POLITECHNIKA BIAŁOSTOCKA

2016 Purdue Conferences
23rd Compressor Engineering
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Assesment Of Refrigerant Selection For Ejection System Driven By Low-Grade Heat

Kamil ŚMIERCIEW, Jerzy GAGAN, Dariusz BUTRYMOWICZ

- **Introduction**
- **Analysis and results**
- **Experimental investigations and results**
- **Conclusions**

Introduction

synthetic working fluids

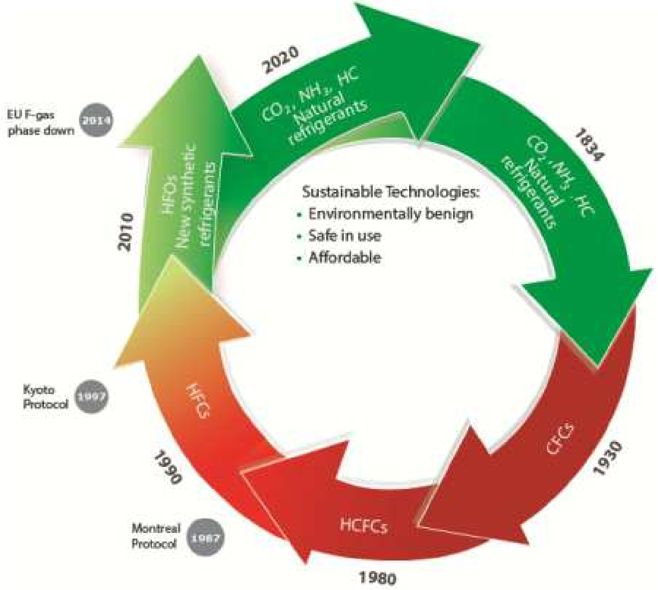
low efficiencies

GWP = 1000 ÷ 50000

ecologic solutions,
Renewable energy,
efficiency improvements,

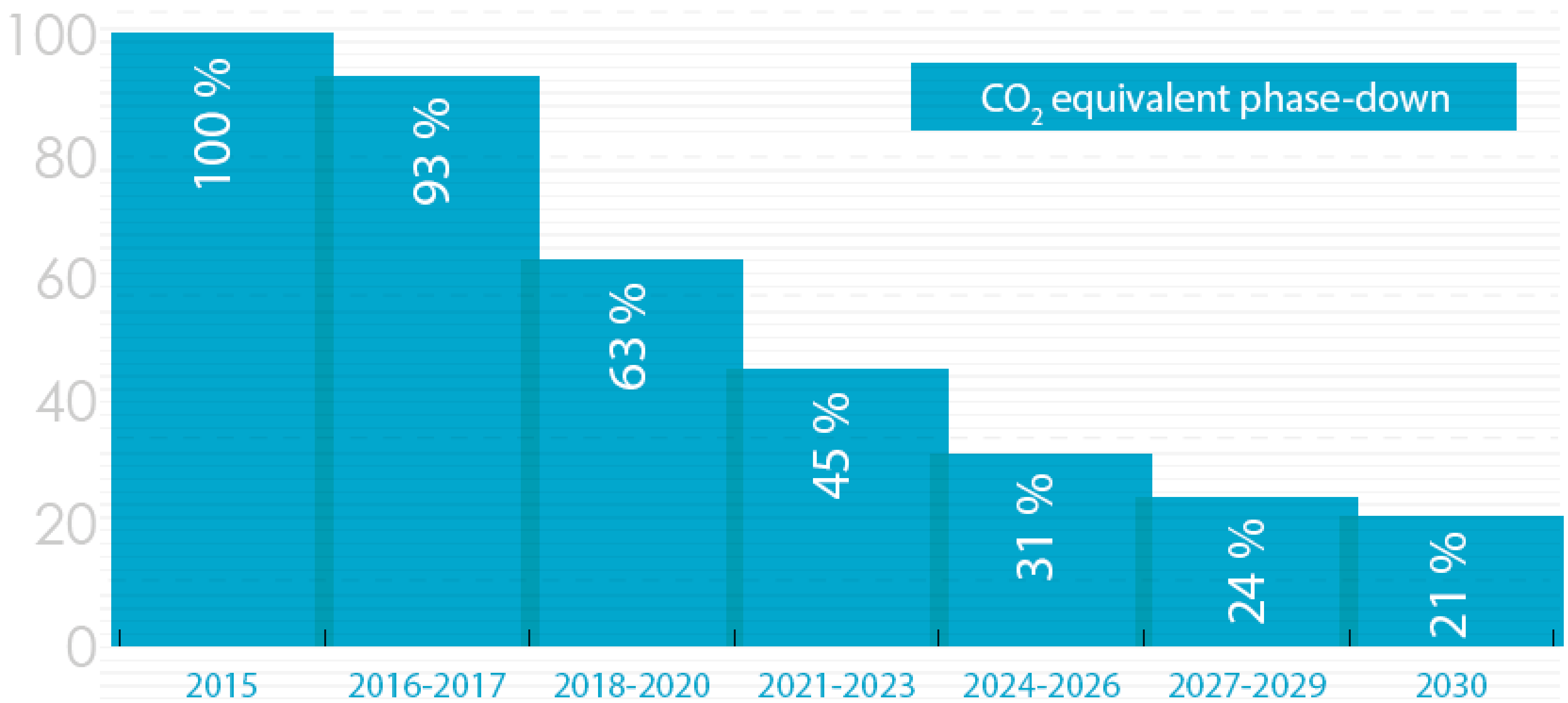
EU Regulations

- ✓ new technology,
- ✓ natural working fluids,
- ✓ improvement of efficiency



EU F-GAS REGULATION EU/517/2014

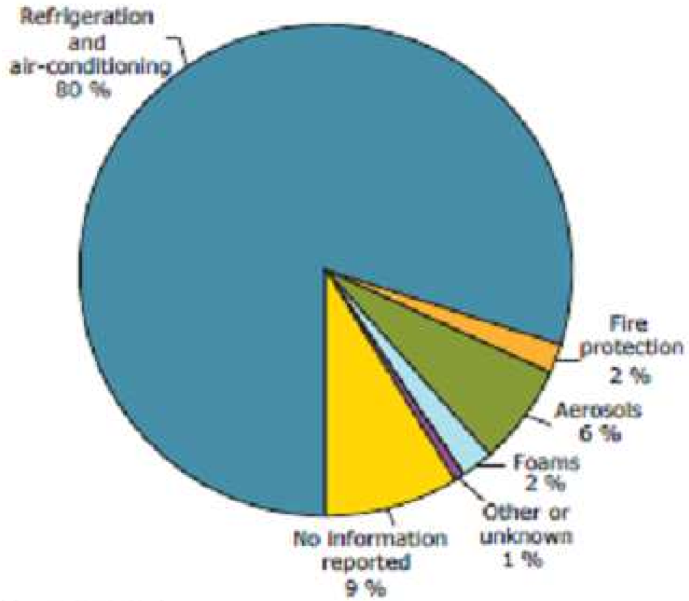
HFC cap and phase-down scheme



Problems for working fluid selection:

- system efficiency
- safety
- operating parameters
- thermodynamic properties
- economics (price, availability)
- technical aspects (e.g. materia compatibility)

EU: Consumption/Use



Source: EEA.

Transition to lower GWP alternatives

Most Current HFCs	Some Future Alternatives
✓ Non-flammable	✗ Flammable
✓ Non-toxic	✗ Toxic
