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THE PERFORMANCE AND THE CHARACTERISTIC FIELD OF A CENTRIFUGAL COMPRESSOR

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ABSTRACT

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The performance and the characteristic field of a centrifugal compressor

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The basic calculations related to the compression process of a centrifugal compressor are examined in this study. The effects of air humidity are considered, and the characteristic field of a compressor is presented. Points of a characteristic field are calculated as an example.

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INDEX OF USED SYMBOLS

Symbols

M	molecular mass	[kg/mol]
N_s	specific speed	[-]
R	gas constant	[J/kgK, kJ/kgK]
T	temperature	[K, ºC]
V	volume	[m^3]

c_p	specific heat capacity in constant pressure	[J/kgK, kJ/kgK]
h	enthalpy	[J/kg, kJ/kg]
m	mass	[kg]
n	amount of substance	[mol]
p	pressure	[Pa, bar,mmAq, atm]
p'	pressure for water vapour	[Pa, bar]
q_m	mass flow rate	[kg/s, kg/min]
q_v	volumetric flow rate	[m^3/min,m^3/s]

η	efficiency	[-]
μ	ratio of vapour molecular mass to air molecular mass	[-]
π	pressure ratio	[-]
ρ	density	[kg/m^3]
φ	relative humidity	[-]
ω_{sp}	angular speed	[1/s,1/min]
ω_{vap}	water vapour humidity	[-]

Sub-indexes

air	air
aks	axial
cr	critical
el	electro-mechanic
i	specific
in	in the intake
out	in the outtake

p	polytropic
s	isentropic
tot	total
u	universal
vap	vapour
water	water
humid air	humid air

1. INTRODUCTION

When working with turbomachinery, it is important to understand and interpret correctly the performance and the characteristic field of a compressor. Calculating a simple compression process is straightforward and the characteristic field of a compressor can be mastered with the same equations.

Different efficiencies have to be considered in the calculations and working with humid air affects the process, but it is possible to calculate the compression process a bit more accurately with small additions to the original equations.

The calculations related to the performance of a centrifugal compressor are examined in this study. The influence of air humidity in the performance of the compressor is considered as well. A characteristic field published by a compressor manufacturer, KTurbo, is calculated as an example.

1.1 A centrifugal compressor

A compressor is a piece of machinery that compresses a fluid, a liquid or a gas, that flows in the compressor into greater pressure. As the pressure of the fluid rises, the fluid flows through the compressor from lower pressure into higher pressure. Compressors working in a small pressure ratio can also be referred as blowers.

In this study, a centrifugal compressor designates a kinetic compressor working in one phase, keeping the rounding speed of the fluid mainly radial.

In a centrifugal compressor the fluid is first accelerated into a certain speed and then, as the speed of the fluid is reduced in a reversible manner, the pressure of the fluid rises. The main parts of a centrifugal compressor are presented in figure 1. The main parts are an impeller and its vanes, a suction eye, a volute casing and a discharge. (Wirzenius 1968, 52-53)

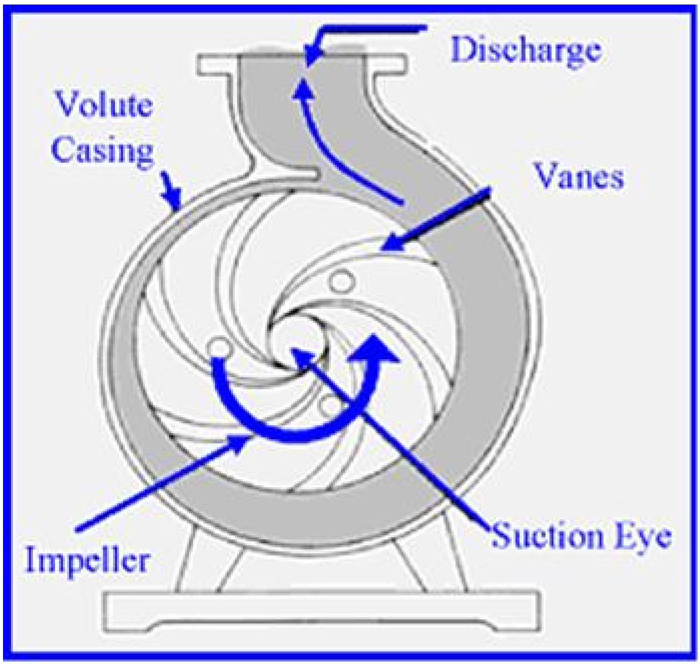

Figure 1. The parts of a centrifugal compressor [1]

1.2. The manufactures

Some manufacturers working in the field of manufacturing high-speed centrifugal compressor technology like KTurbo, the manufacturer whose compressor is calculated in this study, are Neuros, AenTL, High-Speed Tech, Atlas Copco and Piller. Siemens Turbomachinery Equipment manufactures compressors for almost all purposes.

The trend in manufacturing compressors seems to be manufacturing whole systems, where a compressor is only one part of the whole system, whose purpose is for example blowing air to an air conditioning system. The compressor itself is seldom visible for the user, because it is inside a casing, which includes a lot of other components.

Some compressor manufacturers publish the performances of their products and even characteristic fields through the Internet. A characteristic field exposes a lot of compressor data to the consumers. In this study some points of a characteristic field by the compressor manufacturer KTurbo are calculated with basic default data. The calculated data is then revised in the light of other information published by the manufacturer.

2. THE PERFORMANCE OF A CENTRIFUGAL COMPRESSOR

The performance of a compressor is a wide-ranging term indicating the accessible pressure ratio and input power of the compressor on a certain volumetric flow rate of the fluid. The performance of a centrifugal compressor is usually announced in a characteristic field, where uniform rotational speed curves are presented in pressure ratio – flowing speed plane. Calculating the performance of a centrifugal compressor begins with calculating the basic compression process of the compressor.

2.1. Primary data

To calculate the compression process of a centrifugal compressor, some primary data has to be known. First the characteristics of the fluid are needed and the pressure and temperature of the fluid in the intake must be known.

The desired pressure ratio π has to be known as well. The obtained pressure rise is dependent on the characteristics of the compressed fluid. In the calculations done in this study, the used fluid is air, and the pressure ratio is mainly between 1 and 2. Other important values are the volumetric flow rate q_{v} and either the polytropic efficiency η_{p} or the isentropic efficiency η_{s} of the compression process in the calculating point.

2.1.1. Isentropic efficiency

The isentropic efficiency expresses how much the compression process resembles an isentropic compression process. When the value of efficiency is one, the compression process is an ideal process, which has no losses. Isentropic efficiency is defined by calculating the change in specific enthalpy in the real compression process and comparing it to the change in specific enthalpy in an ideal compression process. Isentropic efficiency is calculated throughout the whole compressor system.

Isentropic efficiency for a compression process can be calculated with the equation

$$\eta_s = \frac{\overline{c}_{p,s}\left(T_{in} - T_{out,s}\right)}{\overline{c}_p\left(T_{in} - T_{out}\right)}, \tag{1}$$

where $\overline{c}_{p,s}$ is the specific heat capacity in average temperature of an ideal isentropic compression process, $T_{\text{out,s}}$ is the outtake temperature in an isentropic compression process, T_{in} is the intake temperature, $\overline{c}_p$ is the specific heat capacity in constant pressure computed in average temperature of a real compression process and T_{out} is the outtake temperature in a real compression process. (Saari J. 2001)

2.1.2. Polytropic efficiency

The polytropic efficiency expresses how much the real compression process resembles an ideal compression process, but different from isentropic efficiency, the polytropic efficiency is defined across a differential part in the system, and so calculated through the whole system. Polytropic efficiency can be calculated by assuming that in an ideal process the temperature ratio is relative to the pressure ratio according to equation

$$\frac{T_{out}}{T_{in}} = \frac{p_{out}}{p_{in}}^{\frac{R_i}{\overline{c}_p}} , \tag{2}$$

where p_{out} is the outtake pressure, p_{in} is the intake pressure and R_{i} is the specific gas constant of the fluid.

When calculating a real compression process, the polytropic efficiency is included in the equation (2) by adding it to the exponent according to the equation

$$\frac{T_{out}}{T_{in}} = \frac{p_{out}}{p_{in}}^{\frac{R_i}{\eta_p \cdot \overline{c}_p}} . \tag{3}$$

The polytropic efficiency is better for compressor comparison than the isentropic efficiency, because the value of the polytropic efficiency does not change as much as the value of the isentropic efficiency does. (Schobeiri M. 2005, 223) It is possible to have the same value of polytropic efficiency for two different compressors working in the same conditions. The greater the pressure ratio, the more the isentropic and polytropic efficiency values differ. Figure 3 presents how the isentropic efficiency changes for a compressor and a turbine in conditions, where the polytropic efficiency is constant. (Saari J. 2001)

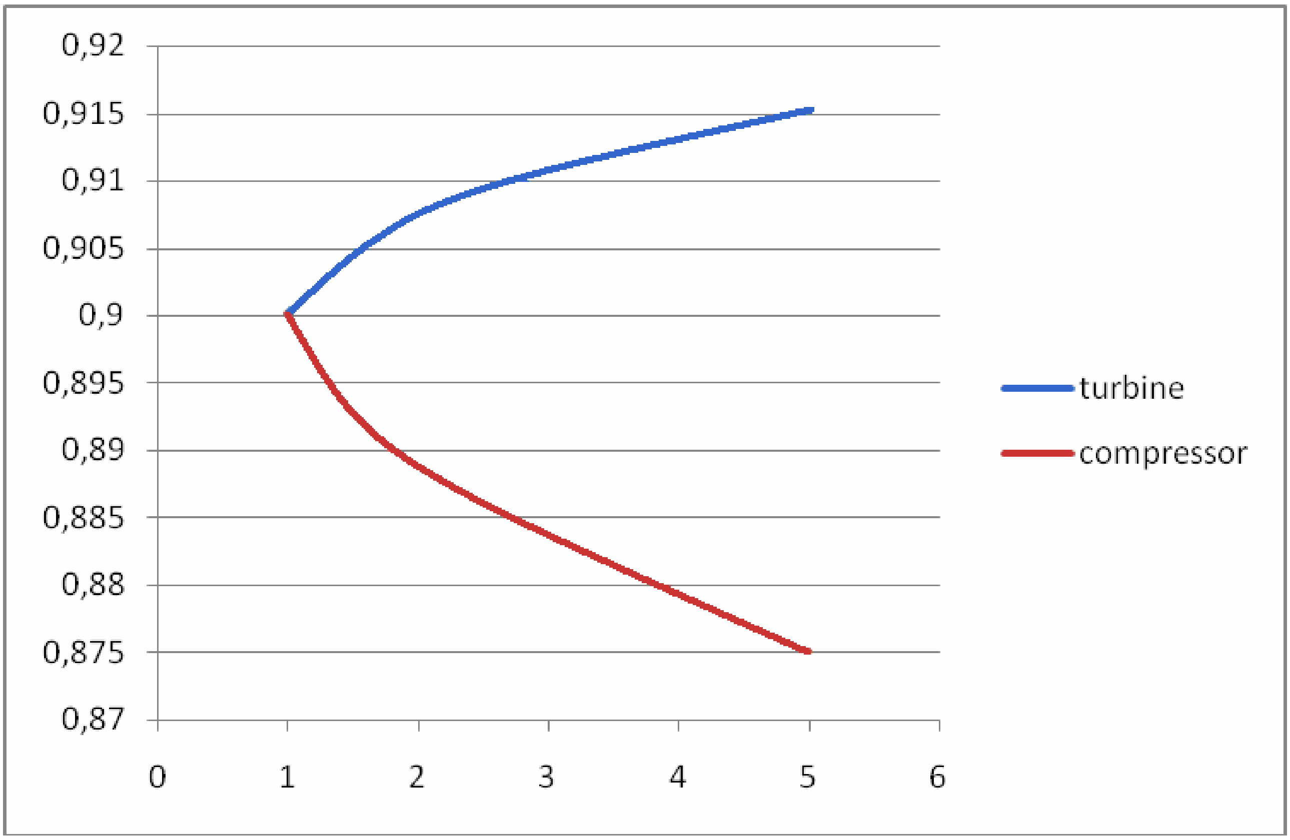

Figure3. Changes in isentropic efficiency for turbine and compressor, polytropic efficiency is constant 0,90. [2]

It seems that the compressor manufacturers often prefer the use of isentropic efficiency in their characteristic fields, because it gives a greater value to the efficiency.

