



## Hybrid Heat Pump Solutions for Industrial Energy Savings

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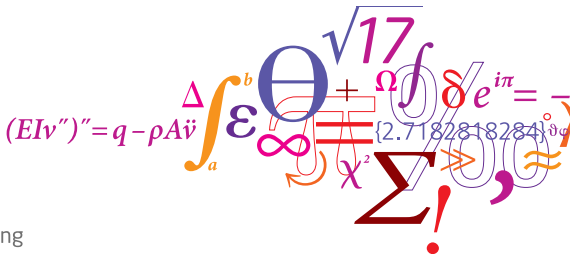
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# Hybrid Heat Pump Solutions for Industrial Energy Savings

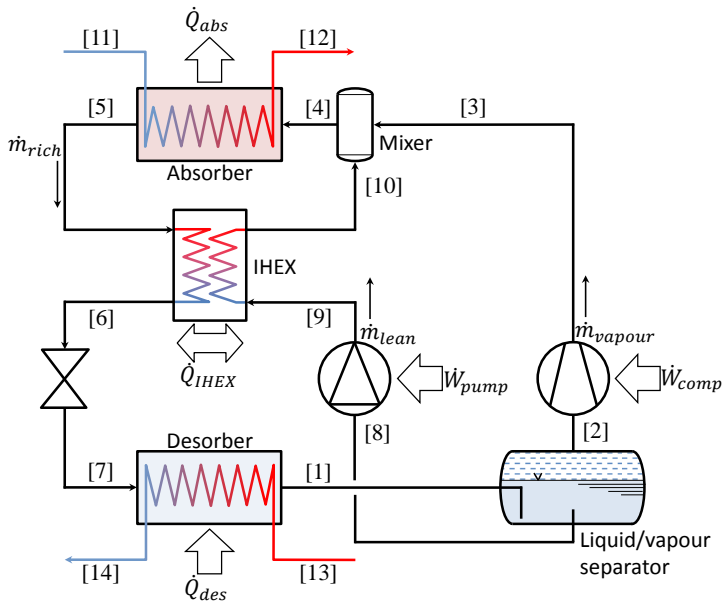
DTU International Energy Conference  
September 10<sup>th</sup>-12<sup>th</sup> 2013

Jonas Kjær Jensen  
PhD Student  
Thermal Energy Section



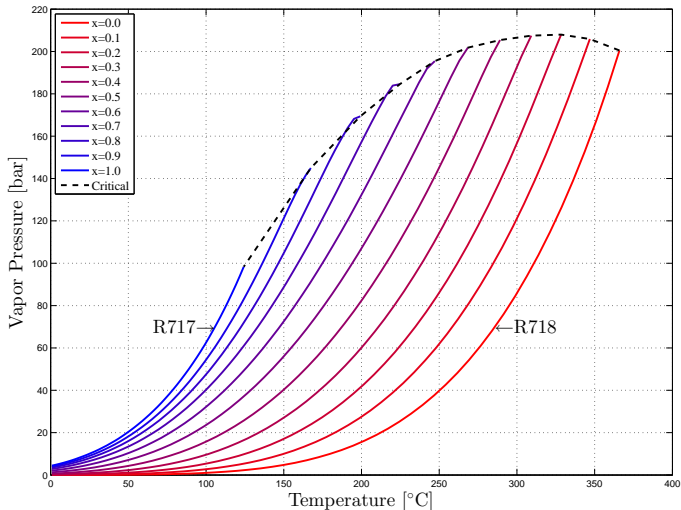
- Introduction to the hybrid absorption compression heat pump
- Advantages of zeotropic mixtures specifically  $\text{NH}_3/\text{H}_2\text{O}$
- Evaluation of important design parameters.
- Prospect for high temperature development  $T_{supply} < 110^\circ\text{C}$ .
- Conclusion & future work

# The Hybrid Heat Pump



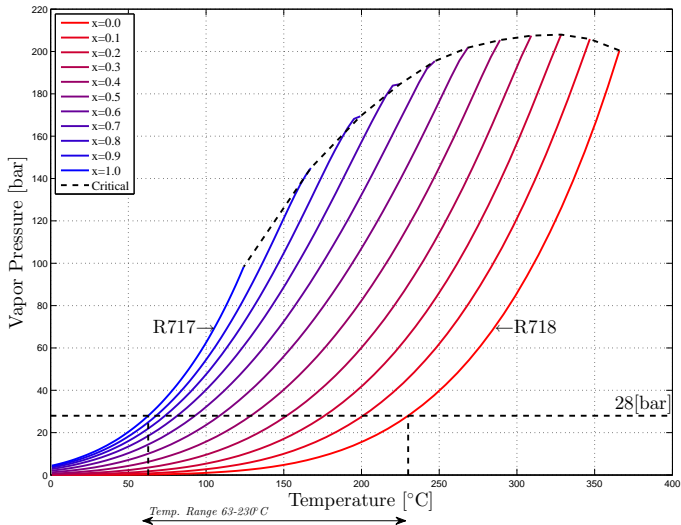
# Advantages of Zeotropic Mixtures

## Reduction of Vapor Pressure



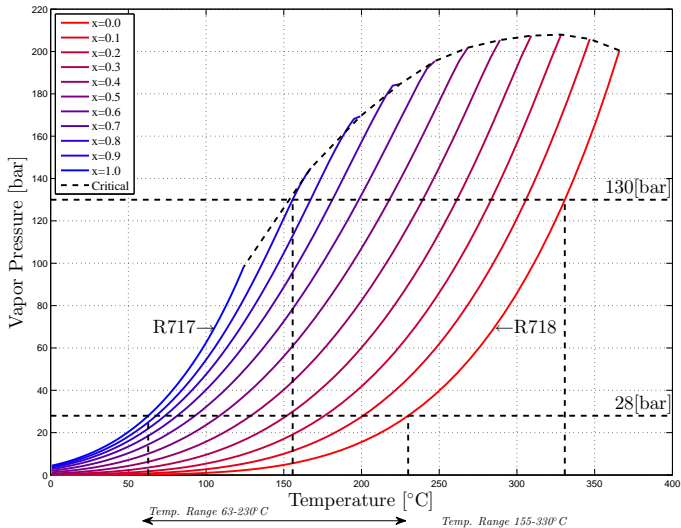
# Advantages of Zeotropic Mixtures

## Reduction of Vapor Pressure



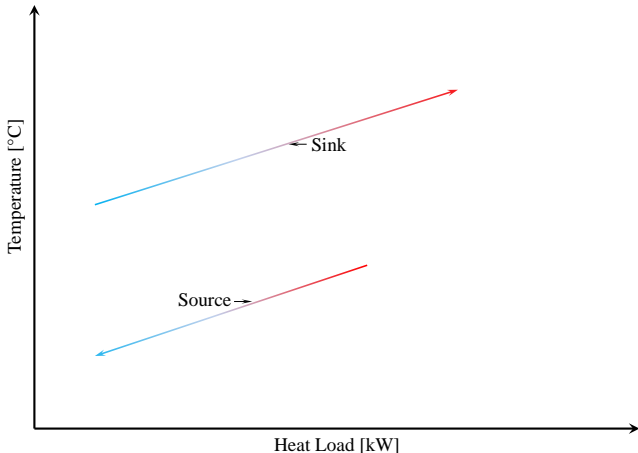
# Advantages of Zeotropic Mixtures

## Reduction of Vapor Pressure



# Advantages of Zeotropic Mixtures

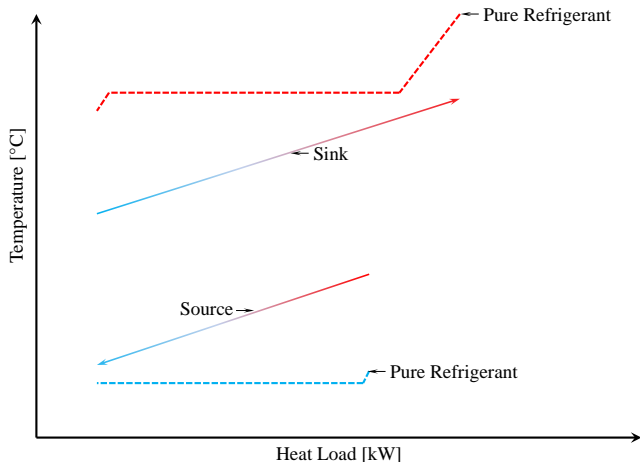
## Reduction of Entropy Generation





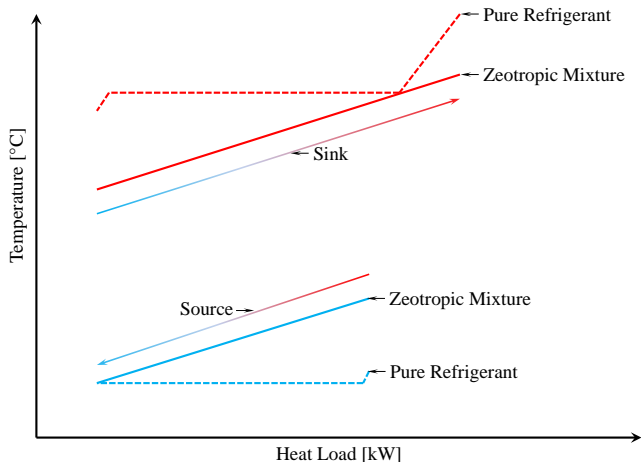
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## Reduction of Entropy Generation



