ENERGY TRANSFORMER DEVICE
THEORY

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ABSTRACT

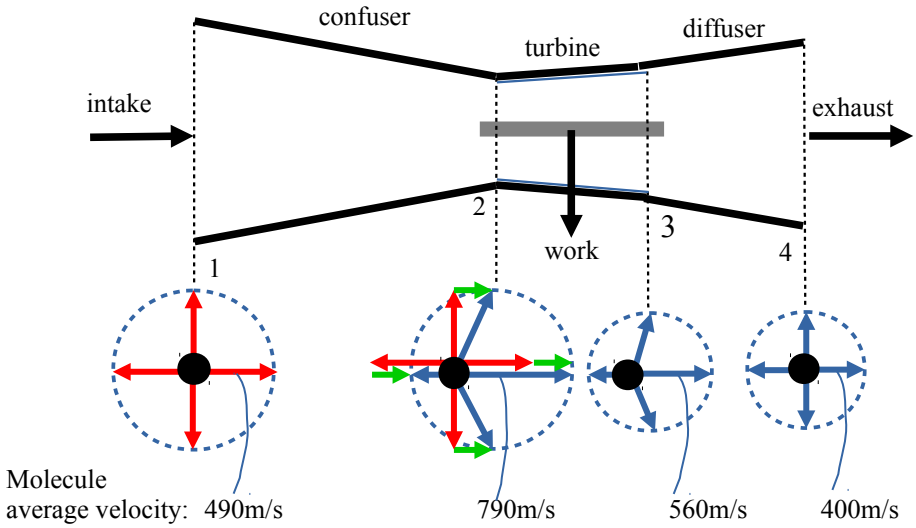
The **Energy Transformer Device (ETD)** has a controlled and opened process which transforms kinetic energy of the gas molecules to mechanical work – **without any additional energy source**. Kinetic energy of the shocks / collisions accelerate gas molecules in the converging nozzle (confuser) because of the pressure difference. At the starting process we generate the pressure difference by an outer drive and later the process keeps it up in steady-state. Accelerated gas molecules generate mechanical work on the turbine while their kinetic energy is reduced. The total / stagnation pressure of the exhaust is increased, which is caused by the reduced entropy of the gas flow. With the suitable design of the impulse-turbine a higher stagnation pressure can be reached at exhaust than the stagnation pressure was at intake.

Kinetic energy difference of the intaken and exhausted gas molecules produces extracted work on the turbine shaft.

The ETD is usable to produce mechanical or electrical energy and to cool the air or gas.

GENERAL DESCRIPTION

An average molecule moves with average velocity to a random direction in static gas as seen on Fig. 1. Endpoints of the velocity vectors define a concentric circle around the molecule on a 2D plane. It would be a sphere in 3D. At intake point 1 the average velocity of the molecules on *273 K* temperature is *490 m/s*. Cooler molecules move with *400 m/s* velocity at point *4*. The „intake" shows the volumetric work of the ambient air and the „exhaust" shows the volumetric work of



Red vectors: initial velocity of the molecules (R. Clausius-motion)
Green vectors: velocity of the accelerated gas/air flow before the turbine
Blue vectors: results of the acceleration and deceleration related to the fixed point

Fig. 1.

the ETD against the ambient air with reduced temperature and volume. If we accelerate the gas by the pressure difference, as the Bernoulli equation defines, the velocity vectors end on the same circle, but they are eccentric to the molecule at point 2 and 3. The dislocation is equal to the green flow velocity vector. The sum of the static and dynamic pressure gives the total, or stagnation pressure. At the stagnation point the molecule moves back to the center of the circle while the dynamic pressure is close to zero.

According to several publications the stagnation- and static pressure are increased in the subsonic gas flow during the entropy reduction (cooling). [1] [2] The stagnation pressure is higher at the exhaust than it was at the intake of the impulse-turbine. Higher stagnation pressure at exhaust results the closing of the cycle-process of the ETD.

Theoretical evidence of the ETD-process: The cooler (ideal) gas / air flows out of the ETD with a higher stagnation pressure than the ambient air has. The question: how are the energy dissipation of real gas and friction covered by the extracted work in real practice?

Other evidence is the following calculation: We calculated the projected effects of the entropy reduction.

