CO_2 emissions produced by flaring on a mature oil field

Domagoj Vulin, Daria Karasalihović Sedlar,
Lucija Jukić, Ivan Smajla

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Content

- Introduction
- Literature overview
- Analysis of CO_2 emissions from flaring in Croatia
- Methods used in the analysis
- Laboratory analysis data and EOS tuning
- Results and discussion
- Conclusion

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Introduction

- Europe is among the largest emitters of GHG in the world
- EU tends toward:
  - highest possible decrease of energy intensity
  - improvement of energy efficiency
  - increased use of renewable energy
- South Korea – replacing coal with natural gas in power plants
- China – planning to start reducing CO_2 emissions after 2030
- aviation industry – looking for alternative fuels to reduce CO_2 emissions

Introduction

- Mitigation of GHG in upstream:
  - **Efficient gas separation from oil**
  - Using natural gas for energy demand near CH production facility
  - Using natural gas for injection back to an oil reservoir
- Industrial emissions account for 40 % in global CO_2 emissions

Introduction

- The research was conducted in terms of:
  - oil production decline through lifetime of a reservoir;
  - oil production constant pressure decrease with different oil and gas composition during separation at pressures below saturation (bubble point) pressure;
  - surface gas composition at different separation conditions;
  - CO_2 production by flaring the gas separated from different production and separation pressure-temperature (p-T) conditions;
  - possible CO_2 emission reduction economic aspects.

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Literature overview

- Su et al. (2016) – emissions reductions in 28 EU in the period from 1991-2012 improved
  - Decrease in average emissions intensity
  - Increase in CO_2 removal
  - Increase of countries showing net decreases in emissions

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Literature overview

- Madaleno et al. (2016)
  - GDP - GHG ratio, estimation of efficiency rankings for each country
  - Oil and gas sector produces significant amounts of CO_2

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Literature overview

- Labeyrie and Rocher (2010) reported emisisons:

  drilling/fracturing operations 15 %

  fuel gas for vehicles and machinery 55 %

  fugitive emissions and emissions from venting < 10 %

  heating and flaring 20 %

Literature overview

- Labeyrie and Rocher (2010)
  - Recommended sensitivity analyses:
    - w/wo heat recovery
    - w/wo flare or blanked gas recovery
    - options for increase of energy efficiency of power generation
    - equipment for natural gas/CO_2 compression

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Literature overview

- Hoffman et al. (2014)
  - economics of natural gas reinjection net positive
- Basu et al. (2010) – separation of gases using membrane systems, gas can be transported by the pipeline rather than flared
- Elvidge et al. (2009, 2016) – space images of flaring

Literature overview

- Nguyen et al. (2014, 2016)
  - possibilities of energy efficiency improvement at offshore facilities,
  - possibilites of WHR, CO_2 capture and electricity generation
  - CO_2 emissions can be reduced by more than 15 % in all considered cases
- Giacchetta et al. (2015) – SAGD applied to unconventional resources – payback period less than 2 years

Literature overview

- Kraemer et al. (2009) – solar powered mid-temperature steam generation for recovery from oil sands might provide huge financial savings in the process
- Olateju et al. (2014), Nimana et al. (2015), Nduagu (2015) – CO_2 reduction by energy efficiency in the recovery of bitumen from oil sands in Canada
- Di Lullo et al. (2016), Rahman et al. (2015) – uncertainties of CO_2 emissions from a well to wheel system

Analysis of CO_2 emissions from flaring in Croatia

Analysis of CO_2 emissions from flaring in Croatia

- ISO 50001:2011 – energy management
  - efficient use of energy
  - increasing company profitability
  - costs optimization
  - decreasing environmental impact
- EOR CO_2 project launched in 2015 – 220 million m^3 of CO_2 injected into reservoirs in 2017

Analysis of CO_2 emissions from flaring in Croatia

Analysis of CO_2 emissions from flaring in Croatia

- Upstream (347 039 t of CO_2 equivalent) & downstream (1 320 153 t of CO_2 equivalent)
  - physical and chemical transformations,
  - flaring,
  - venting,
  - power and heat production
  - transport

