

Transient simulation of kiln car with Simu-Therm 8.0

Hilger & Daniel Software GmbH
www.simu-therm.de

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About this tutorial

Simu-Therm 8.0 comes with a new expansion module for kiln cars which simplifies the transient simulation a lot.

This tutorial enables you to perform simulation of a kiln car independently.

You learn the new procedure step by step in two example applications

- 1.) kiln car running through a furnace, starting from cold state
- 2.) kiln car running in cyclic operation through a furnace

Kiln car simulation with Simu-Therm 8.0

In Simu-Therm 8.0 the heat loss of a kiln car is simulated with an expansion treating the kiln car as a plate composed of sections with different heat loss. Each of the sections is represented by a normal heat loss calculation. A transient simulation is performed simultaneously for all sections in which the heat loss and heat content of every section is accumulated according to its share of the kiln car area.

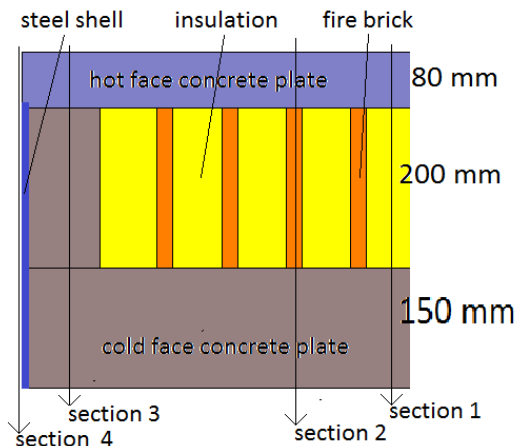
The simulation is based on the approximation that there is no mutual impact of adjacent sections.

The user should be aware that in reality there is an impact in the contact range of adjacent sections which always increases the total heat flow.

Sample kiln car

The sample kiln car for the tutorial is composed of 4 sections with different heat loss.

1. Insulated area
2. Bricks supporting the hot face plate
3. Concrete wall surrounding the car
4. Steel shell in the lower part.



Enter section 1 'Insulated area'

We distinguish four sections of the kiln car as shown in the previous sketch cap

1. we do not need to pay any attention neither to the type of heat transfer nor to the temperatures inside or outside. This is defined in the time schedule of the kiln temperature curve.
2. layers of the first section of the kiln car, 'Insulated area'.

modules file options project expansion extras abc

INS insulated area

thermal condition inside

Type of Heat Transfer Coeff. combustion atmosphere

1000 °C Ti 150 W/m²K input manually

thermal condition outside

Type of Heat Transfer Coeff. ambient air

60 °C Ta 11.54 W/m²K RADIAT

5.0 W/m²K| 0.65 --| >

wall layers from inside to outside

mm	Material	sel
80	Fire Concrete CAST 2500/1600	
200	fiber module 1300-200	
150	Fire Concrete CAST 2800/1600	

Enter section 2 and 3

Enter the sections 2, 3 in the same way as before. Add descriptions in order not to mix up the sections.

1. section 2 'Bricks supporting the hot face plate'

2. section 3 'Concrete wall surrounding the car'

The screenshot shows the Simu-Th software interface with two configuration windows. The top window is for 'BMS' (concrete beams) and the bottom window is for 'SHWL' (shell concrete wall 100 mm). Both windows have a menu bar with 'modules', 'file', 'options', 'project expansion', 'extras', and 'ab'. Below the menu bar, there is a table for 'wall layers from inside to outside' with columns 'mm' and 'Material'. A 'sel' button is located to the right of the table header.

BMS configuration:

mm	Material
80	Fire Concrete CAST 2500/1600
200	FIRECLAY_BRICK (1800)
150	Fire Concrete CAST 2800/1600

SHWL configuration:

mm	Material
80	Fire Concrete CAST 2500/1600
200	Fire Concrete CAST 2800/1600
150	Fire Concrete CAST 2800/1600

Enter section 4 'Steel shell'

Enter the insulation section for the steel shell.

1. above the shell the thickness of the hot face plate is only 70 mm in place of 80 mm (sse the sketch above).
2. corresponding to that, 10 mm is added to the thickness of layer 2

modules file options project expansion extras about

SHELL shell steel 8 mm

wall layers from inside to outside

mm	Material	sel
70	Fire Concrete CAST 2500/1600	
210	STEEL 1.5415	
150	STEEL 1.5415	

Add a project expansion

Switch to the project page. The project should look as shown on the screenshot.

1. enter project information lines
Up to now, our project has no expansion mode. We treat kiln cars as plates and so we add the expansion mode '*sections are part of a plate (1 dimension)*' to our project.

