Workshop G-W-3: Establish objective – The coffee cups

Attention: Fiction case study, for education only

Design brief	
Design brief	In the new generation of Douwe Egberts® coffee machine, the preheat coffee cup feature is introduced. In the preheating process, water steam from the nozzle preheats the cup to a certain temperature before the coffee is served. Experiments indicate that: 1. if the cup is preheated to 92°C , the best coffee can be served; 2. 80% of water steam is condensed inside the cup, the rest is absorbed by the air. Besides, Douwe Egberts® also manufactures its own coffee cups with different sizes and materials, for example, the Hollandsche series and the Standard series. Question: Establish the objective function to find the optimal initial temperature and the optimal amount of steam that should be produced in order to preheat either of the two types of cups as close as possible to 92°C.
We choose:	We choose: 1. The density of water is 1000 kg/m3; 2. The latent heat of water vaporization is 2,260,000 J/kg; 3. The specific heat of water steam is 2080 J/(kg·K); 4. The specific heat of water is 4181 J/(kg·K); 5. The initial temperatures of both cups are 20 °C; 6. The weight of the Hollandsche cup is 0.20 kg, the specific heat is 750 J/(kg·K); The weight of the Standard cup is 0.13 kg, the specific heat is 1070 J/(kg·K); 7. The steam temperature doesn't change before it reaches the cup; 8. The complete process happens in a very short time;

Courtesy of http://www.douweegbertscoffeesystems.com/dg/OutOfHome/OurProducts/Coffee/Cafitesse/Machines/
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Standard series

Hollandsche series

System

Steam

Cup

Cause	Steam cool down	Steam condenses to water	The condensed water cool down	Past of steam is wasted	Cup is heated
Effect	Release heat	Release heat	Release heat	75%	Absord heat

$$\left(m_{steam}c_{steam}(T_{steaminitial}-100)+m_{steam}L_{steam}+m_{steam}c_{water}(100-T_{cupfinal})\right)\cdot 75\%+m_{cup}c_{cup}(T_{initial}-T_{cupfinal})=0$$

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Models for different cups

Model for Hollandsche series

$$\left(m_{steam}c_{steam}\left(T_{steam\,initial}-100\right)+m_{steam}L_{steam}+m_{steam}c_{water}\left(100-T_{Hfinal}\right)\right)\cdot 80\%+m_{Holland}c_{Holland}\left(T_{initial}-T_{Hfinal}\right)=0$$

Model for Standard series

$$\left(m_{steam}c_{steam}\left(T_{steam\,initial}-100\right)+m_{steam}L_{steam}+m_{steam}c_{water}\left(100-T_{Sfinal}\right)\right)\cdot 80\%+m_{Standard}c_{Standard}\left(T_{initial}-T_{Sfinal}\right)=0$$

The final temperature

Model for Hollandsche series

$$T_{Hfinal}\left(m_{steam},T_{steam\,initial}\right)=\frac{0.8m_{steam}c_{steam}\left(T_{steam\,initial}-100\right)+0.8m_{steam}L_{steam}+80m_{steam}c_{water}+m_{Holland}c_{Holland}T_{initial}}{0.8m_{steam}c_{water}+m_{Holland}c_{Holland}}$$

Model for Standard series

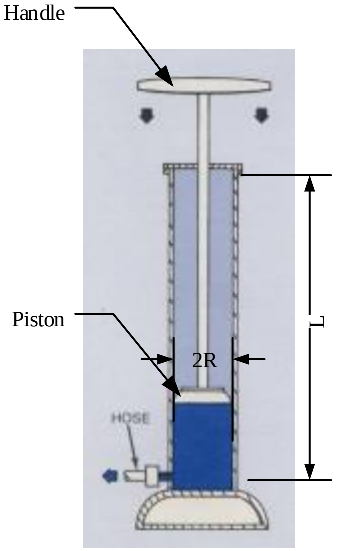
$$T_{Sfinal}\left(m_{steam},T_{steam\,initial}\right)=\frac{0.8m_{steam}c_{steam}\left(T_{steam\,initial}-100\right)+0.8m_{steam}L_{steam}+80m_{steam}c_{water}+m_{Standard}c_{Standard}T_{initial}}{0.8m_{steam}c_{water}+m_{Standard}c_{Standard}}$$

Establish the objective function (to be minimized)

Weight = 0.5 for every metric

$$Obj\left(m_{steam},T_{steam\,initial}\right)=0.5\left(T_{Hfinal}\left(m_{steam},T_{steam\,initial}\right)-92\right)^2+0.5\left(T_{Sfinal}\left(m_{steam},T_{steam\,initial}\right)-92\right)^2$$

Workshop G-W-3: Establish objective – The bike pump



Question

A bicycle pump functions via a hand-operated piston. During the up-stroke, this piston draws air through a one-way valve into the pump from the outside. During the down-stroke, the piston then displaces the air from the pump into the bicycle tyre.