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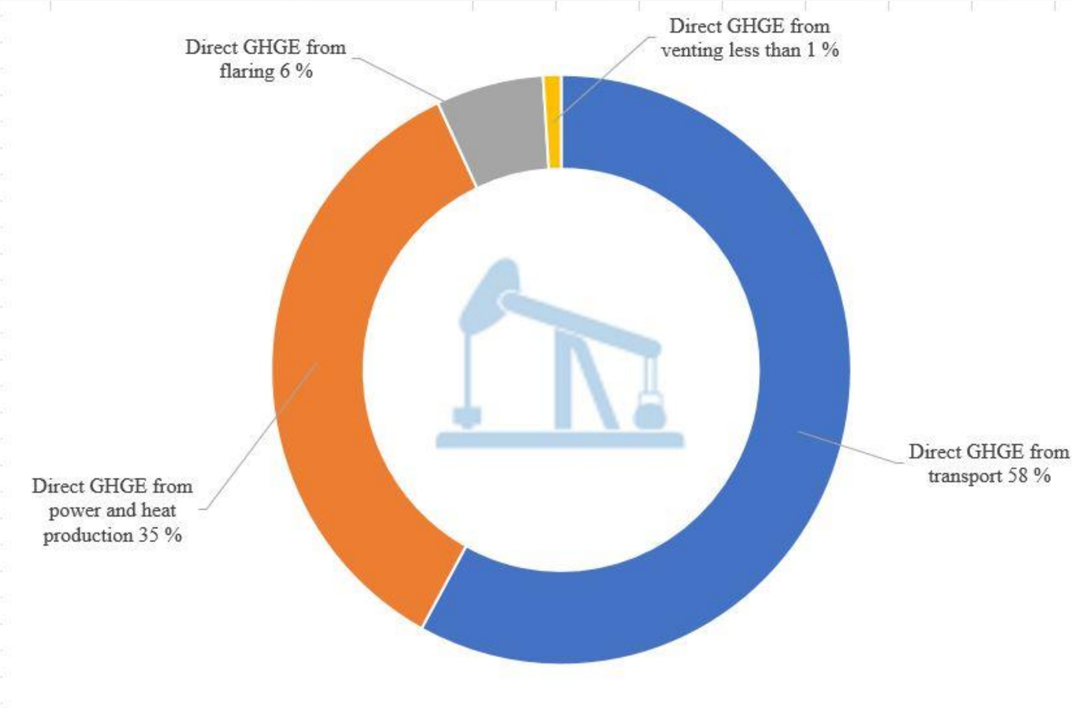
Analysis of CO_2 emissions from flaring in Croatia

