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First experience in operation of cold model of fb-clc-sf (fluidized-bed chemical-looping-combustion solid-fuels) facility

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FIRST EXPERIENCE IN OPERATION OF COLD MODEL OF FB-CLC-SF (FLUIDIZED-BED CHEMICAL-LOOPING-COMBUSTION SOLID-FUELS) FACILITY

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Abstract

The experiences with a cold model of dual fluidized-bed unit designed for chemical looping combustion of solid fuels (FB-CLC-SF) are presented in this paper.

The constructed facility combines two different type reactors. The first one, which is the air reactor (AR) is operated in a regime of fast fluidized bed, whereas, the second one, which is the fuel reactor (FR) works under bubbling fluidized bed conditions. However, the integrated reactors make the whole construction being a CFB-type (Circulating Fluidized Bed) unit. The facility is made entirely of transparent material. This feature supports effectively the measurements, which enables to conduct the comprehensive studies in the field of investigations.

During this research, the air was used for bed fluidization in both reactors. As an inventory, the glass beads were employed, since they size and density (d_p = 100 – 200 μm, ρ_s = 2450 kg/m^3) relate closely to the properties of oxygen carriers developed concurrently in the project, whereas they are significantly less expensive and friendlier in use.

Over a dozen ports for pressure measurements are provided along the main circulation path of the solids. These experimental data enable to determine the pressure balance around the whole CFB loop, which becomes the starting point for further studies.

The cold simulations of solids flow demonstrate the conditions that are expected in a case of the hot test rig operation, which remains under construction. Therefore, the main goal of this work is to establish the operating conditions that consider both: a smooth fluidization throughout the FB-CLC-SF unit and an efficient oxidation/reduction of oxygen carriers in AR and FR, respectively. The effect of gas velocities in air- and fuel reactor on the process performance found to be essential.

Keywords

chemical looping, fluidized bed, cold tests

1. Introduction

Chemical looping combustion (CLC) is one of the technologies that offer near-zero emission of CO_2, since the flue gas contains mostly carbon dioxide that is almost ready for sequestration [1]. Chemical looping combustion can be also considered as advanced oxy-fuel combustion. The main idea of the CLC technology is based on cyclic oxidation and reduction of solid oxygen carriers (OCs), which provide oxygen to the combustion process. Thereby, fuel and air do not contact each other directly, which is the key point of this idea. Therefore, two interconnected reactors are required to perform the CLC process, which are so-called the air reactor (AR) and the fuel reactor (FR), respectively (Fig. 1) [2]. Thus, the whole system makes the circulation loop for the oxygen carriers.

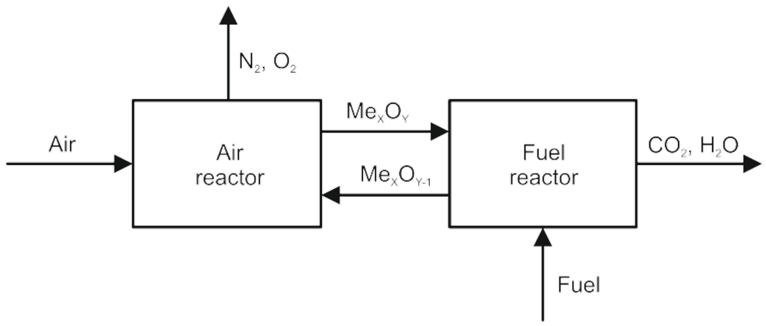

Fig.1. The idea of CLC process

The regenerated OCs (1) leave air reactor and give up oxygen in a combustion process (2) that takes place in a fuel reactor [3]. Then, reduced OCs return to the air reactor to be re-oxidized.

$$Me_xO_{y-1} + 1/2O_2 \rightarrow Me_xO_y \tag{1}$$

$$C_nH_{2m} + (2n+m)Me_xO_y \rightarrow nCO_2 + mH_2O + (2n+m)Me_xO_{y-1} \tag{2}$$

A certain type of chemical looping combustion is called CLOU (Chemical Looping with Oxygen Uncoupling) [4]. The main difference lies in a course of combustion reaction. In the case of CLOU, oxygen releases OCs immediately they get fuel reactor, and hence, fuel reacts directly with gaseous oxygen in an environment of reduced carriers. A tremendous effort was done and comprehensive reviews on the chemical looping combustion technology were recently provided by [5,6,7,8] whereas the current status was concisely defined by [9]. However, a rapid development of the technology, mainly in terms of new oxygen carriers employed to the combustion process, makes further studies of great importance. The results from the cold model of FB-CLC-SF (Fluidized-Bed Chemical-Looping-Combustion Solid-Fuel) test rig are presented in this paper. The obtained information seems to be crucial for the ultimate performance of the chemical looping combustion process under hot conditions.

2. Material and methods

2.1. Test rig

The cold model of FB-CLC-SF (Fluidized-Bed Chemical-Looping-Combustion Solid-Fuel) test rig is made up of two interconnected reactors (Fig. 2). The first one, which is called the air reactor (AR), is operated under bubbling bed conditions in the bottom part, whereas in the upper part a fast fluidization takes place. The second one, however, which is called the fuel reactor (FR), is operated under bubbling fluidized bed regime. Below both chambers, the wind-boxes are located. Chambers and wind-boxes are separated by the fabric grids. The diameter and the height of air reactor are: d = 0.102 m and H = 0.32 m (bottom part) and d = 0.044 m and H = 2.08 m (upper riser), respectively. The converging cone between both tubes has a height of 0.12 m, which gives the total height of AR of 2.52 m. The dimensions of fuel reactor are as follows: D = 0.08 m, W = 0.145 m and H = 0.5 m. However, the volume of FR is divided into 5 connected sections, which forces a labyrinthine flow of fluidized solids. Moreover, the circulation loop consists of the cyclone and two loop-seals, all placed between the reactors, as shown in Fig. 2. All parts of the cold model are fully transparent, which makes the investigations more comprehensible.

The dual fluidized-bed reactor is equipped with a set of pressure measurement ports connected to the pressure transducers. Then, the signals are transmitted via an analog-to-digital converter to the DasyLab software. The locations of measurement ports along the circulation loop are provided in Table 1. The reference level is determined by the grid of air reactor, whereas, the distance between the grids levels of AR and FR is 0.53 m. For each test, the pressure measurements were stated after 1-hour period of stabilization of flow conditions. The data were acquired from all ports simultaneously, with a sampling rate of 1 Hz.

