CAGI/PNEUROP BL 300-2016

Performance Test Code for Electric Driven Low Pressure Air Compressor Packages

Compressed Air and Gas Institute & PNEUROP

Sponsors:

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Compressed Air and Gas Institute (CAGI)
PNEUROP

Foreword (This foreword is included for information only and is not part of Proposed ANSI/CAGI/ PNEUROP BL 300 - Performance Test Code for Electric Driven Low Pressure Air Compressor Packages).

This document is a joint effort of the Compressed Air & Gas Institute Blower Section and the PNEUROP PN2 Low Pressure Working Group (LPWG). It allows for the comparability for all kinds of low pressure compressors (blowers) as defined by existing ISO 1217 and ISO 5389 standards.

The standard provides a uniform method of testing all types of low pressure compressor packages. It also allows for side by side in-field performance comparisons.

The Compressed Air & Gas Institute recognizes the need to periodically review and update this standard. Suggestions for improvement should be forwarded to the Compressed Air & Gas Institute, 1300 Sumner Ave., Cleveland, OH 44115; E-mail address: cagi@cagi.org.

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2 Introduction

The need for a standardized method of testing that allows for the comparison of different low pressure air compressor (blower) package technologies was brought to the attention of CAGI and PNEUROP by the industry and by users of the product. This need arose due to the fact that neither ISO 1217 nor ISO 5389, the two existing standards for positive displacement compressors and dynamic compressors, respectively, provides clear and concise means of comparing different technologies. This document provides simplified wire to air performance test methods that measure true package performance of low pressure air compressors (blowers).

The focus of this comparison is to verify the performance of a compressor (blower) package measured at any facility with inlet conditions, which can differ from guaranteed inlet conditions. For this, it is necessary to know the thermo-dynamical behavior of the compressor (blower) and to describe it by applicable formulas.

For dynamic compressors (blowers), this is already well described in the literature, and the recalculation methods have been found to be exact enough.

For positive displacement compressors (blowers) without internal compression (isochoric system such as Roots- type), it is possible to describe their behavior with the necessary accuracy; however, for positive displacement compressors with internal compression (e.g. screw type compressors/blowers), the situation is more complex. For these types of machines, part of the compression will be internal (comparable with isentropic processes) and part will be external (isochoric process). These processes must be addressed, under both test and guarantee conditions. A method has been created that takes both kinds of processes under consideration and weights them according to the given conditions. This method is valid for single stage positive displacement compressors (blowers) with a known value of the volume ratio (defining the degree of internal compression) and without any liquid injection into the process air stream.

This standardized test method can be applied to prepare performance data sheets of serial products (example data sheets in 0). Another purpose is to verify product performance at default or customer specified ambient conditions.

3 Scope

This document applies to electrically driven low pressure compressor packages utilizing ambient air as the compression gas.

“Low Pressure” is defined in the Definitions section further in the text.

There are two generic principles for the compression of air: positive displacement compression and dynamic compression.

Dynamic compression involves air drawn between the blades of a rapidly rotating impeller. The air is accelerated to a high velocity. Air speed is translated to pressure energy via a diffuser and into a volute or collector. Dynamic compressors (blowers) are of a radial flow design, with the following typical examples: single-stage centrifugal compressors, multi-stage centrifugal compressors without intercooling, and high speed "turbo" compressors.

Positive displacement low pressure compressors (blower) work on the principle of trapping a volume of air and reducing its volume, internally or externally. Two basic types are typical, as follows:

- Rotary Screw Positive Displacement Compressor (Blower): Air is drawn into a compression chamber formed by intermeshing rotors. As the rotors turn, the cavity between the rotors becomes smaller, reducing the volume of the trapped air. When the pressure has reached the designed built in pressure ratio, the rotors uncover the outlet port and the air is discharged into the customer's piping.
- Rotary Lobe Positive Displacement Compressor (Blower): Air is drawn into the case and is trapped between the rotor and the case wall. These pockets are progressively moved to the outlet port. At the outlet, some air from the piping comes back into the compressor, compressing the air.

This document considers the low pressure compression of ambient air performed by all positive displacement and dynamic compressors/blowers, such as:

- Turbo type
- Roots type
- Screw type
- Piston type
- Side channel type

Low pressure positive displacement compressors with a liquid in the compression element (such as liquid ring pumps and liquid injected compressors of screw type) have not been considered and thus the document is not applicable as such for these types of compressors.

Compressors with intercooling between stages of compression are excluded.

Compressors with and without means of controlling flow are covered. The means of controlling flow may be electrical (e.g. with a variable frequency drive) or mechanical or both.

4 References

The following referenced documents are relevant for the application 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.

- ISO 5389: 2005, Turbo compressors – Performance test code
- ISO 1217: 2009, Displacement compressors – Acceptance tests
- EN 60051: 1999, Accuracy classes for measuring instruments
- EN 60688: 2002, Technical basics for measurements
- ISO 5167-1: 2003, Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full – Part 1: General principles and requirements
- ISO 80000: 2009 Quantities and units
- ISO 9300: Measurement of gas flow by means of critical flow Venturi nozzles

In addition, all ISO norms feasible for this work can be used.

5 Definitions

5.1 *Symbols and units*

Wherever feasible, the symbols from ISO 80000 are used in the formulas. These might slightly differ from existing standards like ISO 5389 or ISO 1217.

Latin letters Symbol	Meaning	Unit
c	sonic velocity	m/s
cp , cv	specific heat capacity	J/(kg·K)
D	Outer impeller diameter of the first impeller	m
e	specific energy	J / m3
h	specific enthalpy	J/kg
Ma	Mach number	—
M	molar mass	kg/mol
m	Mass	kg
q_m	mass flow	kg/s
n	speed of rotation	1/s
P	power	W
p	pressure	Pa
R	specific gas constant	J/(kg·K)
$Rmol$	molar gas constant	J/(mol·K)
Re	Reynolds number	—
s	specific entropy	J/(kg·K)
T	thermodynamic temperature	K
t	Celsius temperature	°C
u	tip speed	m/s
v	specific volume	m3/kg
v_i	Internal volume ratio	
V	Volume	m^3
q_V	Volume flow	m^3/s
X_n	ratio of reduced speeds of rotation	—
x	mass ratio of water vapour to dry gas	kg/kg
y	specific compression work	J/kg
Δ	difference	—
η	efficiency	—
ϑ	ratio of (RZ1 T1) values	—
κ	ratio of specific heat capacities	—
π	pressure ratio	—
ρ	density	kg/m3
ϕ	ratio of volume flow ratios	—
φ	flow coefficient	—

φ_{rel}	relative humidity
ψ	reference process work coefficient
σ	standard deviation

Subscripts

Index	Meaning
1	inlet (suction side)
2	outlet (discharge side)
Air	dry air
amb	ambient (air, temperature)
co	converted to guarantee conditions
comb	combined
cool	coolant
d	dynamic
dry	dry
g	guarantee or reference conditions
i	Internal or intermediate
isoc	isochoric
ideal	according to an ideal thermodynamic process
out	output
Pr	reference or standard process
red	reduced speed
ref	reference value
rel	relative
s	isentropic
sat	saturated
st	static
te	test result
test 1	first test in 2-speed testing
test 2	second test in 2-speed testing
tol	permissible deviation
tot	total
u	tip or peripheral
vap	vapour, steam
wet	moist

5.2 Low pressure

The test code applies to compressors by the following limits:

$$0.5 \text{ bar} \leq p_1 \leq 1.1 \text{ bar}$$

and

$$0.1 \text{ bar} \leq (p_2 - p_1) \leq 2.5 \text{ bar}$$

and

$$1.1 \leq \left({}^{p_2}/_{p_1}\right) \leq 3.5$$

5.3 Package

The package shall comprise all components that are necessary for the long term functioning of the compressor under guarantee conditions and are needed to fulfill the object of the guarantee and the preconditions of the guarantee:

> compressor with driver system, variable frequency drive (as applicable), cooling / lubrication system, inlet filter, inlet valve / guide vanes (as applicable), bearing power

supply (as applicable), fully piped and wired internally, including ancillary and auxiliary items of equipment and all power devices that affect power consumption.

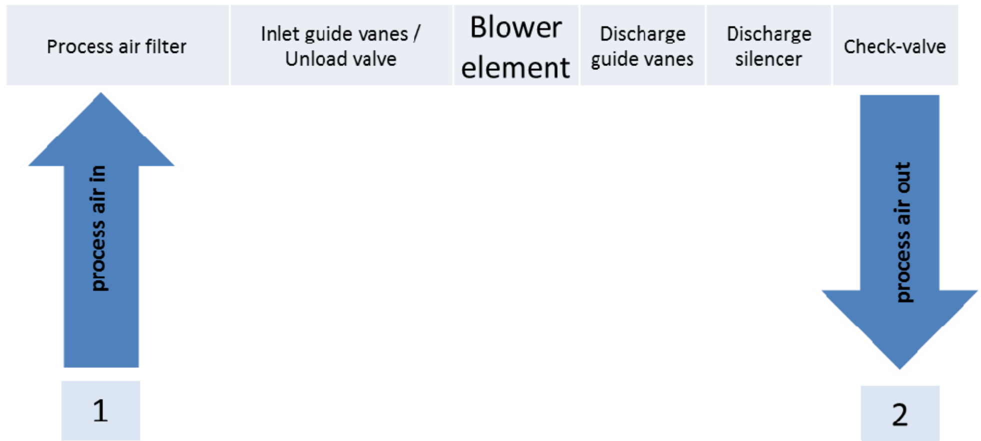


Figure 1: Components and Ancillaries

5.4 Definitions regarding performance

5.4.1 Relative humidity

The relative humidity can be expressed as follows:

$$\varphi_{rel} = \frac{p_{vap}}{p_{vap,sat}}$$

5.4.2 Water vapor content

The water vapor content related to a dry mass of air is:

$$x = 0.622 \cdot \frac{\varphi_{rel} \cdot p_{vap,sat}}{p - \varphi_{rel} \cdot p_{vap,sat}}$$

5.4.3 Isentropic exponent

For dry air close to 1 bar pressure, the approximation for the isentropic exponent is:

$$\kappa_{dry} \approx 1.4$$

The isentropic exponent κ for humid air is then determined as follows:

$$\kappa_{wet} = \kappa_{dry} \cdot (1 - 0.11 \cdot x)$$

5.4.4 Gas constant

Determining the gas constant R of humid air can be done as follows:

$$R_{wet} = R_{air} \cdot \left(\frac{1}{1 - \frac{\varphi \cdot p_{vap,sat}}{p} \cdot 0.378} \right)$$

Or

$$R_{wet} = R_{air} \cdot \left(1 + \frac{x}{x+1} \cdot 0.608 \right)$$

5.4.5 Reference process compression work

5.4.5.1 Specific isentropic compression work

Within limits (table E1, ISO5389) the specific isentropic compression work is defined as:

$$y_s = \frac{\kappa}{\kappa - 1} \cdot R_1 \cdot T_1 \cdot \left[\left(\frac{p_2}{p_1} \right)^{\left(\frac{\kappa - 1}{\kappa} \right)} - 1 \right]$$

5.4.5.2 Specific isochoric compression work

The specific isochoric compression work is defined as

$$y_{isoc} = \frac{1}{\rho_1} \cdot [p_2 - p_1]$$

5.4.5.3 Specific combined isentropic and isochoric compression work

The specific combined isentropic and isochoric compression work is defined as

$$y_{comb} = R_1 \cdot T_1 \cdot \left[\frac{p_2/p_1}{v_i} + \frac{\kappa}{\kappa - 1} \left(\frac{1}{\kappa} \cdot v_i^{\kappa - 1} - 1 \right) \right]$$

If the internal volume ratio v_i is equal to 1 then the specific combined isentropic and isochoric compression work is equal to the specific isochoric compression work.

If the internal volume ratio v_i is equal to $\left(p_2/p_1 \right)^{1/\kappa}$ then the specific combined isentropic and isochoric compression work is equal to the specific isentropic compression work.

5.4.6 Internal volume ratio

The internal volume ratio v_i of a volumetric compressor is defined as the ratio of the enclosed volume at moment of closure of the inlet port to the enclosed volume at the moment of opening of the outlet port.

5.4.7 Inlet volume flow rate

The inlet volume flow rate considers the gas condition at the process air inlet as defined above.
The inlet volume flow rate is defined as the delivered mass flow rate q_{m2} divided by the total density at the compressor package inlet. The delivered mass flow rate shall be measured downstream of the process air discharge in order to exclude all leakage losses.

$$q_{v1} = \frac{q_{m2}}{\rho_1}$$

5.4.8 Specific energy

The specific energy is the absolute work required to compress a volume of gas from the pressure (and temperature) at package inlet, to the package discharge pressure, while accounting for changes in the enthalpy and kinetic energy of the gas during the compression process, including all possible mechanical and electrical losses.

$$e = \frac{P}{q_{v1}}$$

5.4.9 Rotor tip speed

The tip speed results from the rotor outer diameter and speed of rotation.

$$u = \pi \cdot D \cdot n$$

5.4.10 Flow coefficient

The flow coefficient is a flow velocity formed from the inlet volume flow and an impeller cross- section area, rendered dimensionless by the tip speed of the rotor.

$$\varphi = \frac{q_{v1}}{\frac{\pi}{4} \cdot D^2 \cdot u}$$

5.4.11 Work coefficient

The work coefficient of the reference process specific work (for the entire package) is rendered dimensionless by the kinetic energy of tip speed u.

$$\psi = \frac{y}{\left(u^2/2\right)}$$

With $0 \leq \psi \leq 2$.

5.4.12 Machine Mach number

Calculation of the machine Mach number can be done as follows:

$$Ma = \frac{u}{c_1} = \frac{u}{\sqrt{\kappa_1 \cdot R \cdot T_1}}$$

5.4.13 Operational states

5.4.13.1 *Under* load

The operational state in which the compressor is running and delivering pressure and flow.

5.4.13.2 Idling

For compressors equipped with idling functionality, the operational state in which the compressor is not producing flow to the package outlet, but is rotating at a significant speed.

5.4.13.3 Stand by

The operational state in which the compressor is ready for immediate start from non-rotating modus.

5.4.14 Process air inlet point definition (subscript 1)

The process air inlet point (index “1“) is defined as being upstream of any technically required component.

In the case in which a technically required component is not physically present during the test the impact of the component on performance shall be accounted for.

5.4.15 Process air outlet point definition (subscript 2)

The process air discharge point (index “2”) is defined as being downstream of any technically required component.

In the case in which a technically required component is not physically present during the test the impact of the component on performance shall be accounted for.

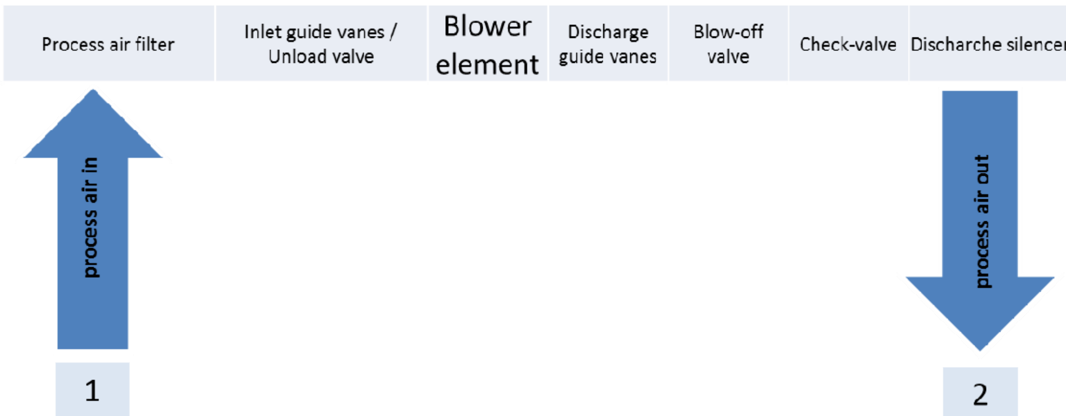


Figure 2: Process Air Inlet & Outlet

5.4.16 Default inlet conditions

Default conditions for the guarantee are:

Table 1: Default Inlet Conditions

Default inlet condition	Value
Inlet air pressure	101,325 kPa [1,01325 bar(a)]
Inlet air temperature	20 °C
Inlet relative humidity	0%
Temperature of the coolants at package inlet	20 °C

5.4.17 Client specified inlet conditions

The client may specify the site conditions to which the equipment is expected to perform.

5.4.18 Definition: Steady state

Steady state is achieved when the difference between inlet and outlet temperature is within 1K and the speed variation is held to within 0.5% for at least three minutes.

6 Guarantee and Measurement

6.1 Preconditions of the guarantee

Preconditions are the conditions the compressor (blower) will be externally exposed to in use and which shall be specified in the contract of supply (meaning “contract”, “data sheet”, “agreement” or similar) or default preconditions shall be applied according to this guideline (or some other applicable instruction).

For testing to be possible at least the following shall be specified:

Table 2: Preconditions of the Guarantee

Preconditions of the guarantee
Air inlet pressure*
Air inlet temperature*
Air inlet humidity*
Coolant inlet temperature*
Coolant flow
Supply voltage
Supply frequency
Electromagnetic emissions
Noise level outside the package (e.g. by law)

*These can be taken from the default conditions defined in 0 – Table 1, 5.4.16 Default inlet conditions. Additional limits can be specified, such as:

- Total harmonics distortion on the electrical supply
- Input current supply
- Minimum permissible starts/hour
- Minimum permissible unload cycles/hour
- Allowable pulsation level at the outlet of the package
- Filtration grade of the air inlet filter

This set can be summarized in a table (see example in 0

Calculation examples), which contains the nominal values or the limits, whichever is applicable.

