To recuperate or not to recuperate - ORC cycles compared to ideal cycles

Pall Valdimarsson

University of Iceland, Reykjavik, Iceland

ORC 2011
First International Seminar on ORC Power Systems
In memory of Prof. G. Angelino

22 - 23 September 2011
Aula Conference Center
TU Delft, The Netherlands

UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

- The performance of real power cycles for heat source in the temperature range from 100°C to 300℃ is studied in this paper.
- A reference is made to three ideal power production cycles:
  - Carnot
  - Triangular
  - Lorenz.

- The source fluid flow is 1 kg/s for all calculations
- The real cycles are assumed to have infinite heat exchanger area
- Pumps and turbines are isentropic
- The cooling fluid is produced by external means, without being a parasite of the power plant.

- The binary cycles studied are:
  - ORC with a single high pressure level
  - ORC with two pressure high levels
  - Saturated Kalina cycle
  - Transcritical cycle
  - Single ~~and double flash~~ geothermal power cycles are included as well
    - A few different working fluids are considered for the ORC cycles
    - ~~A few different ammonia concentrations for the~~ Kalina cycle.

- The results are presented as:
- $$z = f(T_{source}, T_{return})$$
- The produced power for these cycles from the same source is then compared and a range of superiority for each cycle presented.
- The effect of recuperation on the produced power as well as on the calculated efficiency is shown.

- Finally the influence of finite heat exchanger area is analyzed and an estimate of the cooling fluid generation parasitic power made both for air and wet cooling tower system.

Source properties – the denominator

Geothermal

$$\dot{m}_{source} = constant$$

$$\dot{Q}_{in} \neq constant$$

$$\dot{Q}_{available} > \dot{Q}_{in}$$

$$\eta_{max} = \lim_{\dot{Q}_{in} \to 0} \left(\frac{\dot{W}}{\dot{Q}_{in}} \right); \Rightarrow \dot{W}(\eta_{max}) = 0$$

$$PC = \frac{\dot{W}}{\dot{m}_{source}} = \frac{E}{M_{source}} \left[\frac{kWh}{ton} \right]$$

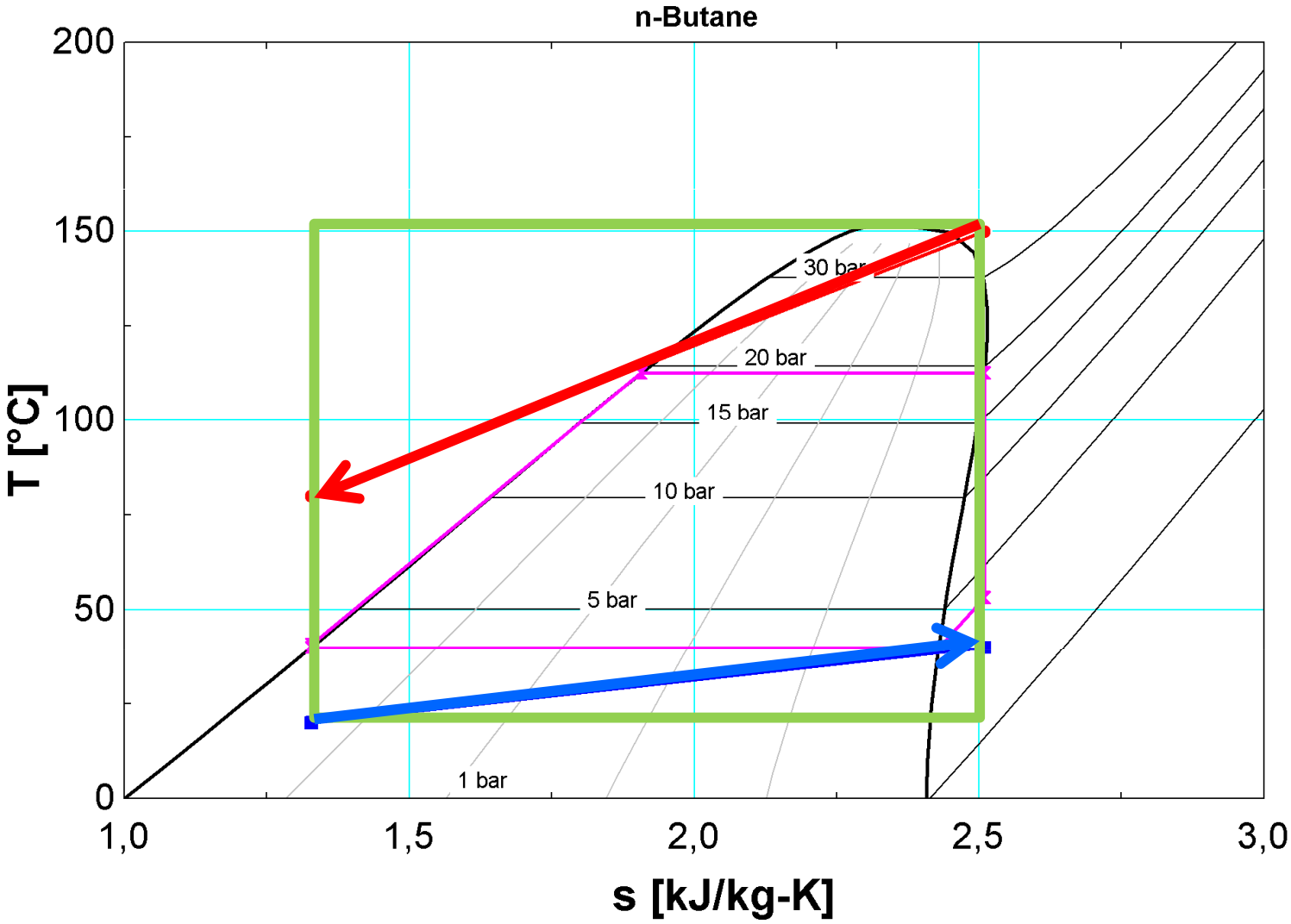
WHR

$$\dot{m}_{source} \neq constant$$

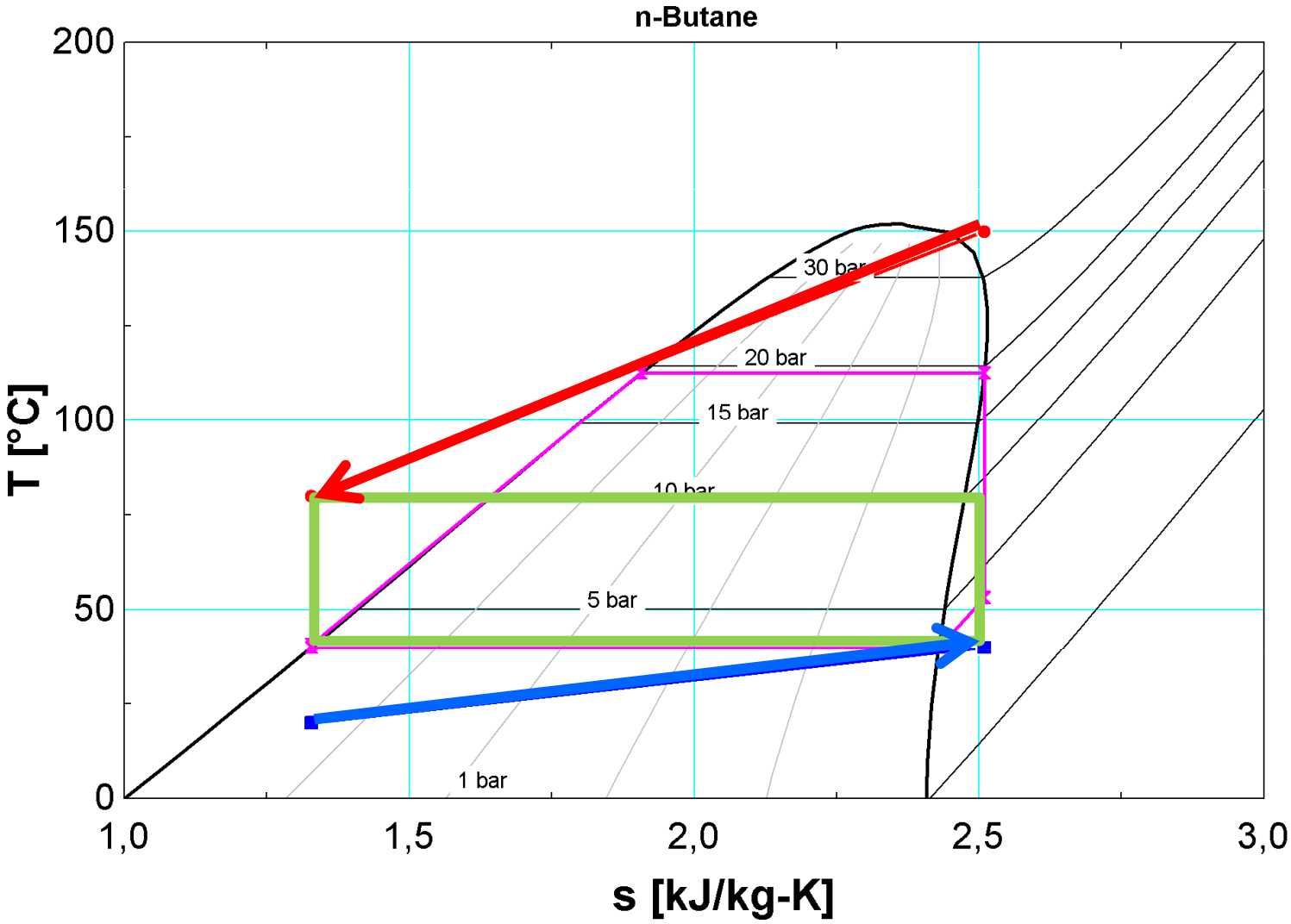
$$\dot{Q}_{in} = constant$$

$$\dot{Q}_{in} = \dot{Q}_{available}$$

$$\eta = \eta_{max} = \frac{\dot{W}}{\dot{Q}_{in}} = \frac{\dot{W}}{\dot{Q}_{available}}$$