Table 1. Levels (in meters) of pressure measurement ports. Level of AR grid: 0.00 m

Fuel Reactor	**Air Reactor**	**Loop-Seals**	**Wind-Boxes**	**Other points**
P1: 0.55	P5: 0.02	**Loop-Seal I**	**Wind-Box I**	**Downcomer**
P2: 0.63	P6: 0.12	P11: 0.39	P17: 0.47	P15: 2.32
P3: 0.80	P7: 0.31	P12: 0.51		
P4: 0.97	P8: 0.46		**Wind-Box II**	**Gas Pass**
	P9: 0.96	**Loop-Seal II**	P18: -0.07	P16: 3.11
	P10: 2.43	P13: 1.21		
		P14: 1.31		

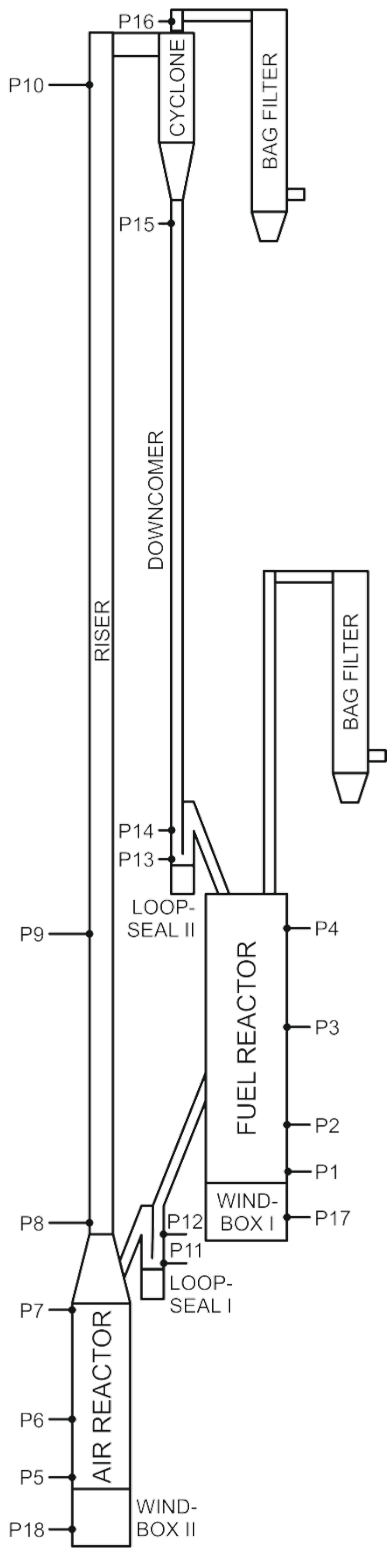

Fig. 2. The cold model of FB-CLC-SF test rig

2.2. Test conditions

For the cold tests, the bed material of glass beads was selected. The particle size ranged from 100 μm to 200 μm, hence Sauter mean diameter of 141 μm and median diameter of 139 μm were calculated. These values correspond directly to the properties of oxygen carriers that are going to be employed for the hot tests. The solids density and the bulk density are determined to be 2450 kg/m^3 and 1500 kg/m^3, respectively. Thus, the bed voidage is estimated at 0.4. Based on the microscopy of the bed material, the particle sphericity is assumed to be 0.9. The total inventory that circulates in a dual fluidized-bed reactor is defined to be 7 kg. The solids mass flux varied under different operating conditions, hence the values and the relations will be discussed later, in the next chapter.

During these investigations, the air at ambient temperature was used for bed fluidization in air reactor, fuel reactor and both loop-seals. For the following tests, the superficial gas velocities in AR and FR (Table 2) were changed while the fluidization in the loop-seals was kept invariable. For the estimations of gas velocities in AR and FR, it was assumed that there is no gas flows between the reactors through the loop-seals. Finally, it was confirmed: a bubbling fluidization regime for the fuel reactor and for the bottom part of air reactor as well as a fast fluidization in an upper riser of air reactor. Moreover, the minimum fluidizing velocity of 0.015 m/s and the terminal velocity of 0.88 m/s were calculated for the employed bed material and gas properties.

Table 2. Gas velocities (in m/s) in AR and FR

Test	**Fuel Reactor**	**Air Reactor**	
		bottom part	**upper part**
1	0.33	0.37	2.00
2	0.33	0.49	2.65
3	0.33	0.62	3.30
4	0.28	0.37	2.00
5	0.23	0.37	2.00

3. Results and discussion

The results from the cold model tests are presented below. In the first measurement campaign (Tests 1-3), the gas velocity in air reactor was subjected to changes from 0.37 m/s to 0.62 m/s in a bottom part of the reactor, which results in an increase in a gas velocity from 2.00 m/s to 3.30 m/s in an upper riser of AR. Otherwise in the second campaign (Tests 1, 4-5), the gas velocity in fuel reactor was varied in a range of 0.23-0.33 m/s (see: Table 2).

Initially, the pressure fluctuations from 1-hour measurements were studied. The experimental data were taken from all ports located around the circulation loop of the test rig. The examples that relate to the air reactor and to the fuel reactor are given separately in Fig. 3.