2.2. The change in specific enthalpy in a real compression process

Because the equation (3) includes the pressure ratio, the equation can be expressed as

$$T_{out} = T_{in} \cdot \pi^{\frac{R_i}{\bar{c}_p \cdot \eta_p}} . \tag{4}$$

Because the specific heat capacity must be defined in the average compression temperature $\overline{T}$, which can be calculated using the equation

$$\overline{T} = \frac{T_{out} + T_{in}}{2}, \tag{5}$$

the outtake temperature must first be estimated.

When the first assumption for the outtake temperature is made, the specific heat capacity $\overline{c}_p$ can be calculated with a third degree polynomial fit

$$\overline{c}_p = a + b \cdot \overline{T} + c \cdot \overline{T}^2 + d \cdot \overline{T}^3, \tag{6}$$

where a, b, c and d are constants and they are in the region 200K $\leq T \leq$ 1800K for dry air

a = 0,982076
b = 16,4395·10 $^{-6}$
c = 22,868·10 $^{-8}$
d = -88,1495·10 $^{-12}$

and for water vapour (Backman J. 1996, 14)

a = 0,180768
b = 17,9273·10 $^{-6}$
c = 68,0617·10 $^{-8}$
d = -22,443·10 $^{-11}$.

With the calculated value of the specific heat capacity in constant pressure the outtake temperature can be calculated more carefully. The average compression temperature has to be also recalculated with the new outtake temperature, and the whole process of defining the outtake temperature should be repeated long enough so that the estimateed outtake temperature is the same as the outtake temperature given by the calculations in desired accuracy.

The change in specific enthalpy Δh can be calculated with the equation (Saari J. 2001)

$$\Delta h = \overline{c}_p \cdot \left(T_{out} - T_{in} \right). \tag{7}$$

2.3 The axial power need

The mass flow q_m of the fluid at the intake can be determined with the volumetric flow rate q_v and density of the fluid ρ at the intake according to the equation

$$q_m = q_v \cdot \rho \,. \tag{8}$$

The pressure of the fluid can be determined in the intake of the compressor, where the thermodynamic equation of state of a perfect gas can be used

$$p = \frac{n \cdot R_u \cdot T_{in}}{V}, \tag{9}$$

where n is the amount of substance of the fluid, V is the volume of the fluid in the intake and R_u is the universal gas constant, which has the value 8,31451 J/mol K.

Density can be determined with the equation

$$\rho = \frac{m}{V}, \tag{10}$$

where m is mass and V is volume.

The amount of substance n can be determined as

$$n = \frac{m}{M}, \tag{11}$$

where m is the mass and M is the molecular mass of the fluid

A specific gas constant R_i is determined as

$$R_i = \frac{R_u}{M}, \tag{12}$$

where R_u is the universal gas constant and M is the molecular mass of the fluid.

After processing the thermodynamic state equation of a perfect gas (9) and including the equations (10), (11) and (12) into it, equation for the density of the fluid can be determined as the equation

$$\rho = \frac{p_{in}}{R_i \cdot T_{in}}. \tag{13}$$

To calculate the axial power need of the compressor P_{aks} can be calculated using the equation

$$P_{aks} = q_m \cdot \Delta h. \tag{14}$$

2.4 Electromechanical efficiency and total efficiency

If the total power need P_{tot} is known for the compressor in some point, the electromechanical efficiency η_{el} can be determined for the compressor in that point with the equation

$$\eta_{el} = \frac{P_{aks}}{P_{tot}}. \tag{15}$$

When the electromechanical efficiency is determined for the compressor, the total efficiency η_{tot} can be determined as well. Total efficiency can be calculated with the equation

$$\eta_{tot} = \eta_{el} \cdot \eta_s. \tag{16}$$

2.5 The Change of specific enthalpy in an isentropic compression process

The compression process must be calculated with the isentropic efficiency as well as with the polytropic efficiency, so that the rotational speed of the compressor could be calculated.

First, one has to estimate, what the outtake temperature would be if the compression process was ideal. The temperature rises somewhat, but the outtake temperature is lower after an ideal compression than the temperature after a real compression process.
The average temperature between the intake temperature and the estimated isentropic outtake temperature can be calculated with the equation (5), and the specific heat capacity in the average temperature of the isentropic compression can be calculated with the equation (6).

Because an ideal isentropic compression gives the value 1 to both polytropic and isentropic efficiencies, the temperature in the outtake of an isentropic compression can be calculated with the equation (4), where the polytropic efficiency has the value 1.

The calculated isentropic outtake temperature is the second estimated temperature and the calculating process of defining the isentropic outtake temperature should be repeated long enough so that the estimated temperature is the same as the calculated isentropic outtake temperature in desired accuracy.

The change of specific enthalpy in an ideal isentropic compression process Δh_s can be calculated with the equation (7). The isentropic efficiency can be calculated with the equation

$$\eta_s = \frac{\Delta h_s}{\Delta h} . \tag{17}$$

2.6 The rotational speed

To calculate the rotational speed as correctly as possible, the first set of calculations should be done in the design point, where the relative speed is 1 and the efficiency of the rotational movement is usually at its best.

The specific speed N_s for a centrifugal compressor is in the design point in between 0,6 and 1,0. In this study, the calculations have been made with the specific speed N_s being 0,8 in the design point (Wirzenius A. 1978, 120).

Angular speed ω_{sp} for a centrifugal compressor can be calculated with the equation (Wirzenius A. 1978, 86).

$$\omega_{sp} = \frac{N_s \cdot \Delta h_s^{\,0,75}}{q_v^{\,0,5}}. \tag{18}$$

The angular speed is the speed at which a rotationally symmetric solid turns one unit. The angular speed can be turned into rotational speed dividing it with a whole revolution (Wirzenius A. 1968, 85-86).

The rotational speed in other points can be calculated by multiplying the rotational speed of the design point with the relative speed in the desired point.

3. THE INFLUENCE OF AIR HUMIDITY TO THE CALCULATIONS

The calculations in this study are made considering the compressed fluid to be air, but the effects of air humidity have to be considered as well. Humid air can be considered to be a mixture of dry air and water vapour. In this study the water vapour is assumed to be near liquefying and humid air is treated as a perfect gas. Air humidity influences the values of air molecular mass, the specific gas constant of air and the specific heat capacity of air.

3.1 Relative humidity

The amount of water vapour in air is defined by the pressure of the vapour in the air. The pressure of the vapour in the air can not be greater than the pressure of saturated water vapour, otherwise the water is in liquid or solid state. Relative humidity states the relation between the pressure of the water vapour in the air and the pressure of saturated water vapour (Backman J. 1996, 9).

$$\varphi = \frac{p_{vap}}{p'_{vap}}, \tag{19}$$

where p_{vap} is the water vapour pressure in the air, p'_{vap} is the pressure of the saturated water vapour and φ is the relative humidity.

The equation for water vapour humidity is (Backman J. 1996,12)

$$\omega_{vap} = \mu \frac{p'_{vap}}{\frac{p}{\varphi} \cdot p'_{vap}}, \tag{20}$$

where $\mu = M_{\mathrm{water}}/M_{\mathrm{air.}}$

The water vapour pressure is expressed with a regressional exponential correlation for the region $273.16\ \mathrm{K} \leq T \leq 647.14\ \mathrm{K}$

$$p'_{vap}(T) = p_{cr} \cdot e^{\left[T_{cr}/T(a_1\tau + a_2\tau^{1.5} + a_3\tau^3 + a_4\tau^{3.5} + a_5\tau^4 + a_6\tau^{7.5}\right]}, \tag{21}$$

where $\tau = 1\text{-}T/T_{\mathrm{cr}}$, $p_{\mathrm{cr}} = 220.64\mathrm{bar}$ and $T_{\mathrm{cr}} = 647.14$ K and the constants are

$a_1 = -7.85823$
$a_2 = 1.83991$
$a_3 = -11.7811$
$a_4 = 22.6705$
$a_5 = -15.9393$
$a_6 = 1.77516$

3.2 The influence of air humidity to the gas constant and the specific heat capacity

After calculating the water vapour humidity, the molecular mass and gas constant can be calculated for the air-water vapour mixture.

The molecular mass for air-water vapour mixture M can be calculated with the equation

$$M = \frac{1}{\omega_{vap} + \mu}(\mu M_{air} + \omega_{vap} M_{vap})\,. \tag{22}$$

The gas constant for humid air can be calculated with the equation (12) where the molecular mass *M* is now the molecular mass of air- water vapour mixture. (Backman J. 1996, 13)

The specific heat capacity for water vapour can be calculated with the equation (6) using the constants for water vapour. The mole fraction of water vapour in the humid air can be calculated with the equation

$$x_{vap} = \frac{p_{vap}}{p}\,. \tag{23}$$

With the mole fraction of water vapour in humid air, the specific heat capacity for humid air can be calculated with the equation

$$\overline{c}_{p,humid\ air} = x_{vap} \cdot \overline{c}_{p,vap} + (1 - x_{vap}) \cdot \overline{c}_{p,air}\,. \tag{24}$$

4. THE CHARACTERISTIC FIELD OF A RADIAL COMPRESSOR

A compressor is seldom used in only one pressure ratio and volumetric flow rate. It is important to be able to regulate both the intake and the outtake of a compressor. The most common way to express the performance of a compressor in changing circumstances is to use a characteristic field.

A characteristic field can be executed in either relative or qualitative way, but they both can be calculated with the same equations. The values given in a characteristic field are measured by using the compressor in sufficient amount of points, that all curves can be calculated with good accuracy.

4.1 Relative characteristic field

In a relative characteristic field the best working conditions are found in the design point. All other volumetric flow rates, speeds and pressure ratios of the compressor are defined relatively to the values measured in the design point. In a relative characteristic field there are uniform speed ratio curves in a relative pressure ratio, relative flow rate –plane (Larjola J. 1988, 45).

When the conditions in the design point are known, all the points in the characteristic field can be calculated by multiplying the values with the ratios given in the characteristic field. Figure 4 gives an example of a relative characteristic field.

