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Rotation Heat Pump (RHP)

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Abstract

The use of heat pumps for high temperatures in the industry is limited nowadays by refrigerant and by oil of the compressor. Another not always considered fact is sensible heat (sliding temperature of medium during heat flow) at source and sink (s&s). In many applications (e.g. district heating and drying processes) supercritical heat pump processes fix this at heat sink but with rarely inflexible temperature changes.

Flexible temperatures at s&s without any modifications, temperatures up to 150°C and sensible heat transfers at s&s are possible by using a Joule Process. This kind of process works profitable only if the compression and expansion is realised with very high efficiencies (>99%). ECOP realises these efficient pressure changes in a rotating system by using centrifugal force instead of high flow speed like in common turbo compressors. The COP depends, similar to two-phase heat pumps, on temperature spread but rarely on temperature level. Due sliding temperatures at s&s the potential will always be better than Clausius Ranking or super critical cycles. The used working gas, extracted from air, has no climate potential, isn't flammable and is natural.

In summary the RHP has wide coverage of temperature, ecologically friendly working gas and higher COP as two phase circles. In industries waste heat is mostly sensible, so these are ideal circumstances for a RHP or just using it for higher temperatures. Measurements verified the realization of high COP for the considered applications.

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Keywords: Rotation Heat Pump, Industrial, high temperatures, ecop, flexible

1. Introduction

Since the last paper from ecop Technologies GmbH with the title "Heat pump for Process Industry"[0], at the Heat pump Conference 2014 in Montreal, it has been done a lot of improvement work on the machine. The function of the rotation heat pump (RHP) is still the same, so after a short summary of the functionality, this paper will discuss the specific values of the current heat pump (Pilot of RHP Type K7 with 700kW heating capacity) in different operating modes. With the rotation heat pump technologies, ecop showed that it is possible to realize a heat pump process based on a counterclockwise joule cycle (also known as Joule-Brayton or Brayton cycle) which has a better COP than a two phase cycle heat pump process, depending on certain circumstances. The reason why there are rarely no heat pumps using a joule process, shows the following tables. For the calculation in Table: 1 is an ideal Joule and a counterclockwise Clausis Rankin cycle with a heating capacity of 1MW at the sink side. In Table: 2 is the same cycle, but instead of 100% efficiency of compression and expansion it is shown with 80% (expansion just at the Joule process). The level of source temperature is (65-43°C) and at the sink side is (70-95°C). The temperature difference is 3K between working gas/refrigerant and sink/source flow.

Table: 1 COP potential of a Joule Process and 2 phase process with NH3

Compression with 100% efficiency @ 1MW heat emission	Joule process – Ar	2-phase process – NH3
P.compression in kW	1319	165
P.expansion in kW	1222	-
Power deviation	97	165
COP	10.3	6.1

Table: 2 Decrease of COP

Compression with 80% efficiency @ 1MW heat emission	Joule process – Ar	2-phasen process – NH3
P.compression in kW (80% efficiency)	1649	207
P.expansion in kW (80% efficiency)	978	-
Power deviation	671	207
COP	1,49	4.8

Fig.: 1 shows the influence of a lower compressor and expansion efficiency to the COP. The lines end at 0,75 because with a lower efficiency, the loss in the Joule process is higher than the heat sink capacity. With a lower efficiency the mass flow has to decrease, otherwise the heat emission is higher than 1MW. The real interesting thing is, that with a higher efficiency than 0.96 in compression and expansion, the Joule process get better and better than the conventional process for this boundary conditions. This is the reason why it wasn't possible in the past to realize a joule process with a better COP than two phase process, if there is a useable refrigerant at this temperature level for the two phase cycle.