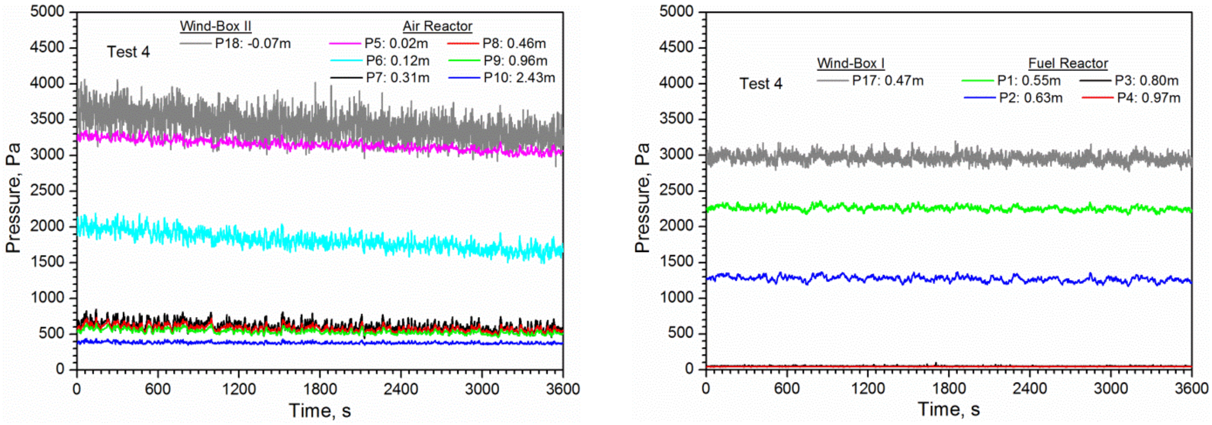

Fig. 3. Pressure fluctuations in AR and FR (Test 4: v^{FR} = 0.28 m/s, $v^{ARdown-up}$ = 0.37 m/s – 2.00 m/s)

The widest range of pressure fluctuations was noted in both wind-boxes, as expected. High fluctuations can also be observed in a bottom part of air reactor where a bubbling bed fluidization takes place, below the solids return level (measurement ports P6 and P7). It was found, however, that the fluctuations measured in a grid zone of AR (P5) and in a dense bed of FR (P1 and P2) are much weaker, which is confirmed for all conducted tests. Finally, the measurements that were carried out in a riser of AR with a lean bed (P8-P10) and in an upper part of FR (P3 and P4) shown that the values of pressure vary in a very narrow ranges compared to those known from the bottom parts of both reactors.

In further evaluations, the average values of pressure were calculated for each measurement port. This enables to determine the pressure profiles in air reactor and in fuel reactor, respectively (Fig. 4). The uniform pressure distribution in air reactor can be seen in both sections: the bottom section with a dense bed (P5-P7) and the upper section with a lean bed (P8-P10). Similarly, the pressure distribution throughout the bubbling bed in fuel reactor (P1-P3) seems to be quite uniform. The pressure balance around the whole circulation loop can be established (Fig. 5) if the values of pressure determined for the other ports are taken into consideration. Similar profiles for the CLC reactor were found among others by Proll et. al [10]. Moreover, the obtained results seem to remain in general agreement with pressure distributions in typical CFB units presented by Basu [11]. This gives complete information on a dual fluidized-bed operation. However, the evaluation of the experimental data seems to be much easier if the distribution of suspension density along the whole height of both reactors is provided (Fig. 6). These values (Eq. 3) can be estimated directly from the data given in Fig. 4, which makes the obtained results more understandable. Each regime of fluidization (in this case: BFB and FFB) has however its own distinctive profile, as mentioned in [12].

$$\rho = \Delta p / (g\ \Delta h) \tag{3}$$

where: ρ – suspension density (kg/m^3), Δp – differential pressure (Pa), g – acceleration of gravity (m/s^2), Δh – distance between pressure measurement ports (m).

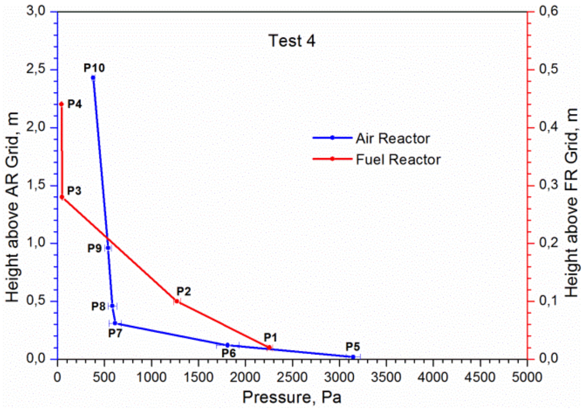

Fig. 4. Pressure distribution in AR and FR (Test 4: v^{FR} = 0.28 m/s, $v^{ARdown\text{-}up}$ = 0.37 m/s – 2.00 m/s)

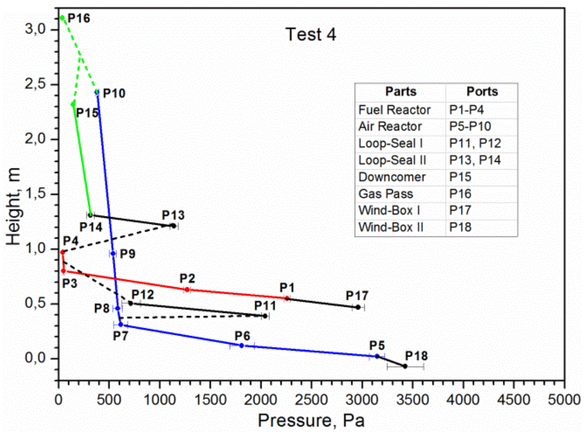

Fig. 5. Pressure balance around a circulation loop (Test 4: v^{FR} = 0.28 m/s, $v^{ARdown\text{-}up}$ = 0.37 m/s – 2.00 m/s)

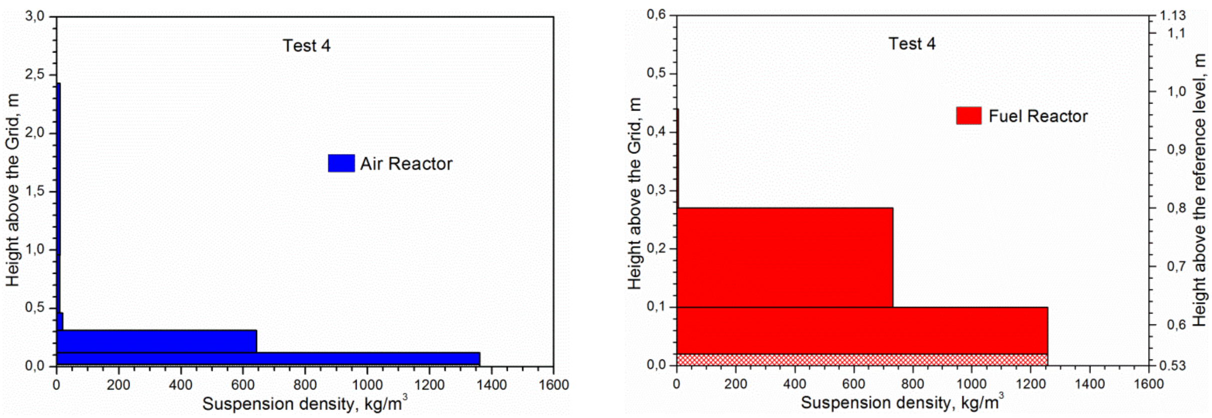

Fig. 6. Suspension density in AR and FR (Test 4: v^{FR} = 0.28 m/s, $v^{ARdown\text{-}up}$ = 0.37 m/s – 2.00 m/s)

