# A turbine based domestic micro ORC system

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# Introduction

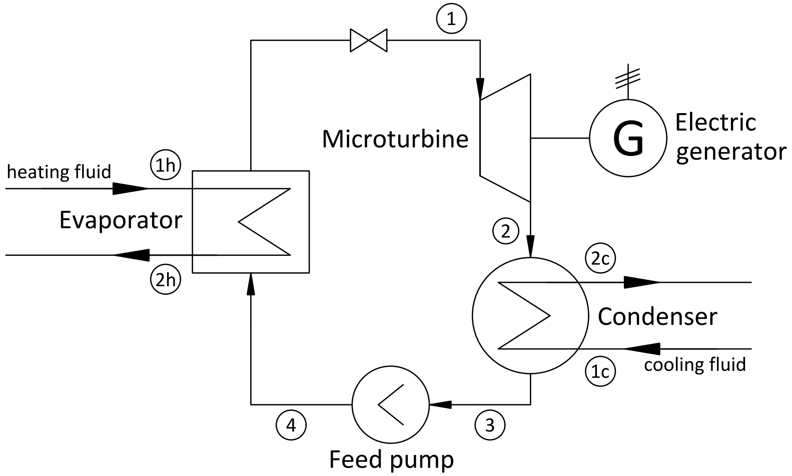
- Nowadays, the world needs more responsible ways of energy conversion and use,
- Lots of households use solid fuel boilers for heating,
- A high quality fuel is used to rise the temperature only by a few degrees,
- The reason: cogeneration in the range up to 20 kW is technologically and economically challenging,
- MicroCHP technologies for solid fuels:
    - Stirling engines,
    - Peltier modules,
    - Steam systems,
    - **ORC systems,**
    - Other.

# Solutions of ORC based systems

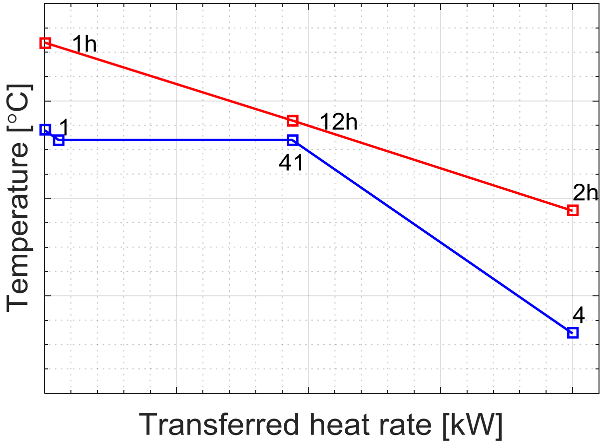
- Coupling an ORC to a typical domestic boiler, low temperature (90 °C) –> poor efficiency,
- Pressurized water loop -> high pressures,
- Thermal oil loop -> relatively expensive,
- Direct evaporation -> dangerous (potential explosions), risk of working fluid decomposition.

# Domestic ORC system layout

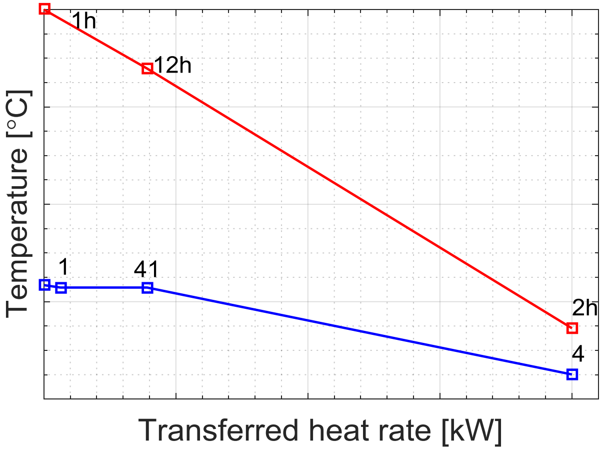
## ORC schematic



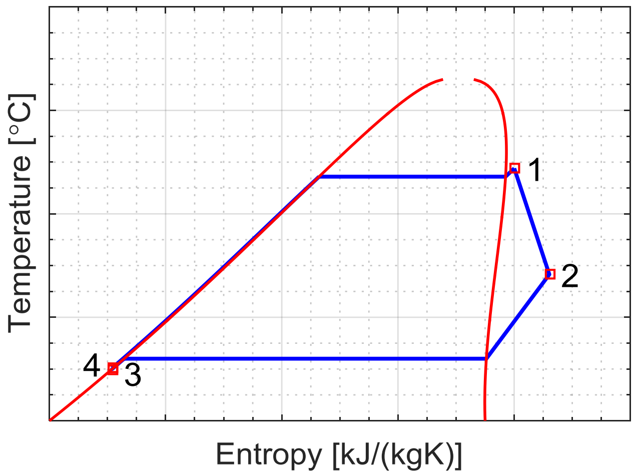

## Indirect evaporation



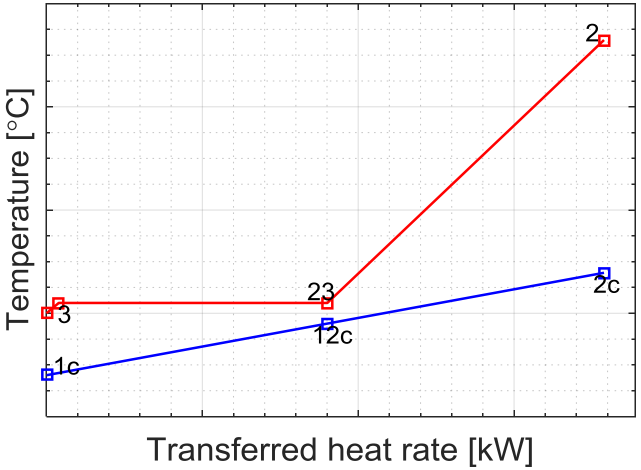

## Direct evaporation




## T-s diagram




## Condensing




- Introducing a regenerator is an option
- Many fluids possible
- Expansion unit is a challenge