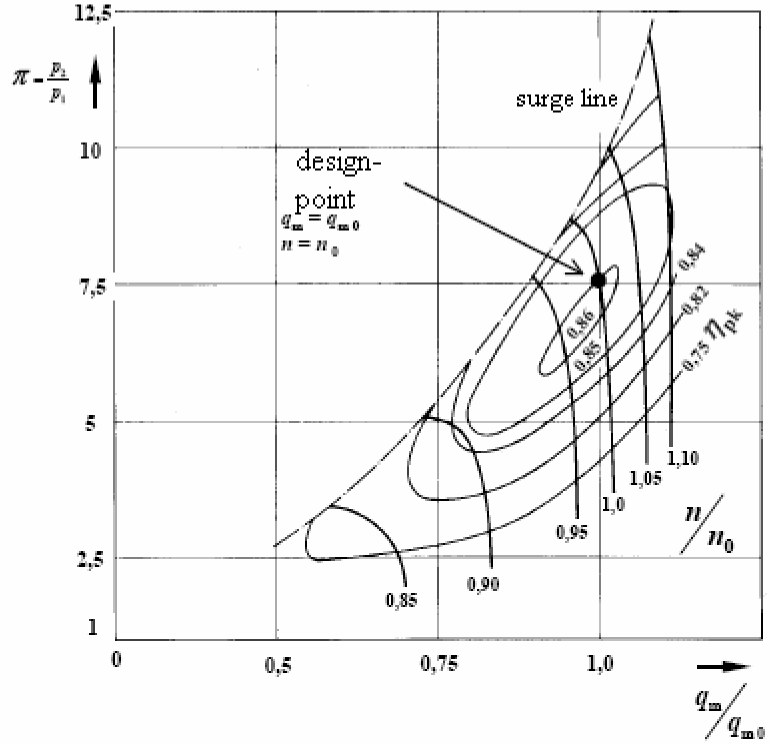

Figure4. Example of a relative characteristic field [3]

4.1.1 Coordinates

The coordinates in a relative characteristic field are relative volumetric flow rate on the x-axis and relative pressure ratio on the y-axis. Both of the coordinates have the value 1 in the design point.

Pressure ratio in a selected point can be calculated by multiplying the pressure ratio in the design point with the relative pressure ratio in the selected point. With a similar multiplication the volumetric flow rate in a desired point can be calculated (Larjola J.1988, 45).

4.1.2 Speed curves

Speed curves are curves of uniform speed in the characteristic field. In a relative characteristic field, the speeds are given as relative speeds, where the relative speed in the design point has the value 1.

A compressor can be regulated by adjusting the rotational speed of the compressor (the rotational speed of the electric motor). The speed curves give the most important data in the characteristic field, because they show at which rounding speed the desired output conditions can be attained (Larjola J. 1988, 45).

4.1.3 Efficiency curves

Efficiency curves are given as the values of efficiency. Depending on the purpose of the characteristic field, the efficiency can be given as isentropic efficiency, polytropic efficiency or total efficiency in some cases there are no efficiency curves in the characteristic field.

Isentropic and polytropic efficiency curves look similar in a characteristic field, but isentropic efficiency gives greater values of efficiency.

Total efficiency curves seem a bit different from isentropic and polytropic efficiency curves, but when making the measurements for a characteristic field of a compressor, total efficiency levels with the shortest running time, so they are sometimes the most correct.

4.1.4 Other curves

A characteristic field may include a range of other curves as well. These other curves give information like relative power need or relative axial power. All the other information given in the characteristic field can be calculated with the basic values given in the characteristic field separately, but for the user of the characteristic field it is useful to get all needed information straight from the characteristic field.

4.1.5 Surge line

Surge line is a line, approximately perpendicular to the speed curves, on the left side of a characteristic field in the characteristic fields presented in this study.

When a compressor is used with too small volumetric flow rate and too high pressure ratio, surge immerses. In the design point the flow of the fluid follows the blades of the impeller in the designed, efficient way. However outside the design point the flow is not as efficient, and when the flow brakes off the blades, it is called surge. In compressors surge can reverse a flow. If surge lasts for a long time, it may cause serious damage to the compressor, mainly to the impeller blades. (Airila 1983, 37)

4.1.6 Choking line

Choking line is approximately aligned with the surge line, but on the right side of the characteristic fields presented in this study.

Choking is a phenomenon which happens when flowing speed reaches the value of the speed of sound in either the intake or the outtake of the compressor. In practice, choking means that although the pressure ratio changes for smaller, the volumetric flow rate does not grow (Larjola J.1988, 48). In the characteristic field for the compressor TB150-0.8S provided by KTurbo there is not a choking line, but on the right side of the characteristic field the restricting line is the overheat line.

4.2 Qualitative characteristic field

A qualitative characteristic field is similar to a relative characteristic field, with the one difference that the values in a qualitative characteristic field are given as the real values itself, not relative to the values of the design point.

Most characteristic fields however include elements of both, relative and qualitative characteristic fields. In example the coordinates can be given qualitatively and speed curves relatively. This method has been used in the characteristic fields provided by KTurbo calculated in this study.

5. REVIEWING AN EXAMPLE OF CHARACTERISTIC FIELDS

To receive a full figure of the usage and practicality of a characteristic field, a characteristic field by KTurbo has been calculated in this study.

The revised characteristic field is a characteristic field of a turbo blower TB150-0.8S from KTurbo. The axial power in the KTurbo compressors of the 150 serie is 150 hp (KTurbo 2008).

5.1 Primary data

In the characteristic field of compressor TB150-0.8S, the outtake pressure was calculated with gauge pressure, which was given in millimetres of water. This unit can be changed into Pascals with equation

$$p = g \cdot \rho \cdot h \, , \tag{25}$$

where p is the gauge pressure in Pascals, g is the acceleration of gravity, ρ is the density of water and h is the height of water.

The density of water in 20 ºC temperature is 998,2071kg/m^3(Water density calculator). The outtake pressure was then calculated by summing the intake pressure and the gauge pressure together.

Other primary information are the volumetric flow rate, the state of air (pressure, temperature and relative humidity) in the intake and the maximum electromechanical efficiency of 95% and the actual characteristic fields (KTurbo. 2008). The efficiency given in the characteristic field was first assumed to be the isentropic efficiency, because it is commonly used among compressor manufacturers. Figure 5 presents the characteristic field of the KTurbo compressor 150-0.8S.

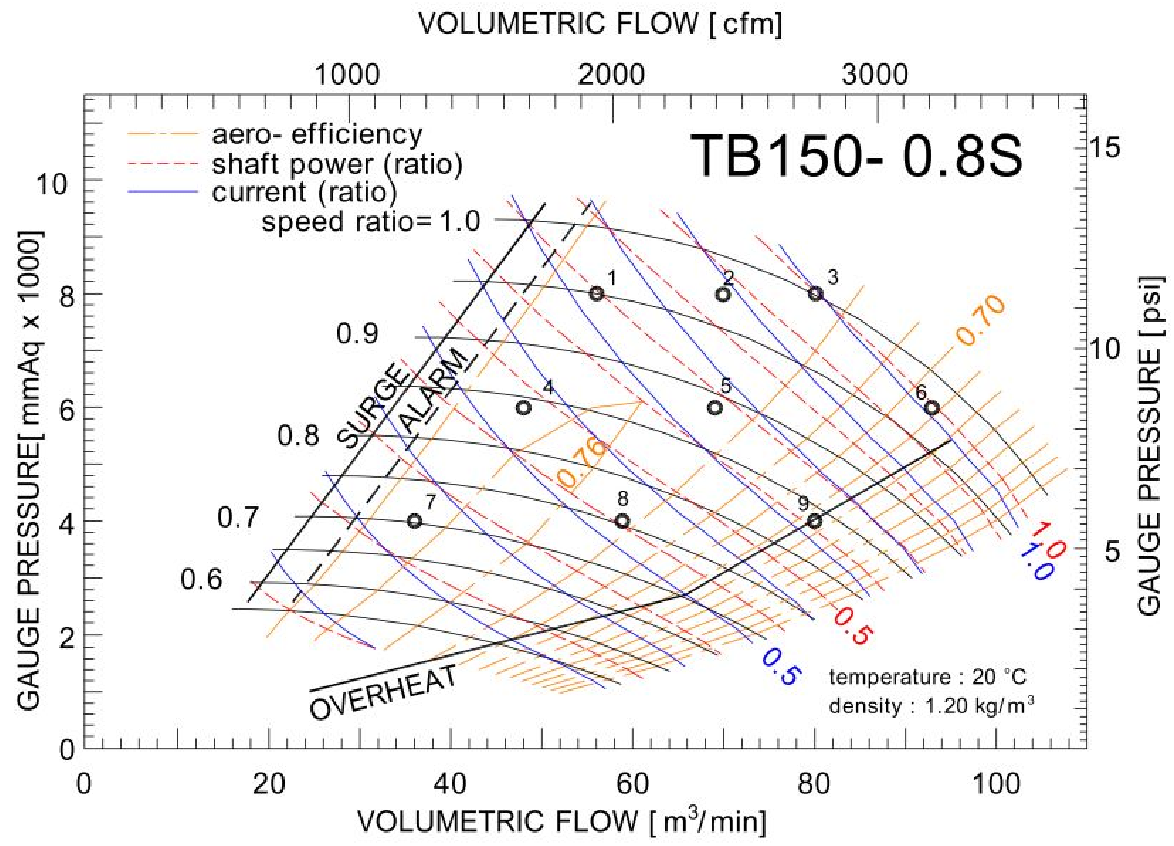

Figure5. The characteristic field of KTurbo compressor TB150-0.8S [4]

The rotational speed in the characteristic field was given as relative speed. According to this, the calculations in this study were first made in the design point, and the other speeds were calculated by multiplying them with the relative speed.

The design point was a point, where the volumetric flow was 80m^3/min and the outtake pressure was 8000mmAq (KTurbo 2008). In the characteristic field this point is referred as point 3 (figure 5).

5.2 Data points in the characteristic field

The data points in the characteristic fields, in which the calculations were made, were chosen from every other constant speed curve, beginning with relative speed 0.6 and ending with rotational speed 1.0. The points were chosen ranging from the choking line up to the surge line.

The data points were mostly chosen in places, where the constant speed curves meet the efficiency curves, to get minimum inaccuracy to the calculations. When the efficiency curves were too far apart, the points were chosen aligned with the given efficiency curves. Figure 6 presents the chosen points in the characteristic field of the KTurbo compressor 150-0.8S, a cross marks a calculated point.

