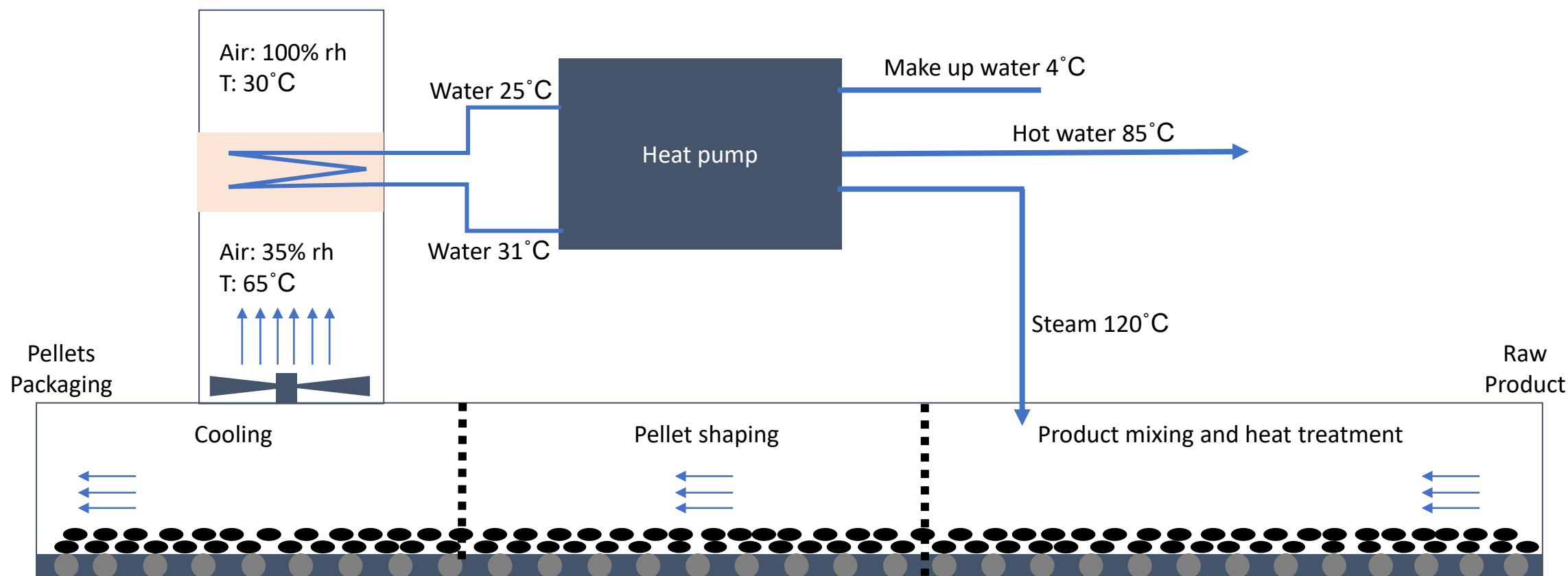


# Ammonia - Steam cascade heat pump for +100°C steam generation

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# Petfood pellets process with heat recycling





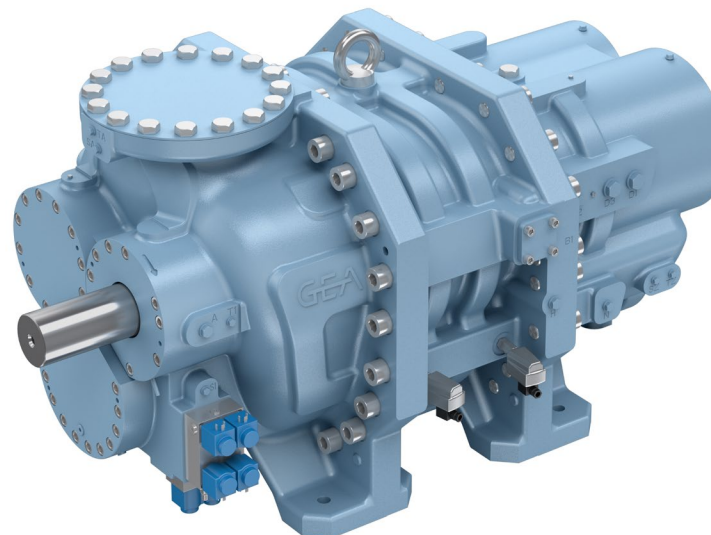
# Refrigerant choice below 100 °C

Refrigerant	R717	R1234ze(E)	R134a	R718
Molecular structure	NH <sub>3</sub>	C <sub>3</sub> H <sub>2</sub> F <sub>4</sub>	CF <sub>3</sub> CH <sub>2</sub> F	H <sub>2</sub> O
Molar weight	17	114	102	18.0
Boiling point at 1.013 bar (°C)	-33.3	-18.95	-26.06	100.0
Critical temperature (°C)	132.4	109.4	101.1	373.9
Critical Pressure (bar)	111.3	36.4	40.6	22.1
Heat of vaporization @ 30 °C (kJ/kg)	1144.8	162.9	173.1	2440.3
Heat of vaporization @ 90 °C (kJ/kg)	800.7	93.4	82.2	2202.2
Volumetric heating capacity @ 90 °C (kJ/m <sup>3</sup> )	34828	15044	17889	933
GWP100 (CO <sub>2</sub> =1)	0	1	1430	0
Safety group (ASHRAE 34)	B2L	A2L	A1	A1
Molar yield of PFA left in atmosphere	0	<10%	10%	0

