cell, in kilograms per cubic metre

$$\varrho_c = \varrho_o \times \frac{T_o}{T_c} \times \frac{p_c}{p_o}$$

where

ϱ_o is the corrected density of the air, in kilograms per cubic metre;

T_o is the reference thermodynamic temperature, in kelvins (= 294 K);

T_c is the thermodynamic temperature of the air entering the grain ($T_c = 273 + \theta_c$);

p_o is the reference atmospheric pressure, in conventional millimetres of mercury (= 760 mmHg);

p_c is the pressure in the cell, in conventional millimetres of mercury.

q_c : Air flow in the cell, in litres per minute

$$q_c = q_r \sqrt{\frac{\varrho_r}{\varrho_c}}$$

where

q_r is the real flow on leaving the flow meter, in litres per minute;

ϱ_r is the density of the air in the flow meter, in kilograms per cubic metre;

ϱ_c is the density of the air in the cell, in kilograms per cubic metre.

U_o : Air velocity in the cell, in metres per second

$$U_o = \frac{q_c}{A}$$

where

q_c is the air flow in the cell, in cubic metres per second;

A is the cross-sectional area of the cell, in square metres.

ΔP : Unit pressure loss, in pascals (per metre)

$$\Delta P = \Delta p \times \frac{100}{30}$$

where Δp is the pressure loss, in pascals, recorded by the miniscope.

5.2.5 Presentation of results

Recorded or calculated results shall be given in a table as follows :

Flow meter reading (standard scale)	TU	Δp	Δp	q_o	p_1	p_r	ϱ_r	p_c	ϱ_c	q_c	q_c	U_o	ΔP
	mmHg	mmH_2O	mmHg	l/min	mmHg	kg/m^3	l/min	mmHg	kg/m^3	l/min	m^3/s	m/s	Pa
140													
130													
120													
110													
100													
90													
80													
70													
60													
50													
40													

The unit pressure losses (ΔP) are then recorded on "log-log 2 module" paper as a function of the velocities at which the air enters the grain (U_o).

5.3 Flow equation

After the experimental curves have been drawn, the regression equation given by Kozeny-Carman is applied as follows :

$$\frac{\Delta P}{\varrho_c \, l} = \frac{k\nu\,(1-\epsilon)^2\, S^2}{g_n \epsilon^3} U_o + \frac{h\beta\,(1-\epsilon)\, S}{g_n \epsilon^3} U_o^2$$

where

ΔP is the pressure loss, in pascals, per metre of the product;

ϱ_c is the density of the air in the cell, in kilograms per cubic metre;

l is the length, in metres, corresponding to ΔP (l = 1 m);

k is a constant (= 5);

ν is the kinematic viscosity of the air, in metres squared per second :

$$\nu = 0{,}152 \times 10^{-4}\,[1 + (\theta_c - 20)\,0{,}006]\,\frac{760}{p}$$

θ_c being the temperature of the air entering the grain, in degrees Celsius;

p being the corrected atmospheric pressure, in conventional millimetres of mercury;

ϵ is the porosity, i.e. the volume of space per unit volume at a point :

$$\epsilon = 1 - \frac{\varrho_s}{\varrho_v}$$

ϱ_s being the apparent density at a point in the grain, in kilograms per cubic metre;

ϱ_v being the density of the grain, in kilograms per cubic metre;

S is the specific area of the product, in square metres per solid cubic metre;

$h\beta$ is the Burke-Plummer constant;

g_n is the standard acceleration of free fall, in metres per second squared (= 9,806 65 m/s²);

U_o is the velocity at which the air enters the grain, in metres per second.

From two suitably chosen points, the corresponding values of S and $h\beta$ may be deduced. Generally the adjustment calculations are made from experimental points using the least-squares method.

5.4 Corrected flow equation

In practice, a flow equation taking a wall correction into account is used to obtain the true value of S :

$$S' = S - \frac{2}{d\,(1-\epsilon)}$$

where d is the diameter, in metres, of the cell.

6 Expression of results

For a given batch of grain and knowing

- the density of the grain,
- the apparent density at a point in the grain, and
- the velocity at which the air enters the grain,

the corrected flow equation enables the unit pressure losses due to single-dimension air flow through the grain to be determined :

$$\Delta P = \frac{\varrho_c k\nu S'^2\,(1-\epsilon)^2}{g_n \epsilon^3} U_o + \frac{\varrho_c\, h\beta S'\,(1-\epsilon)}{g_n \epsilon^3} U_o^2$$

7 Practical application

7.1 Forecast of pressure losses for different apparent densities at a point

The experimental results relate to lightly settled grain. In reality, the apparent density at a point in a silo varies according to the height fallen by the grain and the storage height.

