G-PUMP

Simulation software for gas engine heat pumps

With this TRNSYS-subroutine one can simulate a gas engine heat pump. The cyclic process is based on the computational method of heat pumps and contains following changes of status (Pict.1):

- Irreversible adiabate compression from overheated state (1-2),
- isobar heat dissipation from the compressor to the ambience and the heatingwater in the cylinder head (2-2'),
- isobar cooling of the steam, condensation and condensate undercooling in the condenser (2'-3),
- isenthalpe throttling (3-4),
- isobar evaporation and overheating (4-1).

The tool contains material data for the R12 medium. The procedure calculates the stationary mode.

Pict.1: Cyclic process: computation methods for heat pumps

Since the evaporation and the condensation temperature T_0 and T cannot be computed directly, it must be processed iteratively. These Temperatures will be evaluated in first approximation by using the inlet temperatures of the heatingwater ($T_{Kond,i}$) and the heat distribution fluid of the heat source ($T_{Verd,i}$):

$$T = T_{Kond,i} + 8\ K \tag{1}$$

$$T_0 = T_{Verd,i} - 8\ K \tag{2}$$

The condensation pressure p and evaporation pressure p_0 will be detemined from the steam table by using T and T_0 . The pressure ratio is $\pi = p/p_0$.
To determine the volumetric efficiency of the compressor, one uses a second order polynomial approach,

$$\lambda_{Vd} = a_0 + a_1 \bullet \pi + a_2 \bullet \pi^2 \tag{3}$$

which can copy the graph from /1/ (Pict.2) quite nicely. The values of a_0, a_1 and a_2 for a compressor can be obtained experimentally and entered in the simulation software.

Pict: 2: Volumetric efficiency over pressure ratio /1/

The coolant mass flow $\dot{m}_{KM}$ and the cooling capacity $\dot{Q}_{Verd}$ are calculated as followed:

$$\dot{m}_{KM} = \frac{\dot{V}_{Hub} \cdot \lambda_{Vd}}{v_1} = \frac{n \cdot V_{Hub} \cdot \lambda_{Vd}}{v_1} \tag{4}$$

$$\dot{Q}_{Verd} = \dot{m}_{KM} (h_1 - h_3) \tag{5}$$

The compressor runs in three performance steps. For each step, the piston displacement stream $\dot{V}_{Hub}$ = $n \bullet V_{Hub}$ must be inputted. Given this option, a speed controlled (number of revolutions n variable), as well as a cylinder cutoff by suction valve removal (V_{Hub} variable) compressor can be calculated. The suction gas overheating $\theta_{Ü} = T_1 - T_0$ and the condensate undercooling $\theta_U = T'(p) - T_3$ are entered as constants. State 1 is approximated with T_1 by using the ideal gas law (isobare warming). h_3 is approximated by $h_3 \approx h'(T_3)$.

The mechanical drive power of the compressor is calculated by:

$$P_{mech} = \frac{1}{\eta_{eff}}(h_{2,rev} - h_1)\dot{m}_{KM} \qquad (6)$$

where

$$h_{2,rev} - h_1 = \frac{\kappa}{\kappa - 1} p_0 \cdot v_1 \left[(p / p_0)^{(\kappa-1)/\kappa} - 1 \right] \qquad (7)$$

is the specific enthalpy difference when using reversible compression. The isentropic exponent for R12 amounts to $1/\kappa = 1{,}15$

The compressors effective quality grade $\eta_{eff} = \eta_{el} \bullet \eta_{mech} \bullet \eta_{ind}$ is a function of the pressure ratio π :

$$\eta_{eff} = a_0' + a_1' \bullet \pi + a_2' \bullet \pi^2 + a_3' \bullet \pi^3 + a_4' \bullet \pi^4 \qquad (8)$$

The thermal efficiency $\eta_{GM,th}$ and the waste heat efficiency $\eta_{GM,AW} = \dot{Q}_{AW} / \dot{Q}_{zu}$ ($\dot{Q}_{AW}$: waste heat capacity)are entered constants. The heat flow $\dot{Q}_{zu}$ applied by the fuel is defined as:

$$\dot{Q}_{zu} = \frac{P_{mech}}{\eta_{GM,th}} \qquad (9)$$

The overall heat capacity of the gas engine heat pump is,

$$\dot{Q}_{Heiz} = 0{,}97(P_{el} + \dot{Q}_{Verd}) + \eta_{GM,AW} \cdot \dot{Q}_{zu} \qquad (10)$$

assuming that 3% of the energy fed to the evaporator and compressor, is lost as heat to the ambience.

The temperatures $\vartheta_{Verd,o}$ and $\vartheta_{Kond,o}$ are calculated using the known input-values $\vartheta_{Verd,i}$, $\vartheta_{Kond,i}$, $\dot{m}_{Verd}$ and $\dot{m}_{Kond}$ as well as the heating and cooling capacity. the temperatures T and T_0 are auqired with $\vartheta_{Verd,o}$ and $\vartheta_{Kond,o}$, the heat transfer abilities $(k \bullet A)_{Verd}$ and $(k \bullet A)_{Kond}$, and the average logarithmic temperature differences.
If the difference between these two tempeartures and those evaluated earlier is bigger tha 0.2K, the calculation is repeated with the new values of T and T_0.

