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BSI Standards Publication

Energy efficiency of Industrial trucks — Test methods

Part 1: General

National foreword

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

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European foreword

This document (EN 16796-1:2016) has been prepared by Technical Committee CEN/TC 150 “Industrial Trucks - Safety”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2017, and conflicting national standards shall be withdrawn at the latest by May 2017.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

EN 16796 consists of the following parts, under the general title *Energy efficiency of Industrial trucks — Test methods*:

— *Part 1: General*;

— *Part 2: Operator controlled self-propelled trucks, towing tractors and burden-carrier trucks*;

— *Part 3: Container handling lift trucks*.

The following parts are under preparation:

— *Part 4: Rough-terrain trucks*;

— *Part 5: Trucks with elevating operator position and trucks specifically designed to travel with elevated loads*.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

The EN 16796 series deals with the energy efficiency of industrial trucks and aligns with the New Approach Ecodesign Directive 2009/125/EC (ErP).

Part 1 contains the procedures to determine the efficiency of trucks, traction batteries and battery chargers. The other parts provide a specific test cycle for different truck types.

NOTE The test cycles are based on the VDI 2198 guideline. This guideline is widely accepted by industry and is used to measure the energy consumption of electric industrial trucks and internal combustion industrial trucks. The guideline is in place since 1996 and it is used broadly. This approach allows the evaluation of the energy efficiency of trucks by comparison.

The content of this document is of relevance for the following stakeholder groups:

— machine manufacturers (small, medium and large enterprises);

— market surveillance authorities;

— machine users (small, medium and large enterprises);

— service providers, e.g. for consulting activities.

The abovementioned stakeholder groups have been given the opportunity to participate at the drafting process of this document. The machines concerned are indicated in the Scope of this document.

1 Scope

This European Standard specifies general test criteria and requirements to measure the energy consumption for self-propelled industrial trucks (hereafter referred to as trucks) during operation. For electric trucks, the efficiency of the battery and the battery charger is included.

This part of the EN 16796 series is intended to be used in conjunction with the corresponding EN 16796-2 to -5.

The truck specific requirements in EN 16796-2 to -5 take precedence over the respective requirements of EN 16796-1.

Of the product life cycle, EN 16796 is applicable to the in-use phase.

It applies to the following truck types according to ISO 5053-1:

— counterbalance lift truck;

— articulated counterbalance lift truck;

— lorry-mounted truck;

— reach truck (with retractable mast or fork arm carriage);

— straddle truck;

— pallet-stacking truck;

— pallet truck;

— platform and stillage truck;

— pallet truck end controlled;

— order-picking truck;

— centre-controlled order-picking truck;

— towing, pushing tractor and burden carrier;

— towing and stacking tractor;

— side-loading truck (one side only);

— rough-terrain truck;

— rough-terrain variable-reach truck;

— slewing rough-terrain variable-reach truck;

— variable-reach container handler;

— counterbalance container handler;

— lateral-stacking truck (both sides);

— lateral-stacking truck (three sides);

— non-stacking low-lift straddle carrier;

— multi-directional lift truck.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 589, *Automotive fuels — LPG — Requirements and test methods*

EN 590, *Automotive fuels - Diesel - Requirements and test methods*

prEN 1459-1, *Rough terrain trucks — Safety requirements and verification — Part 1: Variable-reach trucks*

EN 1459-2, *Rough-terrain trucks - Safety requirements and verification - Part 2: Slewing variable-reach trucks*

EN 16796 (all parts), *Energy efficiency of Industrial trucks — Test methods*

EN 60254-1, *Lead acid traction batteries - Part 1: General requirements and methods of tests (IEC 60254-1)*

EN ISO 3691-1:2015, *Industrial trucks - Safety requirements and verification - Part 1: Self-propelled industrial trucks, other than driverless trucks, variable-reach trucks and burden-carrier trucks (ISO 3691-1:2011, including Cor 1:2013)*

EN ISO 3691-2, *Industrial trucks - Safety requirements and verification - Part 2: Self-propelled variable-reach trucks (ISO 3691-2)*

EN ISO 3691-6, *Industrial trucks - Safety requirements and verification - Part 6: Burden and personnel carriers (ISO 3691-6)*

ISO 5053-1:2015, *Industrial trucks — Terminology and classification — Part 1: Types of industrial trucks*

ISO 15500-1, *Road vehicles — Compressed natural gas (CNG) fuel system components — Part 1: General requirements and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5053-1 and the following apply.