✓ Low operating pressure	✗ High operating pressure
✓ Compatible with materials	✗ Less compatible with materials
✗ **Very high GWP**	✓ **Low GWP**

	HFC	Natural			HFO
Refrigerant		HCs	Ammonia	CO_2	1234yf
GWP (100 years)	✗✗ R134a 1300 – R410A 1900	✔ 3 - 5	✔✔ 0	✔✔ 1	✔ 4
Toxicity	✔✔	✔✔	✗✗	✔	✔✔
Flammability	✔✔	✗✗	✗	✔✔	✗
Materials	✔	✔	✗	✔	✔
Pressure	✔	✔	✔	✗✗[1]	✔
Availability	✔✔	✔	✔	✔	✗✗
Familiarity	✔✔	✔	✔	✗	✗

Very poor ✗✗ **Poor** ✗ **Good** ✔ **Very Good** ✔✔

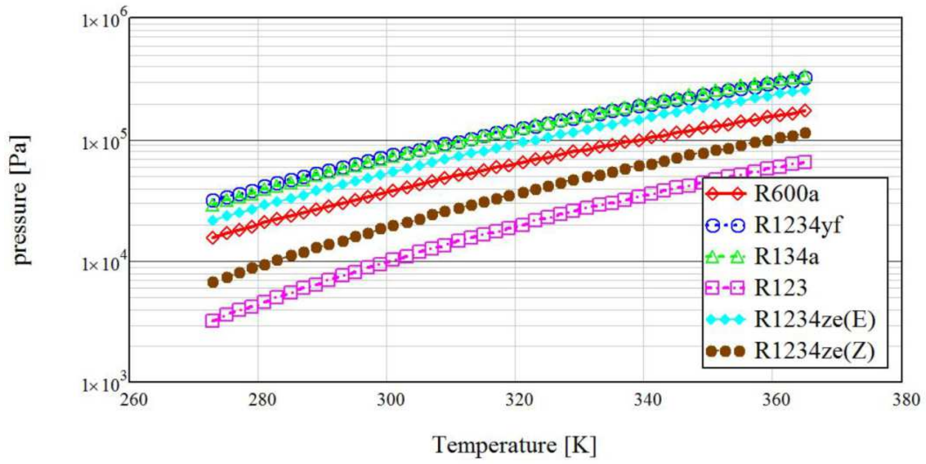
Source: F-gas support Information Sheet - RAC7 alternatives

Transition to lower GWP alternatives

GWP Group	GWP Range	Refrigerant		GWP	Flammability
Ultra-low	0 to 10	HFO-1234yf	R-134a alternative	4	2L
		HFO-1234ze	R-134a alternative	7	2L
		HCFO-1233zd	R-123 alternative	4	1
Low	10 to 150	None currently proposed			
Moderate	150 to 1500	HFC-32	R-410A alternative	675	2L
		L40, XP40	R-404A alternatives	~ 300	2L
		R-446A, R-447A	R-410A alternatives	460, 582	2L
		R-450A, R513A	R-134a alternatives	601, 631	1
		R-448A, R-449A	R-404A alternatives	1387, 1397	1
High	1500 to 2500	R-452A	R-404A alternative	2141	1
Very high	>2500	None being considered			