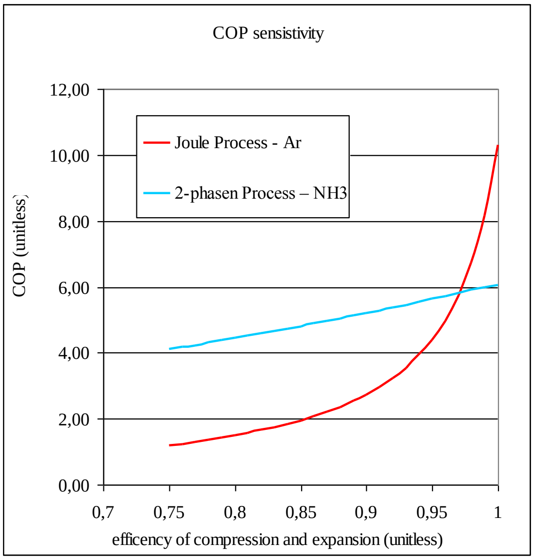

Fig.: 1 Decrease of COP in affect of efficiency of pressure change

With this new possibility of this Joule process, there are three more useful facts, which can give a huge advantage in different applications compared to a two phase cycle.

1. heat transfer at sink and source are often sensible
2. flexible in temperature levels
3. higher temperatures from sink and source

1.1. Sensible Heat Exchange

The circumstance that the working fluid is always gaseous and never liquid during the cycle, it never comes to a phase change and so to a non sensible heat change. Through that there is always a temperature change during heat exchange. In the industry sink and source are often sensible too, so with the same heat capacity flow on both sides (working fluid and source/sink fluid) the temperature difference is along the heat exchanger the same. With a small average temperature between working gas/refrigerant and other fluid the exergy loss in the heat exchanger is lower, and affects positive to the COP. In Fig. 3 is shown the changing space between the two temperature curves. On the left side both medium are sensible on the right side just the colder medium is sensible the other one is changing the phase. The exergy loss relating to 20°C is for the left side of the picture 3,8% and for the right side 17%. The result comes from equation (1).

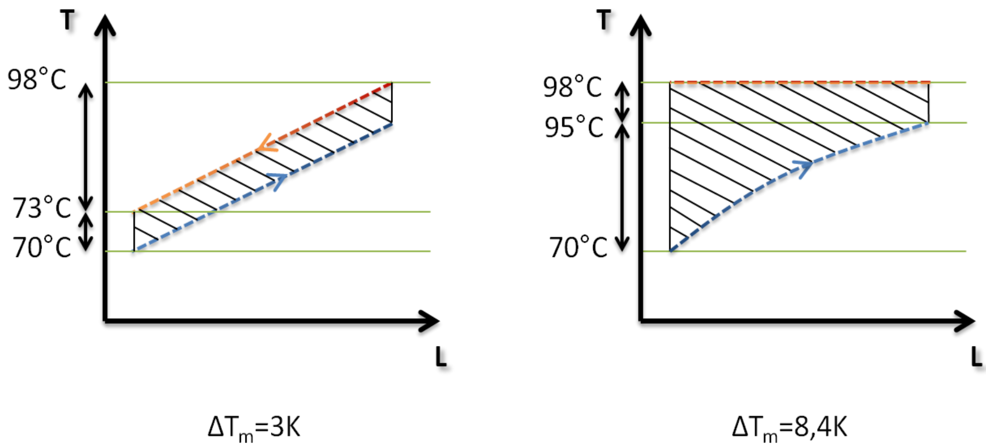

Fig. 3 Exergy loss in a heat exchanger

$$e_v = (1 - \frac{T_U}{T_m}) \cdot \dot{q} \qquad (1)$$

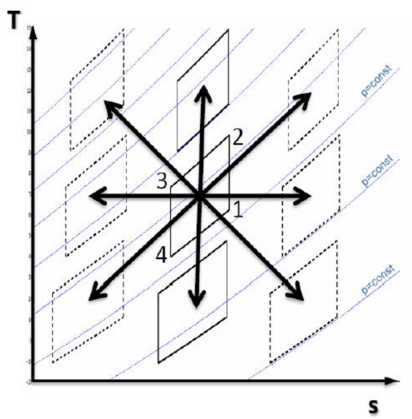

Fig. 2 Flexibility of a Joule Process

1.2. Flexibility in Temperature Level Change

From time to time it´s its very useful, when the level temperature of the heat pump can be changed easily. For example in consequence of seasons. Changes of the temperature level, are also possible with two phase cycles, but many process parameters change more than in a Joule Process. A very critical characteristic thing is especially the high pressure which rises from 54,4 bar up to 91,95 bar (compare with Table 1). More interesting is the change of the volumetric flow of the compressor inlet – increase around 42%. Without any modification the RHP with the Joule cycle can be used on a wide band of temperature level, of course with limits based on design temperature of the mechanical parts of the machine.

