Models for evaluating the performance of chemical looping combustion in industrial size

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Introduction

Development of various modelling and simulation tools is essential for the design, optimization, and upscaling of the CLC process. Reactions and fluid dynamics in a system of two interacting fuidized bed reactors leads to complex operation with many affecting parameters. Moving from small-scale to commercial unit, typical challenges involve aspects of both physical and chemical nature. The models presented here offer a possibility to study the performance of a CLC system in industrial size and acquire further understanding of the operation of large-scale process.

Dual fluidized bed reactor model

- One-dimensional dynamic dual fluidized bed reactor model in Matlab/Simulink environment
- Time-dependent mass and energy balances are derived for each control volume, and semi-empirical correlations for hydrodynamics, reaction kinetics and heat transfer are used
- Includes various sub-models and process adjustment tools
- Succesfully validated against the results obtained from the operation of a 120 kW CLC pilot unit located at Vienna University of Technology

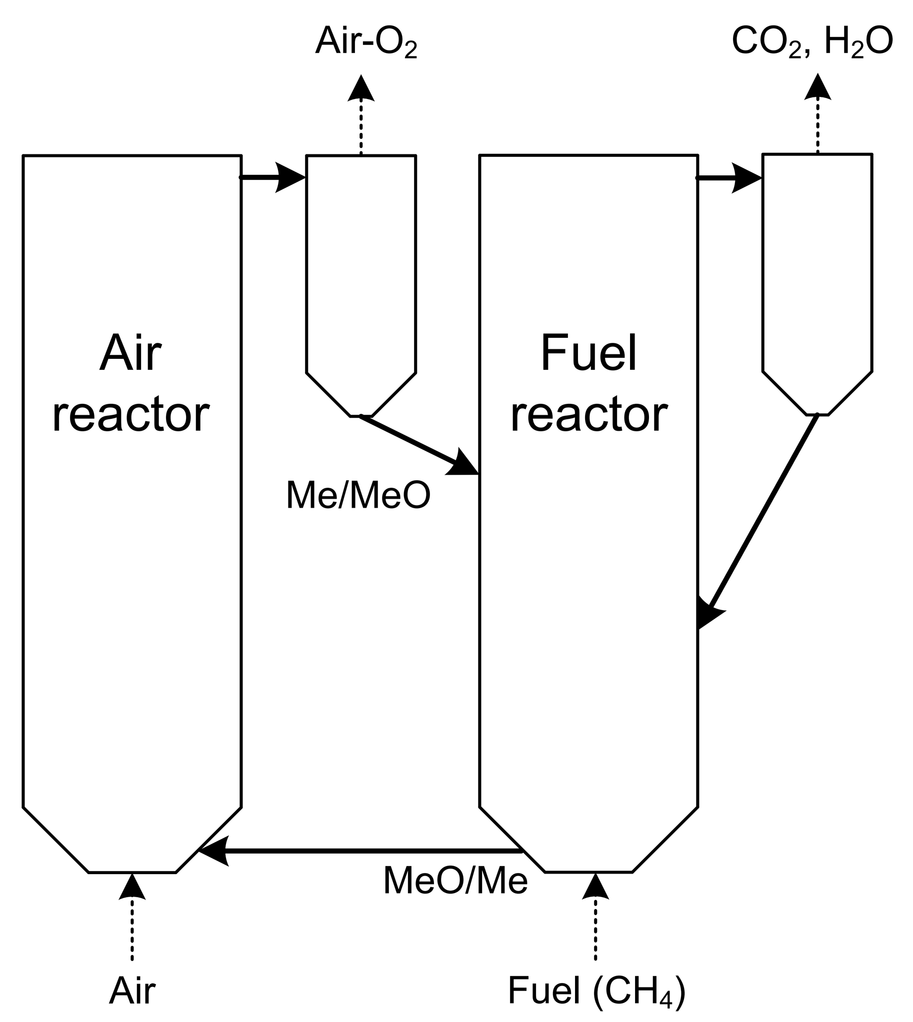

Fig. 1) Schematic layout of the process.

CLC-steam power plant model

- Implemented in IPSEpro environment for investigation of CLC-integrated power generation
- Calculation of overall efficiency of different plant configurations, evaluation of design and off-design performance and process optimization with genetic algorithms