3.1
battery
electrical power source consisting of battery cells, connectors of cells, battery controller (if applicable, e.g. controller for Li-Ion batteries) and battery enclosure that is ready to use in an industrial truck

3.2
battery state of charge
measured capacity (in Ampere hours [Ah]) of the battery divided by the maximum rated capacity [Ah], expressed as a percentage

3.3
carbon dioxide equivalent
CDE
quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP)

3.4
charging factor
ratio between amount of Ah recharged into the battery and the prior discharged amount of Ah from the battery

Note 1 to entry: Typically the charge factor for lead acid batteries is in the range of 1,02 to 1,25.

3.5
cycle time
amount of time it takes a machine to perform a repetitive segment of an operation, typically measured as the time it takes a machine to return to the same position

3.6
power battery factor
PBF
factor that gives the ratio between the battery capacity and the electrical power taken from the battery

3.7
synthetic discharge cycle
typical battery discharge profile that mirrors the actual energy consumption of electric trucks during a test cycle

4 Test conditions

4.1 General

The following test conditions ensure that the measurement of power consumption is performed in a similar and comparable way.

4.2 Test equipment

4.2.1 Test area

The test area shall be a flat and smooth area with a hard, clean and dry surface made of concrete, asphalt or equivalent. The test course shall have no more than 2 % slope in any direction of travel.

4.2.2 Test track

For truck type specific information for a different truck type see the respective part of EN 16796.

4.2.3 Test load and/or towing capacity

Unless it is otherwise stated in the specific part of EN 16796, the test load shall be equal to 70 % of the rated load and standard load centre distance of the truck as defined in EN ISO 3691-1, EN ISO 3691-2, EN 1459-1 or EN 1459-2.

Tractors shall tow with a force according 70 % of the rated drawbar pull as defined in EN ISO 3691-1:2015, A.3.

Burden-carriers shall be laden with 70 % of the maximum load as defined in EN ISO 3691-6.

4.3 Truck conditions

The truck to be tested shall be a sample that is representative of series production. For all parts of the truck, with effect to the energy consumption, a run-in time of up to 100 h is permissible. The run-in time shall be documented.

The truck to be tested shall be in a safe and functional state. All equipment attached shall be in accordance to the specification of the manufacturer of the truck.

The set-up of the truck (e.g. software parameters) shall be available as per the manufacturer's specification. That requirement means that the truck performance as specified is achievable (e.g. driving and lifting speed, acceleration) and all software settings are commercially available to the customer.

NOTE For instance, the test driver can adapt the maximum driving speed to achieve the cycles / hour.

The test truck shall be fitted with new tyres (max. 10 % of tread wear) which shall comply with the specifications of the manufacturer of the truck. Pneumatic tyres shall be inflated to their correct pressure specified by the truck manufacturer or by default from the tire manufacturer.

The fuel tanks of internal combustion engine trucks shall be filled to the maximum specified level prior to the warm up period. All other tanks shall be filled to their correct operating levels, if applicable.

If the test is to be performed on a sample that is representative for a range of trucks with the same rated capacity but different lift heights, the test shall be carried out on the truck with the specification according to EN ISO 3691-1:2015, A.2.1. For trucks covered by prEN 1459-1, EN 1459-2 and EN ISO 3691-2 see the specific requirements of the applicable part of EN 16796.

For trucks covered by EN ISO 3691-1 the specified lift height shall be at least the standard lift height according to EN ISO 3691-1:2015, A.2.2. The truck’s specified lift height shall allow the measurement procedures as defined in the specific part of the EN 16796 series.

If the test is to be performed on a sample that is representative for a range of trucks with the same rated capacity and the lift height is lower than the lift height that is specified in EN ISO 3691-1:2015, A.2.1 and A.2.2, the test shall be carried out on the truck with the greatest lift height.

If the test is to be performed on a sample representative of a range of electrical trucks with the option of different battery capacities the test shall be carried out on the truck with the standard battery/batteries according to the data sheet of the manufacturer.