6.2 Object of the guarantee

The object of guarantee is the set of values to be guaranteed within the defined preconditions[1]:

1. Inlet volume flow rate
2. The discharge pressure at the outlet of the package.
3. The total Specific Energy of the package for the delivered flow at the guaranteed discharge pressure.

6.3 Compressor (Blower) to be tested

The compressor (blower) configuration to be tested shall include all components required to fulfill all the preconditions.

As a general rule, the configuration of the unit under test shall be identical to the configuration of the unit to be delivered.

A package checklist, such as given in 0
Example of Manufacturer's checklist, shall be completed by the manufacturer and shall be part of each compressor test report. The checklist shall be used to ensure that the tested package matches the specified one.

The checklist shall indicate which components are included, excluded, or not applicable for normal functioning at guarantee conditions or accounted for. If any required components are not installed in the test configuration, the correction calculations for these components shall be shown in conjunction with the checklist.

Ancillaries, excluding stand-by ancillaries, are to be running.

6.4 Compressor (blower) specifications to be provided prior to testing.

The compressor (blower) is tested against a specified outlet pressure (at the outlet of the package).
In addition to the preconditions, the default inlet conditions (or the client specified inlet conditions) and the check-list, the description of the compressor (blower) to be tested shall contain specific data for the performance calculation. This includes:

- The compressor (blower) rotational speed.
- The internal volume ratio for positive displacement compressors (blower).
- The variable geometry settings if applicable for the compressor (blower).

This document describes a method to test the performance of a single operating point. For variable flow compressors (blowers) this method can be repeated at several flow rates to establish

[1] Idle power consumption and stand by power consumption could be optionally added to the guarantee provided test and measurement instructions are defined in a future standard.

the performance over the operating range of the compressor at the specified outlet pressure. For the purpose of general data sheets, or in case there is no specific agreement with the client on how to test variable flow compressors, 5 flow rates shall be tested. The minimum and maximum flow rates that can be achieved continuously under guarantee conditions shall be specified and tested by the manufacturer. Furthermore three additional flow rates evenly spread within the total flow rate range of the compressor (blowers) shall be specified and tested. For each test point, the adequate test loads shall be determined in the same way as for a single working point.

7 Measurement equipment and methods

The pressure and temperature measurements shall be total measurements, static measurements corrected to total conditions, or static measurements used as such.

All measurements shall be carried out by suitable devices and applied in a proper way.
Remark: For definitions of static, dynamic, and total measurements, refer to ISO 5389 (chapters 5.2. and 5.3).

No measurement uncertainty tolerances are to be taken into account in corrections or comparisons or acceptance.

For guarantee acceptance, as tested results are taken as absolute accurate.

Below a figure is inserted on a typical measurement installation.

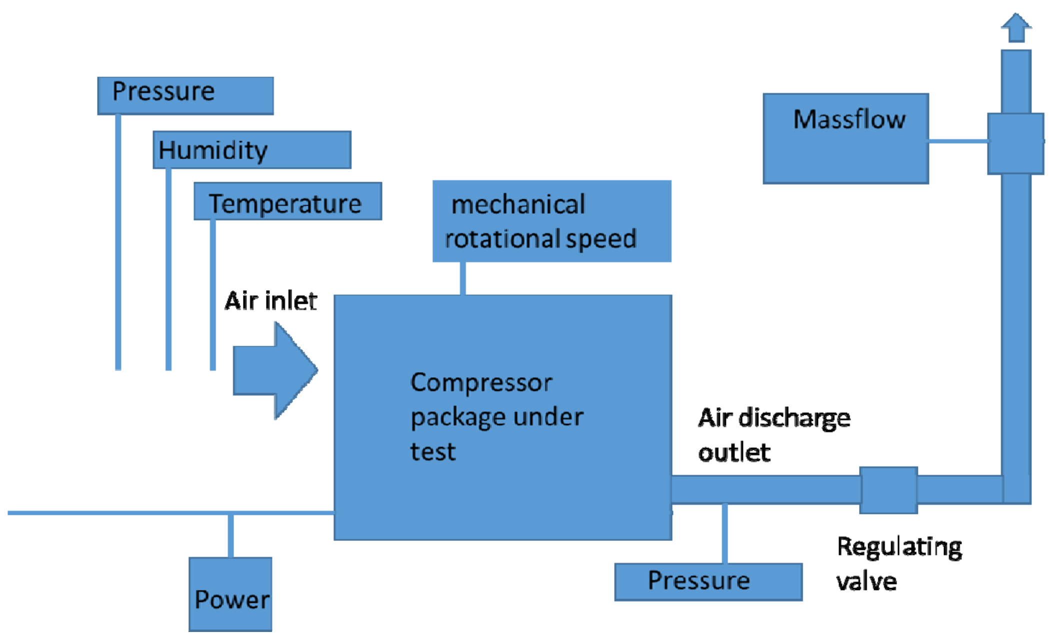


Figure 3: Overview of Typical Measurement Installation

7.1 Calibration of instruments

Calibration certificates shall be available in advance of the test at the request of the client at the latest at the day of the acceptance test for any instruments / transducers / sensors defined in table 2.

All test instrumentation, as individual component or end-to-end measurement chains, shall be calibrated at least on a yearly basis, and the calibrations shall be fully traceable.

In addition, the equipment and system calibrators used for the calibration of the test instrumentation, shall at least be certified / accredited once a year.

7.2 Measurement method and uncertainty

The uncertainty of the measurements during test is the range of values in which the real physical value of the measurement is, with a confidence defined by the confidence interval. In this text the confidence interval is considered as plus and minus two times the standard deviation ($\pm 2\sigma$). This corresponds to a confidence interval of 95%.

7.3 Uncertainty limits

7.3.1 Mass flow measurement

For mass flow measurements, a measuring device with high precision, suitable for the product shall be used.

Measuring devices mentioned in ISO 5167 shall be deemed acceptable. For other devices a calibration certificate issued by an accredited authority is required. The test loop shall be built by preference according to ISO 5167.
Overall uncertainty of the measured value shall be 1.5% or better.

7.3.2 Electrical power measurement

The determination of the electrical power supplied to the complete compressor (blower) unit shall be carried out by measuring voltage and current on the three phases by certified instruments. Alternative measuring methods by certified power meters with proved equivalent precision may be used.

The full power including harmonics shall be captured in the measurement. This is especially important in cases in which Variable Frequency Drives (VFD) or other power electronics are part of the package.

Overall uncertainty of the measured value shall be 0.5% or better.

7.3.3 Temperature measurement

Inlet measurement shall be done with at least two independent temperature measuring devices.

Overall uncertainty of the measured value shall be 1K or better.

7.3.4 Pressure measurement

Amplitudes of low frequency pressure waves at the inlet or outlet pipe shall never exceed 10% of the absolute pressure measured.

Overall uncertainty of the measured value of absolute pressure shall be 0.3% or better.

7.3.5 Speed measurement

Overall uncertainty of the measured value shall be 0.2% or better.

7.3.6 Relative humidity measurement

The relative humidity measurement shall be carried out at the package inlet.

Overall uncertainty of the measured value shall be 5% or better on full scale.

8 Test

8.1 General test process

In order to compare the performance data of compressors (blowers) with different technologies, it is necessary to test these compressors (blowers) under the same similarity conditions and with the same methods by applying the same principles and process steps. The ideal reference process in this methodology is different for different types of compressors. Positive displacement compressors (blowers) with or without internal compression use the combined isentropic and isochoric process. Dynamic compressors (blowers) of any kind use the isentropic process.

The test shall be carried out at an appropriate test field under prevailing conditions. No changes to geometry are allowed between test and specified conditions. For the set-up, the compressor is connected to the test loop. Correct cooling conditions have to be assured. The compressor shall run for warm-up against rated outlet pressure until steady state conditions are reached and the temperature remains constant at the inlet and outlet of the flow measuring device. The compressor (blower) package shall operate at the steady state condition for the duration of data collection for each test point.

In Figure 4, the general process of testing is shown in a schematic.

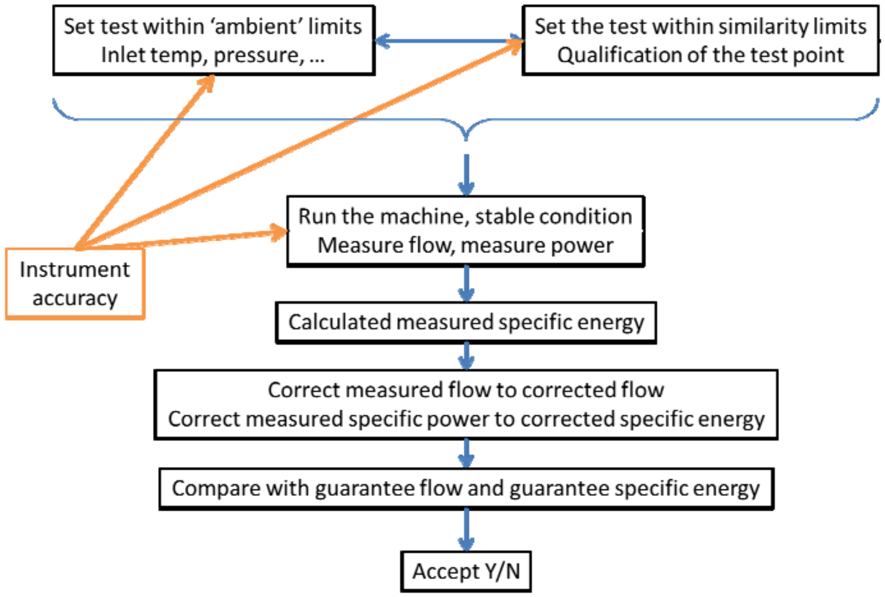


Figure 4: Overview of Test Process

8.2 Allowed deviation of rotational speed between test and guarantee

The supplier shall inform about the expected rotational speed for the specified point while operating at guarantee conditions well in advance of conducting the test.

The allowed deviation for rotational speed is +/- 3%.

For variable speed dynamic compressors (blowers), it is possible that the proper setup of the compressor in order to keep the deviation of the dimensionless numbers within the stated limits, results in a rotational speed that deviates more than +/- 3% from the expected rotational speed. In cases in which the rotational speed deviates more than +/- 3% such cases a second test is to be conducted to verify the efficiency at the guarantee speed (see definition of two speeds testing in 0 8.10 Method in case of too large difference in inlet state (dynamic compressors) – two *speed test*).

8.3 Allowed deviation of ambient conditions

8.3.1 Requirements on test facility

The manufacturer shall keep inlet and ambient conditions within the following limits for the duration of the test:

Temperature limits: 5 ºC – 35 ºC
Pressure limits: 91,325 – 111,325 kPa

8.3.2 Requirements for data to be published and/or verified

The ambient conditions shall not deviate compared to the indicated and/or required reference conditions more than:

Inlet temperature: ±10 K
Inlet pressure: ±10%

8.3.3 Customer specified site conditions

There is no limit of the deviations between the test conditions and the site specified conditions.

8.4 Allowed deviation of preconditions

Below are the allowed deviations of the precondition data, if applicable:

Deviation of liquid coolant temperature: ±15K
Deviation of mass flow of liquid coolant: ±10%

8.5 Allowed deviation of compressor mach number

It is essential to keep the dimensionless numbers as similar as possible between the guarantee conditions and the test conditions.

For dynamic compressors the deviation of compressor Mach number shall be between -5% and +5%.

For positive displacement compressors there is no restriction on the deviation of compressor Mach number.

8.6 Selection of test flow

8.6.1 Selection of flow setting

8.6.1.1 Fixed flow, positive displacement and dynamic compressors

For compressors with no possibility to adjust the flow, the flow will result from the actual speed at which the compressor is running (e.g. constant speed compressors with no flow-adjusting device).

8.6.1.2 Variable flow, positive displacement compressors
The specified volume flow shall be matched within the given tolerance by adjusting the compressor (by speed or by positive displacement per revolution, if adjustable).

8.6.1.3 Variable speed, dynamic compressors
The supplier shall inform about the reference rotational speed and settings of variable geometry for the specified operating point at the guarantee conditions in advance of test.

The speed setting for the test will result from keeping the dimensionless numbers constant as follows:

Rotational speed is determined from the Mach numbers at specified and test conditions keeping Ma constant.

The flow will result from the rotational speed and the outlet pressure setting as explained below.

8.6.1.4 Fixed speed, variable flow, dynamic compressors
The supplier shall inform about the reference rotational speed and settings of variable geometry for the specified operating point at the guarantee conditions in advance of the test. Rotational speed is determined by the speed of the drive. Test setting for flow will result from the outlet pressure setting as explained below.

8.7 Allowed deviation of flow and work coefficient

8.7.1 Allowed deviations to be checked for test validity (ensuring similarity)

8.7.1.1 For dynamic compressors (blowers)
It is essential to keep the dimensionless numbers as close as possible between the guarantee conditions and the test conditions.

Deviation of work coefficient: - 2%, +2%
Deviation of flow coefficient: -2%, +2%
Deviation of Mach number: -5%, +5%

8.7.1.2 For positive displacement compressors (blowers)
For the compressor (blower) under test it is essential to keep the following numbers as close as possible between the guarantee conditions and the test conditions.

Deviation of work y_{comb}: - 2%, +2%
Deviation of flow coefficient: -2%, +2%

Remark: For typical positive displacement compressors (blowers) with fixed geometry, where the flow is linear to speed, this latter condition will be fulfilled.

8.8 Selection of test pressure

8.8.1 For positive displacement compressors (blowers) with or without internal compression

The outlet pressure for positive displacement compressors (blowers) with internal compression (internal volume ratio $v_i > 1$) or without internal compression (internal volume ratio $v_i = 1$) shall be set such that the specific combined compression work in the prevailing test conditions matches the one in the guarantee conditions.

$$y_{comb,te} = y_{comb,g}$$

The required outlet pressure can then be calculated as follows:

$$p_{2,te} = \left[\frac{y_{comb,g}}{R_{te} \cdot T_{1,te}} - \frac{\kappa_{te}}{\kappa_{te} - 1}\left(\frac{1}{\kappa} \cdot {v_i}^{\kappa-1} - 1\right)\right] \cdot \ v_i \cdot p_{1,te}$$

8.8.2 For dynamic compressors (blowers)

The outlet pressure for dynamic compressors shall be set in a way such that the specific isentropic compression work in the prevailing test conditions matches the one in the guarantee conditions multiplied with the square of the speed ratio, in order to achieve similarity.

$$y_{s,te} = y_{s,g} \cdot \left(\frac{u_{te}}{u_g}\right)^2$$

The required outlet pressure can then be calculated as follows:

$$p_{2,te} = p_{1,te} \cdot \left[1 + \left(\frac{\kappa_{te} - 1}{\kappa_{te}}\right)\left(\frac{y_{s,g} \cdot \left(\frac{u_{te}}{u_g}\right)^2}{\left(R_{te} \cdot T_{1,te}\right)}\right)\right]^{\left(\frac{\kappa_{te}}{\kappa_{te}-1}\right)}$$

8.9 Fluctuations on the specific test readings during test at steady state

Readings are to be taken at steady state which is defined as the state in which the difference between inlet and outlet temperatures is within 1 K for a period of three minutes or more.

For individual readings, the limits on fluctuations in table 1 below apply:

Table 3: Permissible Fluctuations of Test Readings

Measurement	Fluctuation
Inlet pressure	1 %
Inlet temperature	1 K
Outlet temperature	1 K
Temperature difference between outlet and inlet	1 K
Outlet pressure absolute	0.5 %
Flow	1 %
Speed (rotational speed)	0.5 %
Electrical power	1 %
Line voltage	2 %
GENERAL NOTES:	
A fluctuation is the percentage of difference or the difference between the minimum and maximum test reading divided by the average of all sets of readings for one test point.	

8.10 Method in case of too large difference in inlet state (dynamic compressors) – two speed test

For dynamic compressors, the limits imposed on rotational speed may lead to a situation in which similarity cannot be achieved within those speed limits.

This can happen if the preconditions at test differ significantly from the specified preconditions. In this case a two speed test can be applied. The procedure for conducting such a test is as follows:

- The first test is set up and executed according to the limits of test setup deviation (e.g. Mach number), except for the absolute value of the rotational speed (n).

Note: E.g. the needed rotational speed may be in excess of compressor capability in which case the test cannot be executed.

- The second test shall be conducted at the specified rotational speed with the outlet pressure set such as to load the compressor to guaranteed input power ± 2 %. This allows determining the efficiency at that speed and that power. The limits regarding flow, pressure, and Mach number do not apply.

The compression power for the two tests are calculated with the following equations:

$$P_{i,test1} = q_{m,test1} \cdot y_{test1}$$

and

$$P_{i,test2} = q_{m,test2} \cdot y_{test2}$$

Here y_{test1} and y_{test2} refer to the real work, which is equal to the change in enthalpy Δh measured by the temperature rise.

The correct value to use for input power as tested is then calculated as follows:

$$P_{te} = P_{i,test1} \cdot \frac{P_{te,test2}}{P_{i,test2}}$$

9 Correction of Test Results

The test results, measured at the test bench (subscript *te*) shall be recalculated to the corrected values (subscript *co*) with the formulas in the sections that follow. The equations take into account the guarantee conditions (subscript *g*) to calculate these corrected values.

Note: In this calculation scheme, there is no correction for the difference in Reynolds number.