Table 1: Effect of Changed Temperature Level

2-phase process -NH_3	Case 1 sink 70/95 in °C source 65/43 in °C	Case 2 sink 100/125 in °C source 95/73 in °C	change in %
$\dot{m}$ *in kg/s*	0,9	1,13	25
$\dot{V}_{compressor.inlet}$ *in m³/s*	0,0708	0,0407	42,5
p_{max} *in bar*	**54,4**	**91,95**	**69**
$\dot{Q}_{overheater}$ *in kW*	191,8	304,2	58,6
$\dot{Q}_{condenser}$ *in kW*	702,4	533,5	24
$\dot{Q}_{undercooler}$ *in kW*	105,8	162,3	53,4
Compression ratio	3,31	2,651	19,9
*COP**	6,05	6,33	4,5
joule process with argon	sink 70/95 in °C source 65/43 in °C	sink 100/125 in °C source 95/73 in °C	change in %
$\dot{m}$ *in kg/s*	71,07	71,74	0,9
$\dot{V}$ *in m³/s*	1,16	1,175	1,2
p_{max} *in bar*	**54,4**	**59,14**	**8,7**
$\dot{Q}$ *in kW*	1000	1000	0
Compression ratio	1,290	1,265	1,9
*COP**	10,3	11,24	8,4

*For this calculation there is a ΔT=3K gap between sink/source and working gas/refrigerant, and also a ideal heat pump cycle. The Reason for higher COP in the second case, is the higher middle Temperature of the source.

1.3. Higher Temperatures

In a two phase cycle, there can be problems in consequence of the stability of the oil or refrigerant. The RHP technology works instead within the main compression without relative moving parts and so without oil or grease. The working gas is a natural inert gas mixture and is stable for temperature higher than 1000°C. For the bearing of the fan there is grease necessary too, but in fact that the working gas flow doesn't touch the oil and is located in a low temperature area in the machine , there are no problems with segregations or stability, and the spectrum of useable grease is much bigger.

2. Functional Principle

The whole RHP is based on 5 steps. The single steps of the thermodynamic circle are shown in Fig. 4, this five steps get explained below.

- Step 1 from point 1 to 2

Te working gas get compressed very efficiently during this compression the working gas get warmer. The power for compression work comes from step 3 (expansion 3 to 4).

- Step 2 from point 2 to 3

In the high pressure heat exchanger the working gas delivers heat to the sink, and during this Step, the working gas get colder and the flow of the sink get warmer.

- Step 3 from point 3 to 4

In this process step the working gas get expanded, that the working gas cools down, the release power (torque and rotation) is equal to the compression in "point 1 to 2)

- Step 4 from point 4 to 5

In this step, the working gas take the heat from the heat source.

- Step 5 from point 5 to 1

The compression works in step 1, is covered with from step 3. The rest of this compression and the whole losses of friction must be delivered from the fan, which happened in this step. The main gap between compression (5-2) and expanding power (3-4) comes from the divergence of the isobar change of state.