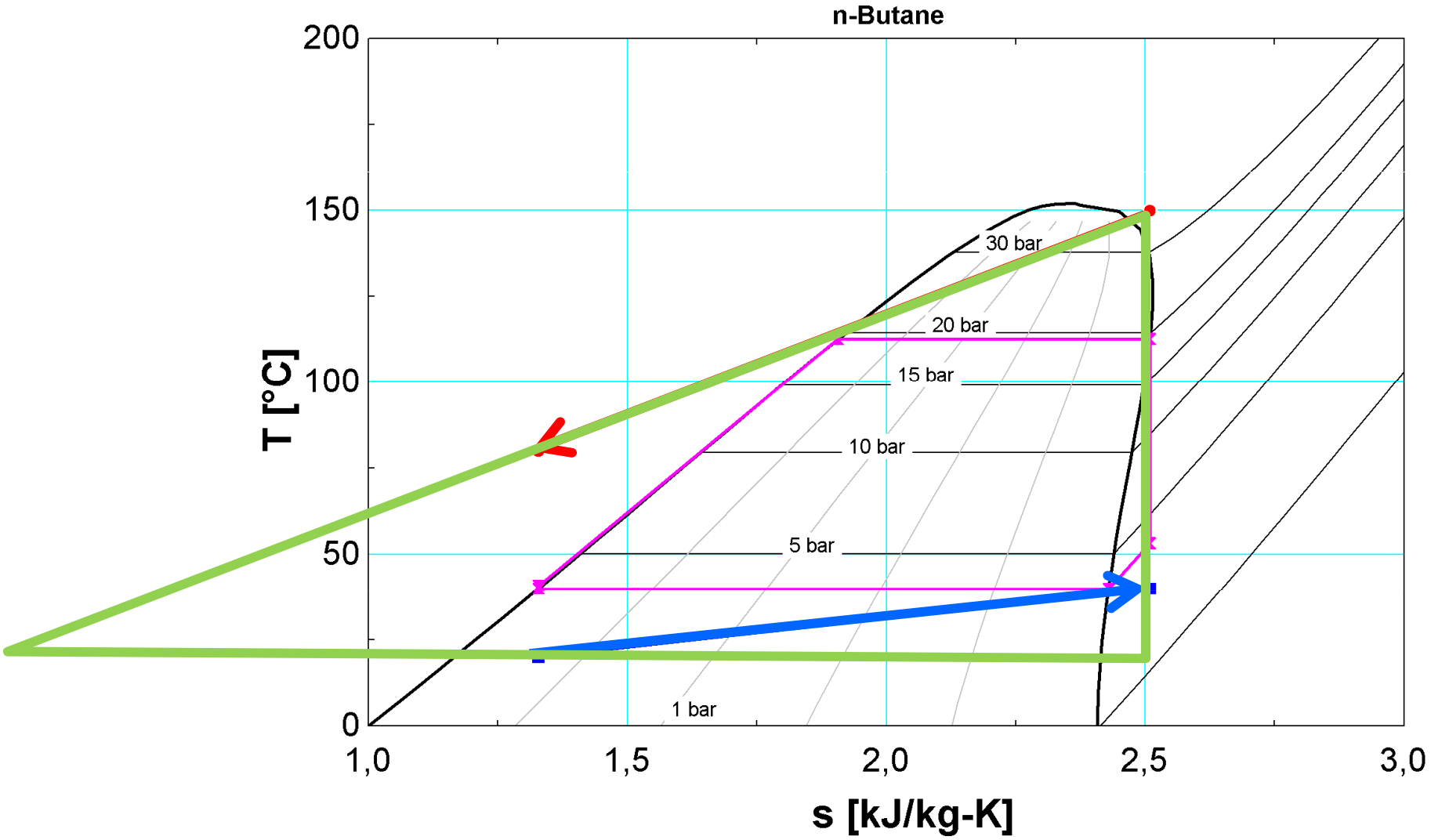


Optimistic Carnot

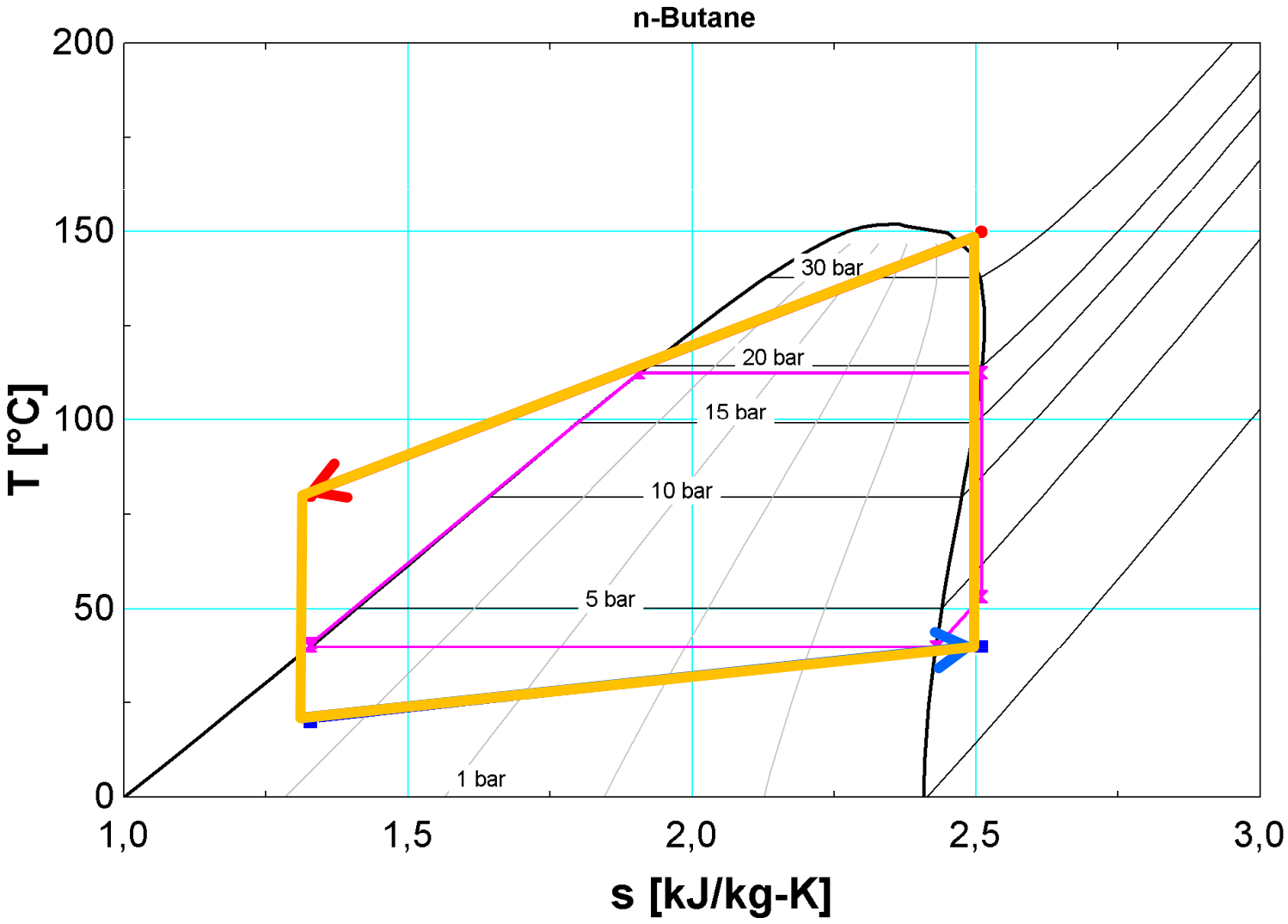


UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

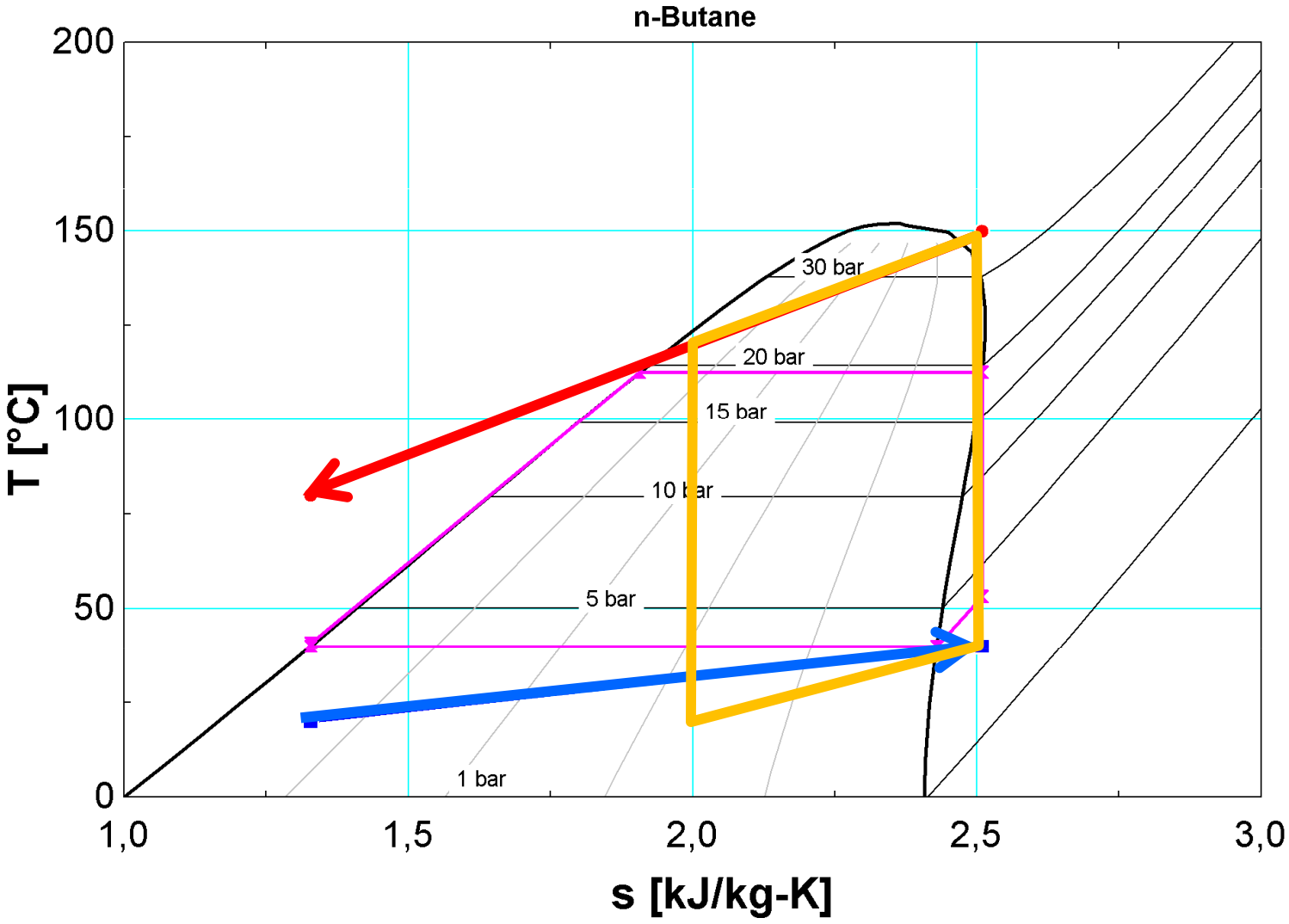
Pessimistic Carnot


n-Butane
200
150
100
50
0
T [°C]
30 bar
20 bar
15 bar
10 bar
5 bar
1 bar
1,0
1,5
2,0
2,5
3,0
s [kJ/kg-K]