DETAILED DESCRIPTION

The flow is steady-state, ideal, subsonic. Confuser, turbine and diffuser are thermally isolated. The v_2 velocity of the flow out of the confuser is calculated as equation (1.1) shows on the basis of the mass and energy conservation in the function of the p_1 stagnation pressure at point 1, p_{s2} static pressure at point 2 and T_1 stagnation temperature at point 1.

$$v_2=\sqrt{v_1^2+\frac{2\gamma}{\gamma-1}RT_1\left[1-\left(\frac{p_{s2}}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right]} \qquad (1.1)$$

where v_1 = intake velocity close to zero, $\gamma = C_p/C_v = 1.4$ adiabatic exponent of ambient air,

$R = C_p - C_v = 287\ (J/kgK)$ universal gas constant.

The T_{s2} static temperature of the accelerated air at point 2 calculated by eq. (1.2).

$$T_{s2}=T_1\left(\frac{p_{s2}}{p_1}\right)^{\frac{\gamma-1}{\gamma}} \qquad (1.2)$$

The 50% of the kinetic energy of the airflow is extracted by the impulse-turbine through the shaft in our example. Molecules were decelerated by the collision in the direction of the turbine displacement. The theoretical range of the extraction is 50-85% of the kinetic energy.

The v_3 velocity of the air flow at point 3 is calculated by the 50 % kinetic energy reduction.

$$v_3=v_2/\sqrt{2} \qquad (1.3)$$

1 P. Balachandran (2010) Gas Dynamics for Engineers, 144p. Table 4.1
2 J. M. Powers (2005) Lecture Notes On Gas Dynamics, University Of Notre Dame 116p.

The extracted energy reduced the entropy of the gas as well. It reduced the average motion velocity of the molecules. (See Fig. 1.)

The results are: Decelerated molecules move out of the turbine closer to each-other and they produce more shocks on the same surface. The molecules produce static pressure with lower kinetic energy, but with higher number of collisions in the same volume. While the molecules are closer to each-other the mean free path is smaller and the number of collisions are higher in time relation as well.

The „compression" of the molecules is done by the collision of the ambient molecules and there is no need for external work or cooling. This is the result of the entropy reduction, produced by work extraction.

Entropy reduction is produced by the moving turbine during the reduction of the kinetic energy of the shocking molecules. **This kind of entropy reduction is possible** even by the blade with higher temperature than the static temperature of the gas. This reduction would be impossible in a contact heat exchanger – as the laws of thermodynamics state.

We name ETD for **engine** not for heat engine.

Macroscopic definition: ETD is an engine which extracts mechanical work from the volumetric work difference of the intake and exhaust and the heat content difference of the intake and exhaust of the ambient air or gas.

The more mechanical work is extracted by the turbine the more amount of heat energy reduction occurs. The k_B Boltzmann-constant provides the link between the macroscopic and molecular thermodynamics: $pV = N\,k_B T$. The multiplication of the pressure and the volume is equal to the multiplication of the Boltzmann-constant and absolute temperature for N molecules. Fig. 2 - 5 show the definition of the temperature changes of the ETD cycle.

The average velocity of the molecules is *500 m/s* for air on *293 K (20 °C)* temperature and 1 bar pressure:

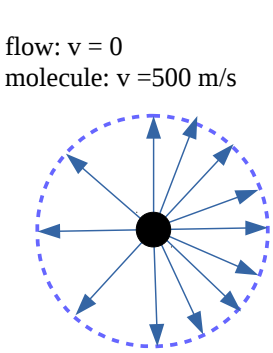


Fig. 2.
Intake point 1

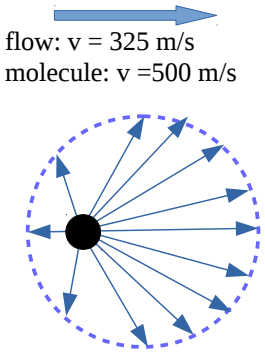


Fig. 3.
Turbine in point 2

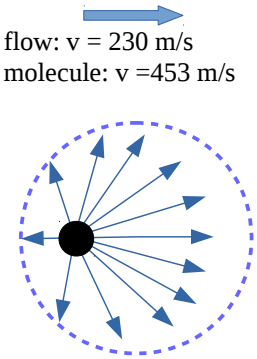


Fig. 4.
Turbine out point 3

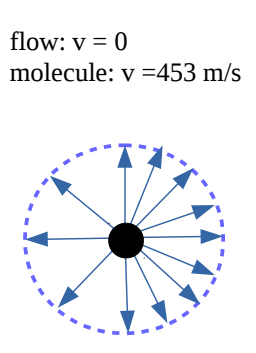


Fig. 5.
Exhaust point 4

Fig. 2. shows the average air molecule with *500 m/s* average velocity thermal motion at point 1. The vectors show the random velocity distribution. Fig. 3. shows the gas molecule at point 2 with *500+325=825 m/s* velocity forward and with *500-325=175 m/s* velocity backward – related to the