The effect of increasing gas velocity on pressure distributions in air- and fuel reactor can be seen in Fig. 7. Additionally, the values of suspension densities that were determined for the following zones of both reactors are shown in Fig 8.
In all cases (Fig. 7), the pressure profiles look quite similar, regardless of the gas velocity. The main difference however seems to be the values of total pressure drop along the height of both chambers, which indicate that the amount of bed material in the reactors depends on the gas velocity. Moreover, two main regions in AR can be easily distinguished, i.e. between measurement ports P5 and P7 with a flat pressure distribution, and between P7 and P10 with a sharp vertical profile. Otherwise, the uniform pressure distribution across the whole bed in FR can be observed. Very similar results from cold model investigations were reported by Markstrom and Lyngfelt [13].

Fig. 8 seems to reveal more details, since the differences in suspension density are more visible compared to those of pressure drops given in Fig. 7. Dense bubbling bed is confirmed for the bottom part of AR (zones 1-2) as well as for the first- and the second zone in FR. Moreover, a significant decrease in bed density with increasing gas velocity can be found in the second zone of both reactors, especially. As a result however, the higher concentration of bed material in an upper part of AR (zones 3-5) as well as in the top part of FR (zone 3) is noticed. All this information appears to be crucial for further analyses provided below.

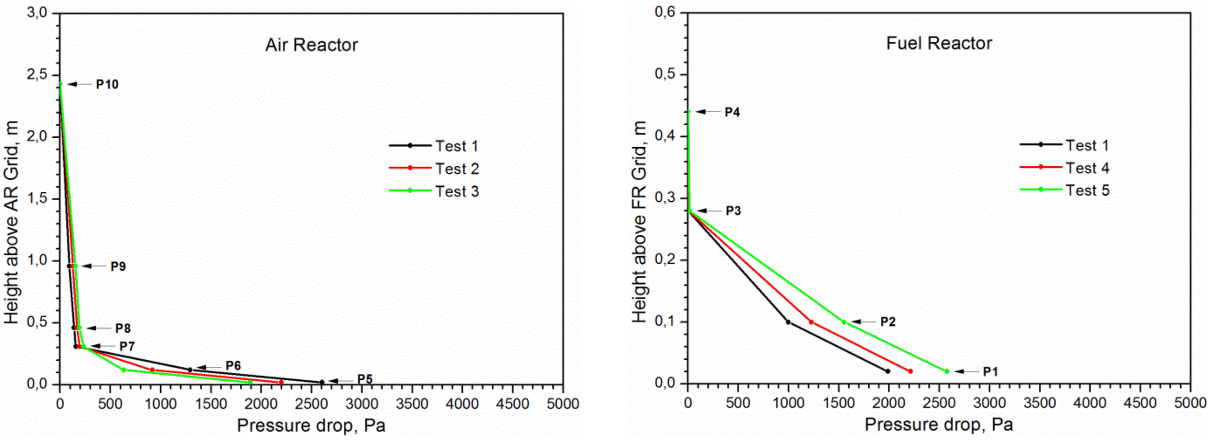

Fig. 7. The influence of gas velocity on pressure distribution in AR and FR (Test 1: v^{FR} = 0.33 m/s; Test 4: v^{FR} = 0.28 m/s; Test 5: v^{FR} = 0.23 m/s; $v^{ARdown-up}$ = 0.37 m/s – 2.00 m/s)

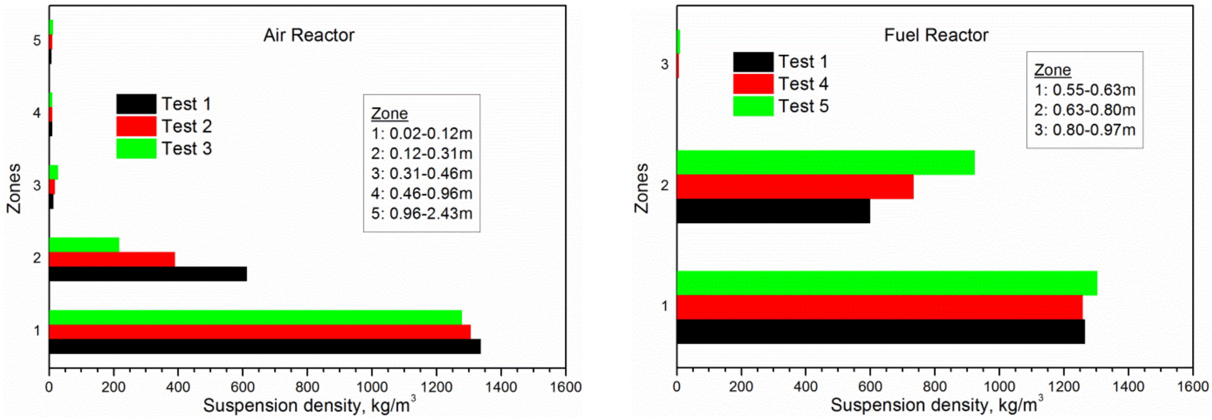

Fig. 8. The influence of gas velocity on suspension density in AR and FR (Test 1: $v^{ARdown\text{-}up}$ = 0.37 m/s – 2.00 m/s; Test 2: $v^{ARdown\text{-}up}$ = 0.49 m/s – 2.65 m/s; Test 5: $v^{ARdown\text{-}up}$ = 0.62 m/s – 3.30 m/s; v^{FR} = 0.33 m/s)

In further studies, other experimental data such as: solids mass flux (G_s), cyclone separation efficiency (η_{cyc}) and solids loss to the bag filters (Table 3) were taken into consideration. The values of G_s were obtained experimentally, since both solids fluxes behind the cyclone (towards the fuel reactor and the AR bag filter) were measured in all tests. These data also enable to estimate the values of η_{cyc}. Moreover, the number of cycles and the residence time (Table 4) were calculated for the air reactor and the fuel reactor, respectively. In the first approach, the gas velocity in air reactor was gradually increased starting with 2.00 m/s, which appears to be the minimum value to achieve a fast fluidized bed in an upper part of AR under the investigated conditions (see: Table 2).