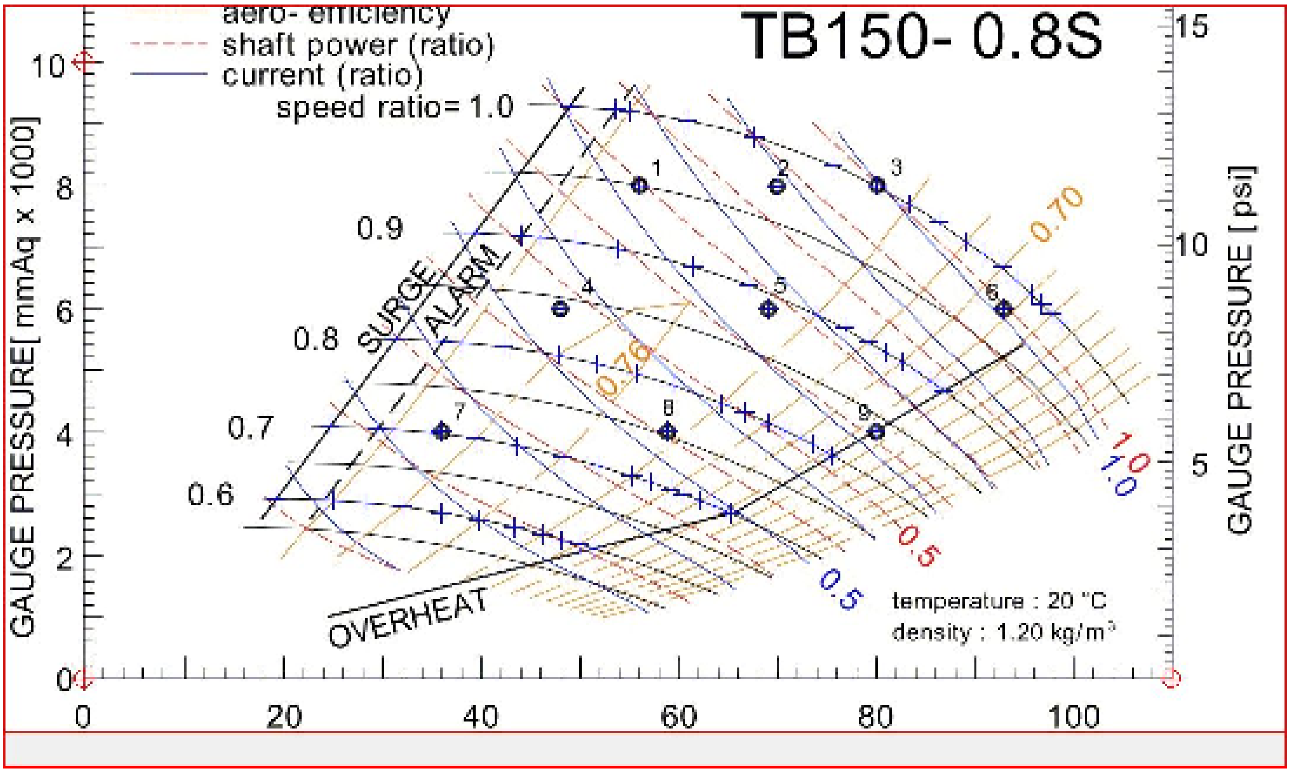

Figure6. The chosen data points in the characteristic field of compressor TB150-0.8S. [5]

Values for volumetric flow rate, gauge pressure, relative speed and isentropic efficiency were determined for every data point from the characteristic field.

Values of total efficiency, total power need, gauge pressure and the volumetric flow rate in 9 points of the characteristic field (marked separately with numbers in figure 6) were known as well (KTurbo, 2008). The given 9 points were calculated as well as other chosen points.

Further in this study these 9 points, of which most specific information is available, are calculated as an example. The calculation in other points, which is executed with the same equations are presented in appendice1.

The primary data for the calculated 9 points is presented in table 1.

Table 1. Primary data for 9 points in the characteristic field of the compressor TB150-0.8S

	T_{in} [K]	p_{in} [Pa]	ρ_{water} [kg/m3]	p_{gauge} [mmAqx1000]	p_{out} [Pa]	η_s [-]	RH [%]	q_v [m^3/min]	q_v [m^3/s]
1	293,15	101325,00	998,21	8	179664,3	0,7455	36,00	56,1297	0,94
2	293,15	101325,00	998,21	7,98095	179477,7	0,7470	36,00	70,0432	1,17
3	293,15	101325,00	998,21	8	179664,3	0,7455	36,00	80,1514	1,34
4	293,15	101325,00	998,21	6	160079,5	0,7510	36,00	48,1622	0,80
5	293,15	101325,00	998,21	6	160079,5	0,7450	36,00	69,2108	1,15
6	293,15	101325,00	998,21	6	160079,5	0,6850	36,00	92,9946	1,55
7	293,15	101325,00	998,21	4,01905	140681,2	0,7510	36,00	36,1514	0,60
8	293,15	101325,00	998,21	4,01905	140681,2	0,7440	36,00	58,9838	0,98
9	293,15	101325,00	998,21	4,01905	140681,2	0,6700	36,00	80,0324	1,33

5.3 The calculations

The compression process is calculated in the selected points according to chapters 2 and 3.

5.3.1 Air humidity

To take into account the affects of humid air, first the changes that air humidity causes to the molecular mass and to the specific gas constant have to be calculated. The water vapour pressure was determined in the intake temperature according to the equation (21). As the relative air humidity was known, the water vapour humidity could be calculated with the equation (20).

The molecular masses for water and air were determined from a molecular mass table. The value used for air molecular mass is in this study 0,028964 kg/mol and for water 0,01801534 kg/mol. The molecular mass for humid air could be now calculated according to the equation (22).

The specific gas constant was calculated according to the equation (12).

Table 2. The calculated values for water vapour pressure, molecular masses and gas constants.

	T_{in}	p_{in}	p'_{vap} (T_{in})	μ	ω_{vap}	M_{water}	M_{air}	$M_{humid\ air}$	R_u	R_i
	[K]	[Pa]	[Pa]	-	-	[kg/mol]	[kg/mol]	[kg/mol]	[J/mol K]	[J/kg K]
1	293,2	101325,00	2338,49	0,622	0,005	0,018	0,029	0,029	8,315	287,968
2	293,2	101325,00	2338,49	0,622	0,005	0,018	0,029	0,029	8,315	287,968
3	293,2	101325,00	2338,49	0,622	0,005	0,018	0,029	0,029	8,315	287,968
4	293,2	101325,00	2338,49	0,622	0,005	0,018	0,029	0,029	8,315	287,968
5	293,2	101325,00	2338,49	0,622	0,005	0,018	0,029	0,029	8,315	287,968
6	293,2	101325,00	2338,49	0,622	0,005	0,018	0,029	0,029	8,315	287,968
7	293,2	101325,00	2338,49	0,622	0,005	0,018	0,029	0,029	8,315	287,968
8	293,2	101325,00	2338,49	0,622	0,005	0,018	0,029	0,029	8,315	287,968
9	293,2	101325,00	2338,49	0,622	0,005	0,018	0,029	0,029	8,315	287,968

5.3.2 The polytropic efficiency and the compression process

The polytropic efficiency was estimated for every point at first. The polytropic efficiency was estimated to be smaller than the isentropic efficiency in all of the calculated points. The outtake temperature had to be estimated as well.

The average temperature was then calculated according to the equation (5). The mole fraction of water vapour in the humid air was calculated according to the equation (23). The specific heat capacity in constant pressure in the average temperature was determined according to the equation (6) for dry air and water vapour and the specific heat capacity in constant pressure and average temperature for humid air was calculated according to the equation (24).

The outtake temperature was then calculated with the estimated value for the polytropic efficiency according to the equation (4). The calculation process was then repeated to get an accurate value for the outtake temperature.

The change in the specific enthalpy during the compression process was then determined according to the equation (7).

Table 3. The calculated values for the specific heat capacity in constant pressure and average temperature, the outtake temperature and the change in specific enthalpy.

	T_{in}	η_p	x_{vap}	$T_{2,estimated}$	T_{aver}	$c_{p,aver,air}$	$c_{p,aver,vap}$	$c_{p,aver,humid\ air}$	T_2	Δh
	[K]	[-]	-	[K]	[K]	[kJ/kg K]	[kJ/kg K]	[kJ/kg K]	[K]	[kJ/kg]
1	293,15	0,767	0,008	362,293	327,721	1,009	1,879	1,016	362,293	70,238
2	293,15	0,766	0,008	362,204	327,677	1,009	1,879	1,016	362,204	70,148
3	293,15	0,765	0,008	362,472	327,811	1,009	1,879	1,016	362,472	70,422
4	293,15	0,766	0,008	347,248	320,199	1,008	1,876	1,015	347,248	54,899
5	293,15	0,761	0,008	347,679	320,414	1,008	1,876	1,015	347,679	55,339
6	293,15	0,704	0,008	352,436	322,793	1,008	1,877	1,015	352,436	60,185
7	293,15	0,762	0,008	331,288	312,219	1,007	1,873	1,014	331,288	38,662
8	293,15	0,756	0,008	331,646	312,398	1,007	1,873	1,014	331,646	39,026
9	293,15	0,685	0,008	335,885	314,518	1,007	1,874	1,014	335,885	43,336

5.3.3 The isentropic efficiency and the compression process

As the efficiency was alleged to be the isentropic efficiency, the compression process had to be calculated with the isentropic efficiency as well.

The outtake temperature for an ideal, isentropic compression process has to be estimated. With the outtake temperature the average temperature could be calculated according to the equation (5). The specific heat capacity in the average temperature was determined according to the equation (6) for dry air and water vapour. The specific heat capacity for humid air was calculated according to the equation (24). The real outtake temperature was then calculated according to the equation (4) with the polytropic efficiency of value 1.

The isentropic outtake temperature calculation process was repeated to get an accurate value for the outtake temperature in an ideal isentropic process. The change in specific enthalpy in isentropic process was determined according to the equation (7) with the values calculated for ideal isentropic compression process. The isentropic efficiency was then determined according to the equation (17).

The whole process of calculating the compression process from polytropic and isentropic point of view had to be repeated so that the calculated isentropic efficiency received the same value as the isentropic efficiency determined from the characteristic field.

Table 4. The calculated values for the specific heat capacity in constant pressure and average temperature, the outtake temperature, the change in specific enthalpy for an ideal, isentropic compression process, and the isentropic efficiency.

	T_{in}	$T_{s,estimated}$	$T_{s,aver}$	$c_{p,s,aver,air}$	$c_{p,s,aver,vap}$	$c_{p,s,aver,humid\ air}$	T_{2s}	Δh_s	η_s
	[K]	[K]	[K]	[J/kg K]	[J/kg K]	[J/kg K]	[K]	[kJ/kg]	[-]
1	293,15	344,893	319,021	1,007	1,879	1,015	344,893	52,502	0,7475
2	293,15	344,791	318,971	1,007	1,879	1,015	344,791	52,399	0,7470
3	293,15	344,893	319,021	1,007	1,879	1,015	344,893	52,502	0,7455
4	293,15	333,811	313,480	1,007	1,876	1,014	333,811	41,227	0,7510
5	293,15	333,810	313,480	1,007	1,876	1,014	333,810	41,227	0,7450
6	293,15	333,810	313,480	1,007	1,877	1,014	333,810	41,227	0,6850
7	293,15	321,810	307,480	1,006	1,873	1,013	321,810	29,036	0,7510
8	293,15	321,810	307,480	1,006	1,873	1,013	321,810	29,036	0,7440
9	293,15	321,810	307,480	1,006	1,874	1,013	321,810	29,036	0,6700

5.3.4 The axial power need and the rotational speed

The density of humid air was calculated according to the equation (13). The mass flow could be determined according to the equation (8). The axial power need was calculated according to the equation (14).

The angular speed was calculated in the design point according to the equation (18), where the value 0.8 is used for the specific speed. The angular speed was changed into rotational speed by dividing it with the whole circle (2π). In other points the rotational speed was calculated by multiplying it with the value of relative speed.

5.3.5 Total efficiency, electromechanical efficiency and total power need

As the values for total efficiency were known in only the 9 points calculated here, the electromechanical efficiency and total power need could only be determined accurately in those 9 points.

The electromechanical efficiency was calculated according to the equation (16), and the total power need was calculated according to the equation (15).