Market	Sub-sector	Current HFC	Possible Future Options
Domestic		HFC-134a	HC-600a, HFO-1234ze
Commercial	Stand-alone	HFC-404A	HC-290, R-744, HFO-1234ze
	Condensing unit	HFC-134a	? 2L alternatives
	Central pack	HFC-410A	R-744, alternative designs
Industrial	Large	HFC-404A	R-717, R-744
	Small	HFC-134a (HCFC-22)	? 2L alternatives
Transport	Road, containers	HFC-404A	R-744, R-452A, ? HCs / 2L alternatives

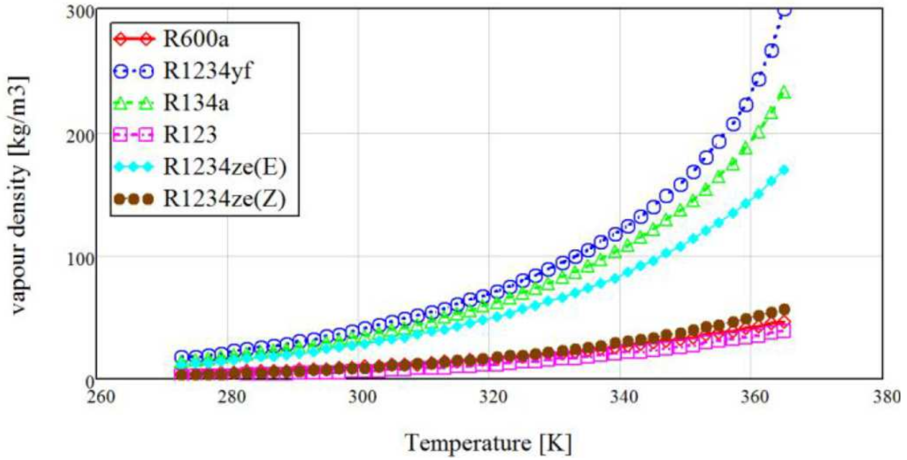
Fluids properties comparison

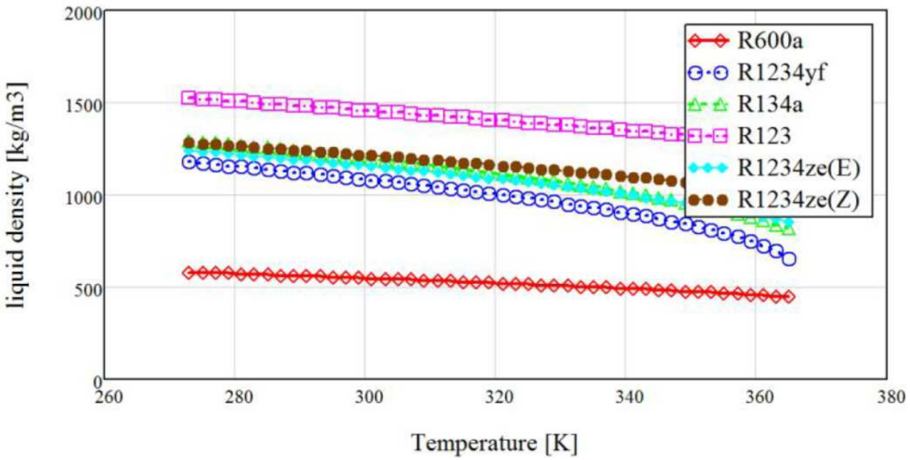


Fluid for ejection system…

e.g. R600a, R601, R601a, R1234yf, R1234ze(Z),R1234ze(E), R290, R717,methan…

R134a, R123 – reference fluids

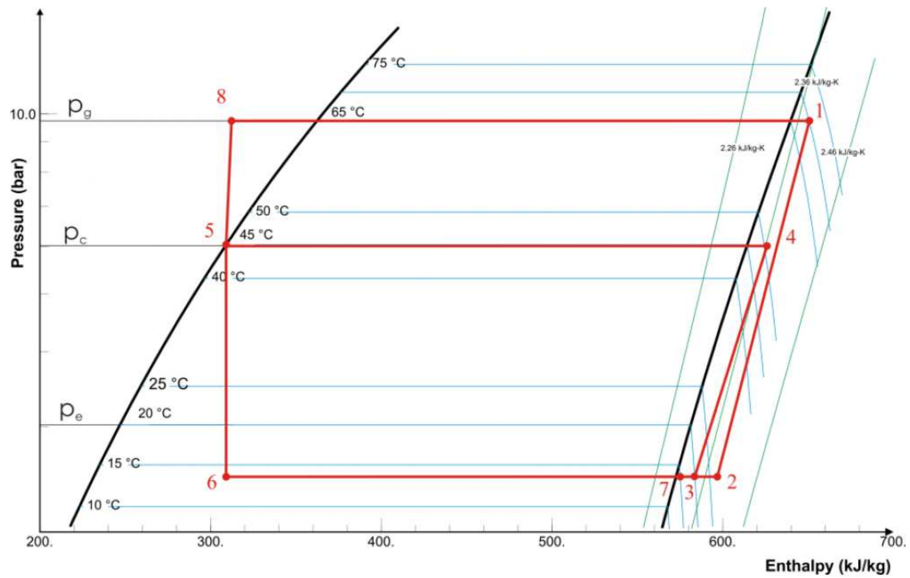




Analysis

assumptions and operating parameters

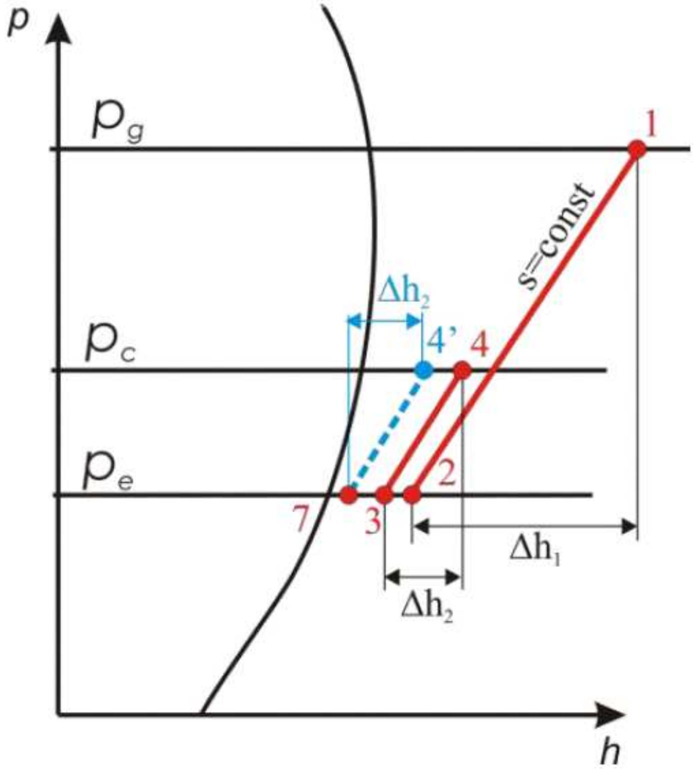
