

Methods of test for drying performance of agricultural grain dryers

Part 2. Additional procedures and crop specific requirements

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Foreword

This Part of BS 3986 has been prepared by Technical Committee AGE/23. It specifies the method for testing the drying performance of continuous-flow and batch grain dryers for specific grains and oil seed crops of economic importance.

BS 3986 : 1991 has been amended and renumbered as BS 3986 : Part 1 : 1998. Part 1 covers only methods for evaluating the drying performance of continuous-flow and batch grain dryers when drying rewetted wheat with a moisture content in the range 20 % to 15 % wet basis.

The methods specified in Part 2 take account of the following factors:

- a greater range in input and output moisture contents;
- other crops as well as wheat;
- the impracticality of rewetting (dampening) some grains and of differing thermal characteristics.

For correcting the observed evaporation rates to those to be expected at different reference ambient and specified grain conditions, the correction formulae given in BS 3986 : Part 1 are augmented by a series of tables from which correction factors are found by interpolation.

The methods specified are for determining the water evaporation rate which the machines concerned are able to achieve when drying wheat and other grains under the steady state conditions prevailing during the tests. Methods for correcting observed performance to other input and reference ambient conditions are also specified.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 72, an inside back cover and a back cover.

1 Scope

This Part of BS 3986 specifies additional procedures and gives guidance for testing and evaluating the drying performance of continuous-flow and batch grain dryers for specific grain crops including wheat, barley, oats, maize, rice, sorghum and rape. It supplements the general procedures given in BS 3986 : Part 1 that are based on drying only wheat over a limited range of moisture content of 20 % to 15 % wet basis.

Methods and data are given for:

- a) determining the evaporation rate of dryers when drying grain crops under steady state conditions; and
- b) correcting the main dryer performance characteristics, including evaporation rate, grain flow rate, drying time and specific energy and fuel consumption, to reference and other ambient conditions.

Procedures are given for sampling input and output grain to assess changes in grain quality.

2 References

2.1 Normative references

This Part of BS 3986 incorporates, by dated or undated reference, provisions from other publications. These normative references are made at the appropriate places in the text and the cited publications are listed on the inside back cover. For dated references, only the edition cited applies; any subsequent amendments to or revisions of the cited publication apply to this Part of BS 3986 only when incorporated in the reference by amendment or revision. For undated references the latest edition of the cited publication applies, together with any amendments.

2.2 Informative references

This Part of BS 3986 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Definitions

For the purposes of this standard, the following definitions apply, supplementing the definitions given in BS 3986 : Part 1.

3.1 reference ambient conditions

The ambient conditions of temperature, relative humidity and barometric pressure to which the results of a dryer test shall be corrected.

3.2 airflow rate

The volume of air flowing in unit time per unit volume of grain. This value is also the number of air changes per unit of time.

NOTE. There are several ways of expressing airflow rate but for comparison between dryers and crops it is convenient to express airflow rate in this way.

3.3 drying period

The period during which drying air passes through the grain.

3.4 cooling period

The period during which ambient or near-ambient air passes through the grain.

3.5 tempering

The process by which partially dried grain is held in temporary storage for a number of hours without ventilation, allowing equalization of moisture content within the grain kernel with minimal stress cracking.

NOTE. When drying rice, a common practice is to cool it to within 2 °C of ambient prior to tempering for a minimum of 4 h. One or more further drying, cooling and tempering cycles may be given.

3.6 dryeration

The process by which hot grain is taken directly from a dryer and allowed to temper for a minimum of 4 h before being cooled slowly so as to extract additional moisture without using additional fossil fuel.

NOTE. The hot grain referred to is usually maize or rice.

3.7 test period

A period during which a continuous-flow dryer operating at a single steady state for at least one residence time, or a batch dryer completing a single full cycle of drying and cooling, is monitored to enable its thermodynamic performance to be assessed.

NOTE. In multi-pass drying there may be several test periods.

3.8 wheat

Grain of the genus *Triticum*. The commercially important species are *T. aestivum* (breadwheat), *T. durum* and *T. compactum* (club wheat)

3.9 barley

Grain of *Hordeum sativum* or *H. vulgare*.

3.10 oats

Grain of *Avena sativa* L.

3.11 naked oats

Grain of *Avena nuda* L. which readily loses the husk at threshing.

NOTE. Naked oats have a high protein and oil content and the loss of husk makes the kernels prone to rancidity.

3.12 maize

Grain of *Zea mays* L.

NOTE. This is commonly referred to as corn in North America and some other countries. There are about seven different types of maize distinguished at the 'convar' level of classification (between species and cultivar) and within each type there are hybrids having different drying properties. The most widely grown type is the convar *indentata* commonly known as 'dent corn'.

3.13 rice

Grain of *Oryza sativa* L.



3.14 paddy or rough rice

Rice with the hull or husk still intact

3.15 brown rice

Rice kernel from which the hull or husk has been removed during the milling process.

3.16 milled or white rice.

The white grain or kernel remaining after the removal of the husk or hull and of the bran (whitening); the embryo or germ may be totally or partly removed and part of the bran may still remain on the grain.

NOTE. For some end uses, rice may be dried in the milled condition.

3.17 head rice

For brown and milled rice, either a whole grain or a broken grain with length equal to or greater than three-quarters of the average length of a whole or unbroken grain.

3.18 full head rice

Unbroken head rice.

3.19 broken rice

Either brown or milled rice grain which has less than three-quarters of the average length of a full head grain.

3.20 sorghum

Grain of *Sorghum vulgare* Pers.

NOTE. Types of cultivated grain sorghum include kaffir corn, milo and durra (Africa), feteritas (Sudan), shallu, jowar, cholum and 'Indian millet' (India) and kaoliang (China).

3.21 rape (canola)

Seeds of *Brassica napus* or *B. campestris* (also known as *B. rapa*)

NOTE. Canola and rapeseed are both members of the same botanical family. The designation 'canola' has been established by Canada and is applicable to varieties that meet the canola standard for the level of erucic acid and glucosinolates in the seed. From the drying performance point of view, there is no evidence of any difference in drying rates or drying characteristics between rapeseed and canola.

4 Symbols and units

Symbol	Quantity	Units
<i>B</i>	rated output	kg/s
<i>E</i>	water evaporation	kg
<i>E'</i>	water evaporation rate	kg/s
<i>F</i>	fuel consumption	kg/s
<i>G</i>	holding capacity of dryer	kg
<i>J</i>	specific fuel consumption	kg/kg

<i>K</i>	factor for correcting evaporation (defined in 7.2.2)	
<i>M</i>	moisture content of grain, wet basis (m.c.w.b)	%
<i>N</i>	anticipated number of test periods	dimensionless
<i>Q</i>	specific heat consumption	J/kg
<i>S</i>	specific energy consumption	J/kg
<i>V</i>	volumetric capacity of dryer	m ³
<i>W</i>	energy consumption	J
<i>a</i>	air volume flow rate	m ³ /s
<i>c</i> _{1...3}	coefficients in equation E.1	
<i>d</i> _{1...3}	coefficients in equation E.2	
<i>c</i> _{pa}	specific heat of air at constant pressure	kJ·kg ⁻¹ ·K ⁻¹
<i>c</i> _{pw}	specific heat of water vapour at constant pressure	kJ·kg ⁻¹ ·K ⁻¹
<i>d</i>	depth of grain bed	m
<i>f</i>	face area at point of air entry to grain bed	m ²
<i>h</i>	specific enthalpy	J/kg
<i>i</i>	coefficient in equation E.3	
<i>m</i>	mass of grain in a single batch or passing through a continuous-flow dryer in a test run	kg
<i>m'</i>	mass flow of grain	kg/s
<i>n</i>	exponent in equation E.3	
<i>p</i>	pressure or pressure drop	Pa
<i>s(y)</i>	standard error of mean of variable <i>y</i>	
<i>t</i>	duration of test period	s
<i>ρ</i>	density	kg/m ³
<i>τ</i>	grain residence time in dryer	s

Subscripts

e	electrical
f	final; at dryer exit
i	initial, at dryer inlet
o	observed value
s	corrected value at reference or specified conditions
p	predicted (for model)
sys	dryer system of ducts and plenum chambers
t	thermal

5 Test procedure

5.1 General

This clause shall be used in conjunction with clause 7 of BS 3986 : Part 1.

NOTE 1. For the general principle of the tests, test equipment and preparation for test, see clauses 3, 5 and 6 respectively of BS 3986 : Part 1 : 1998

NOTE 2. Dryers are most often used to dry grain which is physiologically ripe and for which the variation in moisture content at harvest is largely a function of ambient weather conditions. For the purposes of a dryer test, such grain can normally be rewetted artificially and the test itself be conducted more conveniently outside the harvest period. One advantage of this is that the variation in moisture content of the wet grain is usually very small, i.e. less than $\pm 0.5\%$ w.b. This is important to minimizing uncertainty in the results.