4.4 Environmental conditions

The measurement shall be carried out at an environmental temperature range between 10 °C and 30 °C.

The truck in test configuration shall be at operating temperature.

A minimum warm-up period of 10 min is required for the laden truck, before the test starts.

4.5 Truck maintenance

IC-trucks with emissions control systems that may require cleaning or regeneration of the emission control device shall remain within manufacturer recommended parameters throughout the test. It is allowed to block automatic regenerating of the emission control device during the test.

Machines with other emissions control systems utilizing additional reagents/materials shall remain within manufacturers´ recommended parameters throughout the test.

4.6 Battery condition

Battery efficiencies are influenced by many factors e.g. cell technology, cell type, cell design and geometry. Therefore, the battery efficiency as stated in 6.2.2 is representative for the tested battery type / battery manufacturer.

If the battery technology requires any energy consuming auxiliary device e.g. battery management system, controller, cooling or heating, this shall be included in the test.

The battery shall be charged to the rated capacity prior to the respective test. When tests require discharging to the rated minimum capacity of the battery, this shall be determined by one of the following methods:

a) Lead-acid batteries voltage:

   The battery is discharged if the voltage is less than or equal 1,6 V/cell (according to EN 60254-1 for discharge current I1).

b) Lead-acid rated capacity:

   The battery is discharged if 80 % of the rated capacity is taken from the battery during the test. Recuperation may be considered by calculating with 75 % of the recuperated current over time.

c) Other technologies:

   Discharge criteria are defined by the battery manufacturer. This criterion shall be consistent with all other specification provided with the battery type e.g. identical life time and life cycle characteristic based on endurance tests. Dependent on the technology a discharge value given in energy (Wh) may be used.

5 Measurement procedure

5.1 General

The following clauses are describing the measurement procedure that is applicable for trucks in general. For specific information for different truck types see the respective part of EN 16796.

5.2 Operating sequence

Trucks shall operate according to the manufacturers' instruction handbook and the test specification defined in the specific part of EN 16796 with the load according to 4.2.3. Unless it is otherwise stated in the specific part of the EN 16796 series, pick- and place-cycles may be simulated without depositing the load.

NOTE The test load can be secured.

The speed shall be so adapted as to obtain the specified number of cycles per hour. Unless it is otherwise stated in the specific part of EN 16796 simultaneous operations are not permissible, all load handling and travelling functions shall be operated separately.

For truck types that are not covered exhaustively by a specific part of EN 16796, an appropriate sequence of operations shall be selected depending on the design in accordance with the intended use of the truck.

5.3 Electrical trucks

5.3.1 General

To determine the overall energy consumption of electric trucks the test shall consider:

— the overall efficiency of the truck, including motor, controller and electrical installation;

— the efficiency of the battery/batteries;

— the efficiency of the battery charger.

Because the equipment of trucks with batteries and battery chargers is versatile, it is typically necessary to differ between these elements.

The following clauses are defining the procedure to determine the elements of the system efficiency.

5.3.2 Truck measurement

The battery of the truck shall be charged to the rated capacity prior to the warm-up period.

The measurement of the energy consumption shall start at the first test cycle. The warm-up period shall be excluded from the measurement.

The energy consumption shall be given in terms of the electrical energy that is required for 1 h performing the operating sequence, in kWh/h. This measurement can be done by continuous measurement of voltage and current during the test.

The measurement of voltage and current shall be performed at the connector of the truck and the traction battery.

$$E_{\text{truck}} = \int_0^T U_{\text{batt}}(t) * f * I_{\text{batt}}(t) * dt$$

where

E_{truck} Energy taken from the battery during the test in Wh

U_{batt} Battery voltage in V

I_{batt} Battery current in A

dt Differential (Measurement over time)

T Test duration

f = 1 for $I_{batt} \geq 0$; and

f = 0,75 for $I_{batt} < 0$

NOTE 1 $I_{batt} < 0$ represents recuperation. The factor f = 0,75 refers to the majority of traction batteries, namely lead-acid batteries.

NOTE 2 The factor f differs for other battery technologies, subject to future revisions of this standard.

If the power consumption is determined by measuring electric charge in Ah, the power consumption shall be calculated by multiplication with the nominal battery voltage.