- superheating of the primary fluid (motive vapor): ΔTg = 4 K;
- the secondary vapor is at saturated state;
- isentropic overall efficiency of the ejector: η = 0.70;
- evaporation temperature: variable;
- condensation temperature: variable;



$$U = \sqrt{\frac{h_1 - h_2}{h_4 - h_3}} - 1 = \sqrt{\eta_n \eta_d \cdot \frac{h_1 - h_{2s}}{h_{4s} - h_3}} - 1$$

$$COP = \frac{\dot{Q}_e}{\dot{Q}_g} = \frac{\dot{m}_e \cdot (h_7 - h_5)}{\dot{m}_g (h_1 - h_8)} = U \cdot \frac{(h_7 - h_5)}{(h_1 - h_8)}$$

Analysis



$$U = \sqrt{\frac{h_1 - h_2}{h_4 - h_3}} - 1 = \sqrt{\eta_n \eta_d \cdot \frac{h_1 - h_{2s}}{h_{4s} - h_3}} - 1$$

Results

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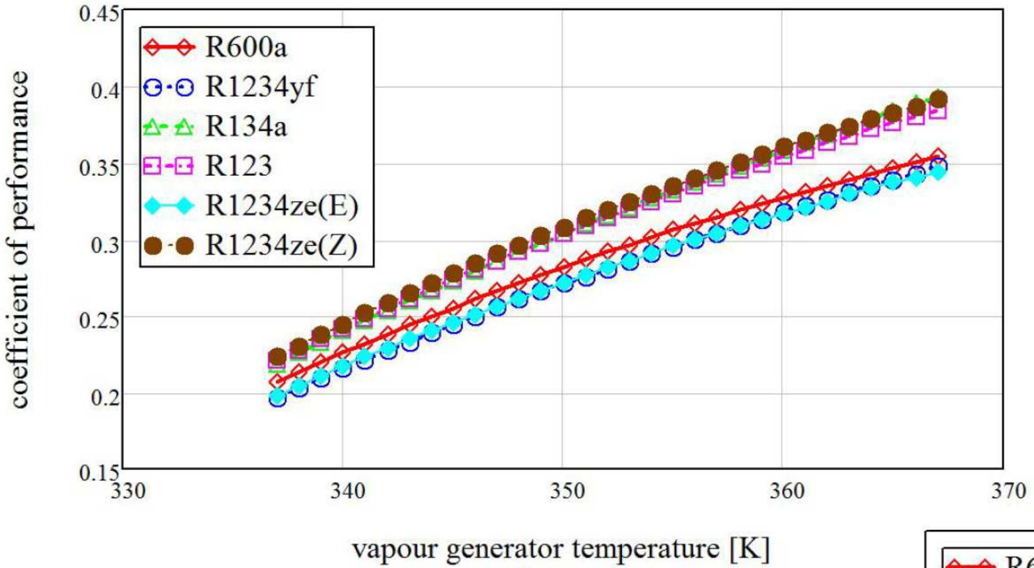
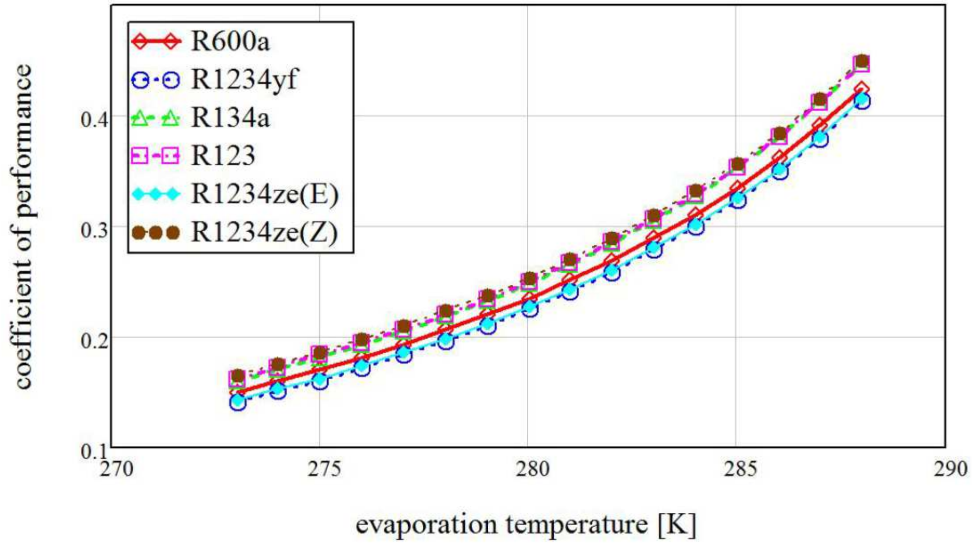