9.1 Correction of measured flow

Calculate the corrected volume flow as:

$$q_{v1,co} = q_{v1,te} \cdot \frac{u_g}{u_{te}}$$

Note: Tip speed ratio $\left(\frac{u_g}{u_{te}}\right)$ is equal to the shaft speed ratio. Scaled test are not allowed.

9.2 Correction of measured pressure

As the outlet pressure during testing differs from the target test outlet pressure, this pressure with its deviations shall be corrected to the guaranteed conditions. This allows the influences these deviations have on the guaranteed performance data to be recognized.

9.2.1 For dynamic compressors (blowers)

First, calculation of the corrected compression work shall be made with:

$$y_{s,co} = y_{s,te} \cdot \left(\frac{u_g}{u_{te}}\right)^2$$

Note: Tip speed ratio $\left(\frac{u_g}{u_{te}}\right)$ is equal to the shaft speed ratio

Then, the corrected pressure ratio is calculated:

$$\pi_{co} = \left[1 + \left(\frac{\kappa_g - 1}{\kappa_g}\right)\left(\frac{y_{s,co}}{R_{1,g} \cdot T_{1,g}}\right)\right]^{\left(\frac{\kappa_g}{\kappa_g - 1}\right)}$$

9.2.2 For positive displacement compressors (blowers):

For positive displacement compressors (blowers), the corrected pressure ratio shall be calculated as follows:

$$\pi_{co} = \left[\frac{y_{comb,te}}{R_1 \cdot T_1} - \frac{\kappa_g}{\kappa_g - 1}\left(\frac{1}{k} \cdot {v_i}^{\kappa_g - 1} - 1\right)\right] \cdot v_i$$

9.2.3 For positive displacement and dynamic compressors (blowers):

To calculate corrected outlet pressure, the follow equation shall be used using the appropriate corrected pressure ratio from above:

$$p_{2,co} = \pi_{co} \cdot p_{1,g}$$

9.3 Correction of specific energy demand

The tested specific energy demand e_{te} is the ratio of the measured power during test P_{te} and the measured flow $q_{v1,te}$.

$$e_{te} = \frac{P_{te}}{q_{v1,te}}$$

The specific energy demand is then corrected for the differences in density ρ and work y between test and guarantee conditions. Although the work is set in test according to the work in guarantee conditions, any difference between actual test conditions and the set point is considered in the correction formula.

Depending on the type of compressor, a different reference process for the specific compression work shall be used.

For positive displacement compressors (blowers) with internal compression (internal volume ratio $v_i > 1$) or without internal compression (internal volume ration $v_i = 1$) the specific energy demand shall be corrected as follows:

$$e_{CO} = \frac{\rho_{1,g}}{\rho_{1,te}} \cdot \frac{y_{comb,g}}{y_{comb,te}} \cdot e_{te}$$

For dynamic compressors (blowers), the correction is as follows:

$$e_{CO} = \frac{\rho_{1,g}}{\rho_{1,te}} \cdot \frac{y_{s,g}}{y_{s,te}} \cdot e_{te}$$

For the guaranteed specific compression work ($y_{comb,g}$ or $y_{s,g}$), the stated guarantee values of pressure and inlet temperature are to be used. For the tested specific compression work ($y_{comb,te}$ or $y_{s,te}$), the measured test values of pressure and inlet temperature are to be used.

9.4 Calculated package power

The power consumption of the package in the guarantee conditions can be expressed in two different ways. The power consumption of the tested package at guarantee conditions (effectively delivering the corrected flow $q_{v1,co}$) will be:

$$P_{co} = e_{co} \cdot q_{v1,co}$$

The power consumption of the package at guarantee conditions and at the guarantee flow (thus this is the case in which the package matches the guarantee flow $q_{v1,g}$):

$$P_{co,g} = e_{co} \cdot q_{v1,g}$$

9.5 Comparison of corrected values with guaranteed values

The test results are corrected to the specified operating conditions with the purpose of comparability with the guaranteed or specified performance.

The comparison shall include:

- Comparison of the corrected specific energy e_{co} with the guaranteed specific energy e_g
- Comparison of the corrected volume flow rate $q_{v1,co}$ with the guaranteed volume flow rate $q_{v1,g}$
- Comparison of the corrected absolute outlet pressure $p_{2,co}$ with the guaranteed $p_{2,g}$
- Comparison of the overall package power consumption P_{co} with the guarantee value P_g.

Values must not exceed the accepted tolerances as given in the guarantee.

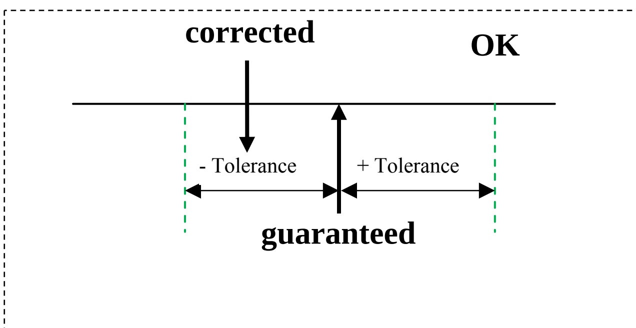


Figure 5: Acceptance Tolerances

Acceptance tolerances for values, corrected over guarantee, are specified in the table below.

Table 4: Acceptance Tolerances

Volume flow rate at specified conditions $q_{v1,g}$ (m3/s) x10^{-3}	Volume flow rate at specified conditions $q_{v1,g}$ (m3/min)	Volume flow rate at specified conditions $q_{v1,g}$ (m3/h)	Volume flow rate $q_{v1,g}$ %	Specific energy demand e %	Outlet Pressure p_2 %
$0 < q_{v1,g} \leq 8.3$	$0 < q_{v1,g} \leq 0.5$	$0 < q_{v1,g} \leq 30$	±7	±8	0÷ +1%
$8{,}3 < q_{v1,g} \leq 25$	$0{,}5 < q_{v1,g} \leq 1.5$	$30 < q_{v1,g} \leq 90$	±6	±7	0÷ +1%
$25 < q_{v1,g} \leq 250$	$1.5 < q_{v1,g} \leq 15$	$90 < q_{v1,g} \leq 900$	±5	±6	0÷ +1%
$250 < q_{v1,g}$	$15 < q_{v1,g}$	$900 < q_{v1,g}$	±4	±5	0÷ +1%

Note: The tolerance band on package power is defined by the tolerance on specific energy consumption.

The corrected values are to be compared to the guaranteed values. If the values are within the limits as defined in this standard, then the compressor passes the test and is accepted. If the values are not within the limits as defined in this standard, then the compressor (blower) fails the test and is not accepted.

10 Test report

10.1 Test report content

At a minimum, the test report shall include the following:

- Test piping arrangement indicating pipe sizes and lengths, pressure and temperature measurement locations, flow measurement arrangement, valve location(s), and verification of compliance with ISO measurement standards referenced in ISO 5167-1: 2003.
- Original test logs including all recorded data required for calculations.
- Detailed sample calculation for one test point.
- Instrument calibration certificates.
- Date of test.
- Test report number.
- Compressor (blower) type, manufacturer, model, serial number, date of manufacture.
- Manufacturer's package checklist per Appendix 2.

10.2 Test results summary

Test results shall be summarized per format below. Use appropriate units of measure. The Reference Section column in this document is provided for clarification purposes only.

	Symbol	Unit (Metric)	Ref Section	Numerical Values			
AS TESTED DATA							
Test Number				1	2	3	4…
Test Period start/end		Mins.					
Barometric Pressure	$p_{amb,te}$	bar abs					
Ambient Relative Humidity	$\varphi_{rel,te}$		0				
Isentropic exponent	$\kappa_{,te}$		0				
Ambient Gas Constant	$R_{amb,te}$	J/(kg*K)	0				
Inlet Temperature	$T_{1,te}$	deg C					
Inlet Pressure	$p_{1,te}$	bar abs					
Outlet Pressure	$p_{2,te}$	bar abs					
Discharge Temperature	$T_{2,te}$	deg C					
Compressor Speed	n_{te}	rpm					
Supply voltage	U_{te}	volts					
Supply frequency	f_{te}	Hz					
External Coolant Inlet Temperature	$T_{1,cool,te}$	deg C					
External Coolant Flow	$q_{m,cool,te}$	kg/sec					
Reference Work	$y_{,te}$	J/kg	3.4.6				
Inlet Volume Flow Rate	$q_{v,1,te}$	m^3/s	3.4.8				
Driver System Input Power -Type B test	$P_{driver,te}$	kW					
Aux. Powers (calc.) - Type B test	P_{aux}	kW					
Total Input Power	$P_{,te}$	kW					
Specific Energy	$e_{,te}$	$kW/m^3/sec$	3.4.9				

	Symbol	Unit (Metric)	Ref Section	Numerical Values			
SPECIFIED / GUARANTEED CONDITIONS							
Barometric Pressure	$p_{amb,g}$	bar abs					
Ambient Relative Humidity	$\varphi_{rel,g}$		3.4.1				
Isentropic exponent	$\kappa_{,g}$		3.4.3				
Ambient Gas Constant	$R_{amb,g}$	J/(kg*K)	3.4.4				
Inlet Temperature	$T_{1,g}$	deg C					
Inlet Pressure	$p_{1,g}$	bar abs					
Outlet Pressure	$p_{2,g}$	bar abs					
Compressor Speed	$n_{,g}$	rpm					
Supply voltage	U_g	volts					
Supply frequency	F_g	Hz					
External Coolant Inlet Temperature	$T_{1,cool,g}$	deg C					
External Coolant Flow	$q_{m,cool,g}$	kg/sec					
Reference Work	$y_{,g}$	J/(kg)	0				
Inlet Volume Flow Rate	$q_{v,1,g}$	m^3/s	0				
Total Input Power	$P_{,g}$	kW					
Specific Energy	$e_{,g}$	kW/m^3	0				
CORRECTED TO SPECIFIED CONDITIONS							
Inlet Volume Flow Rate	$q_{v,1,co}$	m^3/s	0				
Outlet Pressure	$p_{2,co}$	bar abs	0				
Total Input Power	$P_{,co}$	kW	0				
Specific Energy	$e_{,co}$	$kW/m^3/sec$	0				
COMPARISON TO GUARANTEE							
Inlet Volume Flow Rate	q_v	m^3/s	0	Pass/Fail	Pass/Fail	Pass/Fail	Pass/Fail
Outlet Pressure	p_2	bar abs	0	Pass/Fail	Pass/Fail	Pass/Fail	Pass/Fail
Specific Energy	e	$kW/m^3/sec$	0	Pass/Fail	Pass/Fail	Pass/Fail	Pass/Fail

Appendix

Background of thermodynamics

Appendix 1.1 Characteristic curves of dynamic compressors and positive displacement compressors.

From observations it is known that at a constant speed, the fundamental "curves" (head or work or pressure rise versus volume flow or capacity) of the two technologies are different.

The positive displacement compressor (blower) will deliver nearly the same capacity regardless of pressure change. The small volume flow changes are capacity losses from internal leakages.

Typically the dynamic compressor’s (blower’s) capacity changes more as the pressure changes. On rising pressure, the capacity reduces appreciably.

The speed of the wheel in a dynamic compressor (blower) has a marked effect on the flow and head performance of the compressor. It is for this reason that data sheet provides the defined speed of the wheel.

For positive displacement packages, speed also has an influence on the flow and power needed. Packages may be of a gear, belt, or direct drive design. To ensure all losses of the drive system are incorporated, speed of the main driver is reported, rather than the compression or compressor element.

Inlet temperature and the mass flow (or density times volume flow) have a direct effect on power of dynamic compressors. The diagram below shows the effect of inlet temperature on the performance of a dynamic compressor.

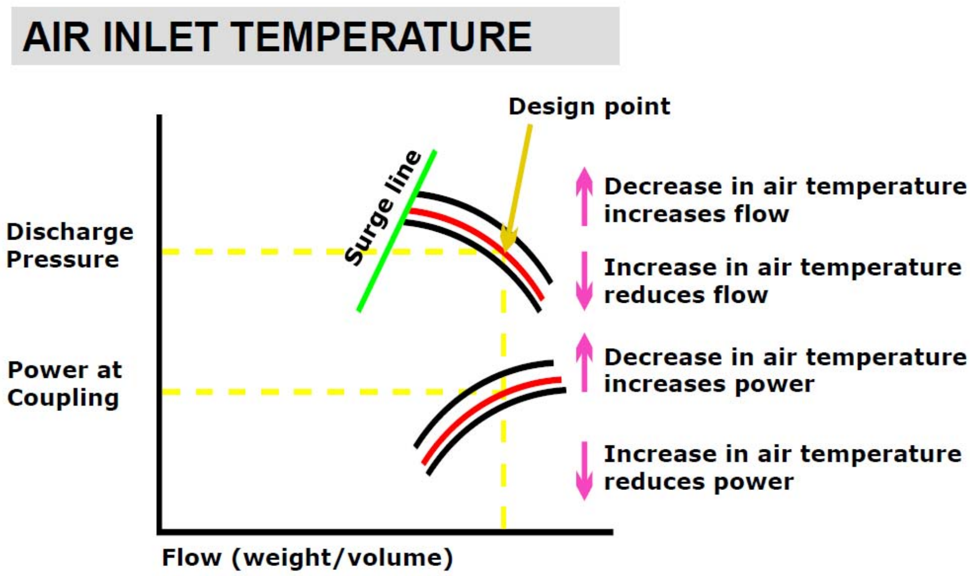


Figure 6: Air Inlet Temperature

Appendix 1.2 Performance test through representative efficiency measurement.

The intention of the compressor performance test of a particular compressor is to verify the delivered compressed air flow and the power or energy consumption at a required outlet pressure. With this test the manufacturer guarantees the performance. This performance is to be verified at a particular ambient condition, this is the guarantee or reference condition. In principle the test should be at this guarantee condition. However, in practice this cannot be achieved. The actual ambient test condition defined by the ambient pressure, temperature and humidity, will deviate from the guarantee condition due to the weather. Also in a controlled environment small differences with the guarantee condition are possible.

To convert the performance from the actual test condition to the guarantee or reference condition the test uses the efficiency of the compressor. The efficiency of the compressor (blower) is the ratio of the ideal power consumption to the real power consumption of the compressor (blower). The ideal power consumption of the compressor (blower) is the power consumption following a known thermodynamic reference process appropriate for the type of compressor (blower). The compressor (blower) in test is operated at a similarity point such that the measurement of the efficiency during this test is representative for the efficiency at the guarantee condition. Subsequently with the known thermodynamic reference process and thus the ideal power consumption, the real performance at the guarantee or reference condition can be calculated easily.

Appendix 0.3 Compressor (blower) in a similarity point

From the non-dimensional analysis of a compressor (blower) we know that the compressor (blower) can be set during test in a similar operating point as in the guarantee or reference condition. In this similarity point all the non-dimensional groups or numbers are identical. With the Buckingham theorem it is possible to identify 5 independent non-dimensional groups for compression of a dry, ideal gas:

- The heat capacity ratio □ = cp/cv (gas property),
- The Reynolds number,
- The machine work coefficient,
- The machine Mach number.
- The machine geometry (for variable geometry compressors)

If these 5 non-dimensional groups are identical for the test condition and the guarantee condition, then all other non-dimensional groups are identical as well: Efficiency, flow coefficient, etc. … With the known measured efficiency during the test the performance at the similar operating point, the guarantee condition can be calculated.

In practice it is not possible to have a perfect match of the 5 independent non-dimensional groups. The test is to be performed in such a way to keep the non-dimensional groups in an acceptable range of values to ensure the efficiency derived from the test measurements is a representative value.

To achieve close similarity the initial provisions for the test are:

- The test is done with ambient air. Thus we consider the deviation of the k value to be small (influenced by humidity) between test condition and guarantee condition.
- The ambient temperature is within a limited range.
- Tests are done on the actual compressor, not a scaled version.
- The mechanical speed during test is set within a limited range of the guarantee condition.
- For variable geometry compressors, the geometry is set so as to match the intended flow coefficient.

These initial provisions limit changes in the Reynolds number and Mach number. In essence with these provisions we limit the changes of the compressor efficiency due to the compressibility of the gas (Mach number) and the viscosity losses (Reynolds number).

The major, final provision is the setting of the machine work coefficient. The work coefficient is controlled by imposing the outlet pressure to the compressor.

Appendix 0.4 Reference process for low pressure compressors

The work coefficient is the non-dimensional ratio of the work of the gas to the mechanical, kinetic energy of the compressor (blower). There are however different definitions of the work that can be used. Usually an ideal work value according to a representative, ideal reference process is chosen for the definition of the work coefficient. For instance the isentropic or isochoric work. For low pressure dynamic compressors (blower) the work coefficient defined by the isentropic reference process is most appropriate. This is already well known and common practice for dynamic compressors [ref. ISO 5389].

For the positive displacement compressor (blower) with or without internal compression it is known that in first order the rotational speed of the compressor (blower) does not influence the work added to the gas. Also the speed difference between test and guarantee is already limited. Therefore the matching of an ideal work value is sufficient (rather than matching a work coefficient).

