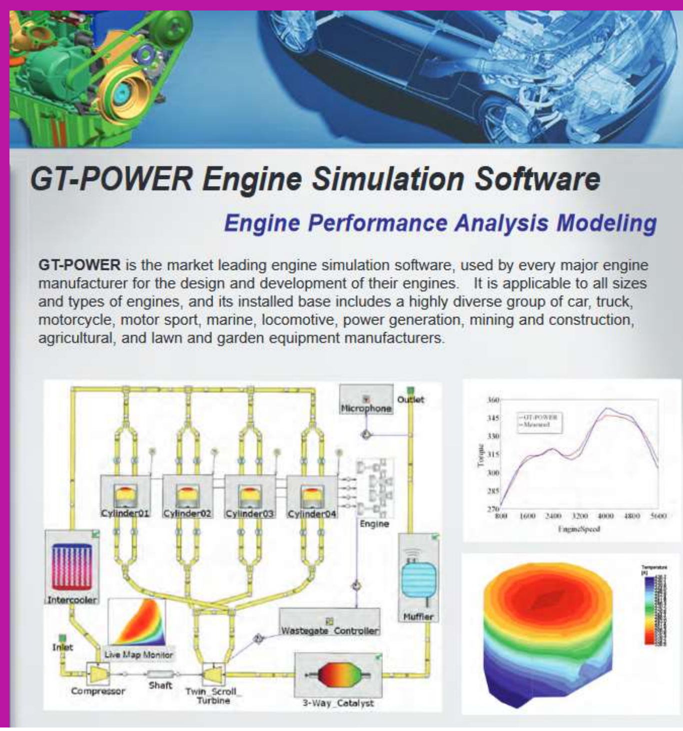
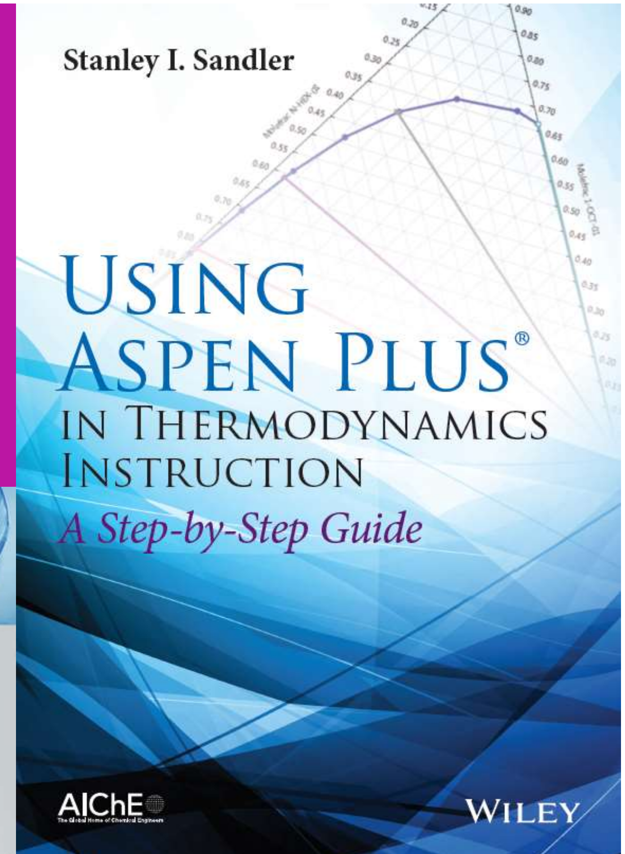
Aalto University
School of Engineering

EEN-E3002 Power Process Simulation





Mika Järvinen

1st March 2023

Welcome to EEN-E3002 Power Process Simulation course ☺

- Eight year, organized since 2016.
- We have ~23 students (21st February 2023).
- Many teachers to have sufficient amount of help for you.
- You need to be active, mostly individual work and group work. Only a few lectures.
- "Learning by doing"

EEN-E3002 Power Process Simulation

- **Organizing unit: Department of Mechanical Engineering, Energy Conversion research group**
- **Teachers: Mika Järvinen, Martti Larmi, Cheng Qiang, Judit Nyàri, Shouzhuang Li**
- **Status of the Course: Energy Technology, Advanced Master's and studies**
- **Teaching Period: IV-V**
- **Good and useful pre-requisites: Basic thermodynamics and basic chemistry, Power process components, Control system basics, Numerical methods**