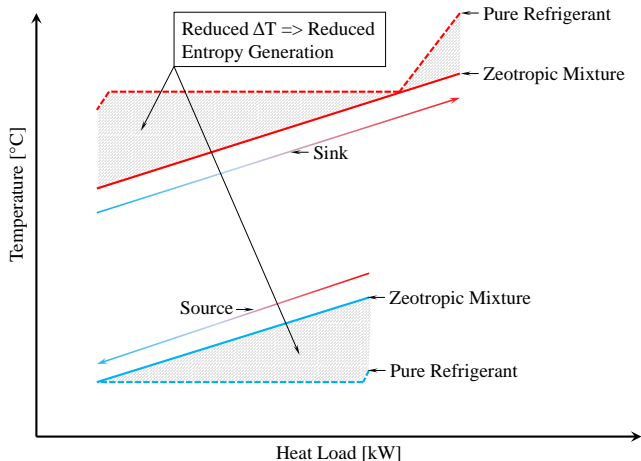
# Advantages of Zeotropic Mixtures

## Reduction of Entropy Generation



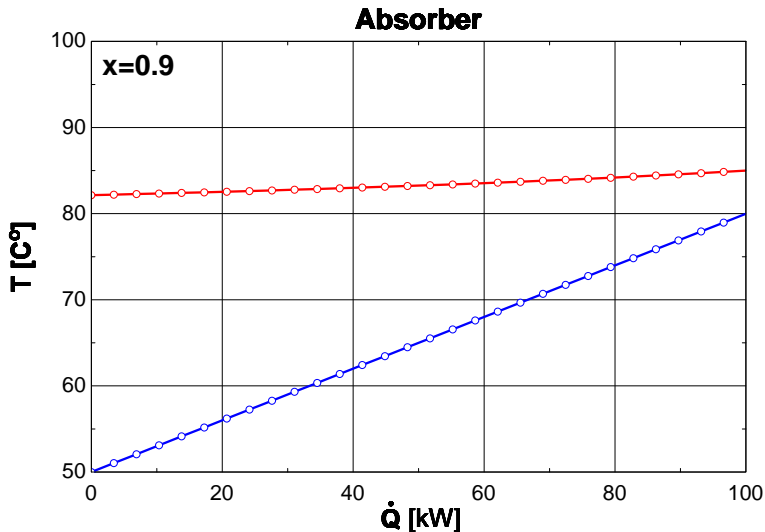
# Advantages of Zeotropic Mixtures

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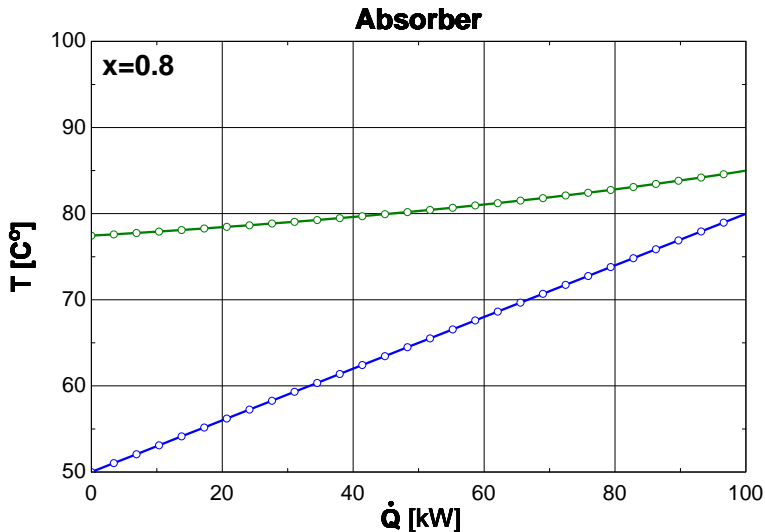
# Advantages of Zeotropic Mixtures

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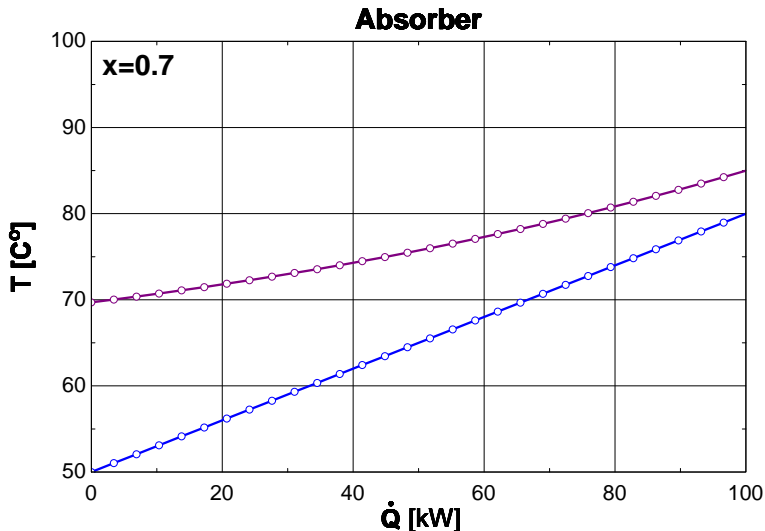
# Advantages of Zeotropic Mixtures