However, some crops, e.g. maize in France, are harvested at moisture conditions in excess of those to which the grain can reasonably be rewetted and the test has to be conducted during the harvest. In these cases there may be considerable variation in the moisture content of the wet grain and residence times may be large.

Clause B.4 of BS 3986 : Part 1 : 1998 prescribes procedures for estimating the uncertainty (or level of confidence) in derived performance measures. Variation in ingoing moisture content is an important component of the determination of uncertainty. The uncertainty in determination of the evaporation rate and related quantities increases if too little moisture reduction is achieved (see annex A). A moisture reduction of more than four percentage points is therefore advisable. Prescriptions for specific crops are given in 5.4.

5.2 Test period

NOTE 1. See also clauses 7.5.3, 7.5.4 and 7.6 of BS 3986 : Part 1 : 1998.

The test period shall normally be a minimum of one residence time in a continuous-flow dryer or one drying and cooling cycle in a batch dryer.

NOTE 2. BS 3986 : Part 1 does not make a direct prescription of the length of the test period although experience has shown that, for a continuous-flow dryer, 1 h is normally sufficient provided that:

- 1.5 residence times are allowed for stabilization; and
- sampling of the input grain begins prior to the start of the test period, so that the initial moisture content of the grain which will leave the dryer during the test period is known.

Where good estimates of the mass flow rate and the measured capacity are available, calculate the residence time by either formulae (4a) or (4b) given in 8.2.2 of BS 3986 : Part 1 : 1998.

NOTE 2. For these formulae, the rated output, B (in kg/s) may be used in place of the observed mass flow of grain, m'_{fo} . Otherwise table 1 may be used to provide a guide to the residence time to be expected.

Table 1 gives a guide to approximate residence times (in h) for combinations of airflow, drying air temperature, moisture removed and specific energy consumption, calculated for a final moisture content of 15 %.

5.3 Frequency of sampling grain

5.3.1 Continuous flow dryers

Unless the range of variation in moisture contents of input grain is known to be less than 1 % w.b. (see annex A), take a minimum of 20 samples from the ingoing and outgoing grain streams of a continuous-flow dryer at a frequency such that they are spaced evenly over the test period.

NOTE 1. Clause 7.1.3 of BS 3986 : Part 1 : 1998 specifies sampling both ingoing and outgoing grain streams at a frequency which will provide at least 12 samples of each, spaced evenly over the test period. For rewetted wheat in which the range of variation is less than 1 % w.b., these prescriptions have given good accuracy for drying from 20 % w.b. to 15 % w.b., but are not adequate for all crops. The aim is to reduce the standard error of the mean to ensure an accuracy of estimation of the evaporation rate of $\pm 5\%$ (see annex A and figure A.2).

NOTE 2. Ingoing samples will need to correspond to the grain exiting from the dryer during the test period (see 7.1.3.1 of BS 3986 : Part 1 : 1998). Some grain samples taken will therefore later be found to be unnecessary although their additional use in rapid moisture tests may well have given essential information on the progress of stabilization.

5.3.2 Batch dryers

Because of the greater variability of moisture content which might occur in the output stream from a batch dryer, a minimum of 50 samples of the output grain shall be taken.

Table 1. Guide to dryer residence times

Moisture removed % w.b.	Specific heat energy consumption MJ/kg water evaporated	Residence time, h						
		Specific air volume flow rate, $\text{m}^3 \cdot \text{s}^{-1} \cdot \text{m}^{-3}$						
		0.3				3.0		
		Drying air temperature,						
		40 °C	90 °C	140 °C	40 °C	90 °C	140 °C	
5	4	7	4	2	0.6	0.2	0.1	
	10	17	7	5	1.4	0.5	0.4	
25	4	34	13	9	3	1.1	0.7	
	10	85	33	23	7	3	2	

5.4 Moisture removal

Except for multi-pass drying, a minimum of 4 percentage points of moisture content shall be removed in each test period. To maintain reasonable accuracy on the estimation of evaporation rate (see annex A), this minimum shall be increased in line with the variability in the ingoing moisture content in accordance with table 2 or figure A.3.

NOTE. Moisture content prescriptions for specific crops are discussed in annex B.

Table 2. Minimum moisture removals	
Range in ingoing moisture content, % w.b.	Minimum moisture removal, % w.b.
0.5	4
1	5
2	8
3	10
4	19
5	23

5.5 Grain dampening

Unless it is freshly harvested (i.e. less than 6 weeks from harvest), cereal grain shall not exceed 17 % m.c.w.b. before dampening, and shall not have received more than one drying treatment.

NOTE 1. The procedure for dampening is described in 6.3.2 of BS 3986 : Part 1 : 1998.

NOTE 2. Experience has shown that Canadian varieties of wheat, barley and canola can be dampened to 25 % w.b., 25 % w.b. and 20 % w.b. respectively.

5.6 Procedure for a multi-pass test

5.6.1 General

This procedure specifies the additional steps necessary for a multi-pass test. It shall be used in conjunction with 7.5 or 7.6 of BS 3986 : Part 1 : 1998, as appropriate.

5.6.2 Quantity of grain

Calculate the minimum quantity of grain for one test from the formula given in 5.3.1.1. of BS 3986 : Part 1 : 1998 but, where in this case, *N* represents the number of passes and *t* is the time for each pass. If more than one multi-pass test is to be conducted, multiply the formula by the number of such tests.

5.6.3 Outline procedure for continuous flow dryers

Fill the dryer, run it as for a single pass, and direct the output grain to a discard store. At the start of the test period, direct the output grain to the test period store. When the test period is complete, direct the output grain to a buffer store and continue drying without adjustment until all the grain has passed through the dryer.

Cool the grain that is in both the test period store and the buffer store to within 2 °C of ambient temperature, and temper it for 4 h.

Fill the dryer with the grain from the previous test period, and sample the input grain for use in calculating evaporation during the previous test period. Restart the dryer, direct the grain to the discard store and continue sampling the input. When the test period store is emptied, switch to feeding from the buffer store.

When the moisture content of the dryer output grain has stabilized, start a new test period by switching the grain to the test period store. When the test period is complete, direct the output grain to a new buffer store and continue drying until all the grain has passed through the dryer.

Repeat the procedure until all passes have been completed.

5.6.4 Outline procedure for batch dryers

5.6.4.1 Grain stationary

A dryer in which the grain remains stationary during drying shall be emptied between successive drying periods, taking samples for moisture content at input and output as in a single pass test.

NOTE. The purpose of removing the grain during rest periods is to aid the process of moisture equalization and destroy any moisture gradient.

5.6.4.2 Grain recirculating

A dryer in which the grain is recirculating during drying shall not be emptied during rest periods. Moisture content at the end and beginning of each test period shall be assessed on samples taken from the recirculating grain stream.

6 Grain quality

NOTE. It is assumed that good quality grain will be used in a dryer test. It is therefore important that its properties exceed the minimum national limits for the grain concerned. Where, as in the US and Canada, grain is categorized into grades, the aim should be to use grain satisfying Grades 1 and 2. A useful summary of cereal grain quality standards worldwide is given by Kent and Evers [1].

6.1 Input grain

6.1.1 All grains

Using the methods given for wheat, barley, oats, rice and sorghum in BS 4317 : Part 3, for maize in BS 4317 : Part 15, and for rapeseed in BS EN ISO 665, determine the moisture content of those samples taken from the input grain stream during the test period.

Record any relevant detail of grain origin or provenance, the variety and/or hybrid.

Either:

- a) obtain a 2 kg sample of the input grain as specified in **6.3.1** of BS 3986 : Part 1 : 1998; or
- b) if the grain is freshly harvested and there is no static bulk, take samples from the input grain stream additional to those being taken to monitor moisture variation with time. If the grain is to be dampened, obtain a 2 kg sample both before and after dampening.

Using a sample divider, remove from each 2 kg sample a 100 g sub-sample. Determine the moisture content using the methods given for wheat, barley, oats, rice and sorghum in BS 4317 : Part 3, for maize in BS 4317 : Part 15 and for rapeseed in BS EN ISO 665.

Dry the remainder of the 2 kg sample(s) with unheated air in a laboratory dryer until moisture contents of approximately 15 % w.b. and 10 % w.b. are reached for cereals' seeds and oilseed rape respectively.

Determine the mass per hectolitre (bulk density) using an instrument (chondrometer) calibrated in accordance with the reference method given in BS 4317 : Part 23.

Draw sub-samples of sufficient size for the determination of mass per 1000 grains in accordance with BS 4317 : Part 1, and of purity and germination using ISTA procedures [2].

NOTE 1. The ISTA procedures [2] contain instructions for checking that the averaged results of purity and germination tests fall within prescribed tolerances. If they do not, retest procedures should be followed. It is particularly important accurately to assess germination capacity because this property is a good guide to quality in general and can be a sensitive indicator of heat damage during drying. (See also **6.1.2**)

NOTE 2. In barley, seed dormancy may be broken by drying.