EEN-E3002 Power Process Simulation

- **Learning Outcomes: Students are able to use simulation software to model and calculate complex power plants processes. Students understand basic simulation concepts and their possibilities and restrictions.**
- **Contents: Different process simulation approaches, developing of a process simulation model, running the simulations with ASPEN PLUS and GT-Power software.**
- **Assessment Methods and Criteria: Learning exercises (50% of the grade), Simulation project (50% of the grade). All parts must be passed at least with the grade 1 which corresponds with c. half of the maximum points.**

Learning exercises

- Learning exercises are individual weekly based exercises including software tutorials and related questions. They can be made in pairs but otherwise copy-pasting is not allowed.
- The period V project is an group work either with ASPEN Plus or GT-Power.
- Proposed projects will include simulating a real process model and making parameter studies with it or building up a new process model and running it successfully.

EEN-E3002 – COURSE REQUIREMENTS & EVALUATION

Instructors: Mika Järvinen (Responsible teacher), Martti Larmi, Judit Nyári, Li Shouzhuang, Zeeshan Ahmad

Status of the Course: M.Sc. and Doctoral studies (level), Energy Technology, Advanced course.

Student Workload:

Learning activity	Hours according to schedule	Total workload (hours)	Remarks
Activated lectures	4×1.5	6	
Additional reading materials		10	Preparing for the lectures
Learning Exercises within exercise session	2×4×1.5	12	6 hours learning exercises and 6 consultation sessions
Learning Exercises self-study		20	5 additional hours per assignment (total 4 assignments)
Project work consultations (contact teaching)	3×1	3	Includes advisor consultation sessions + presentations.
Project work group work		40	Student group work
Presentations	2×1.5	3	Pitch and final presentations
Report writing and presentation		20	
Self-studying and reflection		21	
In total		**135**	5 cr (27 each)

Grade Assessment: The grade for this course will be based on the amount of achieved points. You can achieve a maximum of 100 points and the points will be distributed as follows:

Period IV

1. **Presence in lectures:** There are four lectures scheduled. No points for presence but highly recommended.

2. **Learning exercise:** There are four learning exercises; two for learning to use the Aspen Plus software and two for the GT-power software. You will have one week after each exercise to submit **a solution via MyCourses, the four submissions** will contribute **50% to your grade (12.5 points each)**. An additional consultation session with the instructors is scheduled in the same week the specific learning exercise is given.

Period V

Each student will need to join a group of 3-5 members and perform a simulation project on either Aspen Plus® or GT power software. More instructions on the project tasks will be shared before the end of period IV. The project work grade accounts for **50% of the grade.**

EEN-E3002 - Power Process Simulation, (5 cr) March, 2023
2023 Periods IV and V Version 0.0

Calender Week	Date		Time	Event	Location	Topic	Teacher	Student Deliverables
	25.2.2023	Sat						
	26.2.2023	Sun		Start of period IV				
9	27.2.2023	Mon						
	28.2.2023	Tue						
	1.3.2023	Wed	14-16	Lecture	Online/Pre-recorded	Introduction to Power Process Simulation	Mika Järvinen	
	2.3.2023	Thu	8-10	Lecture	Online/Pre-recorded	Intro to ASPEN+ and flowsheet simulation	Mika Järvinen	
	3.3.2023	Fri						
	4.3.2023	Sat						
	5.3.2023	Sun						
10	6.3.2023	Mon						
	7.3.2023	Tue						
	8.3.2023	Wed	14-16	Learning Ex1	R001/Y338/Online	LE1: Aspen Plus	Mika, Judit, Li	
	9.3.2023	Thu	8-10	Consultation	R001/U257/Online	LE1 support (optional for students)	Mika, Judit, Li	
	10.3.2023	Fri						
	11.3.2023	Sat						
	12.3.2023	Sun						
11	13.3.2023	Mon						
	14.3.2023	Tue						
	15.3.2023	Wed	14-16	Learning Ex2	R001/Y338/Online	LE2: Aspen Plus	Mika, Judit, Li	LE1 deadline 14:00
	16.3.2023	Thu	8-10	Consultation	R001/U257/Online	LE2 support (optional for students)	Mika, Judit, Li	
	17.3.2023	Fri						
	18.3.2023	Sat						
	19.3.2023	Sun						
12	20.3.2023	Mon						
	21.3.2023	Tue						
	22.3.2023	Wed	14-16	Lecture	K1 326	Time dependent power system simulation	Martti Larmi	LE2 deadline 14:00
	23.3.2023	Thu	8-10	Lecture	R001/U257/Online	Using GT-Power	Zeeshan	
	24.3.2023	Fri						
	25.3.2023	Sat						
	26.3.2023	Sun						
13	27.3.2023	Mon						
	28.3.2023	Tue						
	29.3.2023	Wed	14-16	Lecture	R001/Y338/Online	GT Power objects and LE3/LE4a	Zeeshan and Martti	
	30.3.2023	Thu	8-10	Learning Ex3	R001/U257/Online	LE3	Zeeshan	
	31.3.2023	Fri						
	1.4.2023	Sat						
	2.4.2023	Sun						
14	3.4.2023	Mon						
	4.4.2023	Tue						
	5.4.2023	Wed	14-16	Lecture	R001/Y338/Online	1D flow mathematics and LE4b	Martti	LE3 deadline 14:00
	6.4.2023	Thu	8-10	Learning Ex4	R001/U257/Online	LE4a and LE4b	Zeeshan	
	7.4.2023	Fri				Period V project instructions on MyCourses		

