



BSI Standards Publication

Clean cookstoves and clean cooking solutions — Harmonized laboratory test protocols

Part 1: Standard test sequence for emissions and
performance, safety and durability

National foreword

This British Standard is the UK implementation of ISO 19867-1:2018.

The UK participation in its preparation was entrusted to Technical Committee RHE/28, Domestic solid mineral fuel appliances.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2018
Published by BSI Standards Limited 2018

ISBN 978 0 580 92976 2

ICS 97.040.20

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 June 2018.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

INTERNATIONAL STANDARD

ISO
19867-1

First edition
2018-06-04

Clean cookstoves and clean cooking solutions — Harmonized laboratory test protocols —

Part 1: Standard test sequence for emissions and performance, safety and durability

*Fourneaux et foyers de cuisson propres — Protocoles d'essai en
laboratoire harmonisés —*

Partie 1: Séquence générale d'essais en laboratoire



Reference number
ISO 19867-1:2018(E)
Documents
Document Sharing Hub
© ISO 2018



COPYRIGHT PROTECTED DOCUMENT

© ISO 2018, Published in Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

Page

Foreword	vi
Introduction	vii
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Symbols and abbreviated terms	7
5 Laboratory-based measurements of emissions and performance	8
5.1 General	8
5.2 Testing conditions	8
5.3 Measurements	9
5.3.1 Required measurements for standard test sequence	9
5.3.2 Required metrics for standard test sequence	9
5.3.3 Continuous emission data	10
5.3.4 Optional measurements	10
5.3.5 Optional metrics	10
5.3.6 Measurement quality objectives	10
5.3.7 Measurement of carbon monoxide and carbon dioxide	11
5.3.8 Total-capture dilution-tunnel gravimetric method for measurement of PM _{2,5}	12
5.3.9 Measurement of biomass fuel energy content	18
5.4 Calculations	18
5.4.1 Calculation of mass of PM _{2,5}	18
5.4.2 Useful energy delivered calculation	18
5.4.3 Cooking power calculation	19
5.4.4 Cooking thermal efficiency calculation with no energy credit for remaining char	19
5.4.5 Cooking thermal efficiency calculation with energy credit for remaining char	19
5.4.6 Char energy productivity	20
5.4.7 Char mass productivity	20
5.4.8 Emission factor calculation	20
5.4.9 Emission rate calculation	20
5.5 Determination of heating value	21
5.6 Secondary dilution system methods	21
5.6.1 Secondary dilution systems used in the standard test sequence	21
5.6.2 Secondary dilution system calibration	22
5.7 Carbon mass balance method	22
6 Standard test sequence for emissions and performance	22
6.1 General	22
6.2 Phases of the standard test sequence	22
6.3 Standard test sequence diagrams	23
6.4 Limitations	24
6.5 Cookstove system requirements	24
6.5.1 Cookstove	24
6.5.2 Cooking vessel	25
6.5.3 Fuel	25
6.5.4 Operating procedure	25
6.6 Determination of cooking power levels	25
6.6.1 Low power	25
6.6.2 Medium power	26
6.6.3 High power	26
6.7 Procedure for standard test sequence	26
6.7.1 Test preparation	26

6.7.2	Test steps	27
6.7.3	Emission testing	29
6.7.4	Test replicates	29
6.8	Specific procedures for cookstove types	30
6.8.1	Plancha cookstoves	30
6.8.2	Chimney cookstoves	30
6.8.3	Charcoal-fuelled cookstoves	30
6.8.4	Solar cookstoves	31
7	Safety measurements	31
7.1	Measurement equipment	31
7.2	Taking measurements	31
7.2.1	General	31
7.2.2	Test 1: Sharp edges and points	31
7.2.3	Test 2: Cookstove tipping	32
7.2.4	Test 3: Containment of fuel	33
7.2.5	Test 4: Obstructions near cooking surface	34
7.2.6	Tests 5, 6, and 7	35
7.2.7	Test 8: Chimney shielding	36
7.2.8	Test 9: Flames surrounding cooking vessel	37
7.2.9	Test 10: Flames exiting fuel chamber	37
7.2.10	Overall safety score	38
7.2.11	Optional Test 11 for plancha (griddle) stoves	38
7.3	Materials	38
8	Durability measurements	38
8.1	Equipment for durability stress testing	39
8.2	Taking measurements	40
8.2.1	General	40
8.2.2	Test 1: Extended run	41
8.2.3	Test 2: External impact	43
8.2.4	Test 3: Internal impact	44
8.2.5	Test 4: Corrosion	45
8.2.6	Test 5: Coating adhesion	46
8.2.7	Test 6: Quenching	48
8.2.8	Test 7: Material failure temperature	49
8.2.9	Limitations for durability stress tests	50
9	Reporting test results	51
9.1	General	51
9.2	Report contents	51
9.2.1	Administrative information	51
9.2.2	Tests and metrics	51
9.2.3	Reporting against performance targets	52
9.2.4	Quality assurance and quality control	52
9.3	Templates	53
10	Marking and packaging	53
Annex A (informative)	Laboratory-based measurements of emissions and performance — Additional considerations	55
Annex B (normative)	Total-capture dilution-tunnel gravimetric method for measurement of PM_{2,5}	67
Annex C (informative)	Standard test sequence — Additional considerations	73
Annex D (informative)	Cookstove family determination	78
Annex E (informative)	Laboratory-based safety and durability measurements — Additional considerations	80
Annex F (informative)	Scoring tables for safety and durability tests	83

Annex G (informative) Infrared thermometer calibration.....89
Annex H (informative) Reporting template.....90
Bibliography.....103

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 www.iso.org/directives.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received www.iso.org/patents.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 285, *Clean cookstoves and clean cooking solutions*.

A list of all the parts in the ISO 19867 series can be found on the ISO website.

Introduction

This document is intended for use as laboratory measurement procedures to determine performance for cookstoves used primarily for cooking or water heating. Its purpose is to provide metrics that can be used to indicate a cookstove's performance under controlled conditions. This document provides a standard test sequence that can be used to compare the performance of various cookstove types, cookstove fuels, and cooking practices under controlled laboratory test conditions, as specified in this document.

This document was developed to achieve two goals:

- a) greater alignment in methodology and metrics around the world, and
- b) adaptation of methodology and metrics to the wide variety of cookstove types, cookstove fuels, and cooking practices.

For the purpose of this document, the intended user group refers to the approximately 2,8 billion people worldwide who are currently cooking with open fires or rudimentary stoves.

For evaluation of the performance and predicted outcomes of a cooking system in the field [comprising cookstove(s), fuel(s), cooking vessel(s), kitchen, ventilation, and user(s)], ISO 19869¹⁾ applies.

This document was developed from best practices from existing cookstove testing protocols, the experience of cookstove testing centres in many countries, and standards and testing methodology in related sectors.

Air pollutant emissions results are expressed in units of mass of pollutant per useful energy delivered and represent the mass of emissions per unit of cooking energy delivered. Emission results are also expressed in units of mass of pollutant per time and represent the mass rate of emission per unit time. Procedures for determining emissions require a complex set of individual measurements, rather than a single measured value. Thus, the results obtained depend as much on the procedure used to perform the measurements as they depend on the cookstove and the test method. The procedure used to perform the complex set of individual measurements is critical to obtaining the results.

Energy efficiency results are expressed as thermal efficiency. Cooking power results are expressed in units of watts.

Safety and durability results are expressed as a points-based rating system to enable individual countries and organizations to select levels based on their priorities. Durability methods are intended to evaluate the aspects of cookstove designs that can affect usable life and consumers' perceptions of quality. Durability testing methods include evaluation of extended runs, quenching, external and internal impacts, coating adhesion, corrosion, and material failure temperature.

1) In preparation.

This page deliberately left blank

Clean cookstoves and clean cooking solutions — Harmonized laboratory test protocols —

Part 1: Standard test sequence for emissions and performance, safety and durability

1 Scope

This document is applicable to cookstoves used primarily for cooking or water heating in domestic, small-scale enterprise, and institutional applications, typically with firepower less than 20 kW and cooking vessel volume less than 150 l, excluding cookstoves used primarily for space heating. For solar cookstoves, the provisions of this document are applicable only for evaluating cooking power, safety, and durability. Solar cookstoves have zero on-site emissions, and their cooking power can be determined according to ASAE S 580.1. This document does not cover electric stoves. Safety evaluation of electric stoves can be found in IEC 60335-2-6[62].

This document specifies laboratory measurement and evaluation methods for

- a) particulate and gaseous air pollutant emissions,
- b) energy efficiency,
- c) safety, and
- d) durability of cookstoves.