6.1.2 Wheat for baking

Depression in germination (**6.1.1**) shall be taken as an indication of damage to baking quality.

NOTE. A simple and rapid test for heat damage to protein has been shown [3] to be a useful guide to baking quality.

6.1.3 Maize

From the remainder of the 2 kg sample, draw four samples each of 100 grains. Examine the individual kernels on a grain viewer and count the number of cracked grains. Express the number of cracked grains as the mean of the four samples.

NOTE. Cracked grains reduce the value of maize for wet milling.

6.1.4 Rice

6.1.4.1 From the remainder of the 2 kg sample, draw four samples each of 100 grains. Carefully husk by hand, examine the individual kernels on a grain viewer and count the number of cracked grains. Express the number of cracked grains as the mean of the four samples.

6.1.4.2 From the remainder of the 2 kg sample, draw a further four samples each of 200 g and process through a laboratory husker and whitener. From the output from this machine:

- a) draw 100 g samples of brown rice and determine the number of broken grains;
- b) take four samples each of 100 grains and determine the number of cracked grains as given in **6.1.4.1**;
- c) return the material to the remainder of the 200 g samples which passed through the husker.

Separate sufficient whole grains of husked rice to determine the mass per 1000 grains of the brown rice. Return the grains to the sample.

Using the laboratory whitener, mill the brown rice and separate the head rice and broken rice from the rest of the grain materials. Weigh each component, in grams. Calculate the head milled rice recovery.

Draw four 100 grain samples of the milled rice and examine for any damage such as scorching, gelatinization or discoloration that may be due to excessive heat. Record the percentage of heat damaged grains.

6.2 Output grain

6.2.1 All grains

Determine the moisture content (see **6.1.1**) of those samples taken from the output grain stream during the test period.

Combine the remainder of these samples, to produce one or more samples of 2 kg, representative of the output grain. If the moisture content of the output grain is not close to 15 % w.b. for cereals or 10 % w.b. for rapeseed, either use a laboratory dryer or allow it to equilibrate in a laboratory.

Determine the mass per hectolitre, the mass per 1000 grains, and the purity and germination as given in **6.1.1**.

To determine whether any reduction in germination between the input and output grain is significant at the 2.5 % level of probability, use table C.1 in annex C

NOTE. Samples with low initial germination are likely to exhibit much more depression of germination than those with high initial germination.

6.2.2 Wheat for baking

Proceed as for **6.1.2**

6.2.3 Maize

Determine the percentage of cracked grains as in **6.1.2**. Express the increase in cracked grains from input to output as a percentage of the input.

6.2.4 Rice

Follow the procedure of **6.1.3**. Express the values for the output grain as a percentage of those for the input grain.

7 Methods of correction of test results

7.1 General

For the basis of the method of calculation of the test results and correction to standard conditions, see also clauses 8 and 9 of BS 3986 : Part 1 : 1998.

7.2 Evaporation rate

7.2.1 General

The water evaporation rate shall be determined in accordance with 8.2.4 of BS 3986 : Part 1 : 1998, and corrected to specified conditions either by using a computer simulation of the test dryer (7.2.2) or by interpolation of tabular data (7.2.3).

NOTE 1. The evaporation rate will not only be affected by a change in air mass flow rate caused by a change in air density, but will also be directly affected by differences between the observed and specified conditions in:

- drying air temperature;
- grain moisture reduction;
- airflow;
- ambient air humidity;
- ambient air temperature;
- barometric pressure.

In this list, arranged in order of influence on evaporation rate, airflow is assumed to alter either because of a change in resistance of the grain or through positive adjustment of the fan speed or throttling. Barometric pressure affects the psychrometric properties of the air.

Normally it will be required to correct and quote the dryer performance at specified values of the above variables. These specifications will vary both between, and to a lesser extent within, countries.

NOTE 2. Table 3 gives values of reference air ambient conditions that are typically used in three countries.

7.2.2 Using a computer model

The evaporation rate shall be corrected by multiplying the observed test value, E'_o , by the value predicted by the model for the specified conditions, E'_{ps} , and dividing by the value predicted for observed conditions, E'_{po} .

NOTE. No model, however sophisticated, can be expected to give exact agreement with the results observed experimentally because:

- a) there will be a random and systematic error in the experimental observations; and
- b) systematic error in the model.

Therefore, those parameters of the model which describe fundamental properties of air and grain and those which define values peculiar to the test, e.g. temperature, should not be adjusted to make the predicted performance fit that observed experimentally. However, adjustment of the value of airflow used in the simulation is permissible in circumstances where accurate measurement of the airflow is difficult and, for whatever reason, a value calculated by indirect methods is not available.

Grain thermal properties have a significant effect on model results. Where facilities and time are available, the mass transfer coefficients and moisture equilibria used in the model should be those measured on the test grain.

7.2.3 Using tabular data

Calculate the corrected evaporation rate by:

$$E'_s = KE'_o \quad (1)$$

where K is the ratio of the net evaporations for the specified reference conditions and the observed conditions obtained by interpolation from tables in annex D.

NOTE. In the tables in annex D, the quantity 'net evaporation' is the mass of water, in g, evaporated per kg of dry air, as predicted by a computer simulation of a continuous crossflow dryer having a drying to cooling ratio of 3 : 1. The values are calculated for a range of the main variables that affect evaporation in a dryer. The assumption is made that over a limited range of conditions, the proportional change in the evaporation rate of most dryers will be similar. The limits to the range have not been set but it is not intended that these tables should be used to predict dryer performance over a wide range of conditions. In most cases, linear interpolation will be adequate.

Example

Table 4 gives the observed and required specified reference conditions for a dryer test using wheat. In this case it is necessary to interpolate the tables, as shown in table 5, to determine net evaporations at both the observed and required conditions.

The first step is to interpolate to determine the predicted net evaporation at the observed test conditions. Since none of the four values coincide with tabulated values given in table D.2, it is necessary to interpolate for all of them. The number of values which are extracted from the table is equal to two, raised to the power of the number of parameters, i.e. $2^4 = 16$ in this case. The first four columns in table 5 set out the tabulated conditions which effectively bracket the observed conditions. The corresponding tabulated values of net evaporation are contained in the fifth column. The sixth column contains eight values which have been interpolated for an initial grain moisture content of 20.5 % from those in column five. Similarly, in column seven, these eight values are reduced to four which interpolate for a final grain moisture content of 14.8 %, and then further reduced to two in column eight by interpolating for the temperature of 68 °C. The final interpolation, in column nine, is for the airflow and produces a single value (13.20 g/kg) for the predicted net evaporation for the observed conditions of E'_{po} .

Interpolation to determine the net evaporation representing the specified reference conditions requires only a single interpolation between net evaporations at 60 °C and 70 °C, and gives a value for the predicted net evaporation of 11.93 g/kg.

Therefore $K = (11.93/13.20) = 0.905$ and hence in this case $E'_s = 0.905E'_o$

Table 3. Reference air ambient conditions for specifying drying performance

Country	Ambient temperature °C	Ambient relative humidity %	Barometric pressure Pa
UK	15	80	101 325
Canada (prairie regions)	10	50	101 130
Philippines	27	80	100 000

Table 4. Example of observed and required specified reference conditions

Performance parameter	Observed test conditions	Values for interpolation of observed test conditions from table D.2	Specified reference conditions	Values for interpolation of reference conditions from table D.2
Airflow, in $\text{m}^3 \cdot \text{s}^{-1} \cdot \text{m}^{-3}$	0.9	0.5 - 1.0	1	1
Drying air temperature, in $^{\circ}\text{C}$	68	60 - 70	65	60 - 70
Final m.c., in % w.b.	14.8	14 - 15	15	15
Initial m.c., in % w.b.	20.5	20 - 22	20	20

Table 5. Example interpolation of four parameters

1	2	3	4	5	6	7	8	9		
Airflow	Drying air temperature	Final moisture content of grain	Initial moisture content of grain	Net evaporation						
				Tabulated value	Interpolated value for initial moisture content	Interpolated value for final moisture content	Interpolated value for drying air temperature	Interpolated value for airflow		
m ³ ·s ⁻¹ ·m ⁻³	°C	% w.b.	% w.b.	g/kg	g/kg	g/kg	g/kg	g/kg		
0.5	60	14	20	11.73						
			20.5		11.85					
			22	12.22						
		14.8	20.5			11.94				
		15	20	11.83						
			20.5		11.96					
			22	12.36						
	68	14.8	20.5				14.22			
	70	14	20	14.62						
			20.5		14.77					
			22	15.20						
		14.8	20.5			14.79				
		15	20	14.62						
			20.5		14.79					
			22	15.29						
0.9	68	14.8	20.5					13.20		
1	60	14	20	10.26						
			20.5		10.42					
			22	10.88						
		14.8	20.5			10.63				
		15	20	10.51						
			20.5		10.68					
			22	11.18						
	68	14	20.5				12.94			
	70	14	20	13.21						
			20.5		13.4					
			22	13.95						
		14.8	20.5			13.52				
		15	20	13.34						
			20.5		13.55					
			22	14.18						

Using the same procedure, a correction for the change in evaporation with change of seed type can be determined using tables D.3, D.4, D.5 or D.6. It will be necessary first to estimate the change in airflow caused by differing crop resistance. A procedure for doing this is given in annex E.