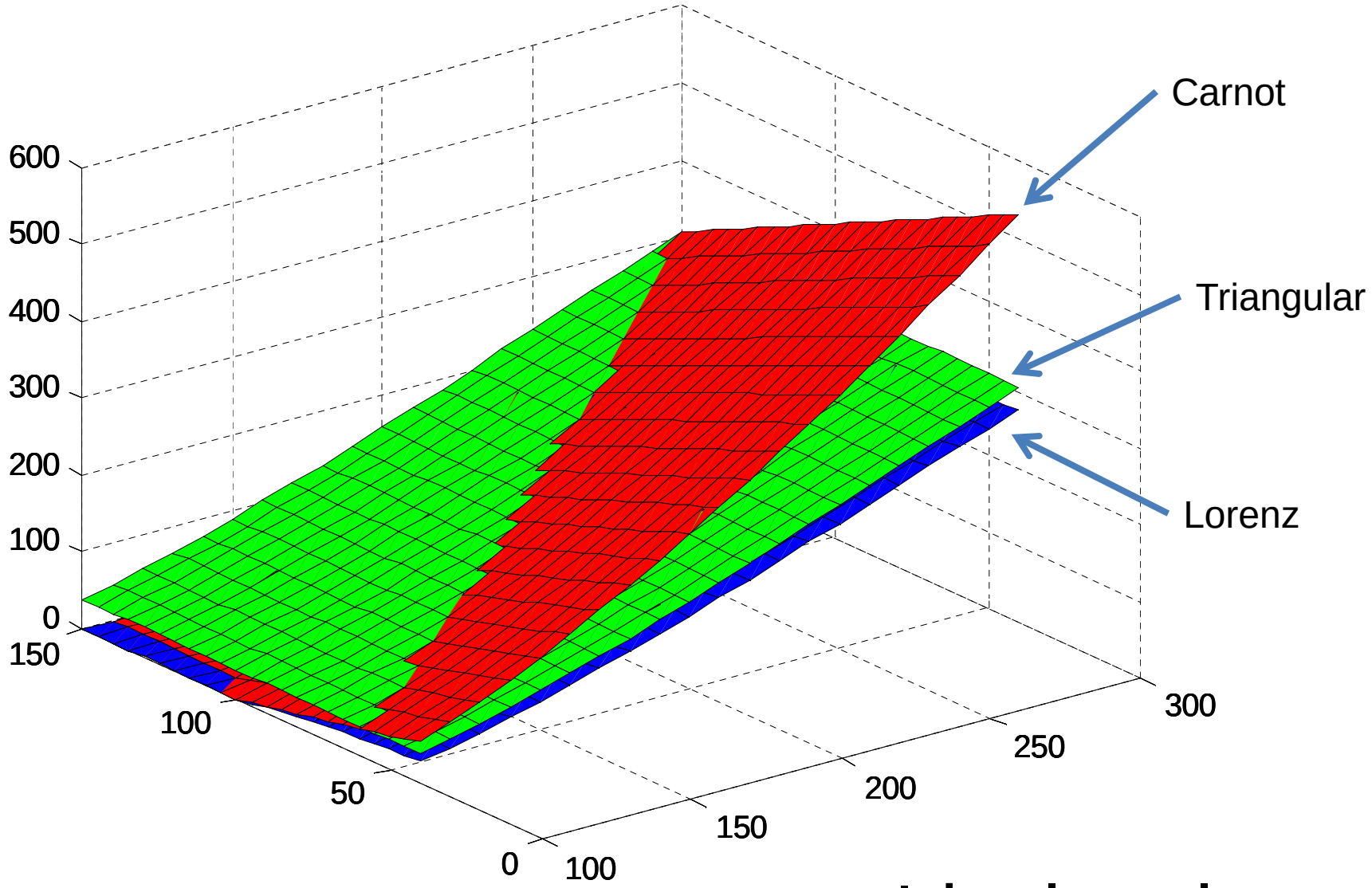
Triangular


n-Butane
200
150
100
50
0
T [°C]
30 bar
20 bar
15 bar
10 bar
5 bar
1 bar
1,0
1,5
2,0
2,5
3,0
s [kJ/kg-K]

Lorenz


n-Butane
200
150
100
50
0
T [°C]
30 bar
20 bar
15 bar
10 bar
5 bar
1 bar
1,0
1,5
2,0
2,5
3,0
s [kJ/kg-K]