Table 3. Solids mass flux, cyclone separation efficiency and solids loss – 1st approach

Test	**G_s** kg/(m²s)	**η_{cyc}** %	**Solids loss (AR bag)** kg/h	**Solids loss (FR bag)** kg/h
1	1.52	96.3	0.30	0.04
2	1.77	96.2	0.36	0.03
3	2.57	96.8	0.45	0.03

Table 4. Number of cycles and residence time in AR and FR – 1st approach

Test	**Number of cycles**		**Residence time**	
	Air Reactor cycles/h	**Fuel Reactor** cycles/h	**Air Reactor** s	**Fuel Reactor** s
1	3.6	3.8	989	940
2	5.2	4.2	697	865
3	9.0	5.9	402	614

It can be seen in Table 3 that the increase of gas velocity in air reactor results in an increase of solids mass flux, as expected. Similar values of G_s for a cold-flow model of CLC unit was obtained by Markstrom and Lyngfelt [13], in spite of lower pressure drop in the riser.

Furthermore, a very slight increase in cyclone separation efficiency can be observed due to the higher load of the separator. The relation between cyclone separation efficiency and solids mass flux is reported among others in [14,15]. However, the amount of bed material that escaped to the AR bag filter was the lowest in Test 1, which results from the lowest value of G_s under the investigated conditions.

Following parameters which are the number of cycles and the residence time in both reactors (Table 4) seem to be complementary. Therefore, the increasing value of the first parameter decreases the value of the second one and vice versa. A strong influence of gas velocity in AR on the number of cycles was found in this part of investigations. This relation results mainly from varying solids flux as well as from the capacities of the reactors, which are specific to the operated unit, and hence, the obtained values are difficult to compare with the data published by other researchers.

On the basis of these results, the lowest value of gas velocity in air reactor was selected for further investigations. This choice stems mainly from the longest residence times in FR and AR, which are close to those that are expected in subsequent hot rig tests with oxygen carriers. Moreover, the lowest solids loss (with the meaning of the lowest OCs loss) that was noted under these conditions is also taken into consideration. Additional benefit can be found in smaller air-fan required in this case, which reduces both capital and operating costs of the whole CLC plant in the future.

In the second approach, the gas velocity in fuel reactor was subjected to progressive reduction, while the gas velocity in air reactor was kept invariable at the level established during the first part of investigations. (see: Table 2).

Strong increase in solids mass flux with a decrease in the gas velocity in fuel reactor can be observed in Table 5. This relation follows from the higher inventory in the unit, mainly in the air reactor, which stabilized under the investigated conditions (Tests 4 and 5). As a result of increasing cyclone load, the separation efficiency was getting higher and ultimately reached the value of 99.9%. It confirms that cyclone separation efficiency strongly depends on the value of G_s for the operated unit, which was already mentioned. In practice, the loss of bed material was significantly reduced due to the increased efficiency of the separator.

Table 5. Solids mass flux, cyclone separation efficiency and solids loss – 2nd approach

Test	**G_s** kg/(m^{2}s)	**η_{cyc}** %	**Solids loss (AR bag)** kg/h	**Solids loss (FR bag)** kg/h
1	1.52	96.3	0.30	0.04
4	2.63	98.3	0.24	0.06
5	6.17	99.9	0.02	0.02

Table 6. Number of cycles and residence time in AR and FR – 2nd approach

Test	Number of cycles		Residence time	
	Air Reactor cycles/h	**Fuel Reactor cycles/h**	**Air Reactor s**	**Fuel Reactor s**
1	3.6	3.8	989	940
4	6.1	6.0	594	602
5	12.8	12.1	281	297

Moreover, it was found that the numbers of cycles in fuel- and air reactor can be further controlled by changing the gas velocity in FR, in spite of fixed gas velocity in AR (Table 6). For lower gas velocity in FR, the process performance becomes more efficient in terms of limited loss of solids, which means limited loss of oxygen carriers in further hot rig investigations. Besides, by smaller FGR-fan and lighter piping the capital costs and the operating costs (energy consumption) of the whole CLC plant are lower, as mentioned above. However, it has to be concurrently considered that even slight decline of gas velocity in FR affects significantly the residence times in both reactors. Therefore, it can be claimed that on the one hand the capabilities of employed oxygen carriers appear to be crucial for further performance of the CLC process. However, on the other hand, a deep knowledge on the OCs kinetics is to be of the highest importance as well. Then, it enables to adjust the thermal conditions in fuel reactor and air reactor respectively, in order to get the best available efficiency of the combustion process.

4. Conclusions

The experimental results from a cold model of FB-CLC-SF (Fluidized-Bed Chemical-Looping-Combustion Solid-Fuel) test rig were presented in this paper. The findings are to be applied to the subsequent investigations under hot conditions.

For these studies, a dual fluidized-bed reactor was constructed. It was confirmed that the first reactor (air reactor) works with a bubbling bed in its bottom part, whereas in the upper part a fast fluidization takes place. The second reactor (fuel reactor), however, is operated under bubbling fluidized bed regime.

During the cold rig tests, the oxygen carriers were substituted for the glass beads and the air was used for bed fluidization in both reactors.

Strong influence of gas velocities in air- and fuel reactor on the solids mass flux and the cyclone separation efficiency was found, which further significantly affect the residence times of circulating particles in both reactors.

Thereby, the operating conditions that will be finally established for the hot rig investigations depend mostly on the capabilities and the kinetics of employed oxygen carriers. Then, the most efficient performance of the chemical looping combustion process will be achieved.