Table 5. The values for axial power need, electromechanical efficiency, total power need, angular rotational speed, relative speed, rotational speed and total efficiency.

	P_{aks}	η_{el}	P_{el}	ω_{sp}	relative speed	N	η_{tot}
	[kW]	-	[kW]	[1/s]	[-]	[rpm]	
1	78,868	0,866	91,117	19,1574	0,95	21779,08638	0,647
2	98,291	0,912	107,814	17,4847	0,97	22237,59346	0,681
3	112,914	0,917	123,074	2400,74	1	22925,35409	0,684
4	52,894	0,874	60,550	14,5277	0,845	19371,9242	0,656
5	76,618	0,925	82,845	13,4066	0,885	20288,93837	0,689
6	111,964	0,978	114,471	12,6766	0,97	22237,59346	0,67
7	27,960	0,865	32,306	11,2801	0,7	16047,74786	0,65
8	46,049	0,933	49,367	9,52485	0,755	17308,64233	0,694
9	69,381	0,988	70,222	9,09754	0,84	19257,29743	0,662

5.4 The results

As the total power need was given in 9 points of the characteristic field, and the axial power need could be calculated in those points, some kind of relation for the electromechanical efficiency can ve attempted to determine.

The 9 points by the manufacturer however were not enough to give any kind of reliable relation to the electrical efficiency. As the axial power was calculated with the efficiency in the characteristic field assumed as isentropic efficiency, the axial power became too high in some of the given points. This lead to calculations giving electrical efficiency values up to 98,8%. Had the efficiency in the characteristic fields been the polytropic efficiency, the electric efficiency would have received even greater values. The electromechanical efficiency did not respond enough to changing the primary values, so that even when the inaccuracy of choosing data points and calculations was readjusted, the value of electric efficiency became too great.

The total efficiency and the total power need in those 9 calculated points seem reasonable (KTurbo 2008). As the calculations did not meet the given values, the accuracy of the characteristic field had to be questioned.

When a characteristic field is measured for a compressor, it takes a relatively long time for the efficiencies to settle in different points, and close to the choking line and surge line it might cause problems to run the compressor long enough. However the value of total efficiency settles relatively fast compared to the other efficiencies. When assumed that the total efficiency data is the most accurate in the characteristic field for compressor TB150-0.8S, too few reliable values remain to base more calculation and presumptions on.

The calculations in this study were made with Microsoft Excel –a spreadsheet software.

6. SUMMARY

The facts presented in this study, help to understand and interpret the values and curves given in a compressor's characteristic fields. The curves in the characteristic field are results from delicate measurements, which are often affected by the phenomena that occur when the compressor is used near its constraint function values.

The characteristic fields are both informative and useful for anyone who has to work with compressors. However, the information received from a characteristic field should be regarded with a reservation.

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Appendix1. Exemplary calculations

The complete calculations made in the point 1 in the characteristic field of the compressor TB150-0.8S are presented in this appendice.

The height of water can be changed into Pascals with the equation (25):

$$p = g \cdot \rho \cdot h = 9{,}81\frac{m}{s} \cdot 998{,}2071\frac{\mathrm{kg}}{\mathrm{m}^3} \cdot 8\, mmAq \cdot 1000 = 78339{,}29Pa$$

The outtake pressure can be calculated by summing together the intake pressure and the gauge pressure:

$$p_{out} = p_{in} + p_{gauge} = 101325{,}0\, Pa + 78339{,}29Pa = 179664{,}29Pa$$

The water vapour pressure can be determined in the intake pressure according to the equation (21):

$$\begin{aligned} p'_{vap}(T) &= p_{cr} \cdot e^{\left[T_{cr}/T(a_1\tau + a_2\tau^{1.5} + a_3\tau^3 + a_4\tau^{3.5} + a_5\tau^4 + a_6\tau^{7.5}\right]} \\ &= 22064000Pa \cdot e^{\left[\begin{array}{l} 647{,}14K/293{,}15K(-7{,}85823\cdot(1-\frac{293{,}15K}{647{,}140K}) + 1{,}83991\cdot(1-\frac{293{,}15K}{647{,}140K})^{1{,}5} - 11{,}7811\cdot(1-\frac{293{,}15K}{647{,}140K})^3 \\ +22{,}6705\cdot(1-\frac{293{,}15K}{647{,}140K})^{3{,}5} - 15{,}9393\cdot(1-\frac{293{,}15K}{647{,}140K})^4 + 1{,}77516\cdot(1-\frac{293{,}15K}{647{,}140K})^{7{,}5} \end{array}\right]} \\ &= 2338{,}49Pa \end{aligned}$$

The water vapour humidity can be calculated with the equation (22):

$$\omega_{vap} = \mu \frac{p'_{vap}}{\frac{p}{\varphi} \cdot p'_{vap}} = \frac{0{,}01801534kg/mol}{0{,}028964kg/mol} \cdot \frac{2338{,}49Pa}{\frac{101325Pa}{0{,}36} - 2338{,}49Pa} = 0{,}005$$

The molecular mass for humid air can be calculated with the equation (22):

$$M = \frac{1}{\omega_{vap} + \mu}(\mu M_{air} + \omega_{vap} M_{vap}) = \frac{1}{0,005 + 0,622}(0,622 \cdot 0,028964 kg/mol + 0,005 \cdot 0,01801534 kg/mol)$$
$$= 0,028877 mol/kg$$

The specific gas constant can be calculated for humid air with the equation (12):

$$R_i = \frac{R_u}{M} = \frac{8,31451 J/molK}{0,028877 kg/mol} = 287,928 J/kgK$$

If the outtake temperature is guessed to be 362K, the average temperature can be calculated with the equation (5):

$$\overline{T} = \frac{T_{out} + T_{in}}{2} = \frac{362K + 293,15K}{2} = 327,575K$$

The specific heat capacity $\overline{c}_p$ for dry air can be calculated with the equation (6):

$$\overline{c}_{p,air} = a + b \cdot \overline{T} + c \cdot \overline{T}^2 + d \cdot \overline{T}^3 = 0,982076 + 16,4395 \cdot 10^{-6} \cdot 327,575K + 22,868 \cdot 10^{-8} \cdot (327,575K)^2$$
$$-88,1495 \cdot 10^{-12} \cdot (327,575K)^3 = 1,008895 kJ/kgK$$

The mole fraction of water vapour can be calculated with the equation (23):

$$x_{vap} = \frac{p_{vap}}{p} = \frac{\varphi \cdot p'_{vap}}{p_{in}} = \frac{0,36 \cdot 2338,49 Pa}{101325,00 Pa} = 0,008$$

The specific heat capacity for humid air can be calculated with the equation (24):

$$\overline{c}_{p,humid\ air} = x_{vap} \cdot \overline{c}_{p,vap} + (1 - x_{vap}) \cdot \overline{c}_{p,air} = 0,008 \cdot 1,879 \frac{kJ}{kg \cdot K} + (1 - 0,008) \cdot 1,009 \frac{kJ}{kg \cdot K} = 1,016 \frac{kJ}{kg \cdot K}$$

The outtake temperature can be calculated with the equation (4):

$$T_{out} = T_{in} \cdot \pi^{\frac{R_i}{\bar{c}_p \cdot \eta_p}} = 293,15K \cdot 1,7731^{\frac{0,287928 kJ/kgK}{1,016 kJ/kgK \cdot 0,765}} = 362,472K$$

The average temperature is calculated again with the estimated value now being 332,195K. These three equations are calculated again for as long as the estimated temperature and the calculated temperature are the same with desired accuracy.

The change in specific enthalpy can be calculated with the equation (7):

$$\Delta h = \bar{c}_p \cdot \left(T_{out} - T_{in}\right) = 1,016 kJ/kgK \cdot (362,472K - 293,15K) = 70,422 kJ/kg$$

If the estimated outtake temperature in an ideal, isentropic process is 362K, the average temperature is 327,575K and the specific heat capacity is 1,015kJ/kgK.

The outtake temperature in an ideal, isentropic process can be calculated with the equation (4), where the value of the polytropic efficiency is 1:

$$T_{out} = T_{in} \cdot \pi^{\frac{R_i \cdot \eta_p}{\bar{c}_p}} = 293,15K \cdot 1,7731^{\frac{0,287928 kJ/kgK}{1,015 kJ/kgK \cdot 1}} = 344,893K$$

The value for the change in specific enthalpy will be 52,502kJ/kg when calculated with the equation (7).

The isentropic efficiency can be calculated with the equation (17):

$$\eta_s = \frac{\Delta h_s}{\Delta h} = \frac{52,502 kJ/kg}{70,422 kJ/kg} = 0,7455$$

These calculations should be repeated for as long as the isentropic efficiency receives the value that it has in the characteristic field.

The density of humid air can be calculated with the equation (13):

$$\rho = \frac{p_{in}}{R_i \cdot T_{in}} = \frac{101325,0 Pa}{0,287928 kJ/kgK \cdot 293,15 K} = 1,200 kg/m^3$$

The mass flow can be calculated with the equation (8):

$$q_m = q_v \cdot \rho = 0,94 m^3/s \cdot 1,200 kg/m^3 = 1,1284 kg/s$$

The axial power need can be calculated with the equation (14):

$$P_{aks} = q_m \cdot \Delta h = 1,1284 kg/s \cdot 70,422 kJ/kg = 79,074 kW$$

The angular speed in the design point was calculated with the equation (18):

$$\omega_{sp} = \frac{N_s \cdot \Delta h_s^{\ 0,75}}{q_v^{\ 0,5}} = \frac{0,8 \cdot (52502 J/kg)^{0,75}}{(1,34 m^3/s)^{0,5}} = 2400,737\ 1/s$$

The angular speed is turned into rotational speed by dividing it with the whole circle:

$$N = \omega_{sp} \cdot \frac{60 min/s}{2 \cdot \pi} = 2400,737\ 1/s \cdot \frac{60 min/s}{2 \cdot \pi} = 22925 rpm$$

The rotational speed in point 1 is calculated by multiplying the rotational speed in the design point with the relative speed in point 1:

$$N_1 = 0,95 \cdot 22944 rpm \approx 21800 rpm$$

Electro-mechanical efficiency is calculated with the equation (16):

$$\eta_{tot} = \eta_{el} \cdot \eta_s \Leftrightarrow \eta_{el} = \frac{\eta_{tot}}{\eta_s} = \frac{0,647}{0,7455} = 0,868$$

The total power need can be calculated with the equation (15):

$$\eta_{el} = \frac{P_{aks}}{P_{tot}} \Leftrightarrow P_{tot} = \frac{P_{aks}}{\eta_{el}} = \frac{79,074kW}{0,868} = 91,117kW$$

APPENDIX2. calculations in all chosen points of the characteristic field of the compressor TB150-0.8S