It is therefore necessary to formulate equations showing the unit pressure losses for different apparent densities at a point; as S' and $h\beta$ are known, this can be done using the formula

$$\epsilon = 1 - \frac{\varrho_s}{\varrho_v}$$

7.2 Total pressure losses

The total pressure losses are equal to

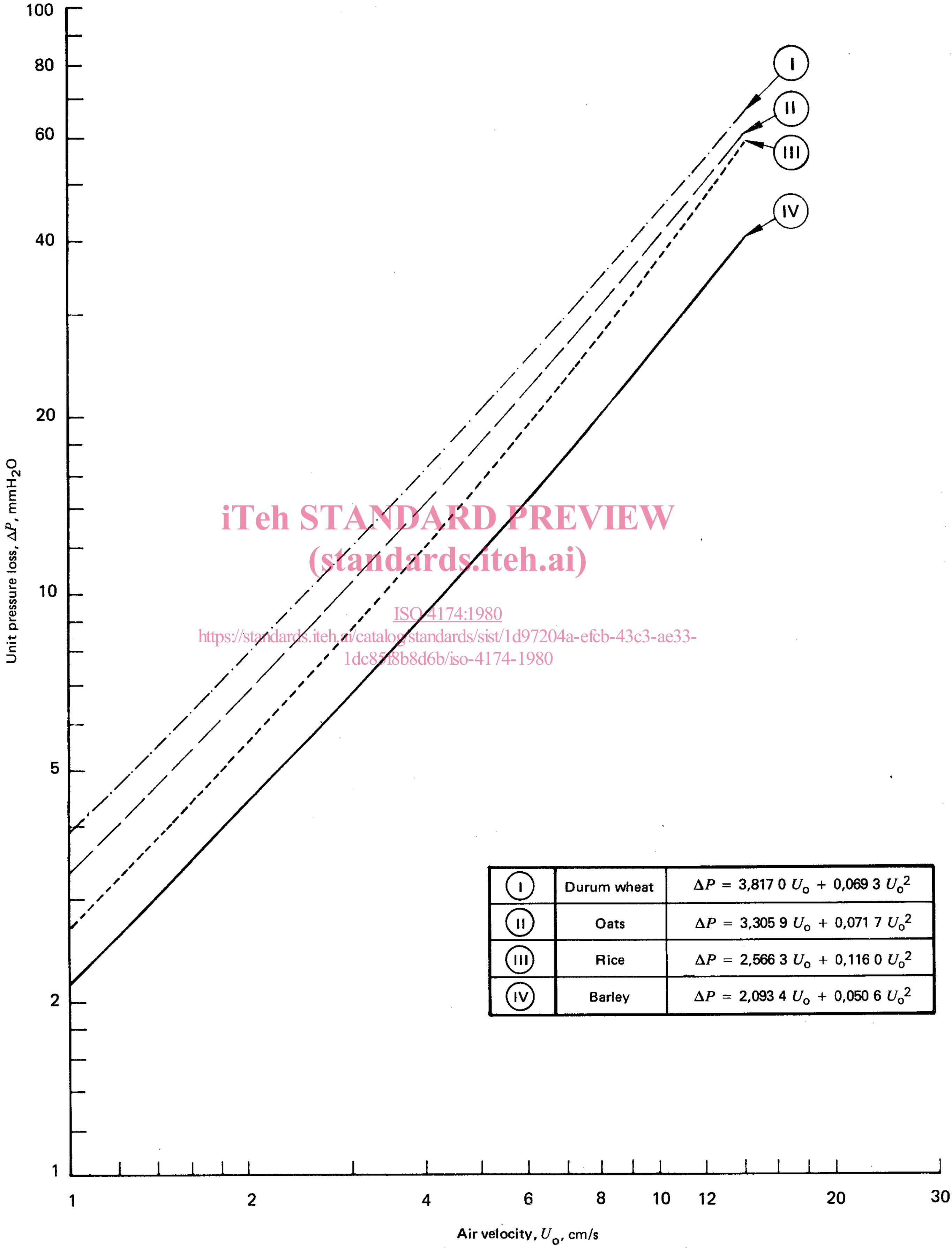
$$\Delta P \times h$$

where h is the height of the cell, in metres, in the case of an upward-flowing ventilation system or, in other cases, the distance travelled by the air, in metres.

8 Test report

The test report shall show the method used and the results obtained. It shall also clearly state the method of expression used and any operating conditions not specified in this International Standard or regarded as optional, as well as any circumstances that may have influenced the results.

The report shall include all details required for complete identification of the sample.



I	Durum wheat	$\Delta P = 3{,}817\,0\ U_o + 0{,}069\,3\ U_o^2$
II	Oats	$\Delta P = 3{,}305\,9\ U_o + 0{,}071\,7\ U_o^2$
III	Rice	$\Delta P = 2{,}566\,3\ U_o + 0{,}116\,0\ U_o^2$
IV	Barley	$\Delta P = 2{,}093\,4\ U_o + 0{,}050\,6\ U_o^2$

Figure 1 — Unit pressure losses due to single-dimension air flow through four types of grain