If the determination of the battery efficiency should be included in the truck measurement procedure, the measurement cycle shall start with a battery charged to its rated capacity and shall continue until the battery is discharged to the rated minimum capacity, see 4.6.

5.3.3 Battery efficiency

The battery efficiency consists of two elements that generate power loss:

— the energy flow to the truck (energy taken by the truck from the battery);

— the energy flow from the charger to the battery (energy for complete recharging of the discharged battery).

NOTE The efficiency varies depending on the battery charging status, the current when discharging, the current and method when charging, the battery temperature and the battery type.

The overall efficiency of the battery shall be determined by:

— Direct measurement of current and voltage during discharging the battery by performing the truck measurement according to 5.3.2 until the battery is discharged to the rated minimum capacity, see last paragraph of 5.3.2 and 4.6, and during recharging the battery, see 5.3.4;

— direct measurement of current and voltage during discharging the battery by performing the synthetic discharge cycle, see Annex A, until the battery is discharged to the rated minimum capacity, see last paragraph of 5.3.2 and 4.6 and during recharging the battery, see 5.3.4[1] or

— using defined battery specific values that are verified to be suitable to determine the battery efficiency for lead acid traction batteries used in a truck, see Annex B.

5.3.4 Charger efficiency

The overall efficiency of the charger shall be determined:

— in combination with the truck measurement according to 5.3.2;

— after the battery efficiency evaluation according to 5.3.3 or

1) The synthetic discharge cycle can be used to determine the efficiency of all kind of batteries.

— by taking into account information of the charger efficiency operating at its optimum operating point, see Annex B.

If a test is performed, the current and voltage at the charger's terminals shall be continuously measured against time to allow calculation of the charger efficiency.

From this test, the charger efficiency is calculated as follows:

$$\eta_{ch} = \frac{E_{ch}}{E_{grid}}$$

where

η_{ch} is the charger efficiency

E_{ch} is the energy delivered to the battery in Wh

E_{grid} is the energy withdrawn from grid supply in Wh

In addition to the efficiency value, information regarding the power factor should be given in the data sheet and on the type plate of the charger.

The power factor shall be determined for the rated operating point. If this is not possible the power factor may be determined at 80 % of the rated power. In this case information should be given in the data sheet.

5.4 IC-trucks

The measurement of the energy consumption shall start at the first test cycle. The warm-up period shall be excluded from the measurement.

The energy consumption of diesel driven trucks shall be given in fuel per hour [l/h] or, for trucks powered by gas (LPG) or natural gas (CNG) in gas consumption per hour [kg/h].

The LPG quality shall be in accordance to EN 589.

The CNG quality shall be in accordance to ISO 15500-1.

Diesel fuel shall be determined by weight, calculated for 15 °C. The density of the fuel of 830 kg/m³ shall be used, which corresponds with the average defined in EN 590.

5.5 Hybrid trucks

Hybrid trucks shall be tested according to 5.4.

After the test, the energy stored in accumulators (e.g. electrical, pneumatic or hydraulic) shall not be less than before starting the test.

NOTE Starter batteries are not subject to the foregoing requirement.

5.6 Measurement accuracy

Suitable measurement equipment shall be selected.

The following tolerances or accuracies of the measurement equipment shall be fulfilled.

All measuring equipment shall have an accuracy of ± 2 % max. The time measuring equipment (e.g. stopwatch) shall have an accuracy of ± 0,1 % max.

The energy/ fuel efficiency test in accordance to the specific part of this standard shall be performed in a way that a tolerance of maximum ± 5 % is ensured for the tested truck.

This shall be verified by:

— evaluation of the test record (e.g. if voltage and current are recorded) or

— repeating the test and calculate a median value and the standard deviation (e.g. if only the electric charge is measured).

Continuous reading of the energy/fuel consumption, e.g. by continuous fuel measurement or electric energy measurement by the controller, can be used for measurement if the accuracy of the system is verified.

The result may be rounded to one decimal place. This test result shall be documented in accordance to Clause 6.

5.7 Calculation

Calculations, computer modelling or other equivalent simulating methods, based on empirical data, are permissible if these methods are producing comparable results.