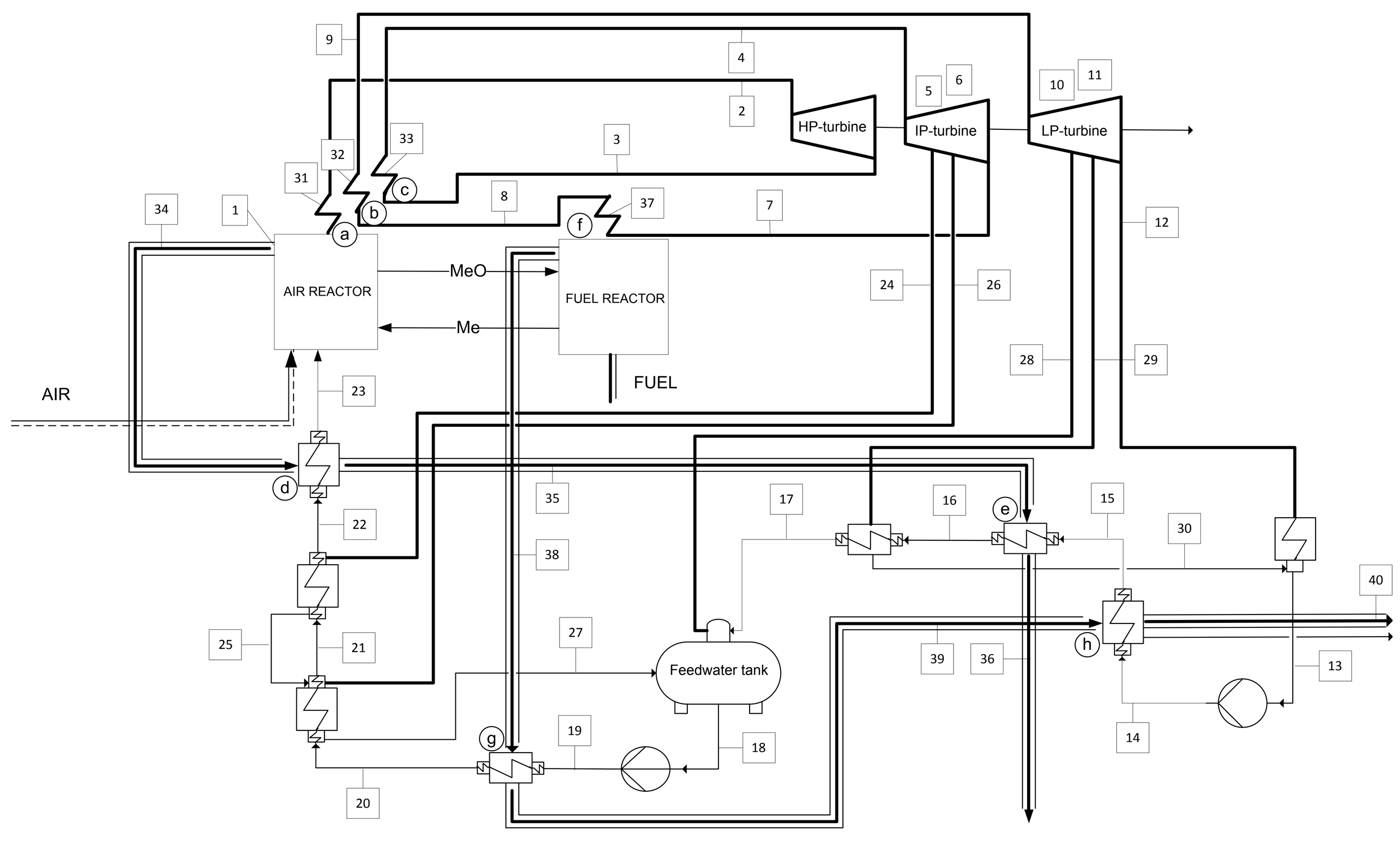

Fig. 2) CLC-integrated steam power process

Case study and relevant results

A case study for evaluating the performance of CLC in industrial scale was defined. The dual fludized bed reactor model was used to simulate the process shown in Fig 1. The air reactor (AR) was operating at fast fludization regime and a turbulent fluidized bed was applied in the fuel reactor (FR). Methane was used as fuel and NiO (40% active) as oxygen carrier (OC). Fuel power was 1000 MW and the heat recovered from the air reactor was varied between 400-600 MW. As a result, temperatures, material fluxes and oxygen carrier conversion states from the air reactor and and fuel reactor were obtained. The most relevant model inputs and results are summarized here:

Parameter	Value	Unit
Inputs		
Fuel power	1000	MW
Global air/fuel ratio	1.1	-
Air reactor cooling	400-600	MW
Results		
Global solids circulation	2166	kg/s
OC degree of oxidation after AR / FR	0.58 / 0.50	-
OC inventory AR / FR	62.6 / 129.9	t
Flue gas from AR / FR	298.3 / 100	kg/s
Flue gas temp. AR / FR	823-1147 / 708-1016	°C

In order to predict the overall efficiency of an atmoshperic CLC-integrated steam process, the results obtained from the dual fluidized bed reactor model were introduced into the IPSEpro model. The simulation layout shown in Fig. 2 includes the CLC boiler system, the heat recovery setup with double steam reheating, and the integrated steam cycle with a three pressure level steam turbine. For comparison, a system including only one steam reheating step was also simulated. In both cases the steam is superheated by the AR flue gas. The calculations were conducted with subcritical and supercritical steam values, and the compression of CO_2 was not taken into account. The results are shown in Fig 3.