# Results examples for a 15 kW boiler

Assumtions:

- Expander efficiency (including electric generator): 55 %
- Pump efficiency: 40 %
- Evaporation temperature: 150 ˚C
- Cooling water temperature: 15 ˚C
- Warm water temperature: above 40 ˚C

| Fluid | Condensing | Turbine power [kW] | Pump power [kW] | Net efficiency [%] | mass flow [kg/s] | $p_{ev}$ [bar(a)] | $p_{cond}$ [bar(a)] |
|---|---|---|---|---|---|---|---|
| Cyclopentane | Above atmospheric pressure | 1.46 | 0.1 | 9.7 | 0.029 | 10.67 | 1.04 |
| Acetone | | 1.32 | 0.07 | 8.8 | 0.023 | 10.34 | 1.01 |
| HFE7100 | | 1.19 | 0.12 | 7.9 | 0.1 | 8.21 | 1.02 |
| Cyclohexane | Below atmospheric pressure | 1.54 | 0.05 | 10.3 | 0.03 | 5.00 | 0.36 |
| MM | | 1.47 | 0.05 | 9.5 | 0.05 | 3.19 | 0.21 |
| HFE7100 | | 1.40 | 0.12 | 9.4 | 0.095 | 8.21 | 0.66 |

# Most important turbine design features

| Fluid | $N_S$ 30 krpm | $N_S$ 60 krpm | $N_S$ 100 krpm | $N_S$ 150 krpm | $N_S$ 200 krpm | $n_{opt}$ [krpm] | $u_{impulse}$ [m/s] | $u_{reaction}$ [m/s] | $A_{1x}$ [mm$^2$] |
|---|---|---|---|---|---|---|---|---|---|
| Cyclopentane | 0.010 | 0.019 | 0.032 | 0.048 | 0.064 | 280 | 203 | 287 | 8.9 |
| Acetone | 0.008 | 0.017 | 0.028 | 0.042 | 0.055 | 325 | 216 | 305 | 7.9 |
| HFE7100 | 0.029 | 0.057 | 0.095 | 0.143 | 0.190 | 94 | 101 | 142 | 19.6 |
| Cyclohexane | 0.016 | 0.031 | 0.052 | 0.078 | 0.104 | 174 | 203 | 286 | 18.2 |
| MM | 0.031 | 0.061 | 0.102 | 0.154 | 0.205 | 88 | 150 | 213 | 33.9 |
| HFE7100 | 0.030 | 0.059 | 0.099 | 0.149 | 0.198 | 91 | 111 | 157 | 18.7 |

Where:

- $N_S$ – specific speed
- $n_{opt}$ – approximate optimal rotational speed
- $u_{impulse}$ – rotor peripheral speed in a single stage impulse turbine
- $u_{reaction}$ – rotor peripheral speed in a single stage reaction turbine
- $A_{1x}$ – total area of nozzle critical section