Question:
Establish the objective function to find the optimal radius R of the piston and the travel length L of the pump to satisfy the following wishes:

1. Kathleen Vandenbranden, a senior expert in ergonomics, said: "For pumping a bike, the maximum force should be around 300 N from ergonomics point of view";
2. Mark Broekhuis, a student cycling to university everyday, said: "I want to pump my tyres as quick as possible, e.g., with the least amount of full strokes.";

We choose:
1. the pump has a cylindrical shape;
2. the temperature of the pump, air and the tyre are constant during the process;
3. the tyre is torus-shaped, the volume of the tyre is 2.2 Liter and it should be pumped to 2 bar (relative pressure) over the outside pressure, which is 1 bar (100,000 Pa);
4. the tyre is flat in the beginning, e.g., there is NO air inside the tyre in the beginning;
5. to ignore all frictions and resistances;
6. to use gradient descent method in the optimization;

The number of strokes

$Pt = Pressure\_tyre = 3 \cdot 10^5$ $\quad Pa = Pressure\_air = 1.0 \cdot 10^5$

$Vt = Volume\_Tyre = 2.2 \cdot 10^{-3}$ $\quad Vc = Volume\_Cylinder = \pi R^2 L$

Boyle's law

$$Pt \cdot Vt = Pa \cdot Vc \cdot n$$

The number of strokes

$$n = \frac{Pt \cdot Vt}{Pa \cdot Vc} = \frac{3 \cdot 2.2 \cdot 10^{-3}}{\pi R^2 L} = \frac{6.6 \cdot 10^{-3}}{\pi R^2 L}$$

Force

$$Force = (Pressure\_tyre - Pressure\_air) \cdot Area\_piston = (Pt - Pa) \cdot \pi R^2 = 2 \cdot \pi \cdot 10^5 \cdot R^2$$

The objective function (to be minimized)

$$Obj(R, L) = (F - 300)^2 + (n - 0)^2 = (2 \cdot \pi \cdot 10^5 \cdot R^2 - 300)^2 + \left(\frac{6.6 \cdot 10^{-3}}{\pi R^2 L}\right)^2$$

Workshop G-W-3: Establish objective – The shower nozzle 1

GROHE

ENJOY WATER®

Question

Friedrich Grohe® AG & Co. KG, the leading manufacturer of sanitary fittings, is working on a new generation of luxury shower systems.

In one of the new designs, two types of shower nozzles are provided: the wide spray and the hand shower . The user can switch between two modes in the shower.

Question:

Establish the objective function for specifying the optimal size of the holes in the wide spray and the optimal size of the holes in the hand shower in order to satisfy the following requirements:

1. The optimal water speed in the wide spray is about **11** m/s;
2. The optimal water speed in the hand shower is about **12** m/s;
3. The system should consume about **150** liters of water after **4** minutes usage of the wide spray and **1** minute usage of the hand spray (Altogether **5** minutes of showering).

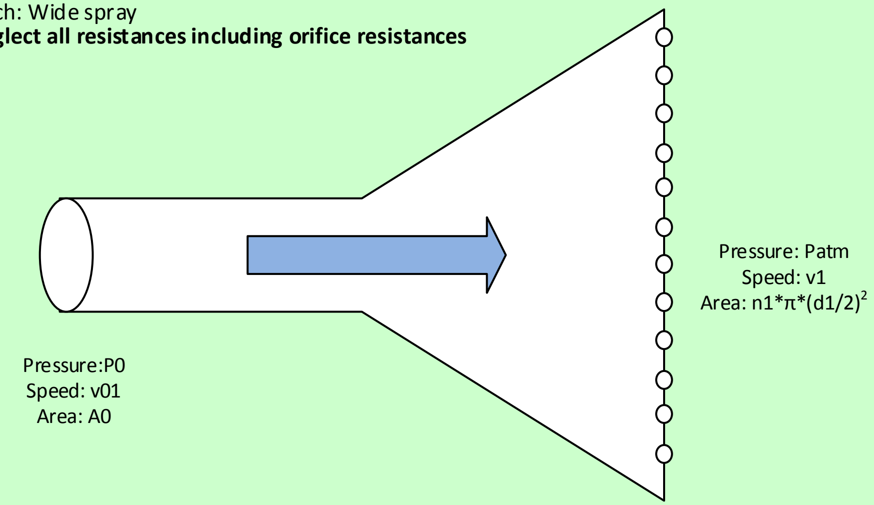
We choose:

We choose:
1. the inlet for both nozzles are the same;
2. the diameter of the inlet is **12.5** mm;
3. the water pressure in the inlet is **1.5** bar (**1** bar = **$1 \cdot 10^5$** Pa);
4. there are **80** holes in the wide spray;
5. there are **50** holes in the hand shower;
6. the density of water is **1000** kg/m^3;
7. the environment (air) pressure is **1** bar ;
8. to neglect all resistances;
9. to neglect the height differences.

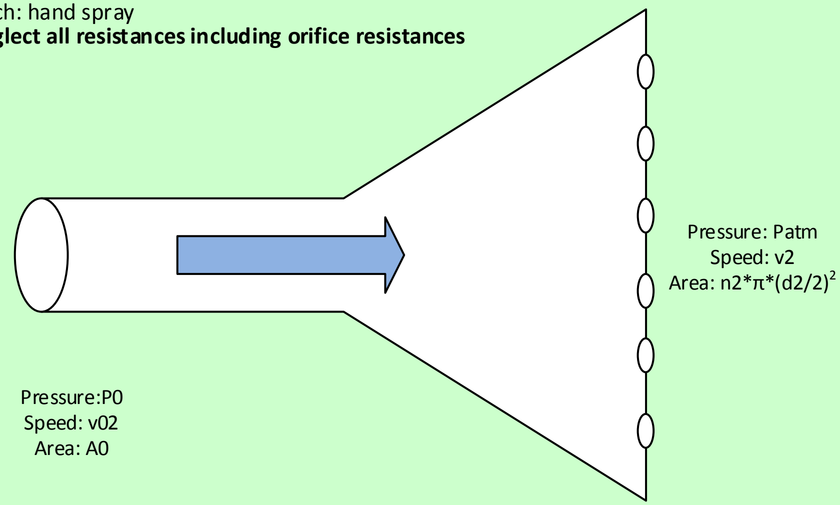
Workshop G-W-3: Establish objective – The shower nozzle 2

Attention: Fiction case study, for education only

Sketch: Wide spray
– **neglect all resistances including orifice resistances**



Sketch: hand spray
– **neglect all resistances including orifice resistances**



Model: Big nozzle – conservation of mass

$$v01 \cdot A0 = v1 \cdot n1 \cdot \pi \cdot \left(\frac{d1}{2}\right)^2$$

Model: Small nozzle

$$v02 \cdot A0 = v1 \cdot n2 \cdot \pi \cdot \left(\frac{d2}{2}\right)^2$$

Model: Big nozzle – conservation of Energy – same height

$$\frac{P0}{\rho} + \frac{v01^2}{2} = \frac{Patm}{\rho} + \frac{v1^2}{2}$$

Model: Big nozzle – conservation of Energy – same height

$$\frac{P0}{\rho} + \frac{v02^2}{2} = \frac{Patm}{\rho} + \frac{v2^2}{2}$$

Speed V1

$$v1 = \frac{10}{\sqrt{1 - 2.62144 \cdot 10^{11} \cdot d1^4}}$$

Water (volume) use in the 5 minutes shower, 4 minute

$$water = time1 * area1 * speed1 + time2 * area2 * speed2$$
$$= 240 \cdot n1 \cdot \pi \cdot \left(\frac{d1}{2}\right)^2 \cdot v1 + 60 \cdot n2 \cdot \pi \cdot \left(\frac{d2}{2}\right)^2 \cdot v2$$

Speed V2

$$v2 = \frac{10}{\sqrt{1 - 1.024 \cdot 10^{11} \cdot d2^4}}$$

Objective function (to be minimized)

$$obj(d1, d2) = (v1 - 11)^2 + (v2 - 12)^2 + (water - 0.15)^2$$