For the positive displacement compressor (blower) with or without internal compression a proper combination of isentropic and isochoric work can be defined. For the positive displacement compressor (blower) with internal compression the work (W_s) on the input volume at closure of the inlet port (V_1) is isentropic up to an intermediate pressure p_i.

$$W_s = p_1 V_1 \frac{\kappa}{\kappa - 1}\left(\left(\frac{p_i}{p_1}\right)^{\frac{\kappa-1}{\kappa}} - 1\right)$$

For isentropic compression of an ideal gas there is a relation between the intermediate pressure p_i and the internal volume ratio $v_i = {}^{V_1}/_{V_i}$

$$\frac{p_i}{p_1} = \left(\frac{V_i}{V_1}\right)^{-k} = {v_i}^k$$

For the positive displacement compressor (blower) without internal compression the internal volume ratio and pressure ration is 1 and thus the isentropic compression work is zero.

In a second phase the compression continues isochoric (W_{isoc}) on the reduced volume as defined by the internal volume ratio.

$$W_{isoc} = (p_2 - p_1)V_i$$

The sum of the work is (W_{comb}):

$$W_{comb} = \left[p_1 V_1 \frac{\kappa}{\kappa - 1}\left(\left(\frac{p_i}{p_1}\right)^{\frac{\kappa-1}{\kappa}} - 1\right)\right] + [(p_2 - p_1)V_i]$$

$$W_{comb} = p_1 V_1 \left[\frac{\kappa}{\kappa - 1}\left(\left(\frac{p_i}{p_1}\right)^{\frac{\kappa-1}{\kappa}} - 1\right) + \left(\frac{p_2 - p_i}{p_1}\right)\frac{V_i}{V_1}\right]$$

$$W_{comb} = p_1 V_1 \left[\frac{\kappa}{\kappa - 1}\left(\left(\frac{p_i}{p_1}\right)^{\frac{\kappa-1}{\kappa}} - 1\right) + \frac{p_2/p_1}{v_i} - \frac{p_i}{p_1}\frac{1}{v_i}\right]$$

$$W_{comb} = p_1 V_1 \left[\frac{p_2/p_1}{v_i} + \frac{\kappa}{\kappa - 1}\left(\left(\frac{p_i}{p_1}\right)^{\frac{\kappa-1}{\kappa}} - 1 - \frac{\kappa - 1}{\kappa}\frac{p_i}{p_1}\frac{1}{v_i}\right)\right]$$

$$W_{comb} = p_1 V_1 \left[\frac{p_2/p_1}{v_i} + \frac{\kappa}{\kappa - 1}\left({v_i}^{\kappa-1} - 1 - \frac{\kappa - 1}{\kappa}{v_i}^{\kappa-1}\right)\right]$$

$$W_{comb} = p_1 V_1 \left[\frac{p_2/p_1}{v_i} + \frac{\kappa}{\kappa - 1}\left(\frac{1}{\kappa}{v_i}^{\kappa-1} - 1\right)\right]$$

The corresponding specific work (work per unit mass) is:

$$y_{comb} = RT_1 \left[\frac{p_2/p_1}{v_i} + \frac{\kappa}{\kappa - 1}\left(\frac{1}{\kappa}{v_i}^{\kappa-1} - 1\right)\right]$$

Initial, rough analysis of the predicted performance changes of positive displacement compressors (blowers) due to changes of inlet temperature, pressure etc. reveal the combined isentropic and isochoric work is a good representation of the ideal process. More detailed experimental analysis and comparison to other work definitions or work coefficient definitions may be valuable.

Appendix 0.5 Isentropic or combined work for the defined compressor (blower) package

Note that the isentropic or combined isentropic and isochoric work is based on the pressures at package inlet and outlet. The package includes losses of inlet filter, check valve and other components if they are part of the package. The pressure and temperature variation through the package can be illustrated as in the figure below.

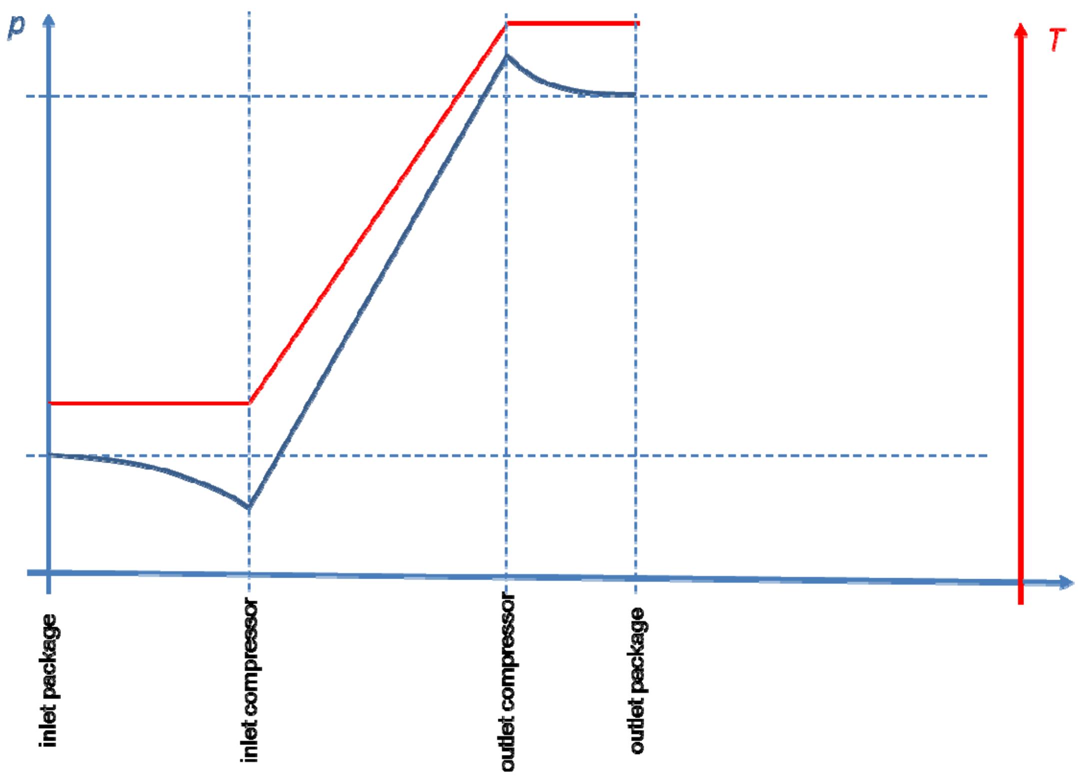


Figure 7: combined work for defined package

The pressure losses result in lowered isentropic or combined isentropic and isochoric work values based on the inlet and outlet pressures. The isentropic or combined isentropic and isochoric work is lower than the real work transferred to the gas. The real work can be determined with the temperatures of the gas, but is not used in this methodology. The package power is derived from the measured electric input power and corrected for ratios between guarantee and test conditions.

Appendix 0.6 Correction formulas

The flow correction is based on the flow coefficient that is indifferent between test and guarantee conditions. From this equation the tested flow is corrected to the guarantee condition. This is the flow that this specific compressor will deliver under the guarantee condition (this is with another rotor tip speed).

$$\varphi_{te} = \varphi_g$$

$$\frac{q_{v1,te}}{u_{te}} = \frac{q_{v1,co}}{u_g}$$

$$q_{v1,co} = q_{v1,te} \cdot \frac{u_g}{u_{te}}$$

The efficiency η is the ratio of the ideal power P_{ideal} to the real power consumption P. The ideal power is according to the appropriate thermodynamic reference process. This is the isentropic process for dynamic compressors and the combined isentropic and isochoric process for the positive displacement compressors.

$$\eta = \frac{P_{ideal}}{P}$$

The correction for power and specific power is based on this efficiency that is identical between test and guarantee conditions as the test is in a similarity point of the guarantee condition.

$$\eta_{te} = \eta_g$$

Two cases are distinguished under guarantee conditions. In a general case, under guarantee conditions the package delivers the corrected flow $q_{v1,co}$ (as derived from the flow correction based on the flow coefficient) and will consume the corrected power P_{co}. In the specific case that the package matches the guarantee flow exactly (e.g. with a variable flow compressor), then the package delivers the guarantee flow $q_{v1,g}$ and will consume the corrected power at guarantee flow $P_{co,g}$. In both cases the efficiency matches the tested efficiency:

$$\frac{P_{ideal,te}}{P_{te}} = \frac{P_{ideal,co}}{P_{co}} = \frac{P_{ideal,g}}{P_{co,g}}$$

From this the formulas for the power corrections are:

$$P_{co} = \frac{P_{ideal,co}}{P_{ideal,te}} \cdot P_{te}$$

$$P_{co,g} = \frac{P_{ideal,g}}{P_{ideal,te}} \cdot P_{te}$$

The specific energy is the ratio of the power to the flow

$$e_{te} = \frac{P_{te}}{q_{v1,te}}$$

$$e_{co} = \frac{P_{co}}{q_{v1,co}}$$

$$e_{co,g} = \frac{P_{co,g}}{q_{v1,g}}$$

The specific energy can be written as a function of the tested power and flows:

$$e_{co} = \frac{P_{co}}{q_{v1,co}} = \frac{P_{ideal,co}}{P_{ideal,te}} \cdot P_{te} \cdot \frac{1}{q_{v1,co}}$$

$$e_{co,g} = \frac{P_{co,g}}{q_{v1,g}} = \frac{P_{ideal,g}}{P_{ideal,te}} \cdot P_{te} \cdot \frac{1}{q_{v1,g}}$$

Also the ideal powers can be written as the factor of mass flow and work. The mass flow in turn is the factor of density and volume flow. These terms are known and are used to make the correction of the specific energy from test to guarantee condition.

$$e_{co} = \frac{\rho_{1,g}}{\rho_{1,te}} \cdot \frac{q_{v1,co}}{q_{v1,te}} \cdot \frac{y_{ideal,g}}{y_{ideal,te}} \cdot P_{te} \cdot \frac{1}{q_{v1,co}}$$

$$e_{co,g} = \frac{\rho_{1,g}}{\rho_{1,te}} \cdot \frac{q_{v1,g}}{q_{v1,te}} \cdot \frac{y_{ideal,g}}{y_{ideal,te}} \cdot P_{te} \cdot \frac{1}{q_{v1,g}}$$

$$e_{co,g} = e_{co} = \frac{\rho_{1,g}}{\rho_{1,te}} \cdot \frac{y_{ideal,g}}{y_{ideal,te}} \cdot e_{te}$$

Using the specific energy, the power consumption can be calculated as follows:

$$P_{co} = e_{co} \cdot q_{v1,co}$$

$$P_{co,g} = e_{co} \cdot q_{v1,g}$$

Appendix 0.7 Isentropic efficiency of a compressor package

The isentropic efficiency of a compressor (blower) package can be used to characterize its energy efficiency. This is an alternative to the use of the specific energy requirement e which is an indicator for energy requirement for a given inlet and outlet pressure. Typically the isentropic efficiency will change less to changes in inlet and outlet pressure compared to the specific energy requirement.

The isentropic efficiency of a package is defined as the inverse ratio of the corrected input power requirement of the compressor (blower) package versus the isentropic power needed to compress the same volume flow at same inlet and outlet conditions of the compressor package.

$$\eta_s = \frac{P_s}{P_{co}}$$

The isentropic power is defined as:

$$P_s = q_{v1,co} \cdot p_1 \frac{\kappa}{(\kappa - 1)} \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{\kappa-1}{\kappa}} - 1 \right]$$

With the definition of the specific energy requirement

$$e_{co} = \frac{P_{co}}{q_{v1,co}}$$

we have a direct relationship between specific energy requirement and isentropic efficiency of a compressor package:

$$\eta_s = \frac{p_1 \frac{\kappa}{(\kappa-1)} \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{\kappa-1}{\kappa}} - 1 \right]}{e_{co}}$$

$$e_{co} = \frac{p_1 \frac{\kappa}{(\kappa-1)} \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{\kappa-1}{\kappa}} - 1 \right]}{\eta_s}$$

Example of Manufacturer's checklist

It is recommended that the manufacturer provides a package checklist, which defines clearly his scope of supply. Such a document should also contain the column “Not applicable”, which indicates, that this item is neither mandatory nor necessary for a faultless operation of the package.

Furthermore such a list allows a precise comparison and avoids misunderstandings. Ancillaries, excluding stand-by ancillaries, are to be running.

Note: For different compressor types different components may be required.

Table 5: Manufacturer's Checklist (example, to be filled in by "X")

Section	Item	Included	Accounted for value (units)	Not applicable
Process air in/out	Process air filter		Δp (Pa)	
	Inlet silencer		Δp (Pa)	
	Inlet guide vanes		------------	
	Inlet unload valve or throttled valve		Δp (Pa)	
	Outlet guide vanes		------------	
	Blow off valve*		Δp (Pa)	
	Check valve		Δp (Pa)	
	Outlet silencer		Δp (Pa)	
	Additional inlet losses**		Δp (Pa)	
	Additional outlet losses**		Δp (Pa)	
Drive train	Main drive motor efficiency		η	
	Frequency inverter		η	
	EMC filter		η	
	Choke		η	
	Starter		η	
	Sinus filter		η	
	Power Transmission (gear box, belts)		η	
Ancillaries, electrical power input	Local control system		P (kW)	
	Cooling circulation (liquid)		P (kW)	
	Lubrication system		P (kW)	
	Main drive cooling fan		P (kW)	
	Cooling air fans		P (kW)	
	Heat exchanger fans		P (kW)	
	Additional components		P (kW)	

*pressure loss when closed
** manufacturers should detail the cause of the additional losses

The complete package needs to be tested. In case some required component is not included in the test, it shall be indicated how the component has been accounted for in the testing; indicated pressure drop should be accounted for either adapted test point or adapted test structure.

Imperial units

This test code uses metric units as its basis. It is possible to use the test code with imperial data. That requires a translation of imperial input data to metric data and metric results into imperial results. To translate input data from imperial units to metric units, please use the conversion factors in reference ISO 80000. To translate the results into imperial units, please use ISO 80000.

Data sheets

This section offers the reader examples of standardized data sheets that allow the customer to compare performance of different compressors.

The bottom line on the data sheet is "Specific Energy”. This value (expressed in kW/m^3/min) is the measure of compressor (blower) package efficiency. The lower the value, the more efficient the package is. This is a quick and easy way to see which blower uses less power at the stated conditions.

Measurement should be done at default inlet conditions as presented in section 0. Acceptance tolerances on the measurements are given in

Table 4: Acceptance Tolerances in section 22.

COMPRESSOR PACKAGE DATA SHEET

CENTRIFUGAL COMPRESSOR PACKAGE DATA SHEET

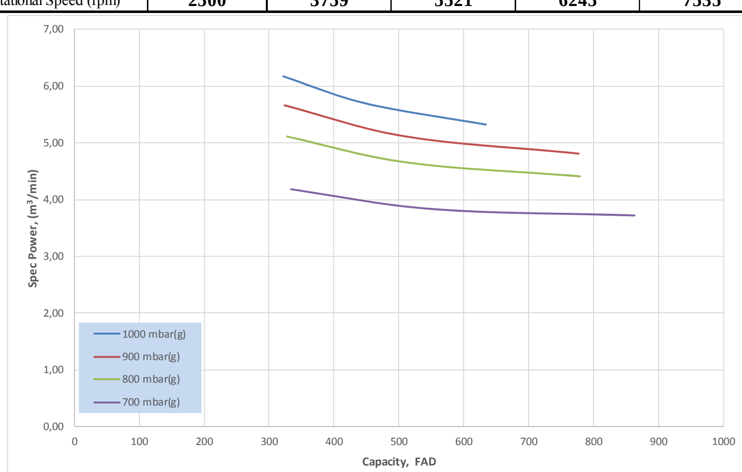
MODEL DATA - Option 2 Standard Conditions

1	Manufacturer:	Date:	
2	Model Number:		
3	☐ Main Drive Motor ☐ Inlet Throttle Valve ☐ Harmonic Filter	☐ Driver Cooling System ☐ Lubrication System ☐ Inlet Guide Vanes	☐ VFD ☐ Gearbox / Belt Drive ☐ Inlet Air Filter

		VALUE	UNITS
4	Volume flow rate at Rated Operating Pressure		m^3/min
5	Rated Operating Pressure - p_2		mbar(g)
6	Drive Motor Nameplate Rating		kW
7	Compressor rotational speed		rpm

8 Performance Table

Discharge Pressure p2 (mbar)		Delivered Volume flow rate(m^3/min)				
		MIN FAD	FAD2	FAD3	FAD4	100% FAD
1000 mbar(g)	Volume flow rate	**322**	**450**	**634**	**675**	**841**
	Spec. Energy	**6,17**	**5,69**	**5,32**	**5,27**	**5,13**
	Rotational Speed (rpm)	**2500**	**3219**	**4225**	**4455**	**5375**
900 mbar(g)	Volume flow rate	**324**	**511**	**777**	**870**	**1067**
	Spec. Energy	**5,66**	**5,11**	**4,81**	**4,78**	**4,74**
	Rotational Speed (rpm)	**2500**	**3556**	**5035**	**5575**	**6725**
800 mbar(g)	Volume flow rate	**328**	**514**	**779**	**871**	**1068**
	Spec. Energy	**5,11**	**4,65**	**4,41**	**4,40**	**4,38**
	Rotational Speed (rpm)	**2500**	**3556**	**5035**	**5575**	**6725**
700 mbar(g)	Volume flow rate	**334**	**554**	**863**	**984**	**1200**
	Spec. Energy	**4,18**	**3,83**	**3,72**	**3,75**	**3,79**
	Rotational Speed (rpm)	**2500**	**3759**	**5521**	**6245**	**7535**