2. click on dropdown menu
project expansion

modules		file	options	project expansion	extras	about
Offer/Order No.	Tutorial 'kiln car simulation'					
Customer						
Project	Sample kiln car					
Location						
Name						

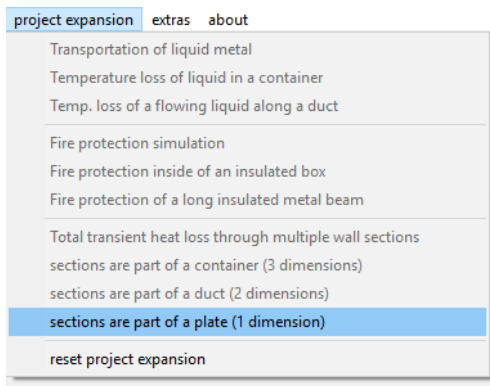
sel	calc.ID	enter description of calculation	press butt edit calcul
<input type="checkbox"/>	INS	insulated area	
<input type="checkbox"/>	BMS	concrete beams	
<input type="checkbox"/>	BMS	shell concrete wall 100 mm	
<input type="checkbox"/>	SHELL	shell steel 8 mm	
<input type="checkbox"/>			
<input type="checkbox"/>			

Project expansion 'Sections are part of a plate'

In the dropdown menu *project expansion* you can choose between several expansions with different features.

1. select '*Sections are part of a plate (1 dimension)*'

This is the expansion to simulate the heat loss and heat absorption of plates which are composed of different sections.



The kiln car simulation page

The kiln car simulation page controls working with the simulation. You can enter areas, select and modify a furnace temperature curve, launch the simulation and printing, view graphical results.

1. enter the inside areas of the insulation sections
2. click on *select a transient temperature schedule* and select the file **KilnCar_temp_curve.STtime**
3. click on *switch to transient page* to view the transient time table

modules file options project expansion extras about

select a transient temperature schedule

3 time intervals, duration 35 h -
max. temperature 1000 °C inside 65 °C outside -
initial wall temp. 20 °C inside 20 °C outside

Heat balance over inside
6165 MJ
-3301 MJ

Heat balance over inside
select a period of time
.0 MJ
.0 MJ

switch to transient page

20 m² total outside surface of all segments

		inside surface
<input type="checkbox"/>	INS insulated area	C 1 14.69 m²
<input type="checkbox"/>	BMS concrete beams	C 2 3.42 m²
<input type="checkbox"/>	BMS shell concrete wall 100 mm	C 3 1.75 m²
<input type="checkbox"/>	SHELL shell steel 8 mm	C 4 0.14 m²
		C 5

The transient page for kiln cars

For details about the transient page see tutorial *Tutorial_transient.pdf*

1. duration of the schedule is 35 hours

The temperature in the kiln raises from 100°C to 1000°C within 15 hours, and is kept at 1000°C for 5 hours. Then the temperature drops back to 100°C

2. click on the button 'initial state' to enter the temperature of the kiln car before it enters the kiln.

assume that the kiln car was for a long time in ambient temperature, e.g. 20°C. Enter this inside for and outside.

3. enter 65°C as the temperature in the space below the kiln car.

The screenshot displays the 'description of the transient time schedule' window in Simu-Th. It shows a table with the following data:

time seq.	duration	ambient temp. inside	ambient temp. outside	heat transfer coefficient inside	heat transfer coefficient outside
-->	-	100 °C	65 °C	150 W/m²K	RADIAT
15	h	1000 °C	65 °C	150 W/m²K	RADIAT
5	h	1000 °C	65 °C	150 W/m²K	RADIAT
15	h	100 °C	65 °C	150 W/m²K	RADIAT

Below the table is a blue bar with '++'. The 'initial temperature' dialog box is open, showing input fields for 'temperature inside' (20) and 'temperature outside' (20), and a button 'set individual initial layer temperatures'. At the bottom are 'Esc' and 'OK' buttons.

Cold face heat transfer for kiln cars xx

For details about the transient page see tutorial *Tutorial_transient.pdf*

1. duration of the schedule is 35 hours

The temperature in the kiln raises from 100°C to 1000°C within 15 hours, and is kept at 1000°C for 5 hours. Then the temperature drops back to 100°C

2. click on the button 'initial state' to enter the temperature of the kiln car before it enters the kiln.

assume that the kiln car was for a long time in ambient temperature, e.g. 20°C. Enter this inside for and outside.

3. enter 65°C as the temperature in the space below the kiln car.