# Single stage impulse turbines

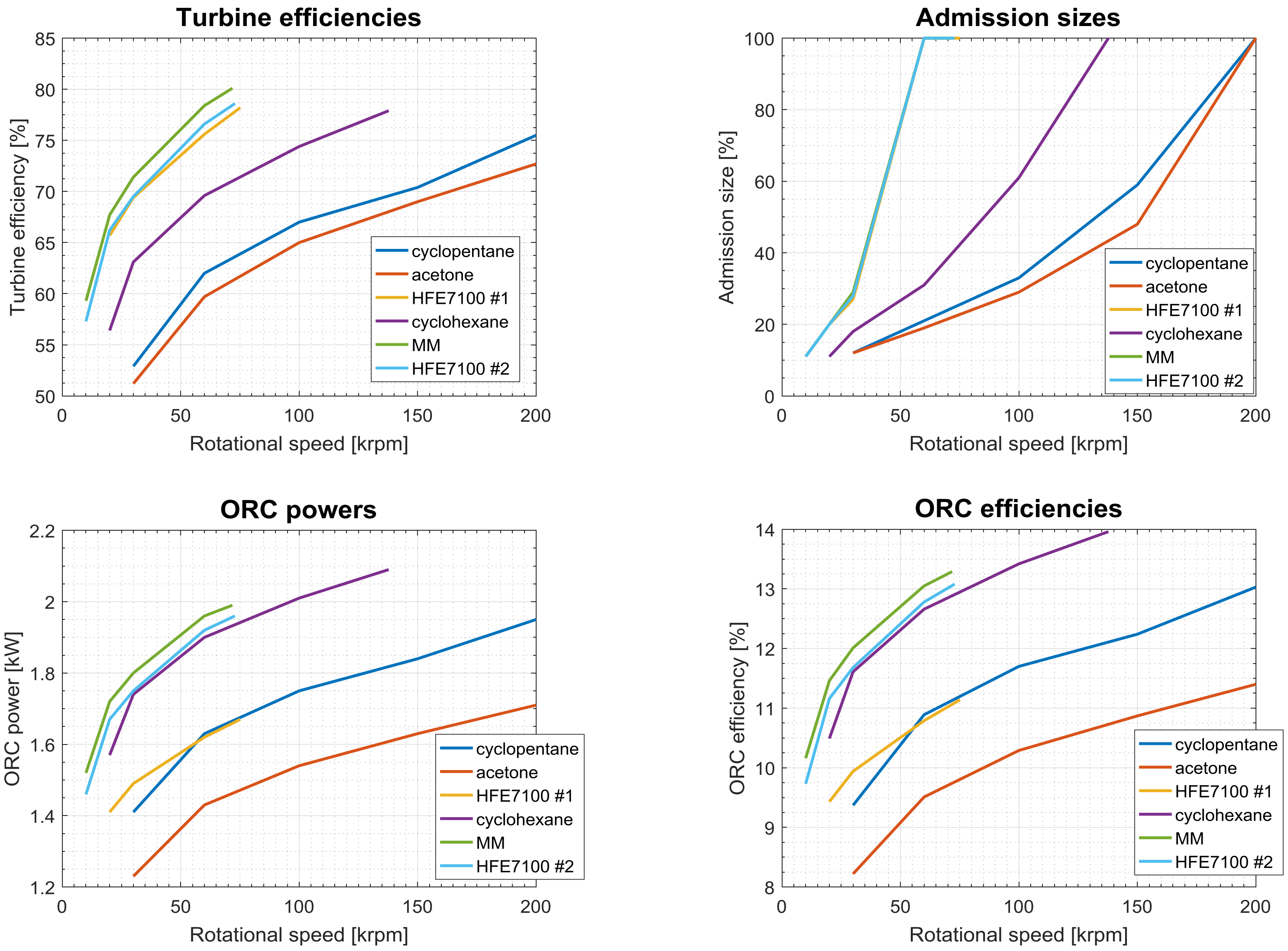
**Advantages:**

- Simple design,
- Low axial thrust,
- Can be relatively efficient even at low specific speeds (partial admission possible).

**Disadvantages:**

- Worse efficiency than reaction stages,
- Worse off-design performance than multistage designs,

# Impulse turbines performance and features (correlation based)

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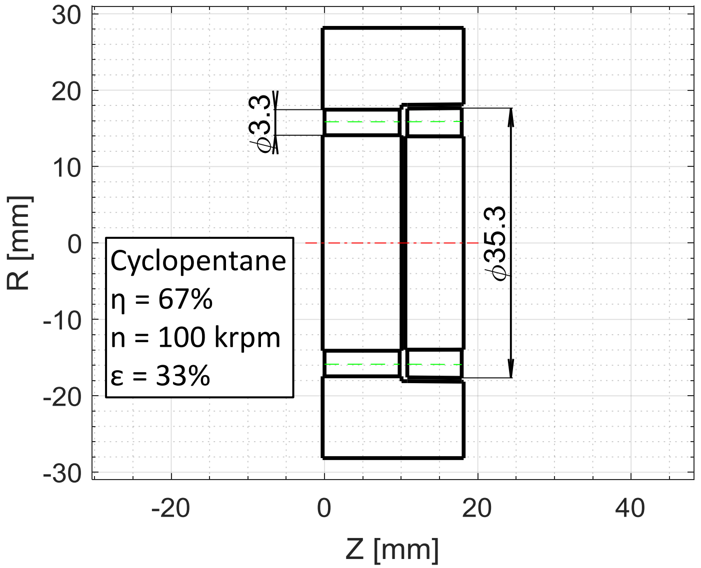
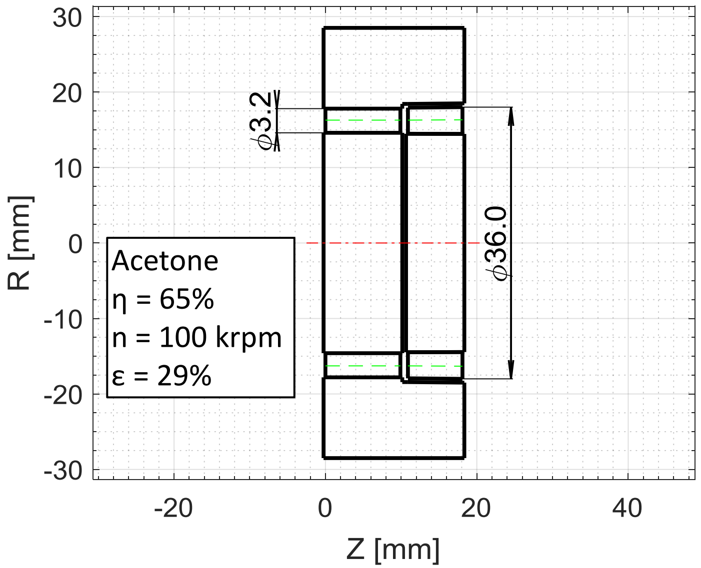
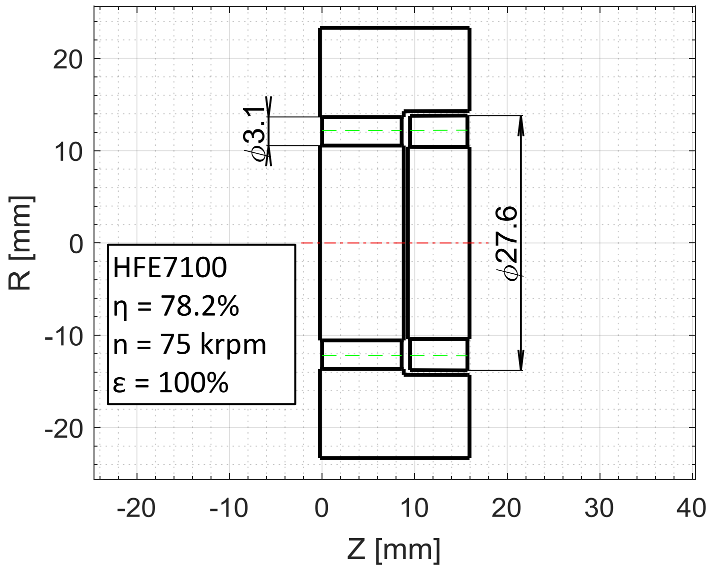
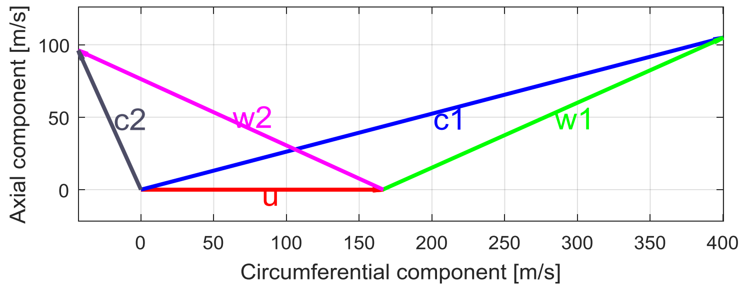
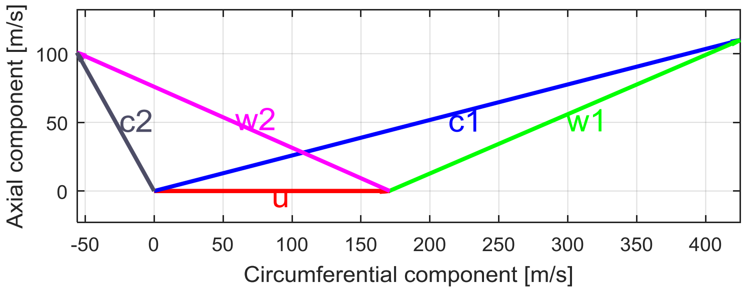
# Examples for 100 krpm limit (high condensing pressure)