This document does not include evaluation of off-gassing from manufacturing oils, coatings, adhesives, and other materials (which can be found in ISO 10377 and [ISO 14159](#)). This document does not include evaluation of safety for cookstoves designed to burn a liquid and/or gaseous fuel, such as LPG (liquefied petroleum gas), alcohol, plant oil, kerosene, etc. Safety evaluation of gas-fuelled cookstoves can be found in ISO 23550 and ISO 23551 (all parts). This document does not include durability evaluation of rechargeable batteries in fan-assisted cookstoves. This document provides a standard test sequence to establish international comparability in measurement of cookstove emissions and efficiency. Guidelines for reporting results from the laboratory measurement and evaluation methods are described. For cookstoves used in applications covered by additional requirements (e.g., local air quality and safety regulations), additional test conditions and special evaluation methods may apply.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at <https://www.iso.org/obp>

— IEC Electropedia: available at <https://www.electropedia.org/>

3.1
as fired

condition of a fuel as it is about to be tested in a *cookstove* ([3.19](#))

3.2
as received

condition of a fuel as it is received for testing in a *cookstove* ([3.19](#))

3.3
ash

non-combustible residue remaining after combustion of a fuel under specified conditions, typically expressed as a percentage of the mass of dry matter in fuel

Note 1 to entry: Ash content can be determined using a muffle furnace under a temperature of 580 °C to 600 °C.

3.4
batch-loaded cookstove

cookstove ([3.19](#)) into which fuel is infrequently loaded during operation

EXAMPLE Batch-loaded cookstoves can include, but are not limited to, TLUD (top-lit up-draft) stoves.

3.5
biofuels

materials of biological origin used as fuel

EXAMPLE Biofuels can include but are not limited to wood, agricultural residues, dung, biogas, and processed lignocelluloses (e.g. charcoal, briquettes, and pellets).

3.6
black carbon

class of highly light-absorbing carbonaceous aerosols, typically composed largely of *elemental carbon* ([3.25](#))

3.7
built-in-place cookstove

cookstove ([3.19](#)) in which the majority of assembly and/or construction takes place where it will be used

3.8
burning rate

rate at which test fuel is consumed in a *cookstove* ([3.19](#)), in g [*dry basis* ([3.22](#))] per minute

3.9
burn sequence

combustion of fuel in a *cookstove* ([3.19](#)) from *ignition* ([3.39](#)) to an end point defined in a specific protocol

3.10
char

carbonaceous residue resulting from pyrolysis or incomplete combustion of solid *biofuels* ([3.5](#))

3.11
char energy efficiency

ratio of the energy of *char* ([3.10](#)) produced to the energy of *fuel fed* ([3.33](#)), *as fired* ([3.1](#))

3.12
char mass productivity

ratio of the mass of *char* ([3.10](#)) produced to the mass of *fuel fed* ([3.33](#))

3.13

continuously fed cookstove

cookstove (3.19) in which fuel is constantly or frequently fed during operation

EXAMPLE Continuously fed cookstoves can include, but are not limited to, rocket stoves.

3.14

cooking efficiency

thermal efficiency (3.57) for *cookstoves* (3.19) used only for cooking

Note 1 to entry: *Thermal efficiency* (3.57) for *space heating* (3.56) can differ from cooking efficiency for *cookstoves* (3.19).

3.15

cooking power

average rate of energy delivered to the contents of a *cooking vessel* (3.18) over any chosen period during the course of a *cooking sequence* (3.16) or other task

Note 1 to entry: The cooking power is expressed in kilowatts.

3.16

cooking sequence

operation of a *cookstove* (3.19) that uses the heat energy released during a *burn sequence* (3.9) for the preparation of food or the heating of water, with a recorded or prescribed series of power level settings, durations, and *cooking vessel* (3.18) utilisations

Note 1 to entry: The *cooking sequence* (3.16) commences with the placement of the first *cooking vessel* (3.18) on the stove and ends when the last cooking vessel is removed.

Note 2 to entry: The entire *cooking sequence* (3.16) is normally embedded within a *burn sequence* (3.9), though in special cases *retained heat cookers* (3.52) might continue cooking after the fire has been extinguished or while additional cooking tasks are undertaken.

3.17

cooking time

elapsed time from the time when the food is placed on the *cookstove* (3.19) to the time that the food is removed from the *cookstove*

3.18

cooking vessel

pot or container in which food or water is heated and prepared

3.19

cookstove

appliance primarily employed for the cooking of food, but which may also be employed for space or water heating, or other purposes

3.20

dilution system

apparatus that mixes a sample stream with air, nitrogen, or other gases of known composition in a controllable ratio

3.21

dilution tunnel

device in which ambient or cleaned air is mixed with an emission stream in a controlled and measured volumetric flow rate

3.22

dry basis

basis for describing the composition of a fuel sample as the ratio of the mass of a component to the mass of a fuel in its *dry fuel* (3.23) state, expressed in percent

3.23

dry fuel

fuel from which most moisture has been removed according to a drying procedure

3.24

durability

ability of a *cookstove* (3.19) to continue to be operated for an extended period in a *safe* (3.53) manner and with minimal loss of performance

3.25

elemental carbon

particulate carbonaceous material emitted during combustion that demonstrates a refractory nature according to a defined thermal-optical protocol

3.26

emission factor

ratio of the mass of a pollutant emitted to a defined measure that quantifies the activity emitting the pollutant

EXAMPLE Potential defined measures for emission factors include the *useful energy delivered* (3.59), mass of the *fuel consumed* (3.31), the dry mass of the *fuel consumed*, or the energy of the *fuel consumed*.

3.27

emission rate

mass of an air pollutant emitted per unit time, reported in units such as mg/h or g/s.

3.28

field

locations where cooking is normally performed in real-world situations, such as homes and target communities

3.29

field testing

observation or measurement of any part or parts of a *cookstove* (3.19) system conducted under various actual use conditions, instead of under controlled conditions in a *laboratory* (3.40)

3.30

firepower

over a specified period in the *burn sequence* (3.9), rate of energy release from the combustion of the fuel assuming complete combustion

Note 1 to entry: The firepower is expressed in kilowatts.

3.31

fuel consumed

mass (kg) of unburned *fuel fed* (3.33) minus mass of *residual fuel* (3.51), if applicable, during a defined *burn sequence* (3.9)

Note 1 to entry: For applicability of *residual fuel* (3.51), see details in testing protocol.

3.32

fuel energy used

product of the *heating value* (3.37) of the *raw fuel* (3.50) and its mass as fired, less the product of the heating value of the *residual fuel* (3.51), if applicable, and its mass

Note 1 to entry: For applicability of *residual fuel* (3.51), see details in testing protocol.

3.33

fuel fed

fuel supplied to a *cookstove* (3.19) during the course of the *burn sequence* (3.9)

3.34

fugitive emissions

emissions that escape from a *cookstove* (3.19) into the surrounding space of the cooking environment, as opposed to emissions that are removed directly from the stove via a chimney

3.35

gravimetric method

quantification of a sample of *particulate matter* (3.46) through the direct measurement of mass

3.36

griddle cookstove

plancha cookstove

cookstove (3.19) with which the majority of cooking occurs by placing the food directly on a heated surface, usually a metal or ceramic plate

Note 1 to entry: Regional terms for a griddle cookstove include *plancha*, *comal* and *mittad*.

3.37

heating value

energy per unit mass released in the complete combustion of a sample of fuel, as determined by combustion in a suitable calorimeter

Note 1 to entry: The state of the fuel is specified [*as received* (3.2), *as fired* (3.1), or *dry fuel* (3.23)].

Note 2 to entry: The heating value is specified as either *higher heating value* (3.38) or *lower heating value* (see 3.42).

Note 3 to entry: The heating value is expressed in MJ/kg.

3.38

higher heating value

measured value of the energy of combustion of a fuel burned in oxygen in a bomb calorimeter under such conditions that all the water of the reaction products is in the form of liquid water

Note 1 to entry: See Reference [36].

Note 2 to entry: The heating value is expressed in MJ/kg.

3.39

ignition

initiation of a period of a self-sustained combustion reaction

3.40

laboratory

facility that provides controlled conditions for conducting research and evaluating performance

3.41

laboratory testing

measurement of product performance quantified under controlled and documented conditions, where performance can be replicated by duplicating those conditions

3.42

lower heating value at constant pressure

absolute value of the specific heat (enthalpy) of combustion per unit mass (MJ/kg) of the fuel burned in oxygen at constant pressure under such conditions that all the water of the reaction products remains as water vapour (at 0,1 MPa), the other products being as for the *higher heating value* (3.38), all at the reference temperature

Note 1 to entry: See Reference [43].

3.43

maximum cooking power

highest *cooking power* (3.15) for which a *cookstove* (3.19) is designed

Note 1 to entry: The maximum cooking power is expressed in kW.

3.44

minimum cooking power

lowest *cooking power* (3.15) for which a *cookstove* (3.19) is designed

Note 1 to entry: The minimum cooking power is expressed in kW.