The screenshot displays the Simu-Th software interface. At the top, a menu bar includes 'modules', 'file', 'options', 'project expansion', 'extras', and 'about'. Below the menu is a section titled 'description of the transient time schedule'. It contains a text box with the description 'Kiln car temperature curve over 35 hours, maximum 1000°C'. Below this, it shows 'total duration 35.000 h' and 'absorbed heat'. A table follows, detailing the temperature schedule over time. The table has columns for 'time seq.', 'duration', 'ambient temp. inside', 'ambient temp. outside', 'heat transfer coefficient inside', and 'heat transfer coefficient outside'. The schedule consists of four segments: a ramp up from 100°C to 1000°C over 15 hours, a constant temperature at 1000°C for 5 hours, a constant temperature at 1000°C for 5 hours, and a ramp down from 1000°C to 100°C over 15 hours. The heat transfer coefficient is set to 150 W/m²K for all segments, and the heat transfer mode is 'RADIAT'. Below the table is a blue button labeled '++'. At the bottom of the screenshot is a dialog box titled 'initial temperature' with a close button 'X'. The dialog has a 'manually' section with two input fields: 'temperature inside' set to 20 and 'temperature outside' set to 20. There is a button 'set individual initial layer temperatures' and two buttons at the bottom: 'Esc' and 'OK'.

time seq.	duration	ambient temp. inside	ambient temp. outside	heat transfer coefficient inside	heat transfer coefficient outside
-->	-	100 °C	65 °C	150 W/m²K	RADIAT
15	h	1000 °C	65 °C	150 W/m²K	RADIAT
5	h	1000 °C	65 °C	150 W/m²K	RADIAT
15	h	100 °C	65 °C	150 W/m²K	RADIAT

Simulate a cycle starting with a cold kiln car

If the simulation considers only one operation cycle, the initial kiln car temperature is taken from the temperature schedule (20°C). In this case the button '**calculate new**' is used.

If the temperature schedule considers the complete time up to the beginning of the next operation cycle, the remaining heat content in the kiln car can be taken into account by repeating the simulation of the cycle without resetting the kiln car temperature. Instead, the temperature at the end of the previous cycle is assumed. For this type of simulation the button '**calculate cycle**' is used.

Our current schedule does not consider the time between the exit of the furnace and the next entry into the furnace. So only '**calculate new**' is possible.

1. click on *calculate new* to launch the simulation

total	20 m ²	6165 MJ	-3301 MJ	2337 MJ	12350 W
calculate cycle		time curves		calculate new	

Simulation overview results

On the main page the simulation results of heat absorption and heat release during the simulated time are shown in MJ. Heat is absorbed when the furnace temperature is higher than the hot face surface temperature.

1. Absorption and release of heat at the hot face. Absorption occurs during the first 20 hours.
2. Heat balance cold face. There is a small heat absorption when the car is colder than the space below it.
- 3,4. Hot face heat balance of the sections.
5. Heat content of the kiln car at the end of the simulation.
6. Static heat loss, calculated with the mean temperature 614°C .

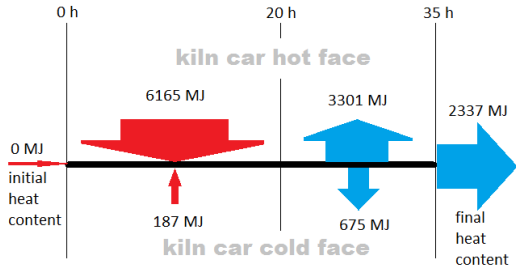
Heat balance over the total simulation time					
inside		outside			
	6165 MJ		186.9 MJ	absorbed heat MJ	
	-3301 MJ		-674.8 MJ	heat release MJ	

	inside surface	absorbed heat	released heat	content heat	static heat loss
1	14.69 m ²	3618 MJ	-2681 MJ	945.8 MJ	2867 W
2	3.42 m ²	1430 MJ	-438.8 MJ	732.5 MJ	4916 W
3	1.75 m ²	969.9 MJ	-175.6 MJ	554.9 MJ	3847 W
4	0.14 m ²	147.8 MJ	-5.139 MJ	103.5 MJ	719.6 W
	20 m ²	6165 MJ	-3301 MJ	2337 MJ	12350 W

Kiln car heat balance

Heat flows per cycle - car enters the furnace in cold state

1. heat content of the kiln car before it enters the furnace.
Zero if a cold car is emulated
2. heat absorbed at the hot face in the heating zone of the furnace.
3. heat release at the hot face.
4. heat release at the cold face.
5. heat content when the car exits the furnace, usually a major portion of the heat loss.