## Reduction of Entropy Generation



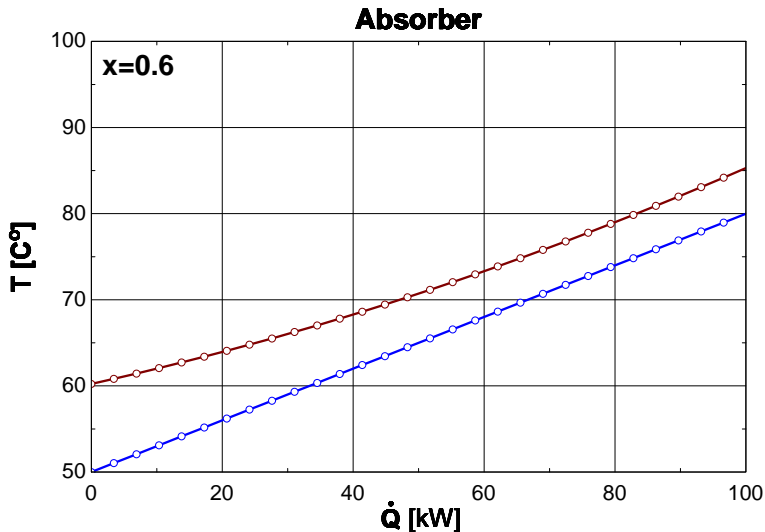
# Advantages of Zeotropic Mixtures

## Reduction of Entropy Generation



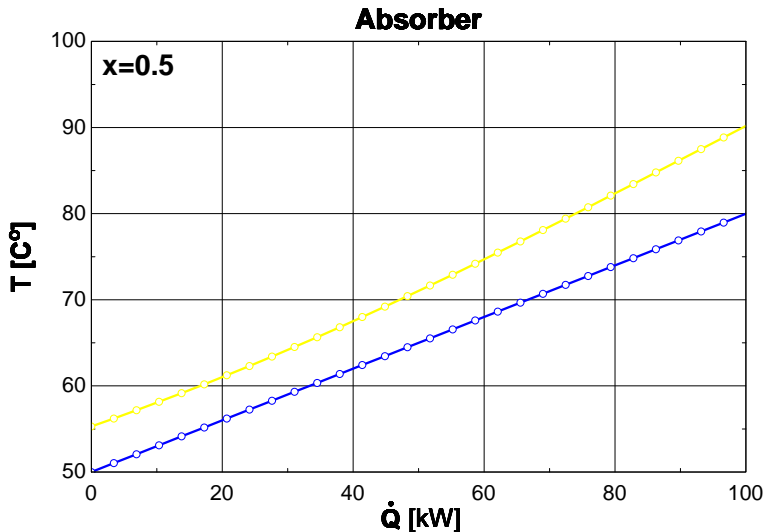
# Advantages of Zeotropic Mixtures

## Reduction of Entropy Generation



# Advantages of Zeotropic Mixtures

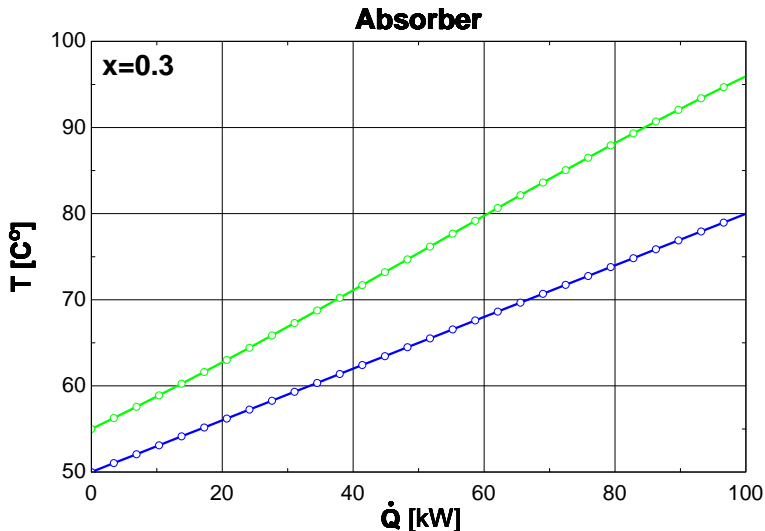
## Reduction of Entropy Generation





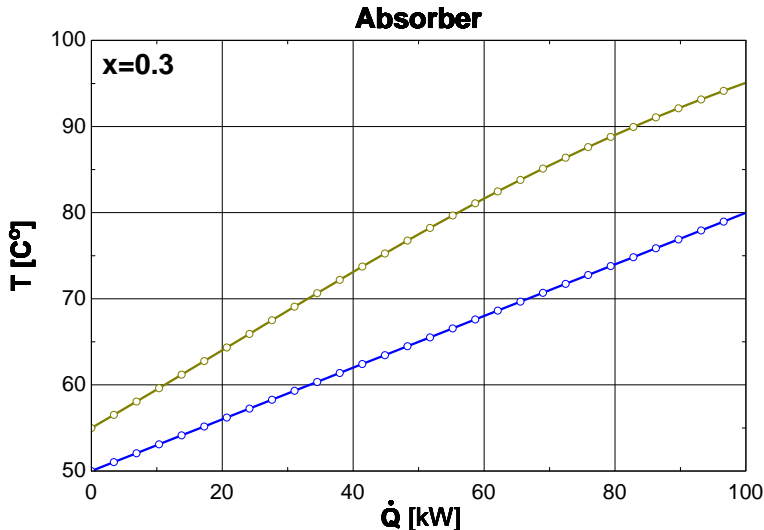
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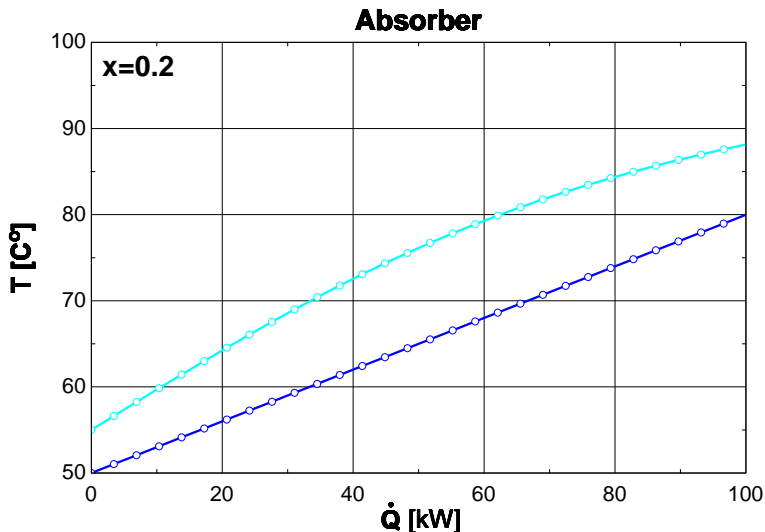
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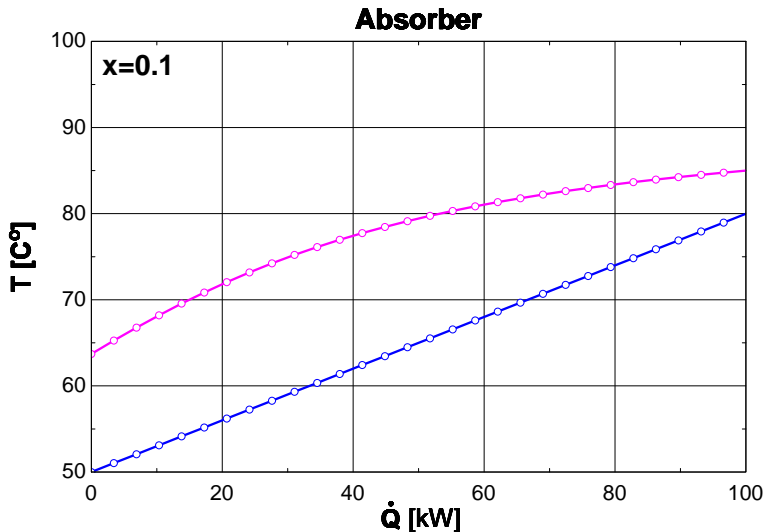
# Advantages of Zeotropic Mixtures

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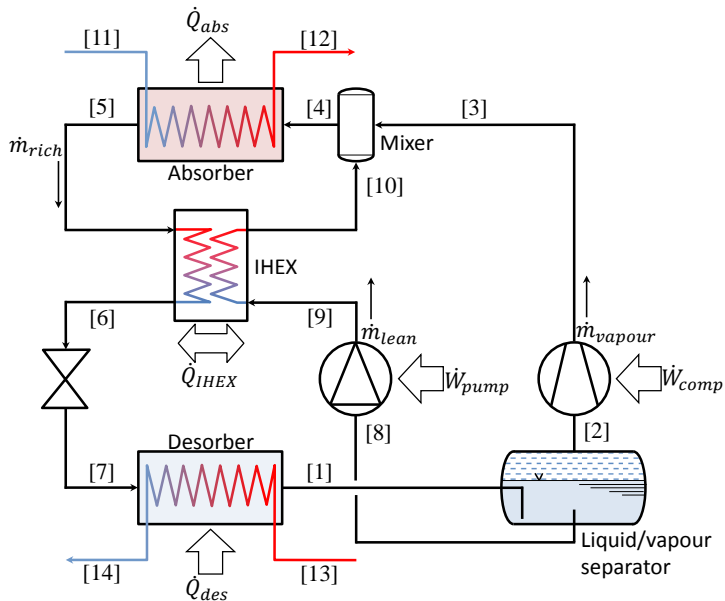


# Advantages of Zeotropic Mixtures

## Reduction of Entropy Generation



# The Hybrid Heat Pump: Design parameters $x_r$ & $f$



# Influence of $x_r$ & $f$ : $T_{sink,out} = 110^\circ\text{C}$ , $\Delta T_{lift} = 30^\circ\text{C}$

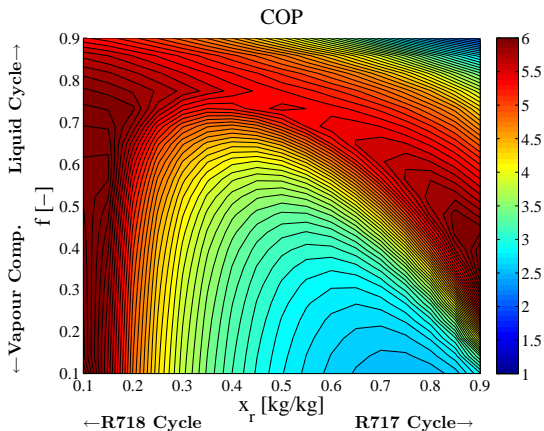
## Inputs and Assumptions

External Inputs	
$T_{sink,in} =$	$80^\circ\text{C}$
$T_{sink,out} =$	$110^\circ\text{C}$
$T_{source,in} =$	$80^\circ\text{C}$
$\dot{m}_{sink} =$	$1\text{kg/s}$
$\dot{m}_{source} =$	$10\text{kg/s}$

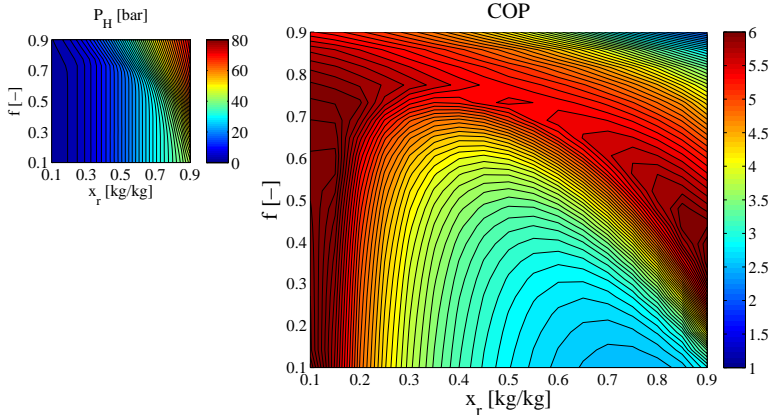
Internal Inputs	
$\Delta T_{pinch,abs} =$	$5^\circ\text{C}$
$\Delta T_{pinch,des} =$	$5^\circ\text{C}$
$\eta_{is,comp} =$	$0.7$
$\eta_{is,pump} =$	$0.7$
$\epsilon_{IHEX}$	$0.8$

Pressure drops are neglected.