	T_{in} [K]	p_{in} [Pa]	ρwater [kg/m3]	p gauge [mmAqx1000]	p out [Pa]	ηs [-]	RH [%]	qv [m3/min]	q_v [m3/s]
1	293,15	101325,00	998,21	8	179664,29	0,7455	36,00	56,1297	0,94
2	293,15	101325,00	998,21	7,98095	179477,75	0,7470	36,00	70,0432	1,17
3	293,15	101325,00	998,21	8	179664,29	0,7455	36,00	80,1514	1,34
4	293,15	101325,00	998,21	6	160079,47	0,7510	36,00	48,1622	0,80
5	293,15	101325,00	998,21	6	160079,47	0,7450	36,00	69,2108	1,15
6	293,15	101325,00	998,21	6	160079,47	0,6850	36,00	92,9946	1,55
7	293,15	101325,00	998,21	4,01905	140681,19	0,7510	36,00	36,1514	0,60
8	293,15	101325,00	998,21	4,01905	140681,19	0,7440	36,00	58,9838	0,98
9	293,15	101325,00	998,21	4,01905	140681,19	0,6700	36,00	80,0324	1,33
10	293,15	101325,00	998,21	2,13333	122215,45	0,7100	36,00	51,4919	0,86
11	293,15	101325,00	998,21	2,19048	122775,08	0,7200	36,00	50,0649	0,83
12	293,15	101325,00	998,21	2,24762	123334,62	0,7300	36,00	48,2811	0,80
13	293,15	101325,00	998,21	2,34286	124267,25	0,7400	36,00	46,3784	0,77
14	293,15	101325,00	998,21	2,45714	125386,33	0,7500	36,00	43,5243	0,73
15	293,15	101325,00	998,21	2,57143	126505,5	0,7600	36,00	39,9568	0,67
16	293,15	101325,00	998,21	2,68571	127624,58	0,7650	36,00	36,1514	0,60
17	293,15	101325,00	998,21	2,8	128743,75	0,7600	36,00	32,227	0,54
18	293,15	101325,00	998,21	2,85714	129303,29	0,7500	36,00	28,4216	0,47
19	293,15	101325,00	998,21	2,89524	129676,38	0,7400	36,00	25,2108	0,42
20	293,15	101325,00	998,21	2,89524	129676,38	0,7375	36,00	24,3784	0,41
21	293,15	101325,00	998,21	2,91429	129862,93	0,7300	36,00	19,3838	0,32
22	293,15	101325,00	998,21	2,68571	127624,58	0,6760	36,00	65,4054	1,09
23	293,15	101325,00	998,21	2,74286	128184,21	0,6800	36,00	64,8108	1,08
24	293,15	101325,00	998,21	2,81905	128930,3	0,6900	36,00	63,6216	1,06
25	293,15	101325,00	998,21	2,89524	129676,38	0,7000	36,00	62,3135	1,04
26	293,15	101325,00	998,21	2,99048	130609,01	0,7100	36,00	60,5297	1,01
27	293,15	101325,00	998,21	3,06667	131355,1	0,7200	36,00	59,3405	0,99
28	293,15	101325,00	998,21	3,2	132660,72	0,7300	36,00	57,3189	0,96
29	293,15	101325,00	998,21	3,29524	133593,35	0,7400	36,00	55,4162	0,92
30	293,15	101325,00	998,21	3,46667	135272,06	0,7500	36,00	51,9676	0,87
31	293,15	101325,00	998,21	3,6	136577,68	0,7600	36,00	48,4	0,81
32	293,15	101325,00	998,21	3,77143	138256,4	0,7650	36,00	43,7622	0,73
33	293,15	101325,00	998,21	3,90476	139562,02	0,7600	36,00	39,6	0,66
34	293,15	101325,00	998,21	4	140494,65	0,7500	36,00	35,0811	0,58
35	293,15	101325,00	998,21	4,0381	140867,74	0,7400	36,00	31,2757	0,52
36	293,15	101325,00	998,21	4,05714	141054,19	0,7375	36,00	29,6108	0,49
37	293,15	101325,00	998,21	4,09524	141427,28	0,7300	36,00	24,8541	0,41
38	293,15	101325,00	998,21	3,61905	136764,23	0,6750	36,00	75,6324	1,26
39	293,15	101325,00	998,21	3,69524	137510,31	0,6800	36,00	75,0378	1,25
40	293,15	101325,00	998,21	3,80952	138629,39	0,6900	36,00	73,7297	1,23
41	293,15	101325,00	998,21	3,92381	139748,56	0,7000	36,00	72,4216	1,21
42	293,15	101325,00	998,21	4,0381	140867,74	0,7100	36,00	70,7568	1,18
43	293,15	101325,00	998,21	4,15238	141986,81	0,7200	36,00	69,2108	1,15

44	293,15	101325,00	998,21	4,32381	143665,53	0,7300	36,00	66,8324	1,11
45	293,15	101325,00	998,21	4,45714	144971,15	0,7400	36,00	64,4541	1,07
46	293,15	101325,00	998,21	4,7619	147955,49	0,7500	36,00	59,5784	0,99
47	293,15	101325,00	998,21	4,95238	149820,74	0,7600	36,00	55,8919	0,93
48	293,15	101325,00	998,21	5,10476	151312,91	0,7650	36,00	51,8486	0,86
49	293,15	101325,00	998,21	5,25714	152805,08	0,7600	36,00	48,0432	0,80
50	293,15	101325,00	998,21	5,39048	154110,8	0,7500	36,00	42,4541	0,71
51	293,15	101325,00	998,21	5,44762	154670,34	0,7400	36,00	38,173	0,64
52	293,15	101325,00	998,21	5,48571	155043,33	0,7375	36,00	36,2703	0,60
53	293,15	101325,00	998,21	5,50476	155229,88	0,7300	36,00	31,5135	0,53
54	293,15	101325,00	998,21	4,66667	147022,95	0,6680	36,00	86,9297	1,45
55	293,15	101325,00	998,21	4,7619	147955,49	0,6730	36,00	86,2162	1,44
56	293,15	101325,00	998,21	4,8381	148701,67	0,6800	36,00	85,5027	1,43
57	293,15	101325,00	998,21	4,99048	150193,83	0,6900	36,00	84,0757	1,40
58	293,15	101325,00	998,21	5,14286	151686	0,7000	36,00	82,7676	1,38
59	293,15	101325,00	998,21	5,29524	153178,17	0,7100	36,00	81,1027	1,35
60	293,15	101325,00	998,21	5,46667	154856,88	0,7200	36,00	79,3189	1,32
61	293,15	101325,00	998,21	5,69524	157095,13	0,7300	36,00	76,9405	1,28
62	293,15	101325,00	998,21	5,90476	159146,84	0,7400	36,00	74,0865	1,23
63	293,15	101325,00	998,21	6,38095	163809,89	0,7500	36,00	67,1892	1,12
64	293,15	101325,00	998,21	6,68571	166794,22	0,7540	36,00	61,6	1,03
65	293,15	101325,00	998,21	6,97143	169592,11	0,7500	36,00	53,9892	0,90
66	293,15	101325,00	998,21	7,08571	170711,19	0,7450	36,00	49,5892	0,83
67	293,15	101325,00	998,21	7,1619	171457,27	0,7400	36,00	46,0216	0,77
68	293,15	101325,00	998,21	7,18095	171643,82	0,7375	36,00	44,2378	0,74
69	293,15	101325,00	998,21	7,2381	172203,45	0,7300	36,00	39,6	0,66
70	293,15	101325,00	998,21	5,79048	158027,76	0,6500	36,00	98,8216	1,65
71	293,15	101325,00	998,21	5,92381	159333,39	0,6600	36,00	97,8703	1,63
72	293,15	101325,00	998,21	6,07619	160825,55	0,6700	36,00	96,8	1,61
73	293,15	101325,00	998,21	6,24762	162504,27	0,6800	36,00	95,8486	1,60
74	293,15	101325,00	998,21	6,47619	164742,52	0,6900	36,00	94,3027	1,57
75	293,15	101325,00	998,21	6,68571	166794,22	0,7000	36,00	92,8757	1,55
76	293,15	101325,00	998,21	6,89524	168846,03	0,7100	36,00	90,973	1,52
77	293,15	101325,00	998,21	7,08571	170711,19	0,7200	36,00	89,1892	1,49
78	293,15	101325,00	998,21	7,40952	173882,07	0,7300	36,00	86,4541	1,44
79	293,15	101325,00	998,21	7,69524	176679,96	0,7400	36,00	83,4811	1,39
80	293,15	101325,00	998,21	8,32381	182835,17	0,7450	36,00	75,7514	1,26
81	293,15	101325,00	998,21	8,78095	187311,68	0,7500	36,00	67,7838	1,13
82	293,15	101325,00	998,21	9,04762	189923,02	0,7450	36,00	61,0054	1,02
83	293,15	101325,00	998,21	9,2	191415,19	0,7390	36,00	55,1784	0,92
84	293,15	101325,00	998,21	9,2381	191788,28	0,7375	36,00	53,7514	0,90
85	293,15	101325,00	998,21	9,27619	192161,27	0,7300	36,00	49,1135	0,82

q_m	η_p	π	T_{cr}	τ	p'_{vap} (Tin)	μ	ω_{vap}	M_{vap}	M_{air}	$M_{humid\ a}$	R_u
[kg/s]	[-]	[-]	[K]	-	[Pa]	-	-	[kg/mol]	[kg/mol]	[kg/mol]	[J/mol K]
1,123	0,765	1,7731	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,401	0,766	1,7713	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,603	0,765	1,7731	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,963	0,766	1,5799	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,3845	0,761	1,5799	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,860	0,704	1,5799	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,7232	0,762	1,3884	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,180	0,756	1,3884	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,6010	0,685	1,3884	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,030	0,718	1,2062	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,002	0,728	1,2117	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,966	0,737	1,2172	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,928	0,747	1,2264	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,871	0,757	1,2375	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,799	0,767	1,2485	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,723	0,773	1,2596	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,645	0,768	1,2706	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,569	0,758	1,2761	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,504	0,749	1,2798	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,488	0,746	1,2798	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,388	0,739	1,2816	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,308	0,686	1,2596	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,297	0,690	1,2651	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,273	0,700	1,2724	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,247	0,710	1,2798	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,211	0,720	1,2890	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,187	0,730	1,2964	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,147	0,740	1,3093	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,109	0,750	1,3185	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,040	0,760	1,3350	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,968	0,770	1,3479	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,875	0,775	1,3645	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,792	0,771	1,3774	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,702	0,761	1,3866	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,626	0,752	1,3903	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,592	0,749	1,3921	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,497	0,742	1,3958	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,513	0,688	1,3498	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,501	0,693	1,3571	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,475	0,703	1,3682	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,449	0,713	1,3792	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,415	0,723	1,3903	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,385	0,733	1,4013	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315

1,337	0,743	1,4179	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,289	0,753	1,4308	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,192	0,763	1,4602	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,118	0,773	1,4786	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,037	0,778	1,4933	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,961	0,773	1,5081	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,849	0,764	1,5210	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,764	0,755	1,5265	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,726	0,753	1,5302	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,630	0,746	1,5320	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,739	0,685	1,4510	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,725	0,690	1,4602	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,710	0,697	1,4676	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,682	0,707	1,4823	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,656	0,716	1,4970	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,622	0,726	1,5118	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,587	0,736	1,5283	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,539	0,746	1,5504	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,482	0,756	1,5707	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,344	0,766	1,6167	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,232	0,770	1,6461	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,080	0,767	1,6737	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,992	0,763	1,6848	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,921	0,758	1,6922	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,885	0,756	1,6940	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,792	0,749	1,6995	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,977	0,671	1,5596	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,958	0,681	1,5725	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,936	0,690	1,5872	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,917	0,700	1,6038	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,886	0,710	1,6259	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,858	0,720	1,6461	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,820	0,730	1,6664	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,784	0,739	1,6848	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,729	0,749	1,7161	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,670	0,759	1,7437	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,515	0,765	1,8044	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,356	0,770	1,8486	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,220	0,766	1,8744	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,104	0,761	1,8891	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
1,075	0,760	1,8928	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315
0,982	0,753	1,8965	647,140	0,547	2338,49	0,622	0,005	0,018	0,029	0,029	8,315