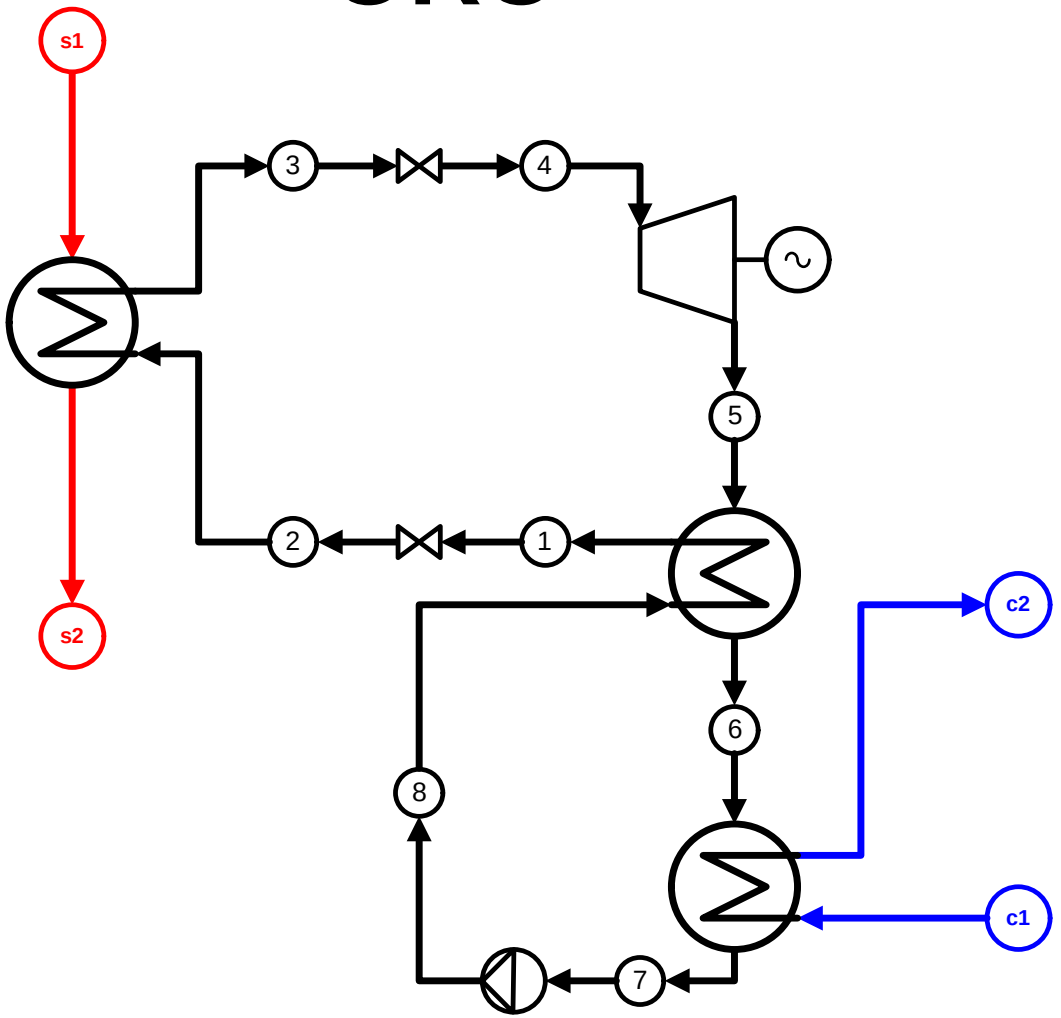
Lorenz

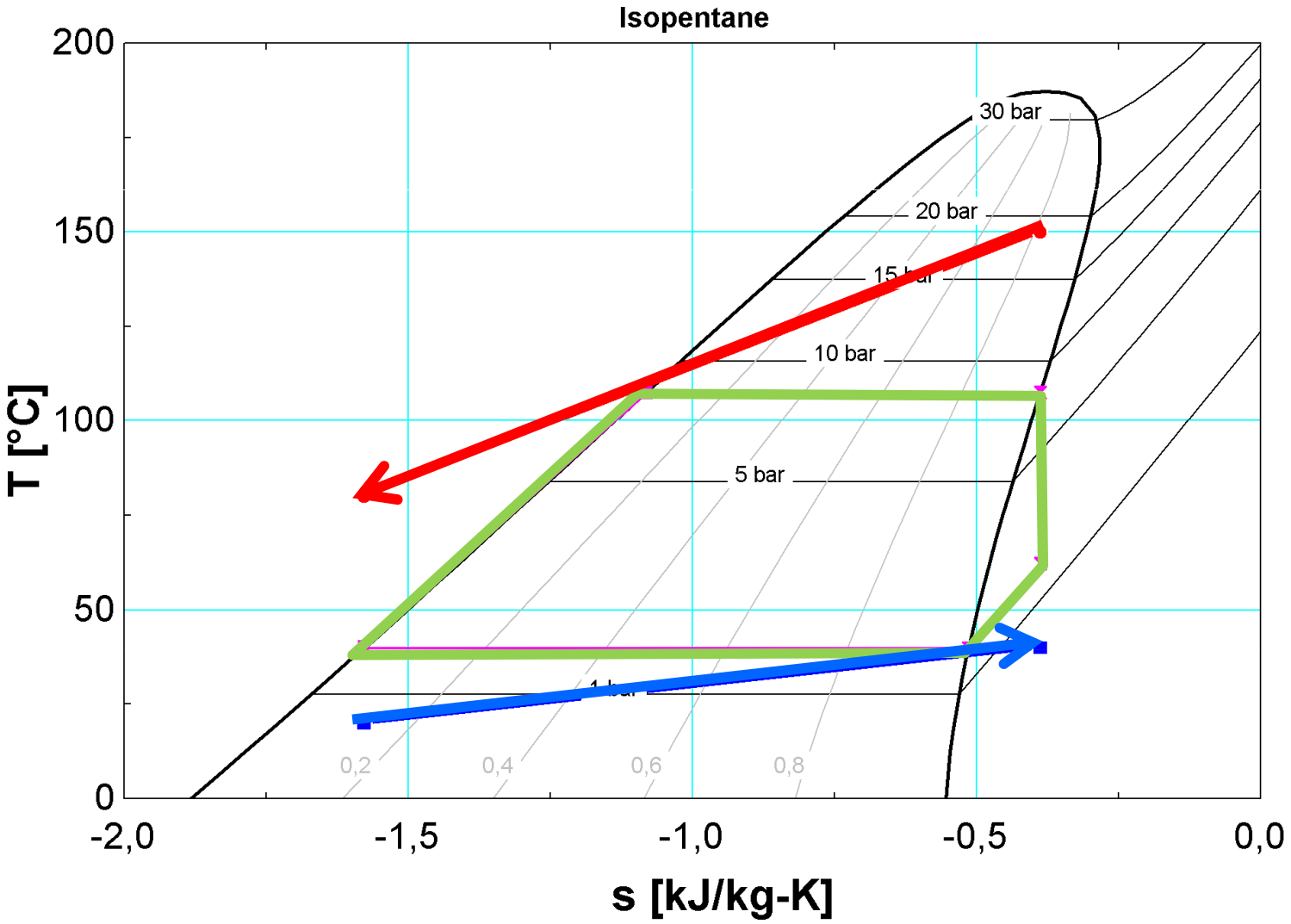


Ideal cycles

UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

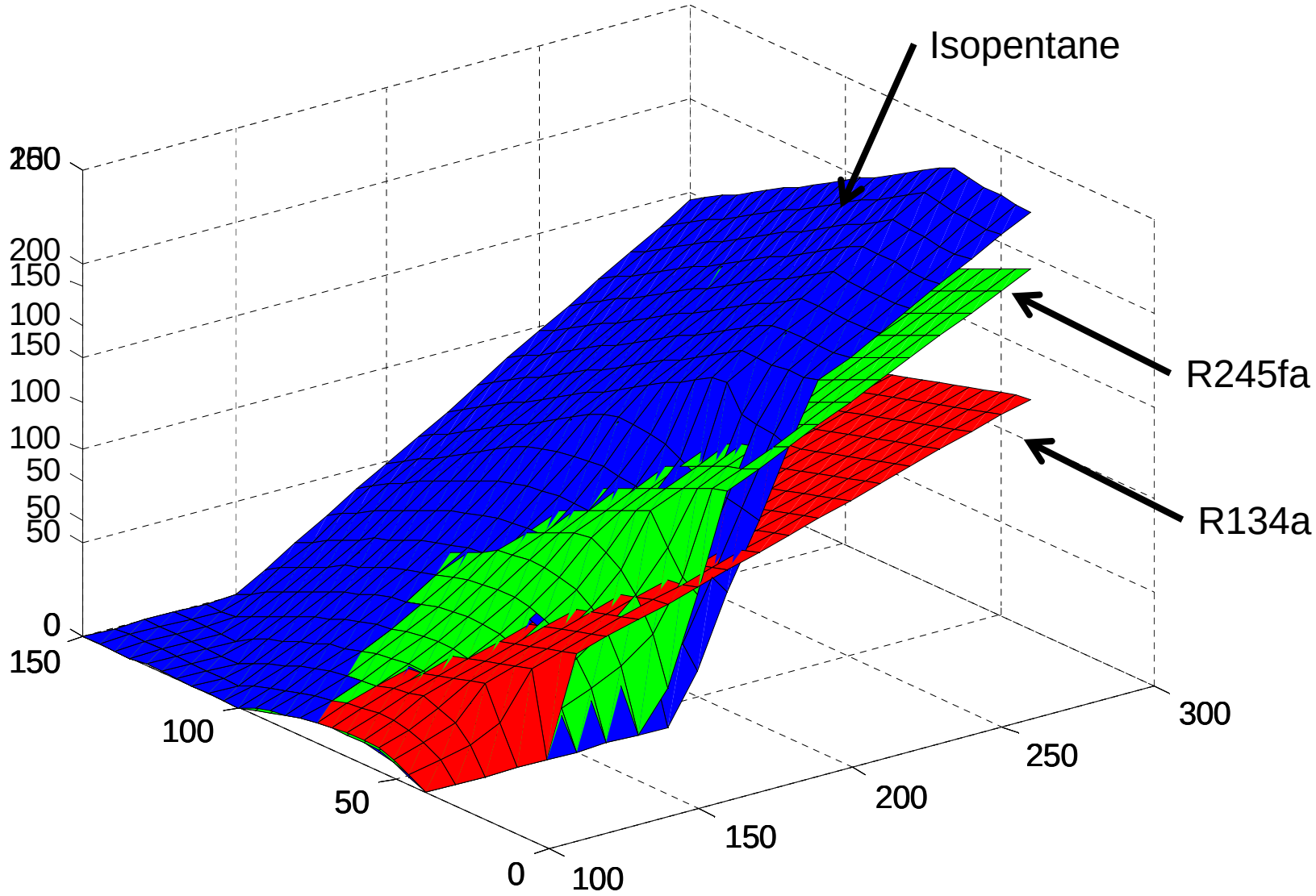
ORC





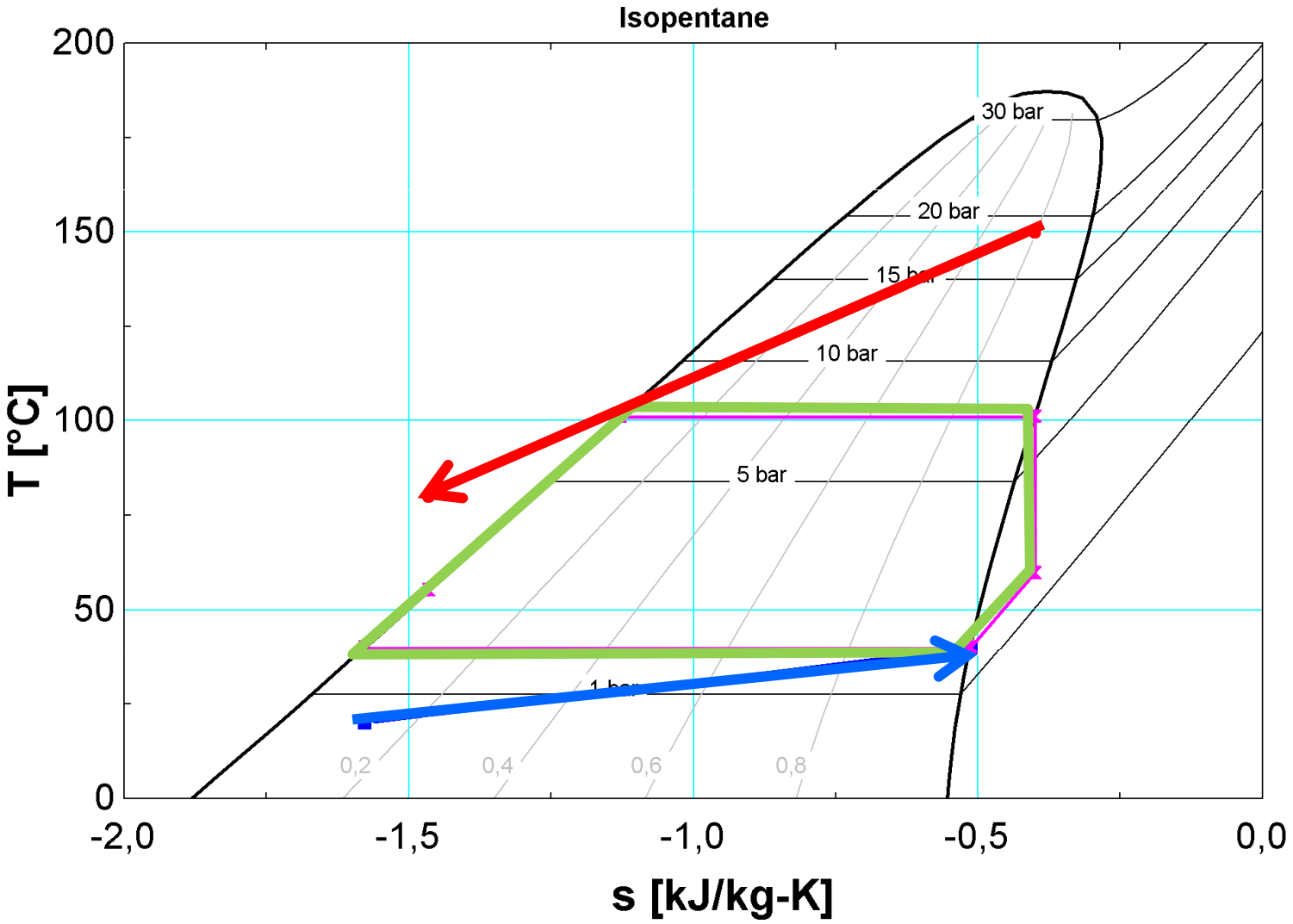
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Saturated Isopentane



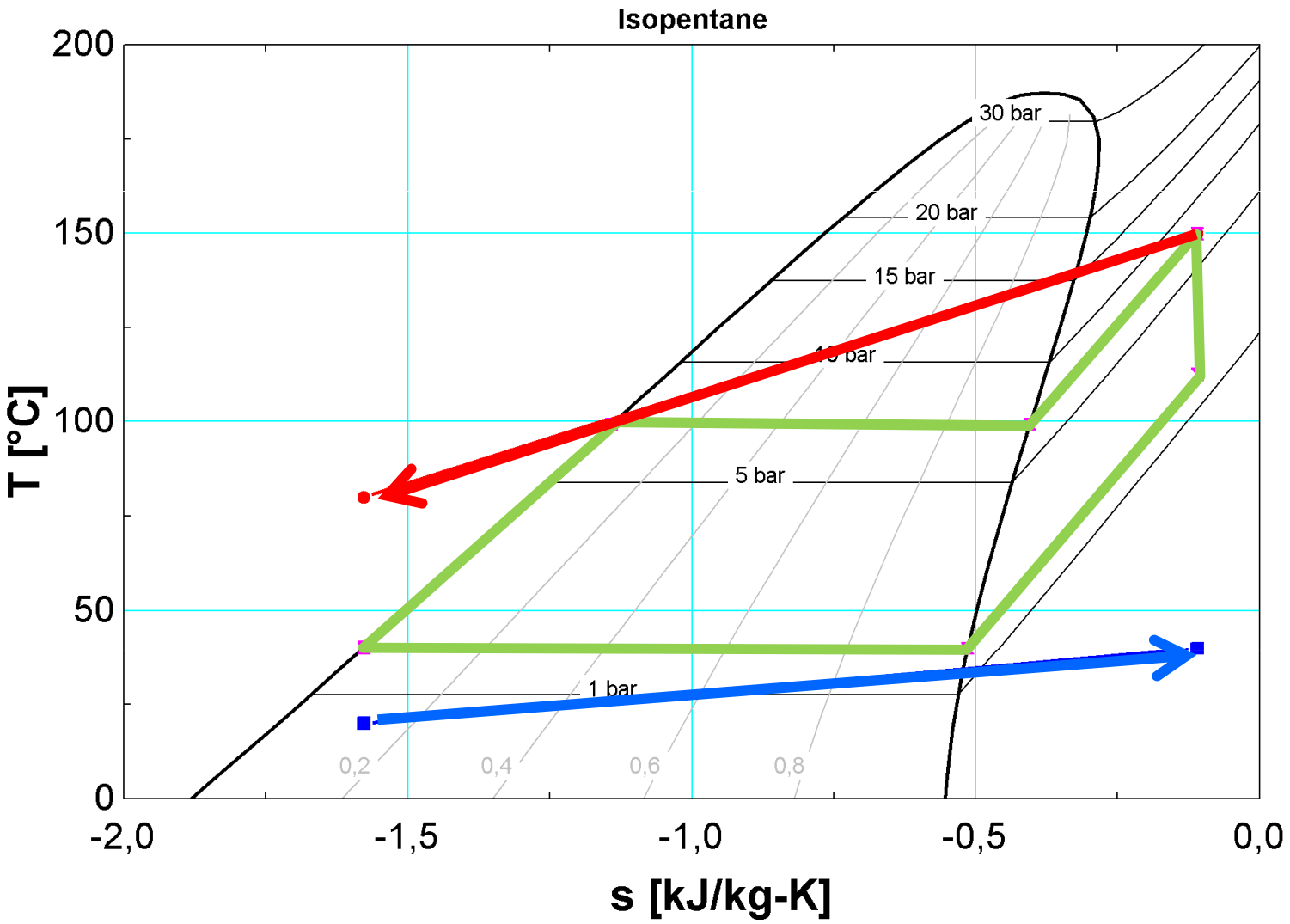
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Saturated comparison