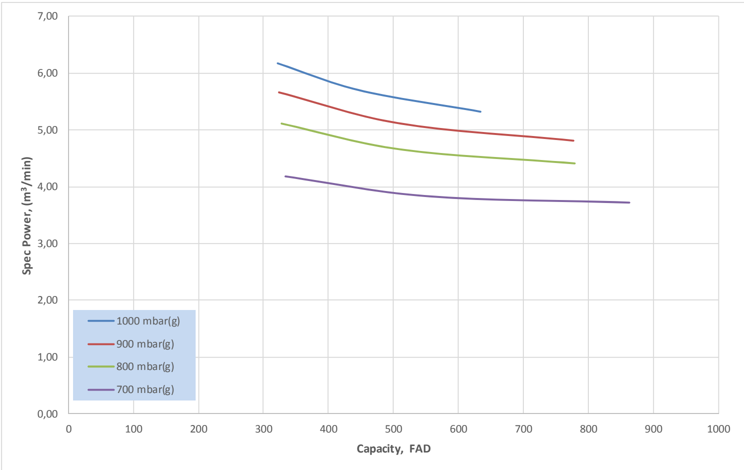
COMPRESSOR PACKAGE DATA SHEET

CENTRIFUGAL AIR BLOWER PACKAGE DATA SHEET

MODEL DATA - Option 2 Standard Conditions							
1	Manufacturer:			Date:			
2	Model Number:						
3	☐ Main Drive Motor ☐ Inlet Throttle Valve ☐ Harmonic Filter		☐ Driver Cooling System ☐ Lubrication System ☐ Inlet Guide Vanes		☐ VFD ☐ Gearbox / Belt Drive ☐ Inlet Air Filter		
						VALUE	UNITS
4	Volume flow rate at Rated Operating Pressure						m^3/min
5	Rated Operating Pressure - p_2						mbar(g)
6	Drive Motor Nameplate Rating						kW
7	Compressor rotational speed						rpm

Performance Table

	Discharge Pressure p2 (mbar)		Delivered Volume flow rate(m^3/min)				
			MIN FAD	FAD2	FAD3	FAD4	100% FAD
8	1000 mbar(g)	Volume flow rate	**322**	**450**	**634**	**675**	**841**
		Spec. Energy	**6,17**	**5,69**	**5,32**	**5,27**	**5,13**
		Rotational Speed (rpm)	**2500**	**3219**	**4225**	**4455**	**5375**
	900 mbar(g)	Volume flow rate	**324**	**511**	**777**	**870**	**1067**
		Spec. Energy	**5,66**	**5,11**	**4,81**	**4,78**	**4,74**
		Rotational Speed (rpm)	**2500**	**3556**	**5035**	**5575**	**6725**
	800 mbar(g)	Volume flow rate	**328**	**514**	**779**	**871**	**1068**
		Spec. Energy	**5,11**	**4,65**	**4,41**	**4,40**	**4,38**
		Rotational Speed (rpm)	**2500**	**3556**	**5035**	**5575**	**6725**
	700 mbar(g)	Volume flow rate	**334**	**554**	**863**	**984**	**1200**
		Spec. Energy	**4,18**	**3,83**	**3,72**	**3,75**	**3,79**
		Rotational Speed (rpm)	**2500**	**3759**	**5521**	**6245**	**7535**



Calculation examples

To guide the reader in applying the described method, this appendix offers multiple calculation examples. The section starts off with a simplified example to show the basic principles of the method. Subsequently, more detailed examples are provided for displacement compressors (blowers), dynamic compressors (blowers) and for the two speed test method from section 0 (two speed test). The calculation results can be rewritten into the test report format as presented in section 0.

Appendix 5.1 Simplified example: displacement compressor with internal compression

This example draws on the general method as described in section 0 and more specifically section 0. for the selection of the test pressure.

1) Conditions for guarantee

Inlet temperature: 293,15 K
Inlet pressure: 100000 Pa
Speed : 1400 rpm

Guaranteed values:

Flow: 1488 m³/h
Outlet pressure: 140000 kPa
Power: 22,0 kW
Specific energy: 53,23 kJ/m³

Calculated combined work: 30013 J/kg

2) Conditions during test

Inlet temperature: 291,88 K
Inlet pressure: 100000 Pa

3) Calculated pressure setting for equal work

Outlet pressure set point: 141487 Pa

4) Measured values during test	*Allowed deviations*	
Inlet temperature: 291.88 K	*+- 10K*	*ok*
Inlet pressure: 100000 Pa	*+- 10kPa*	*ok*
Outlet pressure: 142050 kPa		
Speed : 1388 rpm	*+- 3%*	*ok*
Flow: 1467 m³/hs		
Power: 22.4 kW		
Specific energy: 54,95 kJ/m³		

5) Corrected values — *Comparison corrected test results to guarantee :*

Outlet pressure: 140560 Pa	*-0% … +1%*	*pass*
Flow: 1480 m³/h	*+- 4%*	*pass*
Power: 22.1 kW		
Specific energy: 53,7 kJ/m³	*+- 5%*	*pass*

Appendix 5.2 Advanced examples

To simulate real life, more complete calculation examples are provided as well. This appendix provides calculated examples for

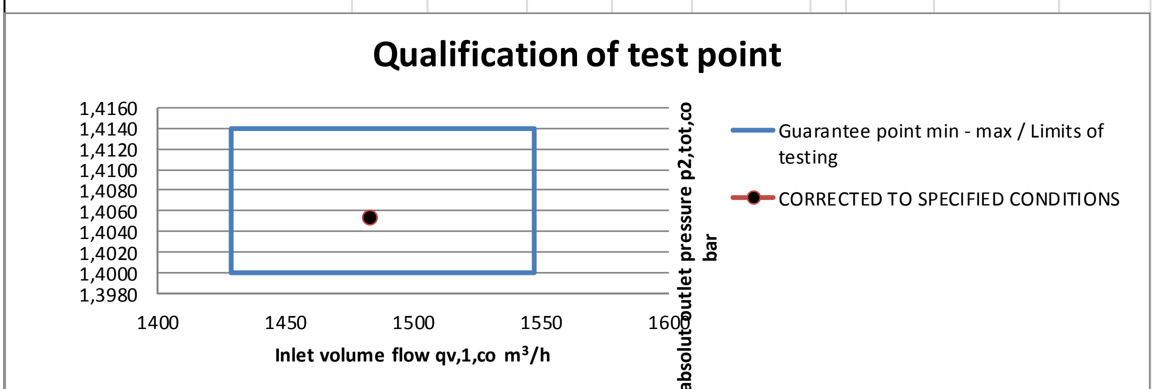
- Displacement compressor (blower) without internal compression
- Displacement compressor (blower) with internal compression
- Dynamic compressor (blower)
- Two speed test (3 calculations)

Displacement compressor without internal compression

Compressor type/					
Manufacturer/ order #/ serial #					
Year of fabrication					
Manufacturer checklist for the package (see)					
Fixed flow, displacement and dynamic compressors			Values during testing	**Setpoint** or deviation te/g	Values under guarantee conditions
Quantity	Symbol	Unit	Value	Value	Value
Table A.1 - Guarantee conditions			**te**	**te/g**	**g**
Test report number	**#**	-	1	-	-
Date of test	*dd-mm-yy*	date	14/12/2015	-	start
Time of test	**-**	h	16:10	0:10	16:00
Barometric pressure "p_1"	$p_{1,tot}$	Pa	101000	-	100000
Relative humidity @ "Barometric pressure point"	φ_{1wet}	%	33	-	0
Inlet temperature	$T_{1,tot}$	K	291,88	-0,4	293,15
Inlet pressure (total)	$p_{1,tot}$	Pa	101000	1,00	100000
Table A.2 -Object of Guarantee			te	**te/g**	g
Outlet pressure	$p_{2,tot}$	Pa	142001	**141467**	140000
Gauge pressure "Pressure rise" (total)	$\Delta p_{2,tot}$	Pa	41001	-	40000
Outlet temperature (total)	$T_{2,tot}$	K	346,00	-	346
Volumetric flow at inlet; Defined @ delivered mass flow	q_{V1}	m³/h	1471	-0,30	1488
Power requirement @ wire input incl. Aux.	P_{wire}	kW	29,0	-	28,0
Specific energy	**e**	J/m³	20	-	19
Reference process	**Pr**	-	Isochoric	-	Isochoric
If combiend; Ratio of internal compression	v_i	-	1	-	1,000
Table A.3 - Design data			**te**	**te/g**	**g**
Speed of rotation (shaft)	**n**	r/min	1388	-0,86	1400
Gear ratio	**i**	ratio	0,9333	-	0,9333
Tip speed of impeller	u_2	m/s	20,3	-0,86	20,5
Rotor tip diameter	D_u	m	0,3	-	0,3
Ratio of internal compression	v_i	-	1,0000	-	1,0000
Inlet guide vane setting	**scale**	#	0,0	-	0,0
Diffuser vane setting	**scale**	#	0,0	-	0,0
Inlet pressure loss "inside the packaged"	**Δptot,1'**	Pa	0	-	0
Outlet pressure loss "inside the packaged"	**Δptot,2'**	Pa	0	-	0
Additional auxiliry losse not accounted for during measurements	$\Delta P_{wire,loss}$	kW	0	-	0
Measured wire Power	Pwire,meas.	kW	29	-	28
				-	
Table A.4 - Air/Gas data			**te**	**te/g**	**g**
Saturation pressure	p_{sat}	Pa	2160	-	2338
Humidity content	**x**	kg/kg	0,00442	-	0,00000
Isentropic exponent	**κ**	-	1,399	-	1,400
Specific gas constant	R_{wet}	J/kg*K	287,9	-	287,1
Density	ρ_1	kg/m³	1,2021	-	1,1882
specific volume @ inlet	v_1	m³/kg	0,8319	-	0,8416
Delivered Mass flow rate of air	$q_{m,2}$	kg/s	0,4911	-	0,4911
Heat capacity	$Cp_{,1}$	J/kg*K	1009	-	1005
Table A.5 - Performance data			**te**	**te/g**	**g**
Volume flow coefficient	**φ**	-	0,2840	-0,30	0,2849
Isentropic specific compression work	y_s	J/kg	30066	-	29725
Specific compression work (reference process)	y_{Pr}	J/kg	34109	1,32	33665
Reel gas work cp*Δt	Y_{real}	J/kg	54594	-	53106
Packaged work	Y_{pac}	J/kg	59050	-	57014
Reference process work coefficient	ψ_{Pr}	-	34109,188	1,32	33665,346
Sonic velocity	**c**	m/s	342,9	-	343,3
Machine Mach number	**Ma**	-	0,0593	-0,75	0,0598
Relative inner efficiency	**y.../Yreal**	-	0,6248	-	0,6339
Relative isentropic/packaged efficiency	**ys/Ypac**	-	0,5092	-	0,5214

Figure 5: Acceptance tolerances					
			Volume	energy	Outlet
Volume flow rate at specified conditions			flow	requirement	pressure
min <qv< max			qv	e	p2
(m^3/h)			± #%	± #%	+#%
0	$<q_v<$	30	7	8	1
30	$<q_v<$	90	6	7	1
90	$<q_v<$	900	5	6	1
900	$<q_v<$	∞	4	5	1
qv=	346	Case Toll.	5	5	1
qv=	1488	Case Toll.	4	5	1

Guarantee point min - max / Limits of testing	Symbol	Unit (Metric)	g	g_min	g_max		%	Δ(g_max-g_min	rule
Outlet Pressure	$p_{2,tot,g}$	bar abs	1,4000	1,4000	1,4140	+	1	0,0140	9.5 table 2
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	1488	1428	1548	±	4	119	9.5 table 2
Total Input Pow er	$P_{wire,g}$	kW	28,0	26,6	29,4	±	5	2,8	9.5 table 2
Specific Energy; Pow er related to volume flo	e_g	kJ/m³	67,7	64,4	71,1	±	5	6,8	9.5 table 2
Reference Work	$y_{Pr,g}$	J/kg	33665	33665	34844		-	1178	9.5 table 2
Reference Work limits	$y_{Pr\_toll,g}$	%	0,0	0,0	3,5		-	3,5	9.5 table 2
Reference process w ork coefficient	$\psi_{Pr,g}$	-	-	-	-		-	-	9.5 table 2
Reference process w ork coefficient limits	$\psi_{Pr\_toll,g}$	%	-	-	3,5		-	-	9.5 table 2
Volume flow coefficient	$\varphi_{,g}$	-	0,2849	0,2735	0,2963	±	4	0,0228	9.5 table 2
Volume flow coefficient limits	$\varphi_{\_toll,g}$	%	0,0	-4,0	4,0	±	4	8,0	9.5 table 2
Designation	Symbol	Unit (Metric)	Guarantee point	Test point	CORRECTED TO SPECIFIED CONDITIONS		tollerance (Δ) or (%)	Pass/Fail ABS(value)	
			g	te	co		-	-	
Test Period start/end		Mins.	-	0:10	0:10	min	0:10	0:10	11,13
Barometric Pressure	$p_{1,tot}$	bar abs	1,0000	1,0100	1,0000	±	10,00%	1,0100	8.2.2 or 8.4
Ambient Relative Humidity	φ_{1wet}	-	0,0	33	0,0000		-	-	
Isentropic exponent	κ	-	1,400	1,399	1,4000		-	-	
Ambient Gas Constant	R_{wet}	J/(kg*K)	287,1	287,9	287,1		-	-	
Inlet Temperature	$T_{1,tot}$	K	293,15	291,88	293,15	±	15	291,88	8.2.2 or 8.4
Inlet Pressure	$p_{1,tot}$	bar abs	1,0000	1,0100	1,0000		-	-	
Outlet Pressure	$p_{2,tot}$	bar abs	1,4000	1,42001	1,4053	+	1,00%	0,38%	9.5 table 2
Outlet Temperature	$T_{2,tot}$	K	346,00	346,00	347,48		-	-	
Compressor Speed	n	rpm	1400	1388	1400	±	3,00%	0,86%	8.2.1
Ratio of internal compression	v_i	-	1,0000	1,0000	1,0000		-	-	
Density of inlet air	ρ_1	kg/m³	1,1882	1,2021	1,1882		-	-	
Machine Mach number	Ma	-	0,0598	0,0593	0,0598	±	5,00%	0,75%	8.4 or 8.2.2
Reference Work	y_{Pr}	J/kg	33665	34109	34109		-	-	
Inlet Volume Flow Rate	$q_{v,1}$	m³/s	1488	1471	1484	±	4,00%	0,30%	9.5 table 2
Total Input Pow er	P_{wire}	kW	28,0	29,0	28,5		-	-	
Specific Energy; Pow er related to volume flo	e	kJ/m³	67,74	70,98	69,25	±	5,00%	2,22%	9.5 table 2
Preconditions to be measured to comply w ith the guarantee									
Supply voltage	U	volts	400	400	-		-	-	
Supply frequency	f	Hz	50	50	-		-	-	
External Coolant Inlet Temperature	$T_{1,cool}$	deg C	20	21	-	±	15	21	8,3
External Coolant Flow	$q_{m,cool}$	kg/s	0,02	0,021	-	±	10,00%	5,00%	8,3
Corrected to specified conditions, guaranteed inlet flow and outlet pressure									
Inlet Pressure	$p_{1,tot,g}$	bar abs	-	-	1,0000		-	-	
Inlet Temperature	$T_{1,tot,g}$	deg C	-	-	293,15		-	-	
Ambient Relative Humidity	$\varphi_{1wet,g}$	-	-	-	0,0		-	-	
Outlet Pressure	$p_{2,tot,g}$	bar abs	-	-	1,4000		-	-	
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	-	-	1488		-	-	
Total Input Pow er	$P_{wire,co,g}$	kW	-	-	28,6	±	5,00%	2,22%	9.5 table 2



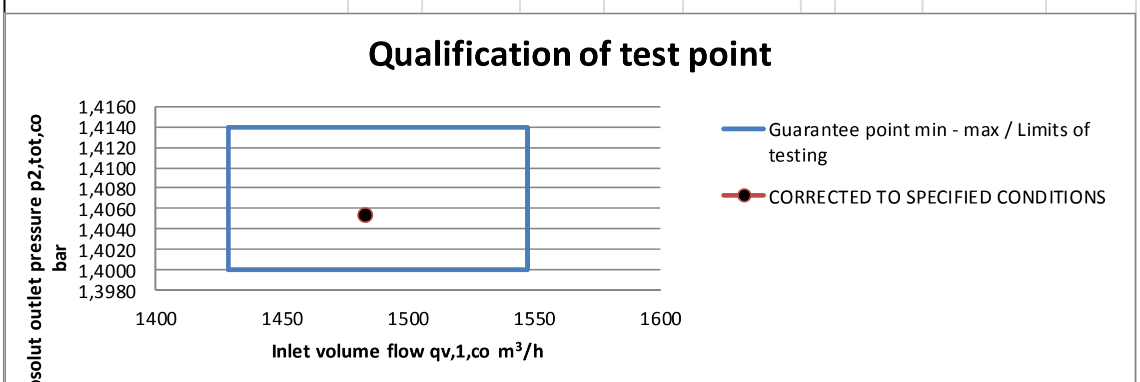
Displacement Compressor with Internal Compression

Compressor type/	
Manufacturer/ order #/ serial #	
Year of fabrication	
Manufacturer checklist for the package (see)	