Analysis of CO_2 emissions from flaring in Croatia



INA, 2015

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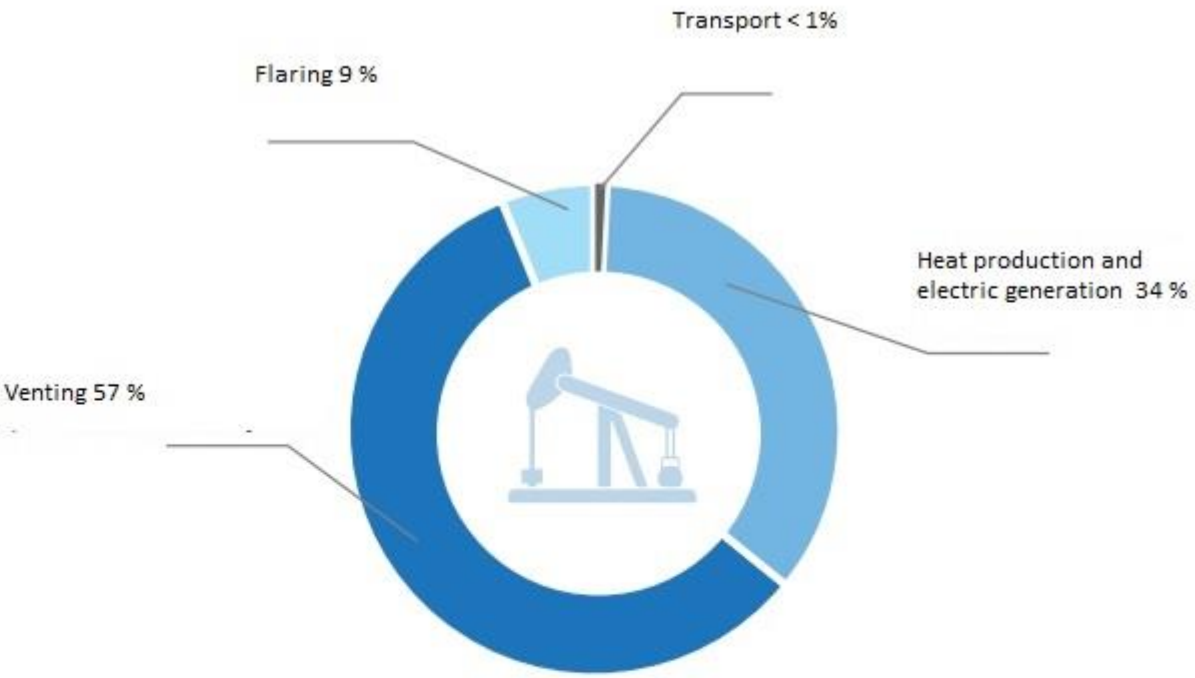

INA, d.d., 2017

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Analysis of CO_2 emissions from flaring in Croatia

- TPP and NGPP Molve – point sources
- Ethane facility near Dugo Selo and NGPP Molve produce 6500 t/y of CO_2 by flaring – was not considered
- 1000 Mt of CO_2 could be stored in Sava Central aquifer

Analysis of CO_2 emissions from flaring in Croatia

Analysis of CO_2 emissions from flaring in Croatia

Regional deep saline aquifers in Croatia

Vulin et al. (2012)

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Methods used in the analysis

Methods used in the analysis

- 4 parts of the analysis:
  - – Production decline analysis and estimates
  - – Simulation of gas liberation
  - – Calculation of CO_2 emissions
  - – Feasibility of separation system

Sensitivity analysis

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Methods used in the analysis

Methods used in the analysis

- Production decline analysis and estimates
  - Mature oil field
  - DCA applicable
  - Exponential decline

$$q_o = q_{oi} \cdot e^{-D \cdot t}$$

q_o – oil production, m^3/year

q_{oi} – initial oil production, m^3/year

D – decline rate 1/year

t – time, year

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Methods used in the analysis

- Simulation of gas liberation
  - Pressure estimation

$$p_b^2 - p^2 = \frac{N_p}{N}\left(p_b^2 - p_a^2\right)$$

  - DL experiments in a laboratory represent real behaviour of fluids in an oil reservoir – EOS tuning
  - Flash – describes surface behaviour - simulated

Methods used in the analysis

- Calculation of CO_2 emissions
  - Gas phase composition at the surface required

$$E_{CO2} = V \cdot \frac{1}{molar\ volume\ conversion} \cdot C_c \cdot \frac{M_{CO2}}{M_C} \cdot \sum_{i=1}^{n} M_i \cdot z_i$$

E_{CO2} - amount of produced CO_2, kg

V – (flaring) gas volume, m^3

molar volume conversion – conversion from molar volume to mass (23.685 m^3/kgmole)

M_{CO2} – molecular weight of carbon dioxide, g/mol

z_i – molar fraction of component *i*

Methods used in the analysis

Methods used in the analysis

- Calculation of CO_2 emissions

C_c - carbon content of the mixture:

$$C_c = \sum_{i=1}^{n} (w_i \cdot wC_{ci})$$

w_i – weight fraction of component *I*

wC_{Ci} - carbon content of (hydrocarbon) component i (mass part of unit):

$$wC_{C_i} = \frac{M_C \cdot x}{M_i}$$

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Methods used in the analysis

- Calculation of CO_2 emissions

M_C - molecular weight of carbon (M_C=12 g/mol)
x - stoichiometric coefficient for carbon (number of carbon atoms in a molecule)
M_j - molecular weight of component, g/mol