R_i	x_{vap}	x_{air}	$\rho_{humid\ air}$	$T_{2,estimated}$	T_{aver}	$c_{p,aver,air}$	$c_{p,aver,vap}$	$c_{p,aver,humid\ air}$	T_2	Δh	$T_{s,estimated}$
[J/kg K]	-	-	[kg/m3]	[K]	[K]	[kJ/kg K]	[kJ/kg K]	[kJ/kg K]	[K]	[kJ/kg]	[K]
287,968	0,008	0,992	1,200	362,472	327,811	1,009	1,879	1,016	362,472	70,422	344,893
287,968	0,008	0,992	1,200	362,204	327,677	1,009	1,879	1,016	362,204	70,148	344,791
287,968	0,008	0,992	1,200	362,472	327,811	1,009	1,879	1,016	362,472	70,422	344,893
287,968	0,008	0,992	1,200	347,248	320,199	1,008	1,876	1,015	347,248	54,899	333,811
287,968	0,008	0,992	1,200	347,679	320,415	1,008	1,876	1,015	347,679	55,339	333,810
287,968	0,008	0,992	1,200	352,436	322,793	1,008	1,877	1,015	352,436	60,185	333,810
287,968	0,008	0,992	1,200	331,288	312,219	1,007	1,873	1,014	331,288	38,662	321,810
287,968	0,008	0,992	1,200	331,646	312,398	1,007	1,873	1,014	331,646	39,026	321,810
287,968	0,008	0,992	1,200	335,885	314,518	1,007	1,874	1,014	335,885	43,336	321,810
287,968	0,008	0,992	1,200	315,754	304,452	1,006	1,870	1,013	315,754	22,891	309,206
287,968	0,008	0,992	1,200	315,998	304,574	1,006	1,870	1,013	315,998	23,139	309,608
287,968	0,008	0,992	1,200	316,234	304,692	1,006	1,870	1,013	316,234	23,378	310,008
287,968	0,008	0,992	1,200	316,819	304,985	1,006	1,870	1,013	316,819	23,972	310,673
287,968	0,008	0,992	1,200	317,560	305,355	1,006	1,870	1,013	317,560	24,723	311,465
287,968	0,008	0,992	1,200	318,274	305,712	1,006	1,870	1,013	318,274	25,448	312,252
287,968	0,008	0,992	1,200	319,131	306,141	1,006	1,871	1,013	319,131	26,317	313,034
287,968	0,008	0,992	1,200	320,325	306,737	1,006	1,871	1,013	320,325	27,529	313,811
287,968	0,008	0,992	1,200	321,203	307,176	1,006	1,871	1,013	321,203	28,419	314,198
287,968	0,008	0,992	1,200	321,926	307,538	1,006	1,871	1,013	321,926	29,153	314,455
287,968	0,008	0,992	1,200	322,027	307,588	1,006	1,871	1,013	322,027	29,256	314,455
287,968	0,008	0,992	1,200	322,497	307,823	1,006	1,871	1,013	322,497	29,733	314,584
287,968	0,008	0,992	1,200	322,548	307,849	1,006	1,871	1,013	322,548	29,785	313,034
287,968	0,008	0,992	1,200	322,946	308,048	1,006	1,871	1,013	322,946	30,188	313,423
287,968	0,008	0,992	1,200	323,264	308,207	1,006	1,871	1,013	323,264	30,511	313,940
287,968	0,008	0,992	1,200	323,569	308,360	1,006	1,871	1,013	323,569	30,821	314,455
287,968	0,008	0,992	1,200	324,040	308,595	1,006	1,871	1,013	324,040	31,299	315,096
287,968	0,008	0,992	1,200	324,322	308,736	1,006	1,871	1,013	324,322	31,586	315,606
287,968	0,008	0,992	1,200	325,110	309,130	1,006	1,872	1,013	325,110	32,386	316,493
287,968	0,008	0,992	1,200	325,529	309,339	1,006	1,872	1,013	325,529	32,811	317,123
287,968	0,008	0,992	1,200	326,599	309,875	1,006	1,872	1,013	326,599	33,899	318,249
287,968	0,008	0,992	1,200	327,303	310,226	1,006	1,872	1,013	327,303	34,613	319,118
287,968	0,008	0,992	1,200	328,526	310,838	1,006	1,872	1,014	328,526	35,855	320,226
287,968	0,008	0,992	1,200	329,882	311,516	1,006	1,873	1,014	329,882	37,234	321,081
287,968	0,008	0,992	1,200	331,180	312,165	1,007	1,873	1,014	331,180	38,552	321,689
287,968	0,008	0,992	1,200	332,019	312,584	1,007	1,873	1,014	332,019	39,405	321,931
287,968	0,008	0,992	1,200	332,311	312,731	1,007	1,873	1,014	332,311	39,702	322,052
287,968	0,008	0,992	1,200	333,044	313,097	1,007	1,873	1,014	333,044	40,447	322,293
287,968	0,008	0,992	1,200	331,773	312,462	1,007	1,873	1,014	331,773	39,155	319,242
287,968	0,008	0,992	1,200	332,213	312,681	1,007	1,873	1,014	332,213	39,602	319,735
287,968	0,008	0,992	1,200	332,714	312,932	1,007	1,873	1,014	332,714	40,112	320,471
287,968	0,008	0,992	1,200	333,194	313,172	1,007	1,873	1,014	333,194	40,599	321,203
287,968	0,008	0,992	1,200	333,653	313,401	1,007	1,873	1,014	333,653	41,066	321,931
287,968	0,008	0,992	1,200	334,098	313,624	1,007	1,873	1,014	334,098	41,518	322,654

287,968	0,008	0,992	1,200	335,009	314,080	1,007	1,873	1,014	335,009	42,445	323,732
287,968	0,008	0,992	1,200	335,570	314,360	1,007	1,874	1,014	335,570	43,015	324,563
287,968	0,008	0,992	1,200	337,508	315,329	1,007	1,874	1,014	337,508	44,986	326,444
287,968	0,008	0,992	1,200	338,454	315,802	1,007	1,874	1,014	338,454	45,948	327,605
287,968	0,008	0,992	1,200	339,361	316,255	1,007	1,874	1,014	339,361	46,871	328,527
287,968	0,008	0,992	1,200	340,864	317,007	1,007	1,875	1,014	340,864	48,400	329,442
287,968	0,008	0,992	1,200	342,558	317,854	1,007	1,875	1,014	342,558	50,125	330,237
287,968	0,008	0,992	1,200	343,680	318,415	1,007	1,875	1,015	343,680	51,267	330,576
287,968	0,008	0,992	1,200	344,158	318,654	1,007	1,875	1,015	344,158	51,753	330,802
287,968	0,008	0,992	1,200	344,832	318,991	1,007	1,875	1,015	344,832	52,439	330,914
287,968	0,008	0,992	1,200	342,062	317,606	1,007	1,875	1,014	342,062	49,619	325,859
287,968	0,008	0,992	1,200	342,568	317,859	1,007	1,875	1,014	342,568	50,134	326,443
287,968	0,008	0,992	1,200	342,748	317,949	1,007	1,875	1,015	342,748	50,318	326,909
287,968	0,008	0,992	1,200	343,371	318,260	1,007	1,875	1,015	343,371	50,952	327,836
287,968	0,008	0,992	1,200	343,964	318,557	1,007	1,875	1,015	343,964	51,555	328,756
287,968	0,008	0,992	1,200	344,536	318,843	1,007	1,875	1,015	344,536	52,138	329,669
287,968	0,008	0,992	1,200	345,237	319,194	1,007	1,875	1,015	345,237	52,852	330,689
287,968	0,008	0,992	1,200	346,367	319,758	1,008	1,876	1,015	346,367	54,002	332,036
287,968	0,008	0,992	1,200	347,303	320,226	1,008	1,876	1,015	347,303	54,955	333,259
287,968	0,008	0,992	1,200	350,220	321,685	1,008	1,876	1,015	350,220	57,928	335,995
287,968	0,008	0,992	1,200	352,201	322,675	1,008	1,877	1,015	352,201	59,946	337,717
287,968	0,008	0,992	1,200	354,631	323,891	1,008	1,877	1,015	354,631	62,423	339,310
287,968	0,008	0,992	1,200	355,890	324,520	1,008	1,878	1,015	355,890	63,707	339,942
287,968	0,008	0,992	1,200	356,877	325,014	1,008	1,878	1,015	356,877	64,713	340,362
287,968	0,008	0,992	1,200	357,235	325,192	1,008	1,878	1,016	357,235	65,078	340,467
287,968	0,008	0,992	1,200	358,322	325,736	1,008	1,878	1,016	358,322	66,187	340,780
287,968	0,008	0,992	1,200	353,747	323,448	1,008	1,877	1,015	353,747	61,522	332,593
287,968	0,008	0,992	1,200	354,002	323,576	1,008	1,877	1,015	354,002	61,781	333,369
287,968	0,008	0,992	1,200	354,413	323,781	1,008	1,877	1,015	354,413	62,200	334,250
287,968	0,008	0,992	1,200	354,955	324,053	1,008	1,877	1,015	354,955	62,753	335,234
287,968	0,008	0,992	1,200	355,944	324,547	1,008	1,878	1,015	355,944	63,762	336,535
287,968	0,008	0,992	1,200	356,736	324,943	1,008	1,878	1,015	356,736	64,570	337,716
287,968	0,008	0,992	1,200	357,488	325,319	1,008	1,878	1,016	357,488	65,336	338,887
287,968	0,008	0,992	1,200	358,065	325,608	1,008	1,878	1,016	358,065	65,925	339,942
287,968	0,008	0,992	1,200	359,604	326,377	1,008	1,878	1,016	359,604	67,495	341,717
287,968	0,008	0,992	1,200	360,795	326,973	1,009	1,878	1,016	360,795	68,711	343,263
287,968	0,008	0,992	1,200	364,812	328,981	1,009	1,879	1,016	364,812	72,810	346,603
287,968	0,008	0,992	1,200	367,500	330,325	1,009	1,880	1,016	367,500	75,555	348,980
287,968	0,008	0,992	1,200	369,831	331,490	1,009	1,880	1,016	369,831	77,936	350,348
287,968	0,008	0,992	1,200	371,489	332,320	1,009	1,881	1,016	371,489	79,631	351,123
287,968	0,008	0,992	1,200	371,916	332,533	1,009	1,881	1,017	371,916	80,067	351,316
287,968	0,008	0,992	1,200	372,980	333,065	1,009	1,881	1,017	372,980	81,154	351,509

