PROCESS FOR COOLING AND FOR THE USE OF ENVIRONMENTAL HEAT

(Offer documentation PCT/HU2025050020)

Introduction:

The present description, prepared based on the PCT international application under provisional protection, is a preparatory document for the national phase. The description has been assigned reference numbers (Ref.x) for easier referencing.

The document consists of four main parts:

- overview (Ref.1)
- basic process (Ref.14)
- basic machine (Ref.35)
- examples (Ref.46)

I. Overview

1. The subject of the invention is a method for cooling and for the utilization of environmental heat, which, when implemented in a thermodynamic machine designed for this purpose, can operate economically even at cryogenic temperatures. Its essence is that the heat energy absorbed during cooling is converted into work. The basic process is realized in such a way that it **converts higher-temperature vapor into lower-temperature liquid.** The cooling process thus created, when used as a base process, is capable, with a conventional power plant process operating below ambient temperature, of utilizing environmental heat.

2. At present, the overwhelming majority of society's energy demand is produced by heat engines and internal combustion engines. Their use involves the consumption of many harmful and expensive energy carriers – coal, gas, gasoline, etc. **Another objective of the present study is to enable the utilization of a large amount of waste and environmental heat energy** – hereinafter referred to as environmental heat – thereby providing clean, inexpensive mechanical and electrical energy. In currently known cooling processes, the deeper cooling we want to achieve, the more uneconomical it becomes. **The cooling process presented here is independent of the ambient temperature, therefore it can operate economically even at cryogenic temperatures.**

3. Basic process (W3), cooling (Co), liquefaction (Lf) (Ref.14)

With regard to the state of the art, the objective was to develop a process for cooling in which the heat energy absorbed during cooling is taken up by the evaporation heat demand of the liquid-state working medium. **The absorbed energy is then converted into work.** In the drawings, the cycle of the basic process is marked as W3.

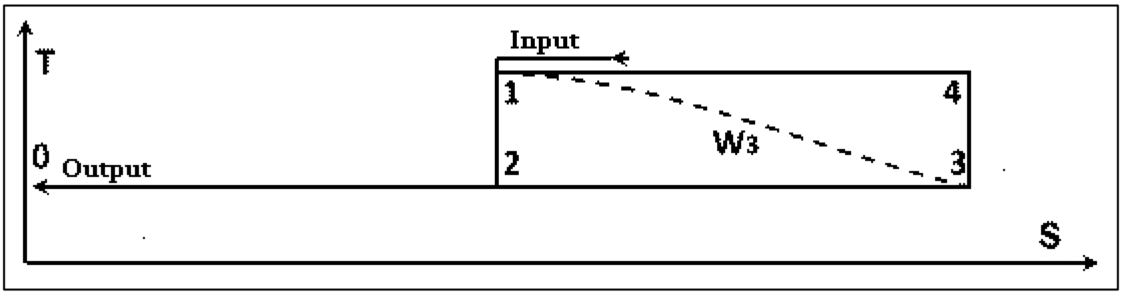
4. Recognition, liquefaction

The greatest cooling effect can be produced by the boiling of the liquid working medium, or in other words by the heat of evaporation. The following can be observed in the figure below:

The high-temperature, high-pressure gas expands and thereby loses its temperature and pressure, moving from point 1 to point 2. During the process, part of the working medium moves to point 0, condenses, while the remaining vapor cools and expands to state 3. By the end of the process, the energy of the liquid becomes smaller by as much as the energy of the vapor becomes larger, but overall, it becomes smaller by the amount of work produced. One of the roles of the low-energy liquid is to provide a cooling effect for the recompression of the vapor.

The vapor moves from point 3 to point 4 by adiabatic compression.

If the predetermined amount of liquid and the vapor compressed to a higher temperature are introduced into a mixing cylinder, an unstable state is created. The liquid begins to evaporate and, with its heat of boiling, removes heat from the vapor. The evaporated liquid mixes with the vapor, thereby increasing the mass and density of the vapor, but the liquid primarily cools the vapor-phase working medium.



5. We have recognized that if the temperature decrease is prevented by compression, the working medium begins to become denser for two reasons:

- on the one hand, due to compression the volume decreases,
- on the other hand, in the decreasing volume the mass of the vapor increases.

As a result, a state change is created which returns the vapor working medium to the original state at point 1. In the process, it is **not necessary to mix in all of the liquid. The remaining liquid can be utilized freely.** (Reproducible calculation Ref.14)

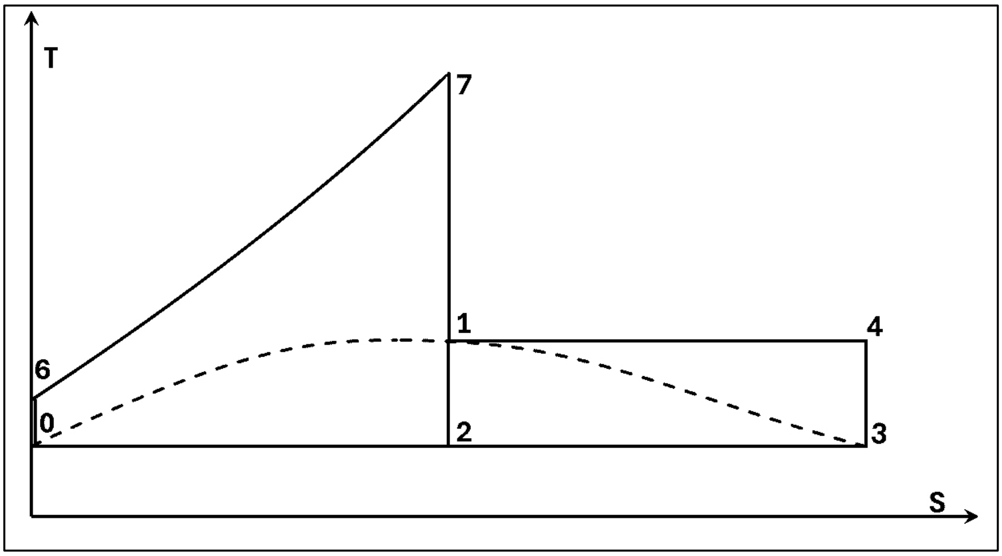
6. Utilization of environmental heat, basic machine (Ref.35)
Since heat energy flows from the warmer place to the colder place, the heat engine must carry out the process at a temperature below the environmental temperature. In a conventional thermal power plant process, the working medium is heated in a boiler to dry steam, and the exhaust steam is cooled to liquid state by environmental heat.

7. In the case of a heat engine operating below environmental temperature, this process is formed in such a way that instead of a boiler, a heat exchanger performs the heating to dry steam. **The cooling of the exhaust steam is carried out by the economical cooling process described here**.

8. Cooling–power source
The process according to the invention, serving for cooling and for the utilization of environmental heat, consumes a part of the produced work, but the remaining part can be used as useful energy. This is the **direct Co/Pp** (Ref.35) **or CoPp** (Ref.47) **cooling–power source.**

As known from the previous description, the cooling unit of the basic process produces cooled liquid from higher-temperature vapor.

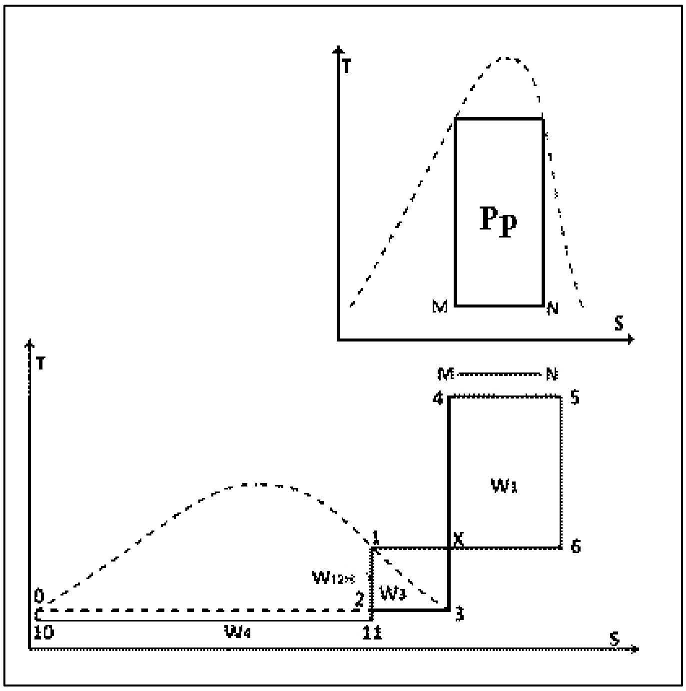
9. The Co/Pp cooling–power source directly uses the remaining useful liquid as the initial-state liquid of the power plant process. The Pp performs the process with a generally accepted power plant procedure: compression, isobaric heating, expansion. It is important that at the end of the process the original vapor returns to the state at point 1, thereby replenishing the used vapor.