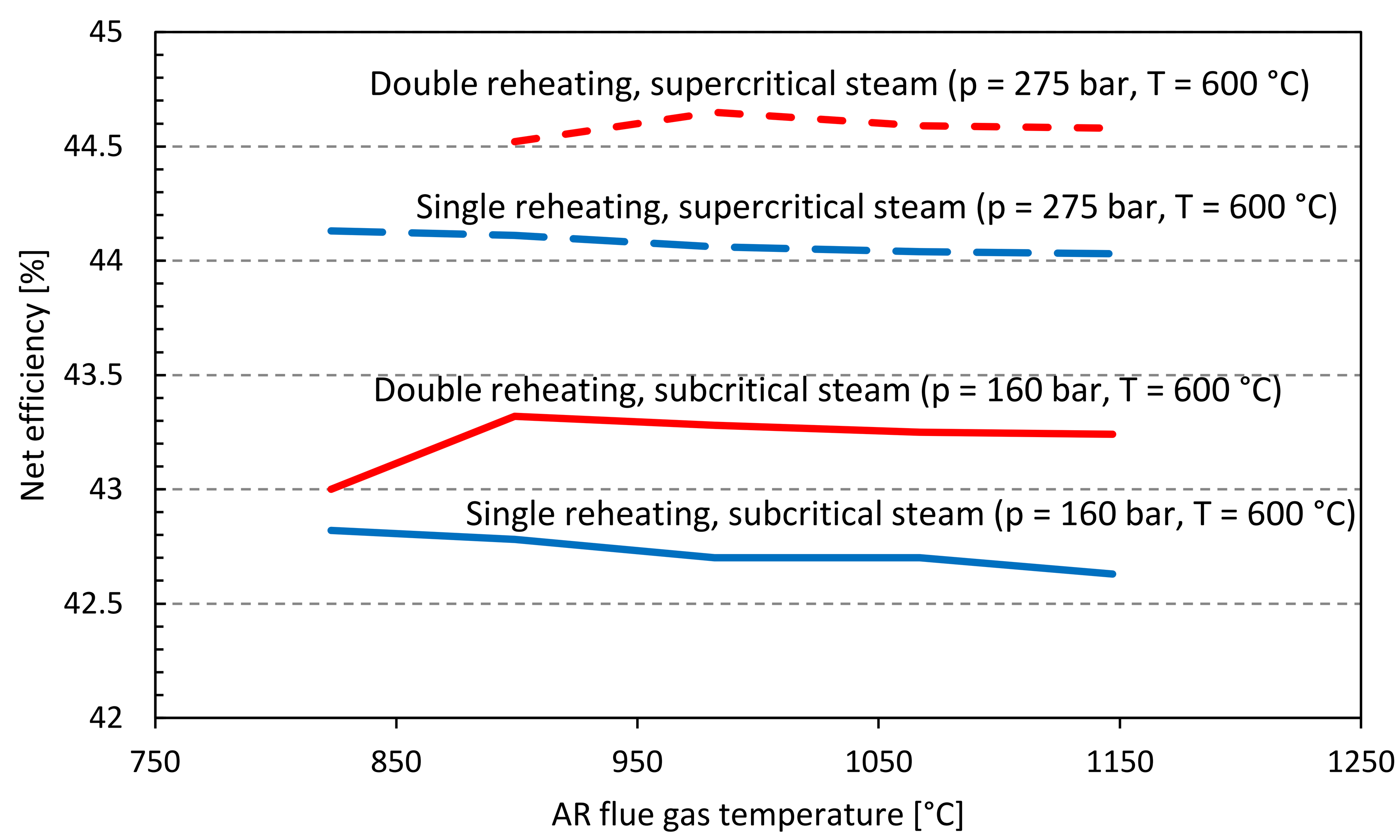

Fig. 3) The net efficiency of a CLC-integrated steam power process versus the AR flue gas temperature.

For subcritical steam values, a CLC-integrated steam process including double steam reheating can reach 0.5-0.6 %-points higher net efficiency than a system including only one steam reahating step. Generally, higher efficiencies are obtained with supercritical steam values. Considering the AR flue gas temperature, the design with one reheating step has wider operational range, and more stable operation can be observed especially at lower temperatures. With intense cooling of the AR, the flue gas does not contain enough energy for double reheating. Assuming that the energy loss for the compression of CO_2 is 100 kWh/t_{CO2}, the overall efficiencies will decrease approximately 2%-points. Compared to other novel CO_2 capture technologies, power production with CLC-integrated steam cycle seems competitive.