Fixed flow, displacement and dynamic compressors			Values during testing	**Setpoint** or deviation te/g	Values under guarantee conditions
Quantity	Symbol	Unit	Value	Value	Value
Table A.1 - Guarantee conditions			**te**	**te/g**	**g**
Test report number	**#**	-	1	-	-
Date of test	*dd-mm-yy*	date	14/12/2015	-	start
Time of test	**-**	h	16:10	0:10	16:00
Barometric pressure "p_1"	$p_{1,tot}$	Pa	101000	-	100000
Relative humidity @ "Barometric pressure point"	φ_{1wet}	%	33	-	0
Inlet temperature	$T_{1,tot}$	K	291,88	-0,4	293,15
Inlet pressure (total)	$p_{1,tot}$	Pa	101000	1,00	100000
Table A.2 -Object of Guarantee			te	**te/g**	g
Outlet pressure	$p_{2,tot}$	Pa	142050	**141487**	140000
Gauge pressure "Pressure rise" (total)	$\Delta p_{2,tot}$	Pa	41050	-	40000
Outlet temperature (total)	$T_{2,tot}$	K	335,00	-	335
Volumetric flow at inlet; Defined @ delivered mass flow	q_{V1}	m³/h	1467	-0,53	1488
Pow er requirement @ w ire input incl. Aux.	P_{wire}	kW	22,4	-	22,0
Specific energy	***e***	J/m³	15	-	15
Reference process	***Pr***	-	combiend	-	combiend
If combiend; Ratio of internal compression	v_i	-	1,36	-	1,360
Table A.3 - Design data			**te**	**te/g**	**g**
Speed of rotation (shaft)	***n***	r/min	1388	-0,86	1400
Gear ratio	***i***	ratio	0,9333	-	0,9333
Tip speed of impeller	u_2	m/s	20,3	-0,86	20,5
Rotor tip diameter	D_u	m	0,3	-	0,3
Ratio of internal compression	v_i	-	1,3600	-	1,3600
Inlet guide vane setting	***scale***	#	0,0	-	0,0
Diffuser vane setting	***scale***	#	0,0	-	0,0
Inlet pressure loss "inside the packaged"	***Δptot,1'***	Pa	0	-	0
Outlet pressure loss "inside the packaged"	***Δptot,2'***	Pa	0	-	0
Additional auxiliry losse not accounted for during measurements	$\Delta P_{wire,loss}$	kW	0	-	0
Measured w ire Pow er	Pw ire,meas.	kW	22,4	-	22
				-	
Table A.4 - Air/Gas data			**te**	**te/g**	**g**
Saturation pressure	p_{sat}	Pa	2160	-	2338
Humidity content	***x***	kg/kg	0,00442	-	0,00000
Isentropic exponent	κ	-	1,399	-	1,400
Specific gas constant	R_{wet}	J/kg*K	287,9	-	287,1
Density	ρ_1	kg/m³	1,2021	-	1,1882
specific volume @ inlet	v_1	m³/kg	0,8319	-	0,8416
Delivered Mass flow rate of air	$q_{m,2}$	kg/s	0,4900	-	0,4911
Heat capacity	$Cp_{,1}$	J/kg*K	1009	-	1005
Table A.5 - Performance data			**te**	**te/g**	**g**
Volume flow coefficient	φ	-	0,2834	-0,53	0,2849
Isentropic specific compression work	y_s	J/kg	30098	-	29725
Specific compression w ork (reference process)	y_{Pr}	J/kg	30358	1,15	30013
Reel gas w ork cp*Δt	Y_{real}	J/kg	43498	-	42053
Packaged w ork	Y_{pac}	J/kg	45714	-	44797
Reference process w ork coefficient	ψ_{Pr}	-	30357,742	1,15	30013,120
Sonic velocity	***c***	m/s	342,9	-	343,3
Machine Mach number	***Ma***	-	0,0593	-0,75	0,0598
Relative inner efficiency	***y.../Yreal***	-	0,6979	-	0,7137
Relative isentropic/packaged efficiency	***ys/Ypac***	-	0,6584	-	0,6635

Figure 5: Acceptance tolerances					
			Volume	energy	Outlet
Volume flow rate at specified conditions			flow	requirement	pressure
min <qv< max			qv	e	p2
(m^3/h)			± #%	± #%	+#%
0	$<q_v<$	30	7	8	1
30	$<q_v<$	90	6	7	1
90	$<q_v<$	900	5	6	1
900	$<q_v<$	∞	4	5	1
qv=	335	Case Toll.	5	5	1
qv=	1488	Case Toll.	4	5	1

Guarantee point min - max / Limits of testing	Symbol	Unit (Metric)	g	g_min	g_max		%	Δ(g_max-g_min	rule
Outlet Pressure	$p_{2,tot,g}$	bar abs	1,4000	1,4000	1,4140	+	1	0,0140	9.5 table 2
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	1488	1428	1548	±	4	119	9.5 table 2
Total Input Pow er	$P_{wire,g}$	kW	22,0	20,9	23,1	±	5	2,2	9.5 table 2
Specific Energy; Pow er related to volume flo	e_g	kJ/m³	53,2	50,6	55,9	±	5	5,3	9.5 table 2
Reference Work	$y_{Pr,g}$	J/kg	30013	30013	30880		-	866	9.5 table 2
Reference Work limits	$y_{Pr\_toll,g}$	%	0,0	0,0	2,9		-	2,9	9.5 table 2
Reference process w ork coefficient	$\psi_{Pr,g}$	-	-	-	-		-	-	9.5 table 2
Reference process w ork coefficient limits	$\psi_{Pr\_toll,g}$	%	-	-	2,9		-	-	9.5 table 2
Volume flow coefficient	$\varphi_{,g}$	-	0,2849	0,2735	0,2963	±	4	0,0228	9.5 table 2
Volume flow coefficient limits	φ_toll,g	%	0,0	-4,0	4,0	±	4	8,0	9.5 table 2
Designation	Symbol	Unit (Metric)	Guarantee point	Test point	CORRECTED TO SPECIFIED CONDITIONS		tollerance (Δ) or (%)	Pass/Fail ABS(value)	
			g	*te*	*co*		-	-	
Test Period start/end		Mins.	-	0:10	0:10	min	0:10	0:10	11,13
Barometric Pressure	$p_{1,tot}$	bar abs	1,0000	1,0100	1,0000	±	10,00%	1,0100	8.2.2 or 8.4
Ambient Relative Humidity	φ_{1wet}	-	0,0	33	0,0000		-	-	
Isentropic exponent	κ	-	1,400	1,399	1,4000		-	-	
Ambient Gas Constant	R_{wet}	J/(kg*K)	287,1	287,9	287,1		-	-	
Inlet Temperature	$T_{1,tot}$	K	293,15	291,88	293,15	±	15	291,88	8.2.2 or 8.4
Inlet Pressure	$p_{1,tot}$	bar abs	1,0000	1,0100	1,0000		-	-	
Outlet Pressure	$p_{2,tot}$	bar abs	1,4000	1,4205	1,4056	+	1,00%	0,40%	9.5 table 2
Outlet Temperature	$T_{2,tot}$	K	335,00	335,00	336,44		-	-	
Compressor Speed	n	rpm	1400	1388	1400	±	3,00%	0,86%	8.2.1
Ratio of internal compression	v_i	-	1,3600	1,3600	1,3600		-	-	
Density of inlet air	ρ_1	kg/m³	1,1882	1,2021	1,1882		-	-	
Machine Mach number	*Ma*	-	0,0598	0,0593	0,0598	±	5,00%	0,75%	8.4 or 8.2.2
Reference Work	y_{Pr}	J/kg	30013	30358	30358		-	-	
Inlet Volume Flow Rate	$q_{v,1}$	m³/s	1488	1467	1480	±	4,00%	0,53%	9.5 table 2
Total Input Pow er	P_{wire}	kW	22,0	22,4	22,1		-	-	
Specific Energy; Pow er related to volume flo	e	kJ/m³	53,23	54,95	53,70	±	5,00%	0,89%	9.5 table 2
Preconditions to be measured to comply w ith the guarantee									
Supply voltage	U	volts	400	400	-		-	-	
Supply frequency	f	Hz	50	50	-		-	-	
External Coolant Inlet Temperature	$T_{1,cool}$	deg C	20	21	-	±	15	21	8,3
External Coolant Flow	$q_{m,cool}$	kg/s	0,02	0,021	-	±	10,00%	5,00%	8,3
Corrected to specified conditions, guaranteed inlet flow and outlet pressure									
Inlet Pressure	$p_{1,tot,g}$	bar abs	-	-	1,0000		-	-	
Inlet Temperature	$T_{1,tot,g}$	deg C	-	-	293,15		-	-	
Ambient Relative Humidity	$\varphi_{1wet,g}$	-	-	-	0,0		-	-	
Outlet Pressure	$p_{2,tot,g}$	bar abs	-	-	1,4000		-	-	
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	-	-	1488		-	-	
Total Input Pow er	$P_{wire,co,g}$	kW	-	-	22,2	±	5,00%	0,89%	9.5 table 2



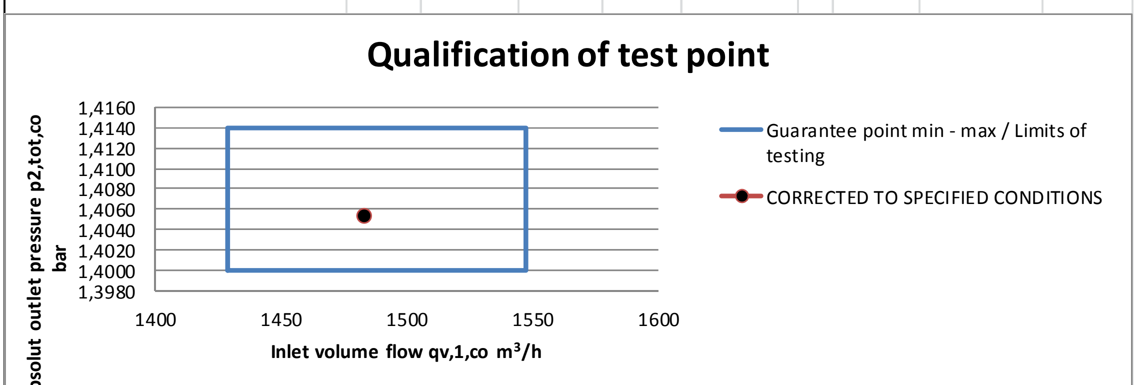
Dynamic Compressor

Compressor type/					
Manufacturer/ order #/ serial #					
Year of fabrication					
Manufacturer checklist for the package (see)					
Variable speed, dynamic machines			Values during testing	**Setpoint** or deviation te/g	Values under guarantee conditions
Quantity	Symbol	Unit	Value	Value	Value
Table A.1 - Guarantee conditions			**te**	**te/g**	**g**
Test report number	**#**	-	1	-	-
Date of test	*dd-mm-yy*	date	14/12/2015	-	start
Time of test	**-**	h	16:10	0:10	16:00
Barometric pressure "p_1"	$p_{1,tot}$	Pa	101100	-	101325
Relative humidity @ "Barometric pressure point"	φ_{1wet}	%	30	-	60
Inlet temperature	$T_{1,tot}$	K	294,5	-	308,15
Inlet pressure (total)	$p_{1,tot}$	Pa	101100	-	101325
Table A.2 -Object of Guarantee			te	**te/g**	g
Outlet pressure	$p_{2,tot}$	Pa	142139	**142139**	140000
Gauge pressure "Pressure rise" (total)	$\Delta p_{2,tot}$	Pa	41039	-	38675
Outlet temperature (total)	$T_{2,tot}$	K	330,50	-	344,2
Volumetric flow at inlet; Defined @ delivered mass flow	q_{V1}	m³/h	1495	0,44	1488
Power requirement @ wire input incl. Aux.	P_{wire}	kW	21,3	-	20,0
Specific energy	**e**	J/m³	14	-	13
Reference process	**Pr**	-	dynamic	-	dynamic
If combiend; Ratio of internal compression	v_i	-	1,2757	-	1,2605
Table A.3 - Design data			**te**	**te/g**	**g**
Speed of rotation (shaft)	**n**	r/min	1395	0,00	1395
Gear ratio	**i**	ratio	10,0000	-	10,0000
Tip speed of impeller	u_2	m/s	219,1	0,00	219,1
Rotor tip diameter	D_u	m	0,3	-	0,3
Ratio of internal compression	v_i	-	1,2757	-	1,2605
Inlet guide vane setting	**scale**	#	0,0	-	0,0
Diffuser vane setting	**scale**	#	0,0	-	0,0
Inlet pressure loss "inside the packaged"	**Δptot,1'**	Pa	0	-	0
Outlet pressure loss "inside the packaged"	**Δptot,2'**	Pa	0	-	0
Additional auxiliry losse not accounted for during measurements	$\Delta P_{wire,loss}$	kW	0	-	0
Measured wire Power	Pwire,meas.	kW	21,26	-	20
				-	
Table A.4 - Air/Gas data			**te**	**te/g**	**g**
Saturation pressure	p_{sat}	Pa	2540	-	5620
Humidity content	**x**	kg/kg	0,00472	-	0,02141
Isentropic exponent	κ	-	1,399	-	1,397
Specific gas constant	R_{wet}	J/kg*K	287,9	-	290,8
Density	ρ_1	kg/m³	1,1923	-	1,1309
specific volume @ inlet	v_1	m³/kg	0,8387	-	0,8843
Delivered Mass flow rate of air	$q_{m,2}$	kg/s	0,4950	-	0,4674
Heat capacity	$Cp_{,1}$	J/kg*K	1009	-	1024
Table A.5 - Performance data			**te**	**te/g**	**g**
Volume flow coefficient	φ	-	0,0268	0,44	0,0267
Isentropic specific compression work	y_s	J/kg	30339	-	30339
Specific compression work (reference process)	y_{Pr}	J/kg	30339	0,00	30339
Reel gas work cp*Δt	Y_{real}	J/kg	36325	-	36904
Packaged work	Y_{pac}	J/kg	42949	-	42787
Reference process work coefficient	ψ_{Pr}	-	1,2637	0,00	1,2637
Sonic velocity	**c**	m/s	344,5	-	353,8
Machine Mach number	**Ma**	-	0,6362	2,70	0,6194
Relative inner efficiency	**y.../Yreal**	-	0,835	-	0,822
Relative isentropic/packaged efficiency	**ys/Ypac**	-	0,706	-	0,709

Figure 5: Acceptance tolerances					
			Volume	energy	Outlet
Volume flow rate at specified conditions			flow	requirement	pressure
min <qv< max			qv	e	p2
(m^3/h)			± #%	± #%	+#%
0	$<q_v<$	30	7	8	1
30	$<q_v<$	90	6	7	1
90	$<q_v<$	900	5	6	1
900	$<q_v<$	∞	4	5	1
qv=	344,2	Case Toll.	5	5	1
qv=	1488	Case Toll.	4	5	1

ratio of reduced speeds of rotation	X_n	-	**1,0270**
Setpoint speed ***"option"***	n_{red}	rpm	**1358**

Guarantee point min - max / Limits of testing	Symbol	Unit (Metric)	g	g_min	g_max		%	Δ(g_max-g_min	rule
Outlet Pressure	$p_{2,tot,g}$	bar abs	1,4000	1,4000	1,4140	+	1	0,0140	9.5 table 2
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	1488	1428	1548	±	4	119	9.5 table 2
Total Input Pow er	$P_{wire,g}$	kW	20,0	19,0	21,0	±	5	2,0	9.5 table 2
Specific Energy; Pow er related to volume flo	e_g	kJ/m³	48,4	46,0	50,8	±	5	4,8	9.5 table 2
Reference Work	$y_{Pr,g}$	J/kg	30339	30339	31322		-	982	9.5 table 2
Reference Work limits	$y_{Pr\_toll,g}$	%	0,0	0,0	3,2	+	3,2	3,2	9.5 table 2
Reference process w ork coefficient	$\psi_{Pr,g}$	-	1,2637	1,2637	1,3046		-	0,0409	9.5 table 2
Reference process w ork coefficient limits	$\psi_{Pr\ toll,g}$	%	0,0	0,0	3,2	+	3,2	3,2	9.5 table 2
Volume flow coefficient	$\varphi\ ,g$	-	0,0267	0,0256	0,0278	±	4	0,0021	9.5 table 2
Volume flow coefficient limits	$\varphi\ \_toll,g$	%	0,0	-4,0	4,0	±	4	8,0	9.5 table 2
Designation	Symbol	Unit (Metric)	Guarantee point	Test point	CORRECTED TO SPECIFIED CONDITIONS		tollerance (Δ) or (%)	Pass/Fail ABS(value)	
			g	*te*	*co*		-	-	
Test Period start/end		Mins.	-	0:10	0:10	min	0:10	0:10	11,13
Barometric Pressure	$p_{1,tot}$	bar abs	1,0133	1,0110	1,0133	±	10,00%	1,0110	8.2.2 or 8.4
Ambient Relative Humidity	φ_{1wet}	-	60,0	30	60,0000		-	-	
Isentropic exponent	κ	-	1,397	1,399	1,3967		-	-	
Ambient Gas Constant	R_{wet}	J/(kg*K)	290,8	287,9	290,8		-	-	
Inlet Temperature	$T_{1,tot}$	K	308,15	294,5	308,15	±	15	294,5	8.2.2 or 8.4
Inlet Pressure	$p_{1,tot}$	bar abs	1,0133	1,0110	1,0133		-	-	
Outlet Pressure	$p_{2,tot}$	bar abs	1,4000	1,42139	1,4000	+	1,00%	0,00%	9.5 table 2
Outlet Temperature	$T_{2,tot}$	K	344,20	330,50	343,63		-	-	
Compressor Speed	n	rpm	1395	1395	1395	±	3,00%	0,00%	8.2.1
Ratio of internal compression	v_i	-	1,2605	1,2757	1,2605		-	-	
Density of inlet air	ρ_1	kg/m³	1,1309	1,1923	1,1309		-	-	
Machine Mach number	*Ma*	-	0,6194	0,6362	0,6194	±	5,00%	2,70%	8.4 or 8.2.2
Reference Work	y_{Pr}	J/kg	30339	30339	30339		-	-	
Inlet Volume Flow Rate	$q_{v,1}$	m³/s	1488	1495	1495	±	4,00%	0,44%	9.5 table 2
Total Input Pow er	P_{wire}	kW	20,0	21,3	20,2		-	-	
Specific Energy; Pow er related to volume flo	e	kJ/m³	48,39	51,21	48,57	±	5,00%	0,38%	9.5 table 2
Preconditions to be measured to comply w ith the guarantee									
Supply voltage	U	volts	400	400	-		-	-	
Supply frequency	f	Hz	50	50	-		-	-	
External Coolant Inlet Temperature	$T_{1,cool}$	deg C	20	21	-	±	15	21	8,3
External Coolant Flow	$q_{m,cool}$	kg/s	0,02	0,021	-	±	10,00%	5,00%	8,3
Corrected to specified conditions, guaranteed inlet flow and outlet pressure									
Inlet Pressure	$p_{1,tot,g}$	bar abs	-	-	1,0133		-	-	
Inlet Temperature	$T_{1,tot,g}$	deg C	-	-	308,15		-	-	
Ambient Relative Humidity	$\varphi_{1wet,g}$	-	-	-	60,0		-	-	
Outlet Pressure	$p_{2,tot,g}$	bar abs	-	-	1,4000		-	-	
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	-	-	1488		-	-	
Total Input Pow er	$P_{wire,co,g}$	kW	-	-	20,1	±	5,00%	0,38%	9.5 table 2