Table D.1, although specific to wheat, provides for other crops an estimate of the adjustment to different reference ambient temperatures and relative humidities.

7.3 Mass flow rate of grain

For a continuous-flow dryer only, calculate the corrected output of dried grain.

$$m'_{fs} = E'_s (M_{is} - M_{fs}) / (100 - M_{is}) \quad (2)$$

7.4 Corrected drying time

For a batch dryer only, calculate E'_s and then calculate the corrected drying time

$$t_{ds} = m_{fs} (M_{is} - M_{fs}) / E'_s (100 - M_{is}) \quad (3)$$

NOTE. Evaporation during cooling is attributed to the drying period, as is assumed in the calculation of E'_o (8.3.1 of BS 3986 : Part 1 : 1998).

7.5 Specific thermal energy, total energy and fuel consumption

Calculate the corrected value of specific thermal energy consumption

$$Q_s = W_{ts} / E_s \quad (4)$$

Correct the specific total energy consumption

$$S_s = (Q_{es} + Q_{ts}) / E_s \quad (5)$$

and the specific fuel consumption

$$J_s = F_s / E'_s \quad (6)$$

8 Test report

The reporting of the dryer test shall be in accordance with clause 10 of BS 3968 : Part 1 : 1998.

Annexes

Annex A (informative)

Grain moisture content and sampling

A.1 Background

The accuracy of estimation of evaporation rate (8.2.4 and B.4.1 of BS 3986 : Part 1 : 1998) depends upon the accuracy of estimation of the mass of grain dried and the moisture removal. This annex recommends the frequency with which it is necessary to sample for grain moisture content and the amount of moisture it is necessary to remove so as to achieve an accuracy of $\pm 5\%$ on the estimate of the evaporation rate.

From B.4.1 of BS 3986 : Part 1 : 1998, the evaporation is

$$E = m \frac{(M_i - M_f)}{(100 - M_f)} \quad (\text{A.1})$$

and the combined relative standard error of the mean evaporation is

$$\frac{s(E)}{E} = \sqrt{\left[\left(\frac{s(m)}{m}\right)^2 + \left(\frac{100 - M_f}{(100 - M_i)(M_i - M_f)} s(M_i)\right)^2 + \left(\frac{-1}{(M_i - M_f)} s(M_f)\right)^2\right]} \quad (\text{A.2})$$

Given that m , the mass of grain dried, can be measured to a good degree of accuracy such that the standard error of the mean is less than 0.0005 of the total mass, the accuracy of measurement of the evaporation is dependent upon the extent of the variation in the inlet and outlet moisture contents [i.e. the standard errors of the means (SEM)] and the amount of moisture removed.

BS 3986 : Part 1 specifies that at least 12 samples are taken of the inlet and outlet grain for a continuous-flow dryer (7.1.3.1) and increases the output sampling to at least 50 for a batch dryer (7.1.3.2). The reason for increasing the number of samples of the output grain in the batch dryer is to minimize the effect of any moisture gradient that has developed during the drying period. In the continuous-flow case it was assumed that, if the dryer was working at steady state, there would be no significant variation in the outlet moisture content; it would certainly be damped relative to variation in the inlet moisture content.

In BS 3986 : Part 1, where the test grain is wheat, rewetted to 20 % moisture content, the variation in inlet moisture content should be quite low (i.e. of the order of $\pm 0.25\%$) so that a minimum of 12 samples for the inlet and outlet grain is adequate. However, this Part of BS 3986 is concerned with tests in which the test grain may be naturally wet and of a higher moisture content than that used for wheat.

An investigation was undertaken into:

- a) the effect of the range of grain moisture content removal on the number of samples necessary to achieve a reasonably good estimate of the mean moisture content, and its standard error; and
- b) the level of combined standard error to be achieved to keep the accuracy of the evaporation to within $\pm 5\%$ at the 95 % level of confidence.

A.2 Frequency of sampling

On the assumption that the variation in grain inlet moisture content is normally distributed about the mean, a random number generator was used to generate values of inlet moisture content spaced about two means of 20 % and 40 % over ranges of variation of inlet moisture content from 1 % to 6 %. The exercise was repeated several times and for numbers of samples from 5 to 50.

The results (see figure A.1) show that the SEM is dependent upon the range in variation of inlet moisture content about the mean but not upon the value of the mean. For means of 20 % and 40 % taken together, the SEMs (% w.b.) could be expressed as a linear function of the range so that:

$$\text{SEM} = 0.003 + 0.0735 (\text{range of inlet moisture content}) \quad (\text{A.3})$$

Figure A.2 shows how the SEM is affected by the number of samples taken.

Although 12 samples may be adequate if the range about the mean moisture content is less than 1 %, for larger ranges a greater number of samples can further reduce the SEM. As the number of samples is increased from 35 to 50, little further reduction in SEM takes place. A reasonable conclusion to draw from figure A.2 is that in all cases the number of samples taken should be increased to 20 and that where the range is likely to be greater than 3 %, the number should be increased to not less than 30.

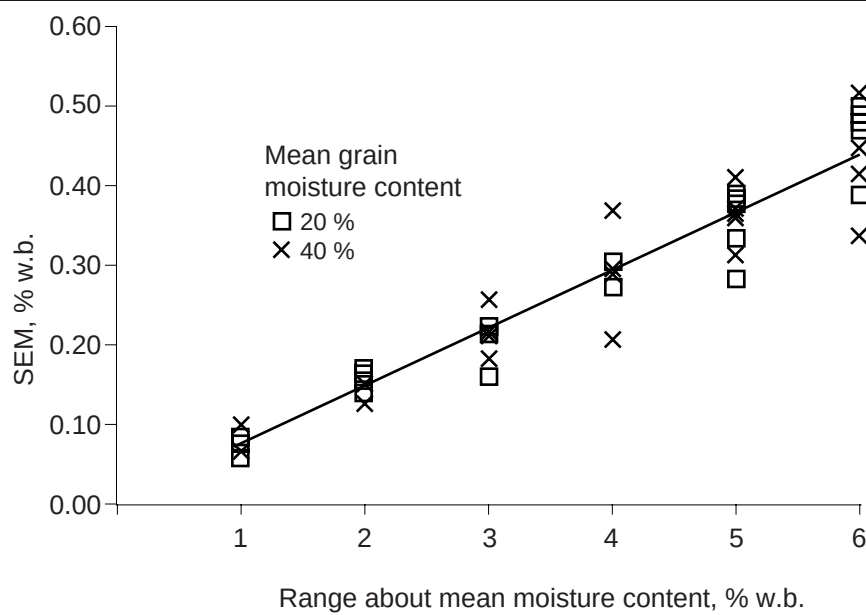


Figure A.1 The effect of range of variation in grain moisture content on the standard error of the means of 15 samples