Te = 278 K, Tc = 301 K

Tg = 333 K, Tc = 301 K



…recomendation:

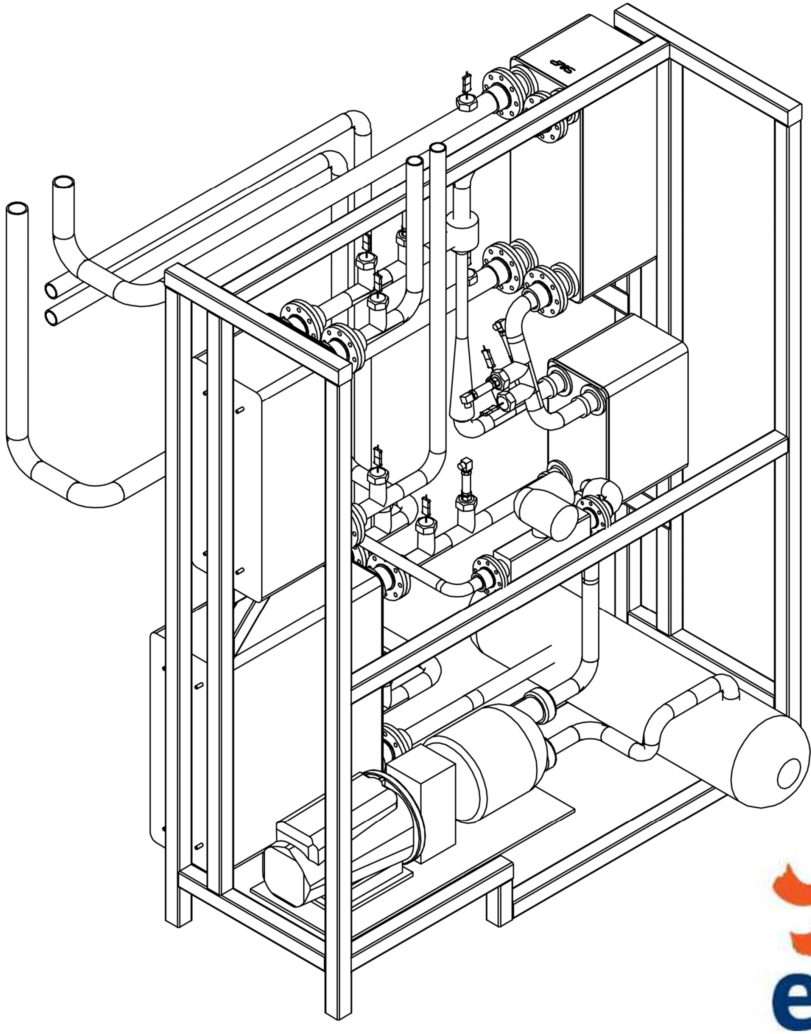
R600a or HFO1234

Results

Geometric parameter	Ratio of geometric parameters R1234ze(E) / R600a
Motive nozzle throat diameter	0.973
Motive nozzle outlet diameter	1.000
Length of diverging part of the motive nozzle	1.066
Mixing chamber diameter	1.000
Length of mixing chamber	1.000
Diffuser outlet diameter	1.000
Length of diffuser	1.000

Parametry wydajnościowe układu	R600a	R1234ze(E)
Mass entrainment ratio U	0.307	0.294
Compression ratio Π	0.282	0.256
Calculated condensation (discharge) pressure p_c [bar]	4.24	5.83
Temperature corresponding to condensation pressure $t_c(p_c)$ [°C]	31.7	30.3
COP	0.272	0.258