When comparing calculated and test values, the test values are considered the true measure of power consumption.

6 Documentation

6.1 Test report

The test report shall contain the following details:

a) reference to this standard;

b) specification of the tested truck in respect to its marking;

c) in case of type testing: Reference to the type series;

d) specification of truck equipment (e.g. attachment, cabin, specification of filled hydraulic oil, etc.);

e) specification of tyres (manufacturer, type, material, dimensions, pressure of pneumatic tyres);

f) operation modes and/or setting of operator assistance devices;

g) set-up of the truck (e.g. software parameters);

h) specification of the traction battery, if applicable;

i) specification of the battery charger, if applicable;

j) power factor of the battery charger;

k) efficiency of the battery and the method used, according to 5.3.3, if applicable;

l) efficiency of the battery charger and the method used, according to 5.3.4, if applicable;

m) description of the test track (material, slope, smoothness);

n) wind speed, if applicable;

o) specification of the measurement equipment;

p) description of the climatic conditions (temperature);

q) date and name of the authorized person;

r) result of the test including the achieved tolerance of the energy consumption according to 5.6.

Where the verification of the truck design is made by other methods e.g. simulation the report shall reasonably be adapted to that specific method.

6.2 Declaration

6.2.1 Industrial truck energy consumption

The manufacturers' instruction handbook accompanying the industrial truck and the manufacturers' documentation[2)] shall include the appropriate version of the following information:

— energy consumption according to the EN 16796 series in kWh/h at truck set up;[3)]

— fuel consumption according to the EN 16796 series in l/h at truck set up;

— gas consumption according to the EN 16796 series in kg/h at truck set up.

6.2.2 Battery efficiency

The battery manufacturers' documentation shall include the following information:

— overall battery efficiency η_{Batt} according to the EN 16796 series including the corresponding charging factor.

The manufacturers' instruction handbook accompanying the battery shall refer to the publicly available manufacturers' document (data sheet).

6.2.3 Charger efficiency

The manufacturers' instruction handbook accompanying the charger and the manufacturers' documentation shall include the following information:

— overall charger efficiency η_{Ch} according to the EN 16796 series.

2) E.g. type sheet according to VDI 2198.

3) The truck set up that is used for the measurement as defined in 4.3.

Annex A
(normative)

Determination of battery efficiency by using the synthetic discharge cycle

A.1 General

As the synthetic cycle is scaled to the Power Battery Factor (PBF), it is possible to transfer measurement results to batteries of the same design but different sizes if a representative element of the battery is used.

The applied charging method shall ensure that the service life stated by the battery manufacturer according to EN 60254-1 is reached.

The nominal battery capacity and the efficiency for lead acid batteries is typically based on the constant discharge current for 5 h (I5). Because this procedure does not represent the application in a truck, the use of the synthetic discharge cycle is recommended.

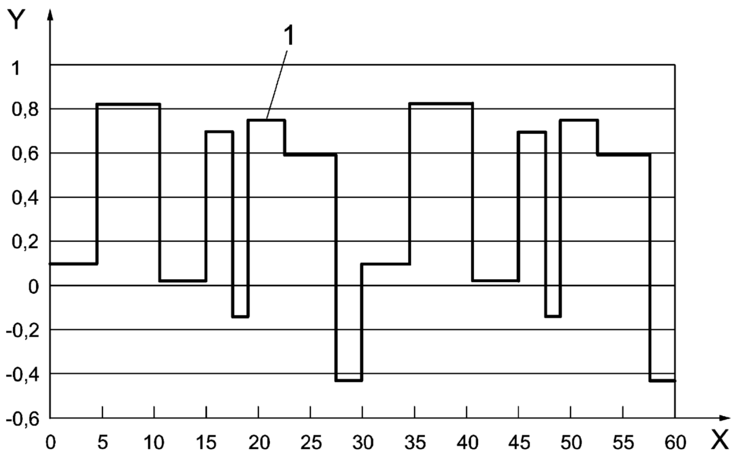
The cycle can be used to determine the efficiency of all kind of batteries.

Typically the battery efficiency should be determined by the battery manufacturer.