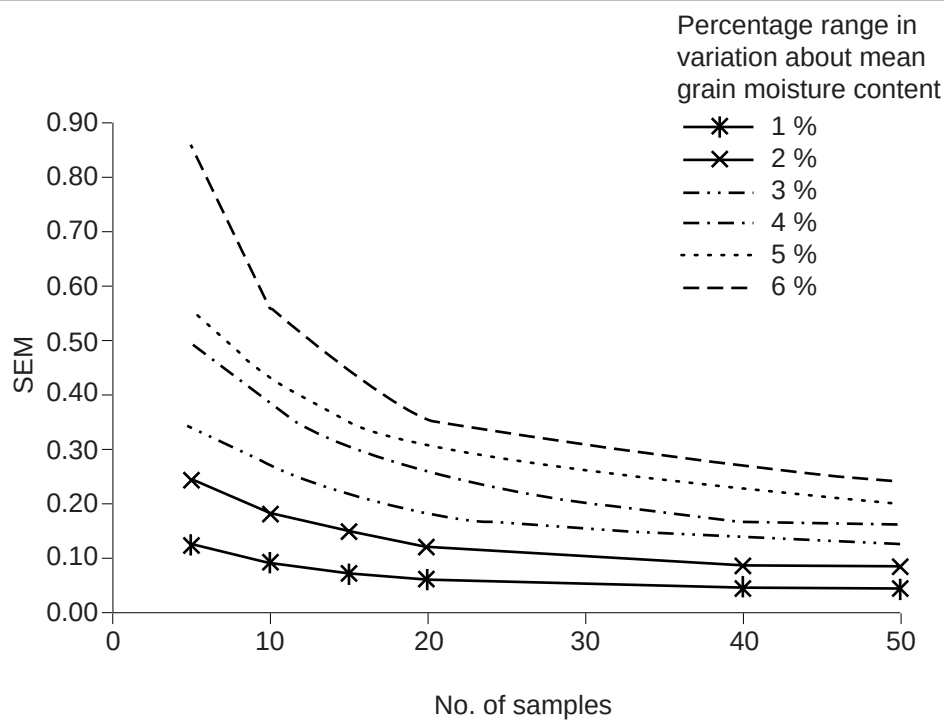
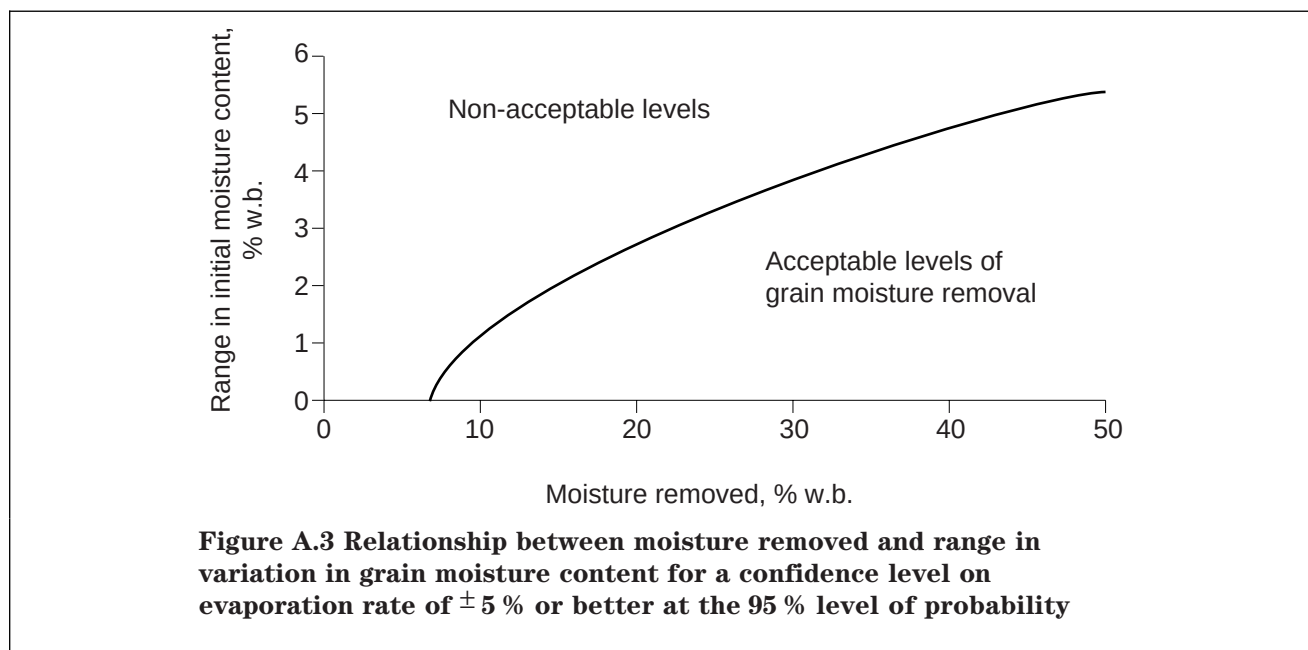


Figure A.2 Effect of number of samples on the standard error of the mean grain moisture content for different ranges in variation



A.3 Acceptable levels of grain moisture removal during testing

Having established the frequency of sampling to achieve reasonably low SEMs, the next steps were to solve equation A.2 which gives a combined standard error on the mean evaporation. This enables the calculation of a value for the combined degrees of freedom from which to find the value of Student's t , and thus to derive an estimate of error at the 95 % level of probability.

A minimization routine was then used to find the values of SEM of the grain inlet moisture content which would be necessary to achieve an accuracy of $\pm 5\%$ of the mean evaporation at the 95 % level of confidence. For this purpose, the SEM of the grain outlet moisture content was assumed to be 0.08 % w.b. From these SEMs, the range in variation in grain inlet moisture content could be estimated from the linear relationship given in equation A.3.

It was found that the dominating factor controlling the accuracy of the estimation of evaporation was the amount of moisture removed from the grain, ($M_i - M_f$) (see figure A.3).

Note that with the SEM of the outlet grain moisture content fixed at 0.08 % w.b., an accuracy of 5 % cannot be achieved even with zero variation in grain inlet moisture content at less than a moisture removal of 3.5 % w.b.

This analysis also confirms that the 5 % moisture removal specified for milling wheat in BS 3986 : Part 1 : 1998 is adequate, and that in the case of French maize, for example, a total range of 5 % w.b. ($\pm 2.5\%$ w.b.) in grain inlet moisture content can be tolerated provided that 25 % moisture is removed from the grain.

Annex B (informative)

Moisture removals in specific crops

B.1 Wheat, barley and oats

It is the convention in England and Wales to specify dryer performance when drying either from 21 % to 16 % w.b. or from 20 % to 15 % w.b., i.e. a moisture removal of 5 % w.b. In Canada, the convention is drying from 19.5 % to 14.5 % w.b. In some countries of northern Europe, e.g. Scotland and Finland, wheat is harvested at moisture contents up to 30 % w.b. In these cases the grain may be dried in two passes.

B.2 Maize (Corn)

Maize is not suitable for dampening, so all the tests are performed with grain fully ripened and at its natural moisture content. In North America, 10 % moisture removal, drying from 25 % w.b. to 15 % w.b. is practised. In France and other parts of mainland Europe, maize is harvested at moisture contents of up to 40 % w.b. and is required to be dried to 15 % w.b. If dryeration is practised, the grain moisture content at exit from the dryer prior to tempering is increased to between 16 % w.b. and 16.5 % w.b.

NOTE. Maize for seed is often dried on the cob prior to shelling. This standard is concerned only with dryers for shelled kernels.

B.3 Oilseed rape (canola)

Either freshly harvested grain or artificially re-moistened grain is used. Moisture removal of 5 % w.b. should be satisfactory when drying from a typical grain inlet moisture content of 15 % w.b.

B.4 Rice

Paddy is not suitable for dampening, so all the tests should be performed with grain fully ripened and at its natural moisture content. In southern Europe, paddy may be dried in one pass from 22 % w.b. to 14 % w.b. (i.e. an 8 % w.b. removal) at low drying air temperatures, depending upon type. For 'pearl' and 'vitreous' kernel types, the respective maximum drying air temperatures are 35 °C and 40 °C. In much of the world, paddy is dried in several passes removing 2 % to 3 % w.b. moisture content per pass. In tropical regions it is reasonable to expect an inlet grain moisture content of 25 % $\pm$ 1.5 % w.b. in the high or wet season and 20 % $\pm$ 1.0 % w.b. in the low or dry season.

B.5 Sorghum

Sorghum is harvested and dried at moisture contents which suggest that it could be suitable for dampening but no information is currently available. In USA conditions, sorghum is harvested at about 25 % m.c.w.b. The maximum limit of moisture content for USA Grade No. 1 is 13 % w.b.

Annex C (normative)

Testing reduction in grain germination

To determine whether a reduction in grain germination during drying is likely to have been caused by the drying, use the following procedure:

- Calculate, to the nearest whole number, the mean of the respective percentage germinations of the ingoing and outgoing grain.
- In either column 1 or column 2 of table C.1, locate the range within which this mean value falls. Read, in column of the same row, the tolerance between two tests.
- If the difference between the ingoing and outgoing germination percentages exceeds this tolerance, the difference is significant at the 2.5 % level of probability.

Table C.1 Tolerances for testing a difference between two percentage germinations

Range in mean germination of ingoing and outgoing grain		Tolerance between two tests
Mean > 50 %	Mean < 50 %	
%	%	% germination
98 to 99	2 to 3	2
95 to 97	4 to 6	3
91 to 94	7 to 10	4
85 to 90	11 to 16	5
77 to 84	17 to 24	6
60 to 76	25 to 41	7
51 to 59	42 to 50	8

NOTE. These data are for comparing germination tests performed on a sample of 400 seeds. They are derived from table 5.2 of the annex to chapter 15 of reference [2] in which a comprehensive description of the origin of the data is given.

Example 1

If the germination percentages of the ingoing and outgoing grain are 95 % and 90 % respectively, their mean is 92.5 % and their difference is 5 %. Reference to table C.1 gives a tolerance value of 4, therefore the difference is significant.

Example 2

If the germination percentages of the ingoing and outgoing grain are 66 % and 60 % respectively, their mean is 63 % and their difference is 6 %. Reference to table C.1 gives a tolerance value of 7, therefore the difference is not significant.

Annex D (normative)**Tables for correction of dryer performance**

This annex contains six tables presenting the net evaporation (in g water/kg dry air) computed for a simple cross-flow dryer having a drying to cooling ratio of 3:1. If a computer simulation of drying is not available, the tables shall be used as prescribed in 7.2.3 for adjusting the evaporation rate to specified reference conditions for a range of the values of the prime variables affecting the dryer evaporating performance.