# Development of ammonia compressors

**High temperatures, higher capacities, higher efficiencies and more robust.**

1. New more robust bearings
2. Up to 95°C Condensing temperature
3. Condensation prevention system during standstill (Piston)
4. New oil distribution system (Piston)
5. Ammonia droplet catcher (Piston)
6. Variable Vi (screw)  
Optimised compression ratio  
Minimised vibration
7. Economised (Screw)  
Improved efficiency



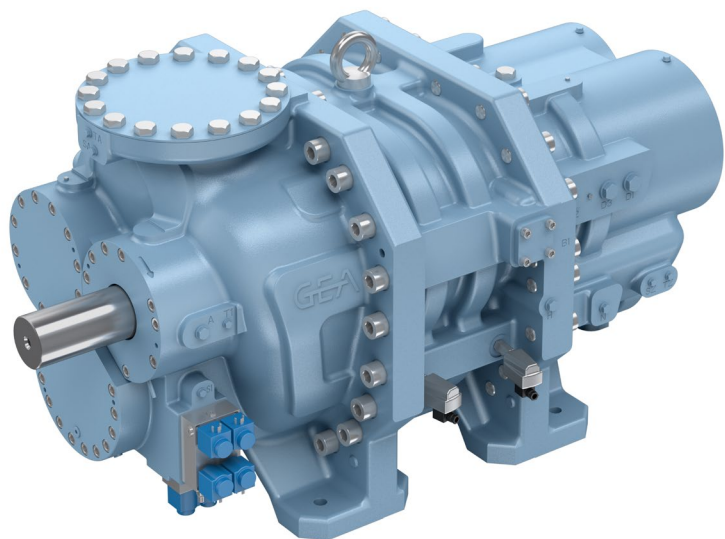


# Refrigerant choice above 100 °C

Refrigerant	R1233zd(E)	R245	R601	R718
Molecular structure	CHCl=CH-CF <sub>3</sub>	CF <sub>3</sub> CH <sub>2</sub> CHF <sub>2</sub>	CH <sub>3</sub> -3(CH <sub>2</sub> )-CH <sub>3</sub>	H <sub>2</sub> O
Molar weight	130.5	134.0	72.15	18.0
Boiling point at 1.013 bar (°C)	18.3	15.14	36.1	100.0
Critical temperature (°C)	165.6	154.0	196.6	373.9
Critical Pressure (bar)	3.57	3.65	3.37	22.1
Heat of vaporization @ 120 °C (kJ/kg)	123.1	112.4	268	2202.2
GWP100 (CO <sub>2</sub> =1)	<5	1030	11	0
ODP	0.00034	0	0	0
Lifetime in atmosphere (days)	10 – 40	~2800		-
Occupational Exposure limit (OEL) (ppm v/v)	800	300	2000	1.000.000
Safety group (ASHRAE 34)	A1	A1	A3	A1
Molar yield of PFA left in atmosphere	2%	<10%	0	0