	8.4.2023	Sat					
	9.4.2023	Sun		**Evaluation week of period IV**			
15	10.4.2023	Mon					
	11.4.2023	Tue					
	12.4.2023	**Wed**					**LE4 deadline 14:00**
	13.4.2023	**Thu**				Project Group registeration on Mycourses	Registration deadline 23:55
	14.4.2023	**Fri**				**Easter**	
	15.4.2023	**Sat**		End of period IV			
	16.4.2023	**Sun**		Start of period V			
16	17.4.2023	Mon				**Easter**	
	18.4.2023	Tue					
	19.4.2023	**Wed**	14-16		R001/U257/Online	First (Pitch) Project Presentation	First Pres. submission deadline 14:00
	20.4.2023	Thu					
	21.4.2023	**Fri**					Project research plan deadline 16:00
	22.4.2023	Sat					
	23.4.2023	Sun					
17	24.4.2023	Mon					
	25.4.2023	Tue					
	26.4.2023	**Wed**	14-16		R001/U257/Online	Project work (scheduled session)	
	27.4.2023	Thu					
	28.4.2023	Fri					
	29.4.2023	Sat					
	30.4.2023	Sun				**Vappu**	
18	1.5.2023	Mon					
	2.5.2023	Tue					
	3.5.2023	**Wed**	14-16		R001/U257/Online	Project work (scheduled session)	
	4.5.2023	Thu					
	5.5.2023	Fri					
	6.5.2023	Sat					
	7.5.2023	Sun					
19	8.5.2023	Mon					
	9.5.2023	Tue					
	10.5.2023	**Wed**	14-16		R001/U257/Online	Project work (scheduled session)	
	11.5.2023	Thu					
	12.5.2023	Fri					
	13.5.2023	Sat					
	14.5.2023	Sun					
20	15.5.2023	Mon					
	16.5.2023	Tue					
	17.5.2023	**Wed**	14-16		R001/luentosali/Online	Concluding lecture/Presentations	Final presentation submission deadline 14:00
	18.5.2023	Thu					
	19.5.2023	Fri					
	20.5.2023	Sat					
	21.5.2023	Sun					
21	22.5.2023	Mon					
	23.5.2023	Tue					
	24.5.2023	**Wed**	14-16		K1 326	No session, only submission	Final Report and simulation submission deadline 2
	25.5.2023	**Thu**				**Helatorstai**	
	26.5.2023	Fri					
	27.5.2023	Sat					
	28.5.2023	Sun		**Evaluation week of period V**			
22	29.5.2023	Mon					
	30.5.2023	Tue					
	31.5.2023	Wed					
	1.6.2023	Thu					
	2.6.2023	Fri					
	3.6.2023	Sat		**End of period V**			

	26.5.2021	Thu		Helatorstai
	27.5.2021	Fri		
	28.5.2021	Sat		
	29.5.2021	Sun	Evaluation week of period V	
22	30.5.2021	Mon		
	31.5.2021	Tue		
	1.6.2021	Wed		
	2.6.2021	Thu		
	3.6.2021	Fri		
	4.6.2021	Sat	End of period V	

EEN-E3002 – PERIOD V PROJECT WORK PLAN AND SCHEDULE

Will be updated soon!!!!