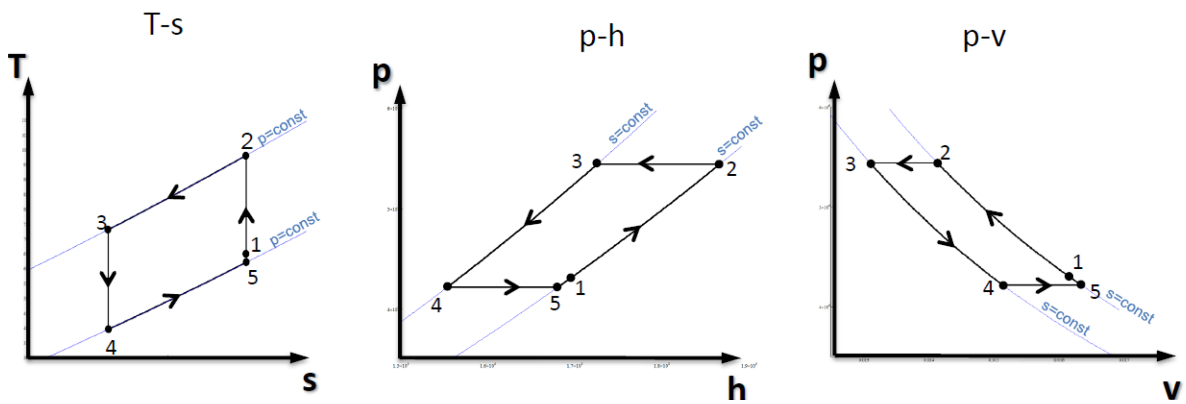

Fig. 4 RHP Process in different Diagrams

The reason for the very high pressure change in Step 1 and Step 3 are the relative low velocity of the gas flow and with that the friction especially between gas and wall is low. Fig.: 5 of shows the pressure change of a water column. The pressure get linear higher in fact of the incompressible of water. Following thought experience should help to understand this process. When you put a water filled U-

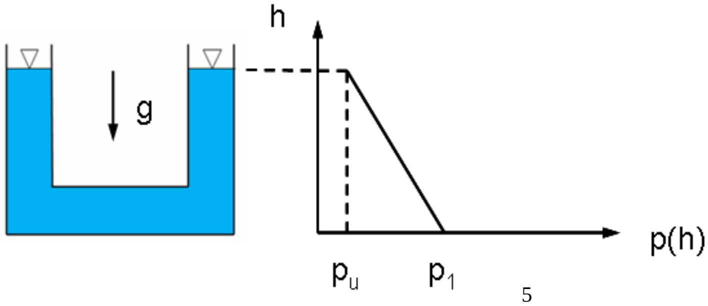

Fig.: 5 Pressure change in consequence of gravitation tube from sea level down to the Mariana trench in the Pacific Ocean and back to sea level, the pressure in the tube rises up to the maximum on the sea ground and back to the beginning pressure on the way up. The first extra water drop on one side will pushes the whole water column a small way further trough the tube. Every further drop continues this process and so all the water drops are going along the tube and getting compressed to the bottom and expand on the way up nearly 100% reversible. The same principle is used is in the RHP with the difference, that instead of the gravitation the centrifugal force changes the pressure. Fig.: 6 shows the pressure change in the RHP of the compressible gas and the square change of the centrifugal force an Fig.: 7 shows the Joule process realized within the Rotation Heat Pump.

