Nestlé Good Food, Good Life

IFTPS

5th European Conference

Sevilla, Spain

Torre Del Oro

Nestlé Research

Holding Tube Calculations

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Aseptic Processing and Filling Line

UHT Plant + Aseptic Tank + Aseptic Filling Machine

From an engineering point of view the **Holding Tube** is the simplest part ...

... but nevertheless the **Holding Tube** determines

the **microbiological food safety** or **spoilage risk** on one hand,

and the **product quality** on the other.

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Awareness

1. Heat Expansion of the Product
2. Amount of Condensate (liquid, dir. heat.)
3. Rheology of Products, Flow Regime
4. Pressure Losses
5. Residence Time Distribution
6. Fouling
7. Physical Properties

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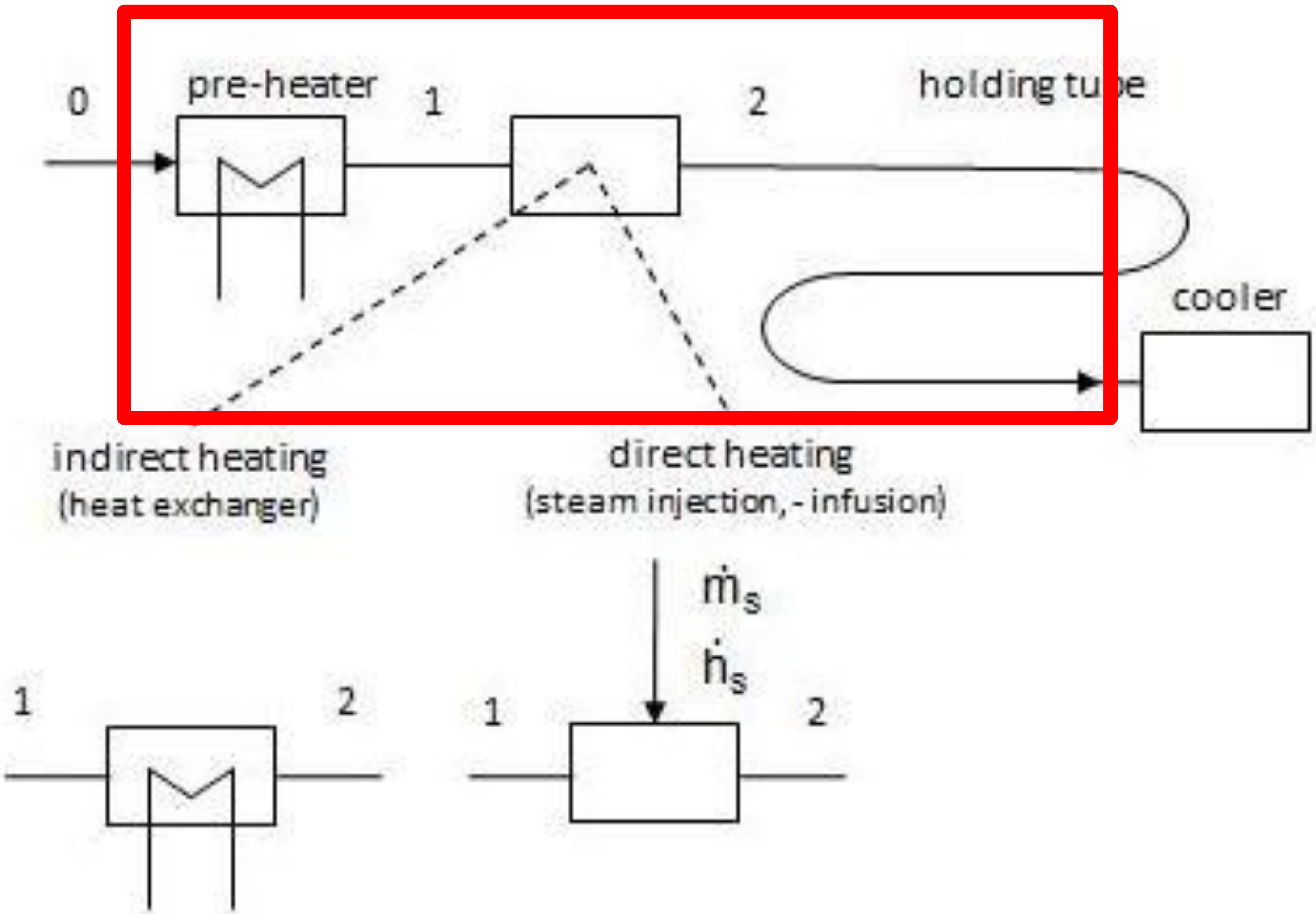
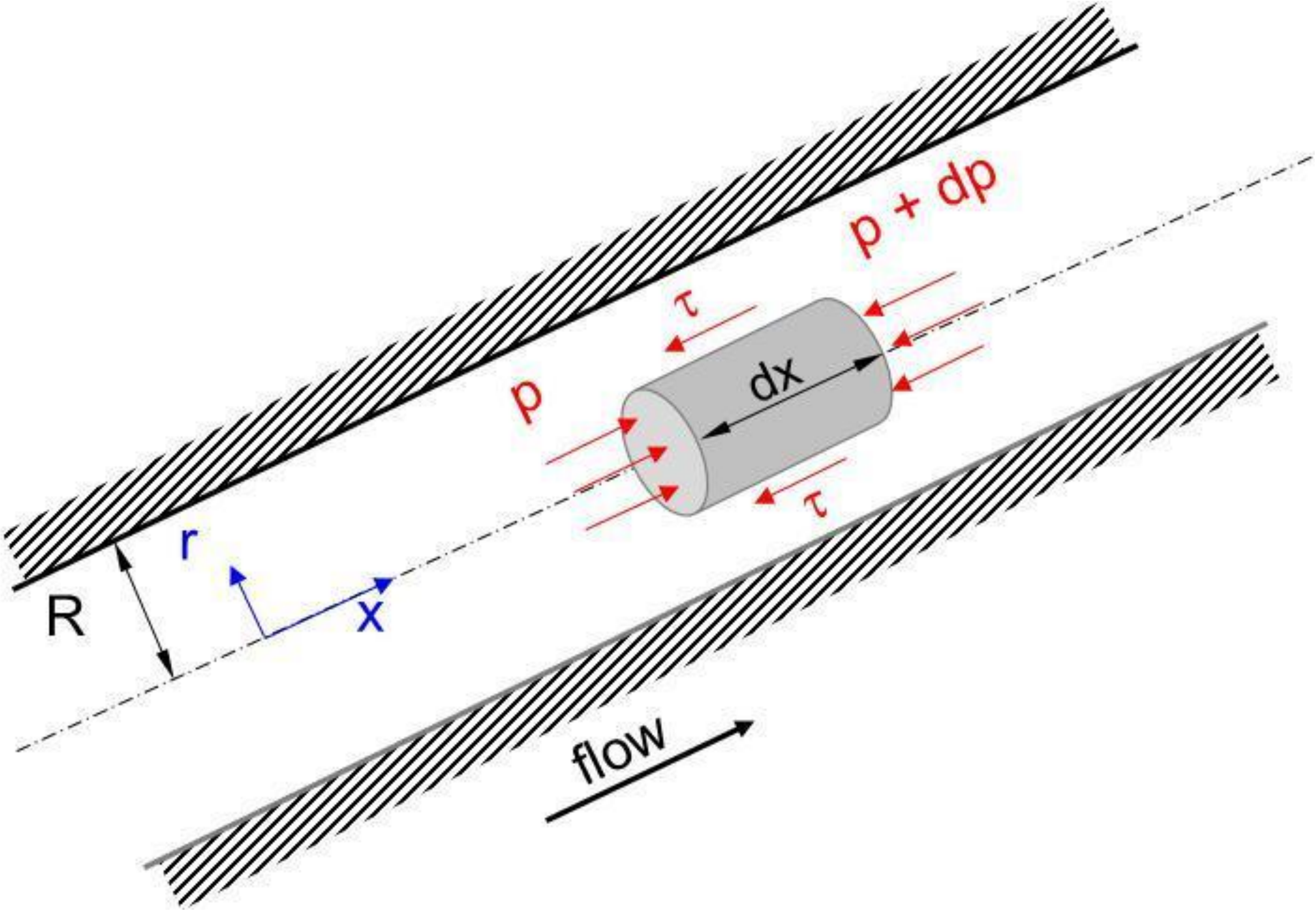
Out-of-container heat treatment device