fixed coordinate system. Fig. 4. shows the molecule at point 3 where the *175 m/s* backward velocity is unchanged and the forward velocity reduced to *825-(325-230)=730 m/s* because of the turbine. The endpoints of the vectors define a new circle with *(730+175)/2=453 m/s* radius. Fig. 5. shows the 453 m/s average velocity around the molecule symmetrically with zero flow velocity.

The equation $\frac{1}{2}mv^2 = 3/2k_BT$ defines the relationship between the m molecule mess, v average velocity of the thermal motion, k_B Boltzmann-constant and T absolute (kinetic) temperature. The changes of the kinetic energy of the molecules are proportional to the changes of the absolute temperature. Fig. 2-5 show the *453/500* radius and velocity reduction as well.

We apply the $\beta=v_3^2/v_2^2$ rate of velocity which is equal to $453^2/500^2=0,82$ in our example.

The l mean free path is calculated by equation (1.4). [3] [4] [5]

$$l=\frac{k_BT}{\sqrt{2}\cdot 4\,p\,\sigma}=\frac{\lambda(T)}{p} \qquad (1.4)$$

where p is the characteristic static pressure, T is the static temperature, σ is the size of the molecules and $\lambda(T)$ is the temperature function.

The cited works 3, 4 and 5 give different results for the mean free path for ambient air with 20 °C temperature and 100 kPa pressure: from $6*10^{-5}$ mm to $6.6*10^{-5}$ mm. 63 % of the molecules collide in this distance and 36 % of the molecules in 5 times larger distance. The difference originates from the statistical calculation difference, but in our case we only use the dependency information and we don't use the actual value. Equation (1.4) shows: the change of the mean free path is proportional to the change of the absolute temperature and to the $\beta=v_3^2/v_2^2$ rate of velocity which is equal to the changes of the molecular kinetic energy as well. The change of the mean free path causes the changes of the specific volume which is proportional to the β^3. The change of density is calculated by equation (1.5):

$$\frac{\rho_3}{\rho_2}=\beta^{-3}=1,814 \qquad (1.5)$$

Density of the flowing air has been increased when temperature and entropy decreased.

The mean free path of the molecules decreased by $T_3/T_2=v_3^2/v_2^2=\beta$ rate of velocity. The number of collisions increased by the β^{-2} function on the reference surface. Molecules collided $\beta^{-1/2}$ times more frequently on the given velocity and moving on shorter „l" distance. The increase of the static pressure depends on the β rate of velocity, β^{-2} rate of the number of collisions and the $\beta^{-1/2}$ rate of booster functions. The p_{s2} static pressure is calculated by the equation (1.6) by multiplying the p_{s3} static pressure and the three β functions above:

$$p_{s3}=\beta\,\beta^{-2}\,\beta^{-1/2}\,p_{s2}=\beta^{-3/2}\,p_{s2}=1,345\,p_{s2} \qquad (1.6)$$

3 Mean Free Path, Molecular Collisions, Hyperphysics.phy-astr.gsu.edu. Retrieved 2011-11-08.

4 Bohátka S. és Langer G. (2012) Vákuumtechnika, atomki.hu A-M1 1-2-3..pdf 15.p

5 Dr.Nagy K. (1990/2011) Termodinamika és statisztikus mechanika, Tankönyvkiadó, www.tankonyvtar.hu, ch02s03 és ch02s06

The T_{s3} static temperature calculation with β rate of velocity:

$$T_{s3} = T_{s2}\,\beta \tag{1.7}$$

The $T_4 = T_3$ stagnation temperature equation gives:

$$T_4 = T_{s3}\left(\frac{p_4}{p_{s3}}\right)^{\frac{\gamma-1}{\gamma}} \tag{1.8}$$