Influence of  $x_r$  &  $f$ :  $T_{sink,out} = 110^\circ C$ ,  $\Delta T_{lift} = 30^\circ C$

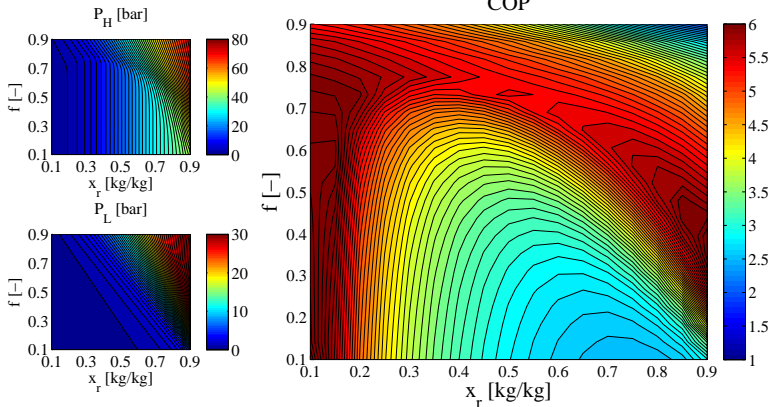


# Influence of $x_r$ & $f$ : $T_{sink,out} = 110^\circ C$ , $\Delta T_{lift} = 30^\circ C$

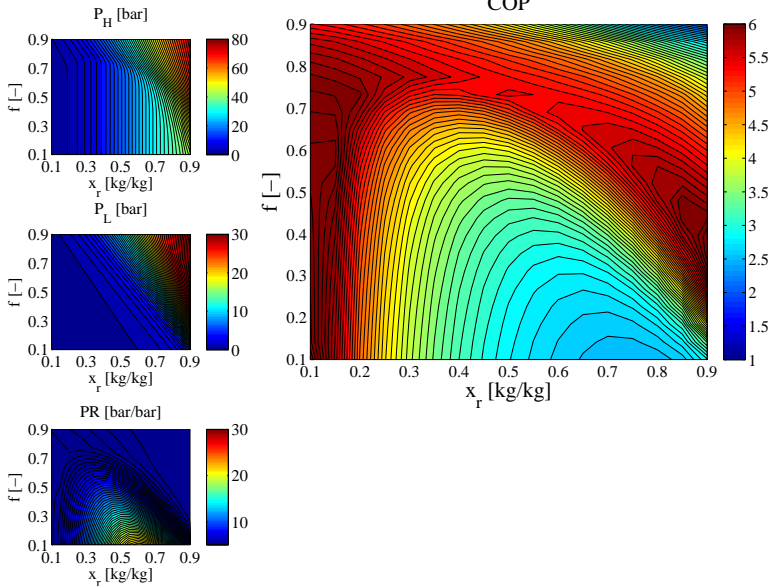




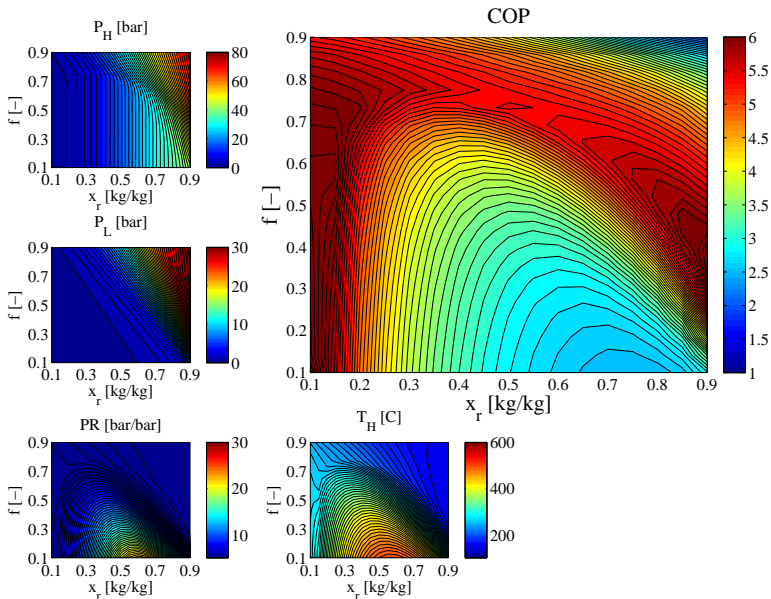
# Influence of $x_r$ & $f$ : $T_{sink,out} = 110^\circ C$ , $\Delta T_{lift} = 30^\circ C$



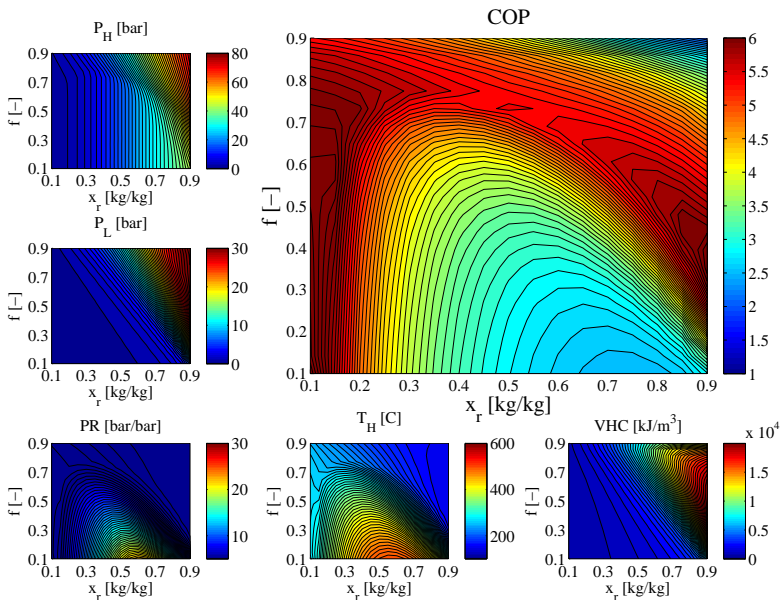
# Influence of $x_r$ & $f$ : $T_{sink,out} = 110^\circ C$ , $\Delta T_{lift} = 30^\circ C$



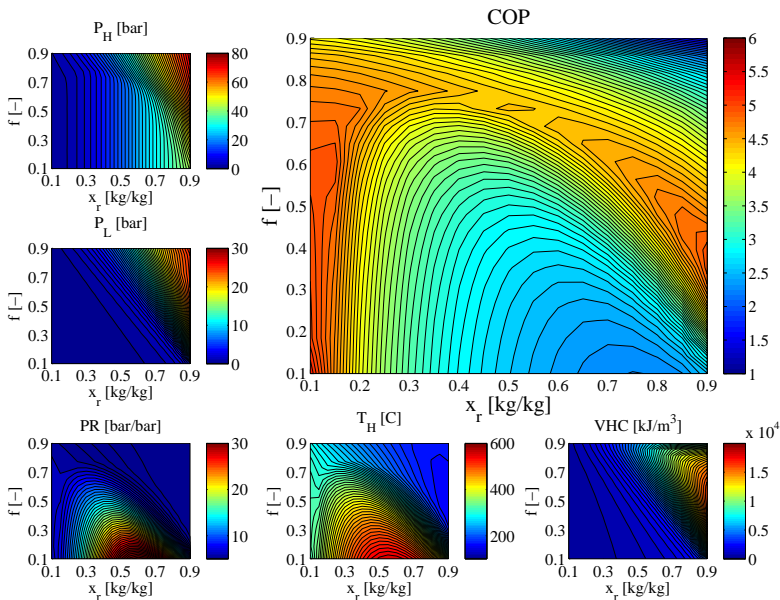
# Influence of $x_r$ & $f$ : $T_{sink,out} = 110^\circ C$ , $\Delta T_{lift} = 30^\circ C$



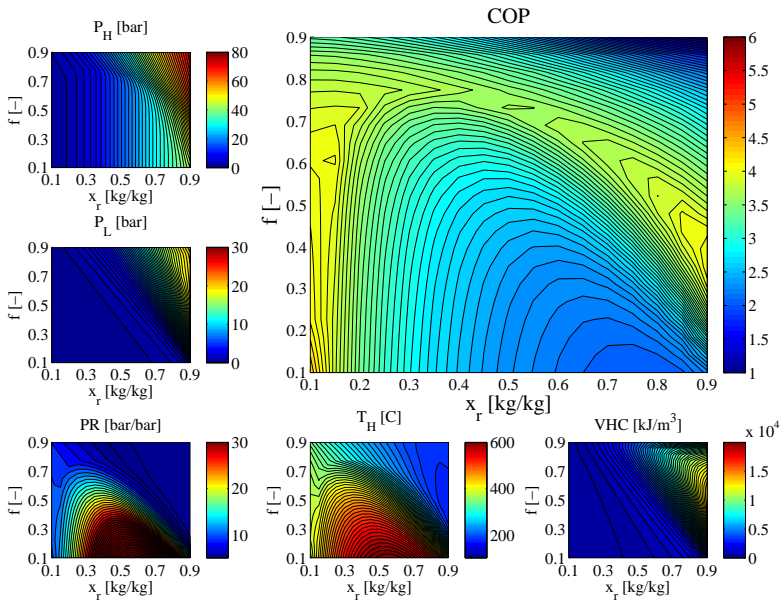
# Influence of $x_r$ & $f$ : $T_{sink,out} = 110^\circ C$ , $\Delta T_{lift} = 30^\circ C$