AspenPlus or GTPower or Matlab will be used as modelling tools for an energy production related case study in Period V. The use of any other complementary computational tools and process modellers is possible after consulting with the project instructor.

The project grading (50 points) includes 5 points for the pitch presentations (week 16), 5 points for the research plan (week 16), 10 points for the final presentation (week 20), 20 points for the report (week 21) and 10 points on submitted simulation files (week 21).

All project activities are expected to be performed remotely, without any specific need to access facilities on campus. Students should make use of platforms such as Zoom and Microsoft Teams to organize their meetings. The use of Virtual Desktop (vdi.aalto.fi) to access Aalto workstations and software is necessary for some of the work so please familiarize yourself with the available tools beforehand.

The **choice of group members** is left entirely for the students themselves. The students must form **groups between 3 (min) to 5 (max) members** for the assignment (project). All group members are required to **enrol via MyCourses by 14th April 23:55**. The only recommendation is to utilize the diverse study backgrounds available in the course to put your group in the best position to address the multidisciplinary nature of some of the modelling tasks.

Keep in mind that you will not have access to submission portals if you are not enrolled in one of the groups. All submissions are done as group submissions on MyCourses.

The **list of topics and data for the case studies** will be shared before the last LEs.

Working schedule:

Week 15: Thursday 14.4.2022 (No session)

The deadline is set at **23:55 for the groups to enrol** their members. Enrol to one of the groups based on the project description using the specified software (Aspen Plus or GT Power).

At this point, each group **will be assigned a project instructor** that will be an extension of the team and would assist and guide the project work throughout the process.

Week 16: Wednesday 20.4.2022, Microsoft Teams or Zoom, 14:15-15:45

The groups perform a 5-10-minute pitch each where they present the content of their research plan including the case study, modelling approach and working plan.

This is followed by 5-10-minute feedback and discussion with the instructor.

*This session will be **recorded** for all groups and shared later in MyCourses for other groups to exchange ideas and share the learning experience*.

The project instructor will be responsible to setup, share the invite link and run the session.

The group should have a presentation plan in place where one member or more are in control of the presentation slides. All group members are expected (even within the short time given) to participate in presenting the material.

Week 16: Friday, 22.4.2022, Submission of research plan

Submit a project research plan report file in MyCourses. The project research plan (2-3 pages only) is based on the pitch presentation and the feedback, and it includes:

1. The group members' names and project title.
2. A brief description of the modelling case study selected.
3. A block diagram showing main conversion steps and units modelled, the specified boundary conditions and the main assumptions in the case study.

A brief description on the working plan and a Gantt chart describing the timetable and distribution of tasks among the group members.

Week 17, 18 and 19: Consultation sessions with project advisors

Groups should schedule a **minimum of one-hour consultation** session in each of the three working weeks with their project instructor to assist in any simulation troubleshooting or to address other questions related to their project.

Additional sessions and other possible communications (via emails etc.) are possible and would be arranged with the instructor.

Week 20: Wednesday, 18.05.2022, Group Presentations

Each group should also upload the presentation material via MyCourses portal before 14:00 o'clock the day of presentations.

Each group will present their project work in a 15 minutes presentation attended by all groups **on Microsoft Teams or Zoom Wednesday 18.05.2022, 14:15-15:45**. Each presentation is followed by a 5-10-minute Q&A session.

Week 21: Final Submissions

Each group **submits all simulation files and report to be graded by Wednesday 25.05.2022, 23:55**.

Study Material

- **Lectures and lecture slides**
- **ASPEN Plus and GT-Power on-line material**
- **Google “Using aspen plus in thermodynamics”, get the pdf-book**
- **Further material adviced during lectures**
- **Flynn, Damian: Thermal Power Plant Simulation and Control. Institution of Engineering and Technology, 2003. ISBN 978-0-85296-419-4, KNOVEL Electronic ISBN 978-1-60119-137-3**
- **Gunnar Stiesch: ”Modeling Engine Spray and Combustion Processes” Chapters 1 to 3, pages 1-100. Springer.**
- **Merker, Schwarz, Otto: “Verbrennungmotoren, Simulation der Verbrennung and Schadstoffbildung, Chapters 1-8, pages 1-300.**