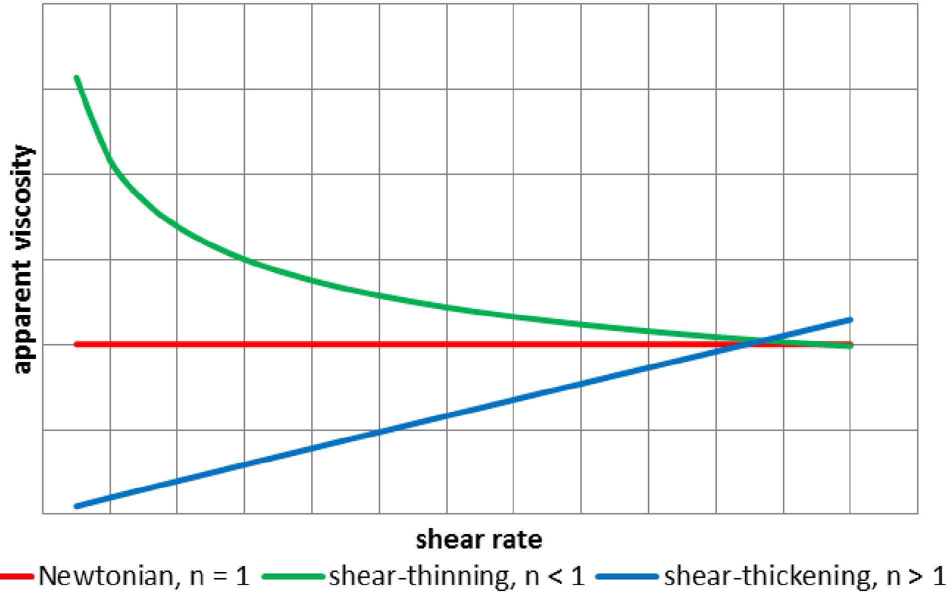


One dimensional forces at a volume element



Power Law Liquids

n	liquid	example
= 1	**Newtonian**	water, fruit juice, skim milk, honey, vegetable oil
0 < n < 1	pseudoplastic, **shear-thinning**, (in German language: “strukturviskos”)	applesauce, banana puree, orange juice concentrate
1 < n < ∞	dilatant, **shear-thickening**	some types of honey, 40% raw corn starch solution