A.2 Definition of the synthetic discharge cycle

The synthetic discharge cycle consists of a number of blocks, defined by the current magnitude and duration approximating to the individual elements of the cycle. Recharged energy can be taken as negative values into consideration. The cycle is clustered in order to keep the number of elements of the synthetic discharge cycles small.

See Figure A.1 and Table A.1 for a typical discharge cycle using the Power Battery Factor (PBF) (ratio of the electrical power taken from the battery over the battery capacity).



Key

1 PBF Factor

X time [s]

Y power/ battery capacity [W/Wh]

Figure A.1 — Typical discharge cycle

Table A.1 — Description of the Synthetic Discharge Cycle

Step	Duration [s]	PBF Factor [W/Wh]	Charge/Discharge
1	4,5	0,10	Discharge
2	6,0	0,83	Discharge
3	4,5	0,03	Discharge
4	2,5	0,70	Discharge
5	1,5	−0,14	Charge
6	3,5	0,75	Discharge
7	5,0	0,60	Discharge
8	2,5	−0,44	Charge
9	4,5	0,10	Discharge
10	6,0	0,83	Discharge
11	4,5	0,03	Discharge
12	2,5	0,70	Discharge
13	1,5	−0,14	Charge
14	3,5	0,75	Discharge
15	5,0	0,60	Discharge
16	2,5	−0,44	Charge

A.3 Testing according to the synthetic cycle

A.3.1 Preconditions

To ensure comparable results the following test conditions shall be observed. If test conditions deviate this shall be clearly stated in the test report.

— The battery can be connected to the test equipment directly or by using connectors which are suitable to conduct the required current.

— The rate of current change between the blocks shall be not less than 150 A / 100 ms.

— Prior to the test the battery shall be charged to the rated capacity according to the battery manufacturer’s definition, e.g. acid electrolyte density for lead-acid batteries, charger control system feedback for Li-ion batteries.

The battery manufacturer shall define the preconditioning of the battery prior to the test. For example this will take into account the battery temperature.

— The test shall be performed using the specific power value, see A.3.2.

— The test using the synthetic discharge cycle ends when the battery is discharged to the rated minimum capacity according to 4.6.

— The battery temperature at the beginning of the test shall be (25 ± 5) °C.

— Using a reduced cell number is permissible, if cell connectors and other components (e.g. battery management systems, if applicable) of the type used for the complete battery assembly are fitted.

A.3.2 Power value

The specific power value depends on the battery voltage and the effective battery capacity. The discharge power value shall be calculated as follows:

$$P_{\text{Cycle}} = Q_{\text{batt}} * PBF * U_{\text{battnom}}$$

where

P_{Cycle}	is the power value in W
PBF	is the power/battery capacity Factor
Q_{batt}	is the effective battery capacity in Ah
U_{battnom}	is the nominal voltage of the battery in V

The effective battery capacity is:

$$Q_{\text{batt}} = Q_{\text{nom}} * f_{\text{eff}}$$

where

Q_{nom}	is the nominal battery capacity in Ah;
Q_{batt}	is the effective battery capacity in Ah;
f_{eff}	is the factor between effective and nominal capacity of the battery.

NOTE For lead acid batteries $f$eff is typically 0,8. This value is based on a constant discharge current for 5 hour I5.

EXAMPLE Table A.2 shows an example for a standard lead acid battery with a nominal voltage of 80 V with a nominal capacity of 500 Ah. The effective battery capacity is:

$$Q_{\text{batt}} = 500 \text{ Ah} * 0,8 = 400 \text{ Ah}$$

Table A.2 — Example for the calculation of the power value

Step	Time [s]	PBF [W/Wh]	P_{Cycle} [W]
1	4,5	0,10	3 200
2	6,0	0,83	26 560
3	4,5	0,03	960
4	2,5	0,70	22 400
5	1,5	−0,14	−4 480
6	3,5	0,75	24 000
7	5,0	0,60	19 200
8	2,5	−0,44	−14 080
9	4,5	0,10	3 200
10	6,0	0,83	26 560
11	4,5	0,03	960
12	2,5	0,70	22 400
13	1,5	−0,14	−4 480
14	3,5	0,75	24 000
15	5,0	0,60	19 200
16	2,5	−0,44	−14 080

A.3.3 Test procedure and measurements

During this test, current and voltage against time are continuously measured to allow calculation of the discharged energy (Ebatt).

$$E_{batt} = \int_0^T U_{batt}(t) * I_{batt}(t) * dt$$

where

E_{batt} is the energy taken from the battery during synthetic discharge cycle in Wh

U_{batt} is the battery voltage in V

I_{batt} is the battery current in A

dt is the differential (Measurement over time)

T is the total time to discharge the battery

After the test the battery shall be recharged to the rated capacity again, using the charging specifications as provided by the battery manufacturer.