3.45

organic carbon

carbonaceous material emitted during combustion in which the carbon is chemically bonded to hydrogen and possibly also oxygen, nitrogen, sulphur, or other elements

3.46

particulate matter

solid and liquid matter of a sufficiently small size to be suspended in gas

3.47

pot skirt

device that encircles a *cooking vessel* (3.18) for the purpose of increasing heat transfer to the *cooking vessel*

Note 1 to entry: A pot skirt can be a design feature or addition to the *cookstove* (3.19), or an integral part of a specialized *cooking vessel* (3.18).

3.48

PM_{2,5}

fine *particulate matter* (3.46) such that the aerodynamic diameter of the particles is less than or equal to 2,5 µm

3.49

procedures

systematic methods specified for accomplishing certain tasks related to the testing or assessment of *cookstoves* (3.19)

3.50

raw fuel

mass of unburned fuel supplied to a *cookstove* (3.19) during the course of a *burn sequence* (3.9)

3.51

residual fuel

material [typically *char* (3.10)] that has a usable energy content that remains after a *burn sequence* (3.9) is completed

3.52

retained heat cooker

insulated container that can accommodate one or more *cooking vessels* (3.18) that have been heated on a *cookstove* (3.19)

3.53

safe

capacity to be used at an acceptable level of risk of harm

3.54

safety

ability of a *cookstove* (3.19) to be operated at an acceptable level of risk of harm

3.55

solar cookstove

device that delivers useful cooking heat from energy received from the sun

3.56

space heating

delivery of useful heat from a heat source into a household or other indoor space

3.57

thermal efficiency

ratio of *useful energy delivered* (3.59) to *fuel energy used* (3.32)

3.58

traditional cookstove

type of *cookstove* (3.19) or three-stone open fire that has been in long existence in a region and has been established from generation to generation

3.59

useful energy delivered

energy transferred to the contents of a *cooking vessel* (3.18), including sensible heat energy that raises the temperature of the contents of the *cooking vessel* and the latent heat of evaporation of water from the *cooking vessel*

Note 1 to entry: For *cookstoves* (3.19) that are used for both cooking and *space heating* (3.56), useful energy delivered may also include heat delivered to a living space.

3.60

water heater

appliance designed to transfer heat into one or more water containers

3.61

wet basis

basis for describing the composition of a fuel sample as the ratio of the mass of a component to the mass of a fuel in its *as received* (3.2) state, expressed in percent

4 Symbols and abbreviated terms

ASTM	American Society for Testing and Materials
BC	black carbon
C	carbon
CI	confidence interval
CO	carbon monoxide
CO ₂	carbon dioxide
D	diameter
dscm	dry standard cubic metre
EC	elemental carbon
EF	emission factor
EPA	U.S. Environmental Protection Agency
H	hydrogen

HAP	household air pollution
IER	integrated exposure-response function
LPG	liquefied petroleum gas
LPM	litres per minute
N	nitrogen
OC	organic carbon
P	pressure
PM _{2,5}	particulate matter with an aerodynamic diameter $\leq 2,5\mu\text{m}$
PTFE	polytetrafluoroethylene
<i>Re</i>	Reynolds number
RTD	resistance temperature detector
SF ₆	sulphur hexafluoride
STP	standard temperature and pressure
WHO	World Health Organization
~	approximately
Δ	change

5 Laboratory-based measurements of emissions and performance

5.1 General

In this clause, measurements and metrics for emissions and for performance are specified. Required and optional measurements are specified for the standard test sequence (see [Clause 6](#)).

Cookstoves that do not use combustion (e.g., solar cookstoves) shall be tested for cooking power using appropriate methods, such as ASAE S580.1, and zero on-site emissions shall be reported.

For the testing of built in place (fixed type) cook stoves, tests shall be carried out on representative models built on site in the testing laboratory.

Further information on laboratory-based measurement of emissions and performance is provided in [Annex A](#).

5.2 Testing conditions

Environmental conditions (temperature, pressure, relative humidity, air current velocity, and background pollutant concentrations) shall be noted and recorded immediately before and immediately after each test, and results shall include correction for background concentrations, as needed.

Testing conditions for cookstoves that use fuel combustion shall be as follows:

- environmental temperature comprised between 5 °C to 40 °C;
- air current velocity $<1,0$ m/s;

- c) cookstove shall be placed to avoid interference or cross-contamination between the cookstove and any other source of emissions or heat production.

Testing conditions for solar cookstoves shall be as specified in ASAE S580.1, except for a deviation for average wind velocity $\leq 1,5$ m/s.

Real-time instruments shall be stored and used in an environment as required by the instrument manufacturers.

If emissions samples are collected in an environment with the potential for liquid condensation (exhaust temperature > saturation temperature), then samples shall be dried prior to reaching any dry-based analyser.

5.3 Measurements

5.3.1 Required measurements for standard test sequence

For [Clause 6](#), measurements shall include for each test phase:

- a) mass of fuel fed;
- b) mass of char remaining at the end of the test phase, if present;
- c) moisture content of fuel, as fired, on a wet basis, if applicable;
- d) energy content of fuel, as fired (lower heating value);
- e) energy content of char remaining at the end of the test phase (lower heating value), if present;
- f) mass of water in cooking vessel(s) at the beginning and end of the test phase;
- g) temperature of water in cooking vessel(s); for tests of thermal efficiency only (without emissions), temperature and time shall be recorded at least every 1 min; for tests of emissions, time during the test phase, as well as all temperatures and emissions measurements, shall be recorded by a data acquisition system at least every 10 s;
- h) mass of emissions of PM_{2,5} by the gravimetric (filter) method;
- i) mass of emissions of CO (according to performance-based specifications in [5.3.7](#));
- j) mass of emissions of CO₂ (according to performance-based specifications in [5.3.7](#));
- k) useful energy delivered ([5.4.2](#)).

5.3.2 Required metrics for standard test sequence

For [Clause 6](#), metrics reported separately for each test phase shall include:

- a) thermal efficiency with no energy credit for remaining char, if present;
- b) thermal efficiency with energy credit for remaining char, if present;
- c) char energy productivity, if char is present;
- d) char mass productivity, if char is present;
- e) cooking power;
- f) fuel-burning rate;
- g) mass of PM_{2,5} per useful energy delivered;
- h) mass of PM_{2,5} per time;

- i) mass of CO per useful energy delivered;
- j) mass of CO per time;
- k) mass of CO₂ per useful energy delivered;
- l) mass of CO₂ per time.

For solid-fuel stoves that produce char, thermal efficiency shall be reported both without energy credit (5.4.4) and with energy credit (5.4.5) for remaining char.

5.3.3 Continuous emission data

For [Clause 6](#), continuous emission data for CO and CO₂ shall be recorded at least every 10 s and shall be reported along with results as specified in [Clause 9](#), Reporting test results.

5.3.4 Optional measurements

For [Clause 6](#), optional measurements may include for each test phase:

- a) mass of emissions of BC by the real-time light absorption (aethalometer) method;
- b) mass of emissions of BC by the transmissometer method;
- c) mass of emissions of OC and EC by the thermal optical method;
- d) count of aerosol particles by the condensation particle counter method;
- e) mass or count of emissions of other pollutants, as needed.

5.3.5 Optional metrics

For [Clause 6](#), optional metrics reported separately for each test phase may include:

- a) mass of BC per useful energy delivered;
- b) mass of BC per time;
- c) mass of OC per useful energy delivered;
- d) mass of OC per time;
- e) mass of EC per useful energy delivered;
- f) mass of EC per time;
- g) count of aerosol particles per useful energy delivered;
- h) count of aerosol particles per time;
- i) mass of other pollutants per useful energy delivered;
- j) mass of other pollutants per time;
- k) other emission factors, such as mass of pollutant per mass of dry fuel consumed.

5.3.6 Measurement quality objectives

For [Clause 6](#), standard test sequence, data shall be rejected if they do not meet the measurement acceptance criteria specified in [Table 1](#). For measurement of PM_{2,5} mass, the analytical balance shall have a resolution of 0,01 mg or better. The mass of filter loading shall be at least 10 times greater than the accuracy and precision of the balance (see [5.3.8.4.1.5](#)).

