Forecast of recoverable Thermal Energy during the Extrusion of Thermoplastic Pipes

Contribution to the ESCC 2017

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June 13th, 2017

Hof University of Applied Sciences, Germany

Hochschule Hof – Prof. Dr.-Ing. Herbert Reichel

Hof - University of Applied Sciences

- Founded 1994
- 3 Faculties
  - Engineering
  - Computer Science
  - Business and Commerce
- 21 Bachelor and 8 Master Programs
- around 3700 students

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ifm – institute for material sciences

- one of the 3 research institutes of the university (ifm, iisys, iwe)
- comprises research activites within the area of materials and manufacturing
- guided by vice president Prof. Ficker
- about 30 researchers

ifm – institute for material sciences

is a provider of innovation for companies, which look for specific support on new developements, ranging from basic scientific efforts to product design.

The ifm can provide:

- engineering,
- an interdisziplinary workforce from fundamental sciences to specific topics in manufacturing and materials.
- a highly specialised research team „Innovative Textiles“,
- support when writing research funding applications.

Research project Efftrusion

- A part of the greater research program „Green Factory Bavaria“ (abbr. GFB)
- Funded by the Free State of Bavaria, which is a federal state within the Federal Republic of Germany
- The coordination of GFB ist done by the University of Erlangen-Nuremberg, especially by Prof. Franke and his team

- Industrial partners within the research project Efftrusion are small / medium sized companies:
  - Hans Weber Maschinenfabrik GmbH, Kronach
  - H.N. Zapf GmbH & Co. KG, Hof

Research Partners

- Hans Weber Maschinenfabrik GmbH:
  - extrusion machinery manufacturer
  - staff of about 300 employees
  - main products: single- and twin screw extruders

- H.N. Zapf GmbH & Co. KG:
  - manufacturer of thermoplastic pipes and profils(z.B. PE, PP und PS)
  - staff around 50 people
  - main products: high precision tubes (Ø from 10 mm to 250 mm; wall thickness from 1 mm to 20 mm)