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Experiences from the Operation of a Cold Model of Fluidized-Bed Chemical-Looping-Combustion Solid-Fuels Facility

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Project

General Information

Title:	Innovative Idea for Combustion of Solid Fuels via Chemical Looping Technology
Acronym:	- *NewLoop* -
Programme:	Polish-Norwegian Research Programme
Duration:	05/2014 – 04/2017
Budget:	1.9 million USD

Partners

- Institute of Power Engineering - IEn
- **Czestochowa University of Technology, Institute of Advanced Energy Technologies**
- Norwegian Institute for Air Research - NILU
- Institute for Energy Technology - IFE

Activities

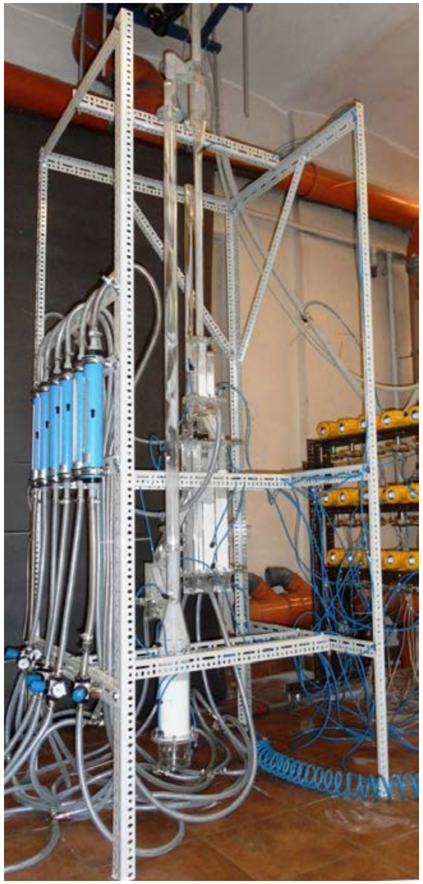
Activities \ Partners	IEN	IZTE	NILU	IFE
Oxygen carriers development	X			X
Micro-scale experiments	X			X
Bench-scale investigations		X		
CFD modeling, scaling-up	X	X		X
Feasibility study for pilot-scale unit	X			
Techno-economic evaluations			X	

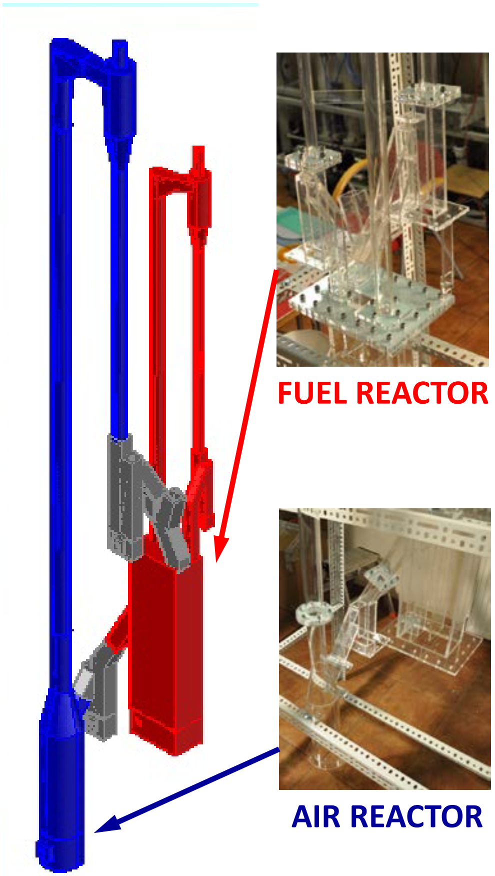
Objectives

Development of high-performance, low-cost CO_2 capture process for coal combustion, (and coal-biomass co-combustion), which is competitive to already existing clean coal technologies.

Bench-scale investigations

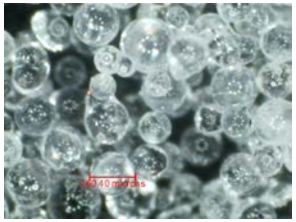
– „Cold" model –

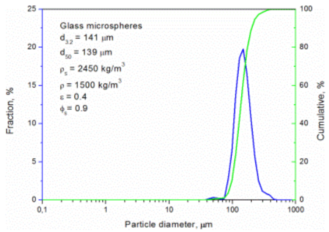




- ✓ **Fuel Reactor**:
  - **- cuboid**
  - - W x D x H: **0.145 x 0.08 x 0.5 m**
  - ***„plexiglass - transparent"***
- ✓ **Air Reactor**:
  - **- tubes**
  - - H = **2.52 m** , d = **0.102 / 0.044 m**

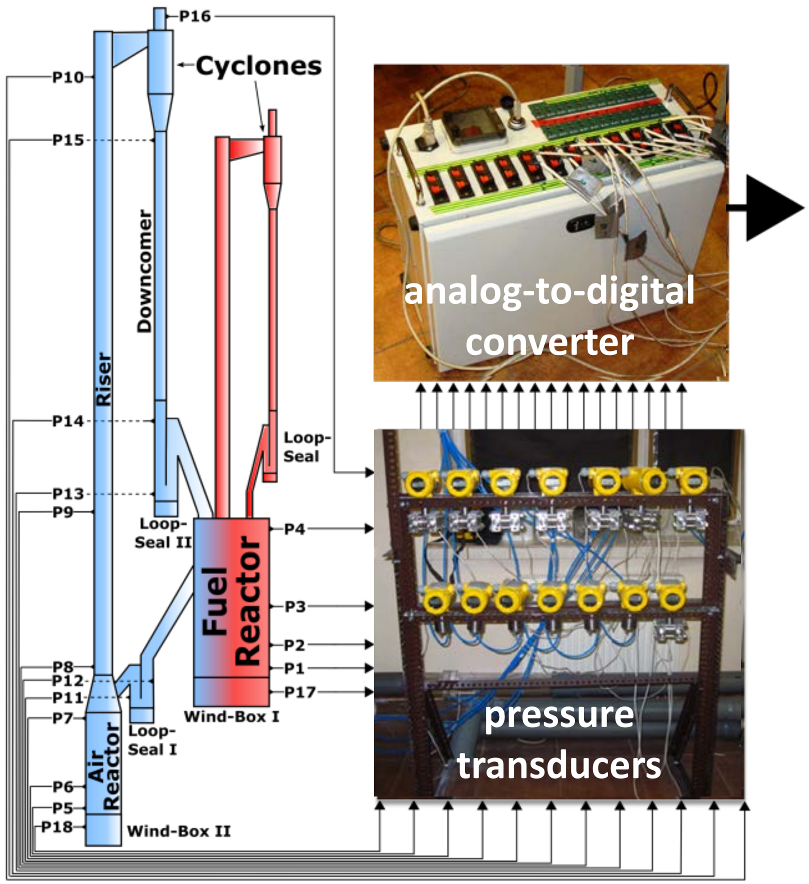
- ✓ **Substitute bed material**:
  - **- glass beads**
  - - d_P: **100 - 200 μm**