Table 1 — Measurement acceptance criteria for standard test sequence

Measurement	Indicators	Acceptance criteria
Water and fuel mass, electronic balance	Accuracy	±1 g
	Precision	±1 g
Water temperature, thermocouple or RTD (resistance temperature detector)	Accuracy	±0,5 °C
	Precision	±0,5 °C
Fuel heat of combustion (lower heating value)	Accuracy	±0,5 %
	Precision	±0,5 %
Fuel moisture content mass, electronic balance	Accuracy	±1 g
	Precision	±0,5 g
PM _{2,5} mass, analytical balance	Accuracy	±0,05 mg
	Precision	±0,05 mg
PM _{2,5} mass, sampling air flow rate	Accuracy	±3 % nominal
	Precision	±3 % nominal
Dilution tunnel gas volumetric flow rate	Accuracy	±5 % nominal
	Precision	±5 % nominal
Dilution tunnel gas temperature, thermocouple	Accuracy	±1 °C
	Precision	±1 °C

5.3.7 Measurement of carbon monoxide and carbon dioxide

Carbon monoxide (CO) and carbon dioxide (CO₂) concentrations shall be measured with a method that can be verified with calibration gases to meet the performance-based specifications given in [Table 2](#). This verification shall be documented. Examples of reference methods are indicated in [Table 2](#).

Table 2 — Performance-based specifications for methods of measuring CO and CO₂

Measurement	Informative reference	Indicators	Acceptance criteria
CO concentration	EPA Method 10[92]	Calibration linearity	±2 % of scale
CO ₂ concentration	EPA Method 3A[86]	Zero bias	±5 % of scale
		Span bias	±5 % of scale
		Zero drift	±3 % of scale
		Span drift	±3 % of scale

5.3.7.1 System operation

All sampling systems shall be tested for leaks on each day of testing. The leak rate shall be less than 0,1 % of the sampling flow rate at operating pressure. The leak-check method used and its validation (as evidence of its effectiveness) shall be documented. The leak-check procedure used and results obtained shall be recorded for each check performed. See [A.7](#) for recommended leak test method.

5.3.7.2 Verification

Measurements of gaseous pollutant concentrations shall be verified per [Table 2](#) with certified calibration gases at the beginning and end of a period of cookstove testing. Verifications shall be documented. A failed final verification shall invalidate all pollutant concentration data obtained subsequent to the last passed verification.

5.3.8 Total-capture dilution-tunnel gravimetric method for measurement of PM_{2,5}

5.3.8.1 General

This method is applicable for the determination of PM_{2,5} emissions from cookstoves, see [Annex B](#). As shown in [Figures B.1 to B.4](#), the exhaust from a cookstove shall be collected with a total collection hood, and shall be combined with ambient dilution air. Particulate matter shall be sampled from a single point in a dilution tunnel and collected on a filter. The particulate mass shall be determined gravimetrically after the removal of unbound water with a desiccator or after equilibration at constant temperature and humidity.

NOTE This method is similar to EPA Method 5G[89].

5.3.8.2 Equipment and supplies

5.3.8.2.1 Sampling train

The sampling train configuration is shown in [Figure B.5](#), and shall consist of the following components:

5.3.8.2.1.1 Probe

The sampling probe shall be constructed of stainless steel (e.g. 316 or grade more corrosion resistant) seamless tubing.

Isokinetic sampling should be performed. See [Annex A](#) for more information on isokinetic sampling.

5.3.8.2.1.2 Particle size-selective sampling device

A cyclone or impactor shall be used to sample PM_{2,5}. The cyclone or impactor for the measurement of PM_{2,5} should be designed such that the separation curve of PM_{2,5} has a similar shape separation efficiency of 50 % at 2,5 µm, as specified in [ISO 25597:2013](#), Figure B.1.

5.3.8.2.1.3 Filter holder

The holder design shall provide a positive seal against leakage from the outside or around the filters.

5.3.8.2.1.4 Metering system

The sampling air flow rate shall be controlled with a critical orifice, mass flow controller, or other control device.

- If a critical orifice is used, then gauge pressure across the critical orifice shall be monitored to ensure critical pressure drop is achieved.
- If a valve is used as a manual control device, then the sampling air flow rate shall be measured with a dry gas meter or other volumetric air flow measurement device.
- If a dry gas meter is used, then a dryer is required. The dryer shall be any system capable of removing water from the sample gas to less than 1,5 % moisture (volume percent) prior to the metering system.
- If a volumetric air flow measurement device is used, then air pressure and temperatures shall be measured and the measurements shall be used to correct for any inconsistent conditions between the dilution tunnel sampling location air flow and sampling system air flow.

5.3.8.2.2 Air flow measurement device

Dilution-tunnel air flow may be measured with a Pitot static tube, Pitot array, orifice plate, constant volume pump, or hot-wire anemometer. If a Pitot tube or other anemometric probe is used, the traverse

measurements are required (see [5.3.8.3.4](#) to [5.3.8.3.6](#)). If an orifice plate or constant volume pump is used, the orifice or pump shall be located downstream of the sampling location.

5.3.8.2.3 Dilution tunnel gas temperature measurement

A temperature sensor capable of measuring temperature to within ± 1 °C shall be used.

5.3.8.2.4 Hood for collecting emissions from cookstoves without tall chimneys

The hood shall be constructed of steel (which may include stainless steel), as shown in [Figure B.1](#), and shall be enclosed on three sides with a face opening of approximately 0,6 m $\times$ 1,2 m. The hood shall have a standard 0,1 m to 0,3 m diameter coupling capable of connecting to a standard 0,1 m to 0,3 m diameter duct. The surface that the cookstove is placed on shall be made of non-combustible heat-resistant material. The hood and duct system shall be electrically grounded to prevent static charging that can cause particle loss due to deposition to the inside walls.

When testing stoves with low emissions, in order to ensure sufficient capture of emissions in the form of mass collected on filters, additional dilution as shown in [Figure B.1](#) should not be applied. When testing stoves with high emissions, additional dilution may be used to prevent overloading filters and to prevent instrument ranges from being exceeded. If increased air flow causes an excessive increase in hood face velocity, additional dilution air should be used to reduce hood face velocity. Hood face velocity should be less than 0,25 m/s. Hood face velocity may be measured with a hot-wire anemometer. Dilution air may be filtered.

5.3.8.2.5 Hood for collecting total emissions from cookstoves with tall chimneys

The hood shall be constructed of steel, as shown in [Figure B.2](#), and shall be enclosed except for a face opening of approximately 1,2 m $\times$ 1,8 m. The hood shall have a standard 0,1 m to 0,3 m diameter coupling capable of connecting to a standard 0,1 m to 0,3 m diameter duct.

5.3.8.2.6 Hood for collecting fugitive (indoor) emissions from cookstoves with tall chimneys

The hood shall be constructed of steel, as shown in [Figure B.3](#), and shall be enclosed except for a face opening of approximately 1,2 m $\times$ 1,8 m. The hood shall have a standard 0,1 m to 0,3 m diameter coupling capable of connecting to a standard 0,1 m to 0,3 m diameter duct.

5.3.8.2.7 Hood for collecting chimney emissions from cookstoves

The hood shall be constructed of steel, as shown in [Figure B.4](#), with a large-end minimum diameter of 4 times the duct diameter, and a small-end standard 0,1 m to 0,3 m diameter coupling capable of connecting to a standard 0,1 m to 0,3 m diameter duct.

5.3.8.2.8 90° Elbows

Steel 90° elbows, 0,1 m to 0,3 m in diameter, shall connect the hood to the dilution tunnel (straight duct) and optional damper assembly. At least one 90° elbow shall be upstream of the sampling section (see [Figures B.1](#) to [B.4](#)).

5.3.8.2.9 Straight duct

Volumetric flow rate through the ducting should be chosen so that flow is fully turbulent at a Reynolds number of at least $Re = 10^4$. See [Annex A](#) for example calculations.

Steel duct, 0,1 m to 0,3 m diameter, shall be used for the sampling section (dilution tunnel). If an anemometry probe (e.g., Pitot tube, hot-wire anemometer probe) is used for air velocity measurement, then in the sampling section, at least 8 duct diameters downstream of the mixing baffles or elbow, there shall be two holes (velocity traverse ports) at 90° to each other of sufficient size to allow entry of the probe for traverse measurements. Alternatively, this downstream point shall be the location of a Pitot

array. At least 12 duct diameters downstream of the mixing baffles or elbow shall be one or more holes (sampling ports) of sufficient size to allow entry of the sampling probe. The length of duct from the hood outlet to the sampling ports shall not exceed 10 m.

5.3.8.2.10 Mixing baffles

Adequate mixing shall be demonstrated. Mixing baffles are optional and not required if adequate mixing is demonstrated without mixing baffles. See [A.8](#) for a method for validating well-mixed emissions in a duct.

To achieve adequate mixing through the use of mixing baffles, two steel semicircles may be attached at 90° to the duct axis on opposite sides of the duct, upstream of the sampling section. The space between the baffles should be approximately 0,3 m.

5.3.8.2.11 Blower

A squirrel cage or other type of fan capable of extracting gas from the dilution tunnel of sufficient flow to maintain the required volumetric flow rate and exhausting the gas to the atmosphere shall be used.

