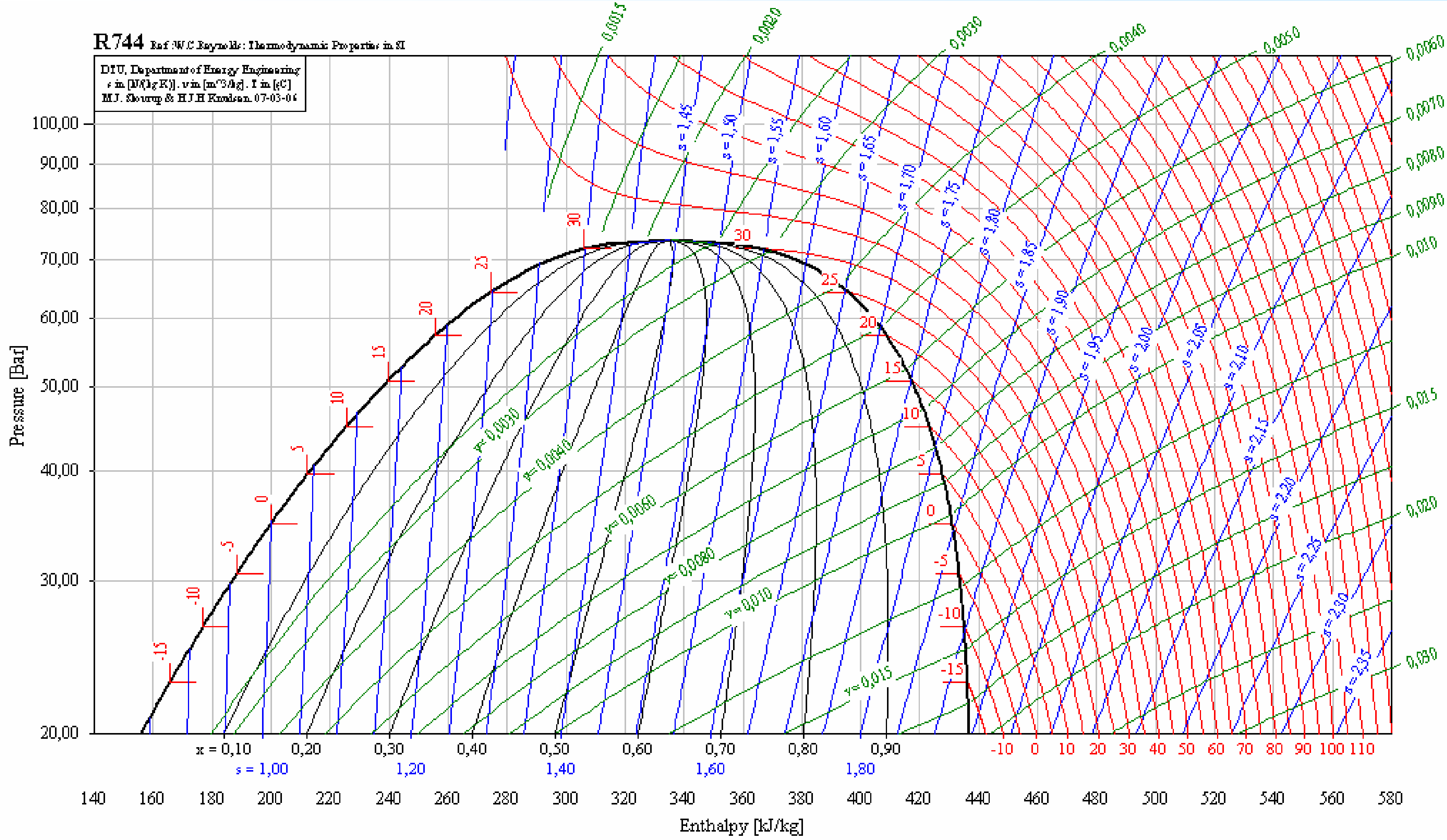
Study on CO_2 Rankine Cycles for Low and Medium Temperature Geothermal Sources for Power Production and Cogeneration

Study on Rankine and Heat cycles for geothermal plants using carbon dioxide as working fluid

The study refers at three types of plants, producing:

1. ***Only electric power***
2. ***Electric power and hot tap water***
3. ***Electric power and district heating***

The CO_2 pressure-enthalpy diagram used for the study of binary and heat cycles



The initial data :

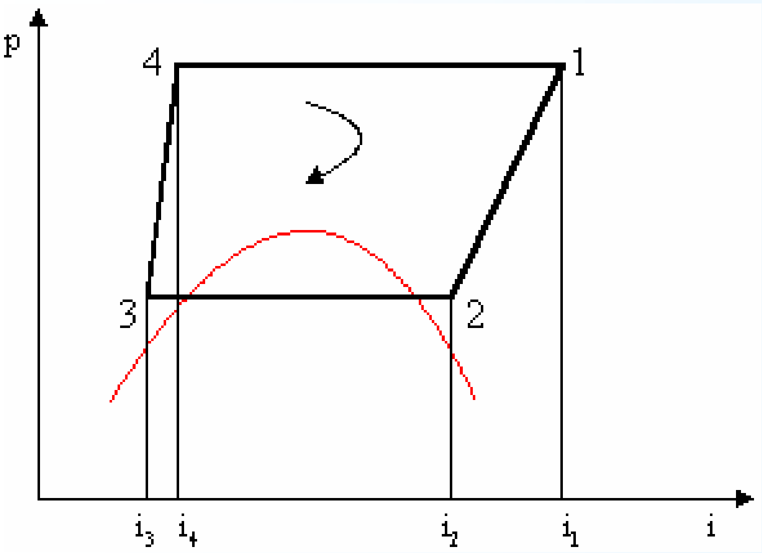
a. Temperature of geothermal source 120°C

b. Temperature of cooling source:

- *10°C – producing only electric power,*
- *40°C – producing electric power and hot tap water,*
- *50-70°C – producing electric power and heating agent for district heating*

c. Working agent CO_2

Clausius-Rankine direct cycle



The thermal efficiency of CO_2 power cycle was determined using the well-known formula:

$$\eta_t = \frac{l_{12} + l_{34}}{q_{41}} = \frac{(i_1 - i_2) + (i_3 - i_4)}{i_1 - i_4} = 1 - \frac{i_2 - i_3}{i_1 - i_4}$$

l_{12} – specific work produced in the turbine

l_{34} – specific work consumed in the pump

q_{41} – heat provided by geothermal water

The theoretical global thermal efficiency of CO2 direct cycle, considering cogeneration of power and heat is 100 %

$$\eta_t == \frac{l_{12} + l_{34} + |q_{23}|}{q_{41}} = \frac{(i_1 - i_2) + (i_3 - i_4) + (i_2 - i_3)}{i_1 - i_4} = \frac{i_1 - i_4}{i_1 - i_4} = 1$$

The power efficiency will be determined for all the cycles with the same formula

q_{23} – heat provided by CO2 to hot tap water or district heating agents

All cycles are consisting of:

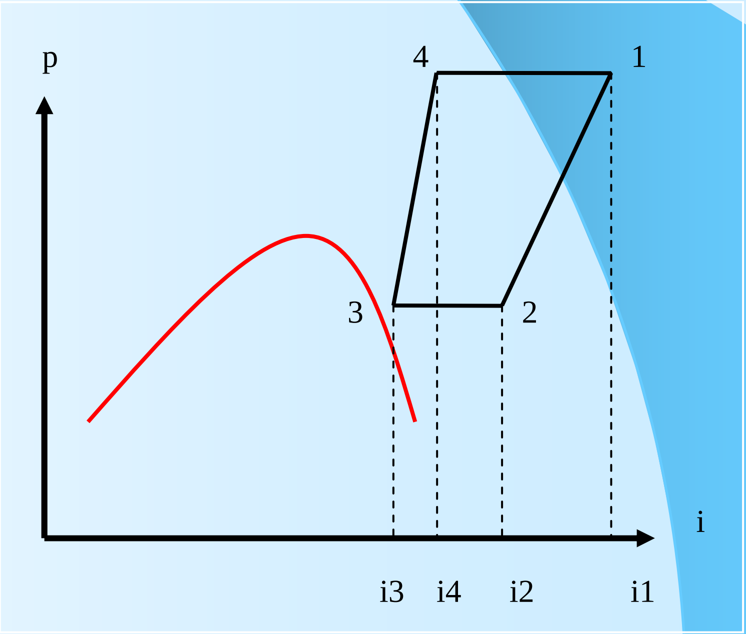
1-2: isentropic expansion

2-3: isobaric cooling

3-4: isentropic compression

4-1: isobaric heating

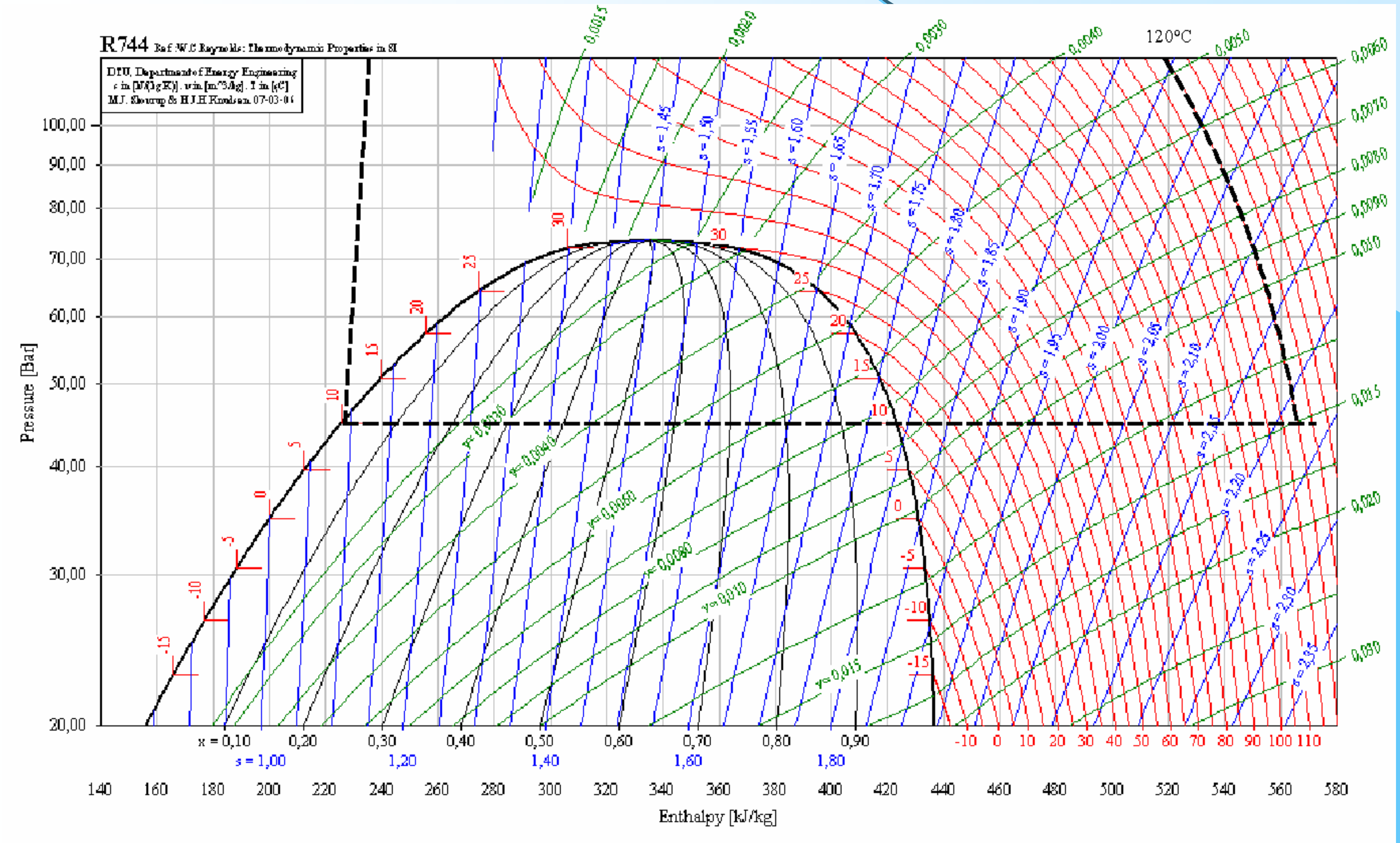
CO_2 vapour (heat) direct cycle



All the studied cycles were limited by following curves:

isothermal curve: t = 120°C; *isobaric curve: p = 120 bar*

isothermal curve: t = 10°C; *isobaric curve: p = 45 bar*

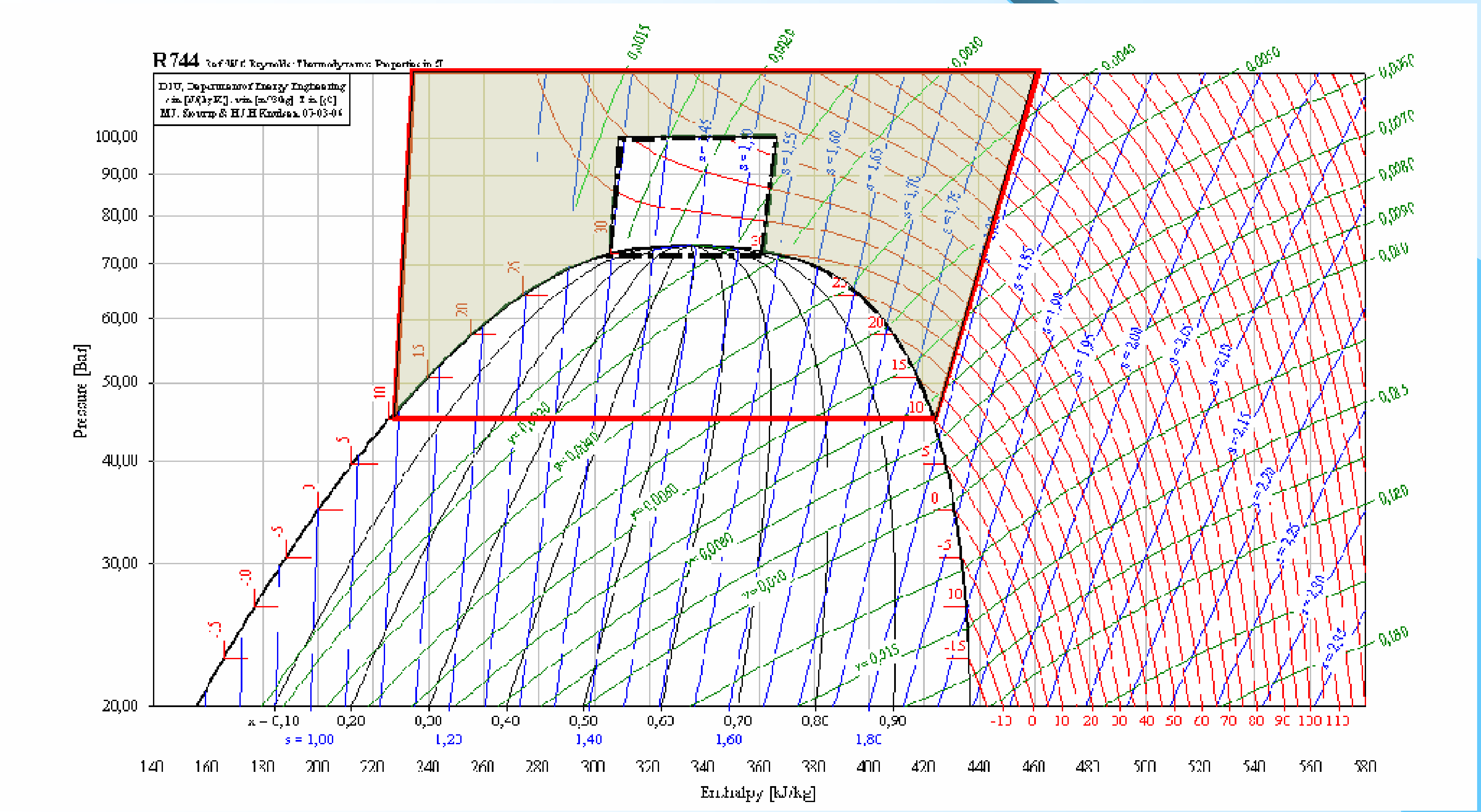


The studied binary cycles, producing only electrical power were limited by following curves:

isothermal curve: t = 115°C; *isobaric curve: p = 120 bar*

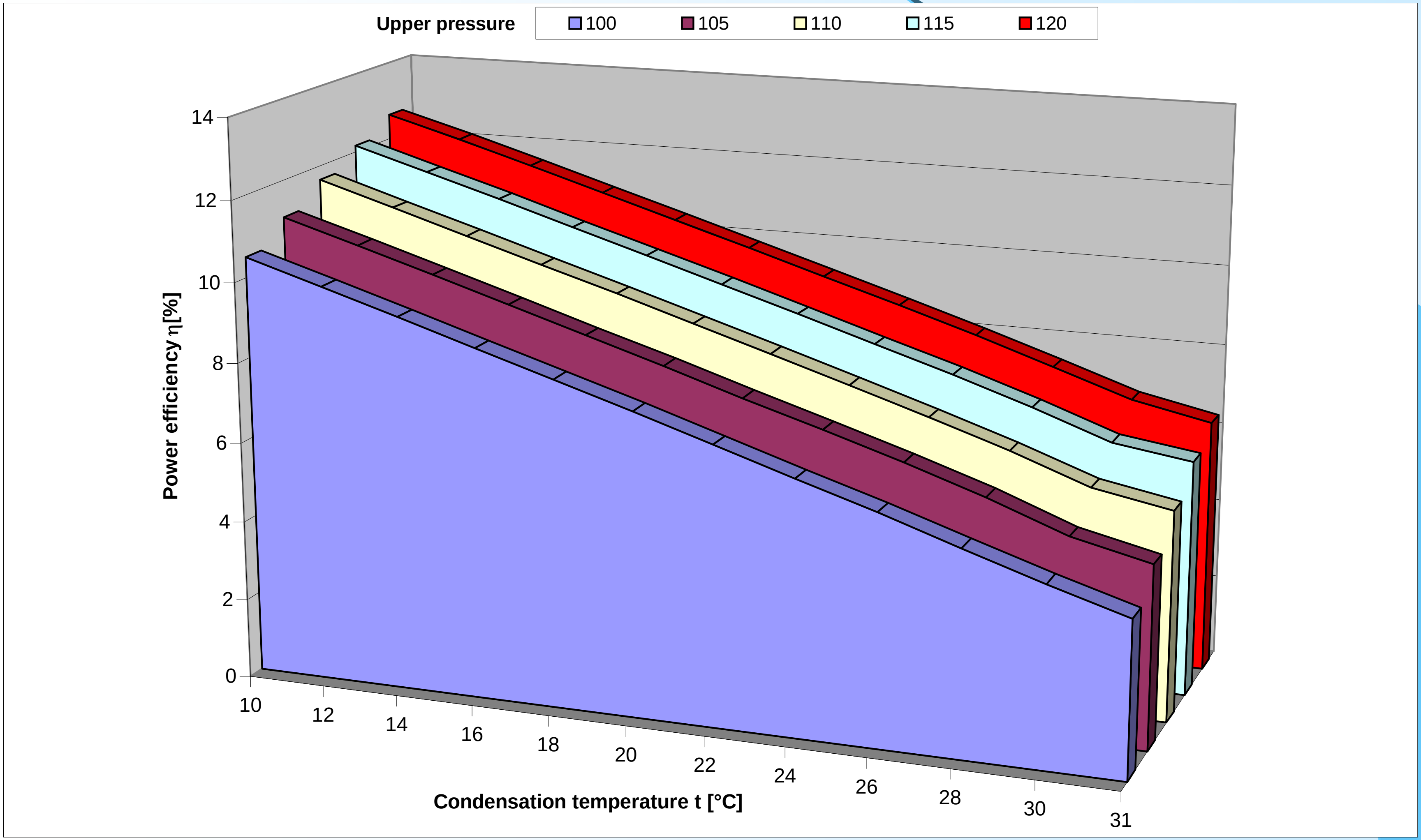
isothermal curve: t = 10°C; *isobaric curve: p = 45 bar*

The studied parameters was the condensation temperature from 10 to 31 °C, and the upper pressure from 100 to 120 bar



The power efficiency is increasing with the growth of upper pressure ($p_1=p_4$) and lowering of condensation temperature ($t_3=t_2$)

The maximum efficiency (≈ 12,5%) was provided for upper pressure 120 bar and condensation temperature of 10 °C