# Influence of $x_r$ & $f$ : $T_{sink,out} = 110^\circ C$ , $\Delta T_{lift} = 40^\circ C$



# Influence of $x_r$ & $f$ : $T_{sink,out} = 110^\circ C$ , $\Delta T_{lift} = 50^\circ C$

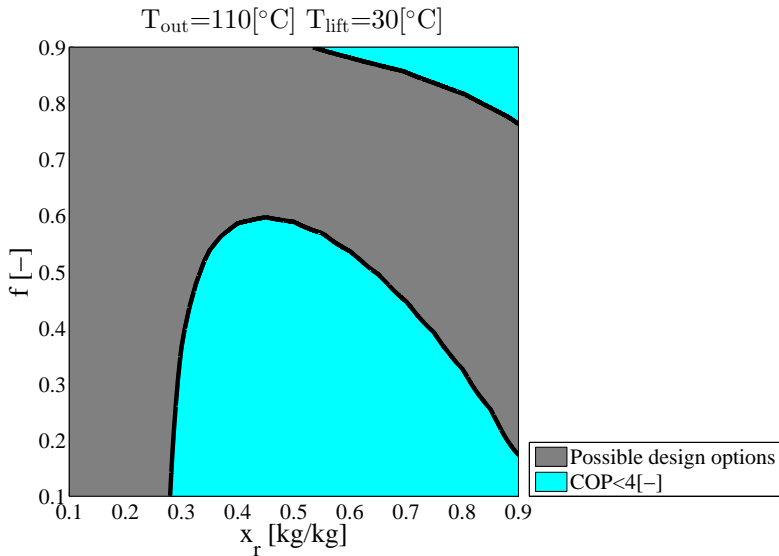


# Working domain hybrid heat pumps

Constraints corresponding to standard refrigeration components

Design Constraints		
$COP$	$> 4[-]$	Economic
$P_H$	$< 25[bar]$	Standard refrigeration equipment
$P_L$	$> 1[bar]$	No entrainment of air from ambient
$VHC$	$> 2[MJ/m^3]$	Economic ( $\dot{Q}_{abs}/\dot{V}_{suc,comp}$ )
$T_H$	$< 160[^\circ C]$	Thermal stability of oil

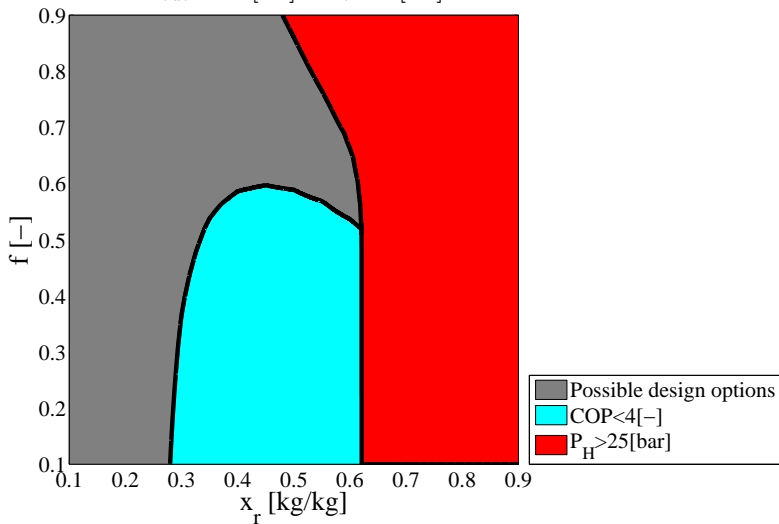
# Working domain hybrid heat pumps





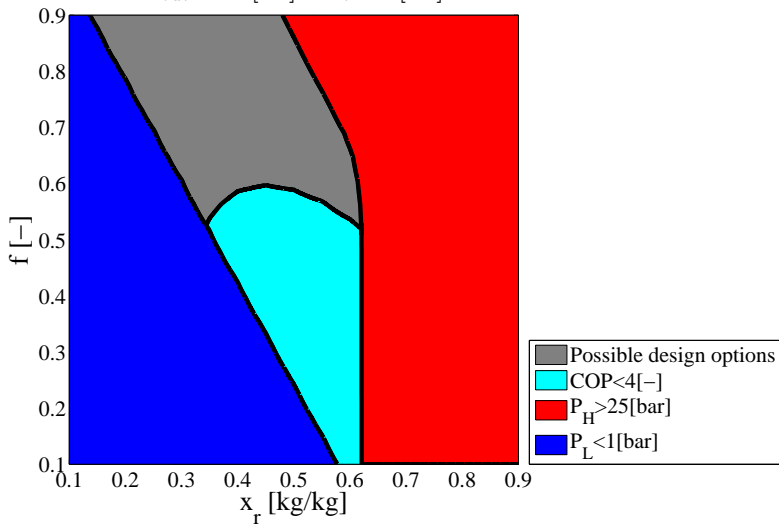
# Working domain hybrid heat pumps

$$T_{\text{out}}=110[^\circ\text{C}] \quad T_{\text{lift}}=30[^\circ\text{C}]$$



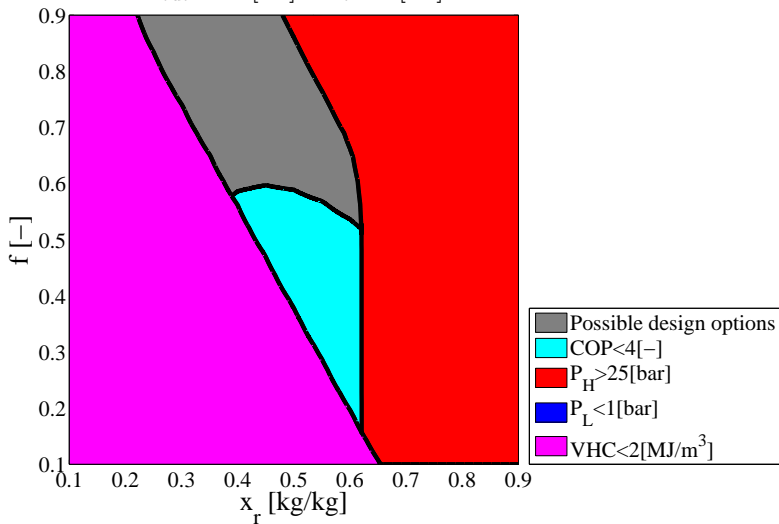
# Working domain hybrid heat pumps

$$T_{\text{out}}=110[^\circ\text{C}] \quad T_{\text{lift}}=30[^\circ\text{C}]$$



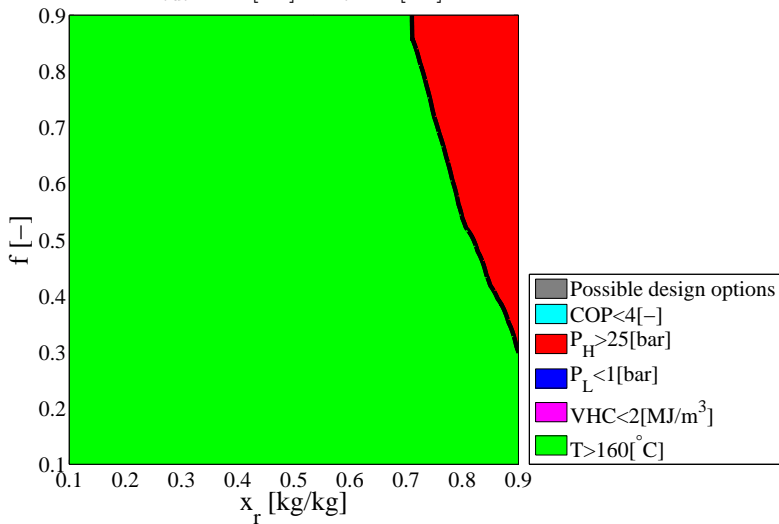
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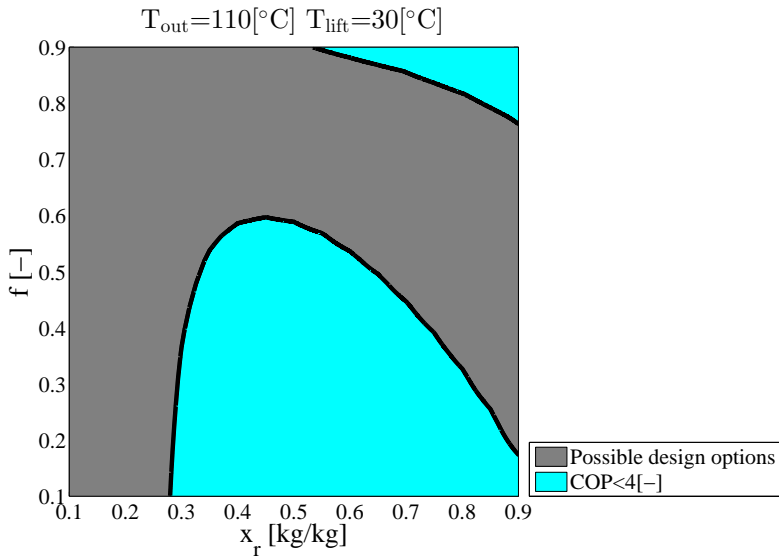