5.3.8.3 System preparation

5.3.8.3.1 Dilution tunnel assembly and cleaning

Schematics of dilution tunnels are shown in [Figures B.1](#) to [B.4](#). The dilution tunnel dimensions and other features are described in [5.3.8.2.4](#) to [5.3.8.2.11](#). The dilution tunnel, sealing joints, and seams shall be assembled to prevent air leakage. The dilution tunnel shall be cleaned with an appropriately sized wire chimney brush as needed before each testing period.

5.3.8.3.2 Draft determination for cookstoves with chimneys

The dilution tunnel hood shall be centrally located over the cookstove chimney exhaust. The dilution tunnel blower shall be operated at the flow rate to be used during the test sequence. The draft imposed on the cookstove by the dilution tunnel (i.e., the difference in draft measured with and without the dilution tunnel operating) shall be measured. The distance between the top of the cookstove stack exhaust and the dilution tunnel hood shall be adjusted so that the dilution-tunnel induced draft is less than 1,25 Pa. During this check and adjustment, no fire shall be in the cookstove, and any air supply controls, fuelling doors, or other movable parts on the cookstove shall be in the same position(s) as during testing.

5.3.8.3.3 Smoke capture

During a trial test sequence with the cookstove, the dilution tunnel shall be operated, and the exhaust shall be visually monitored. The cookstove shall be operated, and it shall be determined whether any visible exhaust is seen to escape. If any visible exhaust is seen to escape, then adjustments shall be made as necessary to the face opening in the fume hood, the air velocity, or the distance between the chimney and the hood, until no visible exhaust is escaping. The cookstove shall be operated, and it shall be confirmed that all visible exhaust is collected by the hood. The trial test sequence shall be stopped, and the draft determination procedure described in [5.3.8.3.2](#) shall be repeated, if a cookstove with a chimney is tested.

5.3.8.3.4 Air velocity measurements with an anemometric probe

If an anemometric probe (e.g., Pitot static tube) is used as an air velocity measurement device, then during a trial test sequence, a velocity traverse shall be conducted, and the probe shall be located in the dilution tunnel as described in [5.3.8.3.6](#).

Pitot ports can clog in particle-laden streams. If a Pitot static tube is used, then it shall be demonstrated that the Pitot ports have not clogged during the measurement period. Back purging may be required to prevent the Pitot ports from clogging (see Reference [83], EPA Method 2, 6.1.2).

5.3.8.3.5 Velocity traverse with an anemometric probe

If a Pitot static tube or other anemometric probe is used as an air velocity measurement device, then the following procedure shall be performed. The diameter of the duct at the velocity traverse port location through both ports shall be measured.

NOTE 5.3.8.2.2 specifies that various devices may be used to measure air flow. This subclause (5.3.8.3.5) provides instructions for using a Pitot static tube — the most common air flow measurement device.

The duct area shall be calculated using the average of the two diameters. A pretest leak-check of Pitot lines should be conducted. The calibrated Pitot static tube shall be placed at the centroid of the dilution tunnel in either of the velocity traverse ports. The damper or similar device on the blower inlet should be adjusted until the velocity indicated by the Pitot static tube is approximately 3,67 m/s, which is the recommended velocity for the recommended dilution tunnel diameter of 0,15 m to ensure fully turbulent flow. Alternatively, dilution tunnel diameters of 0,1 m to 0,3 m may be used. Air velocity may be adjusted to obtain total capture of emissions, and the Reynolds number shall be $>10^4$ to ensure fully turbulent flow.

The Δp and temperature shall continue to be read until the velocity has remained constant (less than 5 % change) for 1 min. Once a constant velocity is obtained at the centroid of the duct, a velocity traverse shall be performed (see informative Reference [83], EPA Method 2, Section 8.3) using four points per traverse. Guidance on collecting appropriate duct traverse measurements can be found in the following references ISO 3966, EPA Method 1[82], or VDI 2640[102].

If the traverse is conducted using a Pitot static tube, then a properly scaled differential pressure measurement device shall be used. Functionality shall be verified by performing a leak test of the Pitot tube assembly immediately before and after traverse measurements. A successful leak test will demonstrate the ability to maintain a stable ($\pm 2,5$ cm H₂O) pressure of 7,6 cm H₂O and 7,6 cm H₂O vacuum on the impact and static pressure ports, respectively, for at least 15 s.

The Δp and tunnel temperature shall be measured at each traverse point and the readings shall be recorded. The total gas dry volumetric flow rate corrected to standard conditions shall be calculated using Formula (1) (see informative Reference [83], EPA Method 2, Section 12). The moisture may be assumed to be 4 % (100 % relative humidity at 29,4 °C). Direct moisture measurements (e.g., those described in informative Reference [87], EPA Method 4) may also be used.

$$Q_d = (1 - H) \times v \times A \times \frac{T_{std} p_s}{T_s p_{std}} \quad (1)$$

where

- Q_d is the total gas dry volumetric flow rate corrected to standard conditions, m³/s;
- H is the water vapor in the gas stream as a proportion of volume, unitless fraction;
- v is the average gas velocity in the duct, m/s;
- A is the cross-sectional area of the duct, m²;
- T_{std} is the standard absolute temperature, 293 K;
- T_s is the absolute temperature of gas in the duct at the location of velocity measurement, K;
- p_{std} is the standard absolute pressure, 760 mm Hg;
- p_s is the absolute pressure of gas in the duct at the location of velocity measurement, mm Hg.

5.3.8.3.6 Testing velocity measurements with an anemometric probe

After obtaining velocity traverse results that meet the flow rate requirements, a point of average velocity shall be chosen, and the anemometric probe (e.g. Pitot static tube) and temperature sensor

shall be placed at that location in the duct. Alternatively, the anemometric probe and the temperature sensor shall be located at the duct centroid and a velocity correction factor shall be calculated for the centroidal position. The anemometric probe shall be mounted to prevent movement during the test sequence, and the port holes shall be sealed to minimize air leakage. The anemometric probe opening shall be aligned to be parallel with the duct axis at the measurement point. This condition shall be checked to ensure it is maintained during the test sequence (at ~30 min intervals). The temperature and velocity shall be monitored during pretest trial test sequences to ensure that the proper flow rate is maintained. Adjustments shall be made to the dilution tunnel flow rate as necessary.

5.3.8.4 Filter sample analysis

The total-capture dilution-tunnel method specified in [5.3.8.1](#) to [5.3.8.3](#) and the filter sample analysis method specified in this subclause shall be used for [Clause 6](#).

5.3.8.4.1 Filter sample analysis equipment and supplies

5.3.8.4.1.1 Desiccator or equilibration chamber

Filters shall be conditioned before and after sampling in either

- a) an air-tight enclosure for removing unbound water from filters through the use of a dessicant, or
- b) a chamber for achieving an equilibration environment through controlling relative humidity and temperature conditions for filters.

5.3.8.4.1.2 Desiccant

Anhydrous calcium sulphate, calcium chloride, or silica gel, indicating type (changes colour with moisture) shall be used in the desiccator.

5.3.8.4.1.3 Hygrometer

A hygrometer with an accuracy of ± 5 % shall be used to measure moisture in the air inside the desiccator or equilibration chamber.

5.3.8.4.1.4 Temperature sensor

A temperature sensor with an accuracy of ± 2 °C shall be used to measure the temperature of the air inside the desiccator or equilibration chamber.

5.3.8.4.1.5 Analytical balance

An electronic analytical balance shall be used for gravimetric analysis of filters. The analytical balance shall have a resolution of 0,01 mg or better, an accuracy of 0,05 mg or better, and a precision of 0,05 mg or better. The accuracy and precision of the balance shall be at least 10 times better than the mass of filter loading.

5.3.8.4.1.6 Filters

Glass fibre, quartz fibre, or PTFE (Teflon) membrane filters with a diameter of 37 mm to 100 mm, without organic binder, exhibiting at least 99,95 % efficiency ($< 0,05$ % penetration) on 0,3 μm dioctyl phthalate smoke particles shall be used.

NOTE The filter media selected can affect the accuracy of gravimetric particulate matter measurements. Factors for consideration include media type, collection efficiency, and pressure drop. Advantages and disadvantages of three common filter media are presented in [Table A.1](#).

5.3.8.4.2 Pretest preparation

5.3.8.4.2.1 Filter check

Using tweezers and/or clean disposable surgical gloves, one labeled (identified) and weighed filter shall be placed in the filter holder. The filter shall be properly centred and the gasket (if present) shall be properly placed so as to prevent the sample gas stream from circumventing the filter. Each filter shall be checked for tears after assembly is completed. If tears are found after a test is completed, then the gravimetric result shall be rejected.

5.3.8.4.2.2 Leak-check

A leak-check of the sampling train shall be conducted on each day of testing. The leak rate shall be less than 0,1 % of the sampling flow rate at operating pressure. See [A.7](#) for recommended leak test method.