We can check the closing of the ETD cycle with the equation (1.1), because the adiabatic (isentropic) acceleration and deceleration are reversible. After substitution of the p_4, p_{s3} *and* T_4 the result gives the minimal flow velocity which is needed for exhaust. If this v_{3x} velocity is equal or smaller than the v_3 velocity of point 3 (see (1.1) and (1.2) equations), the v_3 velocity and the kinetic energy is enough to exhaust the gas and close the ETD cycle.

$$v_{3x} = \sqrt{\frac{2\gamma}{\gamma-1} RT_4\left[1-\left(\frac{p_{s3}}{p_4}\right)^{\frac{\gamma-1}{\gamma}}\right]} \tag{1.9}$$

If p_4 stagnation pressure equal or larger than p_1 stagnation pressure with v_3 velocity at point 3, than the process has a positive feedback in pressure and the v_2 velocity is increasing up to the local sonic velocity. The process or cycle needs the work extraction by the turbine to have a steady working point.

SUMMARY

The transport processes are: intake and exhaust of gas and work extraction by the turbine. The energy balance of the ETD cycle has an **input side** with volumetric work of the ambient air (working fluid) intake and the $q = C_p * \Delta T$ heat reduction of the working fluid and has an **output side** with volumetric work of the fluid exhaust and the extracted mechanical work.

The $\beta(v,t)$ rate of velocity is a time function which defines the molecular kinetic energy changes in the flowing fluid. Because of the time functions we need the molecular tools to explain the ETD cycle. The interpretation of the time-dependent static pressure change is not included in the classical enthalpy-based thermodynamics.

The adiabatic and isentropic gas flow acceleration from point 1 to 2 and deceleration from point 3 to 4 are calculable by the compressible extension of the Bernoulli-equation (1.1) and (1.9). The key is the process between point 2 and 3 – in the turbine. Cited works 1 and 2 describe the static- and stagnation pressure increasing process during the entropy reduction in a gas flow. The entropy can be reduced in a colder heat exchanger or in a turbine. We apply this effect in the turbine to close the ETD cycle at the exhaust. The p_4 stagnation pressure is higher than p_1 ambient air pressure. The extracted work is the "waste energy" of the process. The exhausted gas contains less entropy than the ambient air.

In a real case there are friction and isolation losses also. The projected rate of the loss is less than 50% of the theoretical power. The losses cause pressure decreasing so we need to use this part of

the power to drive a blower before the exhaust. The other 50% or more power is the extractable power. If we build the ETD in to a closed reservoir or tank the static pressure can be 10-50 bar or more. The higher density increases the specific power but then we need a heat exchanger to refuel the extracted energy. Without the additional heat source the ETD cools down the gas until its condensation temperature.

EXAMPLE

Working fluid: Air with $T_1 = 293\ K$ (20 °C) *1 bar* pressure, dry and ideal gas. ($\gamma = 1.4$).

Adiabatic nozzle calculation with eq. (1.1)

$$v_2 = \sqrt{0 + \frac{2,8}{1,4-1} 287 * 293 \left[1 - \left(\frac{0,5}{1,0}\right)^{\frac{1,4-1}{1,4}}\right]} = 325 \text{ m/s}$$

Static temperature at point 2 calculation with eq. (1.2)

$$T_{s2} = 293 \left(\frac{0,5}{1,0}\right)^{\frac{1,4-1}{1,4}} = 240 \text{ K } (-33 \text{ °C})$$

The flow velocity in point 3 with eq. (1.3)

$$v_3 = 325/\sqrt{2} = 230 \text{ m/s}$$

The p_{s3} static pressure at point 3 calculation with eq. (1.6)

$$P_{s3} = \beta^{-3/2}\ p_{s2} = 1,347 * 0,5 = 0,675\ bar$$

The T_{s3} static temperature in point 3 calculation with eq.(1.7)

$$T_{s3} = \beta\ T_{s2} = 0,82 * 240 = 197 \text{ K } (-76 \text{ °C})$$

The stagnation temperature at point 4 calculated with eq. (1.8)

$$T_4 = 197 \left(\frac{1,0}{0,675}\right)^{\frac{1,4-1}{1,4}} = 220 \text{ K } (-53 \text{ °C})$$

The v_{3x} control velocity with eq. (1.9)

$$\sqrt{\frac{2,8}{1,4-1} 287 * 220 \left[1 - \left(\frac{0,675}{1,0}\right)^{\frac{1,4-1}{1,4}}\right]} = 217$$