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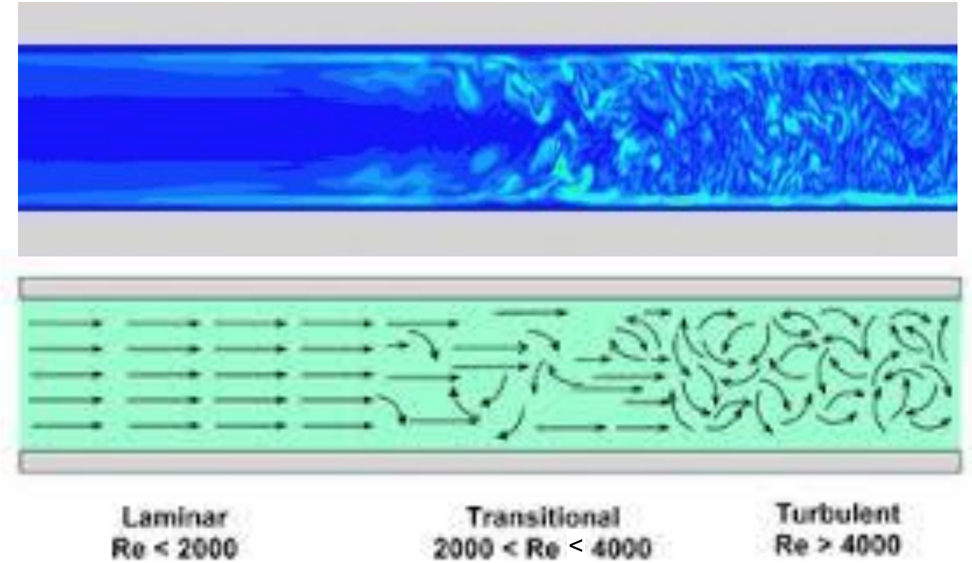
Flow Regime



- For food safety reasons the maxi-mum velocity must be considered.
- The average velocity is determined by the measured flow rate.
- The relation in between average and maximum velocity depends on the flow regime.

$$\hat{u} = \frac{1}{C} \cdot \bar{u}$$

- The reverse correction coefficient 1/C is determined as follows:

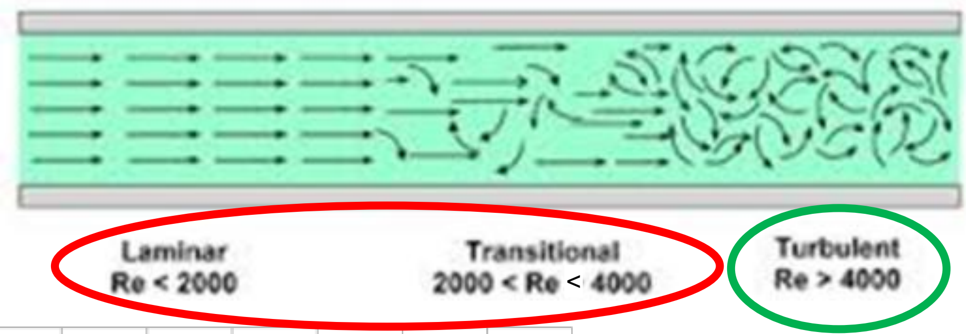
  1/C = 2 for laminar flow (of Newtonian liquids)

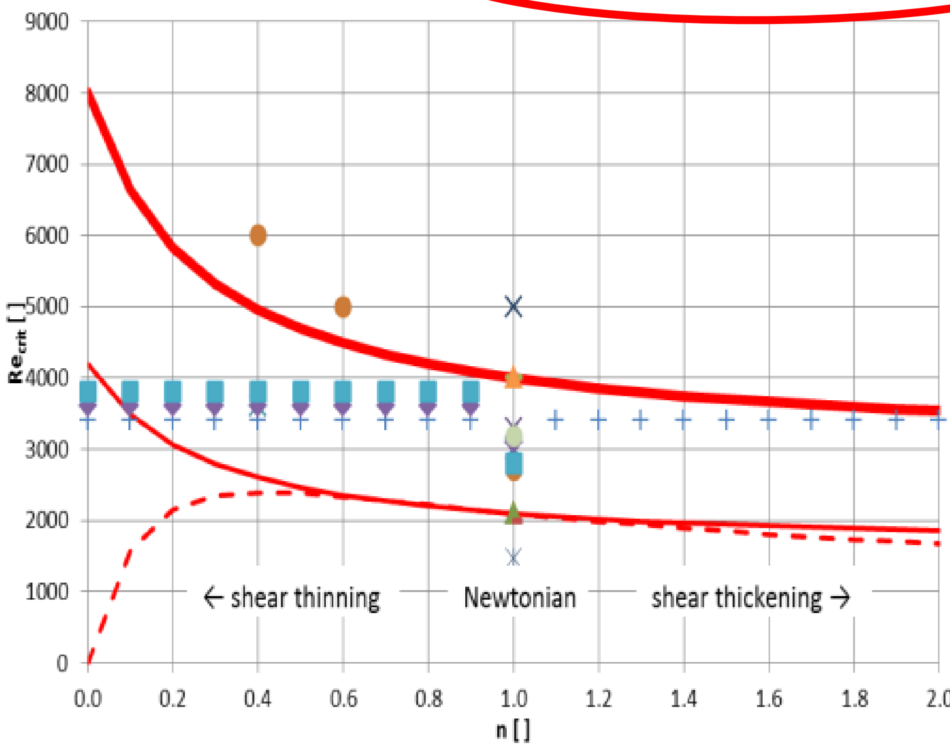
  1 < 1/C < 2 for turbulent flow (of Newtonian liquids).

