1D EJECTOR SIMULATION TOOL

ONE DIMENSIONAL EJECTOR DESIGN FOR HEAT PUMPS

2022

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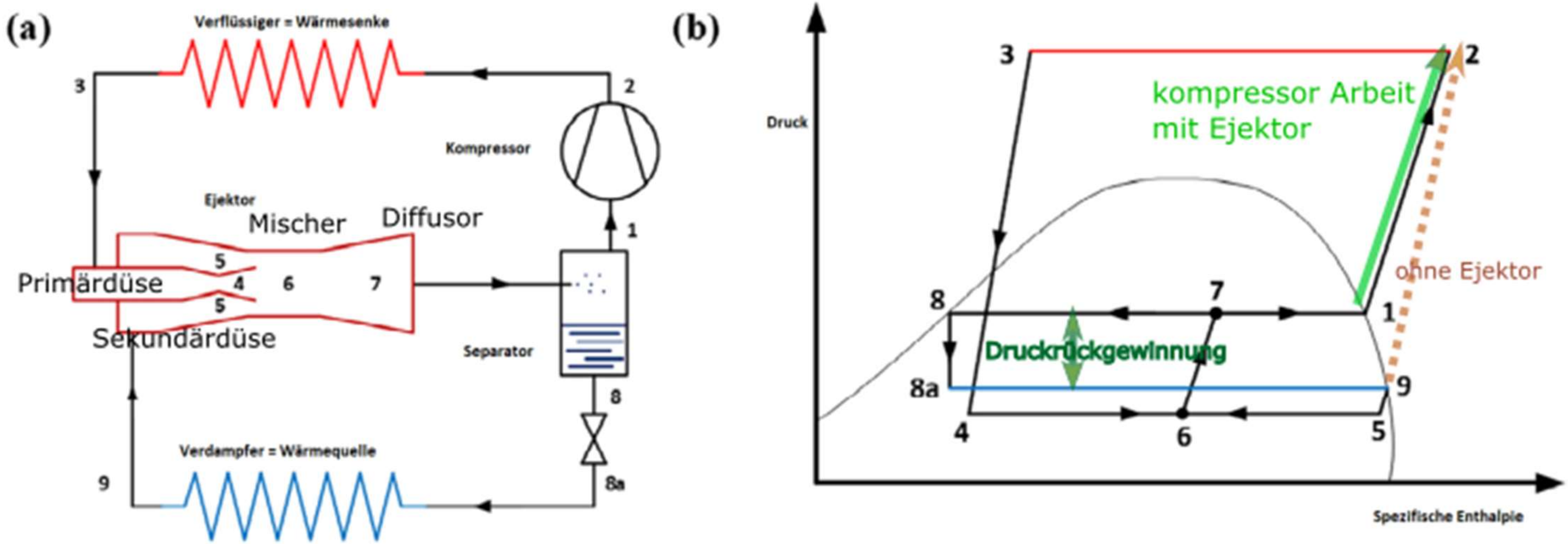
EJECTORS FOR HEAT PUMPS



Pressure recovery ratio = $\frac{p_7}{p_9}$

higher Pressure recovery → Compressor less work → Better COP

Experiment: difficult and expensive.
New Geometrie → new Fabrication

Sensors influence the Fluid Flow

Therefore need for **Simulation**

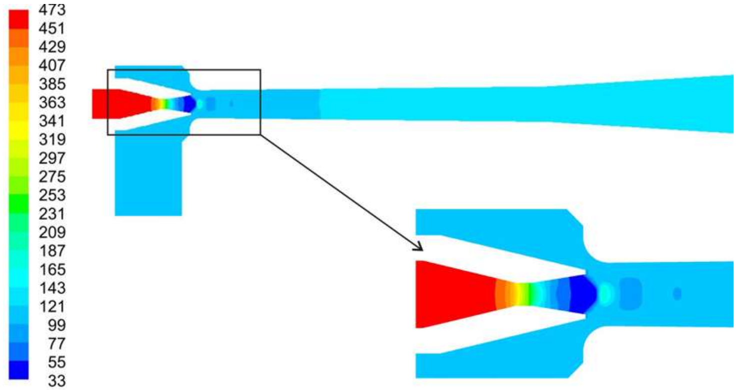
CFD SIMULATION

Advantage:

- Precision: Turbulence etc,
- Equilibrium and Non Equilibrium models.
- Axialsymmetry : 3D → 2D.