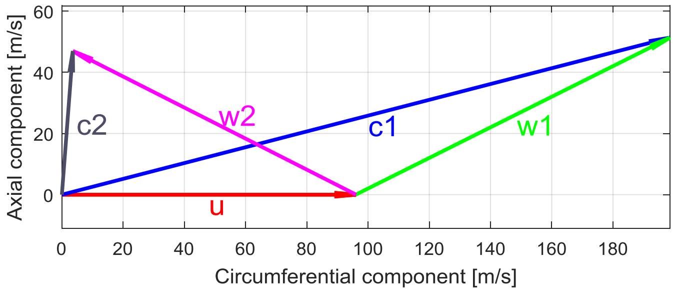
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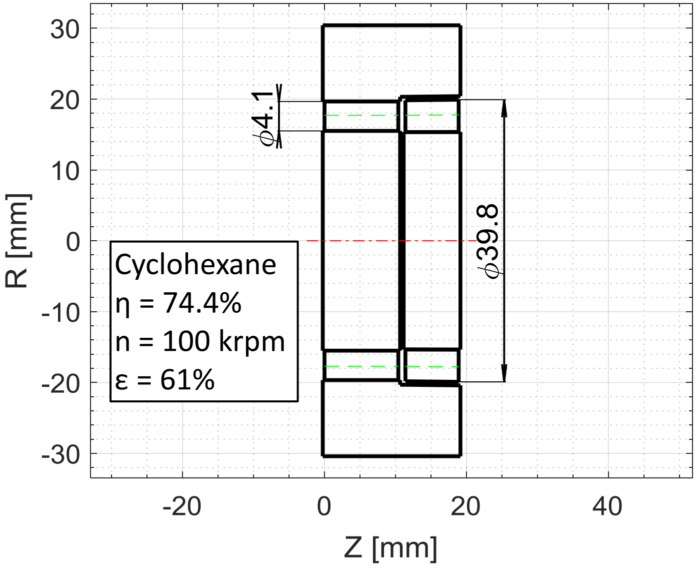
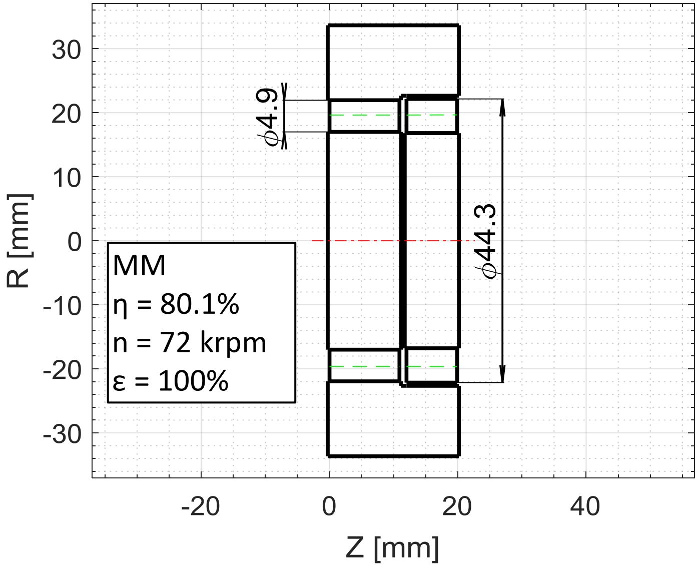
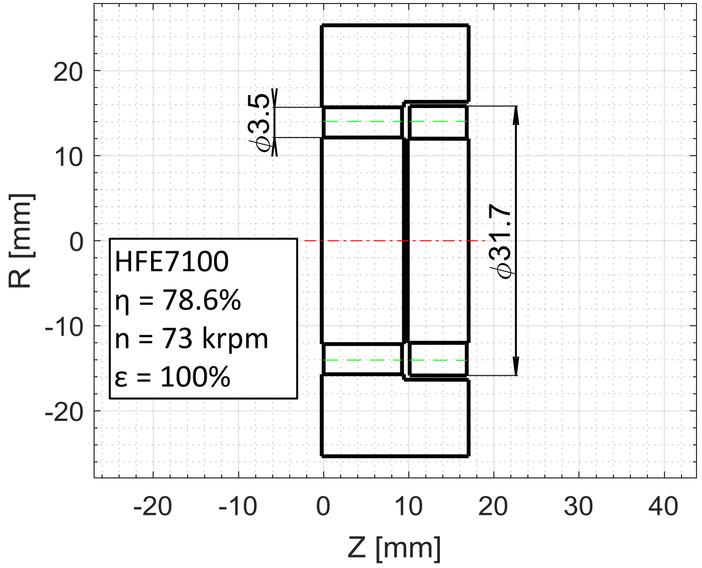
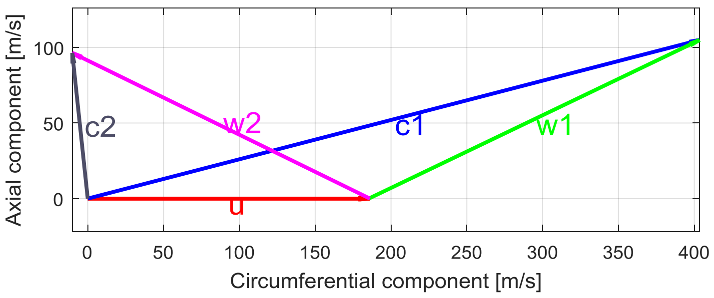
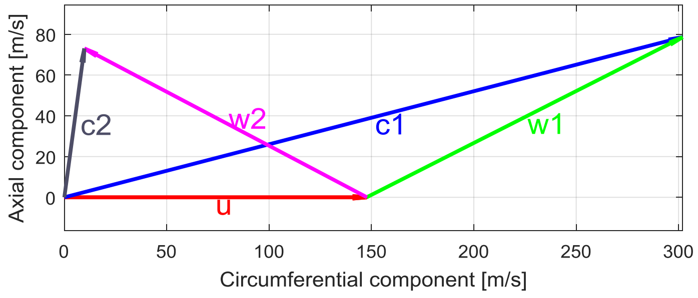
# Examples for 100 krpm limit (low condensing pressure)