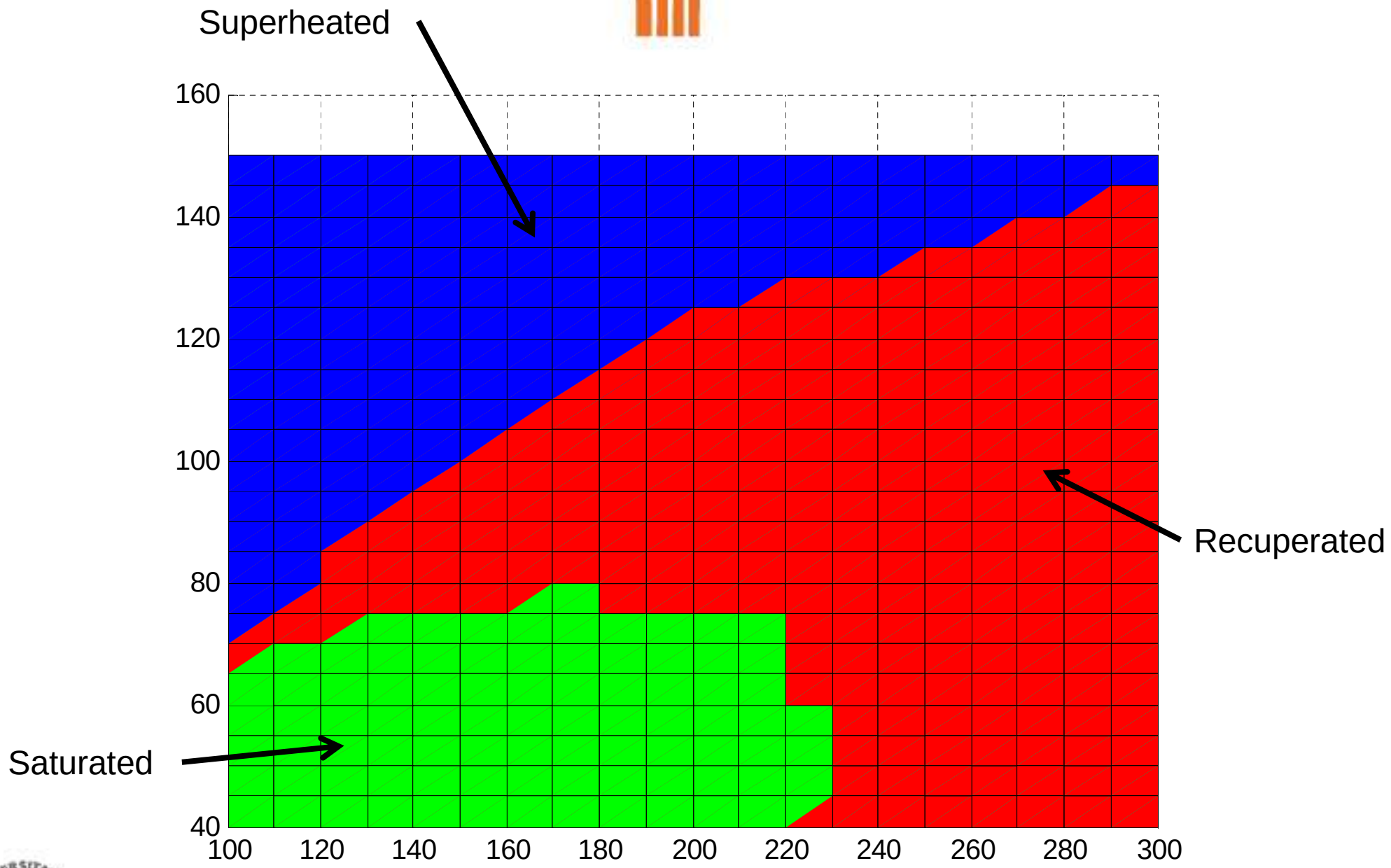
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Recuperated Isopentane



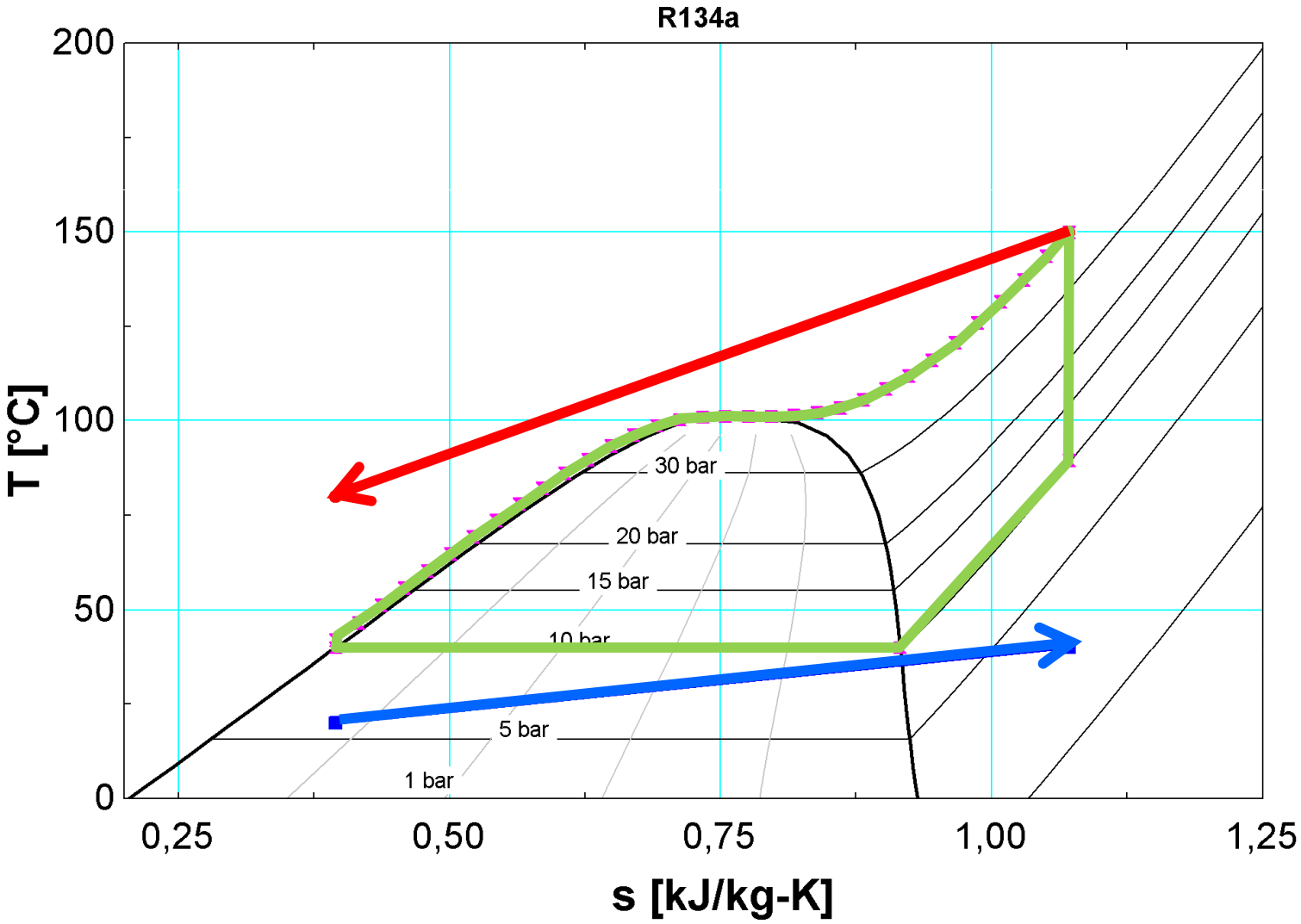
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Superheated Isopentane



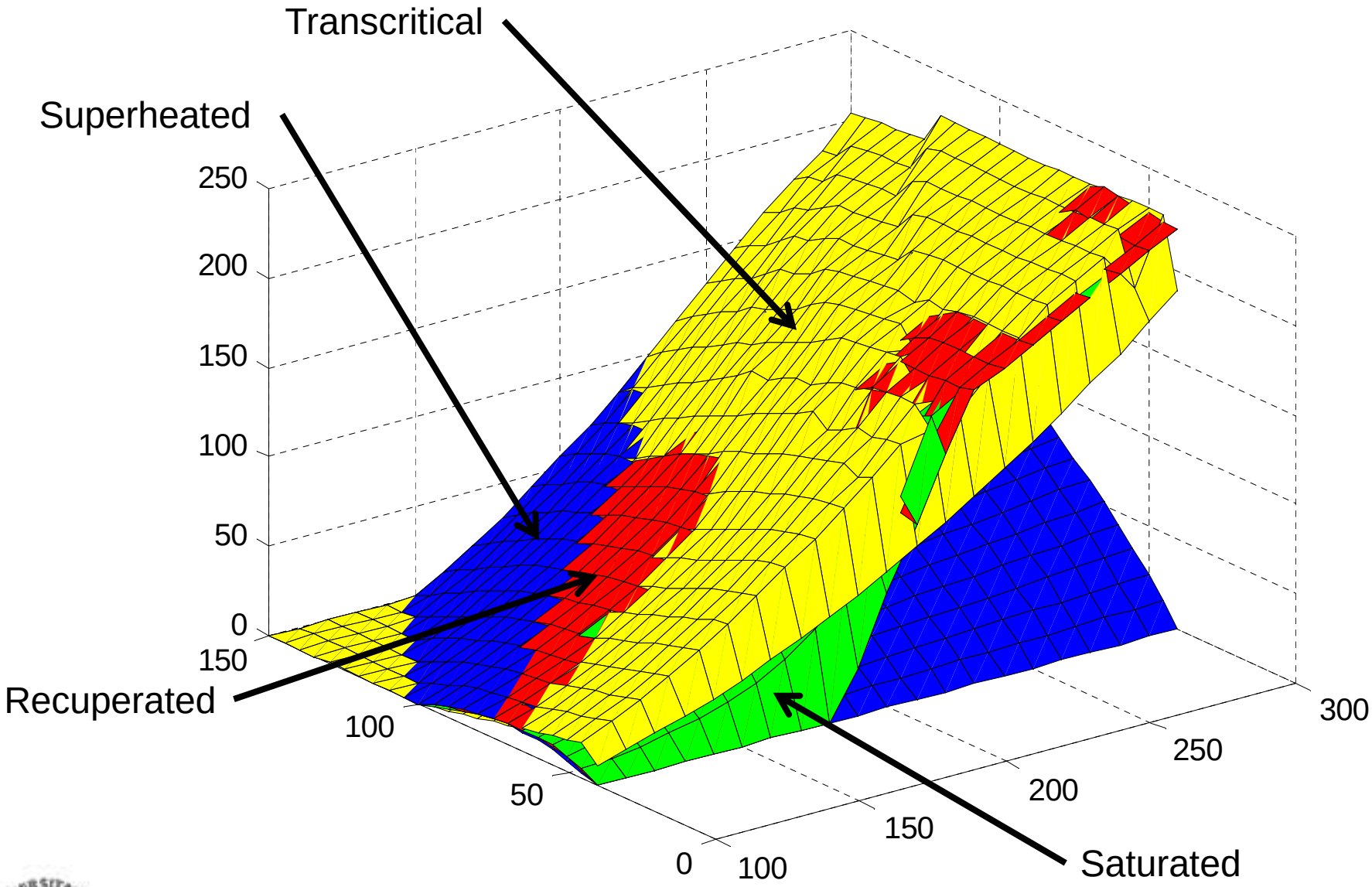
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Superiority ranges