# Working domain hybrid heat pumps

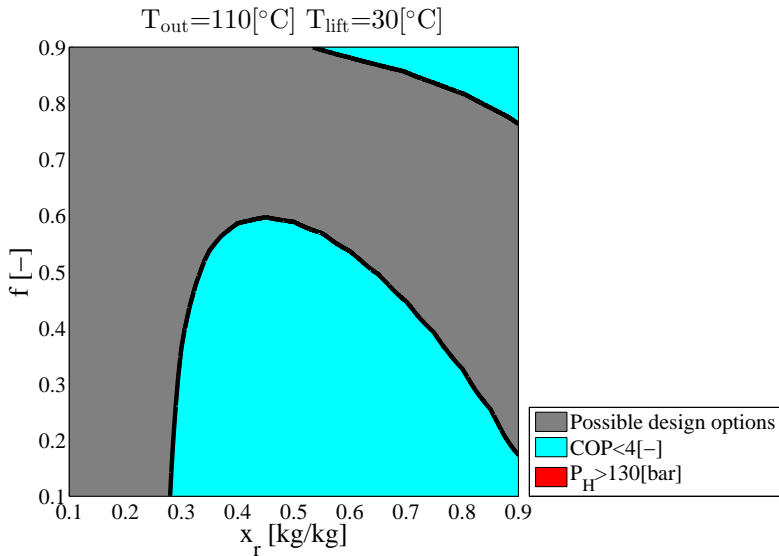
Constraints corresponding to supercritical CO<sub>2</sub> refrigeration components and new synthetic oils

Design Constraints		
$COP$	$> 4[-]$	Economic
$P_H$	$< 130[bar]$	Standard refrigeration equipment
$P_L$	$> 1[bar]$	No entrainment of air from ambient
$VHC$	$> 4[MJ/m^3]$	Economic ( $\dot{Q}_{abs}/\dot{V}_{suc,comp}$ )
$T_H$	$< 250[^\circ C]$	Thermal stability of oil

# Working domain hybrid heat pumps

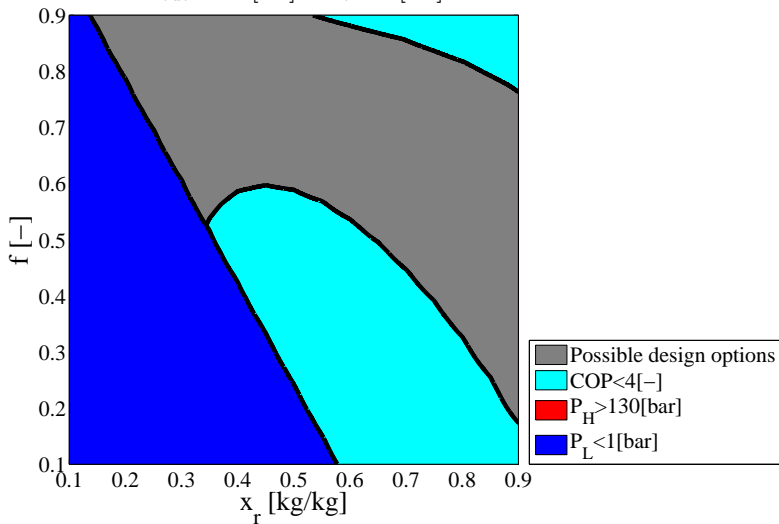


# Working domain hybrid heat pumps



# Working domain hybrid heat pumps

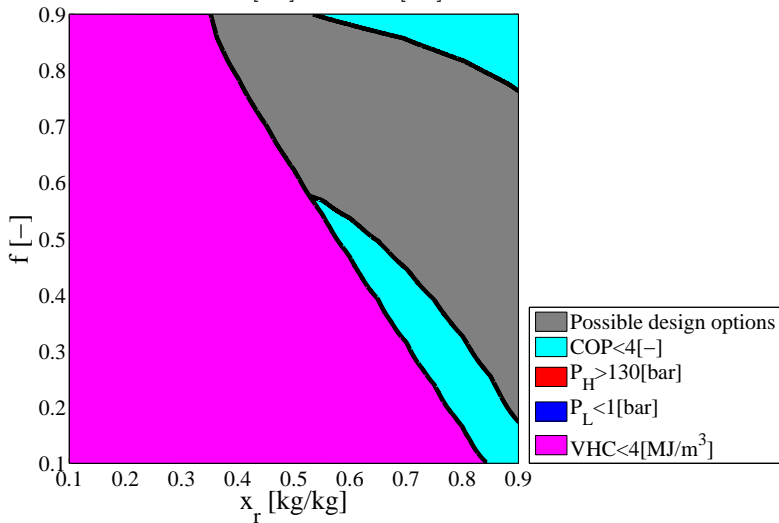
$$T_{\text{out}}=110[^\circ\text{C}] \quad T_{\text{lift}}=30[^\circ\text{C}]$$





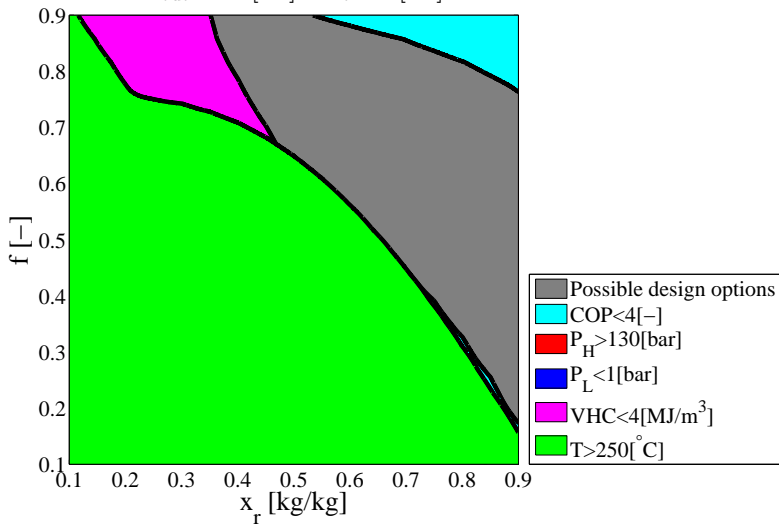
# Working domain hybrid heat pumps

$$T_{\text{out}}=110[^\circ\text{C}] \quad T_{\text{lift}}=30[^\circ\text{C}]$$

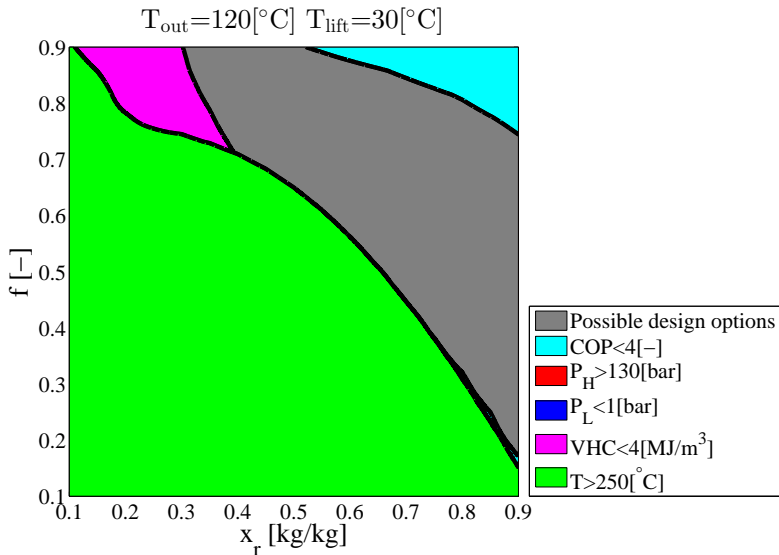


# Working domain hybrid heat pumps

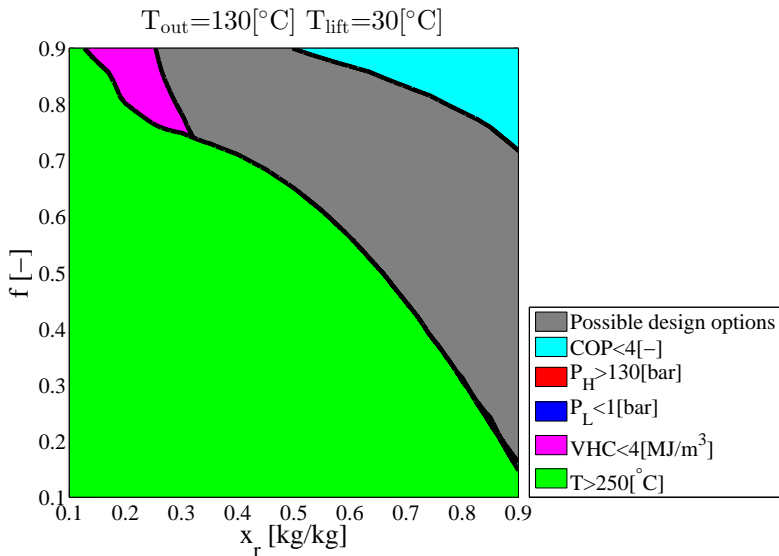
$$T_{\text{out}}=110[^\circ\text{C}] \quad T_{\text{lift}}=30[^\circ\text{C}]$$