10. In the case of CoPp, the working medium also reaches the original state at point 1, but it uses the vapor as the power source, and the smaller amount of liquid is used only during the mixing combined with compression. The cooling unit of the basic process and the complex operations of the **power source cannot be separated**, therefore it can be considered an integrated process. Detailed explanation (Ref.47)

11. Series connection of cooling–power sources (Ref.49), (Ref.50)

Another main objective of the cooling process is to realize the utilization of environmental heat in such a way that the cooler or cooling–power source makes the conventional **Pp power plant process operable at a temperature below the environmental temperature** by cooling the exhaust steam working medium back to liquid state. The advantage of a power plant operating below environmental temperature is that instead of a conventional boiler, the conversion of the working medium into high-pressure saturated steam is carried out by a heat exchanger, which receives its energy from environmental heat. This is another version of a process suitable for the utilization of environmental heat. By applying the cooler or cooling–power source discussed here as a basic machine, the utilization of environmental heat by the **Pp can also be realized with previously known technical solutions**.



12. Second law of thermodynamics

The submission is based on the formalism of the classical second law of thermodynamics, with particular regard to the following relations: $\Delta S \geq \int \delta Q/T$, $\delta Q_{rev} = T\,dS$ and **the area interpretation of the T–s diagram, which is a standard method** applied in the reversible approximation. The calculations are presented along these relations in a reproducible manner.

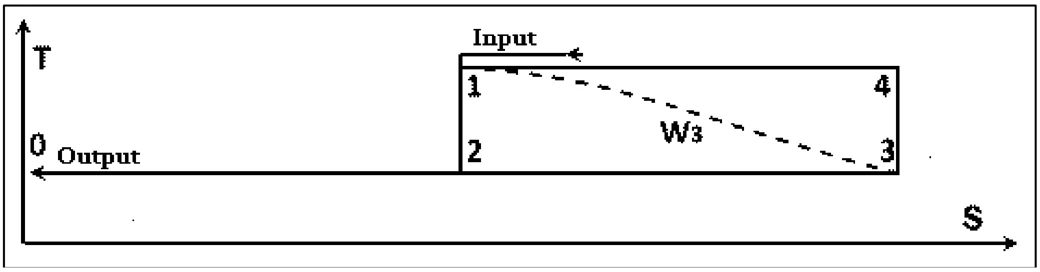
13. In the following, the description uses **the following expressions and notations:**

- basic process symbol **W3**,
- basic machine: machines that realize a basic process and various processes utilizing the liquid produced by it. Symbol: **Lf, Co, Co/Pp**,
- example A: integrated basic machine, symbol **CoPp**,
- example B: basic machine and power plant process, symbol **CoPp+Pp**,
- example C: basic machine and power plant processes, symbol **Co/Pp+2*Pp,**
- in the drawings and diagrams, identical states are marked with **points 1, 2,** etc,

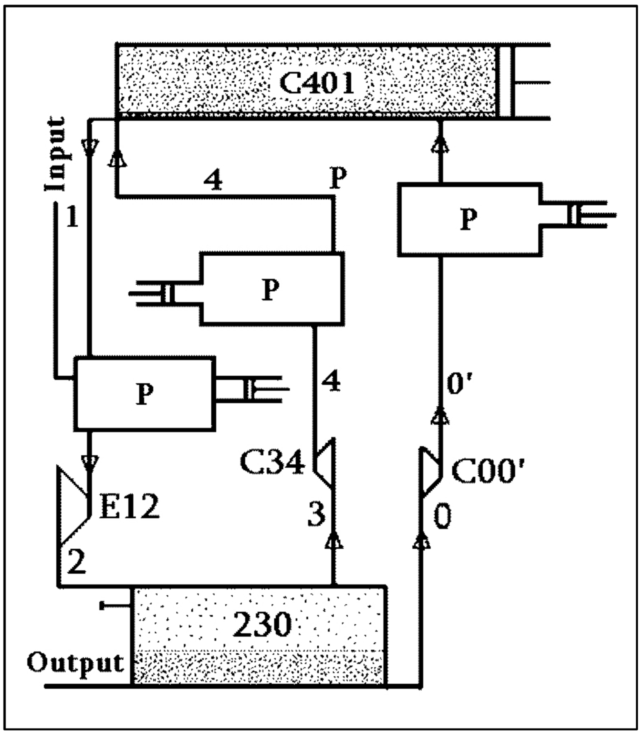
- in the schematic figures, the machine units marked with **C denote compression machines, E denote expansion machines**, and their **numbering corresponds to the inlet and outlet points**. (e.g.: C1–2).

II. The basic process W3

14. In the figure below, the cycle presented by the points 1–2–3–4–1 is the W3 basic process.



The 1–2 (E12) expansion is necessary to split the working medium into liquid and saturated vapor phases, and this is where the conversion of heat into work takes place. During the 1–2 process, the working medium proceeds along the 1–0 and 1–3 saturation curves and separates into (230) liquid at point 0 and saturated vapor at point 3.



With the (C34) compression, the temperature of the vapor at point 3 is increased to the specified temperature at point 4, and the already calculated mass of liquid at point 0' is also compressed into the mixing cylinder by (C00').

The liquid at point 0' and the vapor working medium at point 4 are subjected to a 4–1 (401) compression combined with mixing. In this process step, by introducing the appropriate amount of liquid at point 0 and the vapor at point 4 into the C401 working cylinder and advancing the piston. The temperature decrease of the vapor at point 4 can be prevented and the vapor becomes denser. The higher temperature vapor at point 4 and the lower temperature liquid at point 0 create an unstable state, in which the saturated vapor at point 4 would cool while the liquid at point 0 would evaporate.

If compression is carried out with the piston to such an extent that the temperature remains constant, that is, the unstable state is maintained during the evaporation process, then the mixture can reach point 1. In the case of a properly set mass ratio of liquid and vapor, all of the introduced liquid evaporates, thereby forming a homogeneous, stable vapor at state 1. It is important to note that the full amount of liquid at point 0 is not required for the process described here.

It is important to note that the W3 basic process is present in each basic machine.

15. Physics of mixing combined with compression

The essence of the process is that the heat loss occurring during mixing must be compensated for by compression, thereby:

- the isothermal state change is ensured, the unstable state is maintained,
- the mass in the cylinder increases, the pressure rises,
- the volume decreases, therefore additional pressure increase and densification occur,
- the increase in density during an isothermal **process means a decrease in entropy**.

In order for the working medium to reach a stable homogeneous state at point 1, **the vapor–liquid ratio must be precisely determined**. There are several methods for this calculation.

In the present case, the **mass balance method** is described.

16. This description presents the steps of the **design and interpretation of a thermodynamic cycle**. **The purpose** of the description is not to demonstrate the feasibility or performance of a specific device, but to show that the **described process is feasible on a conceptual level**, and that the internal thermodynamic consistency of the applied cycle can be examined by independent experts.

17. Determination of characteristic states

Determination of point 1: for the sake of simplicity, it has been placed at one point of the saturation curve. In practice, this should of course be avoided, because wet steam may form. When setting the entropy, the main consideration was that upon reaching point 2, the vapor splits into two equal parts (vapor, liquid), thereby forming 1 kg liquid and 1 kg vapor. In order to obtain 1–1 kg, 2 kg of working medium had to be defined at point 1. This is important because the mass of the vapor at point 3 is 1 kg, therefore the saturation curve is also of 1 kg value, which simplifies further calculations. The data given in the NIST tables can be applied in a 1/1 ratio.

Properties of state point 1:

T1 (K)	P1 (MPa)	D1 (kg/m3)	V1 (m3/kg)	U1 (kJ/kg)	H1 (kJ/kg)	S 1(J/g*K)
32,799	1,2598	24,738	0,0404	289,08	340,01	11,004

Properties of point 2: in reality, it is a theoretical value, because its two components, liquid at point 0 and vapor at point 3, have independent properties. It is required for calculation purposes.