5.3.8.4.2.3 Preliminary determinations

The pressure, temperature and the average velocity of the tunnel gases shall be determined. Moisture content of diluted tunnel gases may be assumed to be 4 % for flow rate calculations. The moisture content may be measured directly as in informative Reference [\[87\]](#).

5.3.8.4.2.4 Sampling train operation

The probe inlet shall be positioned at the stack centroid, and the openings around the probe and porthole shall be blocked off to prevent unrepresentative dilution of the gas stream.

5.3.8.4.3 Test

Sampling shall begin at the start of the test sequence as defined in [Clause 6](#). During the test sequence, a constant sample flow rate and dilution tunnel flow rate shall be maintained (within 10 % of the initial proportionality ratio).

The data for sample flow rate and dilution tunnel flow rate shall be recorded at least once every 10 min during each test sequence.

For the purposes of proportional sampling rate determinations, data from calibrated flow rate devices, such as glass rotameters, may be used to determine acceptability limits.

At the end of the test sequence (see [Clause 6](#)), the sampling pump shall be turned off.

5.3.8.4.4 Filter weighing

At the beginning of the weighing session, the balance calibration shall be checked with a certified weight that is of a similar weight to the filter. This check shall be repeated no less frequently than for every tenth filter weighed. The filters shall undergo a drying period of at least 24 h in a desiccator, or an equilibration period of at least 24 h in a chamber with control of temperature and humidity, before the tare and gross weighings. The filters shall be returned to the desiccator or equilibration chamber for at least an additional 6 h before the second weighing. If the weights taken after the 24 h and 6 h equilibrations agree to within 0,05 mg (taking into account the precision of the balance), the filter weight shall be accepted. The 6 h equilibration/weighing cycle shall be repeated until two weights agree to 0,05 mg. Temperature and relative humidity for filter conditioning shall be reported with results.

5.3.9 Measurement of biomass fuel energy content

A sufficient number of biomass fuel samples shall be tested to provide a representative sample. The number of biomass fuel samples needed shall be determined from the number necessary to reduce the standard error on the mean of all samples to less than 0,5 MJ/kg, calculated using [Formula \(2\)](#):

$$\sigma_M = \frac{\sigma}{\sqrt{N}} \quad (2)$$

where

- σ_M is the standard error of the mean;
- σ is the standard deviation of the individual samples;
- N is the number of samples.

5.4 Calculations

5.4.1 Calculation of mass of PM_{2,5}

The mass of PM_{2,5} shall be calculated using [Formula \(3\)](#).

$$m_{PM_{2,5}} = \frac{Q_{\text{tunnel}}}{Q_{\text{sample}}} \times m_{\text{sample}} \quad (3)$$

where

- $m_{PM_{2,5}}$ is the mass of fine particulate matter emitted during the sampling period, mg;
- Q_{tunnel} is the volumetric flow rate of gas in the dilution tunnel, m³/min;
- Q_{sample} is the volumetric flow rate of gas in the sample stream, m³/min;
- m_{sample} mass of fine particulate matter collected on the filter, mg.

5.4.2 Useful energy delivered calculation

Useful energy delivered shall be calculated using [Formula \(4\)](#).

$$Q_1 = C_p \times G_1 (T_2 - T_1) + (G_1 - G_2) \gamma \quad (4)$$

where

- Q_1 is the useful energy delivered, kJ;
- C_p is the isobaric mass-specific approximate heat capacity of water between 20 °C and 100 °C:
4,18 kJ·kg⁻¹·K⁻¹;
- G_1 is the initial mass of water in the cooking vessel, kg;
- G_2 is the final mass of water in the cooking vessel, kg;
- T_1 is the initial temperature of water in the cooking vessel, °C;
- T_2 is the temperature of the local boiling point or the highest temperature attained of the water in the cooking vessel, °C;
- γ is the latent heat of water vaporization at the local boiling point, kJ/kg.

For cookstoves with multiple cooking vessels, [Formula \(4\)](#) shall be used to calculate useful energy delivered for each cooking vessel, and the total useful energy delivered shall be the sum of useful energies calculated for all cooking vessels.

5.4.3 Cooking power calculation

Cooking power shall be calculated using [Formula \(5\)](#):

$$P_c = \frac{Q_1}{(t_3 - t_1)} \quad (5)$$

where

- P_c is the cooking power, kW;
- Q_1 is the useful energy delivered, kJ;
- t_3 is the final time at end of a test phase, s;
- t_1 is the initial time at beginning of a test phase, s.

5.4.4 Cooking thermal efficiency calculation with no energy credit for remaining char

Cooking thermal efficiency with no energy credit for any remaining char shall be calculated using [Formula \(6\)](#):

$$\eta_c = \frac{Q_1}{BQ_{\text{net.af}}} \times 100 \% \quad (6)$$

where

- η_c is the cooking thermal efficiency with no energy credit for remaining char, %;
- Q_1 is the useful energy delivered, kJ;
- B is the mass of the fuel fed, kg;
- $Q_{\text{net.af}}$ is the lower heating value of fuel, as fired, kJ/kg.

5.4.5 Cooking thermal efficiency calculation with energy credit for remaining char

Cooking thermal efficiency with energy credit for remaining char shall be calculated using [Formula \(7\)](#):

$$\psi_c = \frac{Q_1}{BQ_{\text{net.af}} - CQ_{\text{net.char}}} \times 100 \% \quad (7)$$

where

- ψ_c is the cooking thermal efficiency with energy credit for remaining char, %;
- Q_1 is the useful energy delivered, kJ;
- B is the mass of the fuel fed, kg;
- $Q_{\text{net.af}}$ is the lower heating value of fuel, as fired, kJ/kg;
- C is the mass of the remaining char, kg;
- $Q_{\text{net.char}}$ is the lower heating value of remaining char, kJ/kg.

NOTE The metric defined by [Formula \(7\)](#) is equivalent to the term 'exergy efficiency', as used in the biomass energy field and described in ISO/TR 21276.

5.4.6 Char energy productivity

For cookstoves with remaining char, char energy productivity shall be calculated using [Formula \(8\)](#):

$$E_{\text{char}} = \frac{CQ_{\text{net.char}}}{BQ_{\text{net.af}}} \times 100\% \quad (8)$$

where

- E_{char} is the char energy productivity, %;
- C is the mass of the remaining char, kg;
- $Q_{\text{net.af}}$ is the lower heating value of fuel, as fired, kJ/kg;
- B is the mass of the fuel fed, kg;
- $Q_{\text{net.char}}$ is the lower heating value of remaining char, kJ/kg.

5.4.7 Char mass productivity

For cookstoves with remaining char, char mass productivity shall be calculated using [Formula \(9\)](#):

$$m_{\text{char}} = \frac{C}{B} \times 100 \% \quad (9)$$

where

- m_{char} is the char mass productivity, %;
- C is the mass of the remaining char, kg;
- B is the mass of the fuel fed, kg.

5.4.8 Emission factor calculation

The emission factor shall be calculated using [Formula \(10\)](#).

$$EF = \frac{M_i}{Q_1} \quad (10)$$

where

- EF is the pollutant emission factor, mg/kJ;
- M_i is the total mass of pollutant emissions during the test, mg;
- Q_1 is the useful energy delivered, kJ.

5.4.9 Emission rate calculation

The emission rate shall be calculated using [Formula \(11\)](#).

$$ER = \frac{M_i}{(t_3 - t_1)} \quad (11)$$

where

- ER is the pollutant emission rate, mg/s;
- M_i is the total mass of pollutant emissions during the test, mg;
- t_3 is the final time at end of test, s;
- t_1 is the initial time at beginning of test, s.

5.5 Determination of heating value

The heating value shall be determined using a representative sample of the fuel in a bomb calorimeter (see ISO 18125). Representative samples should first be weighed, then the free water content of the samples should be determined by drying at 3 °C above the local boiling point of water. The dry samples shall then be tested in a bomb calorimeter (see ISO 18125) to determine the higher heating value (HHV). Representative samples may also be analysed for C, H, and N (see [ISO 16948](#)).

The lower heating value at constant pressure at the as-fired moisture level shall be calculated by the following formulae per ISO 18125 as follows.