State of the art when recovering thermal energy out of the cooling of pipes

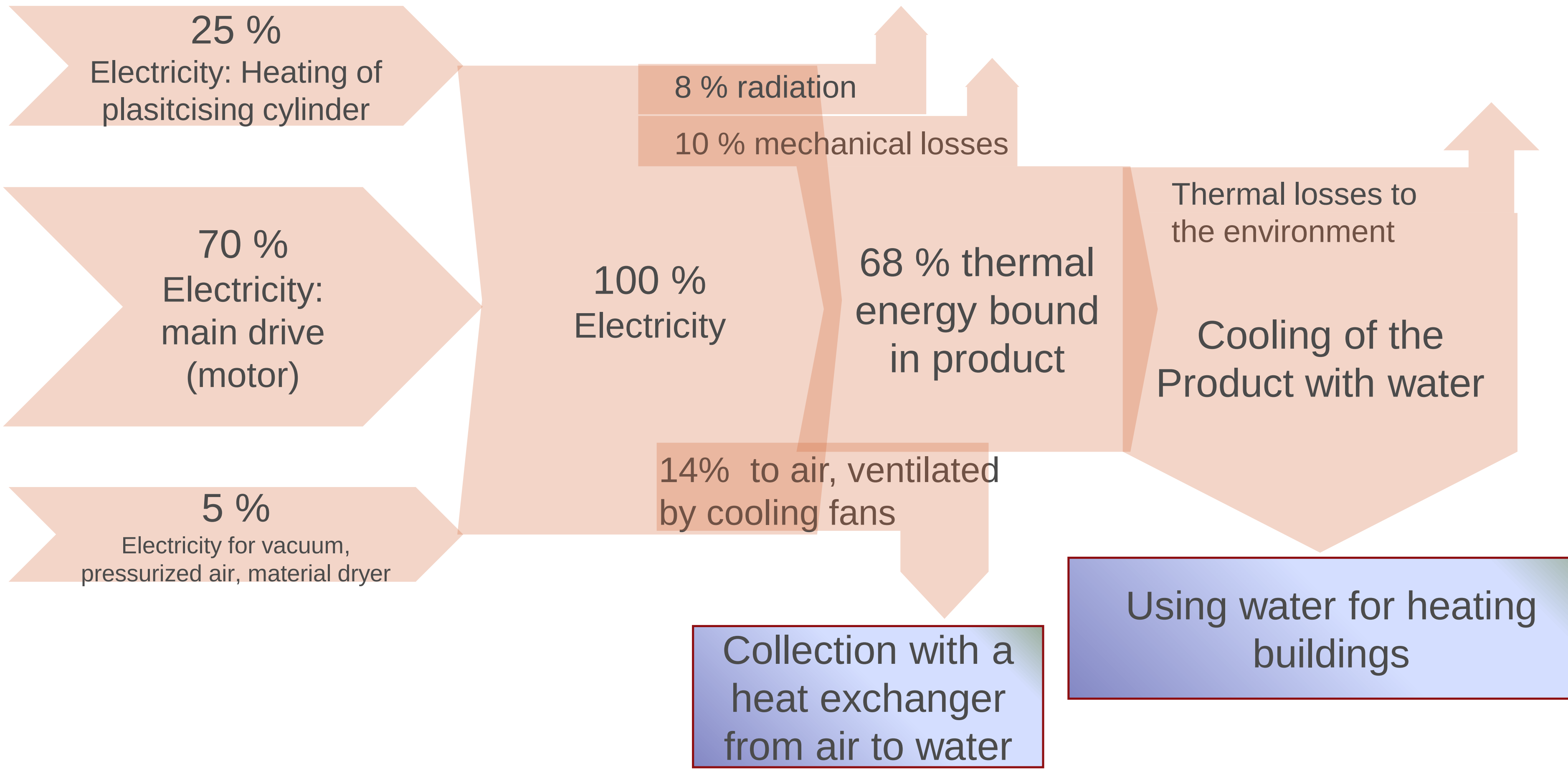
Using the thermal energy to

- convert this energy with Stirling Machines to get mechanical energy (Patents DE 102007039799 B3 / 2007 und DE102008047210B4 / 2008
- run thermal cooling units (Patents 102010030621 A1 / 2010)
- preheat thermoplastic pellets just before the extruder (SHS plus GmbH „INGENIO Granulatvorwärmung)

But up to now the possibilites are rarely used, because

- the amount of recoverable thermal depends on the manufactured product – no investigations are available, which allow an estimation for a new product
- if someone collects thermal energy, there must be a solution to use this energy
- one problem is, that there is time a shift between the recovery of thermal energy and the possibility to use this energy
- to solve this problem, a company has to provide technical equipment, this means to spend money before
- but a company will only spend money if there is a way to calculate the return on investment before

Energy flow in an extrusion line



Investigations during the reasearch project Effitrusion

- Monitoring the energy consumption of all components in extrusion line
- Monitoring the thermal state of cooling water and air
- Monitoring the surface temperature of the extruded pipe along the extrusion line
- Theoretical approach to the cooling of pipes in the extrusion line
- Developing a program to simulate the cooling of pipes and to calculate the recoverable energy amout
- Validating the simulation programm against the monitoring results

Monitoring: energy balance of components

- Extrusion line components

component 1	*component 2*	*component 3*
Extruder →	**Vacuum Calibrator** (**chamber 1**, **chamber 2**) →	**spray cooling bath 1** → **spray cooling bath 2**
Energy consumers		
- Main drive - cylinder heating - Tools heating - Melt pump (i.appl.)	- 2 vacuum pumps - 2 water spray pumps	- 2 water spray pumps
where to collect thermal energy		
- after cooling fans - water from nut bush cooling	- Recirculation of warm water to factory‘s water supply	- Recirculation of warm water to factory‘s water supply