NOTE Depending on the battery technology, these charging specifications as provided by the battery manufacturer can include overcharging.

During this part of the test, current and voltage are continuously measured against time to allow calculation of the charged energy.

$$E_{\mathrm{ch}} = \int_0^T U_{\mathrm{batt}}(t) * I_{\mathrm{batt}}(t) * dt$$

where

E_{ch} is the energy to recharge the battery in Wh

U_{batt} is the battery voltage in V

I_{batt} is the battery current in A

dt is the differential (Measurement over time)

T total time to discharge the battery

From these tests, the overall battery efficiency η_{batt} is calculated as follows:

$$\eta_{\mathrm{batt}} = \frac{E_{\mathrm{batt}}}{E_{\mathrm{ch}}}$$

Annex B
(normative)

Simplified procedure to calculate the battery and charging efficiency for lead-acid batteries

B.1 General

The efficiency of lead acid batteries can be calculated by taking the ratio of:

— the energy taken from the battery including power loss and

— the energy required for the recharging of a discharged battery, including power loss. The applied charging method shall ensure that the service life stated by the battery manufacturer according to EN 60254-1 can be reached.

The battery efficiency depends on various factors, e.g. the battery cell design, the battery state of charge, the discharge current, the battery temperature, the charging current and method (charging curve) and the charging factor.

The charger efficiency is defined as the ratio of the energy delivered to a discharged battery and the energy taken from the public grid. It varies depending on the charging method (charging curves) and the charger technology.

B.2 Formula

B.2.1 Battery efficiency during discharging based on measurement with constant discharge current

In the case that no testing data according to the synthetic cycle according to Annex A are available, the battery efficiency can be calculated based on a constant current discharge with the rated 1 h current (I_1) to a discharge voltage of 1,6 V per cell or to the value as specified by the battery manufacturer.

In this case the discharged energy shall be calculated as follows:

$$E_{\text{batt}} = \int_0^T I_1 * U_{\text{batt}}(t) * dt$$

NOTE The energy efficiency measured by this method results in a lower energy efficiency compared to the measurement with the synthetic cycle, according to Annex A.

B.2.2 Estimation of the battery efficiency based on generally accepted empirical values

If no values resulting from measurements according to Annex A or B.2.1 are available, the efficiency can be estimated according to Table B.1.

The values stated in Table B.1 are based on empirical values.

The value given for efficiency takes into account the difference between the standardized method to determine the nominal battery capacity (discharge current for 5 h, I_5) and the typical current profile in an industrial truck, see also Annex A.

NOTE The estimated values result in a lower efficiency of the battery than the measurement according to the synthetic cycle or according to B.2.1.

Table B.1 — Battery and charging technology specific overall battery efficiency

Battery type	***Charging method***	ηbatt
Flooded battery	Taper charge based on DIN 41774	0,5
Flooded battery	Charging regime with current pulses for electrolyte mixing	0,6
Flooded battery	Charging regime with electrolyte mixing by air pump	0,63
Valve regulated lead acid (VRLA) battery with immobilized electrolyte	Regulated IUIa charging regime based on DIN 41773–1	0,67

NOTE Charging method and charging curve significantly influence the efficiency of a lead acid battery.

B.2.3 Charger efficiency

Battery chargers are differentiated between 50 Hz and high frequency (HF) chargers. The charger efficiency is dependent on the battery charger technology.

The overall efficiency of the charger is related to the complete charging process, including charging characteristic, the battery type, size, and condition. The efficiency for the complete charging process is typically 1 to 2 % lower than the efficiency for the optimum operating point.

Where there are no values available from the manufacturer, Table B.2 can be used.