For plus fraction, stoichiometric coefficient (x) is determined proportionally to its molar weight:

$$x_{C7+} = \frac{M_{C7+} - 2}{14.01}$$

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Methods used in the analysis

Methods used in the analysis

- Feasibility of separation system
  - Different CO_2 prices and discount rates
  - NPV

$$NPV=\sum_{i=1}^{n}\frac{C_i}{\left(1+\frac{d_{\%}}{100}\right)^{i}}-\sum_{i=1}^{n}\frac{T_i-A_i}{\left(1+\frac{d_{\%}}{100}\right)^{i}}-K_u+\frac{K_{ov}}{\left(1+\frac{d_{\%}}{100}\right)^{n}}$$

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Methods used in the analysis

Methods used in the analysis

- Feasibility of separation system

n – project lifetime (years)

C – income

T – expenditures

K_u – capital investment

A – amortization

K_{ov} – project value residue

$d_{\%}$ – discount rate

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Methods used in the analysis

Methods used in the analysis

- Feasibility of separation system
  - IRR
    - NPV = 0
  - **Payout period**
    - Cumulative cash flow = 0

Methods used in the analysis

- Sensitivity analysis
  - Simulation in Eclipse
    - 300 cells
    - Same petrophysical data
    - Single well
  - Different PVT
  - Different initial reservoir pressure

Methods used in the analysis

Methods used in the analysis

- Sensitivity analysis
  - Different model dimensions
  - Different aquifer size
  - Different permeabilities

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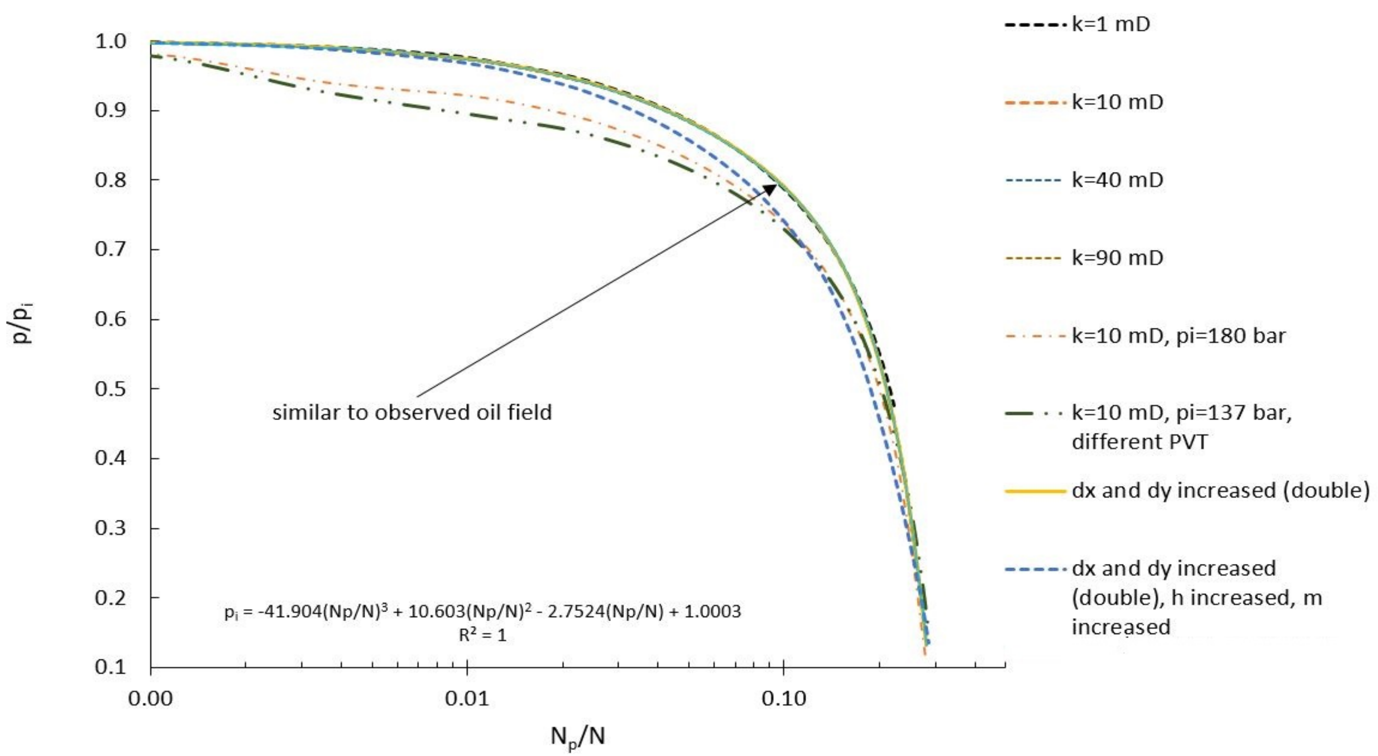

