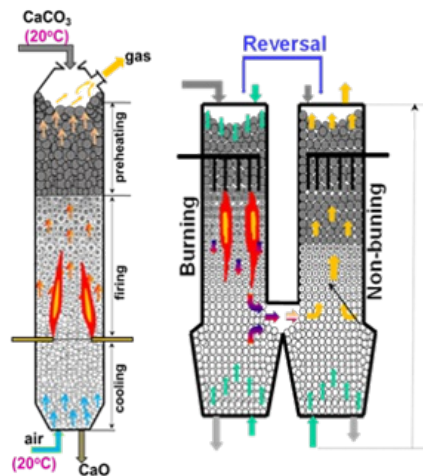


## Simulation of Processes in Shaft Kilns

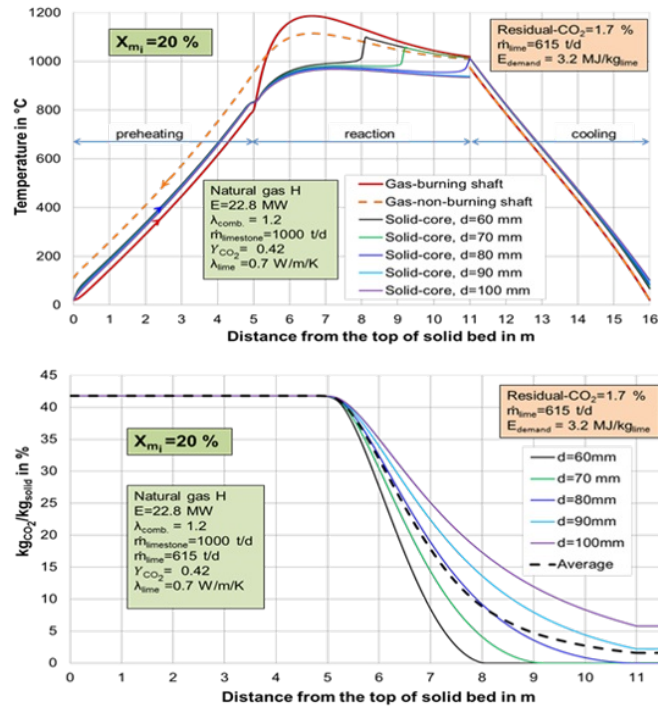


- ▶ Gastemperature
- ▶ Core temperature of five stone fractions
- ▶ Surface temperature of five stone fractions
- ▶ Mean stone temperature
- ▶ Limestone decomposition (residual  $\text{CO}_2$ )
  - mean value
  - individual value of every size fraction

- ▶ Energy consumption
- ▶ Residual  $\text{CO}_2$  content
- ▶ Flue gas temperature
- ▶ Flue gas composition (dry and wet)
- ▶ Discharge stone temperature
- ▶ Pressure drop
- ▶ Wall heat losses.

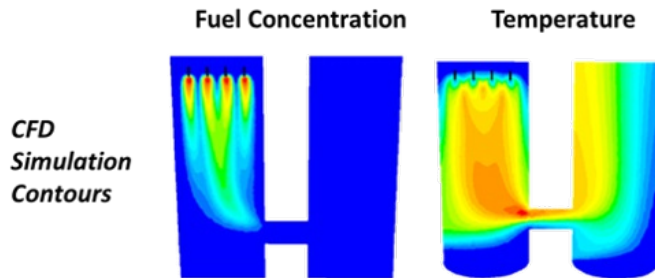
All results are presented using figures and Excel tables.