All the tables consider the effect of changes in volumetric airflow, drying air temperature and final moisture content of grain.

Table D.1 deals with the effect of changes in ambient air relative humidity and temperature specifically for wheat at an input moisture content of 20 % w.b.

Tables D.2 to D.6 deal with the effect of changes in initial moisture content for wheat, oilseed rape, maize, rice and sorghum respectively.

NOTE. Table D.4 is divided into two parts. The first part deals with grain initial moisture contents from 18 % to 28 %. The second part deals with grain initial moisture contents from 30 % to 40 %.

Table D.1 Wheat: effect of ambient air temperature and relative humidity at constant initial moisture content of grain

The initial moisture content of the grain is 20 % w.b.

Volumetric airflow	Drying air temperature	Final moisture content of grain	Relative humidity of ambient air	Net evaporation, in g water/kg dry air				
				Ambient air temperature				
				5 °C	10 °C	15 °C	20 °C	25 °C
[range: 0.25 – 3.0] m ³ ·s ⁻¹ ·m ⁻³	[range: 50 – 90] °C	[range: 12 – 16] % w.b.	[range: 50 – 90] %					
0.25	50	12	50.00	10.44	10.44	10.34	10.13	9.78
0.25	50	12	60.00	10.19	10.08	9.86	9.51	8.99
0.25	50	12	70.00	9.92	9.72	9.38	8.88	8.18
0.25	50	12	80.00	9.66	9.36	8.89	8.24	7.27
0.25	50	12	90.00	9.38	8.98	8.38	7.51	*
0.25	50	13	50.00	10.61	10.64	10.57	10.38	10.03
0.25	50	13	60.00	10.36	10.29	10.10	9.77	9.27
0.25	50	13	70.00	10.10	9.94	9.65	9.19	8.54
0.25	50	13	80.00	9.84	9.59	9.19	8.61	7.82
0.25	50	13	90.00	9.58	9.24	8.73	8.02	7.09
0.25	50	14	50.00	10.71	10.76	10.71	10.52	10.18
0.25	50	14	60.00	10.45	10.41	10.24	9.92	9.41
0.25	50	14	70.00	10.20	10.06	9.78	9.33	8.68
0.25	50	14	80.00	9.94	9.72	9.33	8.75	7.97
0.25	50	14	90.00	9.68	9.37	8.88	8.19	7.30
0.25	50	15	50.00	10.74	10.82	10.80	10.63	10.29
0.25	50	15	60.00	10.48	10.47	10.32	10.00	9.49
0.25	50	15	70.00	10.23	10.12	9.85	9.40	8.74
0.25	50	15	80.00	9.97	9.77	9.39	8.81	8.02
0.25	50	15	90.00	9.71	9.42	8.94	8.24	7.34
0.25	50	16	50.00	10.70	10.83	10.84	10.71	10.40
0.25	50	16	60.00	10.45	10.47	10.35	10.06	9.57
0.25	50	16	70.00	10.19	10.11	9.87	9.44	8.79
0.25	50	16	80.00	9.93	9.76	9.40	8.83	8.05
0.25	50	16	90.00	9.67	9.41	8.94	8.25	7.35



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Table D.1 Wheat: effect of ambient air temperature and relative humidity at constant initial moisture content of grain <i>(continued)</i>								
The initial moisture content of the grain is 20 % w.b.								
Volumetric airflow	Drying air temperature	Final moisture content of grain	Relative humidity of ambient air	Net evaporation, in g water/kg dry air				
				Ambient air temperature				
				5 °C	10 °C	15 °C	20 °C	25 °C
[range: 0.25 – 3.0] m ³ ·s ⁻¹ ·m ⁻³	[range: 50 – 90] °C	[range: 12 – 16] % w.b.	[range: 50 – 90] %					
0.25	60	12	50.00	13.11	13.20	13.20	13.11	12.89
0.25	60	12	60.00	12.88	12.88	12.77	12.55	12.18
0.25	60	12	70.00	12.64	12.55	12.34	11.99	11.48
0.25	60	12	80.00	12.39	12.22	11.91	11.44	10.79
0.25	60	12	90.00	12.15	11.89	11.47	10.88	10.09
0.25	60	13	50.00	13.24	13.36	13.39	13.31	13.09
0.25	60	13	60.00	13.00	13.04	12.96	12.75	12.38
0.25	60	13	70.00	12.77	12.71	12.53	12.20	11.70
0.25	60	13	80.00	12.53	12.39	12.11	11.67	11.04
0.25	60	13	90.00	12.29	12.07	11.69	11.14	10.39
0.25	60	14	50.00	13.29	13.44	13.50	13.44	13.22
0.25	60	14	60.00	13.05	13.12	13.06	12.86	12.49
0.25	60	14	70.00	12.82	12.79	12.63	12.31	11.79
0.25	60	14	80.00	12.58	12.47	12.21	11.76	11.12
0.25	60	14	90.00	12.34	12.15	11.78	11.23	10.47
0.25	60	15	50.00	13.26	13.45	13.55	13.51	13.33
0.25	60	15	60.00	13.03	13.13	13.10	12.93	12.57
0.25	60	15	70.00	12.79	12.80	12.66	12.35	11.85
0.25	60	15	80.00	12.55	12.47	12.23	11.79	11.15
0.25	60	15	90.00	12.31	12.15	11.80	11.25	10.49
0.25	60	16	50.00	13.13	13.38	13.52	13.56	13.44
0.25	60	16	60.00	12.89	13.05	13.08	12.96	12.66
0.25	60	16	70.00	12.66	12.72	12.63	12.36	11.90
0.25	60	16	80.00	12.42	12.39	12.19	11.79	11.17
0.25	60	16	90.00	12.18	12.06	11.75	11.23	10.48
0.25	70	12	50.00	15.84	16.01	16.11	16.12	16.01
0.25	70	12	60.00	15.62	15.71	15.71	15.60	15.35
0.25	70	12	70.00	15.40	15.41	15.31	15.08	14.70
0.25	70	12	80.00	15.17	15.10	14.91	14.57	14.07
0.25	70	12	90.00	14.94	14.79	14.51	14.07	13.45
0.25	70	13	50.00	15.92	16.13	16.26	16.29	16.19
0.25	70	13	60.00	15.70	15.83	15.86	15.76	15.51
0.25	70	13	70.00	15.48	15.53	15.46	15.24	14.86
0.25	70	13	80.00	15.26	15.23	15.06	14.73	14.23
0.25	70	13	90.00	15.03	14.92	14.66	14.23	13.61

Table D.1 Wheat: effect of ambient air temperature and relative humidity at constant initial moisture content of grain (*continued*)

The initial moisture content of the grain is 20 % w.b.

Volumetric airflow	Drying air temperature	Final moisture content of grain	Relative humidity of ambient air	Net evaporation, in g water/kg dry air				
				Ambient air temperature				
[range: 0.25 – 3.0] m ³ ·s ⁻¹ ·m ⁻³	[range: 50 – 90] °C	[range: 12 – 16] % w.b.	[range: 50 – 90] %	5 °C	10 °C	15 °C	20 °C	25 °C
0.25	70	14	50.00	15.92	16.16	16.33	16.39	16.30
0.25	70	14	60.00	15.70	15.86	15.92	15.85	15.61
0.25	70	14	70.00	15.48	15.56	15.52	15.32	14.94
0.25	70	14	80.00	15.26	15.26	15.11	14.79	14.29
0.25	70	14	90.00	15.03	14.95	14.71	14.28	13.65
0.25	70	15	50.00	15.82	16.11	16.32	16.43	16.40
0.25	70	15	60.00	15.60	15.81	15.91	15.87	15.68
0.25	70	15	70.00	15.38	15.50	15.49	15.33	14.98
0.25	70	15	80.00	15.15	15.20	15.09	14.80	14.31
0.25	70	15	90.00	14.93	14.89	14.68	14.27	13.65
0.25	70	16	50.00	15.57	15.92	16.22	16.41	16.47
0.25	70	16	60.00	15.35	15.62	15.79	15.84	15.73
0.25	70	16	70.00	15.13	15.31	15.38	15.28	15.01
0.25	70	16	80.00	14.91	15.01	14.96	14.74	14.30
0.25	70	16	90.00	14.69	14.70	14.55	14.20	13.63
0.25	80	12	50.00	18.60	18.86	19.06	19.16	19.16
0.25	80	12	60.00	18.40	18.58	18.68	18.67	18.53
0.25	80	12	70.00	18.19	18.30	18.30	18.18	17.92
0.25	80	12	80.00	17.98	18.01	17.93	17.70	17.32
0.25	80	12	90.00	17.76	17.72	17.55	17.22	16.73
0.25	80	13	50.00	18.64	18.93	19.16	19.29	19.31
0.25	80	13	60.00	18.43	18.65	18.78	18.80	18.66
0.25	80	13	70.00	18.23	18.37	18.40	18.30	18.04
0.25	80	13	80.00	18.02	18.08	18.03	17.81	17.43
0.25	80	13	90.00	17.80	17.80	17.65	17.33	16.83
0.25	80	14	50.00	18.57	18.91	19.18	19.35	19.40
0.25	80	14	60.00	18.36	18.62	18.79	18.84	18.74
0.25	80	14	70.00	18.16	18.34	18.41	18.34	18.09
0.25	80	14	80.00	17.95	18.06	18.03	17.84	17.46
0.25	80	14	90.00	17.74	17.77	17.64	17.34	16.85
0.25	80	15	50.00	18.38	18.78	19.11	19.34	19.47
0.25	80	15	60.00	18.17	18.48	18.71	18.82	18.78
0.25	80	15	70.00	17.97	18.20	18.32	18.30	18.11
0.25	80	15	80.00	17.76	17.91	17.94	17.91	17.46
0.25	80	15	90.00	17.55	17.62	17.54	17.28	16.82