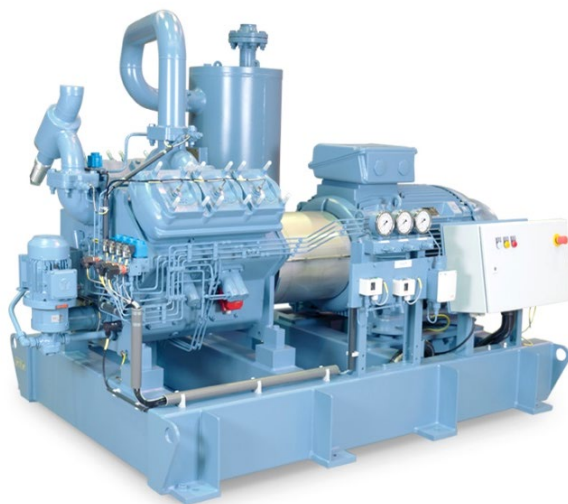
# Chosen compression technology

## 1. 1<sup>st</sup> stage - Ammonia



$\eta_{\text{isentropic}} = 74\%$

## 1. 2<sup>nd</sup> Stage- Ammonia



$\eta_{\text{isentropic}} = 88\%$

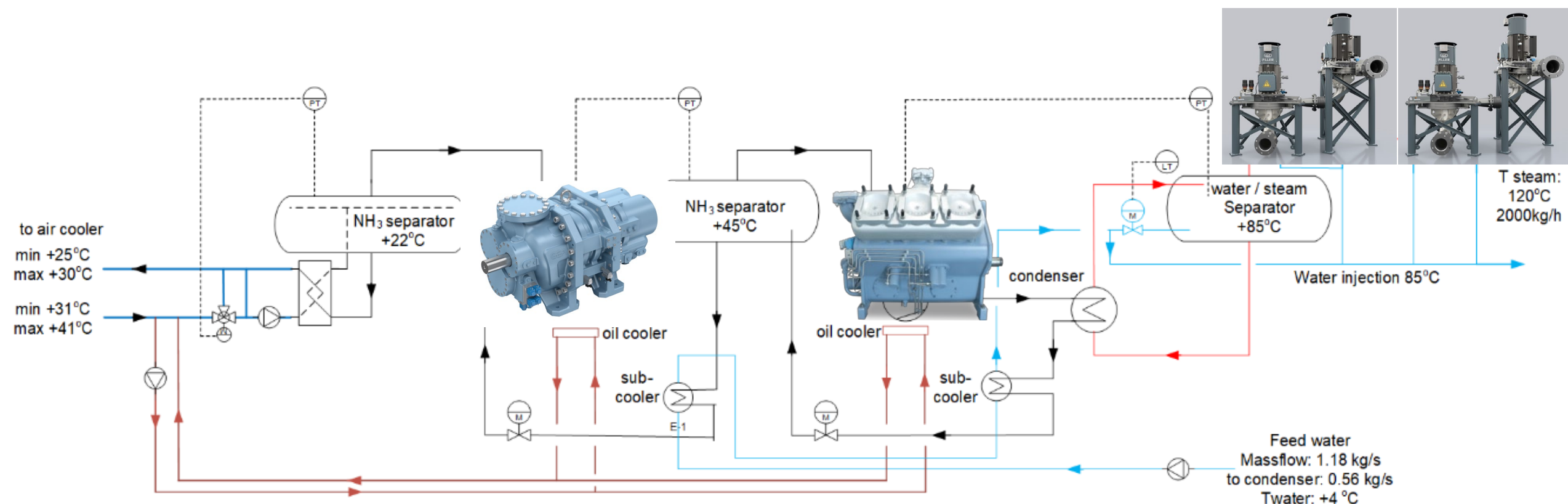
## 1. 3<sup>rd</sup> – 6<sup>th</sup> Stage - Water



$\eta_{\text{isentropic}} = 80\%$



# Heat pump design







# Heat pump performance

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## Heat pump performance

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### Absorbed power

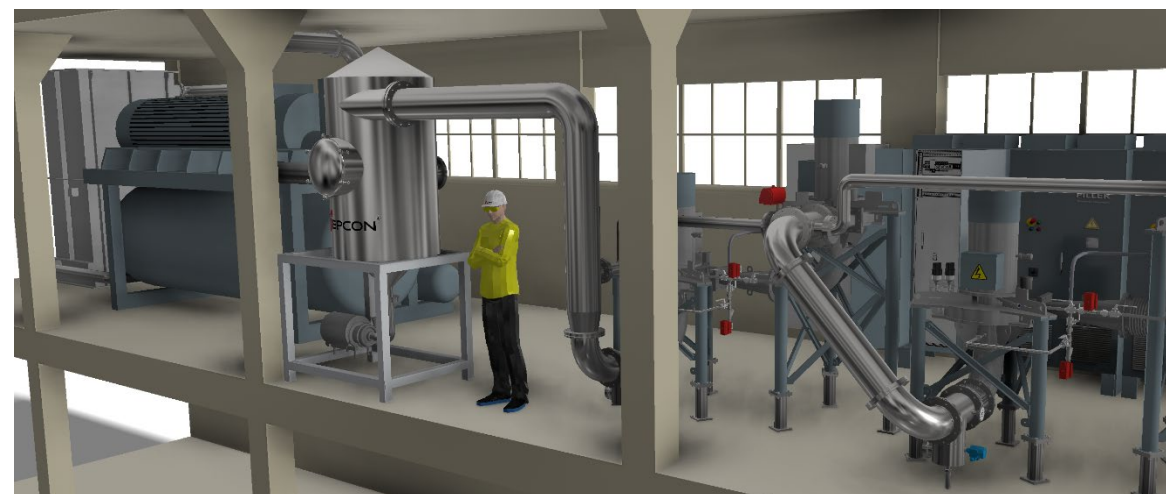
Ammonia screw compressor (22 °C to 45 °C)	kW	158.6
Ammonia piston compressor (45 °C to 89 °C)	kW	212.1
4 x MVR steam compressors (85 °C to 120 °C)	kW	189.0
Total shaft power	kW	559.7
Total power (including electrical losses)	kW	601.8

### Heat output

Steam generation	kW	1464
Heating water 4°C -> 85°C	kW	416
Total heat output	kW	1880

### Performance

Shaft COP steam generation only	n/a	2.6
Shaft COP including water heating	n/a	3.4
Heat pump COP (including electrical losses)	n/a	3.1







Thank you