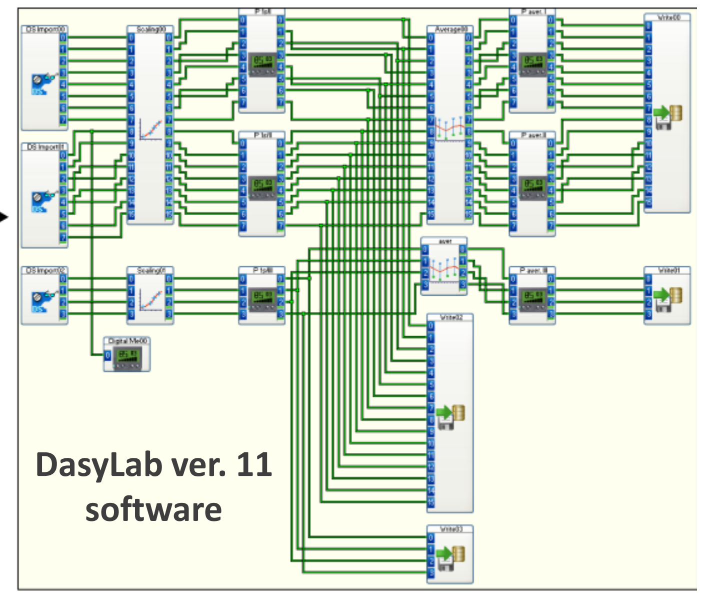




Bench-scale investigations

– Measurement system –



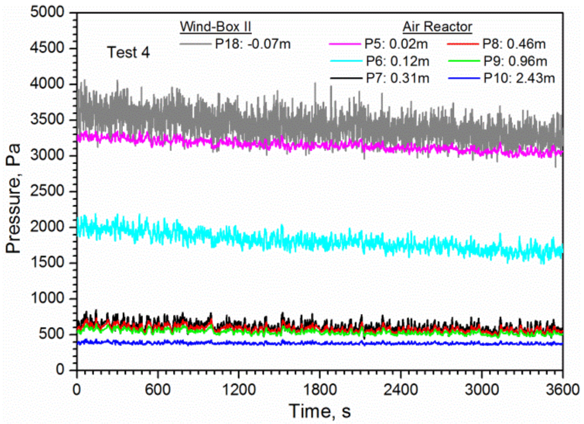


Levels (in meters) of pressure measurement ports. Level of AR grid: 0.00 m

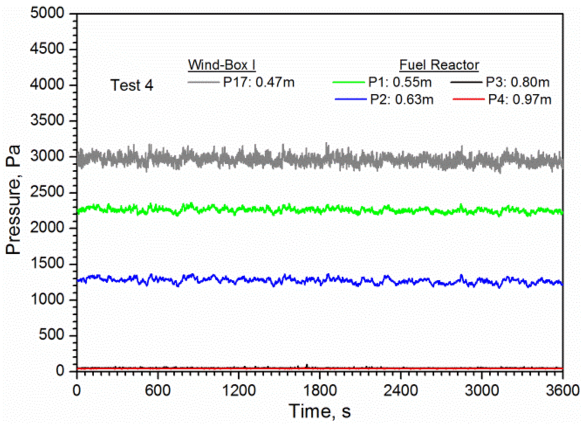
Fuel Reactor	Air Reactor	Loop-Seals	Wind-Boxes	Other points
P1: 0.55	P5: 0.02	**Loop-Seal I**	**Wind-Box I**	**Downcomer**
P2: 0.63	P6: 0.12	P11: 0.39	P17: 0.47	P15: 2.32
P3: 0.80	P7: 0.31	P12: 0.51		
P4: 0.97	P8: 0.46		**Wind-Box II**	**Gas Pass**
	P9: 0.96	**Loop-Seal II**	P18: -0.07	P16: 3.11
	P10: 2.43	P13: 1.21		
		P14: 1.31		

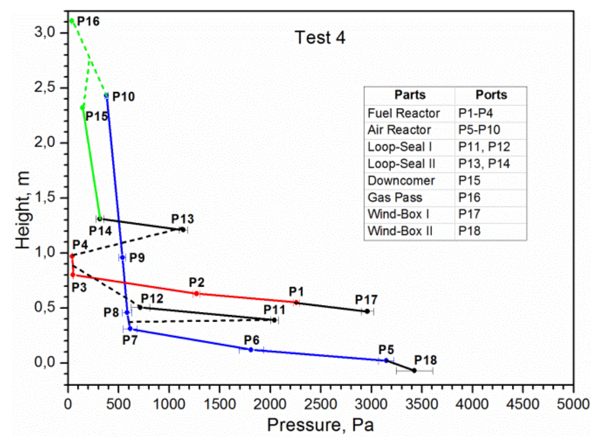
Bench-scale investigations

– First Results –



Pressure fluctuations in **AR ↑** and **FR ↓**





Pressure balance in **Dual F-B Reactor ↑**

✓ **Pressure fluctuations**

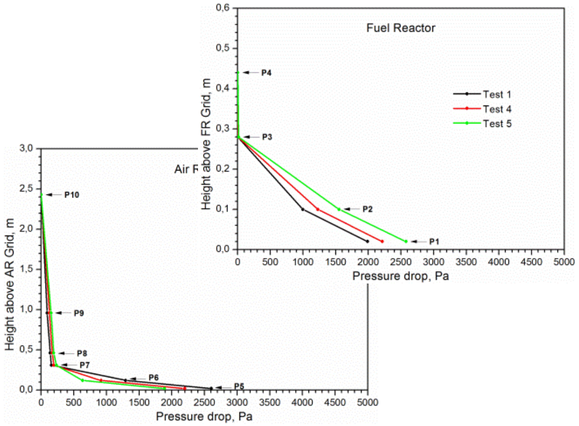
- rather smooth
- the strongest pressure fluctuations in a bottom of AR (P6-P7) - below solids return level; *(W-Bs)*