Example of energy monitoring: electric power demand

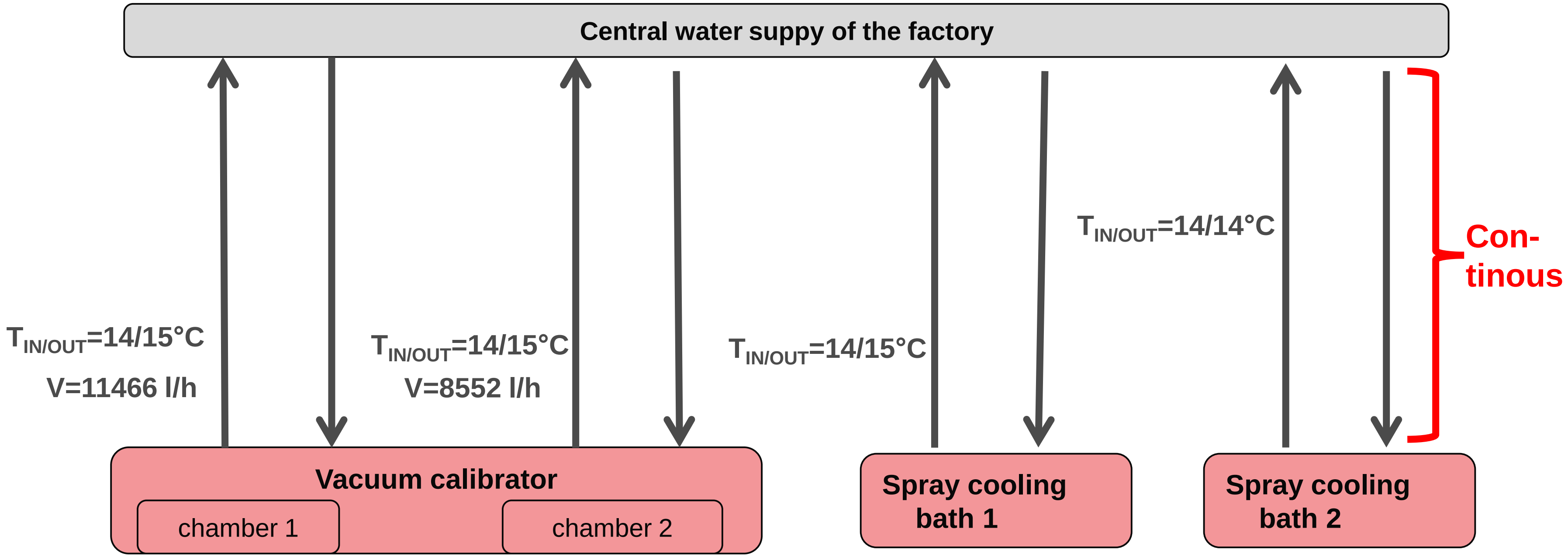
Komponenten	tube diam.:152,5 mm/169 mm		Tube diam. : 76,3 mm/92 mm	
	v=0,7 m/min	v=0,8 m/min	v=1,0 m/min	v=1,3 m/min
Main drive [kW]	43,5	47,8	31,2	34,6
Melt pump [kW]	2,3	3,6	2,1	2,8
Cylinder heating [kW]	0,9	4,7	5,6	6,7
Tools heating [kW]	2,8	3,8	3,8	4,5
2 vacuum pumps [kW]	1,4	1,4	1,4	1,4
2 water spray pumps [kW]	16	16	16	16
Specific power demand [kWh/kg]	**0,28**	**0,30**	**0,38**	**0,33**
Total demand [kW]	**66,9**	**77,3**	**60,1**	**66,0**

Monitoring of water temperature and bound thermal power

	extrusion output 169,7 kg/h; velocity v_A= 0,75 m/min				
	Input T [°C]	recirculation T [°C]	delta T [°C]	volume flow [l/h]	thermal power P [kW]
Vacuum calibrator chamber 1	21,1	26,4	5,3	2854	17,5
Vacuum calibrator chamber 2	21,1	39,4	18,3	392	8,3
Spray cooling bath 1	22,7	39,7	17,0	245	4,8
Spray cooling bath 2	22,5	25,0	2,5	2552	7,3
∑ total					37,9