$T_{s,aver}$	$c_{p,s,aver,air}$	$c_{p,s,aver,vap}$	$c_{p,s,aver,humid\ ai}$	T_{2s}	Δh_s	P_{aks}	η_{el}	P_{el}	ω_{sp}	relative speed	N	η_{tot}
[K]	[J/kg K]	[J/kg K]	[J/kg K]	[K]	[kJ/kg]	[kW]	-	[kW]	[1/s]	[-]	[rpm]	
319,021	1,007	1,879	1,015	344,893	52,502	79,074	0,868	91,117	19,15744	0,95	21779,09	0,647
318,971	1,007	1,879	1,015	344,791	52,399	98,291	0,912	107,814	17,48472	0,97	22237,59	0,681
319,021	1,007	1,879	1,015	344,893	52,502	112,914	0,917	123,074	2400,738	1	22925,35	0,684
313,480	1,007	1,876	1,014	333,811	41,227	52,894	0,874	60,550	14,52774	0,845	19371,92	0,656
313,480	1,007	1,876	1,014	333,810	41,227	76,618	0,925	82,845	13,40657	0,885	20288,94	0,689
313,480	1,007	1,877	1,014	333,810	41,227	111,964	0,978	114,471	12,67664	0,97	22237,59	0,67
307,480	1,006	1,873	1,013	321,810	29,036	27,960	0,865	32,306	11,2801	0,7	16047,75	0,65
307,480	1,006	1,873	1,013	321,810	29,036	46,049	0,933	49,367	9,524851	0,755	17308,64	0,694
307,480	1,006	1,874	1,013	321,810	29,036	69,381	0,988	70,222	9,097538	0,84	19257,3	0,662
301,178	1,005	1,870	1,012	309,206	16,254	23,580	0,900	26,200	5,242931	0,6	13755,21	0,639038
301,379	1,005	1,870	1,012	309,608	16,661	23,175	0,900	25,750	5,416686	0,6	13755,21	0,648024
301,579	1,005	1,870	1,012	310,008	17,067	22,580	0,900	25,088	5,616261	0,6	13755,21	0,657023
301,911	1,005	1,870	1,012	310,673	17,740	22,240	0,900	24,712	5,899017	0,6	13755,21	0,666029
302,307	1,005	1,870	1,012	311,465	18,543	21,526	0,900	23,918	6,294952	0,6	13755,21	0,67501
302,701	1,005	1,870	1,012	312,252	19,341	20,341	0,900	22,601	6,780899	0,6	13755,21	0,684016
303,092	1,005	1,870	1,013	313,034	20,134	19,032	0,900	21,147	7,346944	0,6	13755,21	0,688538
303,481	1,005	1,871	1,013	313,811	20,922	17,747	0,900	19,719	8,008742	0,6	13755,21	0,684
303,674	1,005	1,871	1,013	314,198	21,314	16,158	0,900	17,954	8,647653	0,6	13755,21	0,674977
303,803	1,005	1,871	1,013	314,455	21,575	14,703	0,900	16,337	9,265959	0,6	13755,21	0,666037
303,803	1,005	1,871	1,013	314,455	21,575	14,267	0,900	15,853	9,422824	0,6	13755,21	0,663708
303,867	1,005	1,871	1,013	314,584	21,705	11,529	0,900	12,810	10,61509	0,6	13755,21	0,656999
303,092	1,005	1,871	1,013	313,034	20,134	38,971	0,900	43,301	6,372491	0,7	16047,75	0,60837
303,287	1,005	1,871	1,013	313,423	20,528	39,140	0,900	43,489	6,495538	0,7	16047,75	0,612006
303,545	1,005	1,871	1,013	313,940	21,053	38,833	0,900	43,148	6,681127	0,7	16047,75	0,620989
303,803	1,005	1,871	1,013	314,455	21,575	38,421	0,900	42,690	6,876055	0,7	16047,75	0,629987
304,123	1,005	1,871	1,013	315,096	22,224	37,900	0,900	42,111	7,133588	0,7	16047,75	0,639043
304,378	1,006	1,871	1,013	315,606	22,741	37,495	0,900	41,662	7,330112	0,7	16047,75	0,647983
304,822	1,006	1,872	1,013	316,493	23,641	37,136	0,900	41,262	7,678578	0,7	16047,75	0,656982
305,137	1,006	1,872	1,013	317,123	24,281	36,374	0,900	40,416	7,967085	0,7	16047,75	0,666007
305,700	1,006	1,872	1,013	318,249	25,423	35,241	0,900	39,156	8,515814	0,7	16047,75	0,674972
306,134	1,006	1,872	1,013	319,118	26,304	33,513	0,900	37,237	9,052564	0,7	16047,75	0,683962
306,688	1,006	1,872	1,013	320,226	27,429	31,390	0,900	34,877	9,823804	0,7	16047,75	0,688485
307,116	1,006	1,872	1,013	321,081	28,297	29,496	0,900	32,773	10,57128	0,7	16047,75	0,683976
307,419	1,006	1,873	1,013	321,689	28,913	27,055	0,900	30,062	11,41451	0,7	16047,75	0,674972
307,540	1,006	1,873	1,013	321,931	29,159	24,654	0,900	27,393	12,16598	0,7	16047,75	0,665986
307,601	1,006	1,873	1,013	322,052	29,281	23,518	0,900	26,131	12,54274	0,7	16047,75	0,663777
307,721	1,006	1,873	1,013	322,293	29,526	20,110	0,900	22,345	13,77631	0,7	16047,75	0,656998
306,196	1,006	1,873	1,013	319,242	26,430	59,242	0,900	65,824	8,305808	0,8	18340,28	0,607499
306,442	1,006	1,873	1,013	319,735	26,930	59,447	0,900	66,052	8,456803	0,8	18340,28	0,612021
306,811	1,006	1,873	1,013	320,471	27,677	59,162	0,900	65,736	8,708389	0,8	18340,28	0,621006
307,177	1,006	1,873	1,013	321,203	28,420	58,819	0,900	65,355	8,962965	0,8	18340,28	0,630013
307,540	1,006	1,873	1,013	321,931	29,159	58,127	0,900	64,586	9,243965	0,8	18340,28	0,639043
307,902	1,006	1,873	1,013	322,654	29,893	57,483	0,900	63,870	9,522624	0,8	18340,28	0,648002

308,441	1,006	1,873	1,013	323,732	30,987	56,747	0,900	63,053	9,955324	0,8	18340,28	0,657041
308,857	1,006	1,874	1,013	324,563	31,831	55,462	0,900	61,625	10,34381	0,8	18340,28	0,666009
309,797	1,006	1,874	1,013	326,444	33,741	53,617	0,900	59,574	11,23932	0,8	18340,28	0,675029
310,378	1,006	1,874	1,014	327,605	34,921	51,375	0,900	57,083	11,90703	0,8	18340,28	0,684001
310,838	1,006	1,874	1,014	328,527	35,857	48,615	0,900	54,017	12,61032	0,8	18340,28	0,688513
311,296	1,006	1,875	1,014	329,442	36,786	46,517	0,900	51,686	13,35411	0,8	18340,28	0,684038
311,693	1,006	1,875	1,014	330,237	37,594	42,570	0,900	47,300	14,43938	0,8	18340,28	0,675014
311,863	1,006	1,875	1,014	330,576	37,939	39,149	0,900	43,499	15,33217	0,8	18340,28	0,66603
311,976	1,007	1,875	1,014	330,802	38,169	37,551	0,900	41,723	15,80044	0,8	18340,28	0,663759
312,032	1,007	1,875	1,014	330,914	38,283	33,059	0,900	36,732	16,98918	0,8	18340,28	0,657039
309,504	1,006	1,875	1,013	325,859	33,147	86,288	0,900	95,875	10,32927	0,9	20632,82	0,60123
309,797	1,006	1,875	1,013	326,443	33,741	86,468	0,900	96,075	10,51096	0,9	20632,82	0,605713
310,030	1,006	1,875	1,013	326,909	34,214	86,067	0,900	95,630	10,66555	0,9	20632,82	0,611963
310,493	1,006	1,875	1,014	327,836	35,155	85,696	0,900	95,218	10,97682	0,9	20632,82	0,620977
310,953	1,006	1,875	1,014	328,756	36,090	85,362	0,900	94,847	11,28306	0,9	20632,82	0,630019
311,410	1,006	1,875	1,014	329,669	37,018	84,590	0,900	93,989	11,61738	0,9	20632,82	0,638996
311,919	1,007	1,875	1,014	330,689	38,054	83,863	0,900	93,181	11,99305	0,9	20632,82	0,648007
312,593	1,007	1,876	1,014	332,036	39,423	83,118	0,900	92,353	12,50413	0,9	20632,82	0,657027
313,204	1,007	1,876	1,014	333,259	40,666	81,448	0,900	90,497	13,0428	0,9	20632,82	0,665984
314,572	1,007	1,876	1,014	335,995	43,448	77,860	0,900	86,512	14,39285	0,9	20632,82	0,675037
315,433	1,007	1,877	1,014	337,717	45,199	73,870	0,900	82,078	15,48372	0,9	20632,82	0,678603
316,230	1,007	1,877	1,014	339,310	46,820	67,419	0,900	74,910	16,98208	0,9	20632,82	0,675044
316,546	1,007	1,877	1,014	339,942	47,463	63,198	0,900	70,220	17,90169	0,9	20632,82	0,670523
316,756	1,007	1,878	1,014	340,362	47,891	59,578	0,900	66,198	18,70787	0,9	20632,82	0,666037
316,808	1,007	1,878	1,014	340,467	47,997	57,592	0,900	63,991	19,11316	0,9	20632,82	0,663778
316,965	1,007	1,878	1,014	340,780	48,316	52,432	0,900	58,258	20,30209	0,9	20632,82	0,656998
312,871	1,007	1,877	1,014	332,593	39,989	121,621	0,900	135,135	12,39105	1	22925,35	0,585006
313,259	1,007	1,877	1,014	333,369	40,778	120,959	0,900	134,399	12,63488	1	22925,35	0,594037
313,700	1,007	1,877	1,014	334,250	41,674	120,448	0,900	133,831	12,91331	1	22925,35	0,602998
314,192	1,007	1,877	1,014	335,234	42,675	120,325	0,900	133,694	13,21028	1	22925,35	0,612037
314,843	1,007	1,877	1,014	336,535	43,998	120,287	0,900	133,652	13,62657	1	22925,35	0,621027
315,433	1,007	1,877	1,014	337,716	45,199	119,967	0,900	133,297	14,01109	1	22925,35	0,630003
316,018	1,007	1,878	1,014	338,887	46,390	118,905	0,900	132,116	14,43567	1	22925,35	0,639015
316,546	1,007	1,878	1,014	339,942	47,463	117,623	0,900	130,693	14,83163	1	22925,35	0,647965
317,433	1,007	1,878	1,014	341,717	49,269	116,732	0,900	129,702	15,49228	1	22925,35	0,656972
318,206	1,007	1,878	1,015	343,263	50,843	114,747	0,900	127,497	16,14197	1	22925,35	0,665967
319,876	1,008	1,879	1,015	346,603	54,244	110,335	0,900	122,595	17,78864	1	22925,35	0,670501
321,065	1,008	1,880	1,015	348,980	56,666	102,452	0,900	113,835	19,43132	1	22925,35	0,674994
321,749	1,008	1,880	1,015	350,348	58,059	95,113	0,900	105,681	20,85905	1	22925,35	0,670462
322,137	1,008	1,880	1,015	351,123	58,849	87,899	0,900	97,665	22,15629	1	22925,35	0,665122
322,233	1,008	1,880	1,015	351,316	59,046	86,094	0,900	95,660	22,50477	1	22925,35	0,663717
322,330	1,008	1,881	1,015	351,509	59,243	79,734	0,900	88,593	23,60214	1	22925,35	0,657001