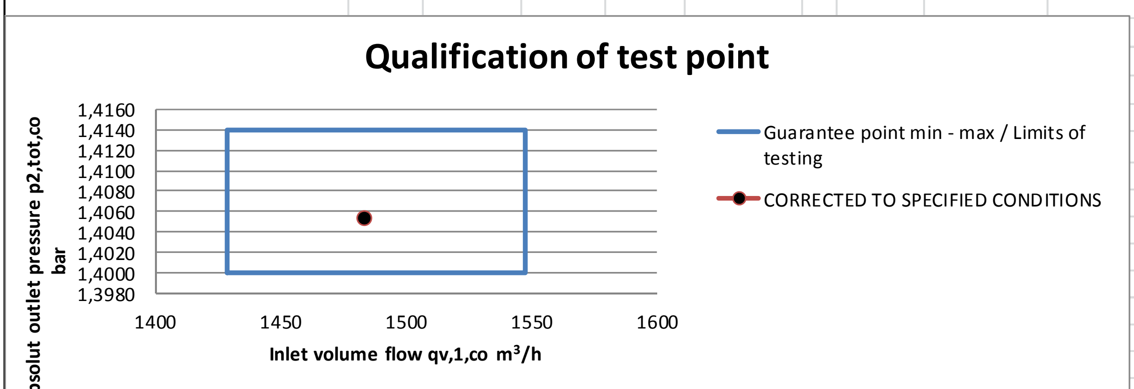
Two speed test (part 1)

Compressor type/					
Manufacturer/ order #/ serial #					
Year of fabrication					
Manufacturer checklist for the package (see)					
Variable speed, dynamic machines			Values during testing	**Setpoint** or deviation te/g	Values under guarantee conditions
Quantity	Symbol	Unit	Value	Value	Value
Table A.1 - Guarantee conditions			**te**	**te/g**	**g**
Test report number	**#**	-	1	-	-
Date of test	*dd-mm-yy*	date	14/12/2015	-	start
Time of test	**-**	h	16:10	0:10	16:00
Barometric pressure "p_1"	$p_{1,tot}$	Pa	101100	-	101325
Relative humidity @ "Barometric pressure point"	φ_{1wet}	%	30	-	60
Inlet temperature	$T_{1,tot}$	K	273,15	-	308,15
Inlet pressure (total)	$p_{1,tot}$	Pa	101100	-	101325
Table A.2 -Object of Guarantee			te	**te/g**	g
Outlet pressure	$p_{2,tot}$	Pa	145886	**145886**	140000
Gauge pressure "Pressure rise" (total)	$\Delta p_{2,tot}$	Pa	44786	-	38675
Outlet temperature (total)	$T_{2,tot}$	K	309,27	-	344,2
Volumetric flow at inlet; Defined @ delivered mass flow	q_{V1}	m³/h	1495	0,47	1488
Power requirement @ wire input incl. Aux.	P_{wire}	kW	23,0	-	20,0
Specific energy	**e**	J/m³	15	-	13
Reference process	***Pr***	-	dynamic	-	dynamic
If combiend; Ratio of internal compression	v_i	-	1,2995	-	1,2605
Table A.3 - Design data			**te**	**te/g**	**g**
Speed of rotation (shaft)	***n***	r/min	1395	0,00	1395
Gear ratio	***i***	ratio	10,0000	-	10,0000
Tip speed of impeller	u_2	m/s	219,1	0,00	219,1
Rotor tip diameter	D_u	m	0,3	-	0,3
Ratio of internal compression	v_i	-	1,2995	-	1,2605
Inlet guide vane setting	***scale***	#	0,0	-	0,0
Diffuser vane setting	***scale***	#	0,0	-	0,0
Inlet pressure loss "inside the packaged"	***Δptot,1'***	Pa	0	-	0
Outlet pressure loss "inside the packaged"	***Δptot,2'***	Pa	0	-	0
Additional auxiliry losse not accounted for during measurements	$\Delta P_{wire,loss}$	kW	0	-	0
Measured wire Power	Pwire,meas.	kW	23,00	-	20
				-	
Table A.4 - Air/Gas data			**te**	**te/g**	**g**
Saturation pressure	p_{sat}	Pa	613	-	5620
Humidity content	***x***	kg/kg	0,00113	-	0,02141
Isentropic exponent	κ	-	1,400	-	1,397
Specific gas constant	R_{wet}	J/kg*K	287,3	-	290,8
Density	ρ_1	kg/m³	1,2883	-	1,1309
specific volume @ inlet	v_1	m³/kg	0,7762	-	0,8843
Delivered Mass flow rate of air	$q_{m,2}$	kg/s	0,5350	-	0,4674
Heat capacity	$Cp_{,1}$	J/kg*K	1006	-	1024
Table A.5 - Performance data			**te**	**te/g**	**g**
Volume flow coefficient	φ	-	0,0268	0,47	0,0267
Isentropic specific compression work	y_s	J/kg	30339	-	30339
Specific compression work (reference process)	y_{Pr}	J/kg	30339	0,00	30339
Reel gas work cp*Δt	Y_{real}	J/kg	36334	-	36904
Packaged work	Y_{pac}	J/kg	42991	-	42787
Reference process work coefficient	ψ_{Pr}	-	1,2637	0,00	1,2637
Sonic velocity	***c***	m/s	331,4	-	353,8
Machine Mach number	***Ma***	-	0,6611	6,73	0,6194
Relative inner efficiency	***y.../Yreal***	-	0,835	-	0,822
Relative isentropic/packaged efficiency	***ys/Ypac***	-	0,706	-	0,709

Figure 5: Acceptance tolerances					
			Volume	energy	Outlet
Volume flow rate at specified conditions			flow	requirement	pressure
min <qv< max			qv	e	p2
(m^3/h)			± #%	± #%	+#%
0	<q_v<	30	7	8	1
30	<q_v<	90	6	7	1
90	<q_v<	900	5	6	1
900	<q_v<	∞	4	5	1
qv=	344,2	Case Toll.	5	5	1
qv=	1488	Case Toll.	4	5	1

ratio of reduced speeds of rotation	X_n	-	**1,0673**
Setpoint speed ***"option"***	n_{red}	rpm	**1307**

Guarantee point min - max / Limits of testing	Symbol	Unit (Metric)	g	g_min	g_max		%	Δ(g_max-g_min	rule
Outlet Pressure	$p_{2,tot,g}$	bar abs	1,4000	1,4000	1,4140	+	1	0,0140	9.5 table 2
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	1488	1428	1548	±	4	119	9.5 table 2
Total Input Power	$P_{wire,g}$	kW	20,0	19,0	21,0	±	5	2,0	9.5 table 2
Specific Energy; Power related to volume flo	e_g	kJ/m³	48,4	46,0	50,8	±	5	4,8	9.5 table 2
Reference Work	$y_{Pr,g}$	J/kg	30339	30339	31322		-	982	9.5 table 2
Reference Work limits	$y_{Pr\_toll,g}$	%	0,0	0,0	3,2	+	3,2	3,2	9.5 table 2
Reference process work coefficient	$\psi_{Pr,g}$	-	1,2637	1,2637	1,3046		-	0,0409	9.5 table 2
Reference process work coefficient limits	$\psi_{Pr\ toll,g}$	%	0,0	0,0	3,2	+	3,2	3,2	9.5 table 2
Volume flow coefficient	$\varphi_{,g}$	-	0,0267	0,0256	0,0278	±	4	0,0021	9.5 table 2
Volume flow coefficient limits	$\varphi_{\_toll,g}$	%	0,0	-4,0	4,0	±	4	8,0	9.5 table 2
Designation	Symbol	Unit (Metric)	Guarantee point	Test point	CORRECTED TO SPECIFIED CONDITIONS		tollerance (Δ) or (%)	Pass/Fail ABS(value)	
			g	*te*	*co*		-	-	
Test Period start/end		Mins.	-	0:10	0:10	min	0:10	0:10	11,13
Barometric Pressure	$p_{1,tot}$	bar abs	1,0133	1,0110	1,0133	±	10,00%	1,0110	8.2.2 or 8.4
Ambient Relative Humidity	φ_{1wet}	-	60,0	30	60,0000		-	-	
Isentropic exponent	κ	-	1,397	1,400	1,3967		-	-	
Ambient Gas Constant	R_{wet}	J/(kg*K)	290,8	287,3	290,8		-	-	
Inlet Temperature	$T_{1,tot}$	K	308,15	273,15	308,15	±	15	273,15	8.2.2 or 8.4
Inlet Pressure	$p_{1,tot}$	bar abs	1,0133	1,0110	1,0133		-	-	
Outlet Pressure	$p_{2,tot}$	bar abs	1,4000	1,45886	1,4000	+	1,00%	0,00%	9.5 table 2
Outlet Temperature	$T_{2,tot}$	K	344,20	309,27	343,64		-	-	
Compressor Speed	n	rpm	1395	1395	1395	±	3,00%	0,00%	8.2.1
Ratio of internal compression	v_i	-	1,2605	1,2995	1,2605		-	-	
Density of inlet air	ρ_1	kg/m³	1,1309	1,2883	1,1309		-	-	
Machine Mach number	*Ma*	-	0,6194	0,6611	0,6194	±	5,00%	6,73%	8.4 or 8.2.2
Reference Work	y_{Pr}	J/kg	30339	30339	30339		-	-	
Inlet Volume Flow Rate	$q_{v,1}$	m³/s	1488	1495	1495	±	4,00%	0,47%	9.5 table 2
Total Input Power	P_{wire}	kW	20,0	23,00	20,2		-	-	
Specific Energy; Power related to volume flo	e	kJ/m³	48,39	55,38	48,62	±	5,00%	0,48%	9.5 table 2
Preconditions to be measured to comply with the guarantee									
Supply voltage	U	volts	400	400	-		-	-	
Supply frequency	f	Hz	50	50	-		-	-	
External Coolant Inlet Temperature	$T_{1,cool}$	deg C	20	21	-	±	15	21	8,3
External Coolant Flow	$q_{m,cool}$	kg/s	0,02	0,021	-	±	10,00%	5,00%	8,3
Corrected to specified conditions, guaranteed inlet flow and outlet pressure									
Inlet Pressure	$p_{1,tot,g}$	bar abs	-	-	1,0133		-	-	
Inlet Temperature	$T_{1,tot,g}$	deg C	-	-	308,15		-	-	
Ambient Relative Humidity	$\varphi_{1wet,g}$	-	-	-	60,0		-	-	
Outlet Pressure	$p_{2,tot,g}$	bar abs	-	-	1,4000		-	-	
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	-	-	1488		-	-	
Total Input Power	$P_{wire,co,g}$	kW	-	-	20,1	±	5,00%	0,48%	9.5 table 2



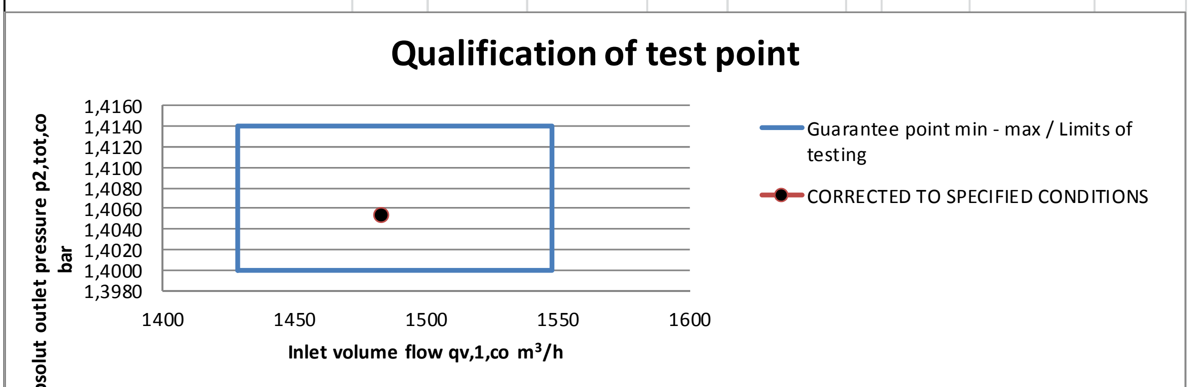
Two speed test (part 2)

Compressor type/					
Manufacturer/ order #/ serial #					
Year of fabrication					
Manufacturer checklist for the package (see)					
Variable speed, dynamic machines			Values during testing	**Setpoint** or deviation te/g	Values under guarantee conditions
Quantity	Symbol	Unit	Value	Value	Value
Table A.1 - Guarantee conditions			**te**	**te/g**	**g**
Test report number	**#**	-	1	-	-
Date of test	*dd-mm-yy*	date	14/12/2015	-	start
Time of test	-	h	16:10	0:10	16:00
Barometric pressure "p_1"	$p_{1,tot}$	Pa	101100	-	101325
Relative humidity @ "Barometric pressure point"	φ_{1wet}	%	30	-	60
Inlet temperature	$T_{1,tot}$	K	273,15	-	308,15
Inlet pressure (total)	$p_{1,tot}$	Pa	101100	-	101325
Table A.2 -Object of Guarantee			te	**te/g**	g
Outlet pressure	$p_{2,tot}$	Pa	139774	**139774**	140000
Gauge pressure "Pressure rise" (total)	$\Delta p_{2,tot}$	Pa	38674	-	38675
Outlet temperature (total)	$T_{2,tot}$	K	305,24	-	344,2
Volumetric flow at inlet; Defined @ delivered mass flow	q_{V1}	m³/h	1401	0,47	1488
Pow er requirement @ w ire input incl. Aux.	P_{wire}	kW	18,9	-	20,0
Specific energy	e	J/m³	14	-	13
Reference process	***Pr***	-	dynamic	-	dynamic
If combiend; Ratio of internal compression	v_i	-	1,2604	-	1,2605
Table A.3 - Design data			**te**	**te/g**	**g**
Speed of rotation (shaft)	n	r/min	1307	-6,31	1395
Gear ratio	i	ratio	10,0000	-	10
Tip speed of impeller	u_2	m/s	205,3	-6,31	219,1
Rotor tip diameter	D_u	m	0,3	-	0,3
Ratio of internal compression	v_i	-	1,2604	-	1,2605
Inlet guide vane setting	***scale***	#	0	-	0
Diffuser vane setting	***scale***	#	0	-	0
Inlet pressure loss "inside the packaged"	***Δptot,1'***	Pa	0	-	0
Outlet pressure loss "inside the packaged"	***Δptot,2'***	Pa	0	-	0
Additional auxiliry losse not accounted for during measurements	$\Delta P_{wire,loss}$	kW	0	-	0
Measured w ire Pow er	Pw ire,meas.	kW	18,9	-	20,0
				-	
Table A.4 - Air/Gas data			**te**	**te/g**	**g**
Saturation pressure	p_{sat}	Pa	613	-	5620
Humidity content	x	kg/kg	0,00113	-	0,02141
Isentropic exponent	κ	-	1,39983	-	1,397
Specific gas constant	R_{wet}	J/kg*K	287,3	-	290,8
Density	ρ_1	kg/m³	1,2883	-	1,1309
specific volume @ inlet	v_1	m³/kg	0,7762	-	0,8843
Delivered Mass flow rate of air	$q_{m,2}$	kg/s	0,5013	-	0,4674
Heat capacity	$Cp_{,1}$	J/kg*K	1006	-	1024
Table A.5 - Performance data			**te**	**te/g**	**g**
Volume flow coefficient	φ	-	0,0268	0,47	0,0267
Isentropic specific compression work	y_s	J/kg	26632	-	30339
Specific compression w ork (reference process)	y_{Pr}	J/kg	26632	0,00	30339
Reel gas w ork cp*Δt	Y_{real}	J/kg	32278	-	36904
Packaged w ork	Y_{pac}	J/kg	37729	-	42787
Reference process w ork coefficient	ψ_{Pr}	-	1,264	0,00	1,264
Sonic velocity	c	m/s	331,4	-	353,8
Machine Mach number	***Ma***	-	0,6194	0,00	0,6194
Relative inner efficiency	***y.../Yreal***	-	0,825	-	0,8221
Relative isentropic/packaged efficiency	***ys/Ypac***	-	0,706	-	0,7091