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Methods used in the analysis

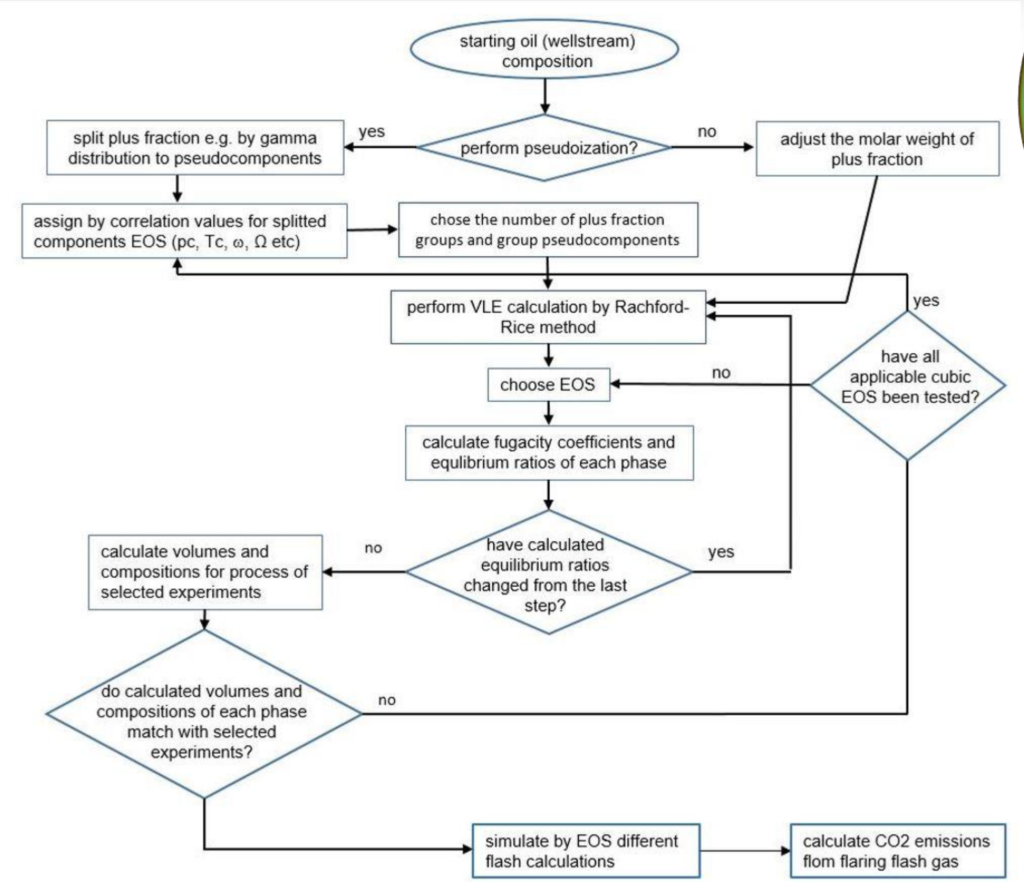
Methods used in the analysis

- Sensitivity analysis
  - decline analysis started at p/p_i =0.6
  - Arps equation and third polynomial for N_p/N vs. p/p_i
  - semi log diagram – maturity factor

$$MF = \frac{d\left(\frac{p}{p_i}\right)}{d\left(\log\left(\frac{N_p}{N}\right)\right)} < -1.$$