Reynolds Number for Power Law Liquids

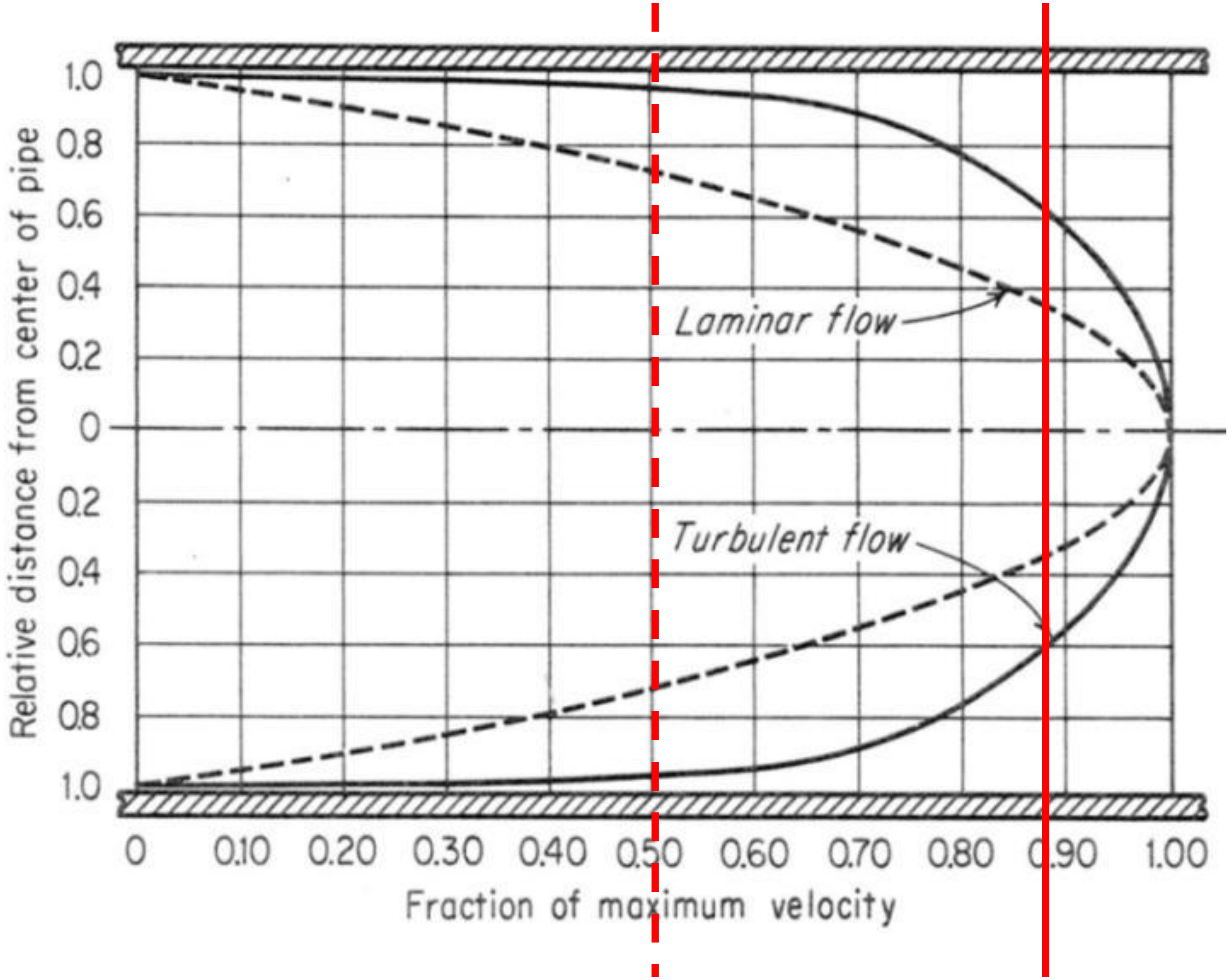
$$Re = \frac{2^n \cdot R^n \cdot v^{2-n} \cdot \rho}{8^{n-1} \cdot K} \cdot \left(\frac{4n}{3n+1}\right)^n$$