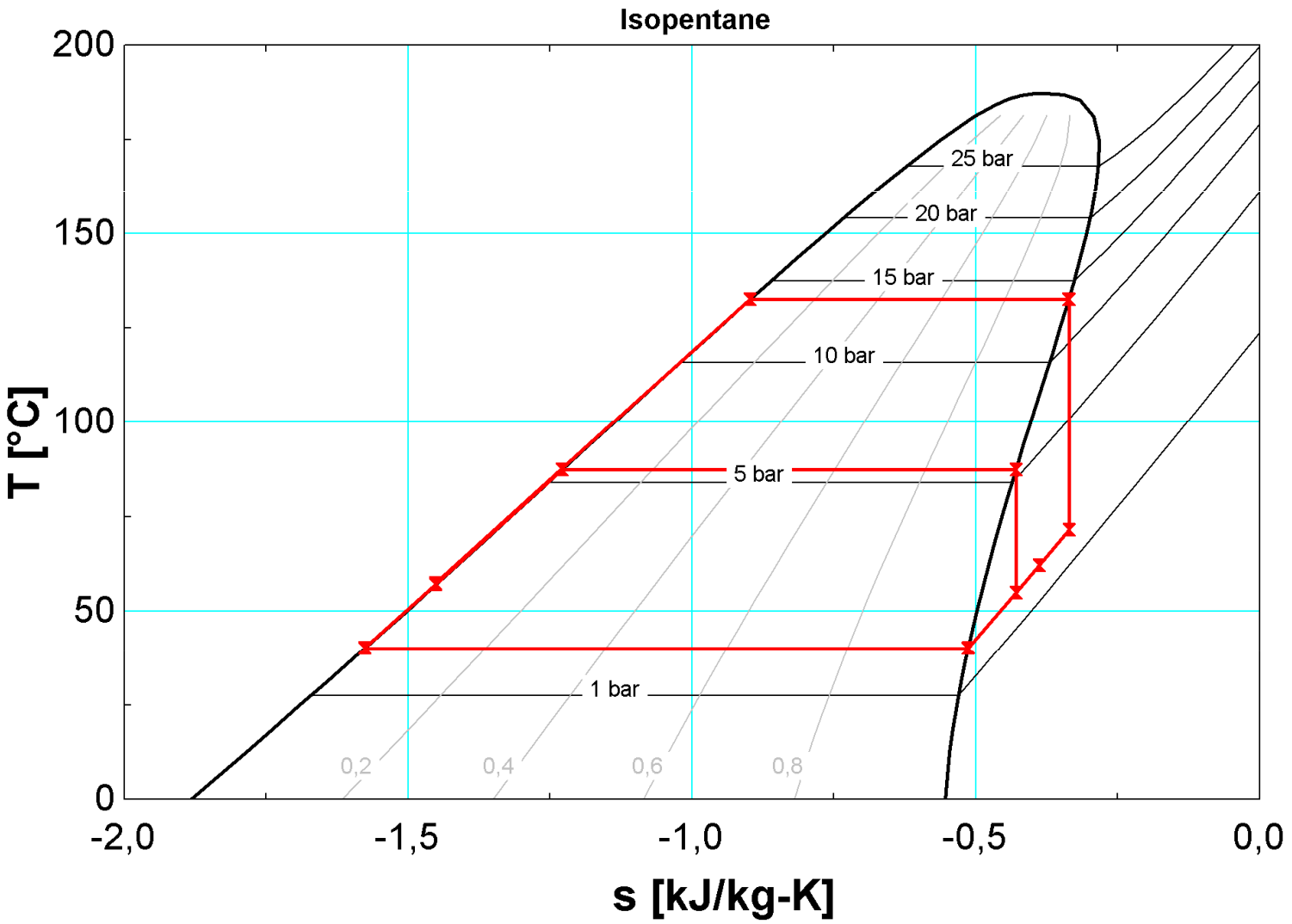
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Transcritical Isopentane



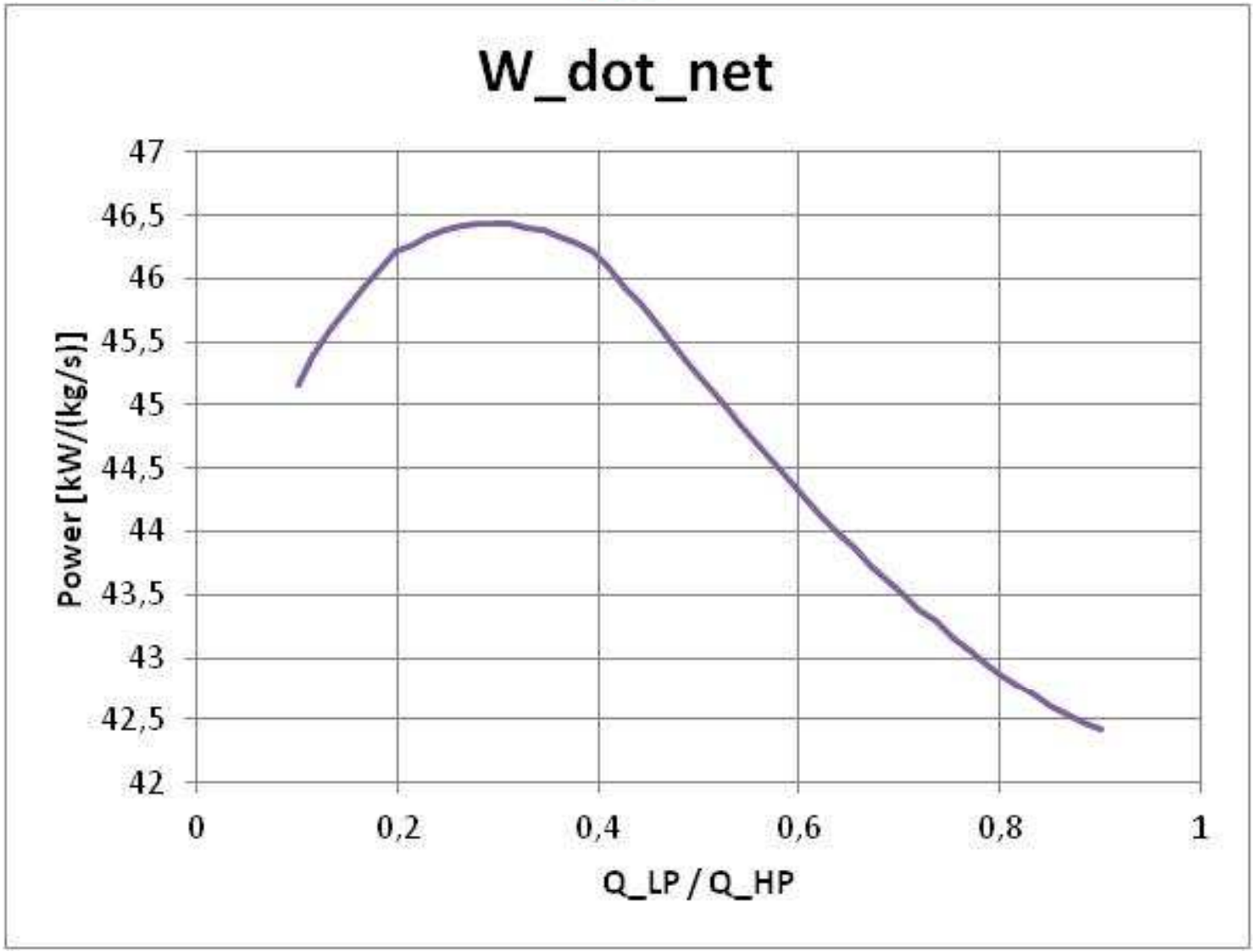
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Superiority