Laboratory analysis data and EOS tuning

Laboratory analysis data and EOS tuning



Laboratory analysis data and EOS tuning

Laboratory analysis data and EOS tuning

DL step	initial composition	1	2	3	4	5	6	7
Pressure (bar)		120	100	80	60	40	20	0
N_2	0.241	0.89	1.01	0.67	0.38	0.19	0.20	0.23
CO_2	0.280	0.47	0.49	0.52	0.57	0.65	0.75	0.62
C_1	34.958	88.24	87.77	87.50	86.46	83.70	75.18	32.53
C_2	3.692	4.18	4.29	4.56	5.02	6.07	9.26	14.59
C_3	4.420	3.03	3.13	3.37	3.87	4.90	7.66	19.29
$i\text{-}C_4$	1.264	0.54	0.55	0.58	0.65	0.81	1.29	5.42
$n\text{-}C_4$	3.604	1.18	1.20	1.26	1.42	1.77	2.83	13.87
$i\text{-}C_5$	1.640	0.34	0.33	0.34	0.37	0.45	0.71	4.04
$n\text{-}C_5$	2.071	0.36	0.36	0.37	0.40	0.48	0.74	4.16
C_6	3.004	0.30	0.31	0.30	0.32	0.37	0.55	3.00
C_{7+}	44.826	0.47	0.30	0.53	0.55	0.62	0.81	2.25

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Laboratory analysis data and EOS tuning

Laboratory analysis data and EOS tuning

- Liquid phase from DL input for flash simulation
- Accuracy of the equation of state important
  - Adjustment of C_{7+} properties
    - Acentric factor
    - Molar weight
    - Parachor
    - T_b
    - P_c & T_c

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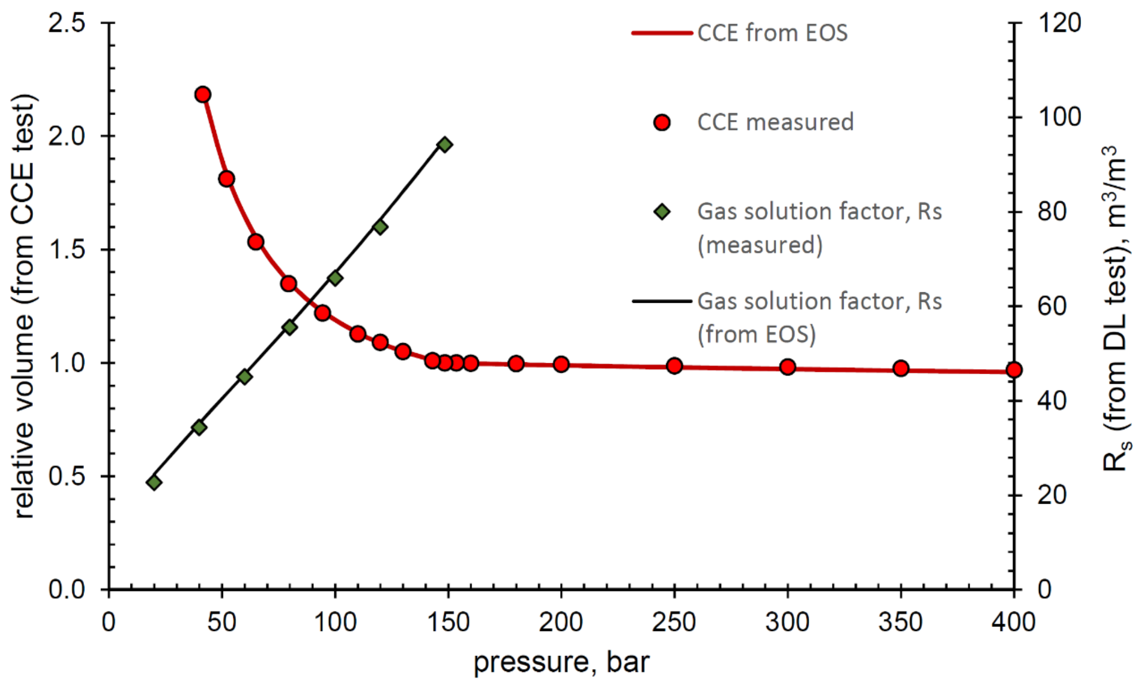