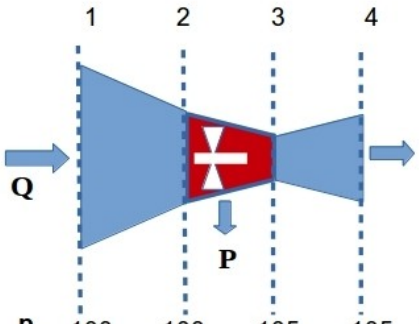
The $v_{3x} = 217$ m/s velocity is enough for exhaust, but we have more: *230* m/s. It is large enough for closing the ETD cycle.

Other control definition: If we calculate the exhaust with $v_3 = 230$ m/s velocity it causes *0,05* bar additional dynamic pressure. The p_4 stagnation pressure is *1,05* bar which is enough for exhaust to $p_1 = 1,0$ bar room pressure.

The stagnation pressure is enough for the exhaust process to close the ETD cycle.

SAMPLE RESULTS:

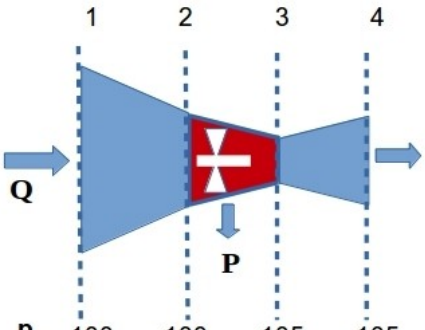
R = 287 (J/kgK)
γ = Cp/Cv = 1,4
Cp = 1000 (J/kgK)



	1	2	3	4	
p_0	100	100	105	105	(kPa)
p_{st}	100	50	68	105	(kPa)
T_0	293	293	223	223	(K)
T_{st}	293	240	197	223	(K)
v	1	325	230	1	(m/s)
ρ	1,19	0,72	1,32	1,81	(kg/m^3)

Q = 362 (m^3/h)
P = 8,5 (kW)
ΔT_0 = 70 (K)

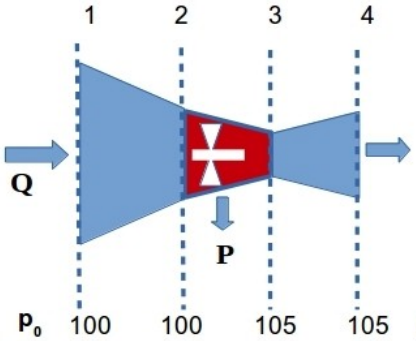
R = 287 (J/kgK)
γ = Cp/Cv = 1,4
Cp = 1000 (J/kgK)



	1	2	3	4	
p_0	100	100	105	105	(kPa)
p_{st}	99	50	68	105	(kPa)
T_0	293	293	222	222	(K)
T_{st}	293	239	196	222	(K)
v	30	328	232	20	(m/s)
ρ	1,19	0,72	1,33	1,82	(kg/m^3)

Q = 365 (m^3/h)
P = 8,7 (kW)
ΔT_0 = 71 (K)

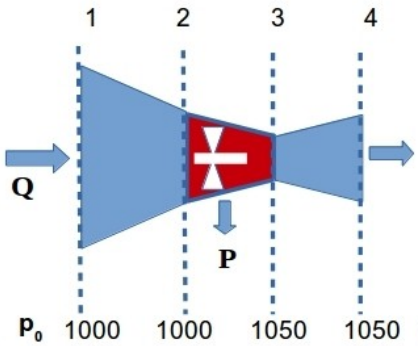
R = 287 (J/kgK)
γ = Cp/Cv = 1,4
Cp = 1000 (J/kgK)



	1	2	3	4	
p_0	100	100	105	105	(kPa)
p_{st}	100	50	66	105	(kPa)
T_0	253	253	197	197	(K)
T_{st}	253	207	172	197	(K)
v	1	302	214	1	(m/s)
ρ	1,38	0,84	1,46	2,04	(kg/m^3)