Introduction

"Process simulation is a model-based representation of chemical, physical, biological, and other technical processes and unit operations in software"

Process model classifications

1. **Flowsheet program: quasi steady processes = stabilized conditions. Algebraic equations describing interaction between components.**
2. **Dynamic program with *single* control volume approach: system behavior is simulated with respect to time. Ordinary differential equations and numerical integration.**
3. **Dynamic program with real 1-3 dimensional dynamic approach: system behavior is simulated with respect to time. Partial differential equations and sophisticated numerical integration routines are needed.**

Process components

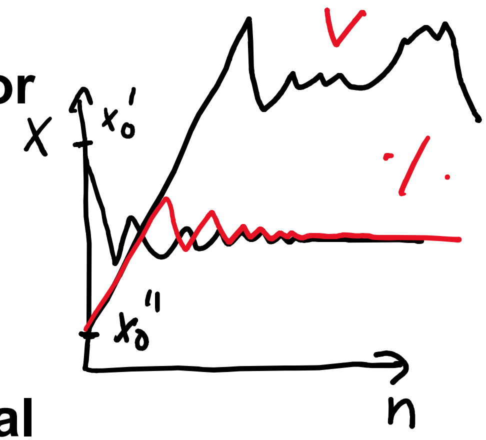
- Component models: control volumes, pumps, valves, pipes, flow restrictions, heat exchangers, evaporators, condensers, combustors, furnaces, combustion chambers, compressors, turbines.
- Properties of the process media, very important to have correctly defined
- Ideal gas law or more sophisticated equation of state.
- Mass, species, heat and momentum balances

Some general rules

- Model should imitate reality, is it able to catch most important system characteristics?
- Do not leave the problem under-defined, number of unknowns = number of equations! Else it becomes an optimization problem.
- Do not over-define, this has no solution in steady state, number of unknowns = number of equations!
- Test some physical limits, mass fractions 0-1, temperature > 0 K

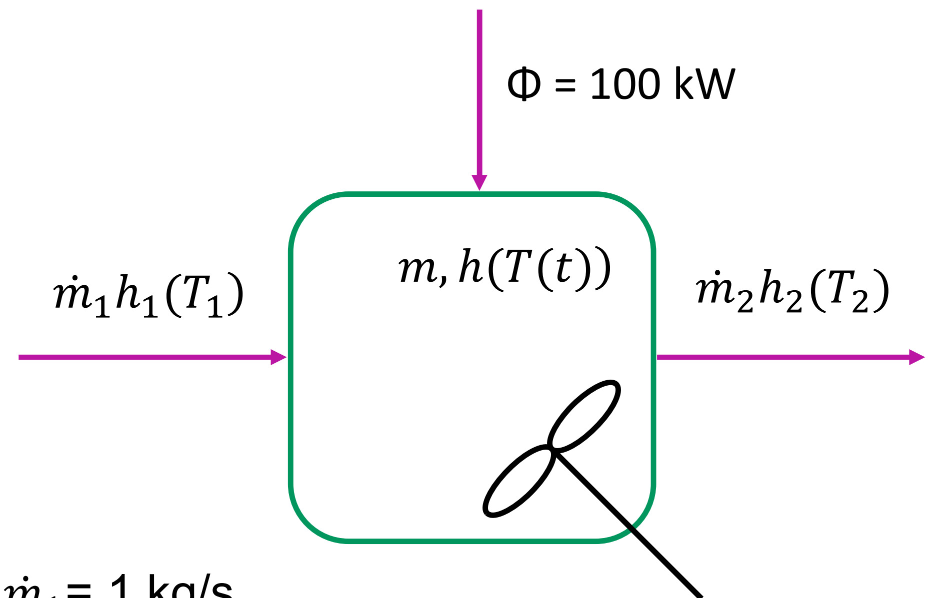
Some general rules

- Model should not have too many free, unknown parameters, do not make the model too complex or detailed.
- Can the model be measured or validated by experiments? One option is to fit the model to experiments, using 1-2 free variables as fitting parameters. Fitting physical properties or chemical kinetics.
- Check convergence, also same result from different initial guess values!