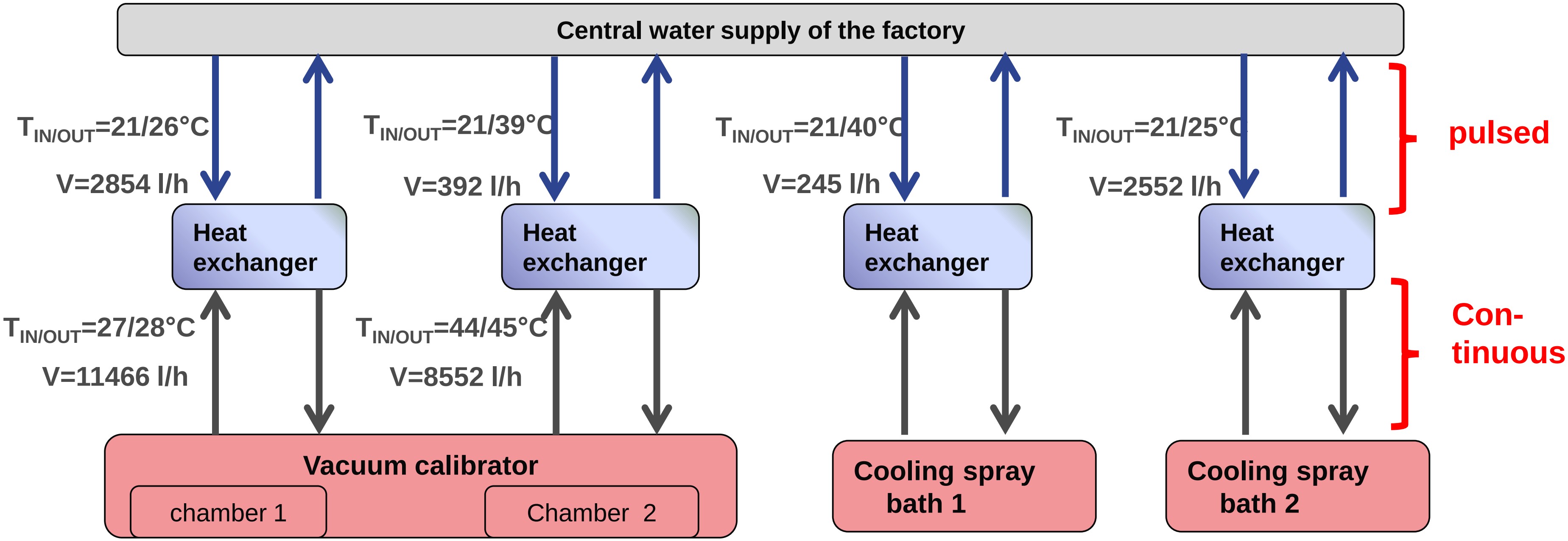
Power input: 0,3 kWh/kg * 169,7 kg/h = 51 kW
This proves that the cooling water collects about 75% of the power input

Water flow in extrusion downstrem of an old fashioned line



- old fashioned lines use cool water direct on the product
- The product surface becomes rapidly cold, but because plastics have a low thermal conductivity, the effect trough the wall thickness is very limited
- The raise of water temperature is small – no way to reach a temperature which is high enough to be used in a recuperation
- A lot of energy is needed to pump a high water flow through the factory

Water flow in extrusion downstrem of a modern state line
Result of monitoring temperatures and volume flows