Investigations



Investigations

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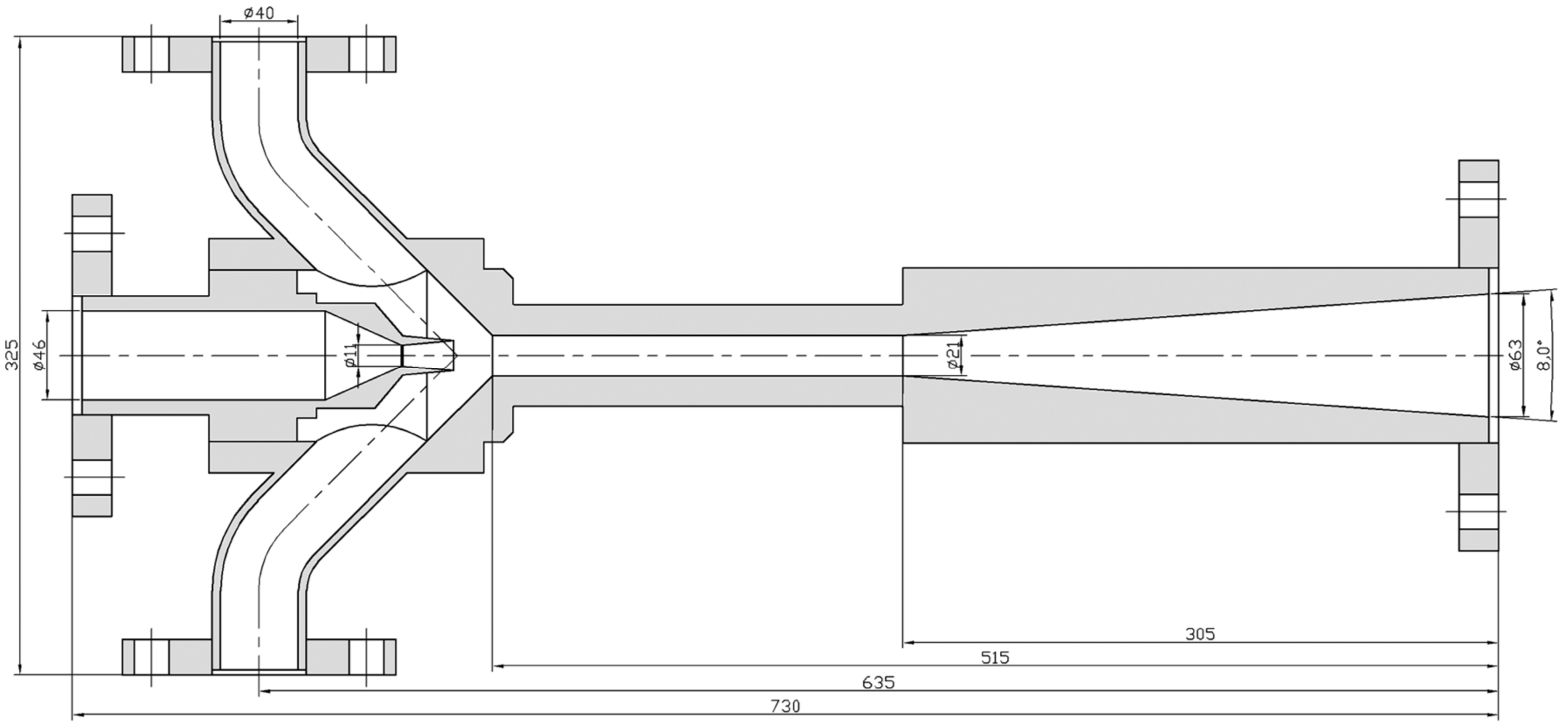
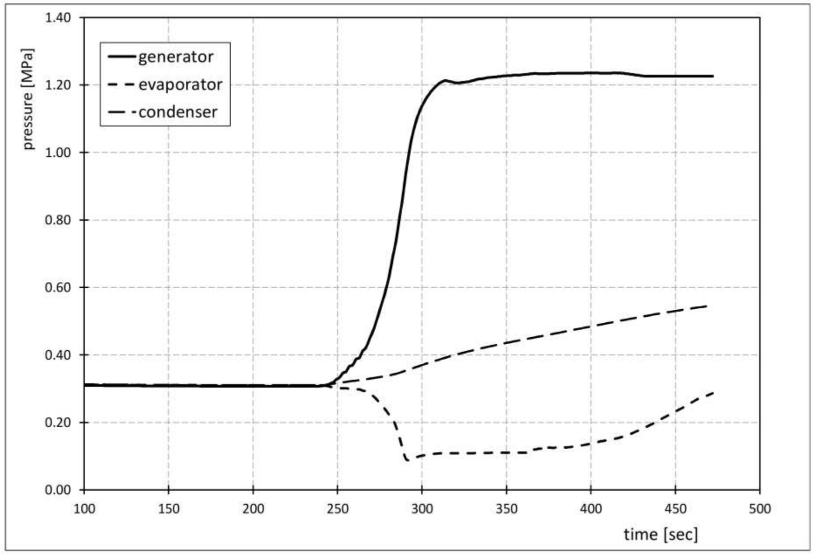
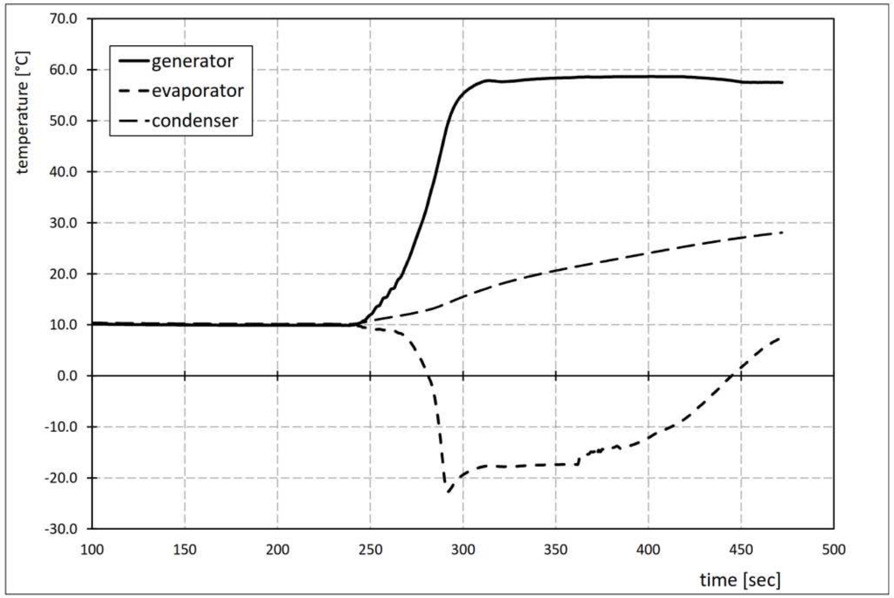