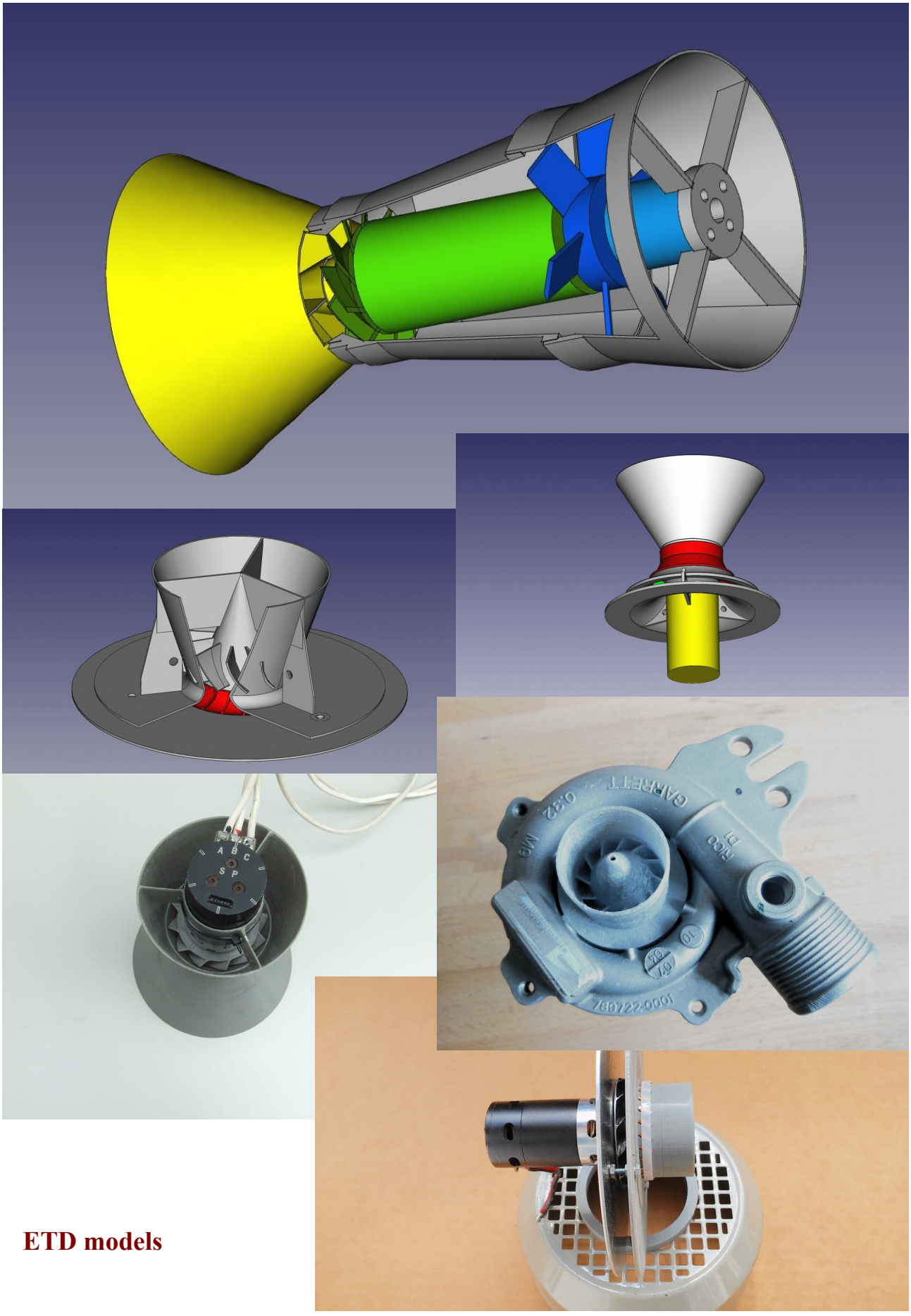
Q = 336 (m^3/h)
P = 6,8 (kW)
ΔT_0 = 56 (K)

R = 287 (J/kgK)
γ = Cp/Cv = 1,4
Cp = 1000 (J/kgK)



	1	2	3	4	
p_0	1000	1000	1050	1050	(kPa)
p_{st}	1000	500	675	1050	(kPa)
T_0	293	293	223	223	(K)
T_{st}	293	240	197	223	(K)
v	1	325	230	1	(m/s)
ρ	11,89	7,25	13,21	18,12	(kg/m^3)

Q = 362 (m^3/h)
P = 84,9 (kW)
ΔT_0 = 70 (K)



ETD models