No not try to fit or force model to something it just do not fit ☺

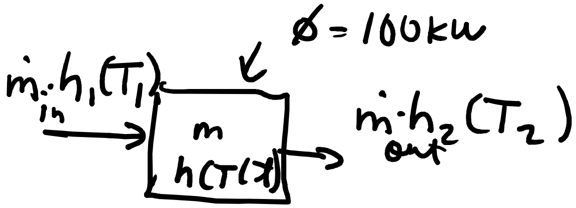
Example 1.



$\dot{m}_1$ = 1 kg/s
T_1 = 25 C

- CSTR (**C**ontinuously Stirred **T**ank **R**eactor) 1 m^3 filled with water
- Perfect mixing.
- No accumulation of mass. $\frac{dm}{dt} = 0$
- No reactions or phase change.
- c_p = 4200 J/kgK

1) Analyse steady state
   a) Φ = 100 kW fixed
   b) T_2 = 100 C fixed
2) Analyse transient case.
T(t=0) = 100 C, Φ = 100 kW



Mass balance

$$\dot{m}_{in} - \dot{m}_{out} = 0$$

$$\dot{m}_{in} = \dot{m}_{out} = \dot{m}$$

$$\frac{dm}{dt} = 0$$

Energy balance

$$\dot{m} h_1(T_1) - \dot{m} h_2(T_2) + \phi = \frac{d(mh)}{dt} = m \frac{dh}{dt}$$

Enthalpy

$$h = h_0 + \int_{T_0}^{T} c_p \, dT$$

$$= h_0 + \Big|_{T_0}^{T} c_p T$$

$$= h_0 + c_p (T - T_0)$$

No reaction, no phase change → drop h_0, $T_0 = 0\,°C$

$$h = c_p \cdot T$$

$$dh = c_p \, dT$$

$$\rightarrow \dot{m} c_p T_1 - \dot{m} c_p T_2 + \phi = m c_p \frac{dT}{dt} \leftarrow T$$

CSTR $\rightarrow$ $T_2 = T$

$$\dot{m} c_p T_1 - \dot{m} c_p T(t) + \phi = m c_p \frac{dT}{dt}$$

1a) Steady state @ 100kW

$$\rightarrow \frac{d(\,)}{dt} = 0$$

$$\dot{m} c_p T_1 - \dot{m} c_p T + \phi = 0$$

$$T = \frac{\dot{m} c_p T_1 + \phi}{\dot{m} c_p}$$

$$T = 25°C + \frac{100\,000\,W}{1\,\frac{kg}{s} \cdot 4200\,\frac{J}{kg\,K}}$$

$$= 48.8°C$$

1b) $T_2 = T = 100°C \rightarrow \phi = \text{free}$

$$\phi = \dot{m} c_p (T - T_1) = 1 \frac{kg}{s} \cdot 4200 \frac{J}{kgK} \cdot (100°C - 25°C)$$

$$= \underline{\underline{315 \text{ kW}}}$$

2. Transient case

$$\frac{dT}{dt} \neq 0$$

$$\underbrace{\dot{m} c_p T_1 + \phi}_{= a} - \underbrace{\dot{m} c_p}_{= b} T = \underbrace{m c_p}_{= d} \frac{dT}{dt}$$

$$a - bT = \underline{d} \cdot \frac{dT}{dt} \qquad \int_{T_0}^{T(t)} \frac{dT}{a - bT} = \int_0^t \frac{dt}{d}$$

$$-\frac{1}{b}\ln\left(\frac{a-bT}{a-bT_0}\right) = \frac{t}{d} \rightarrow \boxed{\frac{a-bT}{a-bT_0} = \exp\left(-\frac{bt}{d}\right)}$$

$$\frac{b}{d} = \frac{\dot{m}\cdot c_p}{m\cdot c_p} = \frac{\dot{m}}{m} = \frac{\dot{m}}{\dot{m}\cdot\tau} = \frac{1}{\tau} \qquad = \exp\left(-\frac{t}{\tau}\right)$$

$$a - b\cdot T = (a - bT_0)\cdot\exp(-t/\tau)$$

$$T = \frac{a}{b} - \left(\frac{a}{b} - T_0\right)\cdot\exp(-t/\tau)$$

$$= \frac{\dot{m}c_pT_1 + \phi}{\dot{m}c_p} - \left(\frac{\dot{m}c_pT_1 + \phi}{\dot{m}c_p} - T_0\right)\cdot\exp(-t/\tau)$$