Results

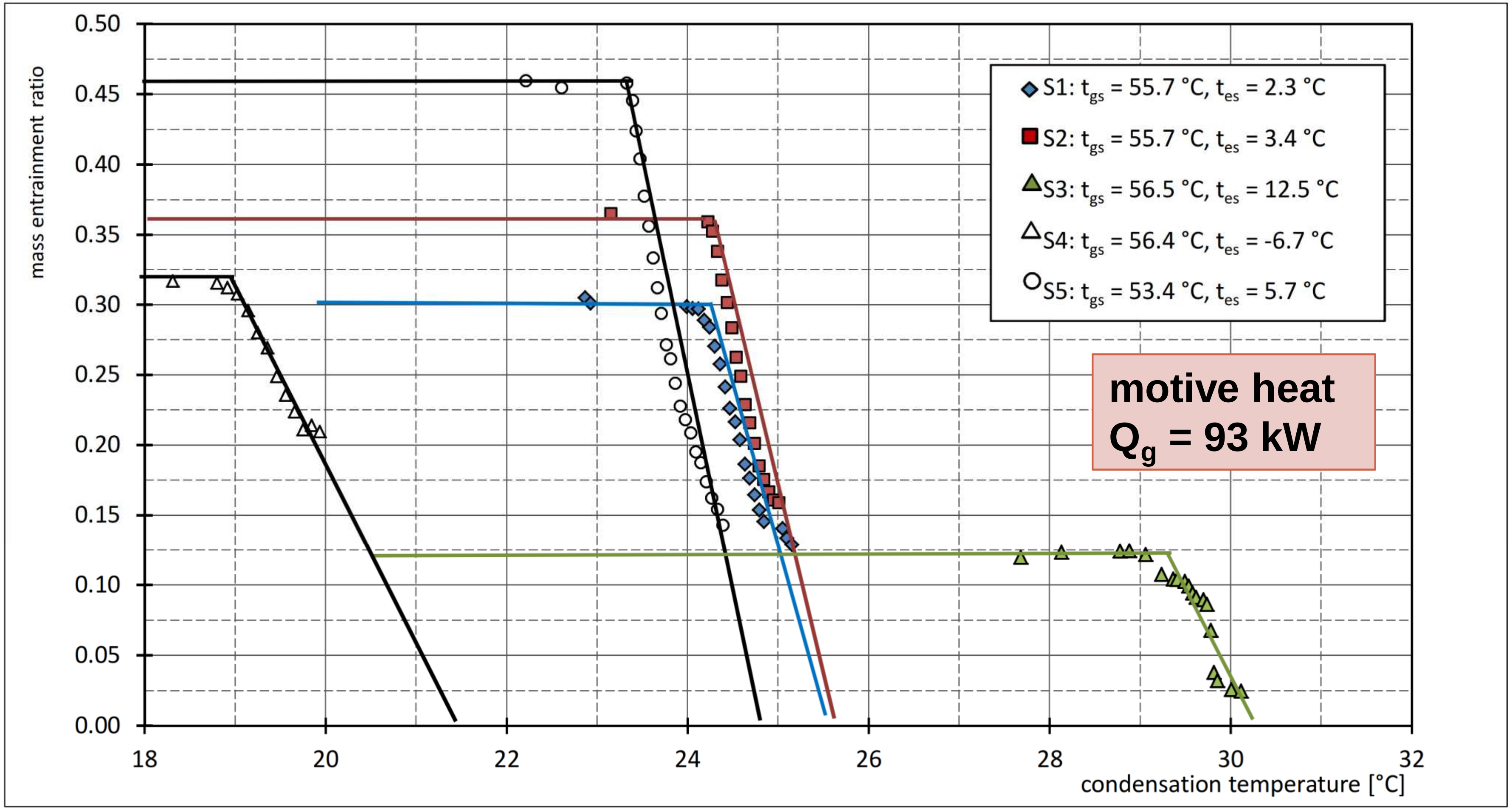


p_g (max)	t_{gs} (max)	p_e (min)	t_{es} (min)	t_{cs} (variable)	p_c-p_e (max)
MPa	°C	MPa	°C	°C	MPa
1.236	58.6	0.088	-22.7	10.1 – 28.1	0.459
1.190	57.1	0.095	-20.9	11.9 – 24.8	0.401
1.189	57.0	0.094	-21.1	12.2 – 27.0	0.435
1.221	58.2	0.098	-20.2	12.8 – 29.7	0.477