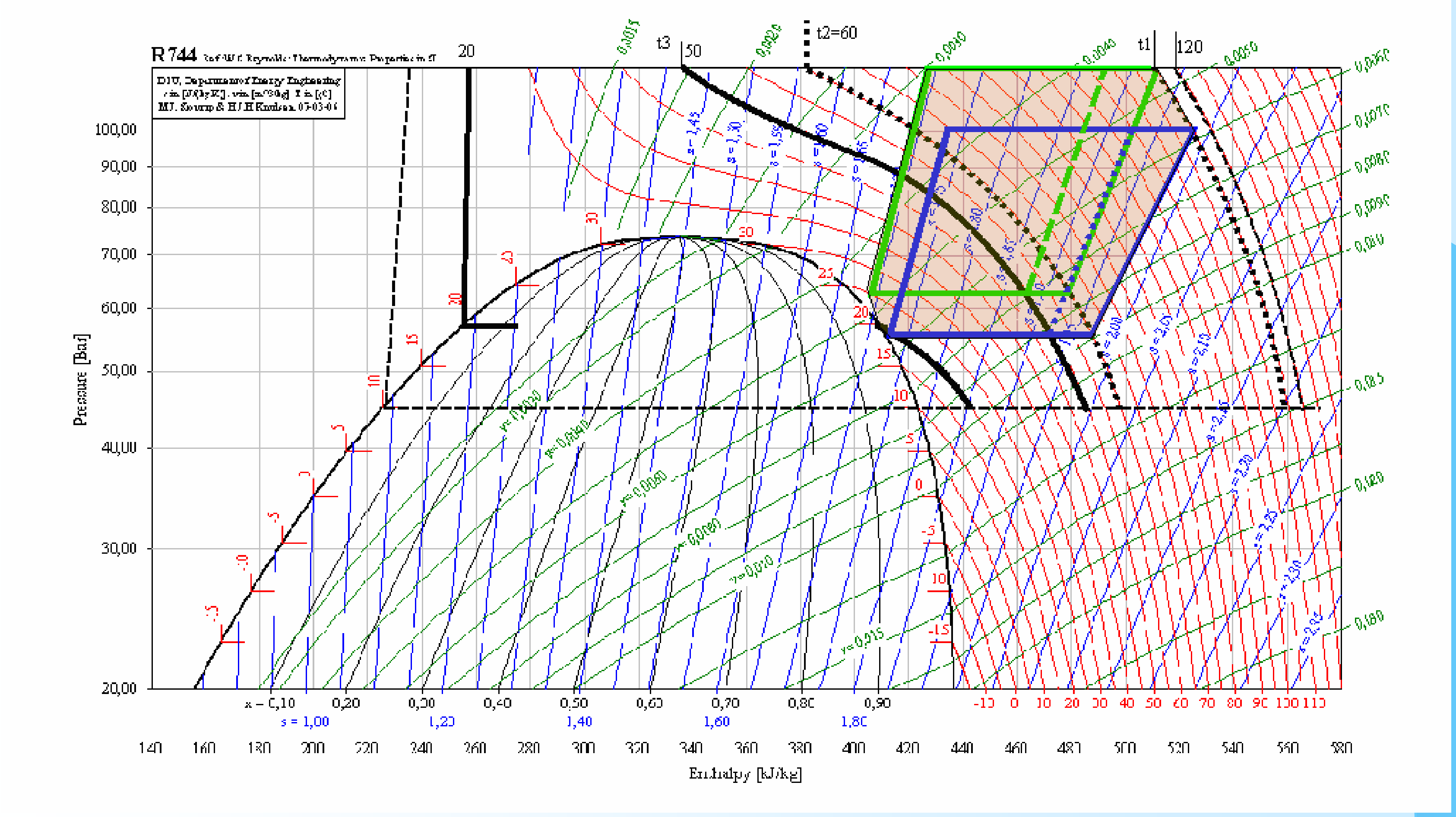


The studied heat cycles, producing simultaneously electrical power and hot tap water were limited by following curves:

isobaric curve: $p_1 = p_4 = 120$ bar; *isobaric curve: $p_2 = p_3 = 45$ bar*

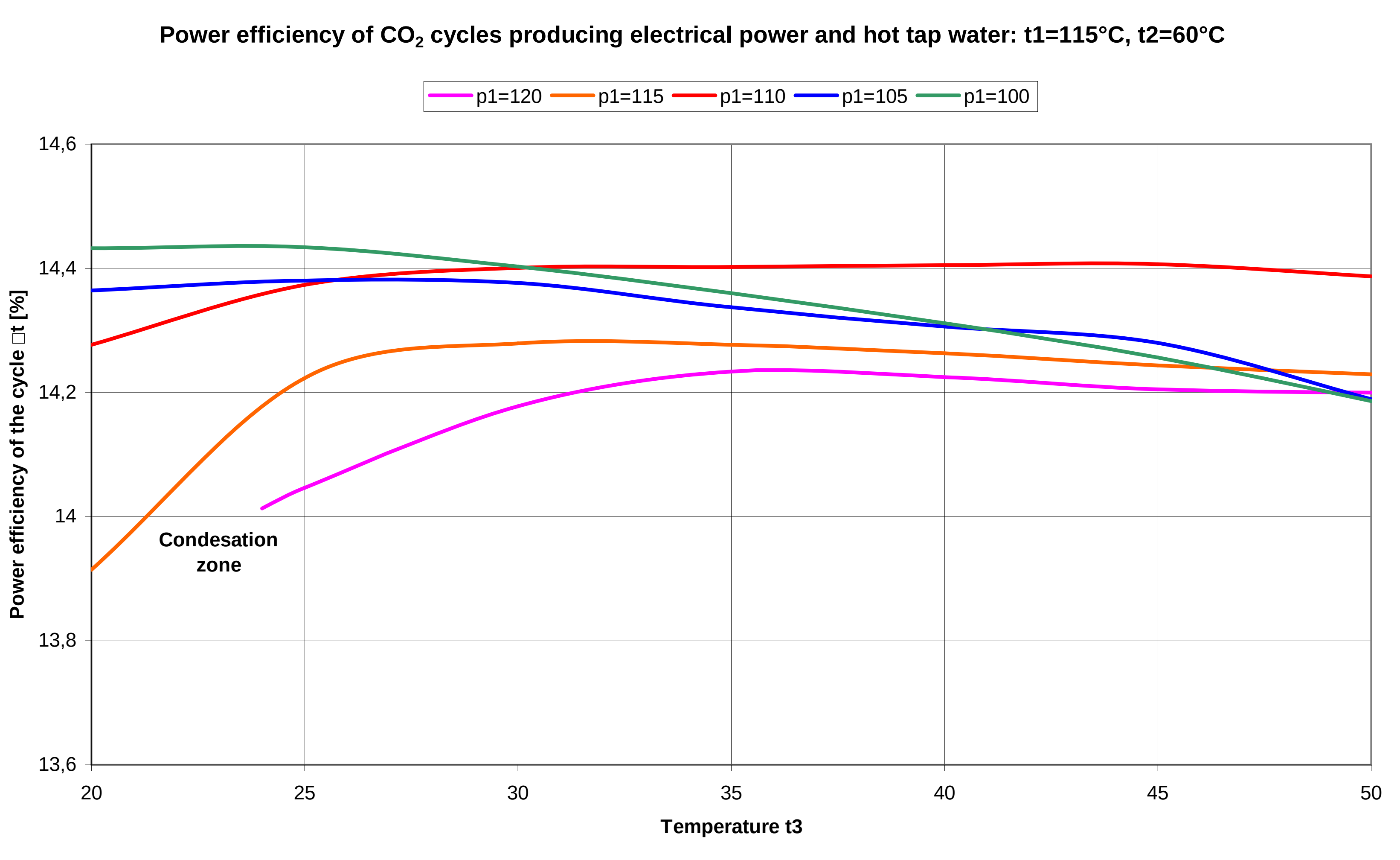
isothermal curve: $t_1 = 115°C$; *isothermal curve: $t_2 = 60$ °C;*

The studied parameters were the exit cooling temperature t_3 from 20 to 50 °C, and the upper pressure from 100 to 120 bar



The power efficiency is decreasing with the growth of upper pressure ($p_1=p_4$) presenting no significant variation with lowest temperature ($t_3=t_2$)

The maximum efficiency (≈ 14.43%) was provided for upper pressure 100 bar and cooling exit temperature of 25 °C

