Development of a measurement technique to determine the air return ratio of open volumetric air receivers with recirculation

Arne Tiddens
DLR - Jülich
Open volumetric air receiver with recirculation
Open volumetric air receiver with recirculation
Open volumetric air receiver with recirculation

Receiver

Hot air

Return air

Heliostat Field

Hot Air (680°C)

Receiver

Return Air

Heat Storage

Steam Boiler
The Air Return Ratio (ARR) influences the total efficiency and depends on environmental and operational conditions. It can be improved by measuring it. The development of a measurement technique and its application at the Solar Tower Jülich are highlighted.

\[ \text{ARR} = \frac{\dot{m}_{\text{return}}}{\dot{m}_{\text{out}}} \]

- Influences the total efficiency
- Depends on environmental and operational conditions
- Can be improved
- Has to be measured

Development of measurement technique
Application at Solar Tower Jülich
Tracer Gas

Difficult measurement: Open system, high temperatures, high air mass flows

- Energy balance – only very rough estimate
  - HiTRec-II 200-kWth (Hoffschmidt et al., 2003)
  - SolAir 3MWth (Téllez et al., 2004)
  - CFD - verified with HiTRec-II (Marcos et al., 2004)

- Tracer gas
  - Easily detectable gas is added - Helium
  - Concentrations are measured before and after the receiver

\[
\text{ARR} = \frac{c_{\text{after}}}{c_{\text{before}}}
\]
Receiver model in Jülich

Receiver

Hot air

TG Measurement

TG Injection

Receiver

Blower
Receiver model in Jülich

Points of measurement

Helium injection

Mass spectrometer

Data acquisition
Method of measurement – overview

Static measurement

Dynamic measurement
Method of measurement – overview

**Static measurement**

- 2 points of measurement

\[
ARR = \frac{c_{\text{after}}}{c_{\text{before}}}
\]

**Dynamic measurement**
Method of measurement – static measurement

**Initial point of measurement**

- **Method of measurement** – static measurement
- **Helium**

![Graph showing initial point of measurement with coordinates and a color scale for Helium concentration.](image-url)
Method of measurement – static measurement

**Initial point of measurement**

**Final point of measurement**

Method of measurement – static measurement

- **Helium [arb.]**
- **y [cm]**
- **x [cm]**

Initial point of measurement:

- **y [cm]**
- **x [cm]**
- **Helium [arb.]**

Final point of measurement:

- **y [cm]**
- **x [cm]**
- **Helium [arb.]**

Initial point of measurement:

- **y [cm]**
- **x [cm]**
- **Helium [arb.]**

Final point of measurement:

- **y [cm]**
- **x [cm]**
- **Helium [arb.]**

Initial point of measurement:

- **y [cm]**
- **x [cm]**
- **Helium [arb.]**

Final point of measurement:

- **y [cm]**
- **x [cm]**
- **Helium [arb.]**
Method of measurement – static measurement

• Only one point of measurement has a homogeneous tracer distribution
→ Static method can only used for validation purposes
Method of measurement – dynamic measurement

**Static measurement**

2 points of measurement

\[
\text{ARR} = \frac{c_{\text{after}}}{c_{\text{before}}}
\]

**Dynamic measurement**

1 point of measurement

ARR from dynamic response
Method of measurement – dynamic measurement

**Prediction**

![Diagram of the measurement setup with labels for Receiver, TG Measurement, TG Injection, Hot air, and a graph showing normalized He concentration over time. The graph includes a timeline for the time of He injection and a y-axis for Normalised He conc. up to 1.2.](chart)
Method of measurement – dynamic measurement

Prediction

- Normalised He conc.
- Time \([T]\)
- Time of He injection
- Initial conc.
- Initial conc. \(\times\) ARR
- 1 \(\times\) ARR

Method of measurement – dynamic measurement

- Method of measurement – dynamic measurement
- Prediction

- Normalised He conc.
- Time \([T]\)
- Time of He injection
- Initial conc.
- Initial conc. \(\times\) ARR
- 1 \(\times\) ARR

www.DLR.de • Chart 16 > Arne Tiddens > Sollab 2014
Exemplary determination of the air return ratio:

\[ ARR = \frac{x_{He,2}}{x_{He,1}} = \frac{0.5}{1} = 50 \% \]

\[ ARR = \frac{x_{He,2}}{x_{He,1}} \approx \frac{0.44}{1} = 44 \% \]

Prediction has to be fitted in:
- Time
- ARR
Method of measurement – dynamic measurement

Measurement and fit

- Time fit creates unnecessary uncertainty
  - Circulation period from measurement

- Tracer dispersion not taken into account
  - Measurements for signal comprehension

Goal: Perfect fit with ARR as only free parameter

- Reducing injection time→0 leads to δ-function
  - Easy determination of circulation period – peak to peak
  - Analytical signal description possible
Method of measurement – dynamic measurement

\[ c(x, t) = \frac{N_0}{2A\sqrt{\pi D}t} e^{-\frac{x^2}{4Dt}} \]
Method of measurement – dynamic measurement

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Method of measurement – dynamic measurement

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He conc. [arb.]