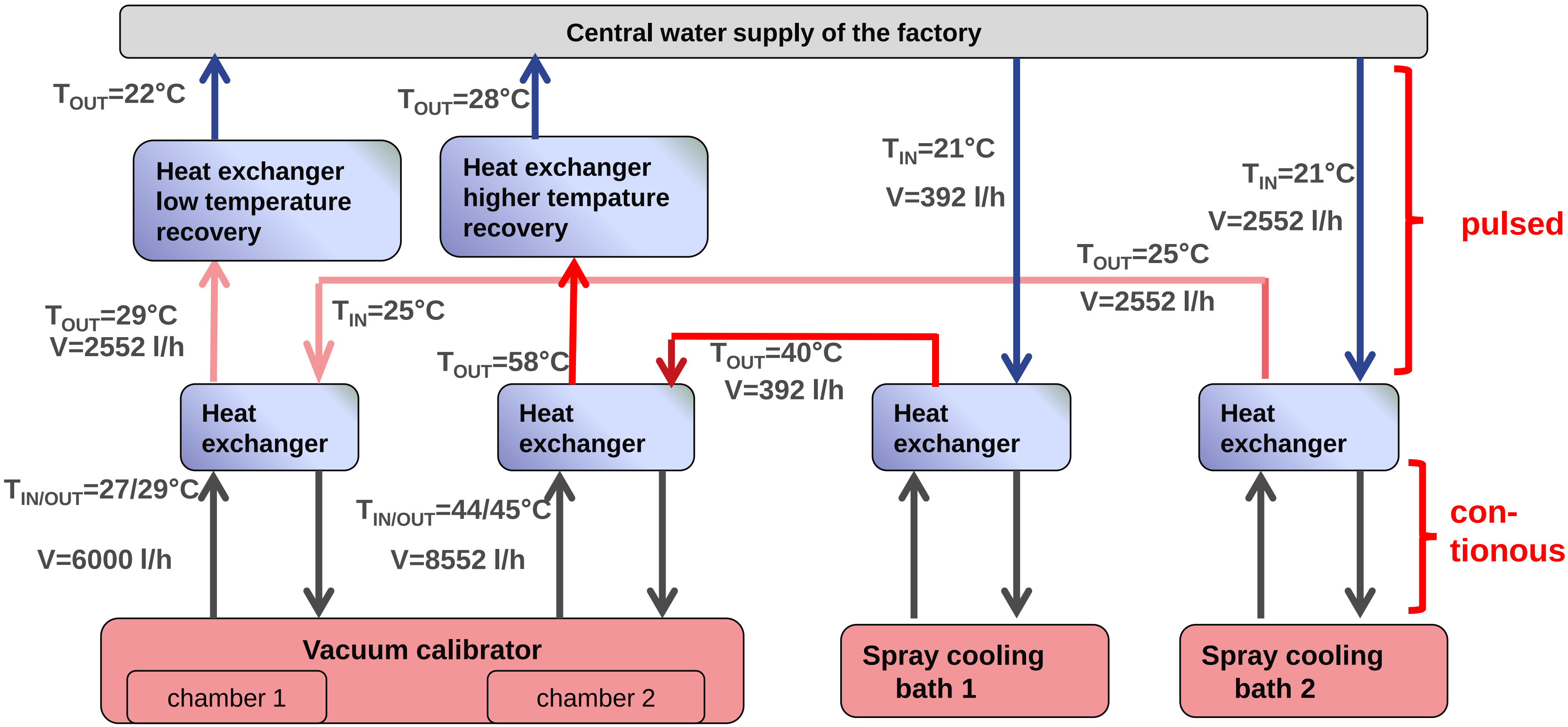
- Two temperature levels (25 to 26°C and 39 to 40°C) recirculate
  → vacuum calibrator chamber 1 & spray cooling bath 2 at about 25°C
  → vacuum calibrator chamber 2 & spray cooling bath 1 at about 39°C
- Volume flow is approximately the same
  (2600-2900 l/h) // (250-400 l/h)

Proposal for an improvement of energy efficiency by changing water flow

component	water input [°C]	Recirculation [°C]	temperature-difference [°C]	Volume flow [l/h]	thermal power [kW]
Vacuum calibrator chamber 1	21,1	26,4	5,3	1994(-860)	12,3(-5,3)
Vacuum calibrator chamber 2	26,4(+5,3)	39,4	13	550(+157)	11,7(+3,4)
Spray cooling bath 1	26,4(+5,3)	39,7	13,3	311(+66)	6,7(+1,9)
Spray cooling bath 2	22,5	25	2,5	2552	7,4