Figure 5: Acceptance tolerances					
			Volume	energy	Outlet
Volume flow rate at specified conditions			flow	requirement	pressure
min <qv< max			qv	e	p2
(m^3/h)			± #%	± #%	+#%
0	$<q_v<$	30	7	8	1
30	$<q_v<$	90	6	7	1
90	$<q_v<$	900	5	6	1
900	$<q_v<$	∞	4	5	1
qv=	344,2	Case Toll.	5	5	1
qv=	1488	Case Toll.	4	5	1

ratio of reduced speeds of rotation	X_n	-	**1,0000**		**qm setpoint**
Setpoint speed ***"option"***	n_{red}	rpm	**1307**		**0,5012509**
Machine Mach number	***Ma***	-	**0,6194**		
			16,2		
			16,7		
eta M	η_m	-	**0,9660**		
Pm			**17,3**		
Pvvfd			**17,8**		
auq losses			1,0		
Ppac			**18,8**		

Guarantee point min - max / Limits of testing	Symbol	Unit (Metric)	g	g_min	g_max		%	Δ(g_max-g_min	rule
Outlet Pressure	$p_{2,tot,g}$	bar abs	1,4000	1,4000	1,4140	+	1	0,0140	9.5 table 2
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	1488	1428	1548	±	4	119	9.5 table 2
Total Input Pow er	$P_{wire,g}$	kW	20,0	19,0	21,0	±	5	2,0	9.5 table 2
Specific Energy; Pow er related to volume flo	e_q	kJ/m³	48,4	46,0	50,8	±	5	4,8	9.5 table 2
Reference Work	$y_{Pr,g}$	J/kg	30339	30339	31322		-	982	9.5 table 2
Reference Work limits	$y_{Pr\_toll,g}$	%	0,0	0,0	3,2	+	3,2	3,2	9.5 table 2
Reference process w ork coefficient	$\psi_{Pr,g}$	-	1,2637	1,2637	1,3046		-	0,0409	9.5 table 2
Reference process w ork coefficient limits	$\psi_{Pr\_toll,g}$	%	0,0	0,0	3,2	+	3,2	3,2	9.5 table 2
Volume flow coefficient	$\varphi_{,g}$	-	0,0267	0,0256	0,0278	±	4	0,0021	9.5 table 2
Volume flow coefficient limits	$\varphi_{\_toll,g}$	%	0,0	-4,0	4,0	±	4	8,0	9.5 table 2
Designation	Symbol	Unit (Metric)	Guarantee point	Test point	CORRECTED TO SPECIFIED CONDITIONS		tollerance (Δ) or (%)	Pass/Fail ABS(value)	
			g	te	co		-	-	
Test Period start/end		Mins.	-	0:10	0:10	min	0:10	0:10	11,13
Barometric Pressure	$p_{1,tot}$	bar abs	1,0133	1,0110	1,0133	±	10,00%	1,0110	8.2.2 or 8.4
Ambient Relative Humidity	φ_{1wet}	-	60,0	30	60,0000		-	-	
Isentropic exponent	κ	-	1,397	1,400	1,3967		-	-	
Ambient Gas Constant	R_{wet}	J/(kg*K)	290,8	287,3	290,8		-	-	
Inlet Temperature	$T_{1,tot}$	K	308,15	273,15	308,15	±	15	273,15	8.2.2 or 8.4
Inlet Pressure	$p_{1,tot}$	bar abs	1,0133	1,0110	1,0133		-	-	
Outlet Pressure	$p_{2,tot}$	bar abs	1,4000	1,39774	1,4000	+	1,00%	0,00%	9.5 table 2
Outlet Temperature	$T_{2,tot}$	K	344,20	305,24	344,07		-	-	
Compressor Speed	n	rpm	1395	1307	1395	±	3,00%	6,31%	8.2.1
Ratio of internal compression	v_i	-	1,2605	1,2604	1,2605		-	-	
Density of inlet air	ρ_1	kg/m³	1,1309	1,2883	1,1309		-	-	
Machine Mach number	*Ma*	-	0,6194	0,6194	0,6194	±	5,00%	0,00%	8.4 or 8.2.2
Reference Work	y_{Pr}	J/kg	30339	26632	30340		-	-	
Inlet Volume Flow Rate	$q_{v,1}$	m³/s	1488	1401	1495	±	4,00%	0,47%	9.5 table 2
Total Input Pow er	P_{wire}	kW	20,0	18,9	20,2		-	-	
Specific Energy; Pow er related to volume flo	e	kJ/m³	48,4	48,6	48,6	±	5,00%	0,45%	9.5 table 2
Preconditions to be measured to comply w ith the guarantee									
Supply voltage	U	volts	400	400	-		-	-	
Supply frequency	f	Hz	50	50	-		-	-	
External Coolant Inlet Temperature	$T_{1,cool}$	deg C	20	21	-	±	15	21	8,3
External Coolant Flow	$q_{m,cool}$	kg/s	0,02	0,021	-	±	10,00%	5,00%	8,3
Corrected to specified conditions, guaranteed inlet flow and outlet pressure									
Inlet Pressure	$p_{1,tot,g}$	bar abs	-	-	1,0133		-	-	
Inlet Temperature	$T_{1,tot,g}$	deg C	-	-	308,15		-	-	
Ambient Relative Humidity	$\varphi_{1wet,g}$	-	-	-	60,0		-	-	
Outlet Pressure	$p_{2,tot,g}$	bar abs	-	-	1,4000		-	-	
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	-	-	1488		-	-	
Total Input Pow er	$P_{wire,co,g}$	kW	-	-	20,1	±	5,00%	0,45%	9.5 table 2



Two speed test (part 3)

Manufacturer/ order #/ serial #					
Year of fabrication					
Manufacturer checklist for the package (see)					
Variable speed, dynamic machines			Values during testing	**Setpoint** or deviation te/g	Values under guarantee conditions
Quantity	Symbol	Unit	Value	Value	Value
Table A.1 - Guarantee conditions			**te**	**te/g**	**g**
Test report number	**#**	-	1	-	-
Date of test	*dd-mm-yy*	date	14/12/2015	-	start
Time of test	**-**	h	16:10	0:10	16:00
Barometric pressure "p_1"	$p_{1,tot}$	Pa	101100	-	101100
Relative humidity @ "Barometric pressure point"	φ_{1wet}	%	30	-	30
Inlet temperature	$T_{1,tot}$	K	273,15	-	273,15
Inlet pressure (total)	$p_{1,tot}$	Pa	101100	-	101100
Table A.2 -Object of Guarantee			te	**te/g**	g
Outlet pressure	$p_{2,tot}$	Pa	141067		141067
Gauge pressure "Pressure rise" (total)	$\Delta p_{2,tot}$	Pa	39967		39967
Outlet temperature (total)	$T_{2,tot}$	K	306,2		306,2
Volumetric flow at inlet; Defined @ delivered mass flow	q_{V1}	m³/h	1464		1464
Power requirement @ wire input incl. Aux.	P_{wire}	kW	20,2	**0,65**	20,1
Specific energy	**e**	J/m³	14	-	14
Table A.3 - Design data			**te**	**te/g**	**g**
Speed of rotation (shaft)	**n**	r/min	1395	**0,00**	1395
Gear ratio	**i**	ratio	10,0000		10
Tip speed of impeller	u_2	m/s	219,1		219,1
Rotor tip diameter	D_u	m	0,3		0,3
Ratio of internal compression	v_i	-	1,2687		
Additional auxiliry losse not accounted for during measurements	$\Delta P_{wire,loss}$	kW	1		0
Measured wire Power	Pwire,meas.	kW	19,2		20,1

Table A.4 - Air/Gas data			**te**		
Saturation pressure	p_{sat}	Pa	613		
Humidity content	**x**	kg/kg	0,00113		
Isentropic exponent	κ	-	1,39983		
Specific gas constant	R_{wet}	J/kg*K	287,3		
Density	ρ_1	kg/m³	1,2883		
specific volume @ inlet	v_1	m³/kg	0,7762		
Delivered Mass flow rate of air	$q_{m,2}$	kg/s	0,5240		
Heat capacity	$Cp_{,1}$	J/kg*K	1006		
Table A.5 - Performance data			**te**		
Volume flow coefficient	φ	-	0,0263		
Isentropic specific compression work	y_s	J/kg	27426	eta setpoint	
Specific compression work (reference process)	y_{Pr}	J/kg	27426	0,825	
Reel gas work cp*Δt	Y_{real}	J/kg	33244		
Packaged work	Y_{pac}	J/kg	38590		
Reference process work coefficient	ψ_{Pr}	-	1,142		
Inlet Power	**Ps**	kW	14,4		
Real Power	**Ps1**	kW	17,4		
Relative inner efficiency	***y.../Yreal***	-	0,825		
Mechanical losses	**Pmec**	kW	0,6		
Shaft power	**Pshaft**	kW	18,0		
eta M	η_m	-	0,9664		
Motor power	**Pmotor**	kW	18,7		
VFD losses	**PVFD**	kW	0,560		
VFD input power	**Pvfd**	kW	19,2		
Relative isentropic/packaged efficiency	***ys/Ypac***	-	0,711		

	$q_{m,2,te}$	$y_{s,te}$	Pi.test	Ppac,te	eta_two_speed,te
test1	0,5013	32278	16,2	18,9	85,6
test2	0,5240	33244	17,4	20,2	86,1
eta correction two speed testing,te (test1/test2)					0,993

Corrected to specified conditions, guaranteed inlet flow , outlet pressure and two speed.					
Inlet Pressure	$p_{1,tot,g}$	bar abs	1,0133	-	
Inlet Temperature	$T_{1,tot,g}$	deg C	308,1500	-	
Ambient Relative Humidity	$\varphi_{1wet,g}$	-	60,0000	-	
Outlet Pressure	$p_{2,tot,g}$	bar abs	1,4000	-	
Inlet Volume Flow Rate	$q_{v,1,g}$	m³/s	1488,0000	-	
Total Input Power	$P_{wire,co,g,test1,co}$	kW	20,0	0,24%	9.5 table 2

Inputpower		compressor		gear+bearings…		Motor input		VFD input		additional electric equipment
		gaspower	+	mechpwer	+	motorpower	+	vdfpower	+	auxpower
Pis		(Pgas	+	Pmec	+	Pm	+	Pvfd	+	Paux)

eta_Pis_related_imp	=	(Pis/Pgas)	,	*this is the thermodynamic boundary which is used to setup the compressor*
eta_Pis_related_shaft	=	(Pis/(Pgas+Pmec))		
eta_Pis_related_motor	=	(Pis/(Pgas+Pmec+Pm))		
eta_Pis_related_vfd	=	(Pis/(Pgas+Pmec+Pm+Pvfd))		
eta_Pis_related_pac	=	(Pis/(Pgas+Pmec+Pm+Pvfd+Paux))	=	(Pis/Ppac)

eta_twospeed	**=**	***Pgas/(Pgas+Pmec+Pm+Pvfd+Paux)***
	=	***Pgas/Ppac***
Pgas	**=**	***Cp*(t2-t1)*m***
Pmec	**=**	***Pmec*(Nt1/Nt2)^2.5***
Pm	**=**	***related to load and speed***
Pvfd	**=**	***constant ratio***
Paux	**=**	***constant***

Additional notes for testing

Appendix 7.1 Specific Test Point Data Collection

The compressor package shall operate at the steady state condition for the duration of data collection for each test point. The compressor (blower) shall be operated at the required conditions for a sufficient period of time to reach steady state each test point.

Steady-state is defined as demonstrating the difference between inlet and outlet temperatures $\Delta T = (T_2 - T_1)$ is within the limit Section 6.4.Table 1 for a period of three minutes interval or more.

A minimum of three sets of data shall be collected. The minimum duration of a test point, after steady state has been reached, shall be 10 minutes from the start of the first set of readings to the end of the third set of readings.

A test point considers one complete set of instrument readings obtained in a one minute period. The individual readings are summed and divided by the total number of readings to establish an average, and used for the test point.

Recorded data of the test point shall be included in the test report to demonstrate the thermal and fluid stability at time of measurement.

Date and time of data collection shall be reported for each set of data.

The use of data acquisition systems shall be allowed and the test logs may be print outs resulting from the system.

Appendix 7.2 Flow measurement

The delivered flow rate is the net mass flow rate through the process connection of the compressor package outlet. All seal losses and side streams not delivered to the process piping connection of the compressor package shall be excluded from the delivered mass flow rate evaluation.

Flow shall be measured on the process side of the compressor package outlet. It can be measured according to the principle and requirements of ISO 5167.

The mass flow rate is determined from the gas condition of the fluid at a flow meter measurement station. The general equation for mass flow is found in ISO 5167-1.

In cases of high temperature or dissimilar materials, the thermal effects of diametrical changes of the fluid meter and pipe may not be negligible in the determination of the ratio of diameters.

Measuring lines installed between the sampling point and the display instrument shall be installed with great care. Any leaks shall be eliminated. Provisions shall be made to prevent blockage by foreign bodies. Where condensate occurs in the measuring lines, such lines shall be completely filled with condensate or shall be reliably kept free of condensate (e.g. by arranging the measuring instrument at a geodetic higher level than the measuring point).

Appendix 7.3 Electrical power measurement

Measurement of the total wire power supplied to the compressor package shall be recorded at test conditions with the compressor operating at the specified operating point.

Appendix 7.4 Power measurement for non-inverter applications

For non-inverter applications, a standard power analyser based on 50/60Hz RMS sine wave is acceptable.

Appendix 7.5 Power measurement for inverter applications

For inverter applications, the wire power measuring instrument shall be capable of handling the distorted voltage and current waveforms and phase relationship of the power factor caused by the harmonics and EMI as a result an inverters high-speed switching mode. Wire power shall be measured by a precision power analyzer with high accuracy, broad bandwidth, fast sampling rate and high-speed data update.

The frequency bandwidth shall cover 0,1 Hz to 1 MHz. The sampling rate shall be approximately 200 kS/s or greater. The maximum data updating period shall be 50 ms.

The precision power analyzer shall be capable of simultaneous measurement of normal and harmonic waves. It shall provide a variety of display formats for viewing waveforms as well as numerical values. It shall also combine the use of digital filtering and total-average methods for sampling instantaneous values.

The precision power analyzer shall have compensation functions for instrument-related losses. It shall also have a variety of integration functions for active power, current, apparent power and reactive power.

The current transducer shall be capable of measuring a dynamic range and peak greater than the maximum current consumption of the package. The measurement frequency range shall be from DC to 100 kHz or a minimum of eight times greater than the switching mode of the inverter driving the package.

Appendix 7.6 Temperature measurement

A minimum of two temperature measuring instruments shall be utilized for each measurement location spaced at 180° intervals around the pipe circumference. The temperature measuring devices shall have the required resolution for accuracy.

The thermometers or the pockets shall extend into the pipe to a distance of 100 mm, or one third the diameter of the pipe, whichever is less.

Appendix 7.7 Temperature measurement Ambient

The compressor package ambient temperature is the atmospheric temperature measured at the compressor package in the plane of the intake system.

Appendix 7.8 Temperature measurement Inlet

The compressor inlet temperature is the total temperature (T_1) measured at the compressor inlet [1]. The temperature instrumentation shall be located ½ pipe diameter upstream of the compressor inlet. The location shall include all heating or cooling affecting the process fluid prior to the compressor inlet. If inadequate space is available within the package, the measurement location shall be as agreed to in advance of test by all parties including equipment owner, owner's engineer, and supplier.

Appendix 7.9 Temperature measurement Outlet

The compressor outlet temperature is the total temperature (T_2) measured at the compressor outlet [2]. The temperature instrumentation shall be located 1 pipe diameter downstream of the compressor outlet and 90° relatively rotated to the pressure measurement.

Appendix 7.10 Pressure measurement

A minimum of two static or total pressure measuring instruments shall be utilized for each measurement location spaced at 180° intervals around the pipe circumference, and 90° to temperature instrumentation. The pressure measuring devices shall have the required resolution for accuracy.

Appendix 7.11 Pressure measurement for ambient inlet

The compressor package inlet pressure p_1 is the atmospheric pressure measured by a barometer in the vicinity of the compressor package where the velocity is zero.

Appendix 7.12 Pressure measurement for pipe inlet

The compressor inlet pressure is the total pressure (p_1) measured at the compressor inlet.

The compressor inlet pressure shall be measured at a location at least 1pipe diameter upstream of the compressor inlet or at a location to include all intake pressure losses impacting the process fluid prior to the compressor inlet. If inadequate space is available within the package, the measurement location shall be as agreed to in advance of test by all parties including equipment owner, owner's engineer, and supplier. The pressure measurement shall be a total measurement, or static measurement corrected to total conditions.

Appendix 7.13 Pressure measurement Outlet

The compressor package outlet pressure is the pressure (p_2) measured in the outlet piping at a prescribed location following the compressor package design consideration and code requirements to ensure a stable and accurate reading.

The pressure instrumentation shall be located 2 pipe diameters downstream of the compressor outlet.

Appendix 7.14 Speed measurement

Where measurement of the speed of rotation is necessary for the performance test, it shall be determined with the accuracy necessary for this purpose using a cyclometer, tachometer, frequency meter; etc.