$$Re_{crit} = \frac{4000 \cdot (4n+2)(5n+3)}{3 \cdot (1+3n)^2}$$



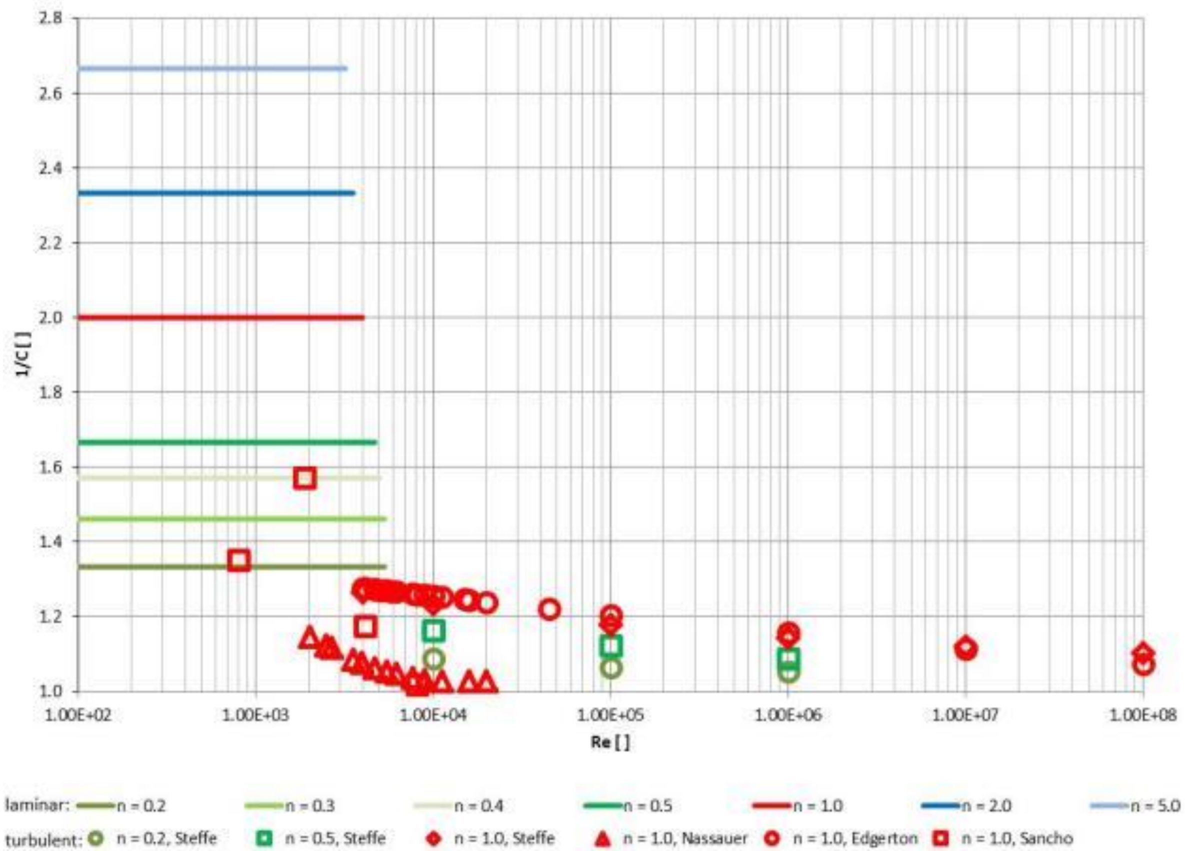


Velocity profiles



Reverse Correction Coefficient I

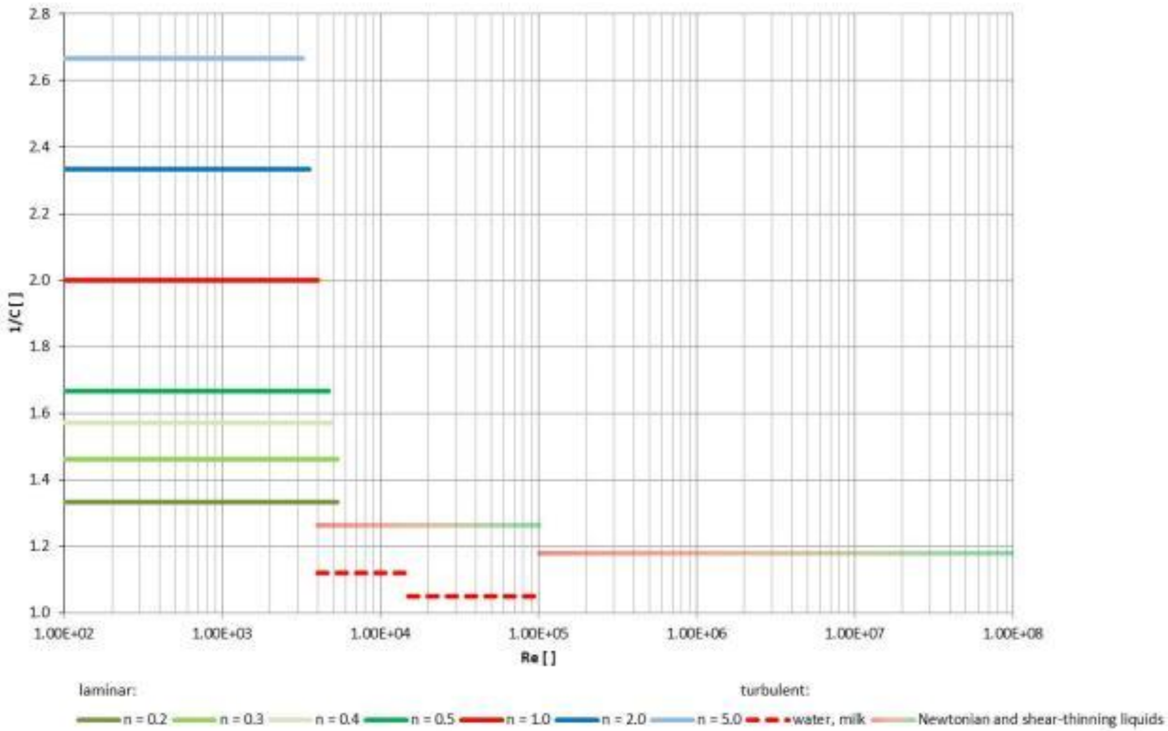
$$\hat{u} = \frac{1}{C} \cdot \bar{u}$$



with n as flow behavior index: 0 < n < 1:shear-thinning liquid
n = 1:Newtonian liquid
1 < n < ∞:shear-thickening liquid