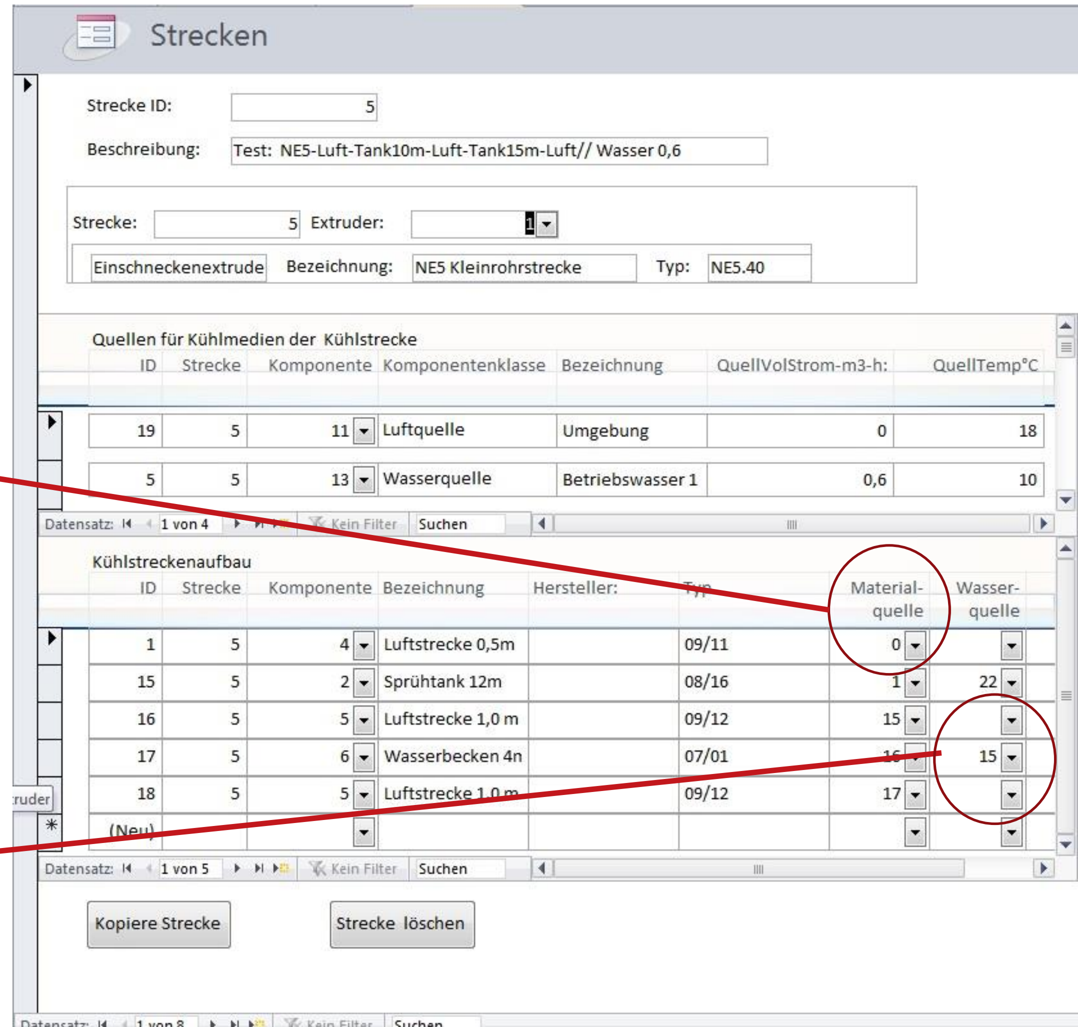
To reuse thermal energy, a higher temperature is preferable. This can be achieved by arranging the water flow in a cascade.

Proposal of an improved water flow in extrusion downstrem of a modern state line



Definition of material stream and water flow within the simulation software

- the material stream ist defined by a material source for each component. Source no. 0 ist reserved for the extruder
- The water flow is defined by giving a water source to each component



Method of calculation

- The cooling of the tube wall is calculated by a method of Finite Differences.
- The material (the tube) is regarded as quasi-static (no change of state at certain location down the line, although the material moves in reality)
- The material is divided down the line into sections. One bit of material needs a certain time to move from on section to the next.
- The wall thickness is sliced into ten layers of similar thickness
- The thermal conduction within the plastic is calculated between the layers (radial direction), for each section down the line.
- Boundary conditions:
  - when cooling with water, the surface temperature is fixed by the water temperature
  - When moving in free air, the heat transfer coefficient defines the temperature change