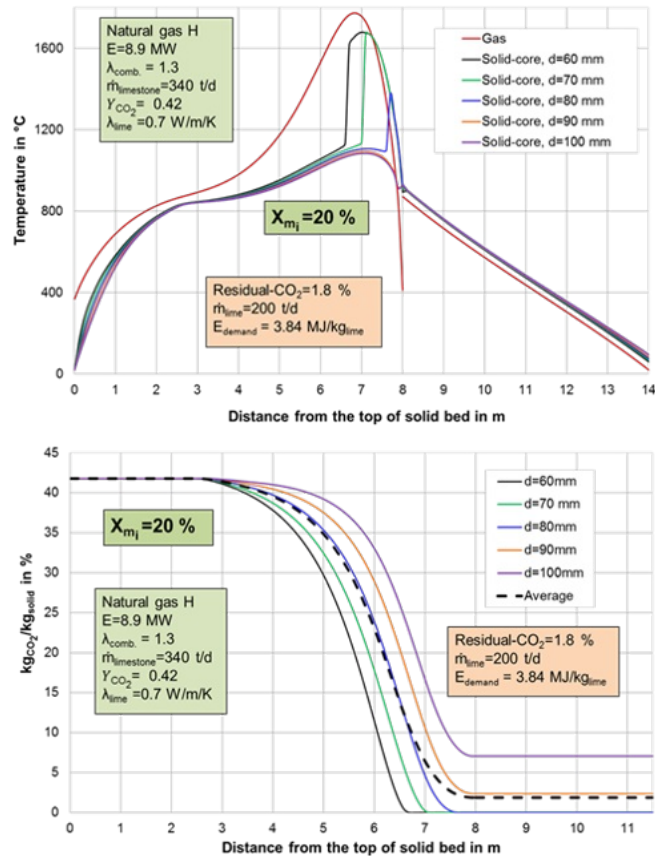
The program can be installed on every laptop.



- ▶ Optimization of the calcination process for energy consumption, quality and regulation by changing
  - Throughput
  - Size distribution of stones
  - kind of fuel
  - kind of limestone
  - kiln geometry
- ▶ Training of technical staff
 

Analogous to an aircraft simulator the kiln can be operated by persons using various conditions. Therewith, the understanding of the process and the influence of the lot of parameters can be trained
- ▶ Reduction of maintenance costs e. g. refractory replacement
- ▶ Interpretation of measured kiln data





### 1. Interface: Kiln Geometry and Environment

- ▶ Length of preheating zone
- ▶ Length of burning zone
- ▶ Length of cooling zone
- ▶ Internal diameter or cross sectional area
- ▶ Working refractory (thickness and conductivity)
- ▶ Insulation refractory (thickness and conductivity)
- ▶ Environment conditions (temperature, wind speed)
- ▶ Insert temperature of cooling air
- ▶ Charging temperature of limestone

### 2. Interface: Process parameter and lime properties

- ▶ Mass flow input of limestone for every shaft
- ▶ Void fraction
- ▶ Mean particle diameter or
- ▶ Particle size distribution up to five classes
- ▶ Material properties of limestone and lime
  - Composition ( $\text{CaCO}_3$ ,  $\text{MgCO}_3$ , inerts, water)
  - Density
  - Decomposition (equilibrium) pressure
  - Thermal conductivity
  - Reaction coefficient

### 3. Interface: Parameters of Fuel

- ▶ Type of fuel (gaseous, liquid, solid)
- ▶ Gaseous fuels:
  - Composition, heating value will be calculated
  - Heating value, if composition is not known
- ▶ Liquid fuels: heating values (typical values are given)
- ▶ Solid fuels: heating values (typical values are given)

### 4. Interface: Combustion Parameters

- ▶ Power of burners
- ▶ Mass or volume flow of fuel
- ▶ Combustion air at top (PFR kilns)

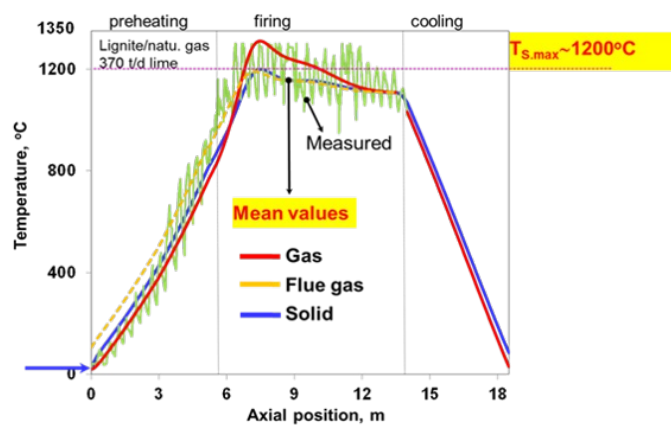
- ▶ Combustion air through lances (PFR- and CFS-kilns)
- ▶ Cooling air burning shaft (PFR kiln)
- ▶ Cooling air regenerative heating shaft (PFR kiln)
- ▶ Cooling air (CFS-kiln)