Lower heating value at constant pressure for a dry sample (dry basis, in dry matter):

$$\begin{aligned} q_{p,\text{net,d}} &= q_{V,\text{gr,d}} + 6,15 \times w(\text{H})_{\text{d}} - 0,8 \times [w(\text{O})_{\text{d}} + w(\text{N})_{\text{d}}] - 218,3 \times w(\text{H})_{\text{d}} \\ &= q_{V,\text{gr,d}} - 212,2 \times w(\text{H})_{\text{d}} - 0,8 \times [w(\text{O})_{\text{d}} + w(\text{N})_{\text{d}}] \end{aligned} \quad (12)$$

Lower heating value at constant pressure at a required moisture content M (e.g., as received, M_{ar} , whereupon the symbol of heating value is $q_{p,\text{net,ar}}$) is calculated:

$$\begin{aligned} q_{p,\text{net,m}} &= \left\{ q_{V,\text{gr,d}} - 212,2 \times w(\text{H})_{\text{d}} - 0,8 \times [w(\text{O})_{\text{d}} + w(\text{N})_{\text{d}}] \right\} \times (1 - 0,01M) - 24,43 \times M \\ &= q_{p,\text{net,d}} \times (1 - 0,01M) - 24,43 \times M \end{aligned} \quad (13)$$

where

$q_{p,\text{net,m}}$	is the lower heating value at constant pressure, in J/g, of the biofuel with moisture content; (usually as received M_{ar});
$q_{V,\text{gr,d}}$	is the higher heating value at constant volume, in J/g, of the moisture-free fuel;
$w(\text{H})_{\text{d}}$	is the hydrogen content, in percentage by mass, of the moisture-free (dry) biofuel (including the hydrogen from the water of hydration of the mineral matter as well as the hydrogen in the biofuel substance);
$w(\text{O})_{\text{d}}$	is the oxygen content, in percentage by mass, of the moisture-free biofuel;
$w(\text{N})_{\text{d}}$	is the nitrogen content, in percentage by mass, of the moisture-free biofuel;
M	is the moisture content, in percentage by mass, for which the calculation is required. On the dry basis $M = 0$; on the air-dried basis, $M = M_{\text{ad}}$; on the as-sampled or as-fired (as received, ar) basis, $M = M_{\text{ar}}$ (total moisture content as received).

The enthalpy of vaporization (constant pressure) for water at 25 °C is 44,01 kJ/mol. This value corresponds to 218,3 J/g for 1 % (mass/mass) of hydrogen in the biofuel sample or 24,43 J/g for 1 % (mass/mass) of moisture, respectively.

NOTE $w(\text{O})_{\text{d}} + w(\text{N})_{\text{d}}$ may be derived by subtracting from 100 the percentages of ash, carbon, hydrogen and sulphur.

5.6 Secondary dilution system methods

An air pollutant sample stream may be diluted with air, nitrogen, or other gases for purposes including

- drying the sample,
- cooling the sample, and
- decreasing the sample concentration to the range of the measurement instruments used.

5.6.1 Secondary dilution systems used in the standard test sequence

In [Clause 6](#), direct sampling from the dilution tunnel, without the use of an additional dilution system, shall be used for determining emissions of PM_{2,5}, CO, and CO₂. For determination of emissions of other pollutants, the measurement of which is optional, secondary dilution system methods may be used.

5.6.2 Secondary dilution system calibration

The secondary dilution system shall be calibrated by the direct measurement of the volumetric flow rate through the system using a primary flow instrument, such as a bubble flow meter or equivalent, with an accuracy and precision of $\pm 3\%$ (or better) of the nominal flow rate, or by using a tracer gas with a corresponding gas analyser.

5.7 Carbon mass balance method

The carbon mass balance method may be used as an optional quality assurance check with the total-capture method specified in [Clause 6](#). See [Annex A](#) for more information.

6 Standard test sequence for emissions and performance

6.1 General

This clause is applicable only to fuel-burning cookstoves (e.g. not applicable to solar cookstoves).

The standard test sequence characterizes performance of cookstove systems (including appropriate fuel, cooking vessel, and operating procedure) with international comparability for cookstoves tested at three power levels — low, medium, and high — and results at each power level shall be reported separately. The standard test sequence allows for both

- a) comparing cookstove systems of different types, and
- b) comparing the same cookstove system at different facilities.

Cookstoves that are designed for operation at only one power level shall be tested at only that power level. Cookstoves that are designed for operation at only two power levels shall be tested at only those power levels. Separate results for the two or three power levels may be weighted based on the percentage of time that typical users operate cookstoves at each power level, if such field data are available. If field data are used to support weighted results, then a detailed description of the methodology and statistical indicators of the representativeness of the field data shall be provided along with the laboratory test results. Weighted results may be reported, but results shall also be reported separately for low, medium, and high power.

EXAMPLE 1 Fieldwork in a certain region could estimate that typical combined cooking sequences are 50 % low-power, 10 % medium-power, and 40 % high-power. If $\text{PM}_{2,5}$ emissions are 38 mg/MJ_d at low-power, 24 mg/MJ_d at medium-power, and 46 mg/MJ_d at high-power, then the weighted average would be: $(0,50 \times 38) + (0,10 \times 24) + (0,40 \times 46) = 39,8 \text{ mg/MJ}_d$.

If field data are not available, then results cannot be weighted, but averaged results may be used for voluntary performance targets (ISO/TR 19867-3).

If the manufacturer's instructions and field information are in conflict, then the conflict shall be reported along with the information used to test the cookstove. The test report shall include a statement indicating whether the tests were performed according to manufacturer's instructions or based on field information. Supplementary information on the standard test sequence is provided in [Annex C](#).

6.2 Phases of the standard test sequence

As depicted in [Figures 1](#) and [2](#), the duration of each phase shall include a fuel burning period plus the variable time needed for shut-down. Cookstoves designed for variable power should be tested with fuel burning periods of approximately 30 min for each test phase. Cookstoves designed for only one power level should be tested with fuel-burning periods of either approximately 30 min or approximately 60 min. The optional 30 min or 60 min period shall be determined by the manufacturer's specifications for the cookstove.

Phase 1. At the beginning of the phase, the cookstove and the water in the cooking vessel shall be at ambient temperature. Emissions shall be captured during startup, operation at high power, and during shutdown. Any char remaining shall be removed from the cookstove and weighed before commencing Phase 2. For cookstoves designed for one power only, Phase 1 shall be the only test phase, as shown in [Figure 1](#).

Phase 2. At the beginning of the phase, the cookstove shall be at operating temperature after completion of Phase 1 (see illustration of phases in [Figure 2](#)), and the water in the cooking vessel shall be at ambient temperature. Emissions shall be captured during startup, operation at medium power, and during shutdown. Any char remaining shall be removed from the cookstove and weighed before commencing Phase 3.

Phase 3. At the beginning of the phase, the cookstove shall be at operating temperature after completion of Phase 2 (see illustration of phases in [Figure 2](#)), and the water in the cooking vessel shall be at ambient temperature. Emissions shall be captured during startup, operation at low power, and during shutdown. Any char remaining shall be removed from the cookstove and weighed.

NOTE Cookstove operating temperature is not specified, because it varies for cookstoves.

6.3 Standard test sequence diagrams

The standard test sequence for cookstoves with only one power level is illustrated in [Figure 1](#).

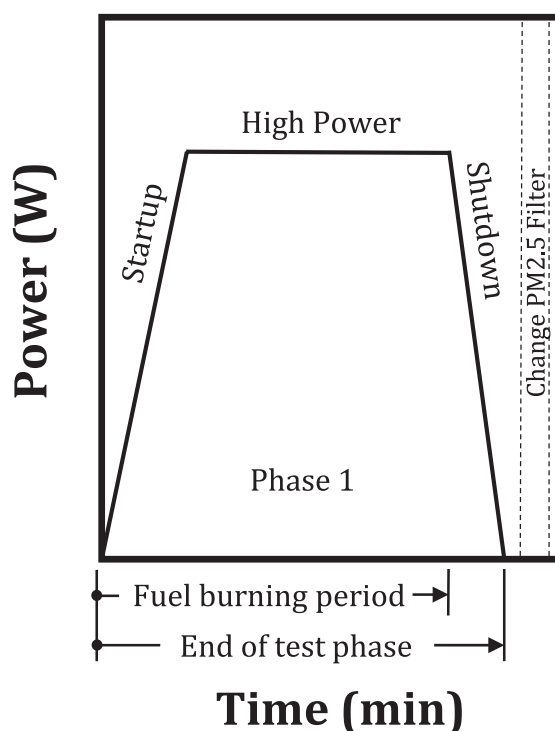


Figure 1 — Diagram of the standard test sequence for cookstoves with a single power level

The standard test sequence for cookstoves with a range of cooking power is illustrated in [Figure 2](#).