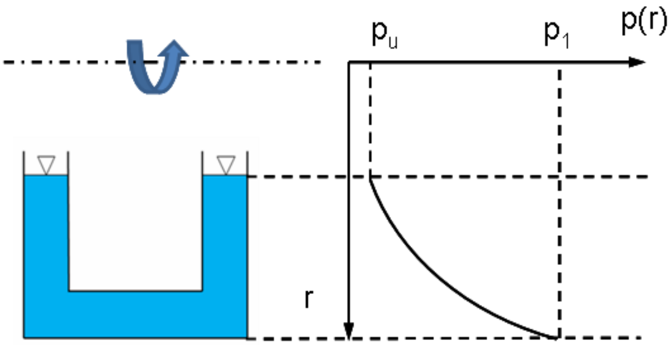

Fig.: 6 Pressure change in consequence of centrifugal force

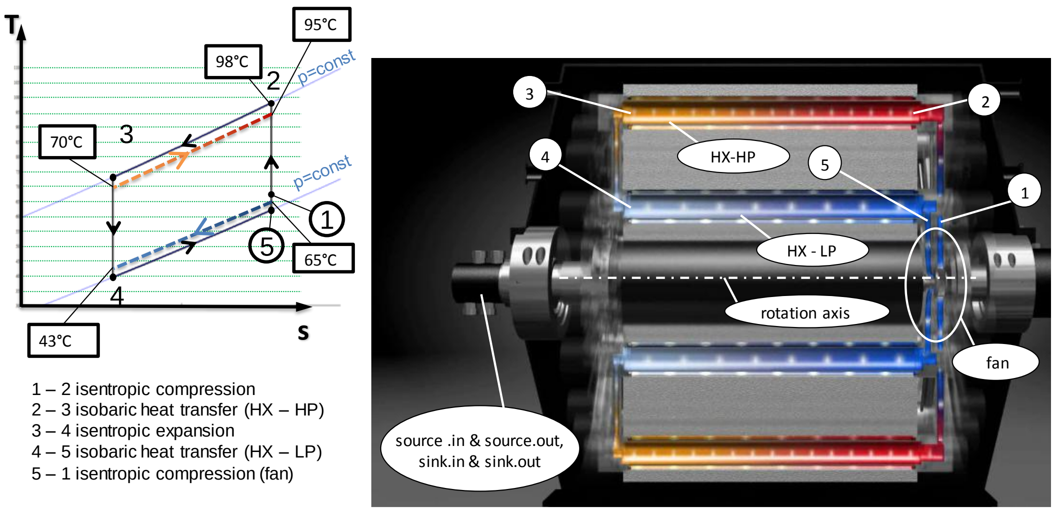

Fig.: 7 Joule process within the rotation heat pump

3. Facts about RHP K7

Fig. 8 shows the RHP K7 pilot ready to ship and in

Table: 3 there are some facts about the realization of a rotation heat pump.

Fig. 8 RHP K7 pilot

Table: 3 Facts about RHP K7

Technical data	
Weight:	15t
Dimensions (W x H x L):	2400 x 2500 x 7000mm
Connection heat source:	DN80 (3")
Connection heat sink:	DN80 (3")
Maximum flow temperature on heat sink:	150°C
Maximum flow temperature on heat source:	110°C
Maximum temperature spread between sink out and source in:	40 °C
Minimum flow temperature:	-20°C
Designed heat transfer medium:	H_2O
Heat output:	400-700 kW
Working gas	ECOP Fluid 1 (inert gas)
Nominal heating water flow rate / pressure drop:	21m³/h / 0,5bar
Main supply:	400V-3-N ~50Hz
Nominal power consumption:	70 - 280kW

3.1. Implementation of RHP K7 Pilot

The Implementation of the RHP K7 pilot is in a biomass heating plant near to Vienna. In reason of the flexible temperature level it can be used in summer and winter. The calculation is based on 4500 h in winter and 2500 h in summer. In fact of the flexibility of the Joule Process the heat pump can be used the whole year. So the useable heat energy in summer is 1600 MWh and 2880 MWh in winter: The return of Investment is 55% higher else without summer operating.