Table D.1 Wheat: effect of ambient air temperature and relative humidity at constant initial moisture content of grain <i>(continued)</i>								
The initial moisture content of the grain is 20 % w.b.								
Volumetric airflow	Drying air temperature	Final moisture content of grain	Relative humidity of ambient air	Net evaporation, in g water/kg dry air				
				Ambient air temperature				
				5 °C	10 °C	15 °C	20 °C	25 °C
[range: 0.25 – 3.0] m ³ ·s ⁻¹ ·m ⁻³	[range: 50 – 90] °C	[range: 12 – 16] % w.b.	[range: 50 – 90] %					
0.25	80	16	50.00	18.00	18.47	18.90	19.24	19.48
0.25	80	16	60.00	17.79	18.18	18.50	18.71	18.76
0.25	80	16	70.00	17.59	17.90	18.11	18.17	18.08
0.25	80	16	80.00	17.38	17.61	17.71	17.65	17.41
0.25	80	16	90.00	17.18	17.32	17.32	17.13	16.74
0.25	90	12	50.00	21.40	21.74	22.02	22.22	22.31
0.25	90	12	60.00	21.21	21.47	21.66	21.75	21.71
0.25	90	12	70.00	21.01	21.21	21.31	21.29	21.13
0.25	90	12	80.00	20.81	20.93	20.95	20.83	20.55
0.25	90	12	90.00	20.61	20.66	20.59	20.37	19.99
0.25	90	13	50.00	21.37	21.75	22.07	22.31	22.43
0.25	90	13	60.00	21.18	21.49	21.72	21.83	21.82
0.25	90	13	70.00	20.99	21.22	21.35	21.36	21.22
0.25	90	13	80.00	20.79	20.95	20.99	20.89	20.63
0.25	90	13	90.00	20.59	20.68	20.63	20.43	20.04
0.25	90	14	50.00	21.23	21.66	22.03	22.32	22.50
0.25	90	14	60.00	21.04	21.39	21.66	21.83	21.86
0.25	90	14	70.00	20.85	21.12	21.30	21.35	21.24
0.25	90	14	80.00	20.65	20.85	20.94	20.87	20.63
0.25	90	14	90.00	20.45	20.58	20.57	20.39	20.03
0.25	90	15	50.00	20.94	21.42	21.86	22.22	22.52
0.25	90	15	60.00	20.75	21.16	21.50	21.74	21.86
0.25	90	15	70.00	20.56	20.89	21.13	21.25	21.22
0.25	90	15	80.00	20.36	20.62	20.77	20.77	20.59
0.25	90	15	90.00	20.16	20.34	20.40	20.28	19.97
0.25	90	16	50.00	20.41	20.99	21.55	22.04	22.46
0.25	90	16	60.00	20.23	20.73	21.16	21.53	21.77
0.25	90	16	70.00	20.03	20.46	20.80	21.03	21.10
0.25	90	16	80.00	19.85	20.18	20.42	20.53	20.46
0.25	90	16	90.00	19.65	19.91	20.05	20.03	19.82
0.5	50	12	50.00	9.40	9.40	9.32	9.13	8.83
0.5	50	12	60.00	9.20	9.10	8.91	8.59	8.10
0.5	50	12	70.00	8.98	8.80	8.49	8.01	7.32
0.5	50	12	80.00	8.74	8.47	8.04	7.40	6.39
0.5	50	12	90.00	8.50	8.13	7.56	6.67	*

Table D.1 Wheat: effect of ambient air temperature and relative humidity at constant initial moisture content of grain (*continued*)

The initial moisture content of the grain is 20 % w.b.

Volumetric airflow	Drying air temperature	Final moisture content of grain	Relative humidity of ambient air	Net evaporation, in g water/kg dry air				
				Ambient air temperature				
[range: 0.25 – 3.0] m ³ ·s ⁻¹ ·m ⁻³	[range: 50 – 90] °C	[range: 12 – 16] % w.b.	[range: 50 – 90] %	5 °C	10 °C	15 °C	20 °C	25 °C
0.5	50	13	50.00	9.73	9.77	9.73	9.59	9.32
0.5	50	13	60.00	9.52	9.48	9.34	9.06	8.63
0.5	50	13	70.00	9.31	9.19	8.93	8.53	7.94
0.5	50	13	80.00	9.09	8.88	8.52	7.99	7.24
0.5	50	13	90.00	8.86	8.57	8.10	7.42	6.48
0.5	50	14	50.00	9.95	10.02	10.02	9.91	9.66
0.5	50	14	60.00	9.74	9.73	9.63	9.38	8.97
0.5	50	14	70.00	9.53	9.44	9.23	8.85	8.30
0.5	50	14	80.00	9.31	9.14	8.82	8.33	7.62
0.5	50	14	90.00	9.09	8.83	8.41	7.79	6.95
0.5	50	15	50.00	10.06	10.18	10.22	10.14	9.91
0.5	50	15	60.00	9.85	9.89	9.81	9.60	9.20
0.5	50	15	70.00	9.64	9.59	9.41	9.06	8.51
0.5	50	15	80.00	9.42	9.29	9.01	8.53	7.84
0.5	50	15	90.00	9.20	8.98	8.59	8.00	7.18
0.5	50	16	50.00	10.06	10.23	10.32	10.28	10.09
0.5	50	16	60.00	9.85	9.94	9.91	9.73	9.36
0.5	50	16	70.00	9.64	9.64	9.50	9.18	8.65
0.5	50	16	80.00	9.42	9.33	9.09	8.64	7.95
0.5	50	16	90.00	9.20	9.03	8.67	8.10	7.28
0.5	60	12	50.00	12.20	12.28	12.31	12.24	12.07
0.5	60	12	60.00	12.01	12.02	11.94	11.75	11.43
0.5	60	12	70.00	11.81	11.74	11.57	11.26	10.79
0.5	60	12	80.00	11.60	11.46	11.18	10.75	10.13
0.5	60	12	90.00	11.39	11.16	10.78	10.22	9.44
0.5	60	13	50.00	12.43	12.57	12.63	12.61	12.47
0.5	60	13	60.00	12.24	12.30	12.27	12.13	11.84
0.5	60	13	70.00	12.05	12.03	11.90	11.64	11.22
0.5	60	13	80.00	11.85	11.75	11.53	11.15	10.59
0.5	60	13	90.00	11.64	11.46	11.15	10.66	9.97
0.5	60	14	50.00	12.55	12.73	12.84	12.86	12.75
0.5	60	14	60.00	12.36	12.46	12.48	12.37	12.11
0.5	60	14	70.00	12.17	12.19	12.11	11.88	11.48
0.5	60	14	80.00	11.97	11.91	11.73	11.39	10.86
0.5	60	14	90.00	11.76	11.63	11.36	10.90	10.24