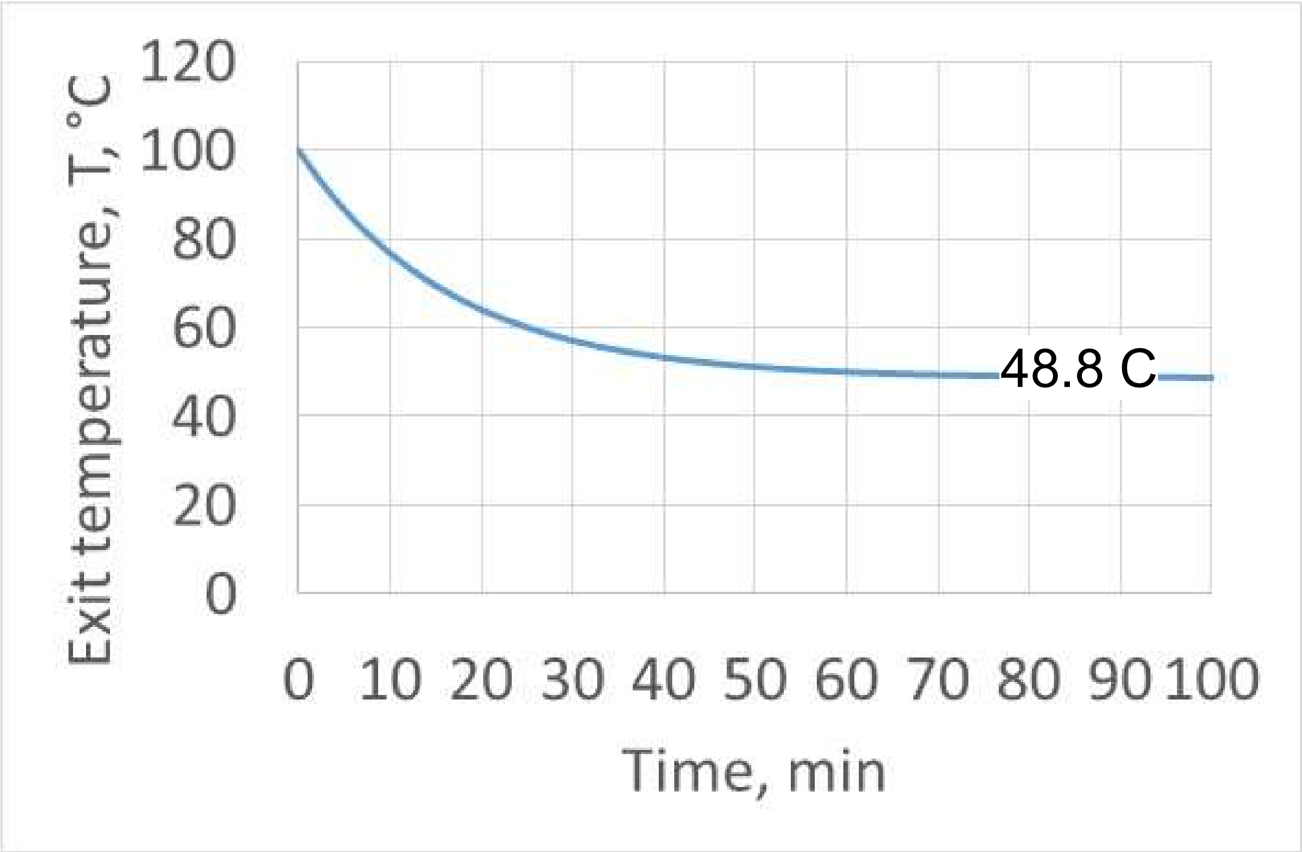
$$T(t) = \left(T_1 + \frac{\phi}{c_p \dot{m}}\right)\left(1 - \exp\left(-\frac{t}{\tau}\right)\right) + T_0 \cdot \exp\left(-\frac{t}{\tau}\right)$$

$T_1 = 100\,°C$

$\phi = 100\,000\ W$

$\dot{m} = 1\ kg/s$

$m = 1000\ kg$



120
100
80
60
40
20
0
Exit temperature, T, °C
0
10
20
30
40
50
60
70
80
90
100
Time, min
48.8 C

More software

MATLAB Thermolib toolbox:
https://se.mathworks.com/products/connections/product_detail/product_35808.html

APROS: http://www.apros.fi/en/