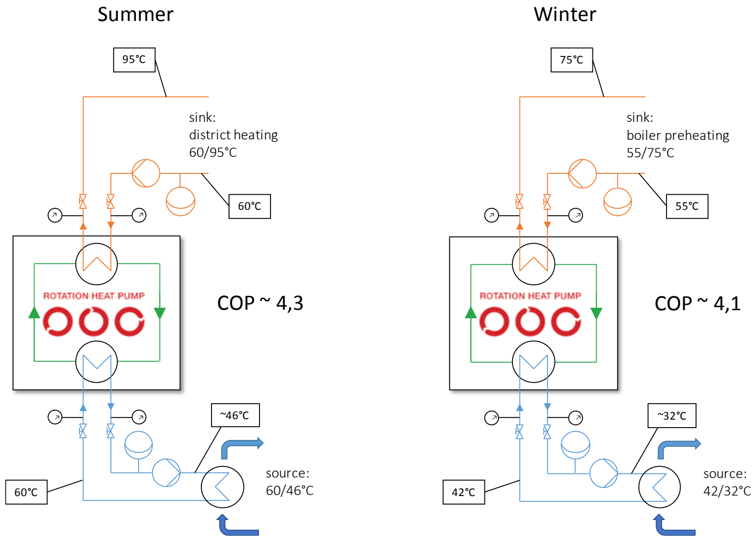

Fig. 9: Implementation of RHP K7 pilot

3.1.1. District Heating

In the following schema (Fig. 9**Fehler! Verweisquelle konnte nicht gefunden werden.**) shows the implantation of the RHP K7 pilot. The heat pump is a part of the heat producer of a 10MW grid

3.1.2. Alternative application spectrum

The range where the RHP K7 can be implemented is very big. The following examples shows some of them. All the counted cases in Table: 4 Spectrum of RHP K7 are shown in fig. 9 and can be realized with the same heat pump without any change.

Table: 4 Spectrum of RHP K7

Case	Application	Source	Source in °C	Sink	Sink in °C	COP
#1	all season district heating	extern heat source	60/30	district heating	60/100	5,5
#2	summer district heating	lake water	20/2	district heating	55/70	3,7
#3	Summer district heating (waste heat from boiler)	waste heat boiler	60/46	district heating	60/95	4,3
#4	winter district heating	flue gas condensation	55/30	district heating	55/75	5,8
#5	preheating of inlet district heating in winter (preheating inlet temperature)	waste heat boiler	42/32	preheating of inlet district heating	55/75	4,1
#6	wood drying	condensate from drying process	65/45	process heating	75/95	4,9

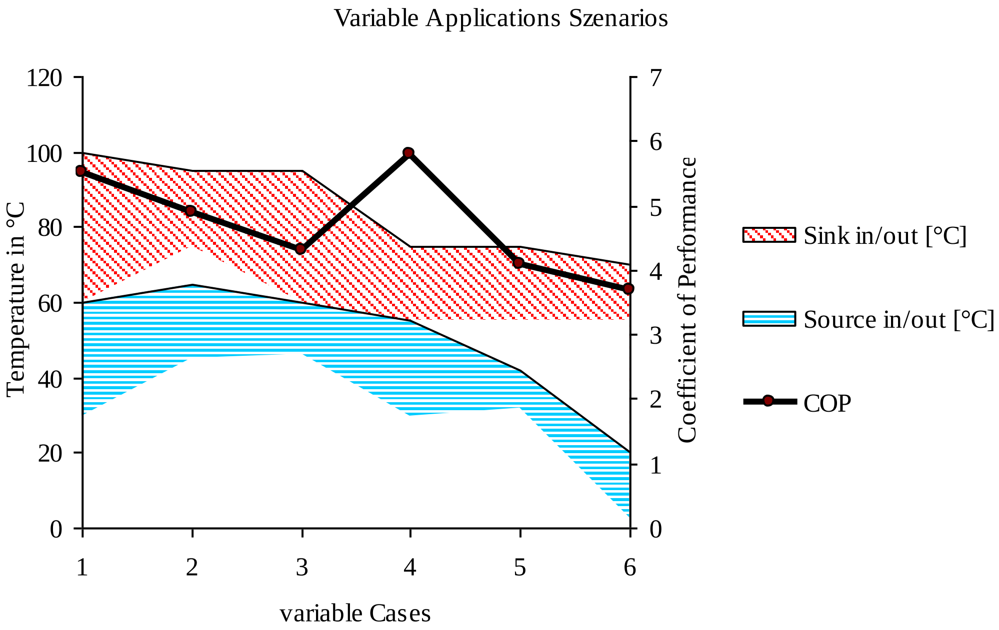

Fig. 9 visualization of example cases from table 4

References

B. Adler, S.Riepl. "HEAT PUMP FOR PROCESS INDUSTRY"; 11th IEA Heat Pump Conference 2014, May 12-16 2014, Montreal (Quebec) Canada