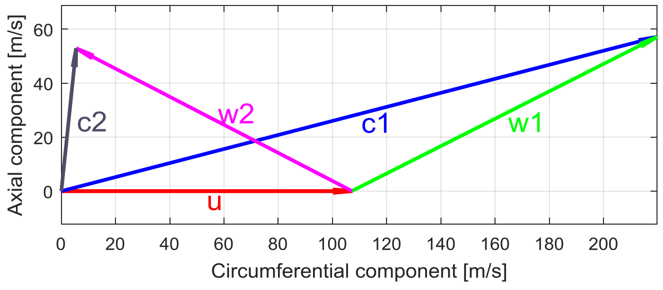


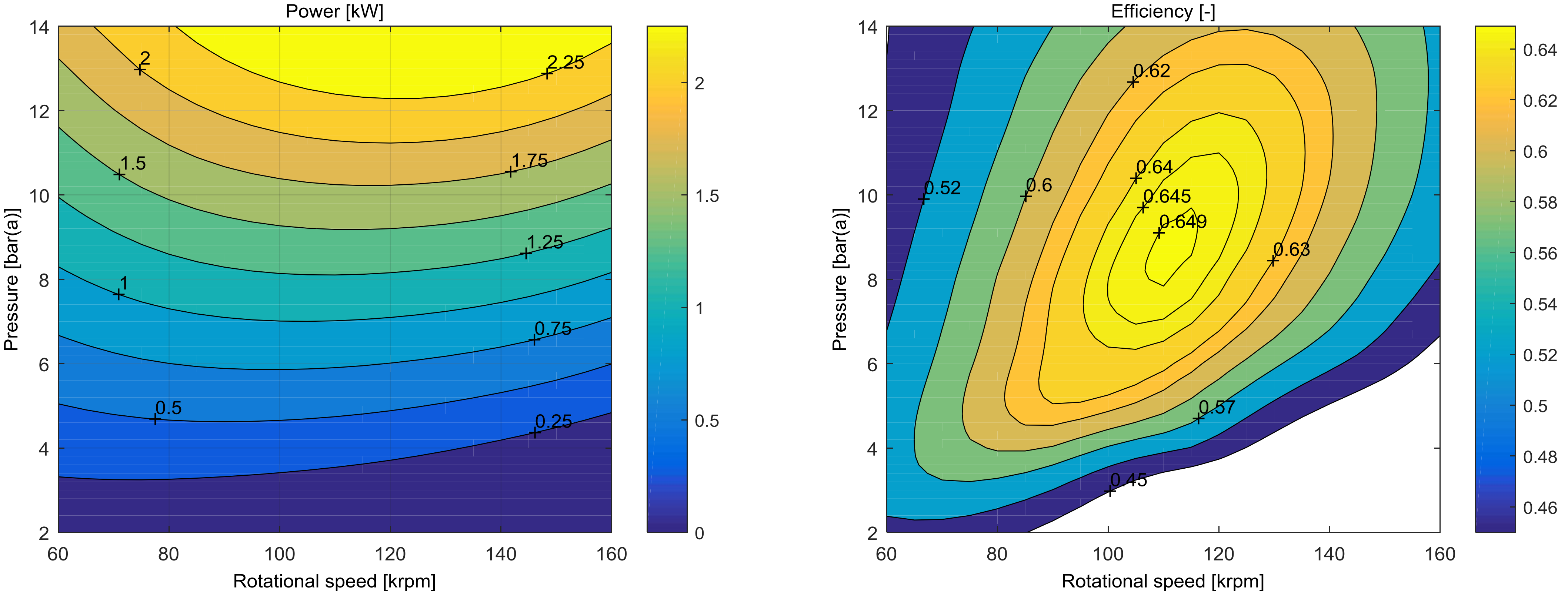



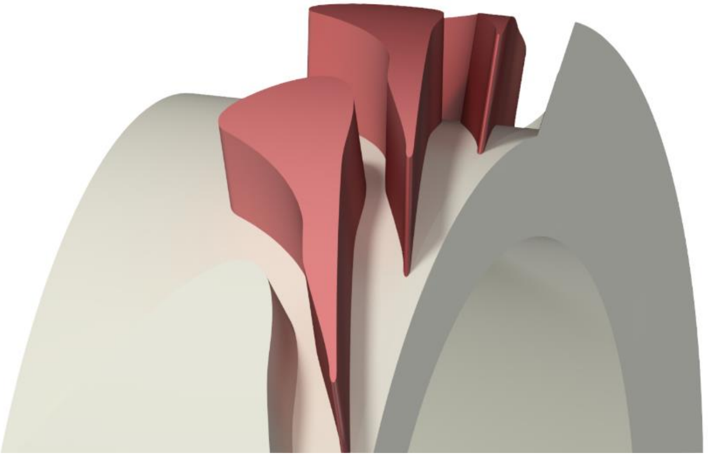



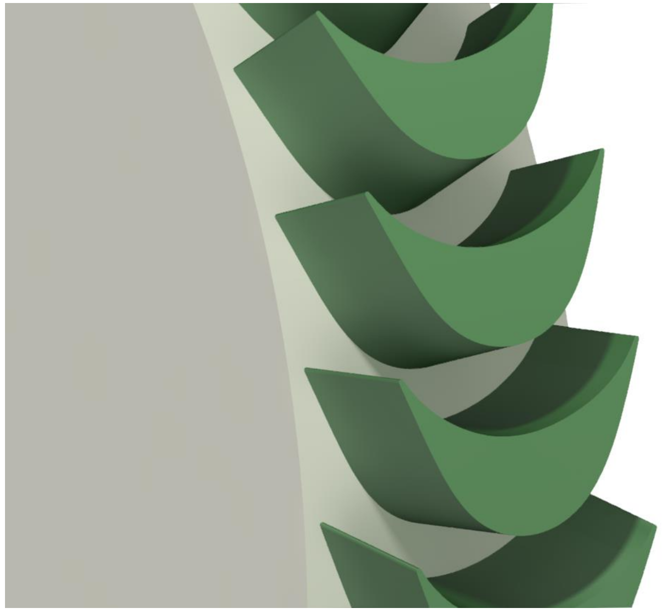



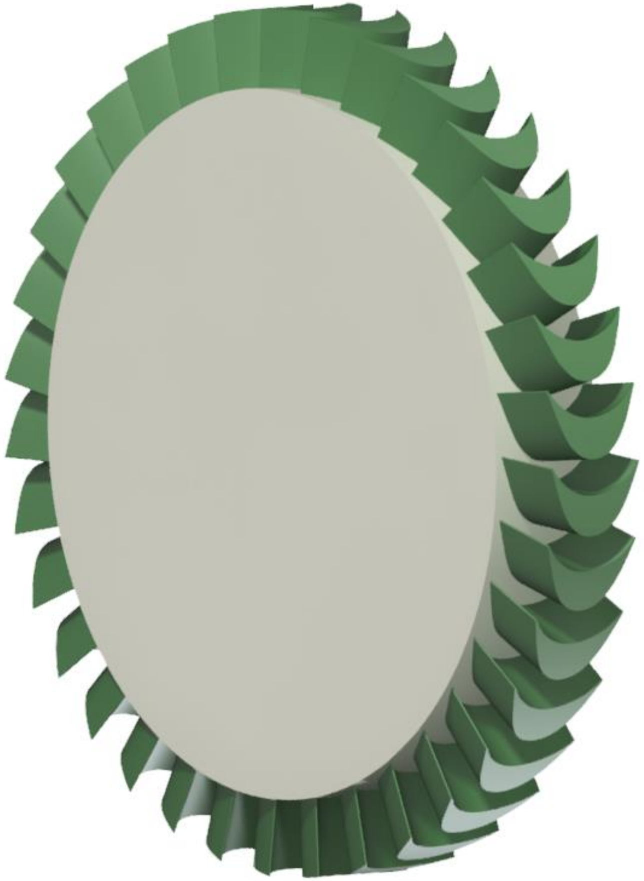