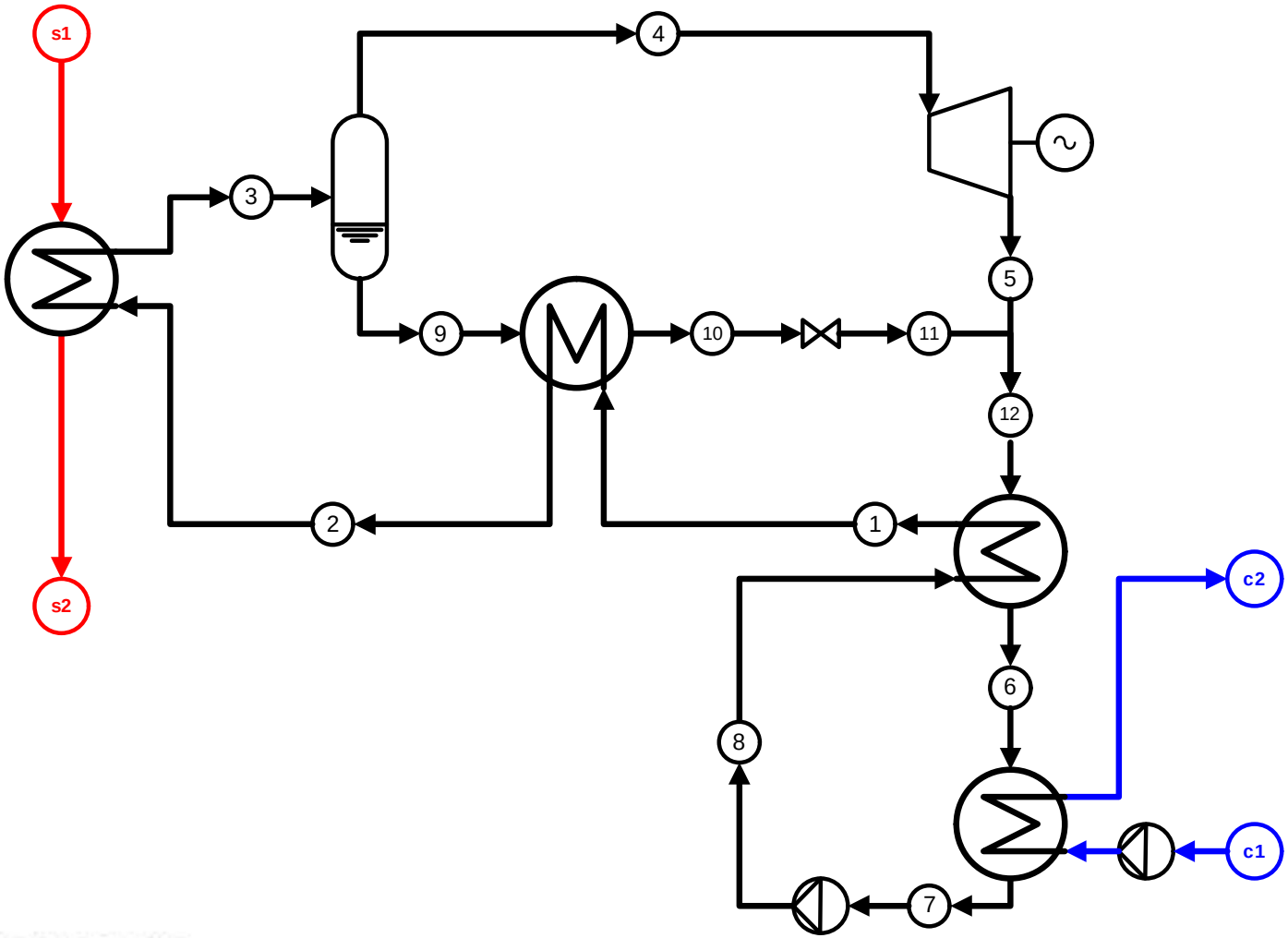


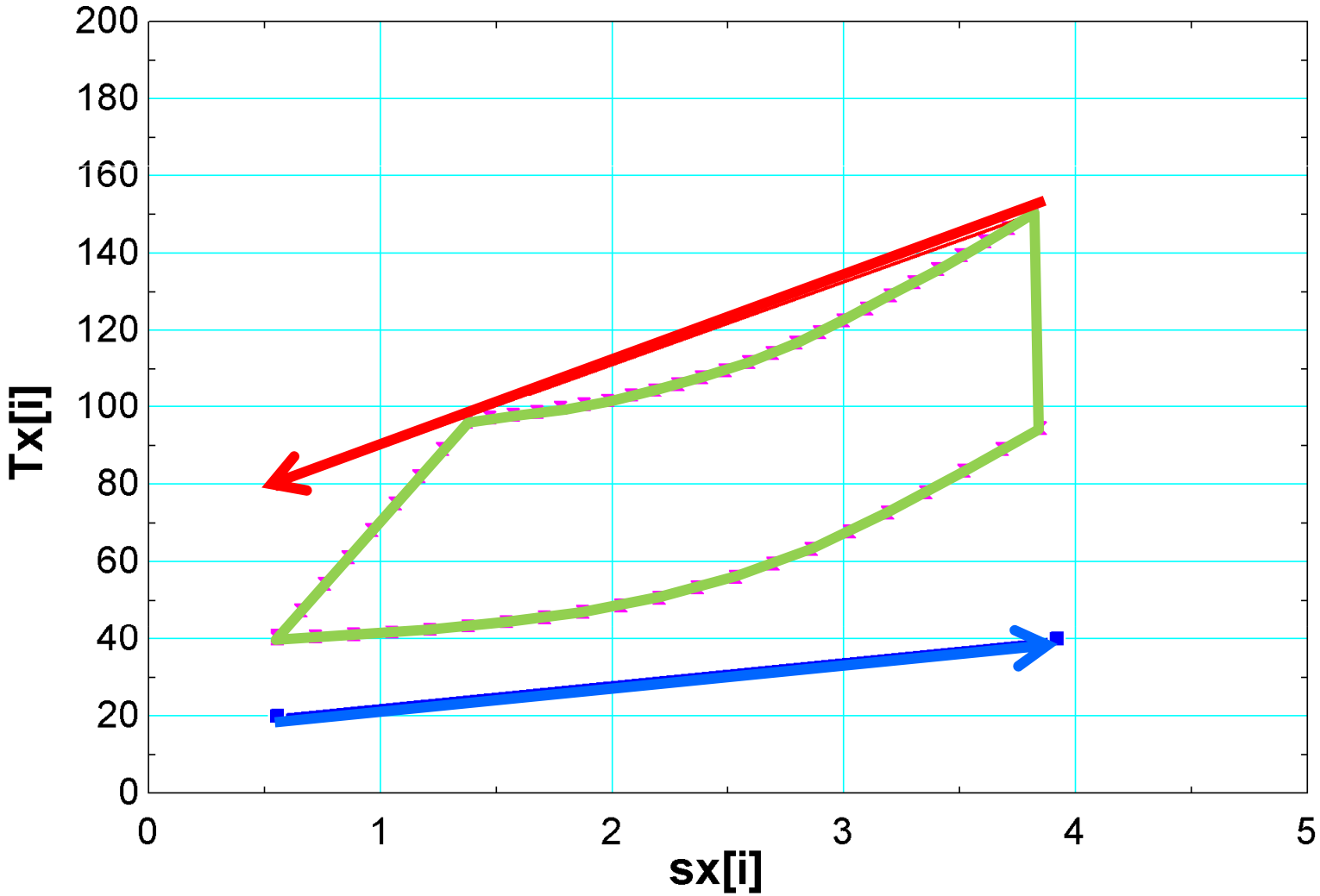
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Double pressure


W_dot_net
47
46,5
46
45,5
45
44,5
44
43,5
43
42,5
42
Power [kW/(kg/s)]
0
0,2
0,4
0,6
0,8
1
Q_LP / Q_HP

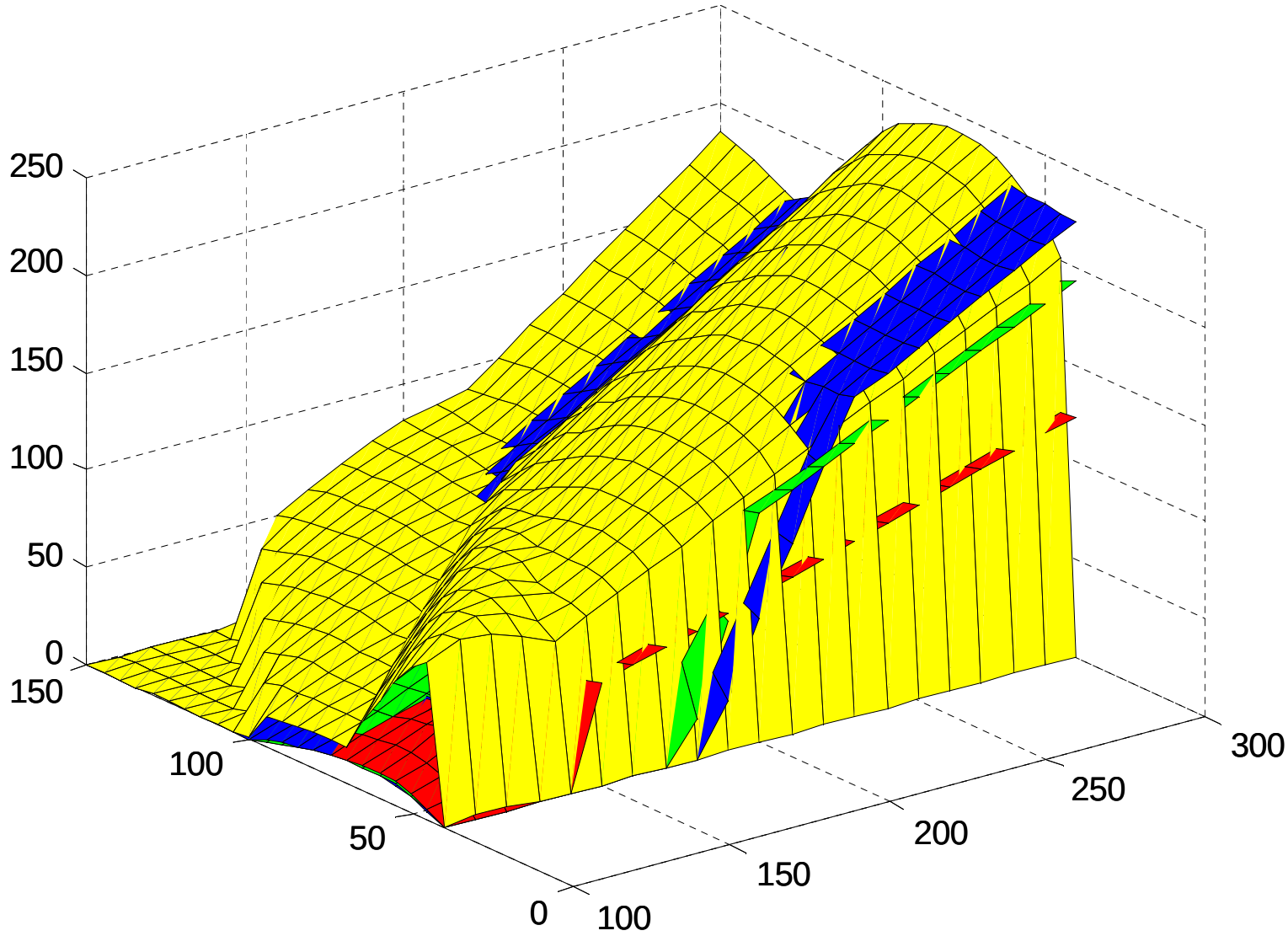
Kalina





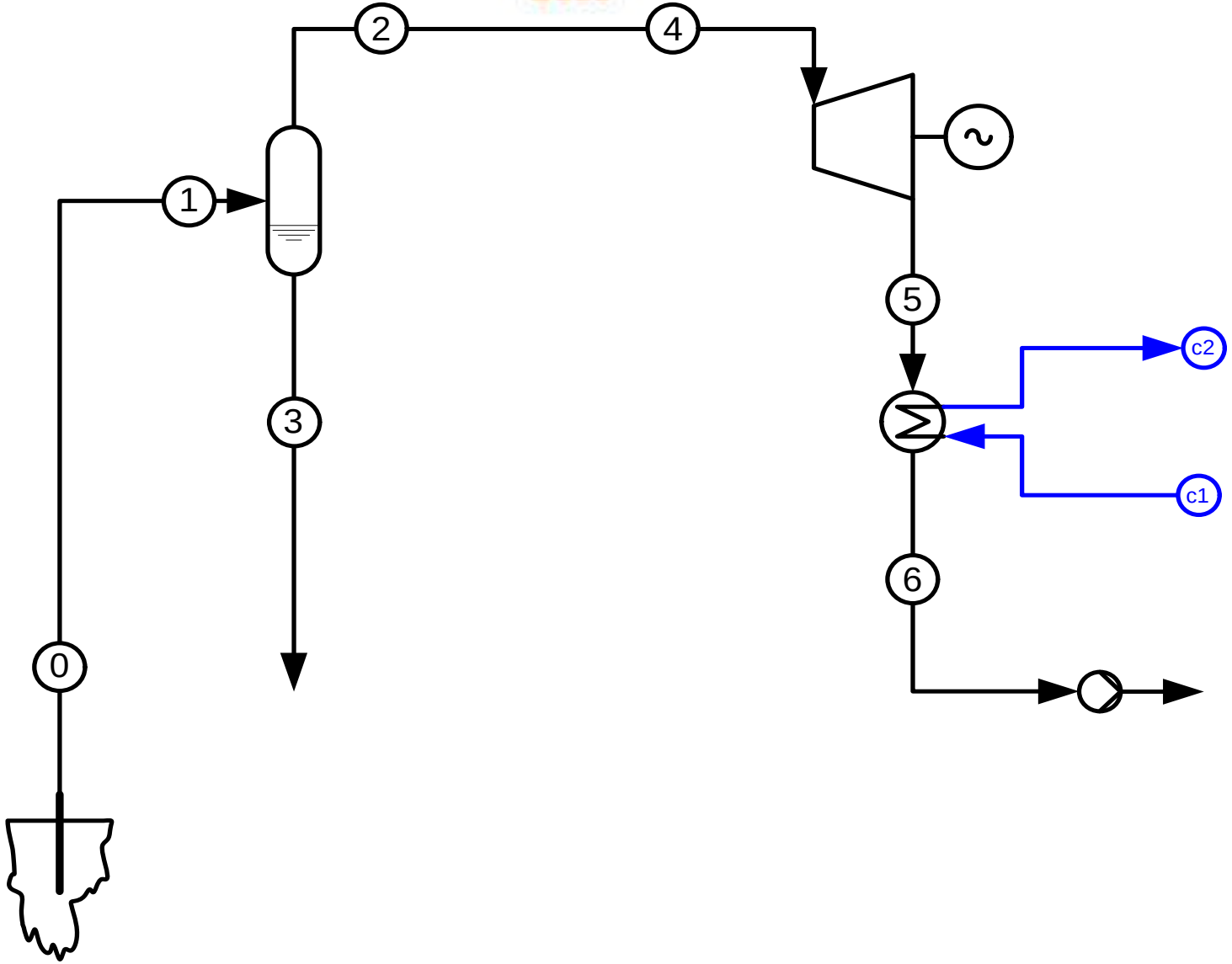
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Kalina 80% ammonia