Results of calculation

Cooling water

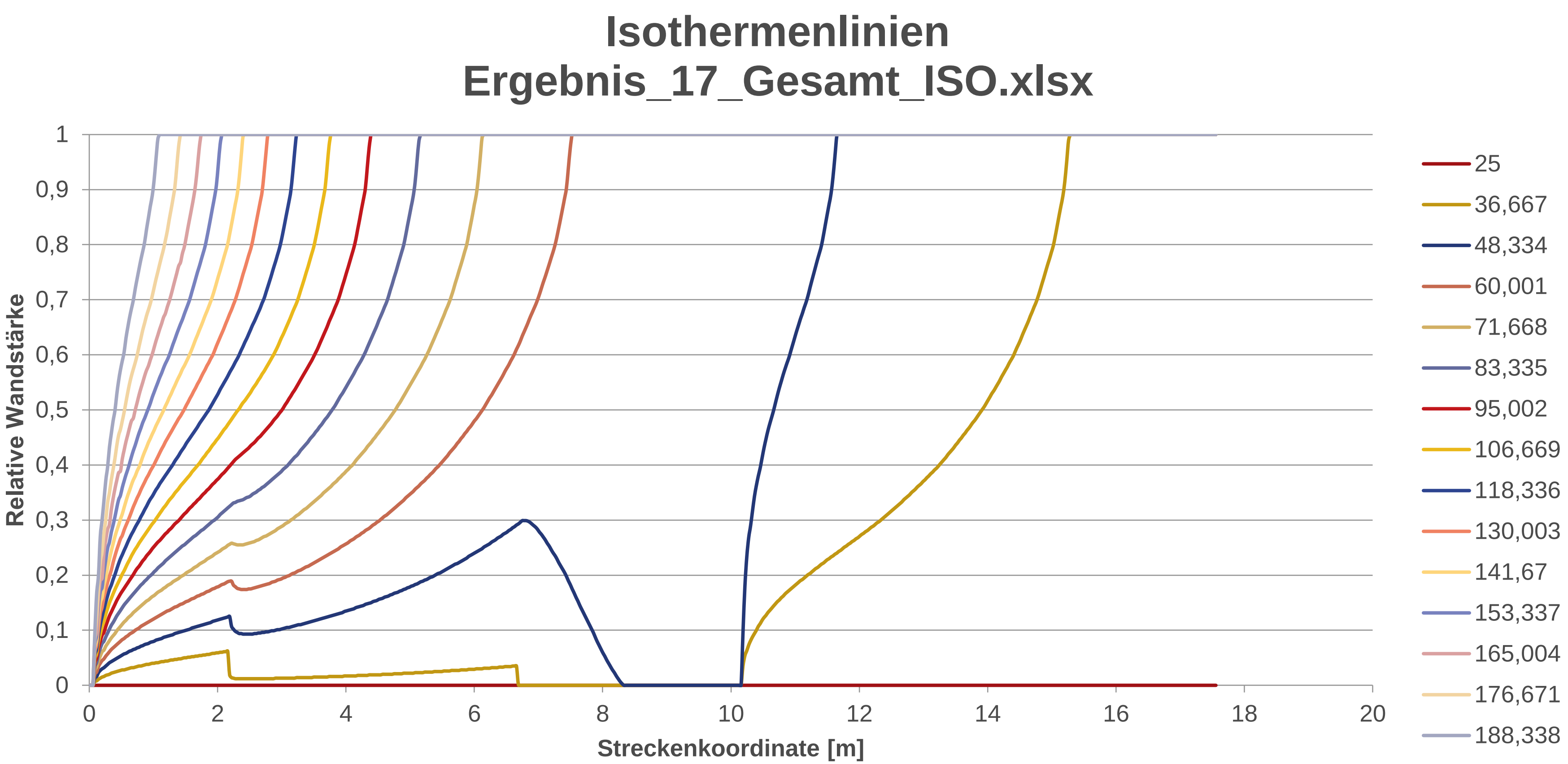
for each component (e.g. spray bath) the thermal power tranferred to the cooling water is calculated.

Some losses (e.g. radiation to the environement) are taken into account by a factor), that means that not all the power taken out of the tube ends up in the cooling water

Ergebnis_8_W | Ergebnis_9_W

ID	Komponent	T in	T out	Vol out m3h	P therm in k
8	15	18	41,213	1	26,966
8	17	41,213	41,653	0,95	0,485

Example of a result: wall temperature isothermic lines down a extrusion line (outer diameter„0“, inner diameter „1“, length of the line about 18 m)



Thanks for your attention!

Hochschule Hof
Alfons-Goppel-Platz 1
95028 Hof

Phone +49 9281 409-3000
Fax +49 9281 409-4000

mail@hof-university.de
www.hof-university.de