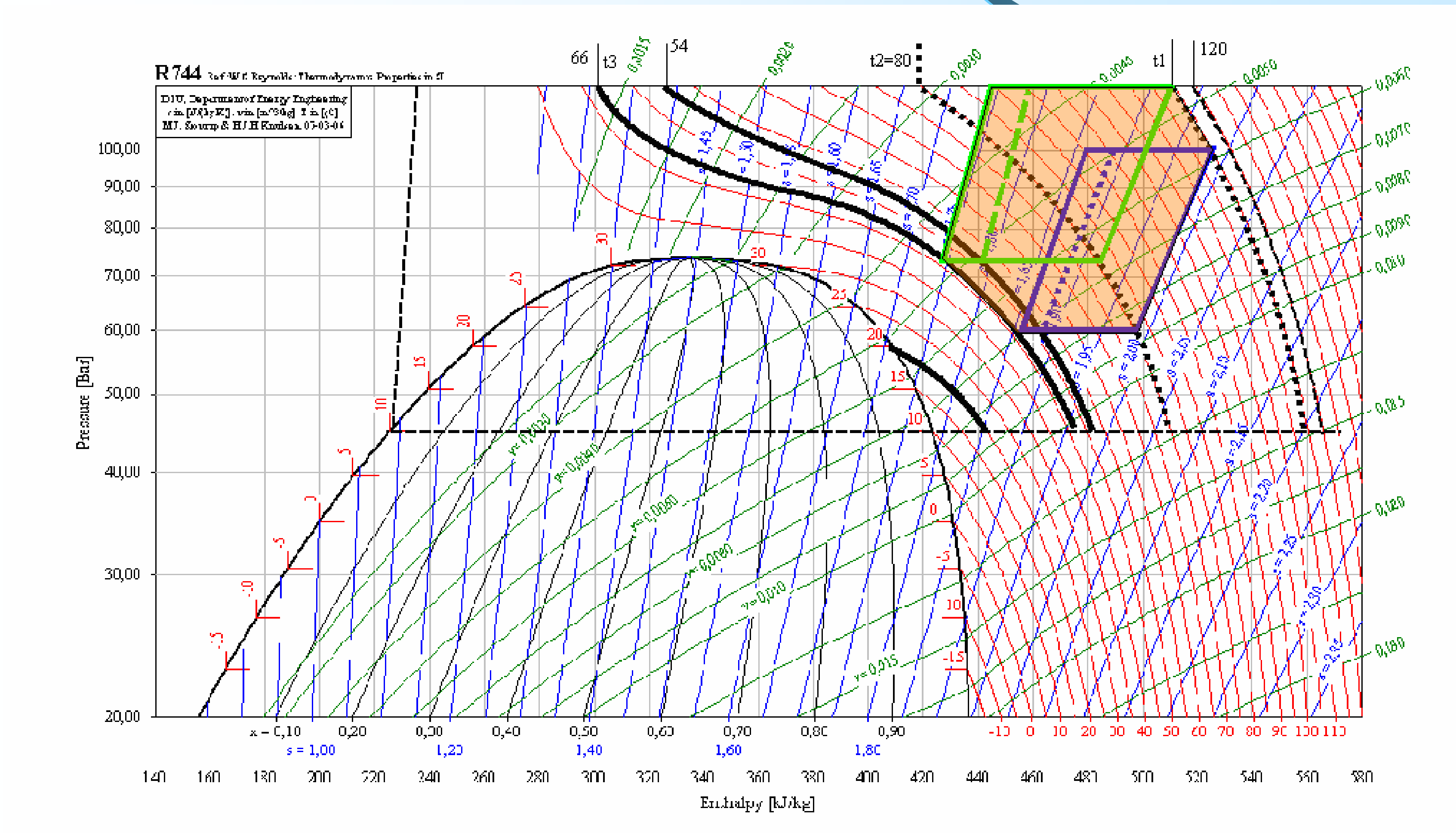


The studied heat cycles, producing simultaneously electrical power and heating agent for district heating were limited by following curves:

isobaric curve: $p_1 = p_4 = 120$ *bar;*　　*isobaric curve:* $p_2 = p_3 = 60$ *bar*

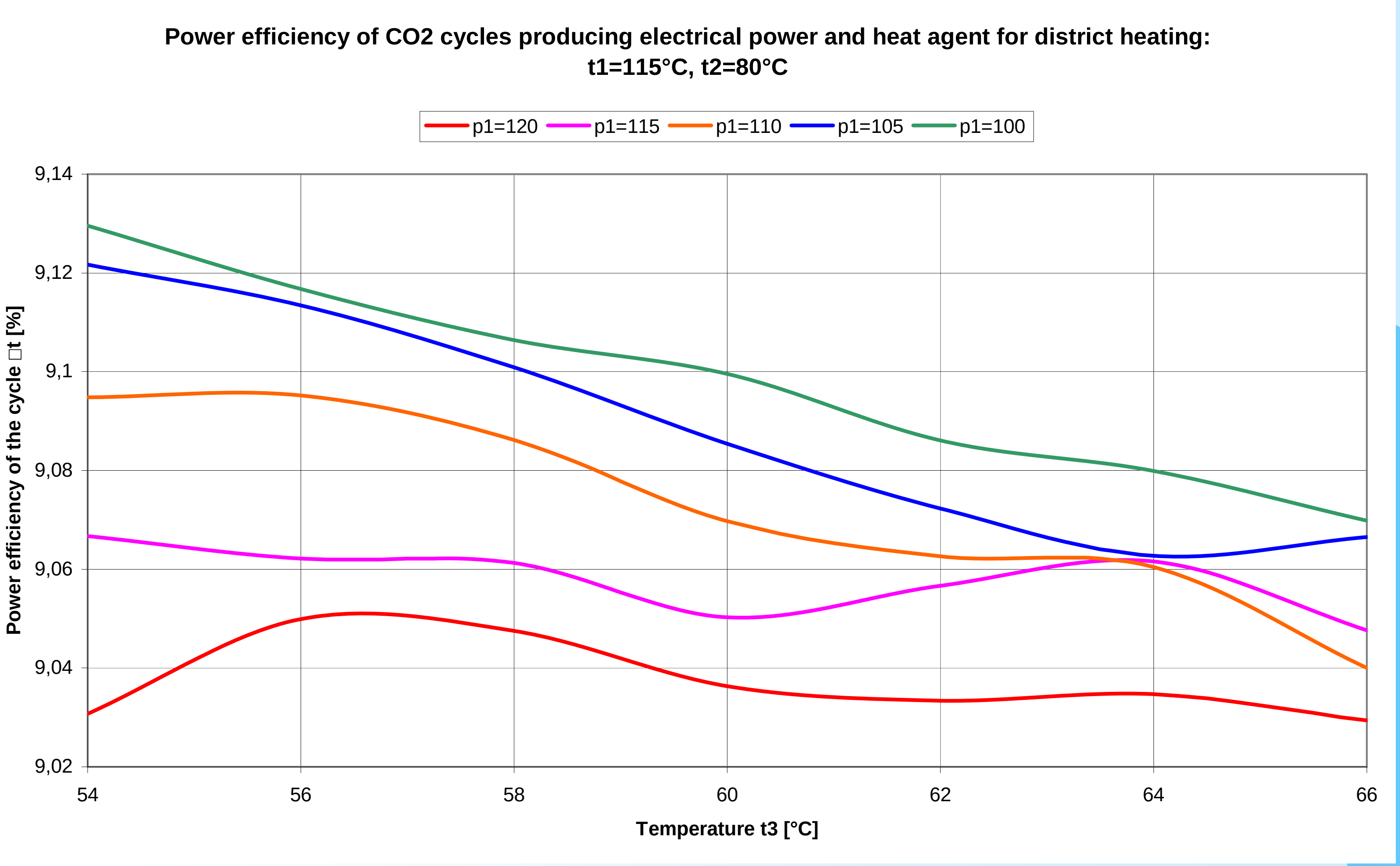
isothermal curve: $t_1 = 115°C$*;*　　*isothermal curve:* $t_2 = 80\ °C$*;*