Therefore, it has its own values.

T2	p2	d2	% 2	u2	h2	s2
20,271	0,1013	2,627	0,5%	184,5	223,06	11,004

Properties of point 0: pure liquid. During the process, the liquid is separated from the vapor. Later, it is used in two parts.

T0	p0	d0	v0	u0	h0	s0
20,271	0,1013	70,828	0,0141	-1,433	0,00	0

Properties of point 3: pure vapor. Separated from the liquid, it takes part in further processes (3–4, 4–1).

T3	p3	d3	v3	u3	h3	s3
20,271	0,1013	1,339	0,7471	370,37	446,06	22,005

Properties of point 4:

T4	p4	d4	v4	u4	h4	s4
32,799	0,3329	2,710	0,3690	438,89	561,73	22,005

18. State changes

1–2 points adiabatic expansion: between the two points, the decrease of the enthalpy of the working medium appears in the form of mechanical work ($w_{12} = h_1 - h_2$).

(On the perpi.hu website, I applied a closed system illustration in a schematic diagram for easier understanding.) In this section, the heat energy taken up by the working medium during the cooling process appears in the form of mechanical work.

The working medium splits into liquid at point 0 and vapor at point 3. Their utilization takes place separately.

3–4 points adiabatic compression: its task is to raise the working medium to a higher temperature. Practically, it is advisable to raise the temperature of the working medium to the temperature at point 1. Its essence is to ensure an unstable state during the later mixing combined with compression. Meanwhile, its pressure also increases, thereby approaching the pressure to be achieved at point 1. Its formula: ($w_{34} = h_4 - h_3$)

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19. 4–1 point mixing combined with isothermal compression:

The task of the 4–1 point section is to **return the vapor at state point 4 to the original state, point 1.** The process can be interpreted as an isothermal compression combined with mixing.

In practice, this can be illustrated in such a way that by **injecting liquid at state point 0 into the vapor at state point 4, an unstable state is created**. During mixing, the vapor phase would tend to cool, and the liquid would tend to evaporate, however the continuous compression prevents the temperature decrease.

As a result**, the process takes place as an isothermal-type compression**. Due to compression, the density of the vapor working medium increases, its entropy decreases, while due to the evaporating liquid, the mass of the vapor phase continuously increases.

The increasing vapor mass in the system with decreasing volume results in further densification and entropy decrease. This **dual effect makes it possible for the working medium to return to point 1** corresponding to the base state, and for the cycle to close.

For the **execution of the process, it is not necessary to use the entire amount of liquid at** state point 0. The **remaining liquid quantity can be utilized in further steps** of the cooling and work-producing processes.

It is an important requirement that, regardless of the way the remaining useful liquid is utilized, the working medium at point 0 must return to state point 1 at the end of the cycle, since this is the basic condition for the realizability of the closed thermodynamic cycle.

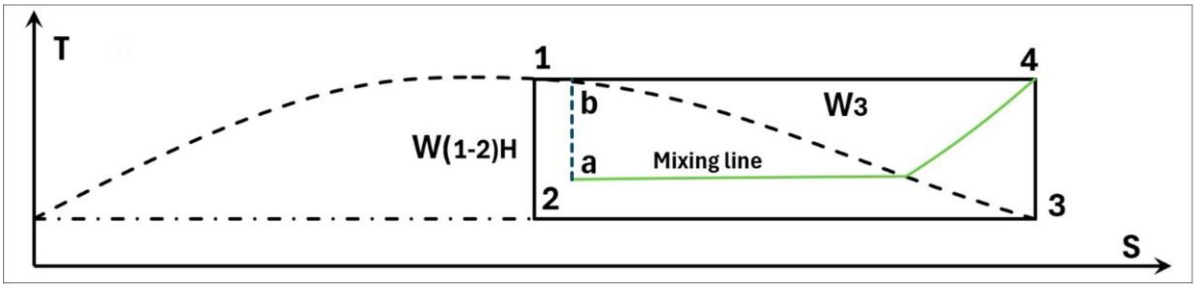
Mass ratio calculation

20. The purpose of the mass ratio calculation is to determine **how much liquid at state point 0 must be injected into the cylinder** in order that, upon reaching state point 1, the **liquid is completely consumed, and a stable thermodynamic state is formed**. For the calculation, the application rules of two known processes must be clarified.

mixing curve:

To understand the mixing process, as a first step we examine the case when the **piston does not move**, that is, the **volume of the cylinder is constant**. In this state, the mixing of the vapor in the cylinder and the injected liquid at state 0 point takes place. The injected liquid becomes vapor during the mixing, while the resulting vapor mass **continuously occupies space proportional to its mass** relative to the total mass. As a consequence, **the density of the vapor in the given volume increases**, since an increasingly larger mass of gas enters the same volume.

At the same time, the evaporation of the **liquid cools the temperature of the vapor**, which in itself would result in a decrease in density. However, during the mixing process, these two effects are present simultaneously, and the resulting state change is formed as a combination of temperature, density, and entropy changes.



On the above T–s diagram, the **4–a represents the state change resulting from mixing at constant volume.** This mixing curve describes the transition along which the state of the vapor working medium changes as a function of the amount of vapor formed from the injected liquid. The state corresponding to the mixing of the entire 1 kg of liquid is at point a.

21. It is important to observe that the objective could not be achieved for two reasons. Its **temperature is lower**, while its **entropy is higher** than the value at point 1. In order to achieve the objective, the working medium must be **compressed simultaneously** with mixing in such a way that the temperature does not decrease. **This has three favorable effects**:

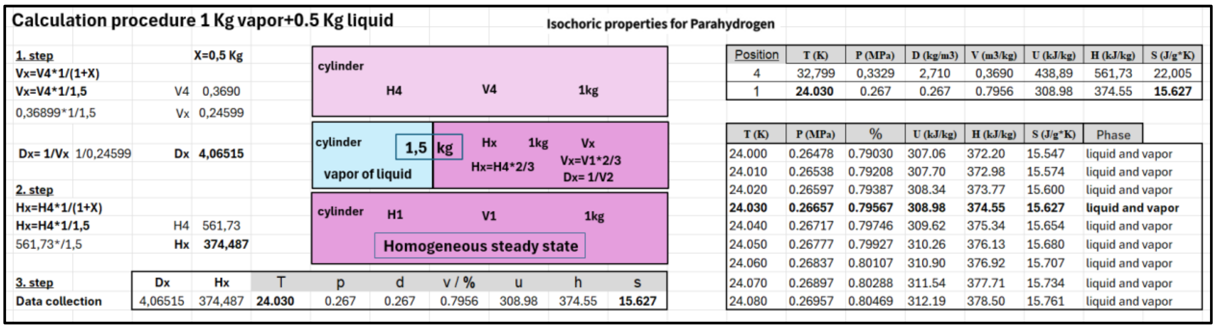
- due to compression, the cylinder volume decreases, the vapor becomes denser, its entropy decreases,
- due to the increased mass of vapor, it becomes even more intensively denser, its entropy decreases,
- the temperature remains at the desired value, the unstable state is ensured up to the full 1p state.

It can be seen in the figure that even without compression, more than 90% of the entropy decrease has been achieved. The area bounded by the points 4–a–b–4 in the figure is the Q heat loss suffered by the working medium. If not all of the available 1 kg of liquid is used, then the heat loss will be less and less compression will also be sufficient.

The determination of the mixing curve is of fundamental importance, because it serves as the basis for calculating the required liquid–vapor mass ratio, as well as for determining whether the working medium is capable of reaching the stable state at point 1 at the end of the mixing process.

22. Theory of mass ratio calculation (Simplified example Ref. 22-26)

The theory of the mass ratio calculation is based on the fact that the two state variables of 1 kg of vapor (in this case density and entropy) determine all other values. In the example below, for the sake of illustration, 1 kg of vapor and 0.5 kg of liquid are used.