# Case study – acetone turbine off-design performance (constant back pressure)

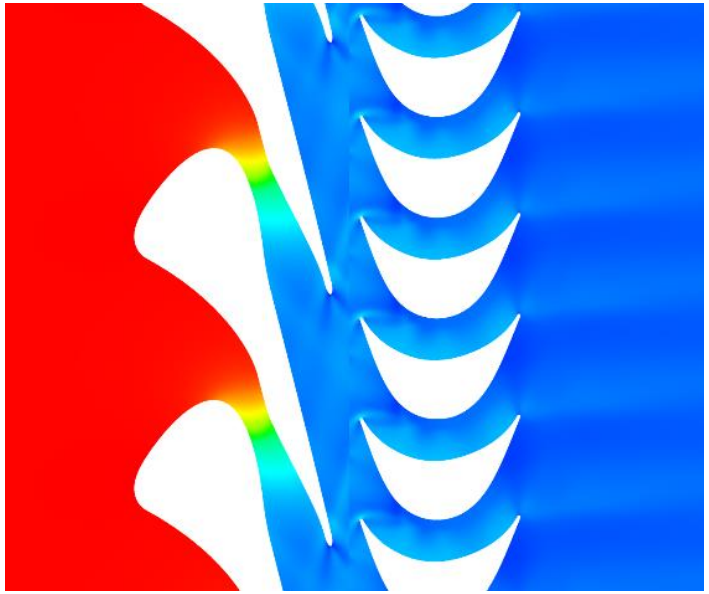


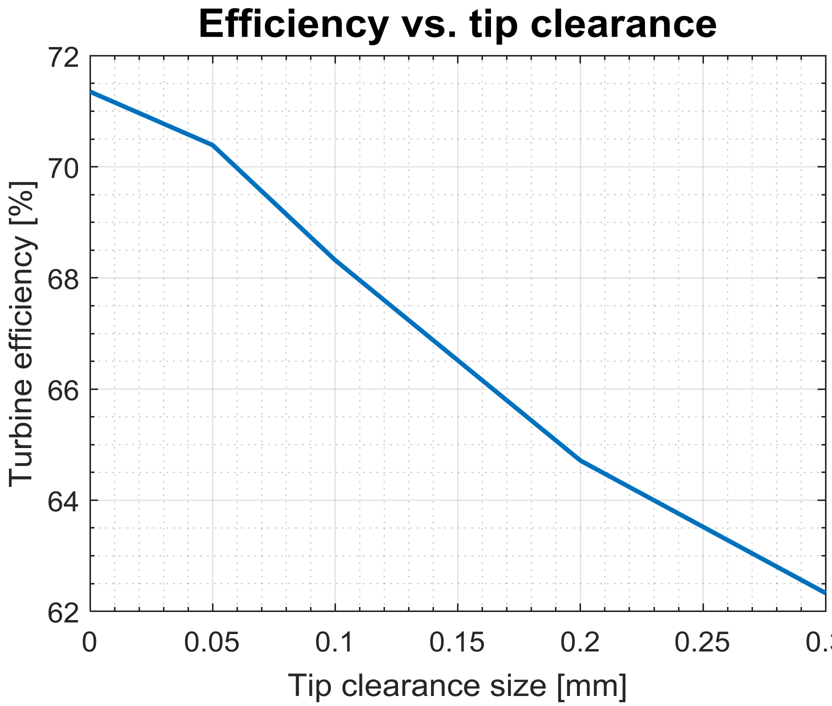
# Case study – acetone turbine blade geometry and CFD