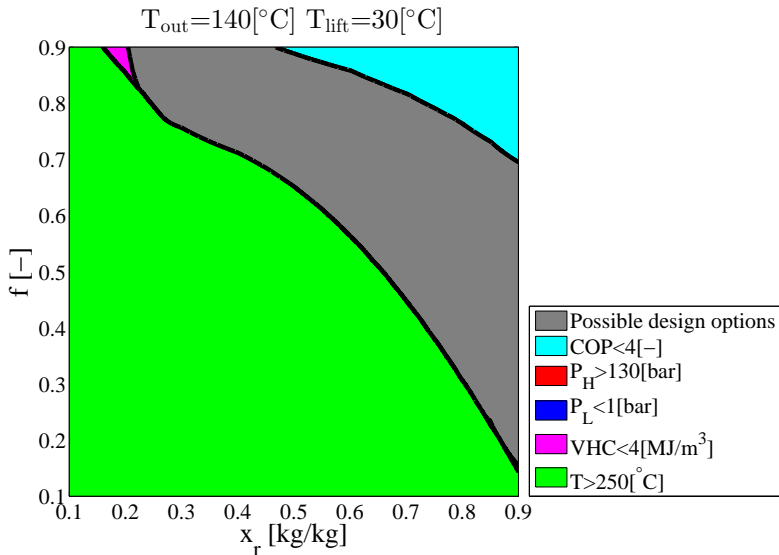
# Working domain hybrid heat pumps: $T_{sink,out}$



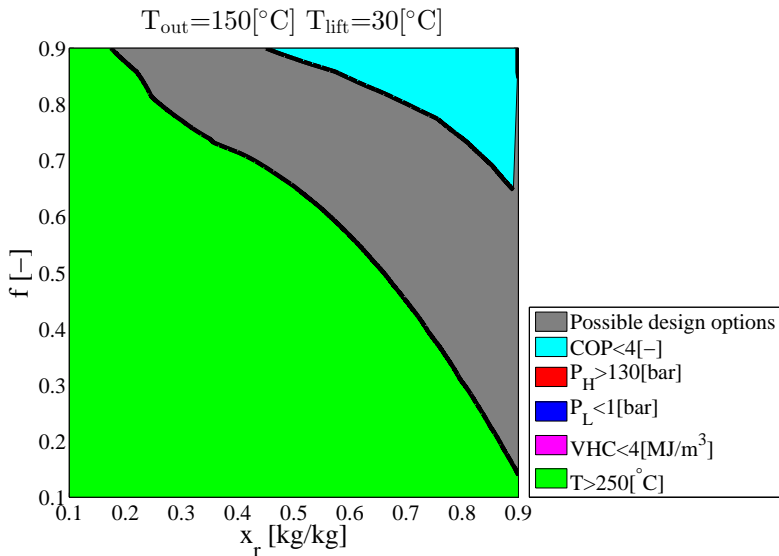
# Working domain hybrid heat pumps: $T_{sink,out}$



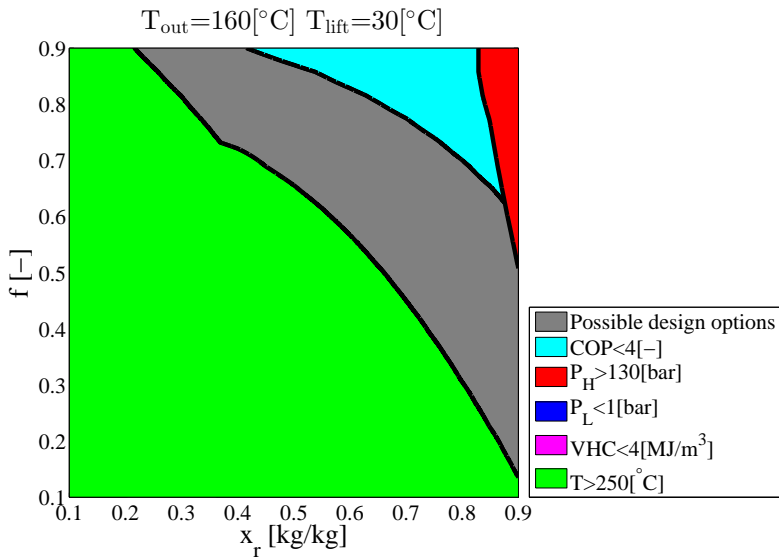
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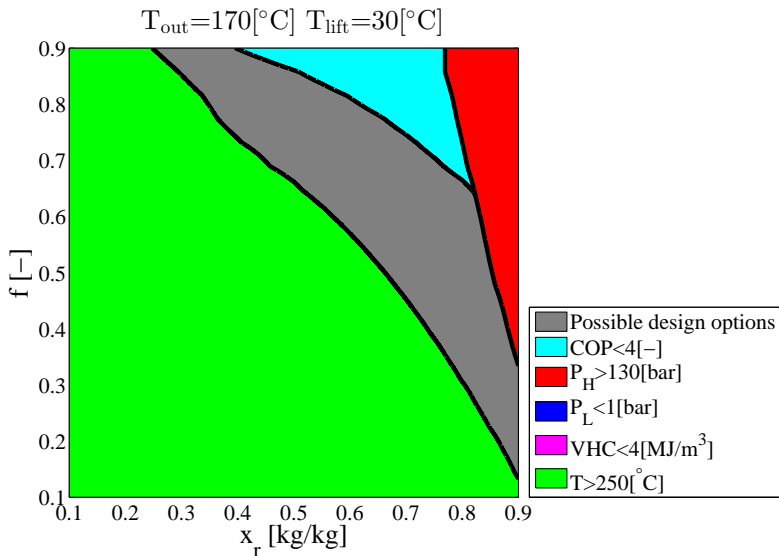
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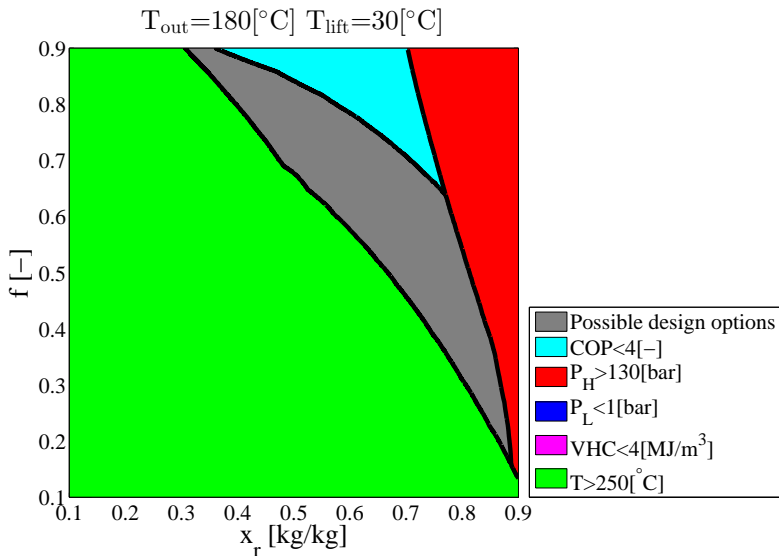