A constant heat transfer ability produces only a rough approximation when used with a evaporator, since the heat-transfer coefficient from the coolant depends on the heat-transfer coefficient if nucleate boiling is involved /2/.

$$\alpha_{Verd} = C \cdot \dot{q}_{Verd}^{\ n} \qquad n = 0{,}5 \ldots 0{,}8 \qquad (11)$$

When using tubular evaporators with evaporation in the tubes, the heat transfer coefficient from the coolant can drop to 1/10 of the heat transfer coefficient due to convection on the outside of the tubes. In conclusion, one chooses the following approach for the heat transfer ability of the evaporator:

$$(k \cdot A)_{Verd} = C \cdot \dot{Q}_{Verd}{}^{n} \tag{12}$$

Regarding the condenser, the thermal resistance from the coolant represents the biggest fraction of the heat transfer resistance. The heat transfer coefficient from the coolant depends on the heat flow density if laminar film condensation is involved /3/.

$$\alpha_{Kond} = C \cdot \dot{q}_{Kond}{}^{-1/3} \tag{13}$$

Because of this small connection, one calculates the condenser with constant heat transfer ability. The electrical heating power for the oil pan heating which is added to the program as a constant value, is applied to the heat pump, if it is turend of.

Literature

/1/ Linge, K.: Berechnungsgrundlagen von Kolbenkompressoren. In: Plank, R. (Hrsg.): Handbuch der Kältetechnik, Fünfter Band, Springer-Verlag, Berlin, 1966

/2/ VDI-Wärmeatlas. VDI-Verlag, 4. Auflage, Düsseldorf, 1984

/3/ Jungnickel, H., R. Agsten, W.E. Kraus: Grundlagen der Kältetechnik. VEB Verlag Technik, Berlin, 1980.

Parameter	variable	description	unit
1	KAVFAC	Constant ones in equation for warming are able the evaporator $(kA)_{Verd} = KAVFAC \cdot Q_{Verd}^{KAVEXP}$	$[(kJ/h)^{(1-KAVEXP)}/K]$
2	KAVEXP	Exponent in equation for Waermeuebertragungsvermoegen the evaporator	[-]
3	KACOND	Heat transfer ability of the condenser	[kJ/hK]
4	NSTMAX	Number of performance levels of the compressor (maximum 4)	[-]
5	TSH	Suction gas overheating	[K]
6	TSC	Condensate undercooling	[K]
7	CPVERD	specific thermal capacity of the heat source fluid	[kJ/kg K]

For each level (max. 4) NSTEP:

Parameter	variable	description	unit
9·NSTEP - 1	VGEO(NSTEP)	Piston displacement stream	[m³/h]
9·NSTEP	L0(NSTEP)	Coefficient for the equation of the	[-]
9·NSTEP + 1	L1(NSTEP)	Volumetric efficiency of the compressor	[-]
9·NSTEP + 2	L2(NSTEP)	$\lambda_{Vd} = L0 + L1 \cdot \pi + L2 \cdot \pi^2$	[-]
9·NSTEP + 3	G0(NSTEP)		[-]
9·NSTEP + 4	G1(NSTEP)	Coefficient for the equation of the	[-]
9·NSTEP + 5	G2(NSTEP)	effective quality grade of the compressor	[-]
9·NSTEP + 6	G3(NSTEP)	$\eta_{eff} = G0 + G1 \cdot \pi + G2 \cdot \pi^2 + G3 \cdot \pi^3 + G4 \cdot \pi^4$	[-]
9·NSTEP + 7	G4(NSTEP)		[-]
9·NSTMAX + 8	PEL0	electrical achievement of the oil pan heating	[kJ/h]
9·NSTMAX + 9	ETAGM	thermal efficiency of the gas engine	[-]
9·NSTMAX + 10	ETAAW	Waste heat efficiency of the gas engine (waste heat/fuel energy)	[-]

For each level (max. 4) NSTEP:

Parameter	variable	description	unit
9·NSTMAX + 10 + NSTEP	PMAX(NSTEP)	maximally possible mechanical achievement of the gas engine	[kJ/h]

INPUT	variable	description	unit
1	TVERDI	Inlet temperature of the heat source fluid into the evaporator	[°C]
2	MVERD	Mass flow of the heat source fluid by the evaporator	[kg/h]
3	TCONDI	Inlet temperature of the heating water into the condenser	[°C]

4	MCOND	Mass flow of the heating water by the condenser	[kg/h]
5	NSTEP	Performance level of the compressor	[-]

OUTPUT	**variable**	**description**	**unit**
1	TVERDO	Outlet temperature of the heat source fluid from the evaporator	[°C]
2	MVERD	Mass flow of the heat source fluid by the evaporator	[kg/h]
3	THWO	Outlet temperature of the heating water	[°C]
4	MCOND	Mass flow of the heating water	[kg/h]
5	QHEIZ	Amount of heat	[kJ/h]
6	QVERD	Cooling capacity	[kJ/h]
7	QFUEL	Thermal output from fuel	[kJ/h]
8	COP	Thermal output relationship QHEIZ/QFUEL	[-]
9	TVERD	Evaporation temperature	[°C]
10	TCOND	Condensation temperature	[°C]
11	PVERD	Evaporation pressure	[bar]
12	PCOND	Condensation pressure	[bar]
13	LG	Volumetric efficiency	[-]
14	MKM	Mass flow of the refrigerant	[kg/h]
15	H1	specific enthalpy in inlet state	[kJ/kg]
16	H3	- specific enthalpy to condenser from steps	[kJ/kg]
17	V1	specific volume in inlet state	[m^3/kg]
18	ETAVD	Quality grade of the compressor	[-]
19	H2REV	specific enthalpy after reversible compression	[kJ/kg]
20	PEL	Amount of heat for oil pan heating	[kJ/h]
21	PMECH	mechanical drive power	[kJ/h]