Main results of a selected time interval

The user can determine a time interval for which more information is needed. The same heat balance as for the complete time (see 1) is figured out for that interval. Click on the arrow button (2) to show the results. It is not necessary to repeat the simulation.

3,4. enter the beginning and the end of the time interval to be considered.

5,6. hot face: during the interval almost the whole absorption occurs, but no release of heat.

7,8. cold face: heat absorption merely occurs within the first 20 hours, heat is released mainly in the last 15 hours.

Heat balance over the total simulation time			
inside	outside		
6165 MJ	186.9 MJ	absorbed heat MJ	
-3301 MJ	-674.8 MJ	heat release MJ	

Heat balance over a user defined time period of interest			
select a period of time		from	to
		0	20
inside	outside		
5988 MJ	186.9 MJ	absorbed heatMJ	
.0 MJ	-62.61 MJ	heat releaseMJ	

Time diagrams of simulation results

When the simulation is performed, you can click the button '**time curves**' to view time diagrams of several figures recorded in the simulation.

1. use the arrow buttons to switch between diagrams
2. surface temperatures inside and outside
3. layer temperatures of the segments
4. total heat absorption inside and outside
5. total heat flow inside and outside
6. total heat content of the segments

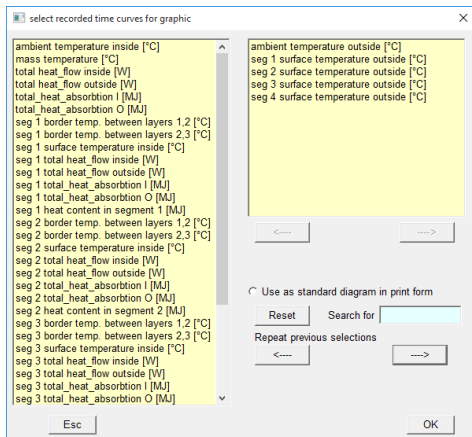


Diagram: Cold face temperatures over time

Cold face temperatures simulated independently for each segment. Due to a thermal exchange in the bottom plate the real temperatures are less different.

1. segment 1
2. segment 2
3. segment 3
4. segment 4

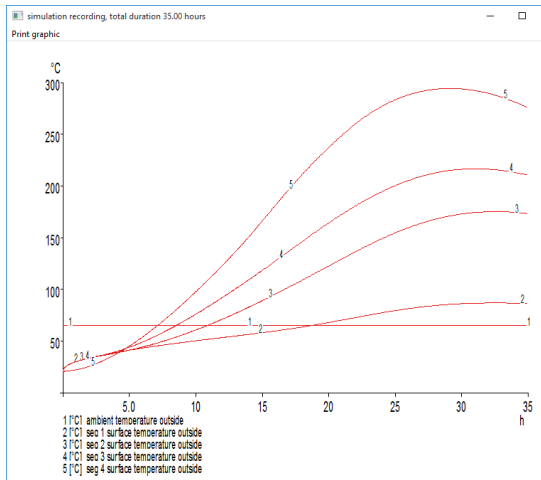


Diagram: Total heat absorption hot face

The total heat absorption on the hot face during the cycle reflects the amount of energy (in MJ) which a car draws out of the furnace. In the cooling phase a portion of that energy flows back into the furnace.

1. segment 1
2. segment 2
3. segment 3
4. segment 4
5. sum of all segments

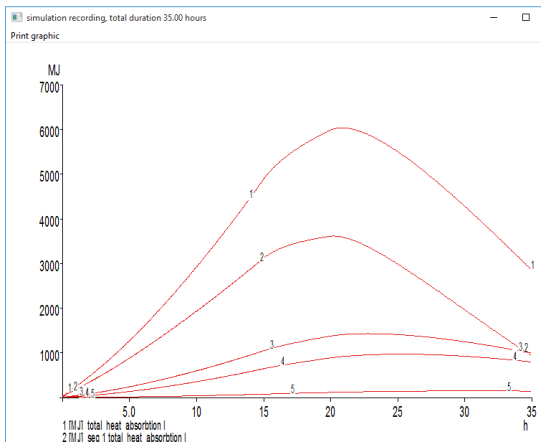


Diagram: Heat flow on the hot face

The heat flow on the hot face is given in Watt (Joule per second). The heat flow in the heating phase is delivered by the furnace burners. It can be used to estimate the additional burner power necessary for the kiln car.