Table B.2 — Approximate values for charger efficiencies

Charger technology	η_{ch}
HF	0,88
50 Hz regulated	0,78
50 Hz taper	0,73

Annex C
(informative)

Calculation of the Carbon dioxide equivalent

C.1 General

Where conversion of values from Subclauses 5.3.2, 5.4 and 5.5 into carbon dioxide equivalents is desired in order to calculate the related Greenhouse gas emissions of different systems, the methods according to this Annex should be applied.

The calculation is based on the CO_2 equivalent (CDE) value that takes into account all effects of greenhouse gases that are emitted during electric power generation or the combustion of fuels respectively.

The CDE contains the amount of direct energy consumption as well as the amount of energy that is necessary to supply the energy to the energy consuming equipment.

NOTE 1 Data are based on: Well-to-Wheels analysis of future automotive fuels and powertrains in the European context; WELL-TO-TANK (WTT) Report; Version 4a, January 2014.

NOTE 2 The proposed calculation methodology is not intended to substitute for or regulate the calculation of Greenhouse gas emissions in other applications, e.g. life cycle assessments.

C.2 Calculation of CO_2 equivalent for electric trucks

The energy consumed by operation of an electric truck according to 5.3.2 can be translated into an equivalent mass of CO_2 by the following calculation:

$$m_{\mathrm{CO_2}} = CDE_{\mathrm{e}} * E_{\mathrm{truck}} = \frac{0{,}540\,38\,\mathrm{kg}}{1\,\mathrm{kWh}} * E_{\mathrm{Truck}}$$

where

m_{CO2} is the mass of carbon dioxide equivalent emissions

CDE_{e} is the CO_2 equivalent emission for electrical grid energy

E_{truck} is the energy taken from the battery during the test in kWh

NOTE 1 The CDE value is based on European data; see C.1.

NOTE 2 Above calculation does not include the energy lost while charging and discharging the battery.

C.3 Calculation of CO_2 equivalent for Diesel powered combustion engine trucks

The Diesel consumed in operation according to 5.4 of a Diesel powered combustion engine truck can be converted into an equivalent mass of CO_2 by the following calculation:

$$m_{\mathrm{CO_2}} = CDE_{\mathrm{Diesel}} \cdot V_{\mathrm{Diesel}} = \frac{3{,}177\,2\ \mathrm{kg}}{1\ \mathrm{l}} \cdot V_{\mathrm{Diesel}}$$

where

V_{Diesel} is the Diesel consumption during the test in litres

CDE_{Diesel} is the CO_2 equivalent emission for Diesel fuel

NOTE The CDE value for Diesel fuel is the sum of the CO_2 equivalent produced directly by the combustion engine and the equivalent that is necessary to supply the fuel at a petrol station, see C.1.

C.4 Calculation of CO_2 equivalent for liquid petroleum gas (LPG) powered combustion engine trucks

The liquid petroleum gas (LPG) consumed by operation according to 5.4 of an LPG powered combustion engine truck can be converted into an equivalent mass of CO_2 by the following calculation:

$$m_{CO_2} = CDE_{LPG} * m_{LPG} = \frac{3{,}391\,27\ \text{kg}}{1\ \text{kg}} * m_{LPG}$$

where

m_{LPG} is the LPG consumption during the test in kg

CDE_{LPG} is the CO_2 equivalent emission for LPG fuel

NOTE The CDE value for LPG fuel is the sum of the CO_2 equivalent produced directly by the combustion engine and the equivalent that is necessary to supply the gas fuel, see C.1.

C.5 Calculation of CO_2 equivalent for natural gas (CNG) powered combustion engine trucks

The natural gas (CNG) consumed by operation according to 5.4 of a CNG powered combustion engine truck can be converted into an equivalent mass of CO_2 by the following calculation:

$$m_{CO_2} = CDE_{CNG} * m_{CNG} = \frac{3{,}124\,21\ \text{kg}}{1\ \text{kg}} * m_{CNG}$$

where

m_{CNG} is the CNG consumption during the test in kg

CDE_{CNG} is the CO_2 equivalent emission for CNG fuel

NOTE The CDE value for CNG fuel is the sum of the CO_2 equivalent produced directly by the combustion engine and the equivalent that is necessary to supply the gas fuel, see C.1.

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