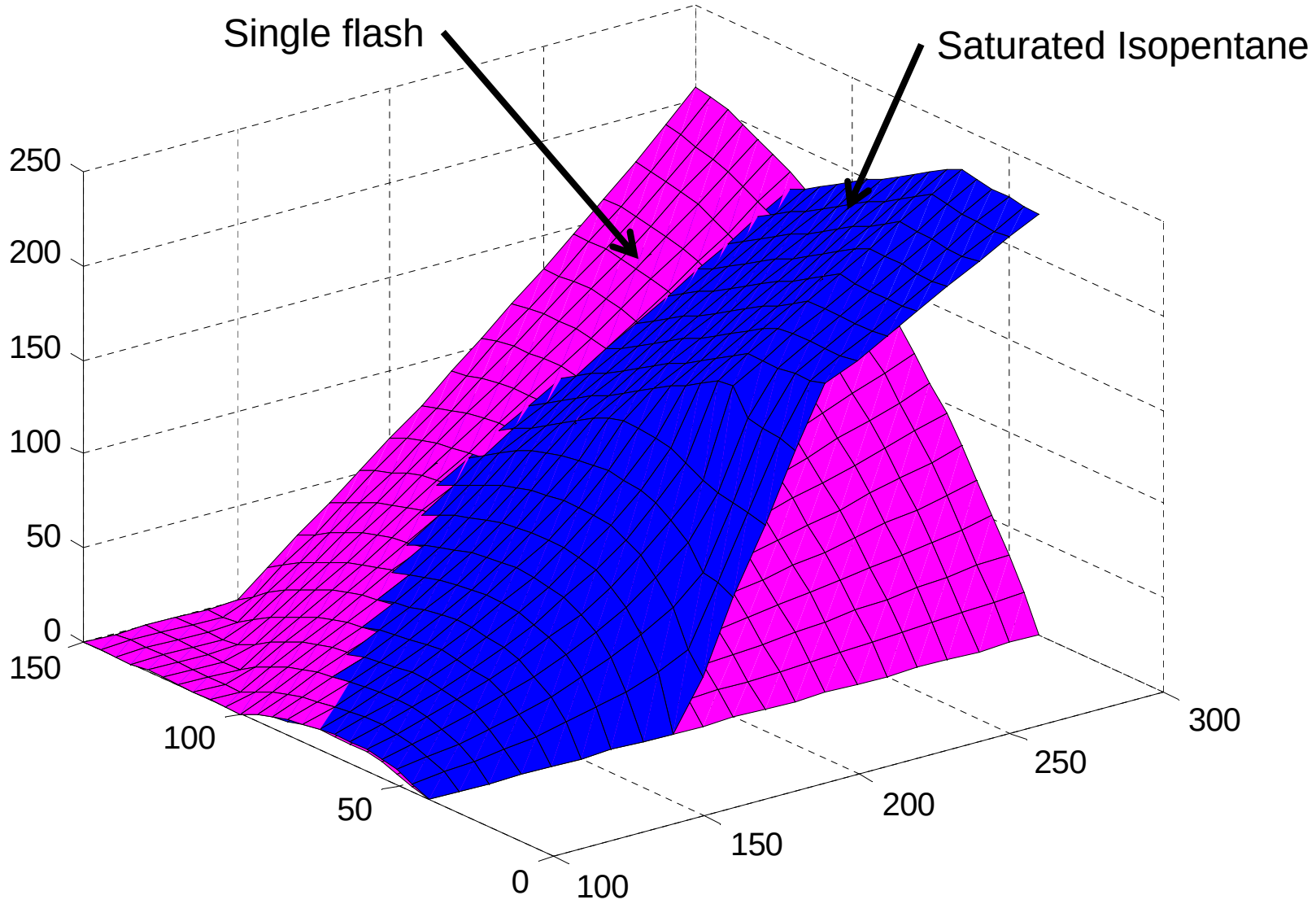
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Kalina compared



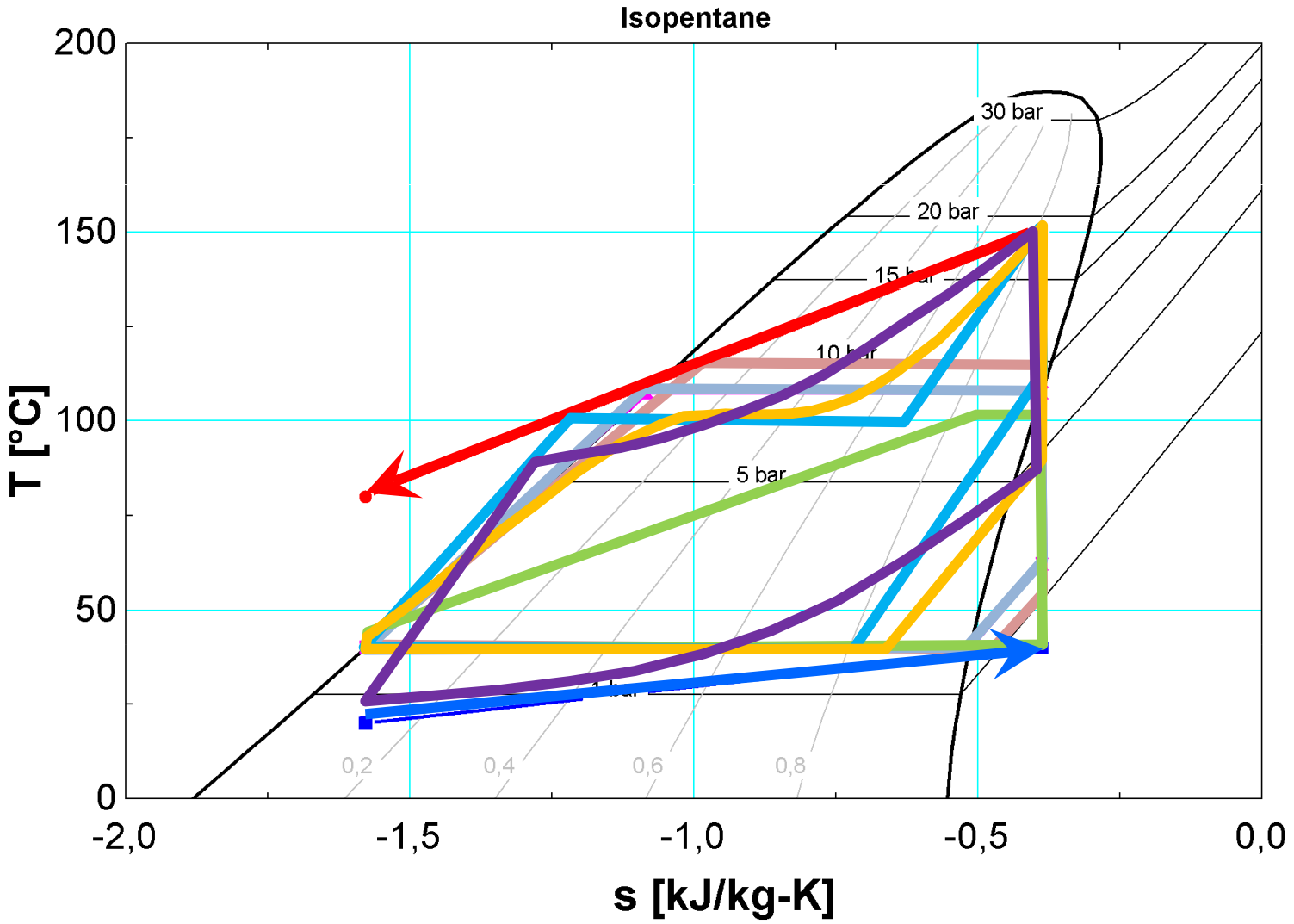
UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Single flash



UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE

Sf compared



Source

Sink

Isopentane

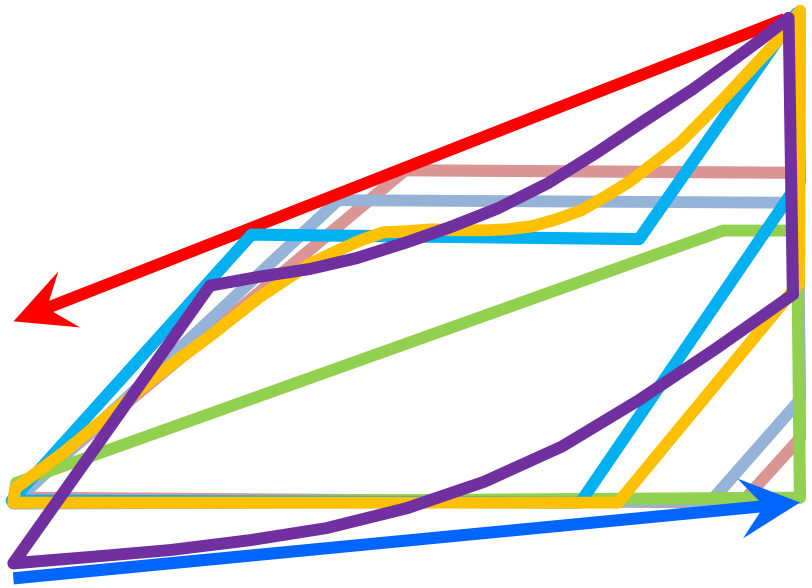
n-butane

R134a

IP superheat

IP transctitical

Kalina



Source

Sink

Isopentane

n-butane

R134a

IP superheat

IP transctitical

Kalina

Dank U wel !!

UNIVERSITY OF ICELAND
FACULTY OF INDUSTRIAL ENGINEERING,
MECHANICAL ENGINEERING AND COMPUTER SCIENCE