# Working domain hybrid heat pumps: $T_{sink,out}$



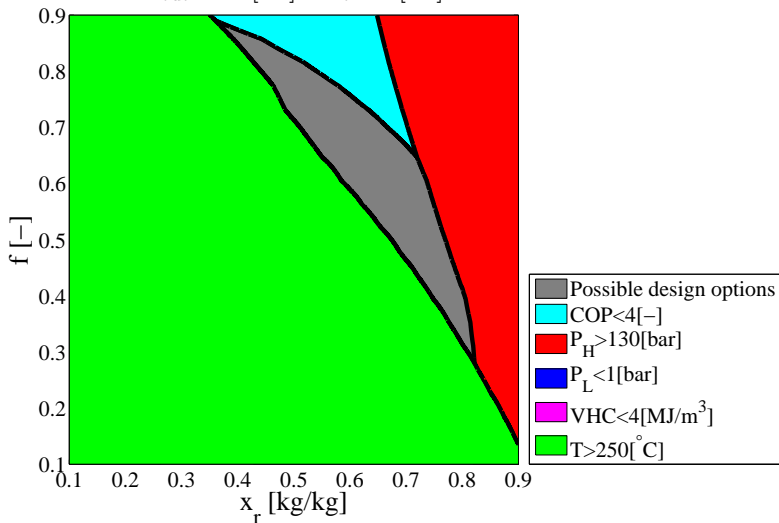


# Working domain hybrid heat pumps: $T_{sink,out}$

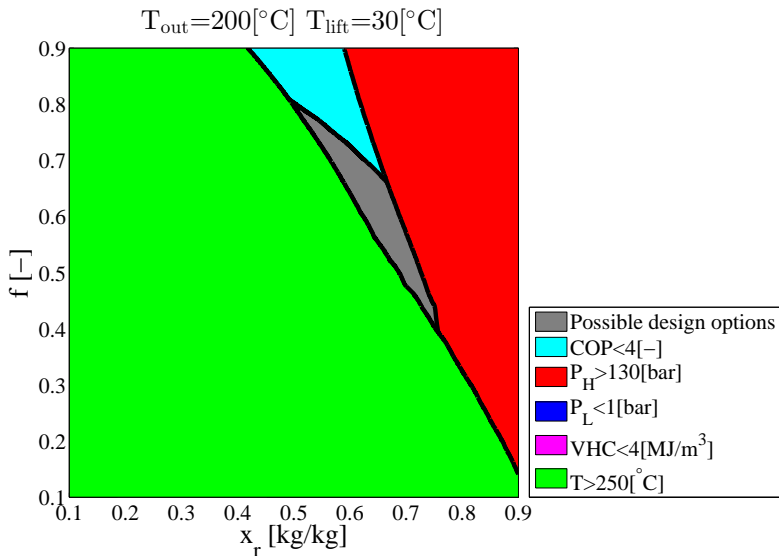


# Working domain hybrid heat pumps: $T_{sink,out}$

$$T_{out}=190[^\circ\text{C}] \quad T_{lift}=30[^\circ\text{C}]$$

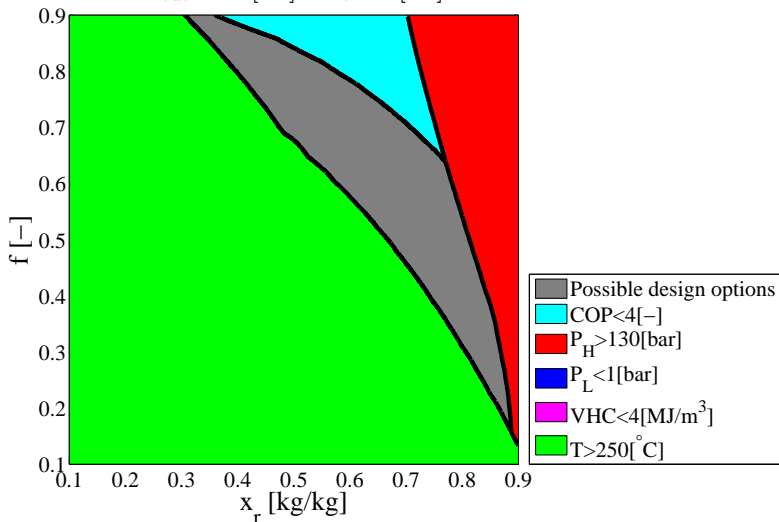


# Working domain hybrid heat pumps: $T_{sink,out}$



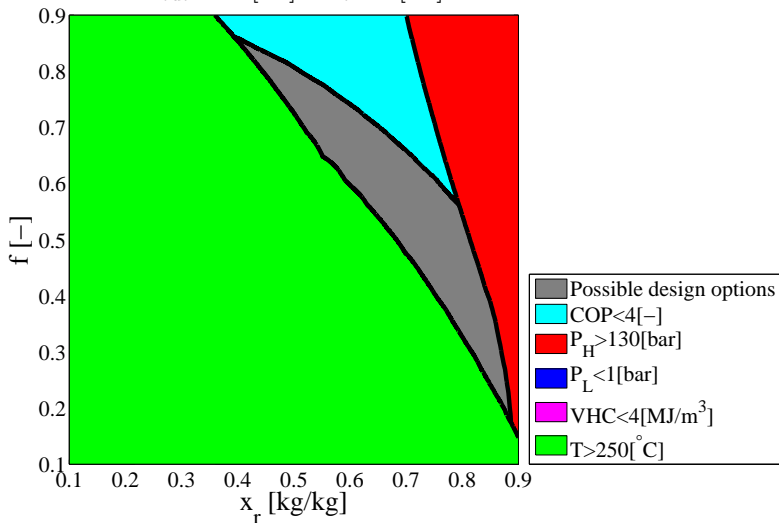
# Working domain hybrid heat pumps: $\Delta T_{lift}$

$$T_{out}=180[^\circ\text{C}] \quad T_{lift}=30[^\circ\text{C}]$$



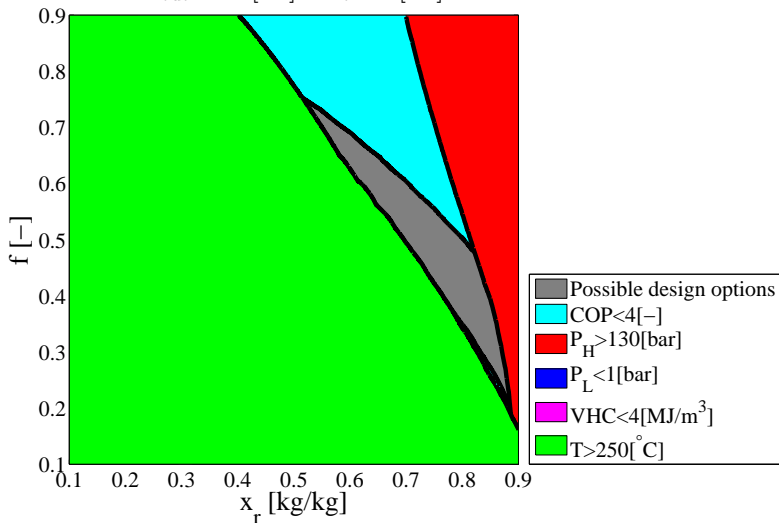
# Working domain hybrid heat pumps: $\Delta T_{lift}$

$$T_{out}=180[^\circ\text{C}] \quad T_{lift}=35[^\circ\text{C}]$$



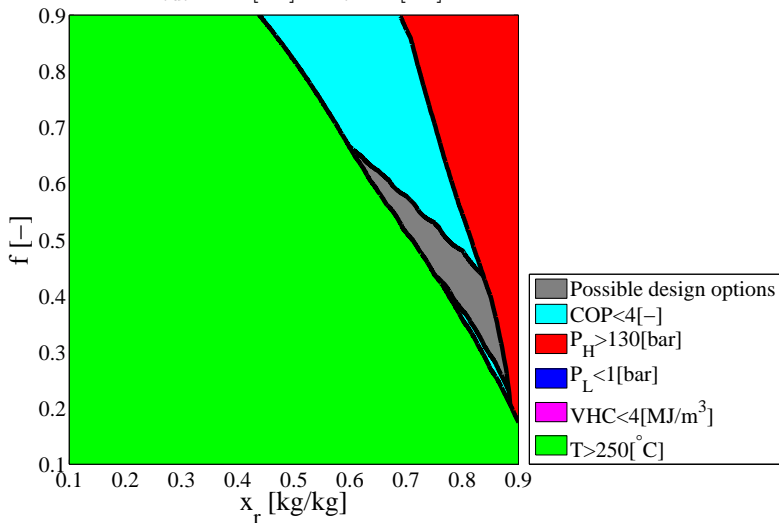
# Working domain hybrid heat pumps: $\Delta T_{lift}$

$$T_{out}=180[^\circ\text{C}] \quad T_{lift}=40[^\circ\text{C}]$$

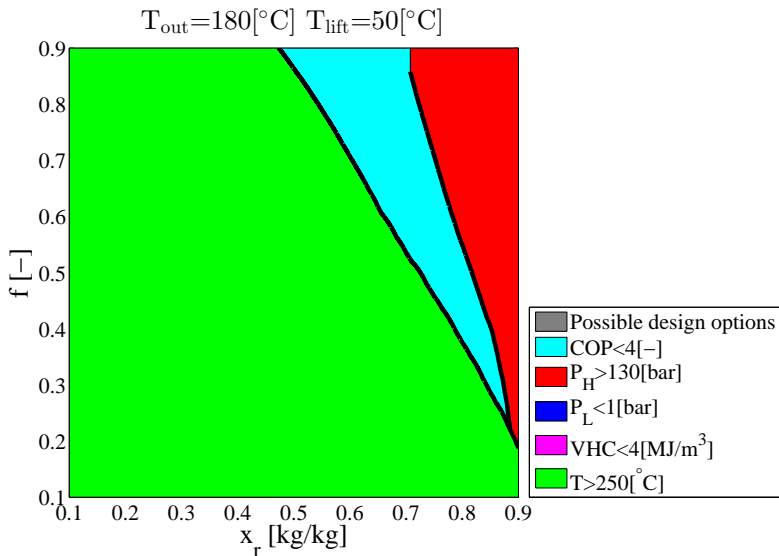


# Working domain hybrid heat pumps: $\Delta T_{lift}$

$$T_{out}=180[^\circ\text{C}] \quad T_{lift}=45[^\circ\text{C}]$$



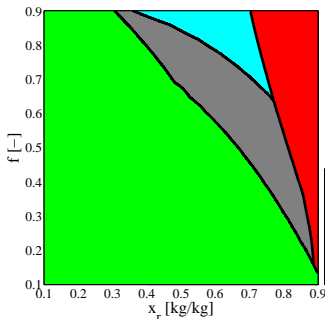
# Working domain hybrid heat pumps: $\Delta T_{lift}$





## Future work

- Heat transfer characteristics, influence of  $x_r$ .
- Identification of suitable oils.
- Material compatibility with  $\text{NH}_3/\text{H}_2\text{O}$  should be investigated
- Two-stage concepts should be evaluated, this could reduce compressor discharge temperature and increase COP.
- Thermoeconomic analysis and optimization should be applied to find cost efficient designs.



- COP and design parameters are highly dependent on  $x_r$  and  $f$ .
- Standard refrigeration components can be used upto 110[°C].
- Supercritical CO<sub>2</sub> components can be used upto 200[°C].
- $\Delta T_{lift}$  upto 45[°C] can be attained.
- Dominating constraint is the compressor discharge temperature.
- Hence thermal stability of oil should be tested.
- Case studies should be performed to show the feasibility of the hybrid heat pump implementation.

**Thank you for your attention.  
Questions?**