The studied parameters was the exit cooling temperature t_3 *from 54 to 66 °C, and the upper pressure from 100 to 120 bar*



The power efficiency is decreasing with the growth of upper pressure (p_1=p_4) and slightly descending with growth of lowest temperature (t_3=t_2)

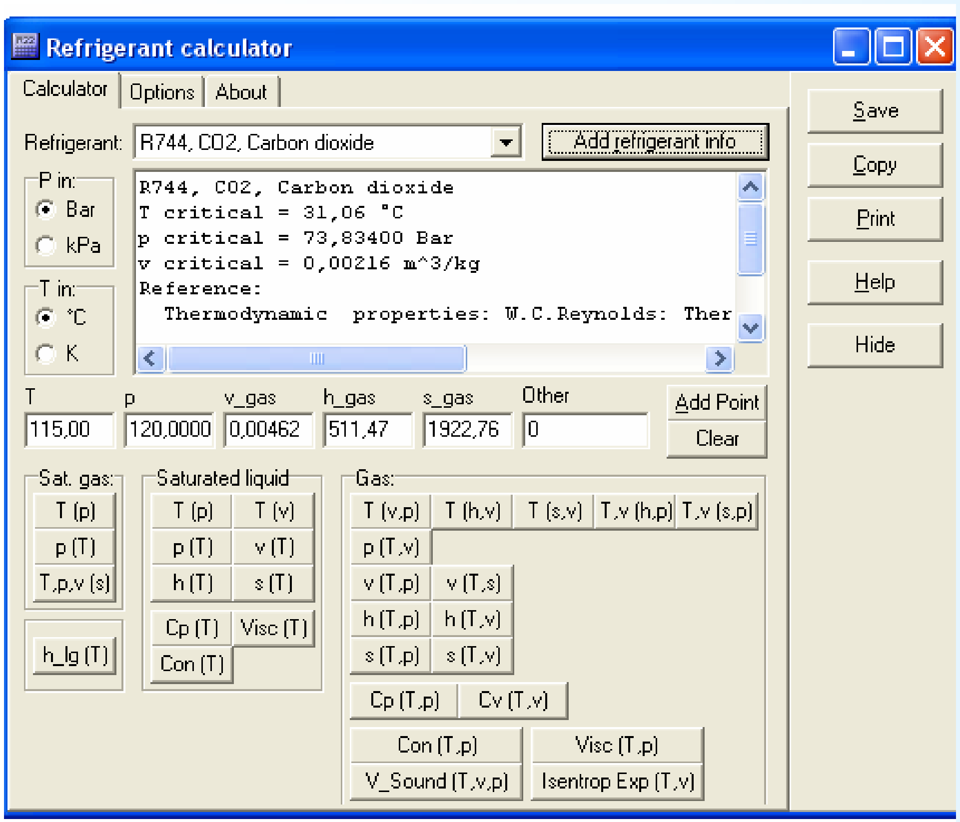
The maximum efficiency (≈ 9.13%) was provided for upper pressure 100 bar and cooling lowest temperature of 54 °C



The study was conducted developing Excel spreadsheets using data for CO_2 properties provided by:

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST)

and *COOLPACK* software



We also developed Interpolation (User Defined) Visual Basic Function to calculate the CO_2 properties at any given state inside the limited studied field:

-s = s (t, p)

-h= h (p, s)

-h = h (p, t)

-t= t (p) – saturation curve

-p = p (t) – saturation curve

Conclusions (I)

We can use CO_2 as working fluid in power plants working on the Clausius – Rankine cycle using geothermal water as heat source, but the thermal efficiency is relatively low (≈ 12,5 %), consisting off power efficiency only.

We can improve the power efficiency of binary cycle by :

- *Working with higher upper pressures (more than 120 bar)*
- *Lowering the temperature of condensation agent (below 10 °C)*
- *Make sure that points 2 and 3 are on the saturation curve (no cooling before condensation and no overcooling of liquid CO_2 are needed)*

Conclusions (II)

We can also use CO2 as agent in plants working on vapour cycle using geothermal water and also producing hot tap water in CO_2 cooling process. The thermal efficiency is theoretically high (100%), consisting off power efficiency (14,4%), and heating efficiency (85,6%).

The same sort of cycles may be used for plants producing electrical power and heating agent for district heating in CO_2 cooling process. The thermal efficiency is theoretically the same (100%), consisting off power efficiency (9,14%), and heating efficiency (91,86%).

We can improve the power efficiency of the vapour cycle by

- *Working with higher upper temperatures, if possible (more than 115 °C)*
- *Working with moderate upper pressures (100 °bar)*