Calculation procedure 1 Kg vapor+0.5 Kg liquid

Isochoric properties for Parahydrogen

1. step X=0,5 Kg
Vx=V4*1/(1+X)
Vx=V4*1/1,5 V4 0,3690
0,36899*1/1,5 Vx 0,24599

Dx= 1/Vx 1/0,24599 Dx **4,06515**

2. step
Hx=H4*1/(1+X)
Hx=H4*1/1,5 H4 561,73
561,73*/1,5 Hx **374,487**

3. step	Dx	Hx	T	p	d	v / %	u	h	s
Data collection	4,06515	374,487	**24.030**	0.267	0.267	0.7956	308.98	374.55	**15.627**

Position	T (K)	P (MPa)	D (kg/m3)	V (m3/kg)	U (kJ/kg)	H (kJ/kg)	S (J/g*K)
4	32,799	0,3329	2,710	0,3690	438,89	561,73	22,005
1	**24.030**	0.267	0.267	0.7956	308.98	374.55	**15.627**

T (K)	P (MPa)	%	U (kJ/kg)	H (kJ/kg)	S (J/g*K)	Phase
24.000	0.26478	0.79030	307.06	372.20	15.547	liquid and vapor
24.010	0.26538	0.79208	307.70	372.98	15.574	liquid and vapor
24.020	0.26597	0.79387	308.34	373.77	15.600	liquid and vapor
24.030	**0.26657**	**0.79567**	**308.98**	**374.55**	**15.627**	**liquid and vapor**
24.040	0.26717	0.79746	309.62	375.34	15.654	liquid and vapor
24.050	0.26777	0.79927	310.26	376.13	15.680	liquid and vapor
24.060	0.26837	0.80107	310.90	376.92	15.707	liquid and vapor
24.070	0.26897	0.80288	311.54	377.71	15.734	liquid and vapor
24.080	0.26957	0.80469	312.19	378.50	15.761	liquid and vapor

In the above figure, the 3 rectangles show the 3 states of a cylinder. The first is the initial state at point 4. The second rectangle corresponds to the state of the third one, therefore it is vapor of the same color and pressure; it is marked in blue only because that volume is the volume of the vapor of the liquid. The red part next to the blue illustrates that although the cylinder volume has not changed, because of the vapor of the liquid, the original 1 kg of vapor has been forced into a smaller area. Therefore, its density increased, and its volume, enthalpy, and entropy decreased.

23. Formulas of mass ratio calculation

The formulas of the calculation described here can be checked with concrete numbers in the table. Based on this, the required data can be obtained with the following calculations:

- With the formula **Vx = V4*1/(1+X)**, (X kg liquid), we determine the volume, then its density with **Dx = 1/Vx.**
- With the formula Hx = **H4*1/(1+X),** its enthalpy is determined, because the vapor transfers one third of its energy to the liquid.

With this calculation, two new state values of the original 1 kg vapor at state point 4 have been determined, on the basis of which the **other state values can be read from the table**.

24. Practical implementation of mass ratio calculation

By opening the following link, the Isochoric properties for Parahydrogen page opens, and the following data must be entered into the appropriate fields:

- density: Dx
- it is advisable to enter a larger range into the temperature field at first
- the previously determined enthalpy Hx must be found
- it is advisable to refine this by an approximation method until the desired accuracy is reached.

Website address:
https://webbook.nist.gov/chemistry/fluid/
https://webbook.nist.gov/cgi/fluid.cgi?ID=B5000001&TUnit=K&PUnit=MPa&DUnit=kg%2Fm3&HUnit=kJ%2Fkg&WUnit=m%2Fs&VisUnit=uPa*s&STUnit=N%2Fm&Type=IsoChor&RefState=DEF&Action=Page

After setting the desired units of measurement, in the present case: Kelvin, MPa, kg/m3, kJ/kg, by setting the units of measurement we can proceed to the next webpage, where the above search can be carried out.

Thermophysical Properties of Fluid Systems

Accurate thermophysical properties are available for several fluids. These data include the following:

- Density
- C_p
- Enthalpy
- Internal energy
- Viscosity
- Joule-Thomson coefficient
- Specific volume
- C_v
- Entropy
- Speed of Sound
- Thermal conductivity
- Surface tension (saturation curve only)

Please follow the steps below to select the data required.

1. Please select the species of interest: Parahydrogen
2. Please choose the units you wish to use:
   - Temperature: ● Kelvin ○ Celsius ○ Fahrenheit ○ Rankine
   - Pressure: ● MPa ○ bar ○ atm. ○ torr ○ psia
   - Density: ○ mol/l ○ mol/m³ ○ g/ml ● kg/m³ ○ lb-mole/ft³ ○ lbm/ft³
   - Energy: ○ kJ/mol ● kJ/kg ○ kcal/mol ○ Btu/lb-mole ○ kcal/g ○ Btu/lbm
   - Velocity: ● m/s ○ ft/s ○ mph
   - Viscosity: ○ μPa*s ● Pa*s ○ cP ○ lbm/ft*s
   - Surface tension*: ● N/m ○ dyn/cm ○ lb/ft ○ lb/in

   *Surface tension values are only available along the saturation curve.
3. Choose the desired type of data:
   - Data type: ○ Isothermal properties ○ Isobaric properties ● Isochoric properties ○ Saturation properties — temperature increments ○ Saturation properties — pressure increments
4. Please select the desired standard state convention:
   - Standard state convention: ● Default for fluid ○ Normal B.P. convention ○ ASHRAE convention ○ IIR convention
5. Press to Continue

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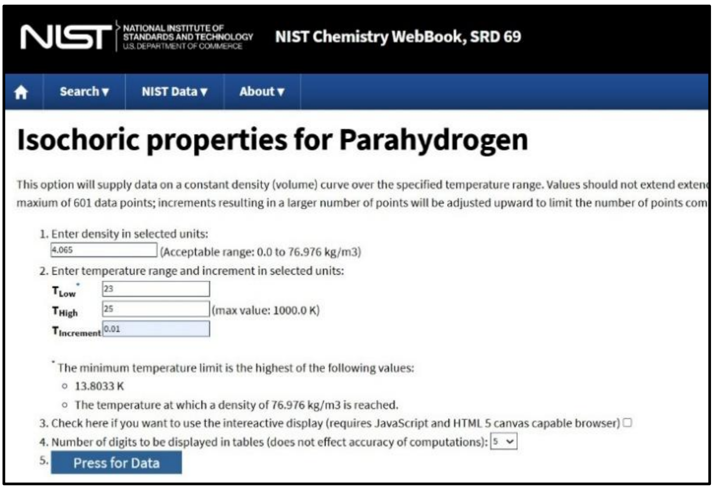


Isochoric properties for Parahydrogen

This option will supply data on a constant density (volume) curve over the specified temperature range. Values should not extend exten
maxium of 601 data points; increments resulting in a larger number of points will be adjusted upward to limit the number of points com

1. Enter density in selected units: 4.065 (Acceptable range: 0.0 to 76.976 kg/m3)
2. Enter temperature range and increment in selected units:
   - T_{Low}*: 23
   - T_{High}: 25 (max value: 1000.0 K)
   - $T_{Increment}$: 0.01

   *The minimum temperature limit is the highest of the following values:
   - 13.8033 K
   - The temperature at which a density of 76.976 kg/m3 is reached.
3. Check here if you want to use the intereactive display (requires JavaScript and HTML 5 canvas capable browser) ☐
4. Number of digits to be displayed in tables (does not effect accuracy of computations): 5
5. Press for Data

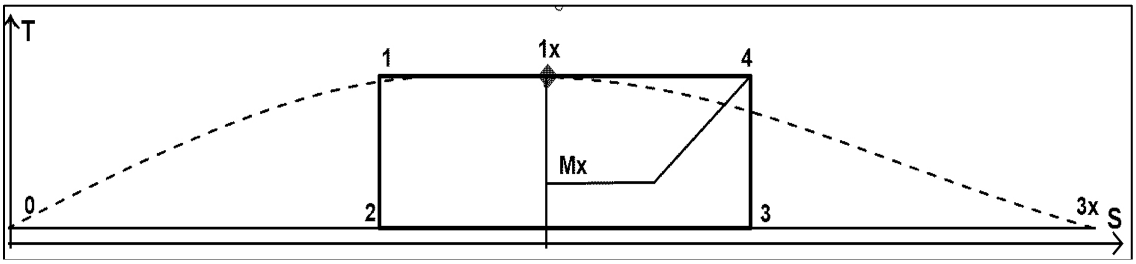
By selecting different liquid masses, even the entire mixing curve can be drawn.
It is important to notice that by **increasing the mass of the mixed-in liquid, the entropy of the mixture decreases.**

25. Saturation curve

The saturation curve, however, increases with the increase of vapor mass caused by the evaporation of the liquid, because the unit of entropy is kJ/kg*K.* (Due to the additive property of entropy.) As a result, the entropy of point 1 also increases. (Point 1: 11 kJ/kgK, 1x: 16 kJ/kg*K.) Therefore, with the **increase of the vapor mass, the entropy of point 1 increases** and takes the value of point 1x.