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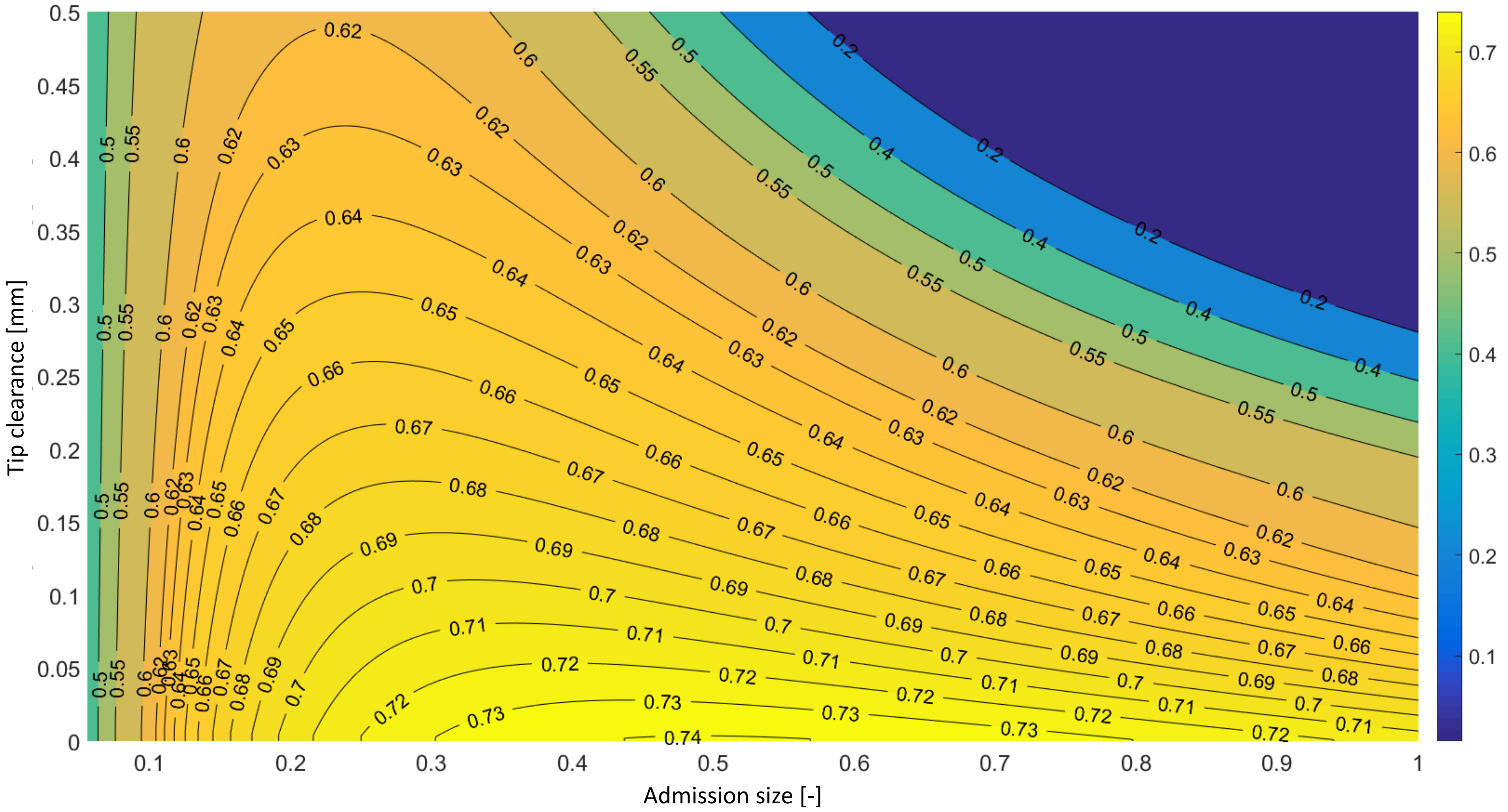
# Case study – 3 kW HFE7100 turbine influence of tip clearance on optimal admission