Reverse Correction Coefficient II

$$\hat{u} = \frac{1}{C} \cdot \bar{u}$$



Laminar flow : Re < Re_{crit}. $\frac{1}{C} = \frac{1+3n}{1+n}$

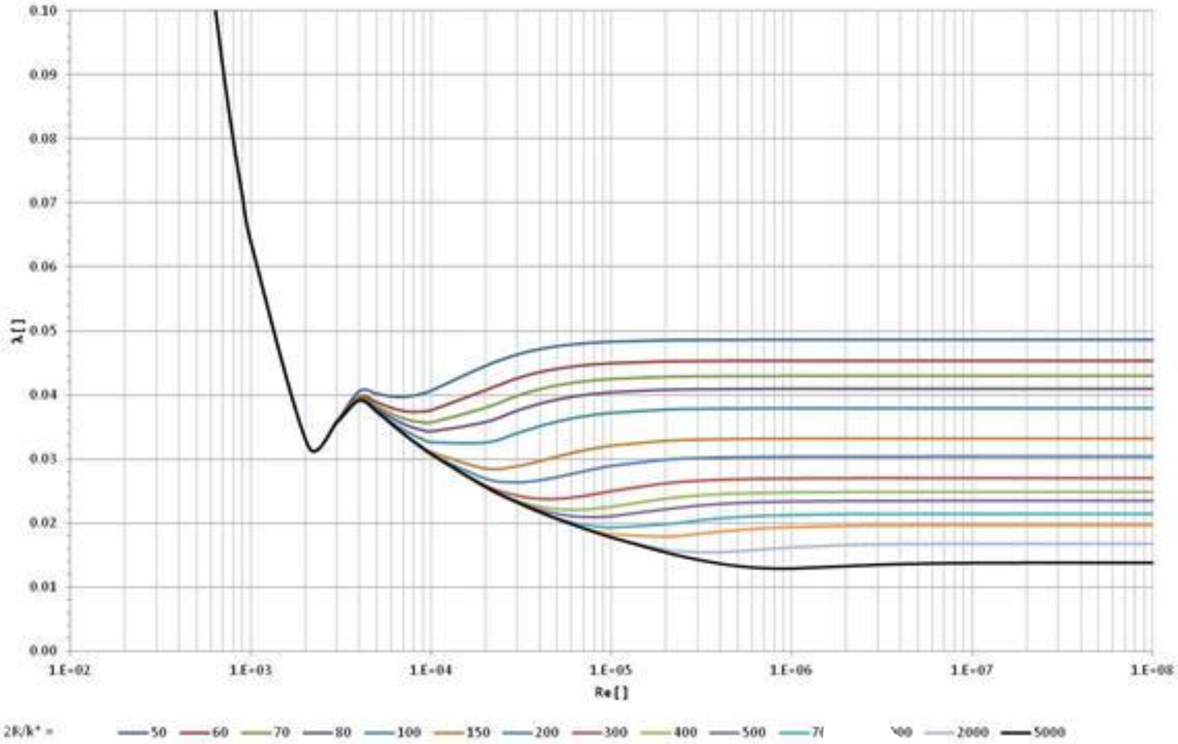
1. Turbulent flow for Newtonian and shear-thinning liquids (0 < n ≤ 1):

   Re_{crit} < Re < 100'000: 1/C = 1.266
   100'000 < Re < 1'000'000: 1/C = 1.180.

2. Turbulent flow for water and milk (n = 1, skim milk and whole milk):

   3'000 < Re < 15'000: 1/C = 1.120
   15'000 < Re < 100'000: 1/C = 1.050

Nikuradse- or Moody-Diagram



$$\breve{p}_{2abs} = \Delta p_{ltube} + \Delta p_{lfitt} + p_{boil,\,abs} + \underbrace{2\ bar}$$

$$\Delta p_{ltube} \equiv \lambda \cdot \frac{l}{2 \cdot R} \cdot \frac{\rho}{2} \cdot \overline{u}_L^2$$

experimental by PTC Konolfingen

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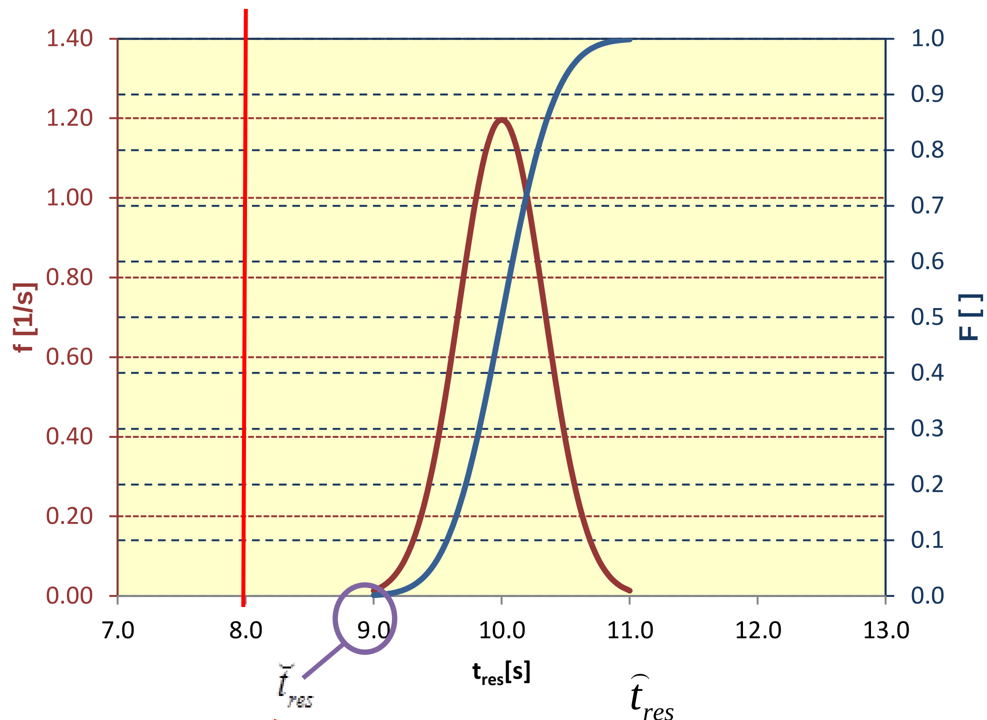
$$f(t_{res}) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left(\frac{t_{res}-\mu}{\sigma}\right)^2}$$



$$\mu = \bar{t}_{res} = \frac{l}{\bar{u}}$$

$$\sigma = \frac{1}{3} \cdot \left(\bar{t}_{res} - \breve{t}_{res}\right) = \frac{l}{3} \cdot \left(\frac{1}{\bar{u}} - \frac{1}{\hat{u}}\right)$$