26. Determination of mass

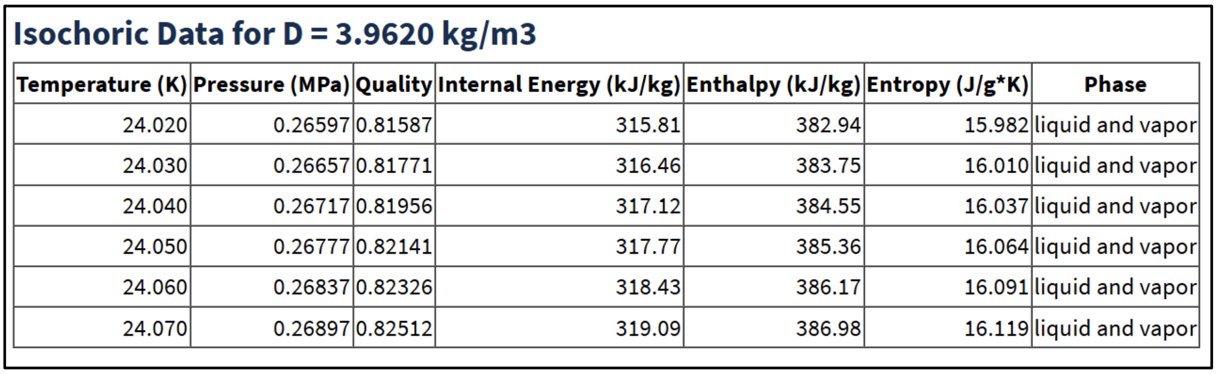
The **two entropies moving in opposite directions progress toward each other** as the mass of the mixed-in liquid increases. Where the entropy of the two functions is equal, there is the mass ratio of the liquid.



(End of simplified example Ref. 22-26)

27. Summary of mass ratio calculation

During the 4–1 point compression combined with mixing, the mass of the vapor working medium increases due to the evaporation of the liquid. Therefore, the vapor side of the saturation curve will have a higher entropy at point 3 and point 3x. As a consequence of this, the entropy of point 1 also takes a higher value at point 1x. However, despite the increase in vapor mass, the 4–Mx mixing curve becomes denser due to the volume decrease, and therefore its entropy decreases. **The amount of liquid required for the process is determined by the mass value of the mixing curve**. Where the entropy values of Mx and 1x meet (in the real process this is 16.05 kJ/kg*K, D = 3.9620, Enthalpy 384.55, in the table below), **there is the theoretical mass value required for mixing.**



Isochoric Data for D = 3.9620 kg/m3

Temperature (K)	Pressure (MPa)	Quality	Internal Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (J/g*K)	Phase
24.020	0.26597	0.81587	315.81	382.94	15.982	liquid and vapor
24.030	0.26657	0.81771	316.46	383.75	16.010	liquid and vapor
24.040	0.26717	0.81956	317.12	384.55	16.037	liquid and vapor
24.050	0.26777	0.82141	317.77	385.36	16.064	liquid and vapor
24.060	0.26837	0.82326	318.43	386.17	16.091	liquid and vapor
24.070	0.26897	0.82512	319.09	386.98	16.119	liquid and vapor

At this mass, all of the mixed-in liquid becomes vapor and a stable working medium at state point 1x is formed. **In the case of the real process, this value is 0.46 kg.** Accordingly, the mass of the vapor at point 3x is 1.46 kg. The remaining 0.54 kg liquid is the result of the cycle. For the purpose of illustrating the calculation, the quantity of the working medium was defined as 2 kg, therefore the result must also be divided by two. **Thus, the executing cooling machine theoretically produces 0.27 kg of liquid per cycle from 1 kg of vapor working medium in state one per cycle.**

28. Mass summary

The following mass ratios are formed:

- 1 kg vapor and the vapor of 0.46 kg liquid, therefore 1.46 kg,
- the quantity of the remaining liquid is 0.54 kg,
- total 2 kg.
- **in the case of 1 kg, 0.27 kg.**

The remaining liquid is the usable gain. In order for the cycle to operate cyclically, either 0.27 kg of working medium at state point 1 must be replenished into point 1, or the liquid must be brought to state point 1. In the **first case liquefaction** takes place, in the **other case cooling**.

Work requirement

29. The **work requirement of liquefaction consists of 3 parts:** W3 (1 kg), W(1–2) (0.46 kg), WLf (0.54 kg) (Ref.13). Calculated with a total of 2 kg initial working medium. **Since the official specific work requirement is usually given for 1 kg of initial working medium, we also give it under the name specific work at every step.**

30. W3 in the presented T–s diagrams (which is the characteristic figure in the patent application) has been made rectangular for easier understanding, because the determination of work ($W = Q = \oint T\,ds$) can be established by simple multiplication. In the case of the present cycle, **$Q = W = \Delta T * \Delta S$.**

In the table below (Ref.40), the work requirement of W3 can be established with the following calculations:

30. Work of W3

1–2p adiabatic 2 kg, but if only 1 kg of this is taken into account, then 1 kg

2–3p is clearly 1 kg, because the other 1 kg goes in the direction of the liquid 1 kg

3–4p is clearly 1 kg 1 kg

The mass of 4–1 point, however, continuously changes between 1–1.46 kg. But since it proceeds along the isothermal line, the shape of the p*V hyperbola remains unchanged. Therefore, from the point of view of work, it can be considered as 1 kg. There may be some inaccuracy in this, because it reaches point 1 state earlier, since the mass is larger in the piston space.

This raises the question whether the machine will be a closed or an open system? Will the cylinder space be larger by the volume of the liquid, because it is introduced together with the vapor?

During injection, does the entire liquid enter immediately, or continuously, at varying pressure? These are already product development problems. Thus, from the point of view of work estimation, the mass of 4–1 point is 1 kg

If every side of the (1–2–3–4) point area is 1 kg, then the work requirement develops as follows: W3 = (T1–T2)*(S3–S2), W3 = (32.799–20.271)*(22.005–11.004) = 137.8205, W3 = 137.82 kJ/1 kg. This amount was obtained with 2 kg of initial working medium. Therefore its **specific work requirement is rounded 69 kJ/1 kg.**

32. W(1–2) (0.46 kg), work of the mixed-in liquid

At the end of the compression combined with mixing, **1.46 kg of vapor arrives at state point 1**. Since in the cycle, in the 1–2p section, only 1 kg of working medium was taken into account so that every side of the cycle should be 1 kg, at the 1p point there is still 0.46 kg of vapor not accounted for. Wh(1–2) = 53.80 kJ/0.46 kg (Ref.13) performs useful work. Therefore its **specific produced work is 27 kJ/1 kg.**

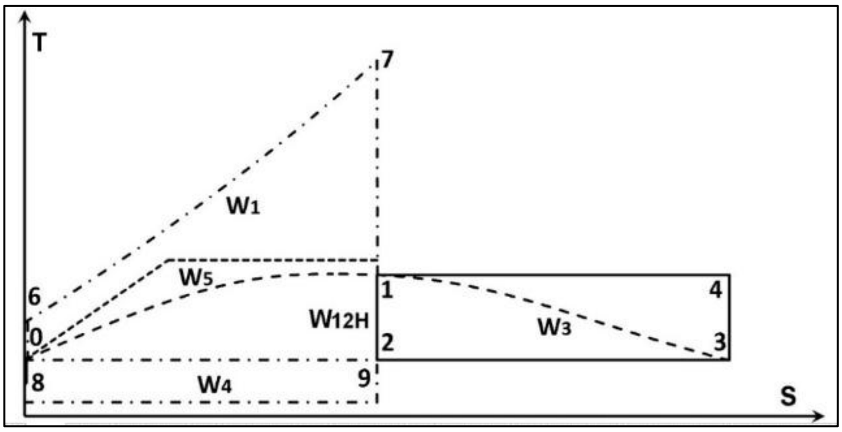
The combined effect of the two steps, W3 = 137.82 kJ/1 kg work requirement minus Wh(1–2) = 53.80 kJ/0.46 kg useful work, results in a total work requirement of 84 kJ/2 kg. Therefore **its specific work requirement is 42 kJ/1 kg.**

33. WLf (0.54 kg), work of the replenished working medium
In the case of liquefaction, the replenished vapor at state point 1, 0.54 kg, is not accounted for, therefore WLf(1–2) = 63.15 kJ/0.54 kg performs useful work. Therefore its **specific produced work is 31.6 kJ/1 kg.**

34. Summary
-W3 (1 kg) + W(1–2) (0.46 kg) + WLf (0.54 kg) = - W3 = 137.82 kJ/1 kg + 53.80 kJ/0.46 kg + 63.15 kJ/0.54 kg = -20.87 kJ/2 kg. In the case of 1 kg, -10.5 kJ/kg.
In the case of liquefaction, with slightly more than 10 kJ of work, it produces 0.27 kg of liquid at 20 K^{0} temperature and 1 bar pressure from 1 kg of vapor at 33 K^{0} temperature and 12.6 bar pressure.