Laboratory analysis data and EOS tuning

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Results and discussion

Results and discussion

- CO_2 emissions calculated with shown methodology
- Repeated for several different reservoir pressures and for different surface temperatures

-correlation: reservoir depletion/CO_2 emissions

-recovery → p/pi → p

Results and discussion

- Unit emission from obtained correlation → overall emissions for given production

- Flash separation to 1 and 7 bar (including from 7 to 1 bar)

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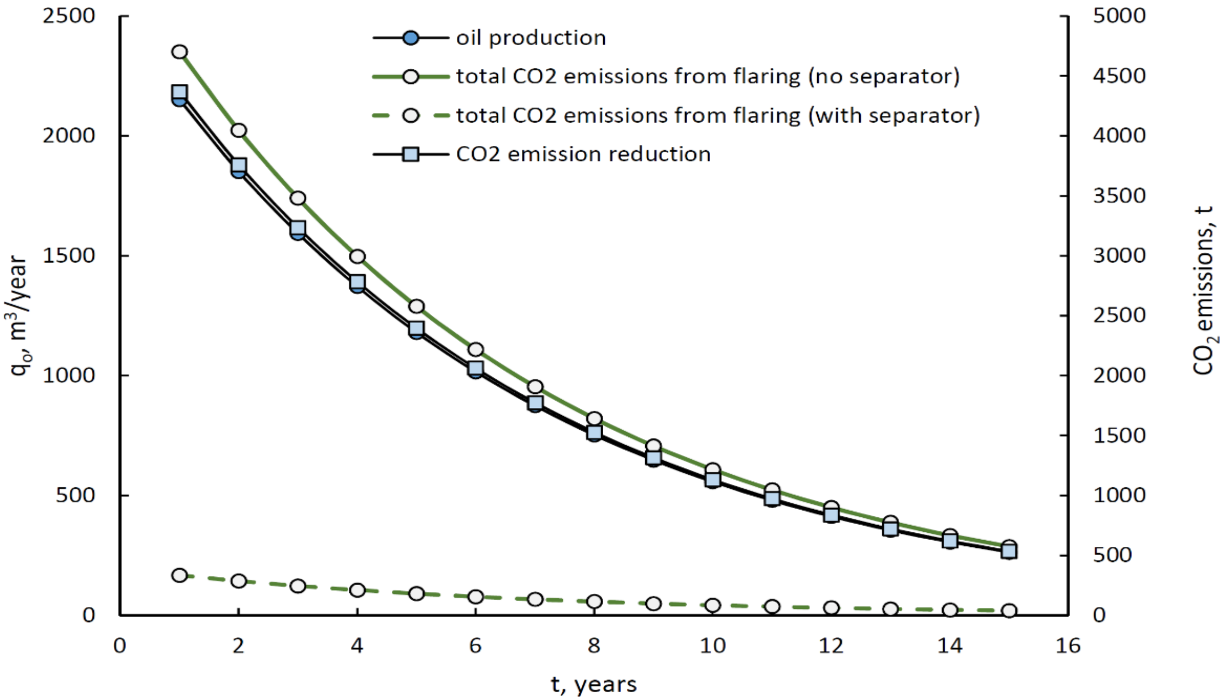

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Results and discussion

- Economic analysis made based on emissions at 15 ˚C
- Difference between emitted amounts with and without the separator multiplied by CO_2 price
- Several CO_2 prices and discount rates