Disadvantage:

- Disadvantage: Time: Hours / Days
- Often problems with convergence
- Great Know-how + Experience from the Engineer is needed

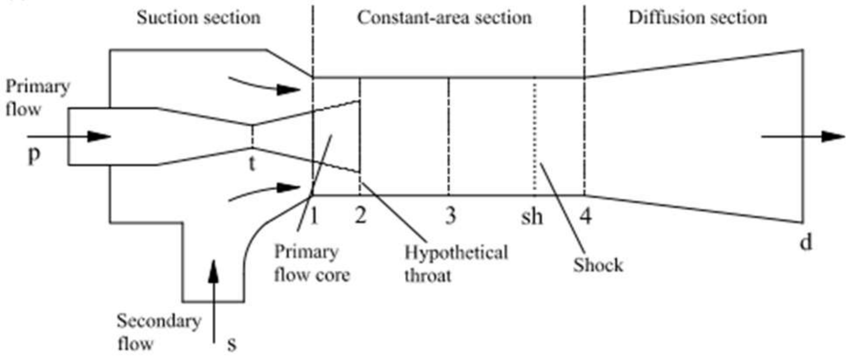


From Smolka et al. 2013

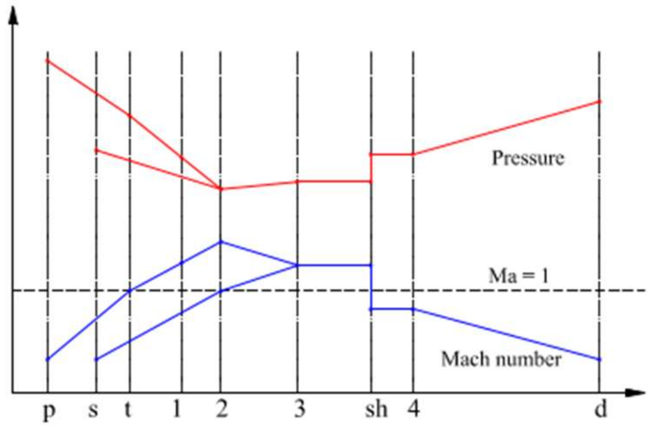
Need for fast, simple to use Simulation tool
For Ejector design and optimization

ONE DIMENSIONAL MODELS

(a)



(b)



Assumption of *Munday-Bagster*: no mixing before the hypothetic throat

Solving the equations for

- Mass conservation
- Momentum equation
- Energy Conservation
- Thermodynamics: Equilibrium, one or two phase flow with Homogeneus Equilibirum models..

Choking :

The Primary mass flow reaches a maximum value → Primary nozzle works like a supersonic Laval-Nozzle.

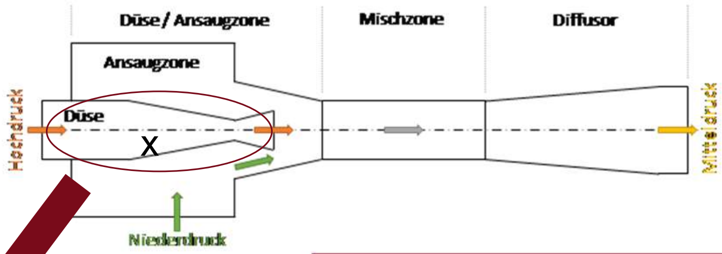
Double Chocking:

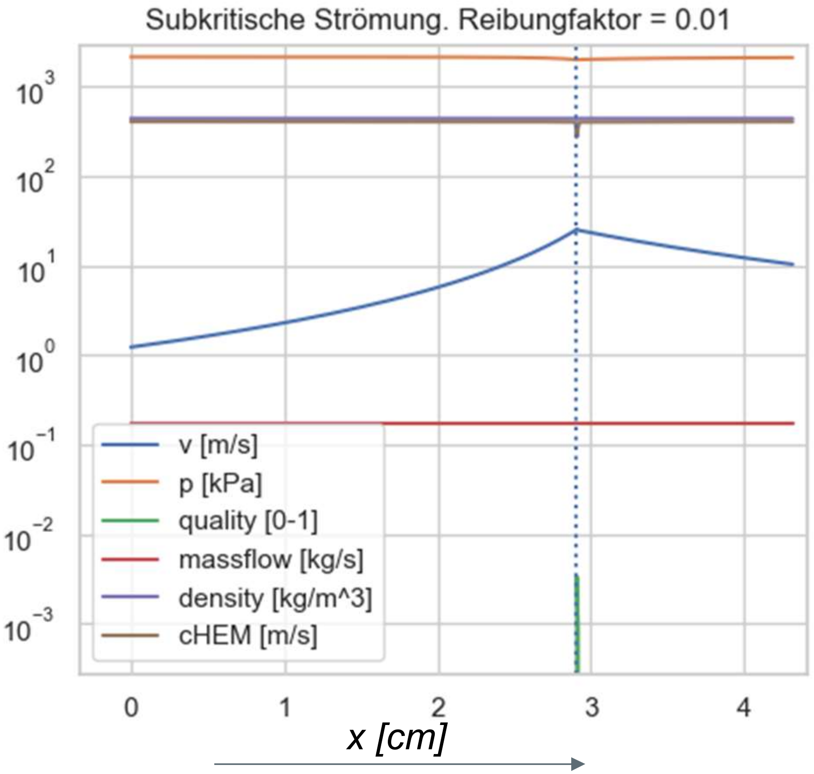
The secondary nozzle mass flow als reaches critical maxium value

Single Choking:

- The secondary mass flow below the critical maximal value.
- The mass flow will be governed by the pressure ratio.

MOTIVE NOZZLE
1D MODELL





Mass conservation	$\dot{M} = \rho A\, v = const.$
Momentum	$-\mathrm{f}\sqrt{\frac{\pi}{A}}\frac{\dot{M}}{A}\mathrm{v}(x) = \frac{\dot{M}}{A}\frac{dv}{dx} + \frac{\mathrm{dp}}{\mathrm{dx}}$
Energy	$0 = v(x)\frac{dv}{dx} + \frac{dh}{dx}$
Homogeneus Equilibrium (HEM) **Density** from RefProp library	$\rho(x) = RP_{\rho}\big(p(x), h(x)\big)$

Assumption:

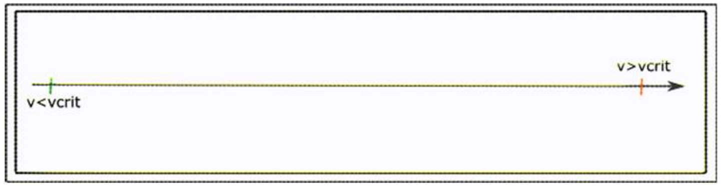
- Viscosity neglected
- Friction with Faktor f (Darcy Weisbach Eq.)
- Turbulence neglected
- Homogeneus Fluid after the phase transition

Solution:

- Initial value problem: from the speed by the prim nozzle inlet → Equation System of Differences (Forward differencial)
- Self made adaptive Solution method

MOTIVE NOZZLE II:
CHOKING: CRITICAL MASS FLOW

Finding the critical Mass flow with Bisection method:



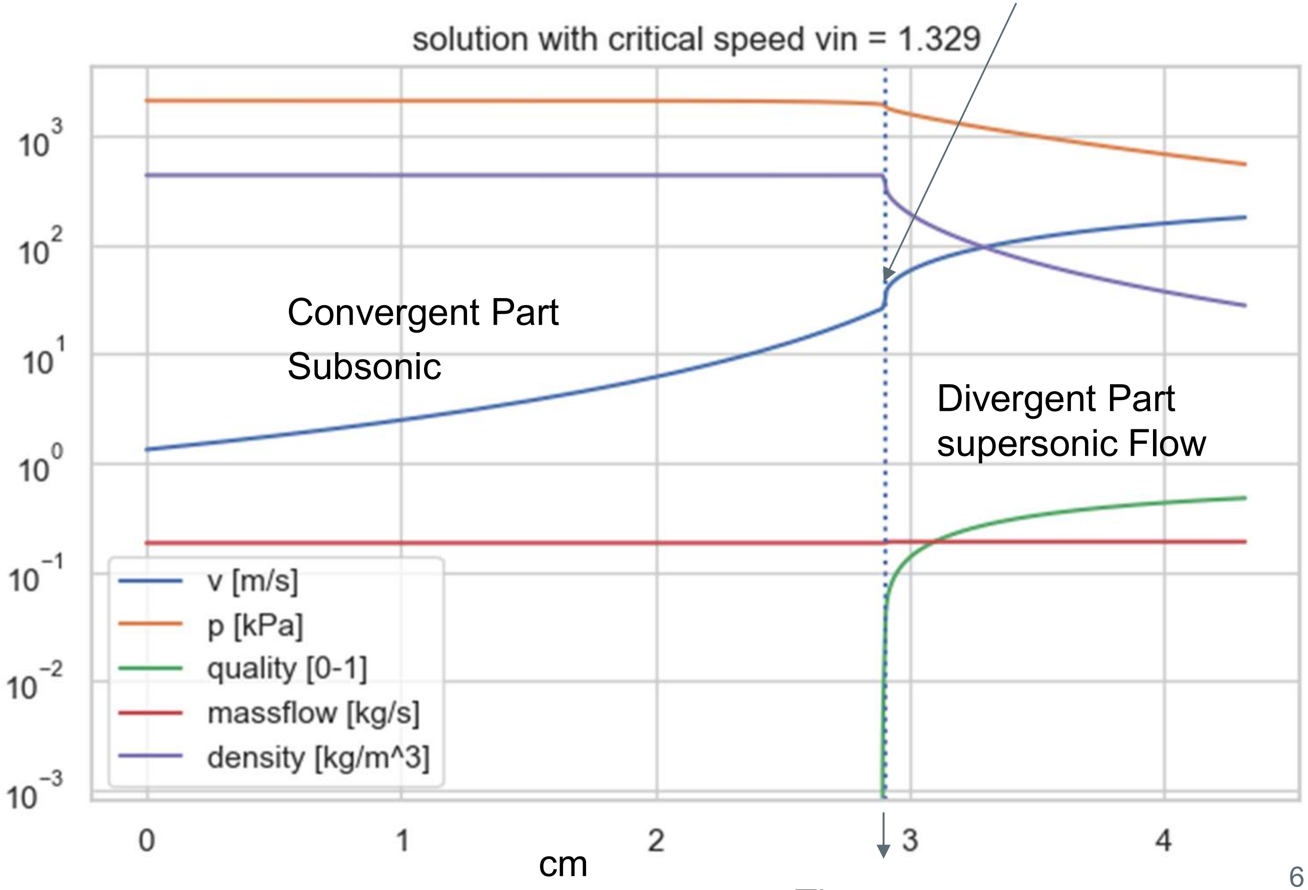
Experiment : Primary nozzle of a Butan Ejector from *Schlemminger et al. 2019*

P = 21.4 bar, T = 114 ^{0}C

Primary nozzle Mass flow:

Simulation	Experiment
0.184 kg/sec	0.127 kg/sec

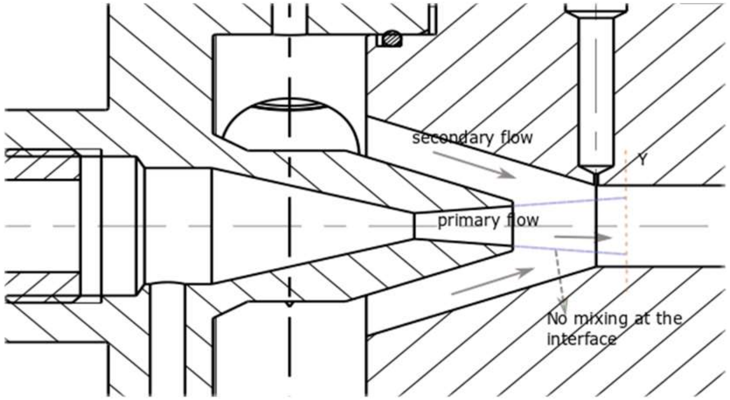
Critical point: needs an artificial
Kick to flip over to supersonic state



Throat

PRE-MIXER (OLD)

0-DIMENSIONAL EQUATIONS



Conservation	Primary (Motive) Flow	Secondary (Suction-) Flow
Mass	$\dot{m}_P = \rho_{pY} v_{pY} A_{pY}$	$\dot{m}_S = \rho_{SY} v_{SY} A_{SY}$
Energy	$h_o + \frac{v_o^2}{2} = h_{pY} + \frac{v_{pY}^2}{2}$	$h_{St} = h_{SY} + \frac{v_{SY}^2}{2}$
Entropy	$s_{po} = RP_s(p_{pY}, h_{pY})$	$s_{St} = \mathrm{RP}_s(p_{SY}, h_{SY})$
Density	$\rho_{pY} = RP_\rho(p_{pY}, h_{pY})$	$\rho_{SY} = RP_\rho(p_{SY}, h_{SY})$
Cross section	$A_m = A_{SY} + A_{PY}$	

Munday-Bagster Hypothesis:

- No mixing until cross section Y

Pressure balance: $p_Y = p_{PY} = p_{SY}$

Critical Operating mode (Double Choking mode):

Secondary flow reaches the speed of sound by Y:

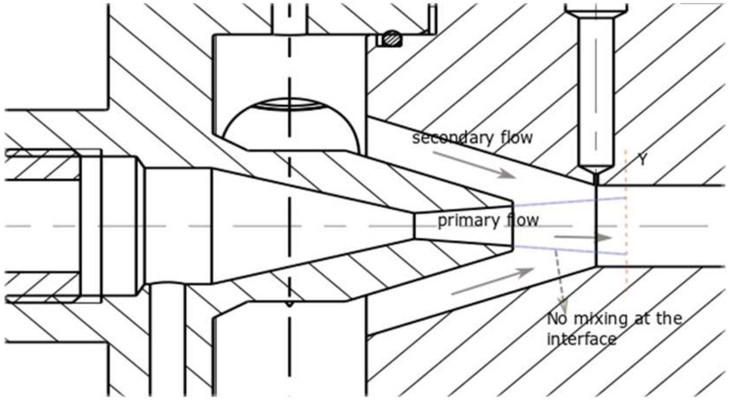
$\mathrm{v_{SY}} = \mathrm{RP_c}(p_Y, h_{SY})$ (RefProp)

$\dot{m}_S$ is calculated from that.