III. Basic machine Co/Pp

35. In the figure below, the rectangle drawn with the points 1–2–3–4–1 is the already presented W3 basic process. The illustrated rectangle is rectangular for best traceability; otherwise, except for the 2–3 line, all may also be polytropic. The processes presented here discuss the utilization of the already known liquefied working medium.



36. The illustrated combined cycle represents four different applications:
- Cool medium-high cooling, 0–2 process,
- W4 deep cooling, 0–8–9–2 process,
- W5 mobile cooler,
- W1 cooling–power source, 0–6–7–2–0 Co/Pp.

37. Cool, medium-high cooling
This is the simplest. In this case, the liquid at point 0 is evaporated along the 0–2 line. The process practically takes place in a heat exchanger until the vapor state, and only half of the mass flows through it. The remaining liquid at point 0 remains in the collecting tank, thereby preserving the mass ratio corresponding to the state at point 2. In this case, the operation of the cooler **requires** W3–W12H **work**. W3 = 137.8 (kJ/1 kg) – Wh(1–2) = 53.80 (kJ/0.46 kg) = 84 (kJ/2 kg). The cooling effect S (kJ/kg*K^{0}) = (S1–S0)0.54 (kg) = 5.94 (2 kg). Therefore, with **1 kg of working medium, within one cycle it produces a cooling effect of S = 3 (kJ/kgK^{0}), at a temperature of 20 (K^{0}), at the cost of 42 (kJ/1 kg) of work.**

38. Cool W4 deep cooling
We speak of Cool lower cooling when the working medium is led along the 0–8–9–2 line, in the previously mentioned manner. In this case, compared with the previous one, it cools at a lower temperature, but its work requirement is at the cost of Cool medium-high cooling, 84 (kJ/2 kg) + W4 (area)*0.54 (kg) work.
84 + 46.90.54 = 109.3 (kJ/2 kg). Therefore**, it produces a cooling effect of S = 3 (kJ/kgK^{0}), at a temperature of 16 (K^{0}), at the cost of 54.6 (kJ/1 kg) of work.**

39. W5 mobile cooler

In the case of the mobile cooler, W3 – W12H = W5. It operates without external energy input, using the energy of the internal cycle. With the proper selection of the working medium, it can operate anywhere in the temperature range below environmental heat. By cyclically repeating the process, **continuous cooling can be ensured without any energy input.**

40. W1 cooling–power source

In the Co/Pp upper cooling, the liquid at point 0 is led along the 0–6–7–2–0 line. In this case, the process delivers W1–W3 + W12H work, because the mass-proportional area of W1 is larger than the work requirement of W3–W12H. This is summarized in the table below. The more detailed energy balance is discussed in (Ref.42, 43).

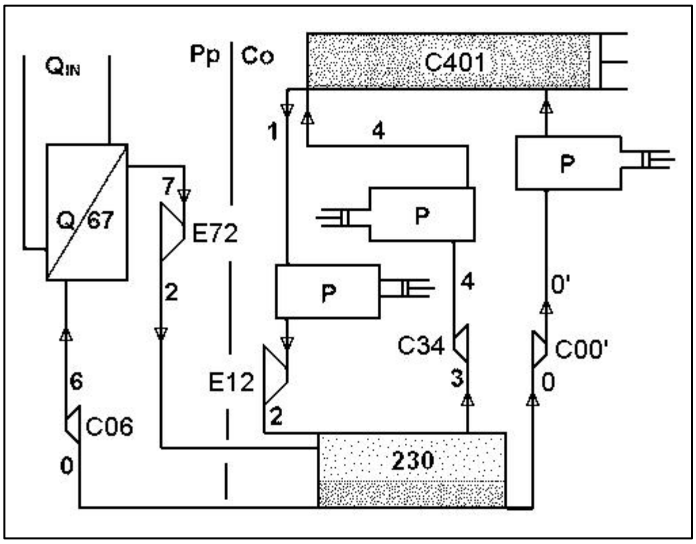
Co/Pp		**Weff**	**31**	KJ/Kg,cycle	**Scool**	**3**	KJ/Kg,K,cycle	**Weff (area carculation)**		
points	T	p	d	v / %	u	h	s	W1		145,4748
1	32,799	1,2598	24,738	0,0404	289,08	340,01	11,004	W(1-2)		53,797
2	20,271	0,1013	2,627	**0,5%**	184,5	223,06	11,004	W3		137,8205
3	20,271	0,1013	1,339	0,7471	370,37	446,06	22,005	2	Kg	61,45124
4	32,799	0,3329	2,710	0,3690	438,89	561,73	22,005	**1**	**Weff**	**30,72562**
0	20,271	0,1013	70,828	0,0141	-1,433	0,00	0		KJ/Kg,cycle	**31**
6	25,78	15	79,347	0,0126	8,4182	197,46	0	**Cooling effect**		
7	64,5	15	50	0,02	380,6	680,60	11,004	S6-7	5,9422	
Masses kg	Total	2	Mixed liquid	0,46	**Useful**	**0,54**	**27%**	1kg	**3**	KJ/Kg,K,cycle

The data in the table are derived from the NIST: https://webbook.nist.gov/chemistry/fluid/
“Thermophysical Properties of Fluid Systems” database.

What we call a (Co/Pp) cooling–power source is one that consists of a conventionally accepted power plant process and a basic process.

41. Steps of the cooling–power source process

The cooling process that realizes the cycle can be followed in the T–s diagram shown at Ref.35 and in the schematic diagram below. Among the units separated by the dashed line, the Pp is a conventional power plant, while W3 performs the restoration of the vapor to state 1.



Since the basic process W3 has already been described in detail earlier (Ref.14), only the conventional Pp power plant process and its connection with W3 are presented now:

- from the tank marked with 230, the remaining liquid at state point 0 is compressed by compressor C06, after adiabatic compression reaching state point 6 with higher pressure and slightly higher temperature, and is pressed into the Q67 heat exchanger,

- in the Q67 heat exchanger, at constant pressure, with external heat energy input, it is transformed into saturated vapor at point 7,
- the energy of the high-pressure saturated vapor at state point 7 is converted into work by the E72 expansion machine, thereby forming exhaust vapor at state point 2,
- the exhaust vapor returns to the 230 tank,
- the process is repeated cyclically.

This cycle is W1, where useful energy is produced. This is a currently generally accepted power plant process.

42. Work of the cooling–power source

If the basic process is used as a cooling–power source, then calculated for 1 kg working medium according to (Ref.37), with 84 (kJ/2 kg) work, 0.54 kg liquid is produced. The remaining 0.54 kg work in the 1–2 section has not been accounted for in this case, therefore the power source can be calculated with 0.54 times the entire 0–6–7–2–0 area. (Not only 0–6–7–1)

Similarly to the previous ones, by calculating the area and multiplying it by the mass of 0.54 kg, W1 = 145.47 kJ/0.54 kg useful work is performed. The cooler requires 84 (kJ/2 kg). 145.47 – 84 = 61.5 (kJ/2 kg).

Thus, **the process is theoretically capable of producing a specific work of 31 kJ/kg per cycle.**

43. Cooling effect

The cooling effect is generated during the utilization of the liquid in the 6–7p section. In this section, the liquid working medium is transformed into saturated vapor, and the energy required for this is obtained from a heat exchanger. On the other side of the heat exchanger, a cooling effect is thereby produced. The value of the cooling effect is apparently 11 kJ/kg*K,* however, taking into account that from 1 kg working medium only 0.27 kg can be used for cooling, **the specific cooling effect is 3 kJ/kgK.**

44. If the system performs one cycle per second, then its power is 31 kW, it produces 31 kW/h energy. The values of the operating points can be found in the table (Ref.40). Based on this, the machine can be constructed and corrected by taking losses into account.