Distance from injection [arb.]
Method of measurement – dynamic measurement

\[
c(x, t) = \frac{N_0}{2A\sqrt{\pi Dt}} e^{-\frac{x^2}{4Dt}}
\]
Method of measurement – dynamic measurement

Air flow inside the system

He conc. [arb.]

Distance from injection [arb.]
Method of measurement – dynamic measurement

Air flow inside the system

He conc. [arb.]

Distance from injection [arb.]
Method of measurement – dynamic measurement

Air flow inside the system

<table>
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<th>He conc. [arb.]</th>
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Method of measurement – dynamic measurement

Air flow inside the system

He conc. [arb.] vs. Distance from injection [arb.]

-15 -10 -5 0 5 10 15 20 25 30

0 2 4 6 8 10 12 14 16 18 20
Method of measurement – dynamic measurement

Air flow inside the system

Distance from injection [arb.]

He conc. [arb.]

Point of measurement

Predicted measurement

He conc. [arb.]

Time [arb.]
Method of measurement – dynamic measurement

Air flow inside the system

Predicted measurement

Distance from injection [arb.]

Point of measurement

Time [arb.]
Method of measurement – pulsed measurement

Air flow inside the system

Predicted measurement

Distance from injection [arb.]

Point of measurement

He conc. [arb.]

Time [arb.]
Method of measurement – dynamic measurement

Air flow inside the system

Predicted measurement

He conc. [arb.]

Distance from injection [arb.]

Point of measurement

Time [arb.]

He conc. [arb.]
Method of measurement – dynamic measurement

Air flow

He conc. [arb.]

Distance from injection [arb.]
Method of measurement – dynamic measurement

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Air flow

Predicted measurement

Time [arb.]
Method of measurement – dynamic measurement

Air flow

Distance from injection [arb.]

Point of measurement

He conc. [arb.]

Time [arb.]

Predicted measurement

He conc. [arb.]
Method of measurement – dynamic measurement

Distance from injection [arb.]  
Point of measurement

He conc. [arb.]

Air flow

Predicted measurement

He conc. [arb.]

Time [arb.]
Method of measurement – dynamic measurement

Distance from injection [arb.]

Point of measurement

Time [arb.]
Method of measurement – dynamic measurement

predicted measurement

He conc. [arb.]

Time [arb.]
Method of measurement – dynamic measurement

predicted measurement

measurement

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<th>Time [arb.]</th>
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x 10^{-13}

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<th>He conc. [arb.]</th>
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Method of measurement – dynamic measurement
Method of measurement – dynamic measurement

predicted measurement

measurement
Method of measurement – dynamic measurement

work in progress

Method of measurement – dynamic measurement

Method of measurement – dynamic measurement

work in progress
Validation

Internal

Further: 100% ARR rate, He→CO₂

External

Further: CFD
Summary & Outlook

• A measurement technique for the ARR has been developed
• First experimental results match the predictions

• Full signal description has to be developed
• Extensive validation of the measurement technique
• Application of the tracer gas technique at Dish & Solar Tower Jülich
Summary & Outlook

• A measurement technique for the ARR has been developed
• First experimental results match the predictions

• Full signal description has to be developed
• Extensive validation of the measurement technique
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Thank you!
Backup Slides
Method of measurement –

**Static measurement**

2 points of measurement

\[ ARR = \frac{c_{\text{after}}}{c_{\text{before}}} \]

**Dynamic measurement**

1 point of measurement

ARR from dynamic response
Method of measurement –

**Static measurement**

2 points of measurement

\[
\text{ARR} = \frac{c_{\text{after}}}{c_{\text{before}}}
\]

**Dynamic measurement**

1 point of measurement

ARR from curve

**Pulsed measurement**

1 point of measurement

ARR impossible
**Development phases**

<table>
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<th>Testing environment</th>
<th>Small experiment</th>
<th>Dish</th>
<th>Solar Tower</th>
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<table>
<thead>
<tr>
<th>Testing phase</th>
<th>Start small, cold</th>
<th>small, hot</th>
<th>Goal large, hot</th>
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</table>
Method of measurement – pulsed measurement

He conc. [arb.]

Distance from injection [arb.]

He conc. [arb.]

Time [arb.]

Measurement