Table D.1 Wheat: effect of ambient air temperature and relative humidity at constant initial moisture content of grain (<i>continued</i>)								
The initial moisture content of the grain is 20 % w.b.								
Volumetric airflow [range: 0.25 – 3.0] $\text{m}^3 \cdot \text{s}^{-1} \cdot \text{m}^{-3}$	Drying air temperature [range: 50 – 90] °C	Final moisture content of grain [range: 12 – 16] % w.b.	Relative humidity of ambient air [range: 50 – 90] %	Net evaporation, in g water/kg dry air				
				Ambient air temperature				
				5 °C	10 °C	15 °C	20 °C	25 °C
0.5	60	15	50.00	12.56	12.79	12.95	13.01	12.94
0.5	60	15	60.00	12.37	12.52	12.57	12.51	12.28
0.5	60	15	70.00	12.17	12.24	12.20	12.01	11.64
0.5	60	15	80.00	11.97	11.97	11.83	11.52	11.00
0.5	60	15	90.00	11.77	11.68	11.45	11.02	10.38
0.5	60	16	50.00	12.42	12.71	12.94	13.06	13.05
0.5	60	16	60.00	12.22	12.43	12.56	12.56	12.38
0.5	60	16	70.00	12.03	12.16	12.18	12.04	11.71
0.5	60	16	80.00	11.83	11.88	11.80	11.54	11.06
0.5	60	16	90.00	11.63	11.60	11.42	11.04	10.42
0.5	70	12	50.00	14.98	15.16	15.29	15.34	15.29
0.5	70	12	60.00	14.81	14.91	14.95	14.89	14.70
0.5	70	12	70.00	14.62	14.66	14.60	14.43	14.12
0.5	70	12	80.00	14.43	14.40	14.26	13.97	13.53
0.5	70	12	90.00	14.24	14.13	13.90	13.51	12.94
0.5	70	13	50.00	15.13	15.36	15.53	15.63	15.61
0.5	70	13	60.00	14.95	15.11	15.19	15.17	15.03
0.5	70	13	70.00	14.77	14.86	14.85	14.72	14.45
0.5	70	13	80.00	14.58	14.60	14.50	14.27	13.87
0.5	70	13	90.00	14.39	14.33	14.15	13.81	13.29
0.5	70	14	50.00	15.15	15.43	15.66	15.80	15.83
0.5	70	14	60.00	14.98	15.18	15.32	15.34	15.23
0.5	70	14	70.00	14.79	14.93	14.97	14.89	14.64
0.5	70	14	80.00	14.61	14.67	14.62	14.43	14.06
0.5	70	14	90.00	14.42	14.41	14.27	13.97	13.47
0.5	70	15	50.00	15.05	15.38	15.67	15.87	15.96
0.5	70	15	60.00	14.87	15.13	15.32	15.40	15.34
0.5	70	15	70.00	14.69	14.87	14.97	14.94	14.74
0.5	70	15	80.00	14.50	14.62	14.62	14.48	14.14
0.5	70	15	90.00	14.31	14.36	14.27	14.01	13.54
0.5	70	16	50.00	14.76	15.15	15.52	15.81	15.98
0.5	70	16	60.00	14.57	14.91	15.17	15.34	15.35
0.5	70	16	70.00	14.40	14.65	14.82	14.86	14.74
0.5	70	16	80.00	14.22	14.40	14.48	14.40	14.12
0.5	70	16	90.00	14.03	14.14	14.12	13.93	13.51

Table D.1 Wheat: effect of ambient air temperature and relative humidity at constant initial moisture content of grain (*continued*)

The initial moisture content of the grain is 20 % w.b.

Volumetric airflow	Drying air temperature	Final moisture content of grain	Relative humidity of ambient air	Net evaporation, in g water/kg dry air				
				Ambient air temperature				
[range: 0.25 – 3.0] m ³ ·s ⁻¹ ·m ⁻³	[range: 50 – 90] °C	[range: 12 – 16] % w.b.	[range: 50 – 90] %	5 °C	10 °C	15 °C	20 °C	25 °C
0.5	80	12	50.00	17.75	18.02	18.25	18.41	18.48
0.5	80	12	60.00	17.59	17.79	17.93	17.99	17.93
0.5	80	12	70.00	17.41	17.55	17.61	17.57	17.39
0.5	80	12	80.00	17.24	17.31	17.28	17.14	16.85
0.5	80	12	90.00	17.05	17.06	16.95	16.70	16.30
0.5	80	13	50.00	17.81	18.13	18.41	18.63	18.74
0.5	80	13	60.00	17.64	17.90	18.09	18.20	18.19
0.5	80	13	70.00	17.47	17.66	17.78	17.78	17.64
0.5	80	13	80.00	17.30	17.42	17.45	17.35	17.10
0.5	80	13	90.00	17.12	17.18	17.12	16.92	16.56
0.5	80	14	50.00	17.74	18.11	18.45	18.72	18.90
0.5	80	14	60.00	17.58	17.88	18.13	18.30	18.34
0.5	80	14	70.00	17.40	17.65	17.81	17.87	17.78
0.5	80	14	80.00	17.23	17.41	17.49	17.44	17.22
0.5	80	14	90.00	17.05	17.16	17.16	17.01	16.67
0.5	80	15	50.00	17.52	17.95	18.36	18.70	18.95
0.5	80	15	60.00	17.35	17.72	18.04	18.26	18.37
0.5	80	15	70.00	17.19	17.49	17.72	17.84	17.81
0.5	80	15	80.00	17.01	17.25	17.39	17.40	17.24
0.5	80	15	90.00	16.84	17.00	17.06	16.97	16.68
0.5	80	16	50.00	17.07	17.59	18.09	18.53	18.89
0.5	80	16	60.00	16.91	17.36	17.77	18.09	18.28
0.5	80	16	70.00	17.74	17.11	17.43	17.64	17.71
0.5	80	16	80.00	16.58	16.88	17.10	17.20	17.11
0.5	80	16	90.00	16.41	16.65	16.77	16.75	16.55
0.5	90	12	50.00	20.50	20.86	21.18	21.45	21.65
0.5	90	12	60.00	20.35	20.64	20.89	21.06	21.14
0.5	90	12	70.00	20.19	20.42	20.59	20.27	20.63
0.5	90	12	80.00	20.02	20.20	20.29	20.27	20.11
0.5	90	12	90.00	19.85	19.96	19.97	19.86	19.60
0.5	90	13	50.00	20.48	20.89	21.27	21.60	21.84
0.5	90	13	60.00	20.32	20.68	20.98	21.20	21.33
0.5	90	13	70.00	20.17	20.46	20.68	20.81	20.82
0.5	90	13	80.00	20.00	20.23	20.38	20.41	20.30
0.5	90	13	90.00	19.83	20.00	20.07	20.01	19.79

Table D.1 Wheat: effect of ambient air temperature and relative humidity at constant initial moisture content of grain <i>(continued)</i>								
The initial moisture content of the grain is 20 % w.b.								
Volumetric airflow	Drying air temperature	Final moisture content of grain	Relative humidity of ambient air	Net evaporation, in g water/kg dry air				
				Ambient air temperature				
				5 °C	10 °C	15 °C	20 °C	25 °C
[range: 0.25 – 3.0] m ³ ·s ⁻¹ ·m ⁻³	[range: 50 – 90] °C	[range: 12 – 16] % w.b.	[range: 50 – 90] %					
0.5	90	14	50.00	20.32	20.78	21.23	21.62	21.93
0.5	90	14	60.00	20.16	20.57	20.93	21.22	21.41
0.5	90	14	70.00	20.01	20.35	20.64	20.82	20.88
0.5	90	14	80.00	19.84	20.13	20.33	20.42	20.36
0.5	90	14	90.00	19.68	19.90	20.02	20.01	19.83
0.5	90	15	50.00	19.99	20.51	21.03	21.51	21.91
0.5	90	15	60.00	19.83	20.30	20.74	21.10	21.36
0.5	90	15	70.00	19.68	20.07	20.44	20.70	20.83
0.5	90	15	80.00	19.51	19.86	20.12	20.29	20.29
0.5	90	15	90.00	19.35	19.63	19.82	19.88	19.75
0.5	90	16	50.00	19.39	19.99	20.62	21.21	21.73
0.5	90	16	60.00	19.23	19.78	20.32	20.80	21.17
0.5	90	16	70.00	19.08	19.55	20.00	20.39	20.62
0.5	90	16	80.00	18.92	19.34	19.70	19.95	20.06
0.5	90	16	90.00	18.75	19.11	19.40	19.54	19.51
1	50	12	50.00	7.36	7.36	7.30	7.17	6.95
1	50	12	60.00	7.21	7.15	7.01	6.77	6.40
1	50	12	70.00	7.05	6.93	6.70	6.33	5.76
1	50	12	80.00	6.88	6.68	6.35	5.83	4.96
1	50	12	90.00	6.69	6.40	5.95	5.20	*
1	50	13	50.00	7.77	7.81	7.80	7.72	7.55
1	50	13	60.00	7.63	7.61	7.53	7.35	7.05
1	50	13	70.00	7.48	7.41	7.24	6.96	6.52
1	50	13	80.00	7.32	7.18	6.93	6.53	5.92
1	50	13	90.00	7.14	6.94	6.59	6.06	5.24
1	50	14	50.00	8.09	8.17	8.20	8.16	8.03
1	50	14	60.00	7.95	7.98	7.93	7.80	7.55
1	50	14	70.00	7.80	7.77	7.66	7.42	7.03
1	50	14	80.00	7.65	7.56	7.36	7.02	6.49
1	50	14	90.00	7.48	7.33	7.04	6.59	5.91
1	50	15	50.00	8.33	8.46	8.53	8.52	8.43
1	50	15	60.00	8.19	8.26	8.26	8.17	7.94
1	50	15	70.00	8.04	8.06	7.98	7.79	7.43
1	50	15	80.00	7.89	7.84	7.69	7.39	6.90
1	50	15	90.00	7.73	7.61	7.38	6.97	6.35