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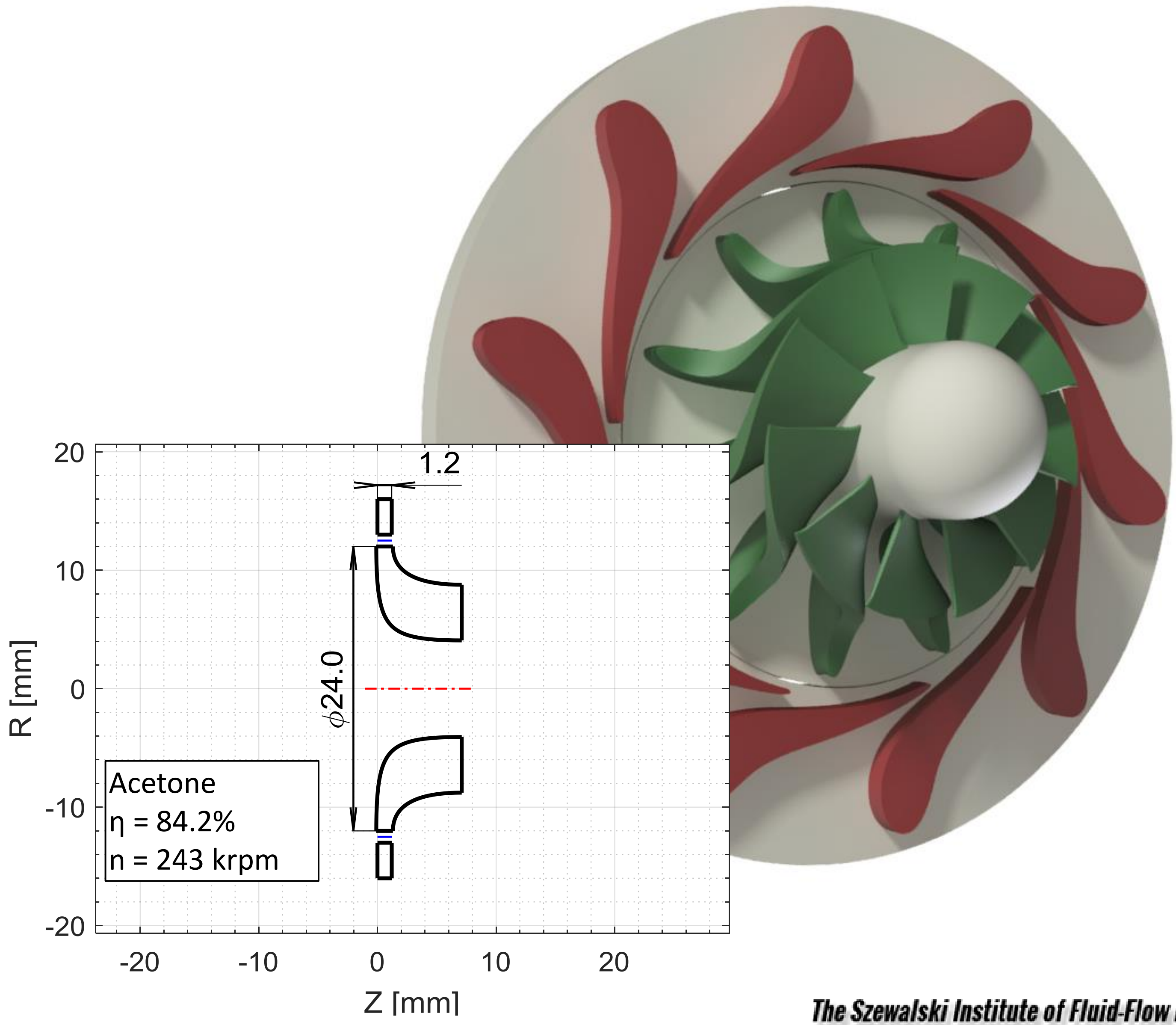
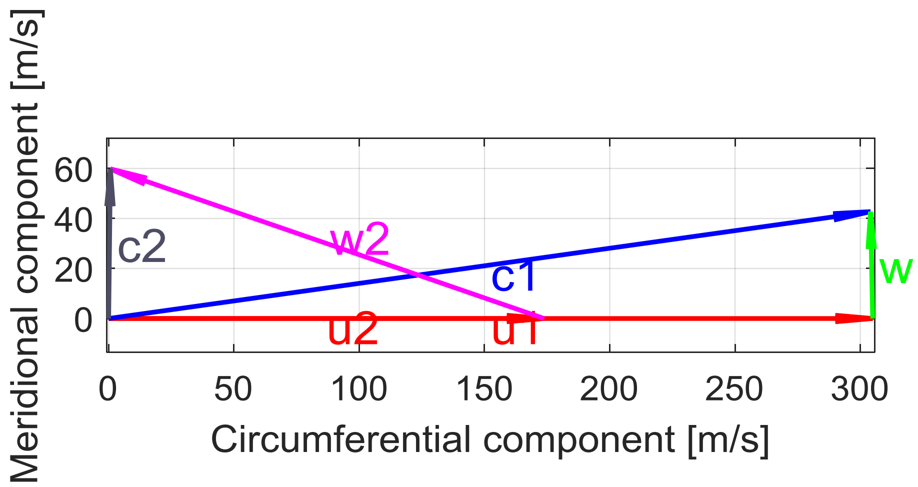
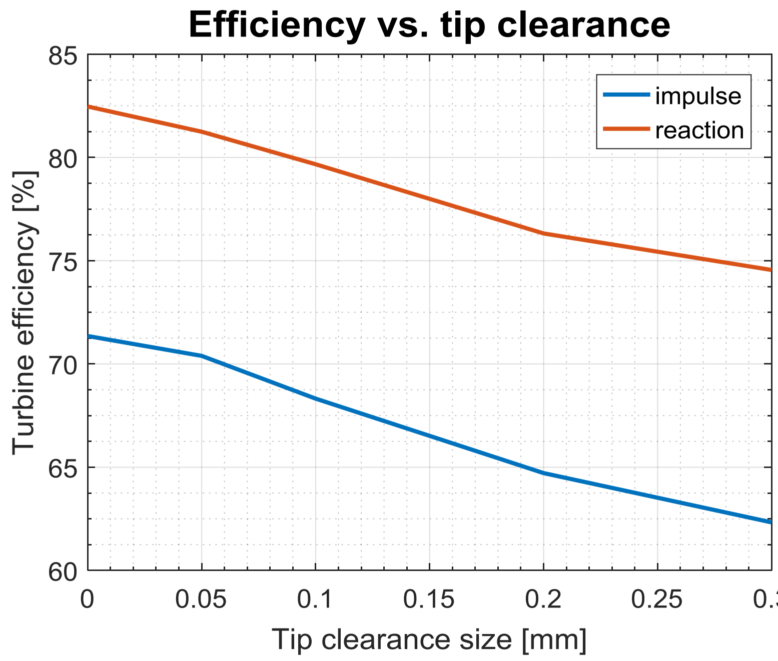
# Reaction (radial inflow) turbine example



# Conclusions

- It is feasible to design turbines for very small power that achieve acceptable efficiencies,
- Single stage impulse turbines are a simple and attractive option,
- Reaction turbines are more efficient but more difficult to build,
- The sizes, efficiencies, peripheral speeds and rotational speeds vary strongly with respect to different working fluids.

# Acknowledgements

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