45. Notes

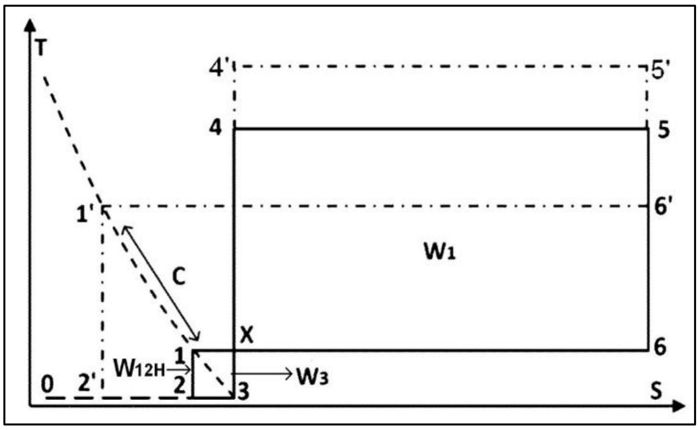
- The description of the process and the presented calculations have been prepared in accordance with the second law of thermodynamics, consistently taking its conditions into account.
- The process refers to static operation, because from the point of view of presenting the process it is easier to follow. In practice, it is highly likely that the liquid at point 0 must be injected into the mixing cylinder by spraying, in order to accelerate the process and reduce the cycle time.
- (Ref.41) C34, C401 may be a single machine element. The vapor at point 4 is suddenly compressed by the piston and further compressed to state 1 by liquid injection.
- Environmental heat can be any heat suitable for utilization, including air, rivers, seas, municipal waste of incineration furnaces, condensation of exhaust steam of coupled power plants, etc.
- In the description, and even in the calculations, the volume of the liquid has not been taken into account, because its magnitude is negligible compared to that of the vapor. Moreover, in continuous injection operation, it does not occupy space in the working cylinder.
- According to preliminary calculations, instead of the 1–2 expansion machine, a solution with an expansion valve used in refrigeration technology can also operate, but its efficiency is far below the process described here. It may have justification only in mass-produced household refrigeration machines for manufacturing technology reasons.

IV. Examples of the utilization of the invention

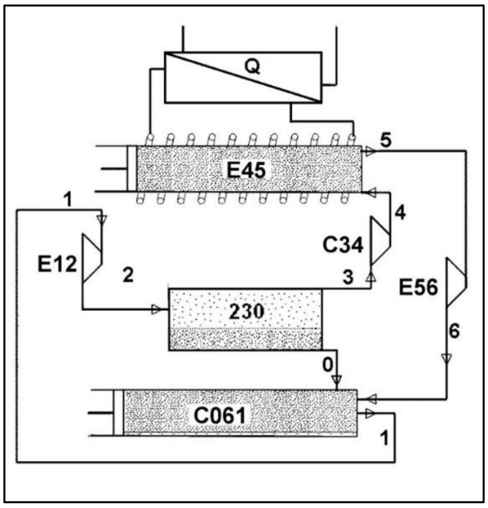
46. So far, the basic process and the cooling method have been presented. In the following examples, settings are described that satisfy different user requirements, demonstrating the versatility of the process. In each example, the basic process can be identified, which is marked with W3.
The examples serve to illustrate the applicability of the basic process.

47. Example A: Integrated cooling–power source CoPp

In Example A, a more advanced, integrated cooling–power source is presented, denoted CoPp. It is important that the cooling–power source be a preferably simple device that can be started and stopped, for which no professional personnel is available. This is achieved by operating at a temperature close to the environmental temperature, therefore the stopped machine, for example with R13 working medium, can be stored even under normal temperature conditions. **This process can be a vehicle and household power source.**



48. The process can be followed on the T–s diagram shown in the figure above.
The main characteristic of the process is that it does not directly use the remaining liquid to perform work, but the vapor working medium performs the work. The liquid only carries out entropy reduction in the 6–1 section. In the following, it is advisable to examine the cycle starting from point 2. The vapor at point 3 proceeds through the state changes 3–4–5–6–1–2. The liquid at point 0 intervenes only in the 6–1 section as one element of the mixing. From the point of view of work, it is advisable to assign the 6–X section to the W1 cycle, thereby the rectangle closes and thus the W1 area determines the magnitude of the useful work. Accordingly, the X–1 section should be assigned to the W3 cycle. According to calculations, approximately 20% liquid is sufficient for recompressing the exhaust vapor at point 6.



The schematic diagram shown in the above figure presents the machine that implements the process described above. The saturated vapor at state 3 of the working medium at state 2 in the 230 settling tank is compressed by the C34 compression machine to the desired temperature and pressure at state 4. The E45 isothermal expansion machine expands the high-pressure vapor at state 4 from 4–5 and thereby performs useful work. The heat energy required for the isothermal process is provided through a Q heat exchanger by environmental heat energy, thereby cooling the environment, thus it also operates as a cooling machine. In the next step, the working medium at state 5 is expanded by the E56 expansion machine to state 6 by adiabatic expansion. At this point, useful work is also produced. The recompression from state 6 to state 1 is realized by the previously discussed mixing combined with compression C061. Finally, the working medium returns from state 1 to state 2 through the E12 adiabatic expansion machine into the 230 settling tank.

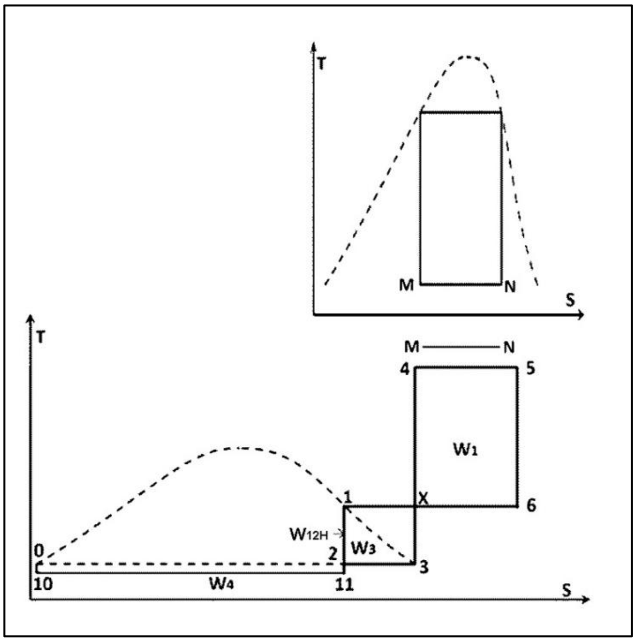
The adaptation of the process to the environmental temperature is manifested in the fact that by changing the temperature of the 4–5 section, the process can be adjusted to the environmental temperature. With the 240 K^0 setting shown in (Ref.47), depending on the heat exchanger, the machine is capable of operating at approximately –24 C^0 environmental temperature at 100% performance. It may occur that we want to utilize higher temperature waste heat. For example, if we want to use the 60 C^0 exhaust steam of a conventional thermal power plant, then the process is guided along the higher temperature state changes 3–4’–5’–6. In this case, a cooling–power source with much higher efficiency is obtained.

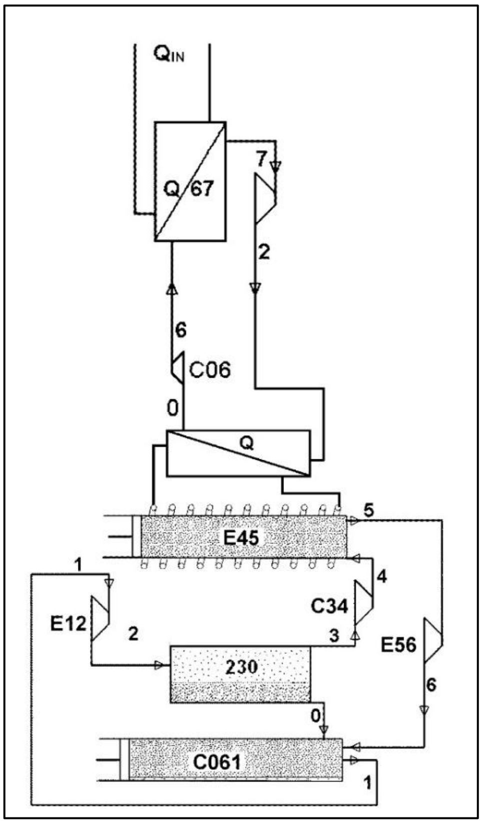
In terms of control possibilities, it can be optimized for cooling or as an energy source mainly by changing the liquid–vapor ratio. This can practically be achieved by varying point C on the boundary curve of the saturated vapor at point 3.