microbiological food safety
or **spoilage risk** ➲

product quality ➲

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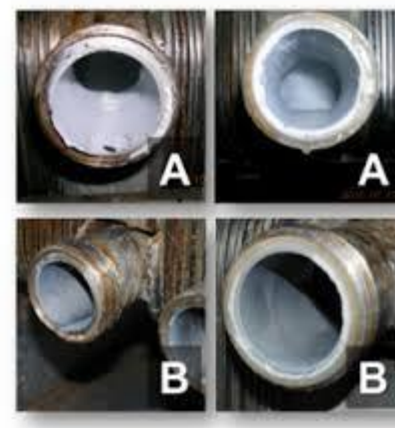
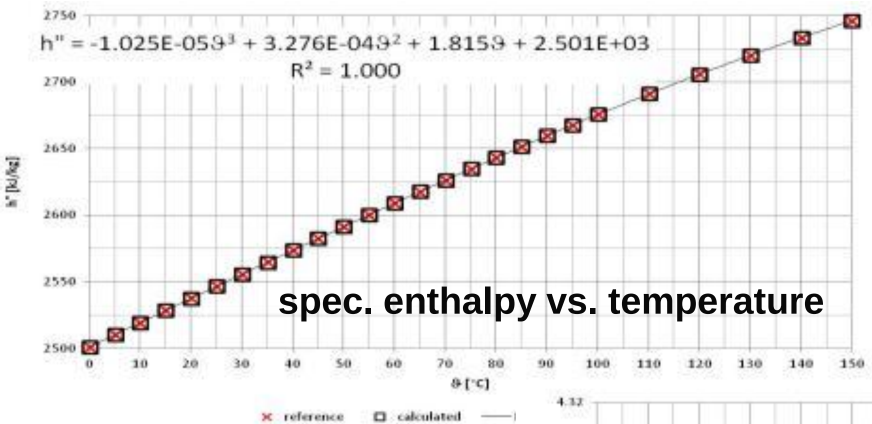
Fouling

Here the composition of a constant fouling layer over the total holding tube lengths is supposed as follows:

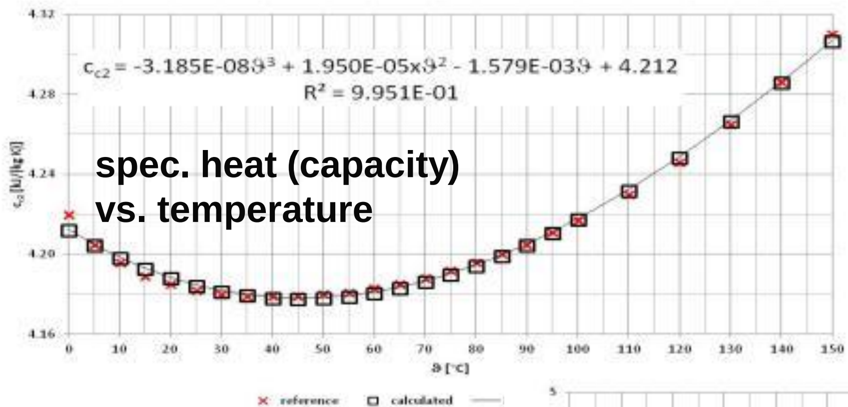
$$R = R_{clean} - \delta_{fouling}$$

R:	inner radius of the holding tube
R_{clean}:	inner radius of the clean (unfouled) holding tube
$\delta_{fouling}$:	thickness of the fouling layer

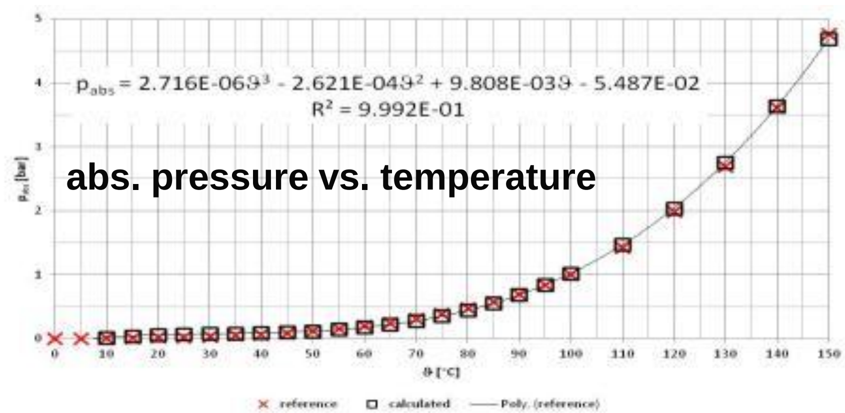




$h'' = -1.025E\text{-}05\vartheta^3 + 3.276E\text{-}04\vartheta^2 + 1.815\vartheta + 2.501E{+}03$
$R^2 = 1.000$
spec. enthalpy vs. temperature
h'' [kJ/kg]
ϑ [°C]
reference
calculated