**Available equipment for measuring material properties and decomposition behavior:**

- Laser Flash Apparatus for thermal conductivity
- Differential Scanning Calorimeter for decomposition pressure
- Thermogravimetry for decomposition behavior of sample cylinders up to 35 mm diameter and 150 mm length in air/CO<sub>2</sub> gas

The program is based on

- ▶ Ten Ph.D. studies at the Institute of Fluid Dynamics and Thermodynamics at Otto von Guericke University Magdeburg
- ▶ Several research projects in cooperation with the German Lime Association funded by the German Ministry for Economic Affairs.
- ▶ It is validated with a lot of measurements in PFR- and CFS-kilns.



Validation of measured and calculated temperature profiles

- ▶ Dr.-Ing. Bassem Hallak: Simulation und Analyse des Kalkbrennens in Normalen-, GGR- und Koksschachtöfen (06.12.2019)
  - ▶ Dr.-Ing. Kamyar Mohammadpour: CFD Simulation of Reactive Flow in Lime Shaft Kilns using Porous Media Model and Experimental Validation (28.11.2019)
  - ▶ Dr.-Ing. Nyein Nyein Linn: Combustion Behaviour of Lumpy Coal Particle under Shaft Kiln Conditions (26.09.2017)
  - ▶ Dr.-Ing. Ali Mohammed Ridha Al-Khalaf: Experimental and Numerical Analysis of Flow Mixing in Packed Beds (20.03.2017)
  - ▶ Dr.-Ing. Purna Chandra Gourisankar Sandaka: Calcination behavior of lumpy limestones from different origins (06.04.2016)
  - ▶ Dr.-Ing. Duc Hai Do: Simulation of Lime Calcinations in Normal Shaft and Parallel-Flow-Regenerative Kilns (25.04.2012)
  - ▶ Dr.-Ing. Magda El-Fakharany: Process Simulation of Lime Calcination in Mixed Feed Shaft Kilns (09.01.2012)
  - ▶ Dr.-Ing. Zhiguo Xu: Reduced Model for Flow Simulation in the Burner Region of Lime Shaft Kilns (19.10.2010)
  - ▶ Dr.-Ing. Thomas Schwermann: Untersuchung des Optimierungspotentials des Ringschachtofens zum Brennen von karbonatischem Gestein (10.04.2007)
  - ▶ Dr.-Ing. Agnieszka Bes: Dynamic Process Simulation of Limestone Calcination in Normal Shaft Kilns (10.04.2006)
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- ▶ Hallak, B.; Specht, E.; Herz, F.; Gröpler, R.; Warnecke, G.: Simulation of lime calcination in Normal Shaft Kilns – Mathematic Model. Int. Journal of Cement Lime Gypsum 9 (2015) 66-71.
- ▶ Hallak, B.; Herz, F.; Specht, E.; Kehse, G.: Energy consumption and CO<sub>2</sub> content in the flue gas of normal shaft kilns: Part 2: Influence of the limestone quality and the process parameter. Cement, Lime, Gypsum 12 (2014) 38-41.
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#### Dynamic Simulation of Heat Treatment Processes

- ▶ Rotary Kilns
- ▶ Shaft Kilns
- ▶ Tunnel Kilns
- ▶ Roller Kilns
- ▶ Combustion Processes
- ▶ Measurement of thermophysical Material Properties
- ▶ Intensive Cooling
- ▶ Drying Processes