Subcritical Operating mode(single Choking mode):

$\dot{m}_S$ is an external Parameter

PRE-MIXING UPDATE

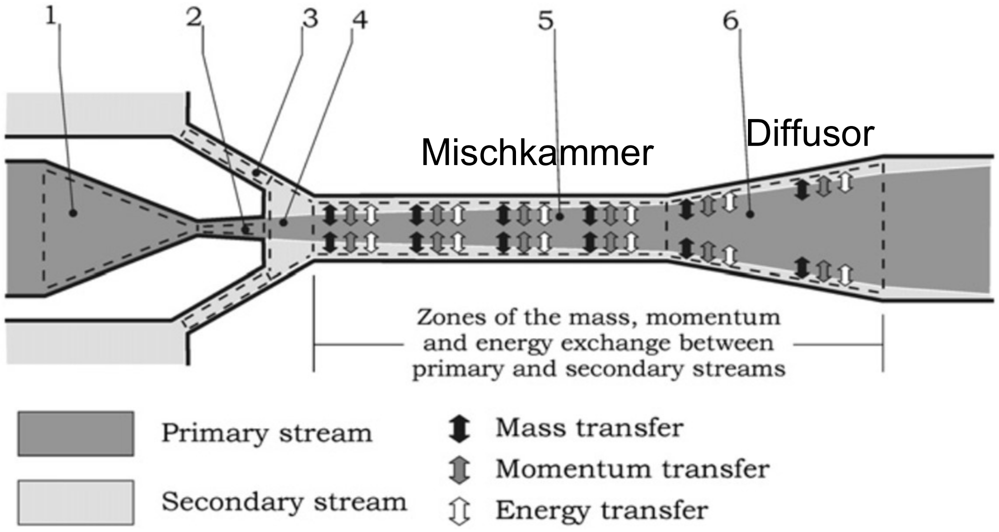


- **Subcritical Operating mode**(single Choking mode):

From the solution of the equations we get $(p_y, v_{pY}, A_{pY}, v_{SY}, h_{SY})$ and **also $\dot{m}_S$!**

Conservation	Primary (Motive) Flow	Secondary (Suction-) Flow
Mass	$\dot{m}_P = \rho_{pY} v_{pY} A_{pY}$	$\dot{m}_S = \rho_{SY} v_{SY} A_{SY}$
Energy	$h_o + \frac{v_o^2}{2} = h_{pY} + \frac{v_{pY}^2}{2}$	$h_{St} = h_{SY} + \frac{v_{SY}^2}{2}$
Entropy	$s_{po} = RP_s(p_{pY}, h_{pY})$	$s_{St} = RP_s(p_{SY}, h_{SY})$
Momentum		$\int_{x_{Si}}^{Y} \rho A v \frac{dv}{dx} dx = -\int_{x_{Si}}^{Y} A(x) \frac{dp}{dx} dx$
Density	$\rho_{pY} = RP_\rho(p_{pY}, h_{pY})$	$\rho_{SY} = RP_\rho(p_{SY}, h_{SY})$
Cross section	$A_m = A_{SY} + A_{PY}$	
Pressure	$p_Y = p_{PY} = p_{SY}$	