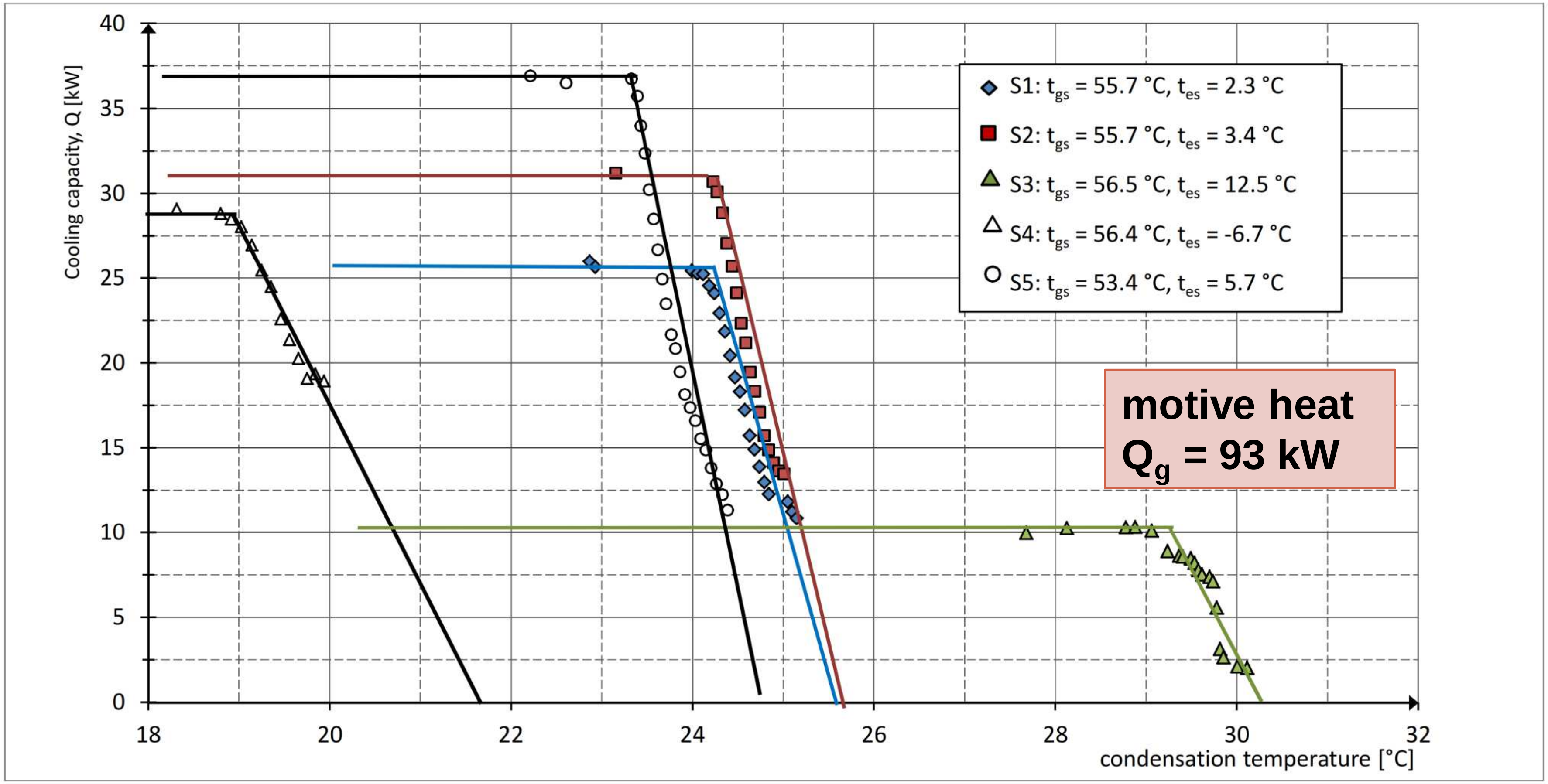


indentification the maximum potential performance of the system

Results


mass entrainment ratio
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
18
20
22
24
26
28
30
32
condensation temperature [°C]
S1: t_{gs} = 55.7 °C, t_{es} = 2.3 °C
S2: t_{gs} = 55.7 °C, t_{es} = 3.4 °C
S3: t_{gs} = 56.5 °C, t_{es} = 12.5 °C
S4: t_{gs} = 56.4 °C, t_{es} = -6.7 °C
S5: t_{gs} = 53.4 °C, t_{es} = 5.7 °C
motive heat
Q_g = 93 kW

Results



motive heat
Q_g = 93 kW

COP up to 0.45

Conclusions

The application of refrigerant R-1234ze requires similar ejector dimensions in comparison of the geometry predicted for isobutane. Therefore this refrigerant may be thought as an alternative for isobutane for safety reasons.

Since isobutane is flammable and explosive refrigerant its use in many cases it might be difficult. Therefore, refrigerant R-1234ze might be real alternative, it is qualified as non-explosive and non-flammable.

The achievable condensation temperature are higher for isobutane than for refrigerant R-1234ze(E). This effect may be thought as a strong surplus of isobutene as a working fluid.

COP achievable for the cycle operating with isobutane is higher which is related with higher mass entrainment ratio for isobutane than for R-1234ze(E)