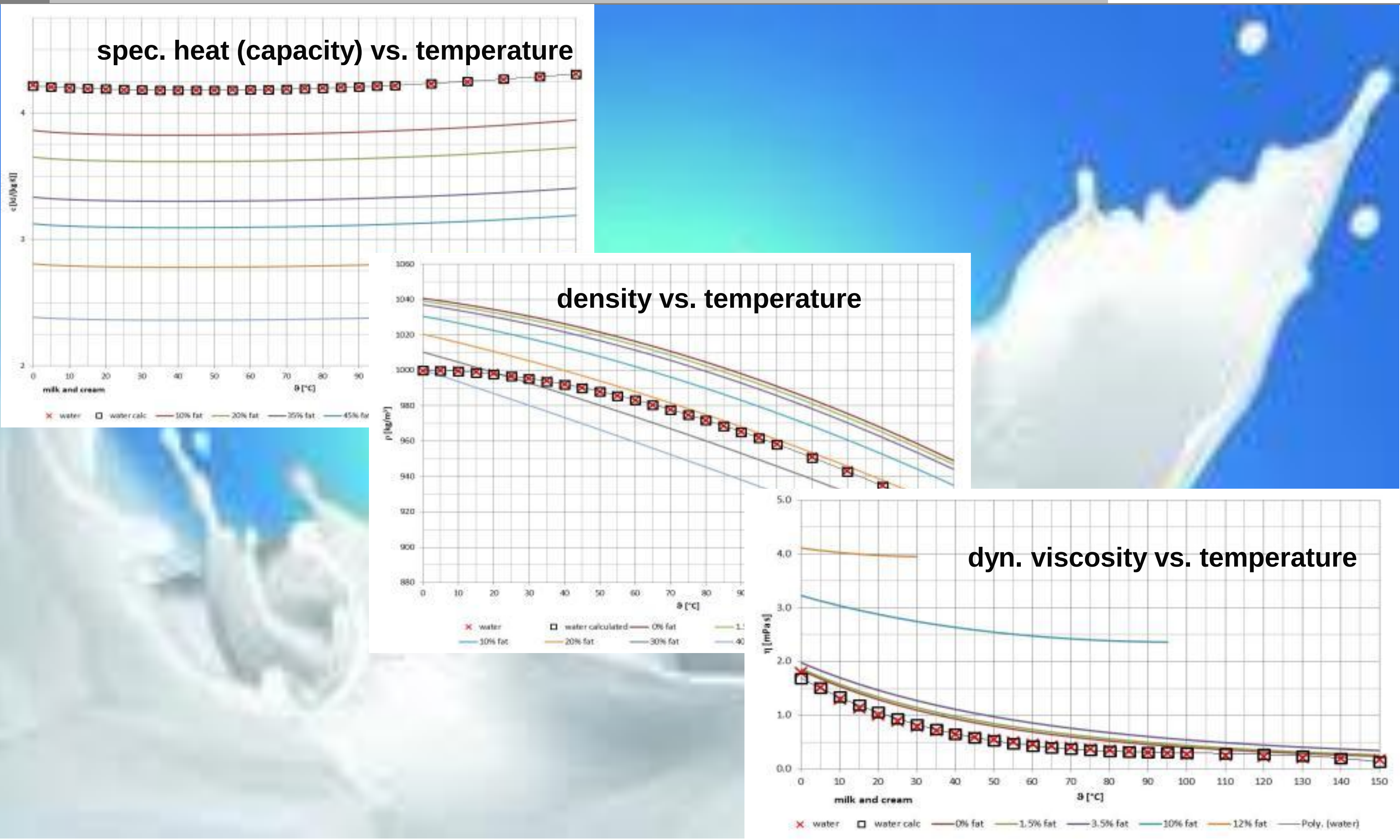


$c_{c2} = -3.185E\text{-}08\vartheta^3 + 1.950E\text{-}05x\vartheta^2 - 1.579E\text{-}03\vartheta + 4.212$
$R^2 = 9.951E\text{-}01$
spec. heat (capacity)
vs. temperature
c_{c2} [kJ/(kg K)]
ϑ [°C]
reference
calculated



$p_{abs} = 2.716E\text{-}06\vartheta^3 - 2.621E\text{-}04\vartheta^2 + 9.808E\text{-}03\vartheta - 5.487E\text{-}02$
$R^2 = 9.992E\text{-}01$
abs. pressure vs. temperature
p_{abs} [bar]
ϑ [°C]
reference
calculated
Poly. (reference)

Physical Properties of Water, Milk, and Cream



Two different tasks

Validation / Qualification

New equipment design

product:	water	
(either or)	milk/cream ≤ 12% fat	x
	any liquid product	
type of calculation:	lengths of the holding tube	
(either or)	residence time	x
type of heating:	direct	
(either or)	indirect	x

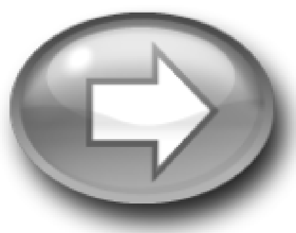
12 cases

Input

either
lengths of the holding tube

or
residence time in the holding tube

several input values
depending on the cases
(9 - 18 values)



Output

either
residence time in the holding tube

or
lengths of the holding tube

Reynolds Number,
minimum pressure,
width of the residence time distribution

9 - 18 input values

1.	product temperature before pre-heater	ϑ_0	always
2.	product temperature after pre-heater	ϑ_1	always
3.	product temperature in holding tube	ϑ_2	always
4.	volume flow rate before pre-heater	V_0	always
5.	inner diameter of clean holding tube	D_{clean2}	always
6.	thickness of fouling layer	$\delta_{fouling2}$	always
7.	roughness at the inside of the holding tube	k^*_2	always
8.	number of 90° bends of the holding tube	n_{bend2}	always
9.	bend radius	R_{bend2}	always
10.	residence time in the holding tube	t_{res2}	either / or
	lengths of the holding tube	l_2	either / or
11.	product mass fraction of fat before pre-heater	x_{f0}	milk/cream ≤ 12% fat
12.	product mass fraction of solids non fat before pre-heater	x_{snf0}	milk/cream ≤ 12% fat
13.	product density before pre-heater	ρ_0	any (other) liquid
14.	product density before holding tube	ρ_2	any (other) liquid
15.	specific heat of the product in holding tube	c_2	any (other) liquid
16.	flow behavior index of the product in holding tube	n_2	any (other) liquid
17.	consistency coefficient of the product in the holding tube	K2	any (other) liquid
18.	reverse correction coefficient	1/C	confirmation

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THANK YOU

“Simplicity is the ultimate sophistication."
(Leonardo da Vinci)