The device is also capable of lower cooling by regulating the 1–2 section to a higher temperature, 1’–2’. In the new setting, enough reserve liquid is already generated to realize the 10–11 lower cooling. From an energetic point of view, this may be necessary when we want to start a cooling–power source operating at a lower temperature, such as in the next example, or when the machine is shut down. In this case, the regulation controls up to the maximum lower cooling and stores as much liquid working medium as possible in a well-insulated double-walled tank.

B. Example: Small-scale power plant

49. The small-scale power plant uses the CoPp basic machine operated with oxygen, working together with a power plant process. Thus, the sum of the CoPp and Pp processes gives the total performance. Naturally, Co/Pp can also be a basic machine.



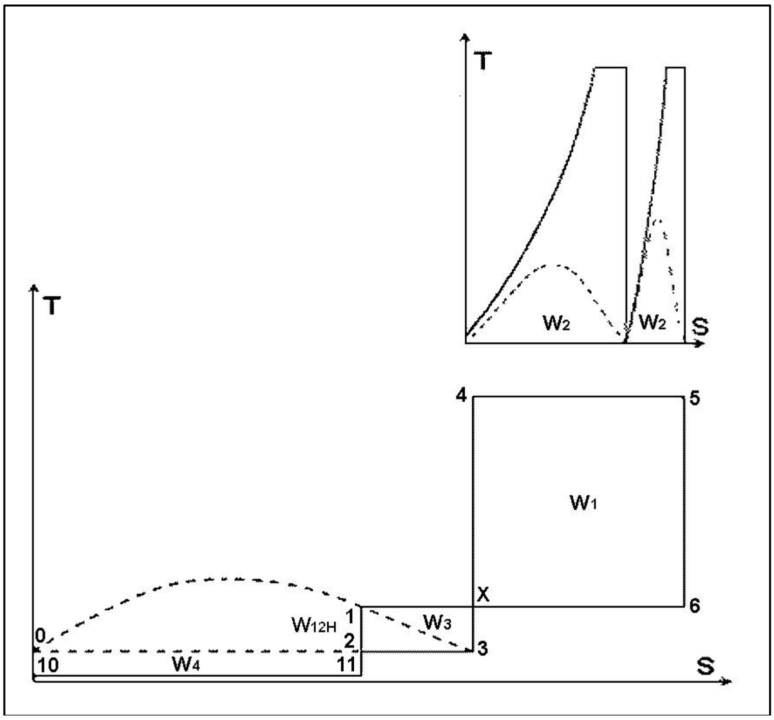


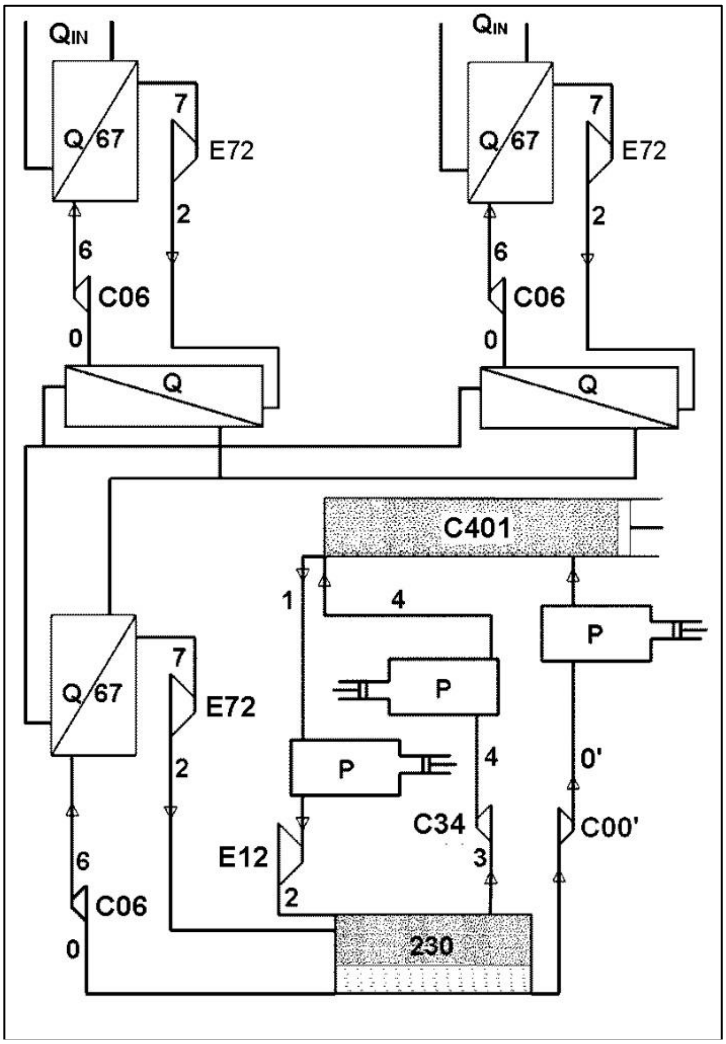
The cooling effect of the basic machine makes it possible to apply the Pp power plant process by performing, with the M–N cooling effect. The basic machine shown in the above figure, the re-liquefaction of the exhaust vapor of the Pp process using R22 working medium in the M–N section. Thus, instead of a boiler, a heat exchanger can perform the creation of high-pressure saturated vapor. This is another version of a process suitable for the utilization of environmental heat.

C. Example: Large-scale power plant

50. Both the Co/Pp and the CoPp described above can be basic machines of a large-scale power plant. In this example, a Co/Pp basic machine with parahydrogen working medium is shown, and above it conventional Pp power plant processes realized with nitrogen and oxygen working media. The ratio of the working media corresponds to the ratio of air. The primary task of the basic machine is the re-condensation of nitrogen and oxygen.

It is worth operating the large-scale power plant with the Co/Pp basic machine shown in Figure 1, because it is also capable of condensing the heating air, since if the heat supply of the system is provided by air, the heating air cools due to the counter-effect. The temperature of the “hot” -13 C^0 heating air decreases to -186 C^0. From here, the heating air can also be condensed with another Co/Pp basic machine, and the liquid air thus formed can be reused by a secondary power plant. And this can be repeated multiple times. If the full capacity of the power plant is not required, the condensed air can be cooled with a basic machine and used for energy storage in storage tanks.


T
W_2
W_2
S
T
4
5
W_1
X
6
0
W_{12H}
1
2
W_3
3
10
W_4
11
S


Q_{IN}
Q 67
7
E72
2
6
C06
0
Q
Q_{IN}
Q 67
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7
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230
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51. Notes

- Since in the presented examples an isothermal process was chosen in the compression combined with mixing section, the control must monitor the temperature prevailing in the cylinder, which is quite complicated, because the mixing does not occur at molecular level and local temperature differences may develop. Therefore, it is advisable to record the pressure curve and rather regulate the piston movement as a function of pressure.
- The processes, where possible, are rectangular in shape because the produced work can be calculated easily and therefore it is easier to understand.

52. From the above it can be seen that the invention is capable of achieving the set objectives, because:

- it is capable of cooling at any temperature,
- it is indirectly suitable for energy storage,
- it is suitable for converting gases into liquid state and for storing them,
- it is suitable for fractional distillation of gases,
- it can be the cooling unit of technologies requiring household and industrial cooling,
- it can be the basic machine of power plants, and
- it can also be a power source.

Patent claim

1. A method for cooling and for the utilization of environmental heat carried out in a thermodynamic machine, characterized in that:

a) expansion is carried out with vapor in the mixed-phase region,
b) the wet vapor state working medium is separated into liquid and vapor components according to phase,
c) vapor temperature increase is performed,
d) mixing of vapor and liquid combined with compression is performed,
e) the remaining liquid is utilized in such a way that it returns to state point 1, or in the case of liquefaction the consumed gas is replenished,
e) the cycle a)–d) is repeated cyclically.