1. segment 1
2. segment 2
3. segment 3
4. segment 4
5. sum of all segments

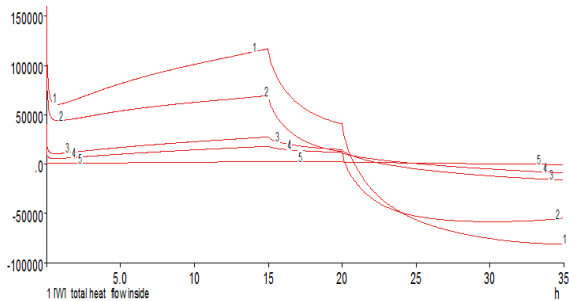
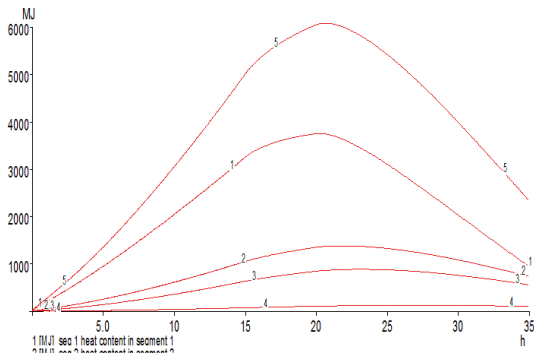


Diagram: Heat content of the kiln car over time

The content of the kiln car in MJ. The initial heat content is zero because the car enters the furnace in cold state.

1. total heat content of the kiln car (sum over all segments)
2. maximum heat content after about 22 hours
3. final heat content when the car exits the furnace.



Simulate a cyclic kiln car operation

1. switch to the transient page and append a 15 hours time period outside the furnace (step 0 h to change conditions and step 15 h at the end of the interval)
2. this time the maximum temperature in the box is 186°C , much better than for an empty box, but still too hot. On the simulation page click once on calculate new and several times on calculate cycle until the results are stable.

modules file options project expansion extras about

description of the transient time schedule

Kiln car temperature curve over 35+15 hours, cyclic operation

total duration 50.000 h absorbed heat

time seq.	duration	ambient temp.		heat transfer coefficient	
		inside	outside	inside	outside
-->	-	100 °C	65 °C	150 W/m²K	RADIAT
15	h	1000 °C	65 °C	150 W/m²K	RADIAT
5	h	1000 °C	65 °C	150 W/m²K	RADIAT
15	h	100 °C	65 °C	150 W/m²K	RADIAT
-->	-	20 °C	20 °C		RADIAT
15	h	20 °C	20 °C		RADIAT

++

Heat balance of the cyclic operation

How has the heat changed in the cyclic operation compared to the first cycle?

1. in order to compare the time in the furnace we consider the first 35 hours as 'time period of interest'.
2. the kiln car absorbs about 450 MJ less from the furnace.
3. the remaining heat exits the car completely on cold side, where the heat loss has increased. The heat content of the car at the furnace entry is the same as it is at the exit.

Heat balance over the total simulation time			
inside	outside		
5717 MJ	6.61e-4 MJ	absorbed heat MJ	
-4072 MJ	-1659 MJ	heat release MJ	

Heat balance over a user defined time period of interest			
select a period of time		from	to
		0	35
inside	outside		
5717 MJ	6.61e-4 MJ	absorbed heatMJ	
-3333 MJ	-905 MJ	heat releaseMJ	

Diagram: Total heat absorption hot face

The total heat absorption of the cyclic simulation is slightly different from the single-cycle simulation above

1. the total heat absorption is a bit lower
2. outside the furnace there is slower drop of heat because the surface is not cooled with fans

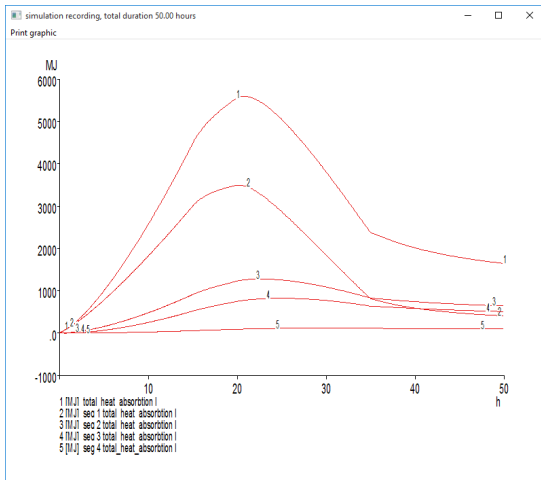


Diagram: Heat content of the kiln car

Again we compare to the single-cycle simulation above.

1. the maximum heat content is a bit higher
2. the initial heat content is the same as the final one (at the of the previous cycle). So the kiln car enters the furnace with a higher heat content than above