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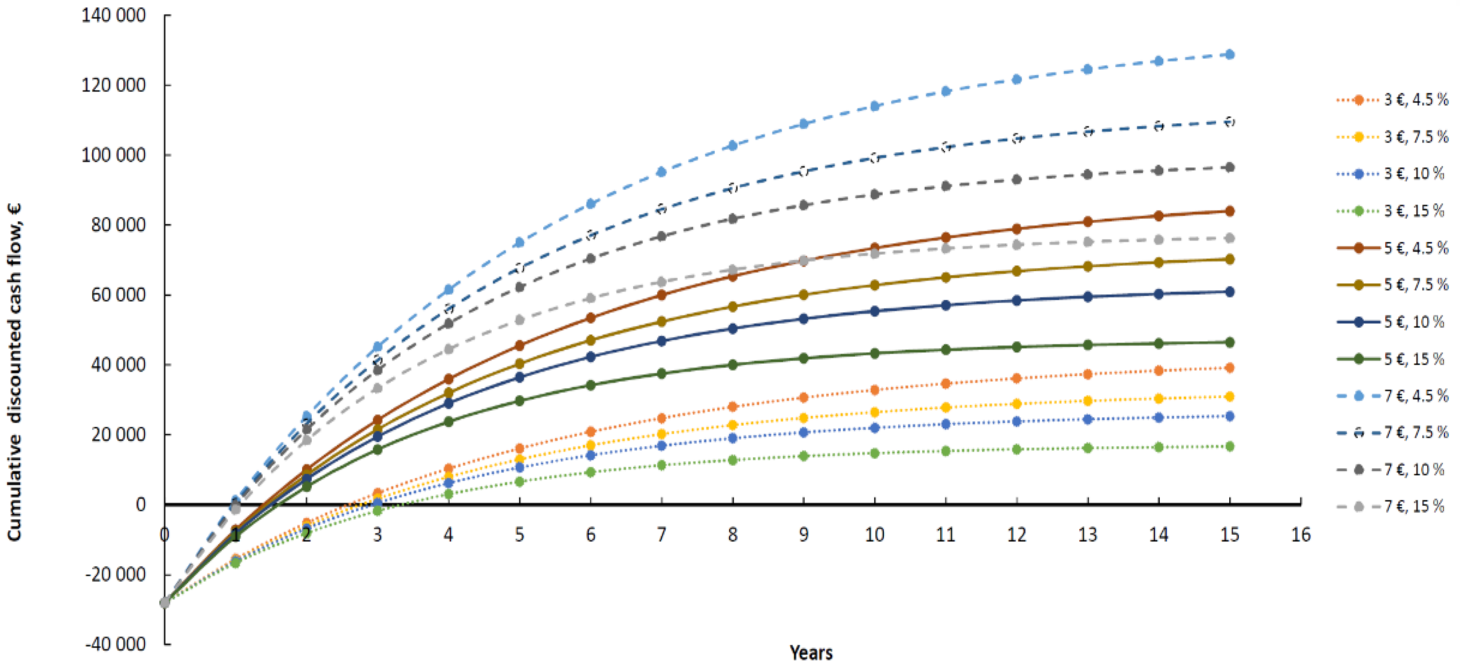
Results and discussion

Results and discussion



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Results and discussion

Results and discussion

- Oil production decline and CO_2 emission reduction follow the same trend and CO_2 emission without the separator shows similar trend.
- At lower reservoir pressures, emissions with the separator exceed the amounts that would be emitted without the separator

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Results and discussion

Results and discussion

- Difference between CO_2 emissions with and without the separator
- Investment highly profitable

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Results and discussion

Results and discussion

Results could be implemented into petroleum industry business practice for achieving specific goals concerning energy efficiency and emission reduction for fulfilling target goals of Low carbon energy strategy in Croatia

Conclusion

- Define net benefits resulting from the capital investment into separator for decreasing CO_2 emissions
- Primary phase – physical indicators

Conclusion

- Secondary phase – economic indicators
  - Measure the impact of the project which could influence socio-economic variables
- Maximum payback period < 4 years, even at very low CO_2 price of 3 €/t and relatively high discount rate (15 %)
- Installation of the separator can be net positive

$ESCO_2M$ PROJECT

Evaluation **S**ystem for **CO_2 M**itigation

Funded by the Environmental Protection and Energy Efficiency Fund with the support of the Croatian Science Foundation

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