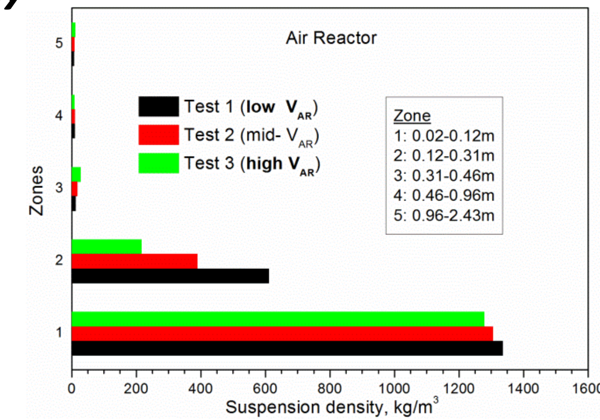
✓ **Pressure profiles**

- uniform pressure distribution in both sections of AR (P5-P7, P8-P10) and throughout the bed in FR (P1-P3)

Bench-scale investigations

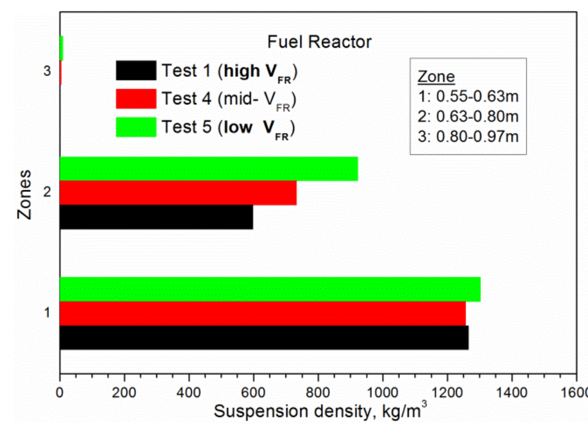
– The Effect of Gas Velocity –





Pressure distributions in **AR and FR ↑**

Suspension density in **AR ↑** and **FR ↓**



✓ **Pressure drop**

- total ΔP (= mass of bed material) in both reactors increases with a decrease in gas velocity

✓ **Suspension densities**

- strong decrease in bed density with increasing gas velocity – in a dense bed region above the grid zone in AR and FR

=> This affects further evaluation of the results

Bench-scale investigations

– The Effect of Gas Velocity –

Test	Fuel Reactor	Air Reactor		Gs	η_{cyc}	Solids loss (Main Bag)	Solids loss (FR Bag)	Number of cycles		Residence time	
		bottom part	upper part					Fuel Reactor	Air Reactor	Fuel Reactor	Air Reactor
	v	v	v								
	$\frac{m}{s}$	$\frac{m}{s}$	$\frac{m}{s}$	$\frac{kg}{m^2*s}$	%	$\frac{kg}{h}$	$\frac{kg}{h}$	cycles/h	cycles/h	s	s
1	0.33	0.37	2.01	1.52	96.3	0.30	0.04	3.8	3.6	940	989
2	0.33	0.49	2.65	1.77	96.2	0.36	0.03	4.2	5.2	865	697
3	0.33	0.62	3.31	2.57	96.8	0.45	0.03	5.9	9.0	614	402

FIRST APPROACH

Middle of the range of BFB

Minimum of FFB then ↗

V_{FR} — & V_{AR} ↗ :
1) slight increase in G_s
2) very slight increase in η_{cyc} (higher cyclone load)
3) increase in solids loss to Main Bag (higher G_s)
4) no influence on solids loss to FR Bag
5) strong effect, increase in number of cycles = decrease in residence time (G_s, m_{bm})

INITIAL CHOICE : "Test 1"
1) the lowest solids (OCs) loss
2) the longest (expected) residence times in FR and AR
3) smaller air-fan (reduction of capital & operating costs)

Bench-scale investigations

– The Effect of Gas Velocity –

Test	Air Reactor		Fuel Reactor	Gs	η_{cyc}	Solids loss (Main Bag)	Solids loss (FR Bag)	Number of cycles		Residence time	
	bottom part	upper part						Fuel Reactor	Air Reactor	Fuel Reactor	Air Reactor
	v	v	v								
	$\frac{m}{s}$	$\frac{m}{s}$	$\frac{m}{s}$	$\frac{kg}{m^2 s}$	%	$\frac{kg}{h}$	$\frac{kg}{h}$	cycles/h	cycles/h	s	s
1	0.37	2.01	0.33	1.52	96.3	0.30	0.04	3.8	3.6	940	989
4	0.37	2.01	0.28	2.63	98.3	0.24	0.06	6.0	6.1	602	594
5	0.37	2.01	0.23	6.17	99.9	0.02	0.02	12.1	12.8	297	281

SECOND APPROACH

Selected for AR in the first approach

First approach then ↘

V_{AR} — & V_{FR} ↘ : 1) strong increase in G_s (higher inventory)

2) strong increase in η_{cyc} (higher cyclone load)

3) strong decrease in solids loss to Main Bag (higher η_{cyc})

4) no influence on solids loss to FR Bag

5) strong effect, increase in number of cycles = decrease in residence time (G_s)

FINDINGS: 1) For fixed V_{AR}, the residence time in FR & AR can be further controlled by changing the V_{FR}

2) For shorter RT, the process performance is more efficient (limited solids (OCs) loss)

3) The capabilities of developed OCs and the knowledge on the OCs kinetics are to be crucial for further performance of the CLC process

4) Smaller FGR-fan and lighter piping (lower capital & operating costs)

Conclusions

- Strong influence of gas velocities in air- and fuel reactor on the solids mass flux and the cyclone separation efficiency was found, which further significantly affect the residence times of circulating particles in both reactors.

- The dual fluidized-bed reactor appears to be flexible in operation, and hence, the conditions that will be finally established for the „hot" investigations depend mostly on the capabilities and the kinetics of developed oxygen carriers.

- The experiences from the operation of a „cold" model of FB-CLC-SF facility have been applied to the investigations on a „hot" test rig =>

Thank you for your attention

Innovative Idea for Combustion of Solid Fuels via Chemical Looping Technology

– NewLoop –