MIXER AND DIFFUSER



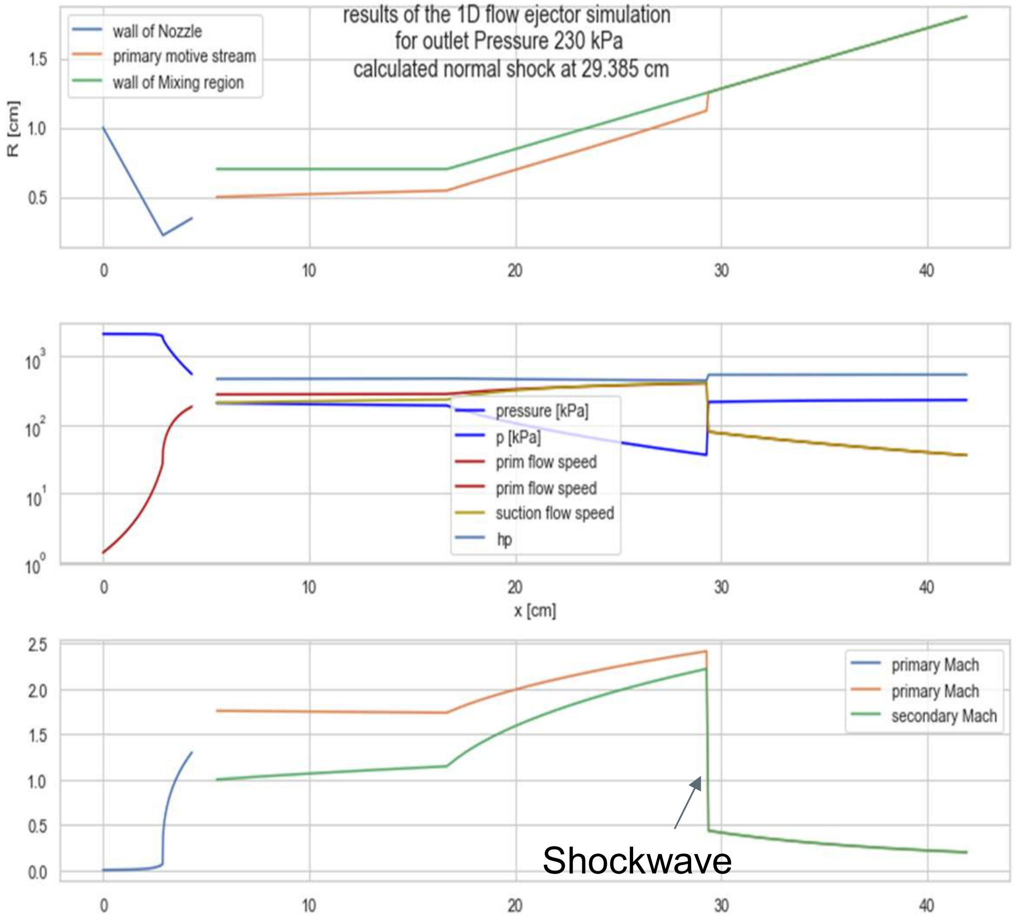
Assumptions after *Banasiak and Hafner (2011):*

Coaxial Flow in the Mixer:

Mass, Momentum and Energy equations

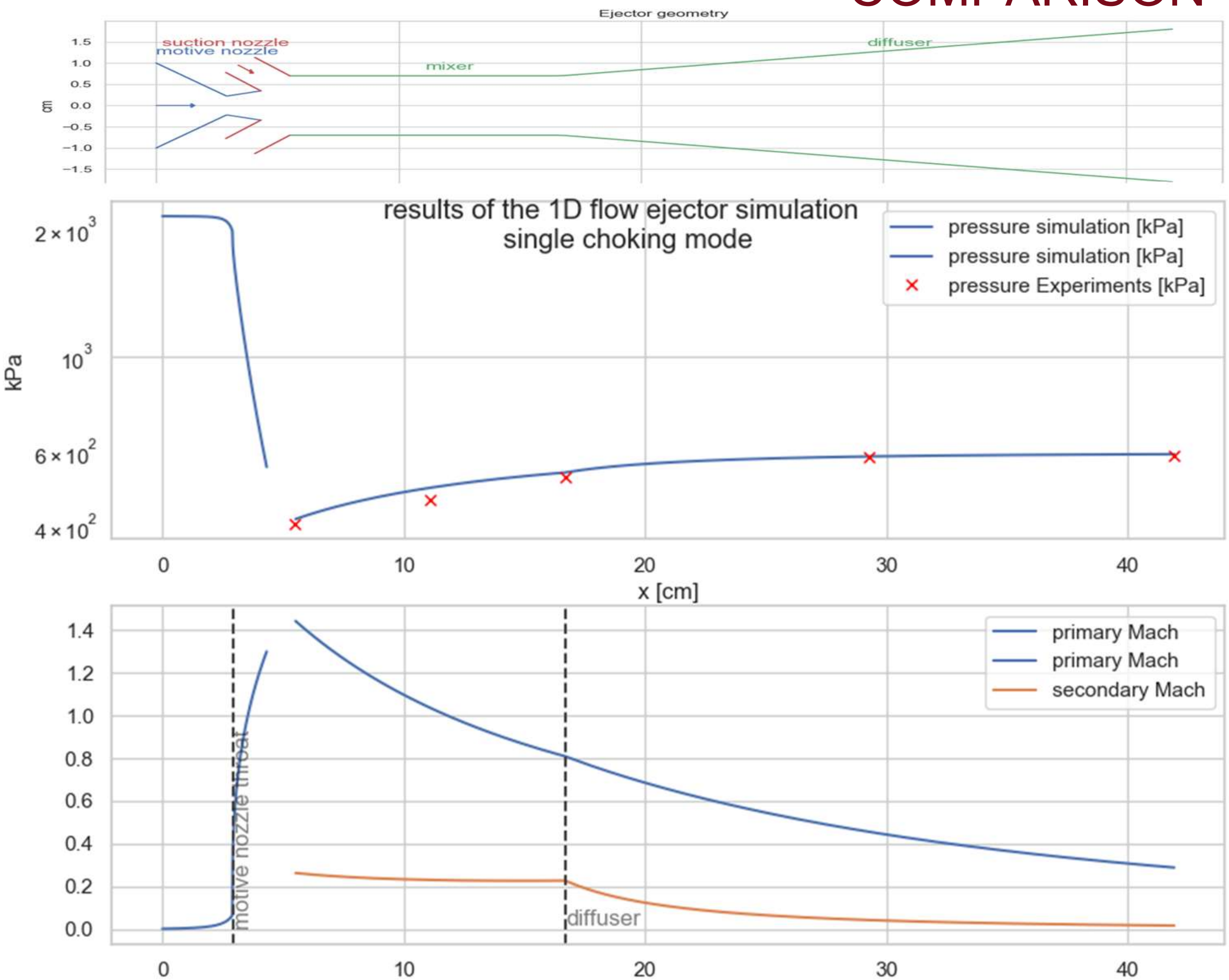
Coefficients for the Mass and Momentum exchange

Critical Operation(Double choking)



Outlet Pressure → Normal Shock Wave Position

COMPARISON WITH EXPERIMENT

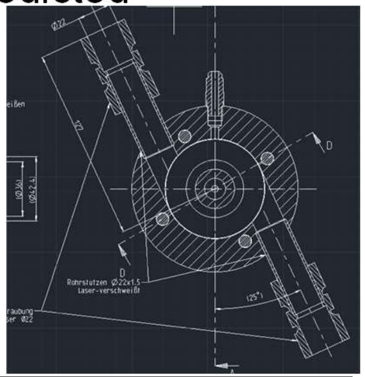


- Experiment: Butan Ejector (Single Choking)

Schlemminger et al 2019

→ good agreement of the pressure values.

→ 7-50% deviation of predicted mass flow rates



MFR g/s	Experiment	Our 1D Simulation
Motive Nozzle	127 g/s	190 g/s
Suction Nozzle	58 g/s	54 g/s

SUMMARY

- I have developed : 1D Ejector Simulation tool.
- Soon will be freely available on Github (open-source!)
- Geometry, Thermodynamic state, refrigerant flexible variable.
- Simulation takes only 20-40 seconds (on 1 CPU core)
- Python Package (run on every Operating System, and every server, you can connect it to any other post-processing tool)
- First experimental validation performed.

Outlook and open points:

- Further Tests/Comparisons with Experiments/CFD simulation needed. (Parameter Settings)
- Integration into Heat Pump Models (Dymola, Modellica)
- Graphical User Interface
- More precise calculation (Viscosity, Non-Equilibrium models, etc.)
- Still potential for speed up (currently runs on 1 CPU core)

THANKS FOR WATCHING/LISTENING!

Dr Adam Buruzs, 06.10.2022.

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