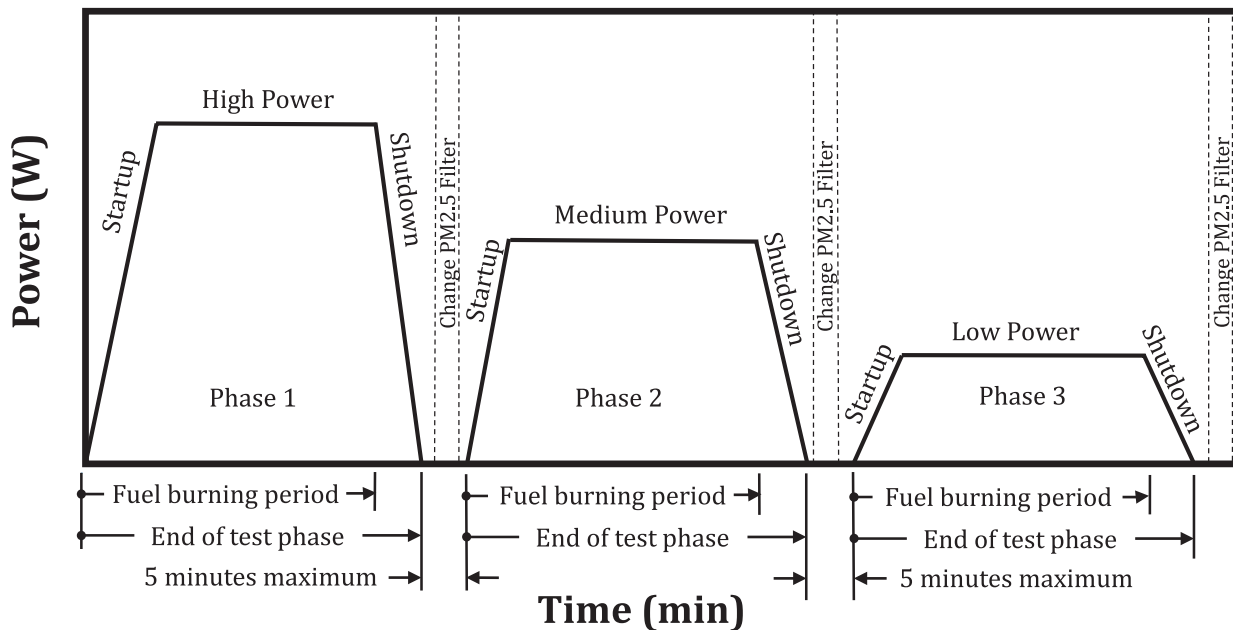


Figure 2 — Diagram of the standard test sequence for cookstoves with a range of cooking power

6.4 Limitations

The standard test sequence is designed to simulate operation of a cookstove system over a range of conditions typical of field use, but laboratory-based tests can have limited ability to predict performance in the field due to variation in fuels, cooking vessels, foods prepared, user behaviour, and environmental conditions. The standard test sequence is designed to produce repeatable and comparable results under controlled conditions, but a limitation of this type of test is that certain conditions can be difficult to control — for example, operator behaviour, including the distribution and addition of fuel, for some continuously fed cookstoves.

NOTE The standard test sequence is based on best practices from established testing protocols and the experience of many testing centres, but the standard test sequence is a new method that is likely to require refinement as data from laboratory and field testing become available.

6.5 Cookstove system requirements

Following are requirements for testing a cookstove system defined as including the cookstove, cooking vessel, fuel, and operating procedure. A detailed cookstove system description shall be included in the test results, as specified in [Clause 9](#).

6.5.1 Cookstove

A representative sample of produced cookstoves shall be used. For manufactured cookstoves produced with a high level of quality control over materials and tolerances, one cookstove can be representative. For artisan-produced cookstoves developed in settings with a lower level of quality control over materials and tolerances, three or more cookstoves might be needed to constitute a representative sample.

NOTE 1 Indicators of a high level of quality control include

- a) cookstoves produced with interchangeable parts,
- b) parts and assemblies are produced according to engineering drawings with tolerances,
- c) parts and assemblies produced using tooling such as jigs, fixtures, dies, and moulds,

- d) parts and assembled cookstoves are inspected for compliance with tolerances,
- e) parts and assembled cookstoves are rejected if out of compliance with tolerances, and
- f) final assembled cookstoves are inspected for compliance with performance criteria.

NOTE 2 Artisan-produced cookstoves are generally made by hand by skilled workers, rather than mass-produced in factories.

6.5.2 Cooking vessel

A cooking vessel (typically a pot) with appropriate size and shape shall be used. The cookstove shall be tested with a cooking vessel similar to those used in the field, if field data are available. If the cookstove is designed for a certain cooking vessel, then the cookstove shall be tested with that cooking vessel.

EXAMPLE Cookstoves designed for round-bottomed pots, pots with built-in pot skirts, or pots of a specific size shall be tested with the corresponding pot.

The cookstove shall be tested with a cooking vessel with appropriate size and water mass that enables water to be heated to within 1 °C of the local boiling point (with no time limit) without a lid on the cooking vessel at the highest power level.

6.5.3 Fuel

A fuel with appropriate size, shape, composition, energy content, and moisture content shall be used. The cookstove shall be tested with fuel similar to that used in the field, if field data are available. If a cookstove is designed for a certain type of fuel, then the cookstove shall be tested with that fuel.

EXAMPLE A cookstove designed for a certain type of pellet fuel shall be tested with that fuel.

A fire start-up fuel with appropriate size, shape, composition, and moisture content shall be used. The cookstove shall be tested with a start-up fuel similar to that used in the field, if field data are available. If a cookstove is designed for a certain type of start-up fuel, then the cookstove shall be tested with that start-up fuel. An accelerant, such as kerosene or alcohol, may be used as a start-up fuel if specified by the manufacturer in written instructions.

6.5.4 Operating procedure

The cookstove shall be operated during testing as specified by the manufacturer's instructions (see [Clause 10](#) for marking and packaging requirements). If field data are available that indicate a cookstove is typically not operated as intended, then the cookstove shall be operated following procedures similar to field use. If field data are used to support operation that does not match the manufacturer's instructions, then a detailed description of the methodology and statistical indicators of the representativeness of the field data shall be provided along with the laboratory test results.

WARNING — Do not exceed design load limits and other possible safety limitations.

6.6 Determination of cooking power levels

6.6.1 Low power

If a cookstove has controls, such as fan speed or air adjustment, then the controls shall be adjusted to their lowest setting that enables operation during the low-power test phase.

If a minimum cooking power level is specified by the manufacturer, then the cookstove shall be operated at that cooking power during the test. If field data are available, then the cookstove shall be operated at the lowest power level typically observed in the field. If field data are not available, then the cookstove shall be operated at a practical low-power level to be determined by the interested parties (e.g., certification bodies, manufacturers, suppliers, customers, inspectors, research organizations, sponsors, testing laboratories). The average low-power level shall be reported in the test results.

If the manufacturer's instructions and field information are in conflict, then the conflict shall be reported along with the information used to test the cookstove. The test report shall include a statement indicating whether the tests were performed according to manufacturer's instructions or based on field information.

6.6.2 Medium power

The medium-power level shall be determined by calculating the mid-point between low power and high power. The average medium-power level shall be reported in the test results.

6.6.3 High power

If a cookstove has controls, such as fan speed or air adjustment, then the controls shall be adjusted to their highest setting that enables operation during the high-power test phase.

If a maximum cooking power level is specified by the manufacturer, then the cookstove shall be operated at that cooking power during the test. If field data are available, then the cookstove shall be operated at the highest power level typically observed in the field. If field data are not available, then the cookstove shall be operated at a practical high-power level to be determined by the interested parties (e.g., certification bodies, manufacturers, suppliers, customers, inspectors, research organizations, sponsors, testing laboratories). The average high-power level shall be reported in the test results.

6.7 Procedure for standard test sequence

Specific procedures shall vary depending on the type of cookstove identified in [Annex D](#), as specified in [6.8](#). The general procedure for testing at each power level is as follows.

6.7.1 Test preparation

The following test preparation steps shall be taken:

- a) Personnel conducting the test shall be familiar with the operation method of the cookstove, and personnel shall possess appropriate qualifications and experience in cookstove testing.
- b) Photographs of test equipment, test setup, and cookstove serial numbers, where available, shall be taken and included with the test report.
- c) Each instrument shall be calibrated to meet requirements specified in [Clause 5](#), Laboratory-based measurement of emissions and performance.
- d) Suitable types of fuel shall be selected (see [6.5.3](#)).
- e) Trial test sequences shall be conducted to determine the amount of fuel required for the fuel-burning period, approximately 30 min of operation at each power level from ignition until the CO₂ concentration measured in the exhaust drops to approximately half of its steady-state background-subtracted value, except for cookstoves designed for only one power level. For these cookstoves, optional fuel-burning periods are either approximately 30 min or approximately 60 min of operation from ignition until the CO₂ concentration measured in the exhaust drops to approximately half of its steady-state background-subtracted value.
- f) The lower heating value of biomass fuel shall be determined (see [5.5](#)).
- g) The water in the cooking vessel shall be weighed and the mass of water, G_1 , and the initial water temperature, T_1 , shall be recorded.
- h) The temperature sensor shall be placed in the cooking vessel using a holder, and the tip of the sensor shall be located in the centre of the volume of water in the cooking vessel. The lid shall not be placed on the cooking vessel.
- i) The ambient temperature, humidity, wind speed, and altitude shall be recorded.